Semiconductor Industry Service
1988 Newsletters

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Research *Bulletin*

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FOURTH QUARTER 1988 SEMICONDUCTOR OUTLOOK GLOOMY

SUMMARY

With end-equipment markets sending mixed signals and some semiconductor manufacturers experiencing declining sales, Dataquest believes that fourth quarter 1988 semiconductor billings, particularly in the North American market, will be lower than third quarter billings as a result of semiconductor inventory adjustments, price erosion of certain devices, and rising equipment inventory levels. Panic has begun to set in as the ghost of bust cycles past appears. However, we continue to forecast single-digit growth in the North American market for 1989; we do not foresee a replay of 1985. We will publish our revised quarterly forecast and outlook for 1989 and 1990 in early February 1989. (It will be available on-line also.)

MARKET STATUS

A survey of the largest U.S. semiconductor manufacturers shows that many will have decreased fourth quarter 1988 billings in the North American market. Our October 1988 forecast for the fourth quarter (predicting a positive 4 percent growth) now appears to be too high, although several U.S. companies—among them LSI Logic and VLSI Technology—continue to do well. Several Japanese companies also continue to see strong growth in the North American market, particularly in DRAMs and SRAMs. Nevertheless, we believe that fourth quarter North American market billings will be down from the third quarter. Products that have been hit hard in this softening of demand are 16-bit and slower 32-bit microprocessors and also programmable array logic (PAL) devices and PAL-replacement devices. (PAL is a registered trademark of Advanced Micro Devices.)

We believe that semiconductor buyers have slowed purchases in order to make up for overbuying earlier in the year brought on by shortages in key products such as the 80386 microprocessor and 1Mb DRAMs. Demand is still high for 25-MHz 80386 and 16-MHz 80386SX devices; however, slower and older versions are in excess supply. Shortages still exist for most SRAMs and 256K DRAMs.

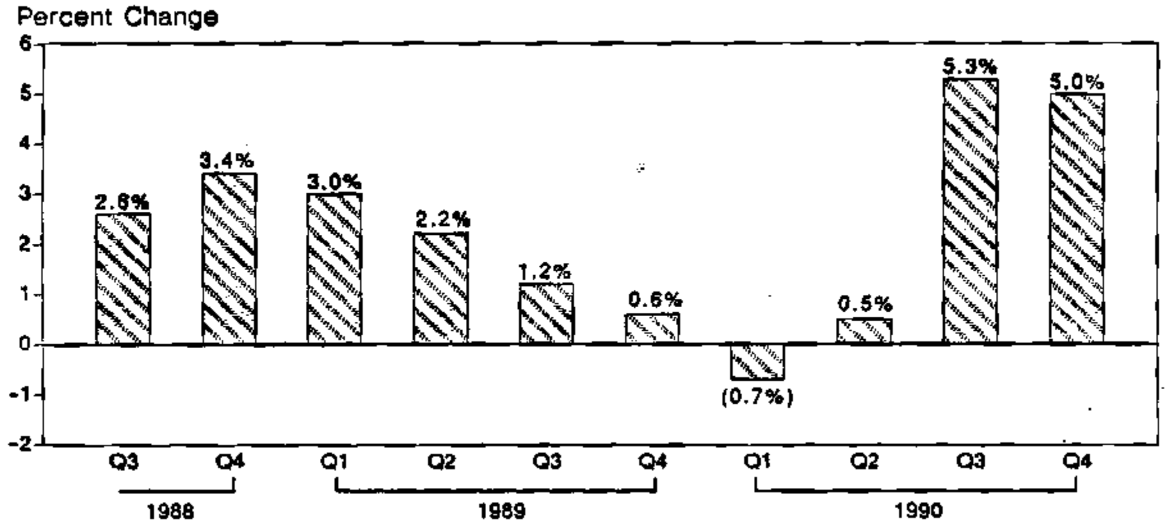
Areas of strength still exist in the end-equipment market. The laptop computer market is poised to explode in 1989; this product consumes large volumes of 80286 microprocessors. IBM, Apple, and Compaq, the big three U.S. personal computer makers, continue to report strong sales and expect a good year in 1989. In the automotive market, Ford Motor Company anticipates another strong year in 1989 and plans to increase semiconductor procurement. The market for facsimile equipment is expected to continue strong growth next year, with semiconductor consumption levels growing almost 30 percent. (Almost all facsimile equipment is produced in Japan.)

U.S. Department of Commerce statistics show inventory levels of the total computer category growing, with October 1988 inventory levels at 8.8 weeks of sales, compared with the October 1987 figure of 8.5 weeks of sales. No trend is yet visible on bookings and billings for this category. Growth has been flat for several months.

On the plus side of the equation, the U.S. economy looks surprisingly strong. Dun & Bradstreet (D&B) continues to forecast total 1988 GNP growth at 3.9 percent, in spite of the drought, which knocked at least $23 billion out of the economy. GNP growth for 1989 and 1990 is forecast to be 2.5 percent and 1.3 percent, respectively. D&B no longer forecasts a recession (two quarters of negative growth) between now and 1991. The current D&B GNP forecast is shown in Figure 1. Other positive economic signs include an October increase in leading economic indicators of 0.1 percent and personal income up a healthy 1.8 percent in October.

Figure 1

Forecast of U.S. GNP Growth



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Source: Dun & Bradstreet

At this time, it appears that our 1988 yearly forecasts for the European, Japanese, and ROW markets are still on track, based on preliminary estimates of company revenue in each region. We will issue any revisions with our quarterly industry forecast in early February 1989.

DATAQUEST CONCLUSIONS

The basic trends underlying our current industry forecast are playing out as we had predicted, with an inventory adjustment occurring earlier than forecast. This is resulting in a much poorer than expected fourth quarter 1988 for the North American market, always the first market to turn. The North American market is undergoing inventory adjustment and price erosion in PALs, standard logic, 16-bit microprocessors, and EPROMs. Products maintaining price firmness include high-speed 32-bit microprocessors, DRAMs, and SRAMs. Fourth quarter 1988 billings in the North American market will probably be lower than third quarter billings, and we continue to foresee slow growth in the first two quarters of 1989, followed by two quarters of slightly negative growth in the last half of 1989.

Patricia S. Cox

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THE SEMICONDUCTOR CHIP PROTECTION ACT IS FINALIZED

This newsletter is the first in a series of several dealing with current intellectual property issues affecting the semiconductor industry. This series is the result of joint research efforts of Dataquest's Semiconductor Industry Service (SIS) and Dr. Judith K. Larsen, senior industry analyst for Dataquest's Research Operations Group.

SUMMARY

The U.S. Patent and Trademark Office recently announced the finalization of regulations concerning the Semiconductor Chip Protection Act (SCPA), a distinct form of intellectual property law that protects mask works fixed in semiconductor chips. Although originally created in 1984, the SCPA has up until now granted protection to mask works from foreign countries only on an interim basis.

The newly enacted regulations describe the procedures the U.S. government will follow in granting permanent protection to chips from foreign countries. As a result, while the finalized version of the SCPA will have only an indirect impact on U.S. chipmakers, foreign semiconductor manufacturers will be affected directly by the ruling.

This newsletter provides a basic description of the Semiconductor Chip Protection Act, discusses the background of the new regulations, outlines the steps that Dataquest's international clients must take if they believe that this unique piece of intellectual property law applies to their business operations in the United States, and, lastly, considers the SCPA's implications for non-U.S. manufacturers.

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WHAT IS THE SCPA?

The Semiconductor Chip Protection Act of 1984 extends copyright protection to semiconductor mask works, making it illegal for companies to reproduce and distribute mask works based on protected chip architectures without the permission of the copyright holder. However, in the strictest sense, the SCPA is neither a traditional patent law nor a traditional copyright law; rather, it is termed a sui generis law—a one-of-a-kind law that is created for a specific purpose. It came about because the traditional intellectual property protection awarded through patents and copyrights did not adequately cover semiconductors.

Because chip architectures are not always original, meeting the criteria for novelty required by the U.S. Patent and Trademark Office has often made patents difficult to obtain. From a more pragmatic consideration, the time required to obtain a patent often exceeds the product life of a semiconductor device, limiting the amount of useful protection that patents can offer. Traditional copyright law has not applied to semiconductors at the mask level because these were considered to be "utilitarian" in nature and, therefore, outside the bounds of copyright protection. Although copyright law prohibits unauthorized persons from copying actual drawings of chip designs, it does not prevent someone from copying the mask-level design itself. As a result, an important intellectual property asset fell through the cracks of a legal system created long before the invention of semiconductors.

Although the SCPA is neither patent nor copyright, it is most similar to copyright law, with the following significant differences:

- It provides protection for only 10 years, compared with 75 years for corporate copyright.
- It requires mandatory registration in which applicants must submit a simple form describing their chip architectures. Protection follows as soon as the form has been filed.
- It permits reverse engineering as a method for getting at the ideas expressed in a mask design, although outright copying of the design itself is prohibited.
- It does not apply to chips that are "commonplace or familiar."

EXTENSION TO NON-U.S. SUPPLIERS

At the time the U.S. Semiconductor Chip Protection Act was passed, few other countries had comparable protection for mask works. Before granting long-lasting protection to mask works from foreign suppliers, the U.S. government wanted to ensure that foreign countries would protect U.S. chips. Non-U.S. semiconductor manufacturers could apply for interim protection under Section 914 of the SCPA, provided they entered into a chip protection treaty with the United States or enacted legislation of their own that would protect U.S. semiconductor devices.

In the years since the passing of the SCPA, all major U.S. trading partners have enacted chip protection legislation. Japan actually passed its own chip protection act in 1984, followed by the 12 member states of the European Economic Community (EEC) plus Sweden, Australia, Canada, Switzerland, and Finland. Naturally, once other nations passed legislation protecting mask works, they thought that they should receive permanent protection in the United States under Section 902 of the SCPA, which grants protection to foreign mask works under any of three conditions:

- The mask work owner's nation is party to a chip protection treaty with the United States.
- The foreign mask work is first commercially exploited in the United States.
- The foreign mask work comes within the scope of a presidential proclamation (which could be made if the mask owner's nation protects U.S. intellectual property owners on substantially the same basis as the SCPA).

The United States was slow in responding to the requests of trading partners to grant chip protection under Section 902, partly because the language of that section was unclear. It referred to rules establishing more binding protection, but the rules proved impossible to implement until clarified.

Earlier this year, the U.S. Patent and Trademark Office began to work on the problem of clarifying Section 902. Comments from the public were invited, and two groups—the Commission of the European Communities and the Semiconductor Industry Association (SIA)—responded. On June 29, 1988, the Patent and Trademark Office announced the final rules, thus clearing the way for Section 902 protection to be granted to mask works from foreign countries.

Protection Procedures

The procedures for applying for mask work protection for non-U.S. companies are covered in Subchapter C, Section 150, of the Code of Federal Regulations. The rules describe how to begin the process of obtaining protection, what information is required, how the review process is to proceed, and how the decision is to be announced. These steps may be summarized as follows:

- The protection process can be initiated by request from a foreign government, from the U.S. Secretary of Commerce (through the Commissioner of Patents and Trademarks), or from an international intergovernmental organization (such as the EEC). It is important to note that <u>individual companies cannot make request for protection</u>.
- Extensive documentation regarding the country's mask protection must accompany the request, including copies of laws, legal rulings, regulations, and administrative orders. If a country has already received interim protection through Section 914, the information gathered in that examination will be considered again in the review for Section 902 protection.

- Once a country has requested protection under Section 902, or once the Commissioner of Patents and Trademarks begins an assessment, a notice will be published in the Federal Register. At that time, the public will have the opportunity to submit written comments, and a hearing may be scheduled if issues are raised that cannot be settled informally.

- The commissioner then reviews all the information and prepares a draft recommendation, which is sent to the Secretary of Commerce. The Secretary of Commerce submits a recommendation to the president, who makes a Section 902 proclamation.

There are certain limitations included in the new regulations. The rules state that the proclamation may contain conditions regarding its duration. In addition, procedures are described for considering suspension or revocation of the Section 902 protection. This essentially states that even when Section 902 protection is obtained, intellectual property rights must continue to be respected.

Who is Affected?

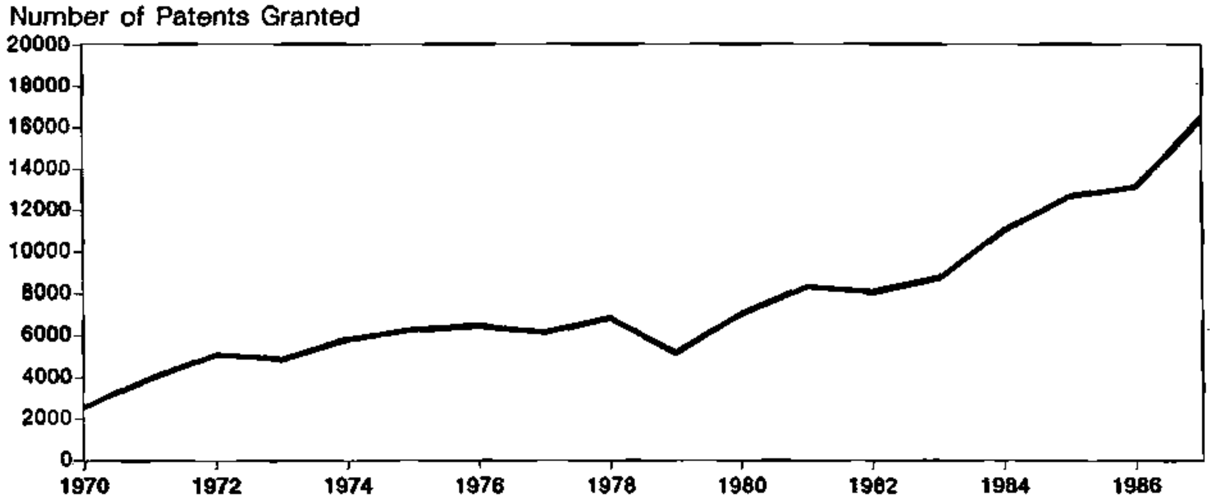
The countries most immediately affected by the new regulations are those that already have effective chip protection acts in place and that currently have interim protection under Section 914. These countries are eligible to apply for Section 902 protection immediately. Countries that do not have chip protection legislation but are moving in that direction would be affected by these rules only when they apply for protection in the United States.

For Japan, the importance of extending permanent protection to the mask works of its semiconductor manufacturers is that it acknowledges Japan's transition from price-cutting copycat to technology innovator. With the Japanese becoming leaders in many technologies (such as ICs, optoelectronics, robotics), protection of intellectual property will be as much an issue in the 1990s as avoiding lawsuits has been in recent times. The pace of Japan's U.S. patent filings alone underscores this trend, as is illustrated in Figure 1. As Japan looks over its shoulder at the newly industrialized countries (NICs) of the Pacific Rim, securing intellectual property assets marks a transition from a defensive to a more aggressive legal posture.

For the Asian NICs, the finalized SCPA may seem more like an obstacle than an opportunity. Although the SCPA has never been tested in court, it is one more legal reef that Pacific Rim competitors will have to avoid as they navigate an increasingly litigious U.S. market. Just as intellectual property law protects the interests of U.S. and Japanese chipmakers, Asian manufacturers eventually will find it working to their advantage as well. In the meantime, a certain amount of education on the intricacies of intellectual property law unfortunately will be attained through lawsuits.

Figure 1

U.S. Patents Granted to Residents of Japan
1970–1987



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Source: Dataquest
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DATAQUEST CONCLUSIONS

The main impact of the new Semiconductor Chip Protection Act regulations may be to underscore international awareness that intellectual property is a valuable resource. All major trading nations have enacted legislation protecting mask works in the last few years. The fact that Section 902 regulations were finally defined indicates that the United States recognizes the actions of other countries. The regulations also illustrate the continuing efforts of the U.S. government to protect intellectual property and to firm up agreements with countries sharing that concern.

Michael J. Boss
Judith K. Larsen

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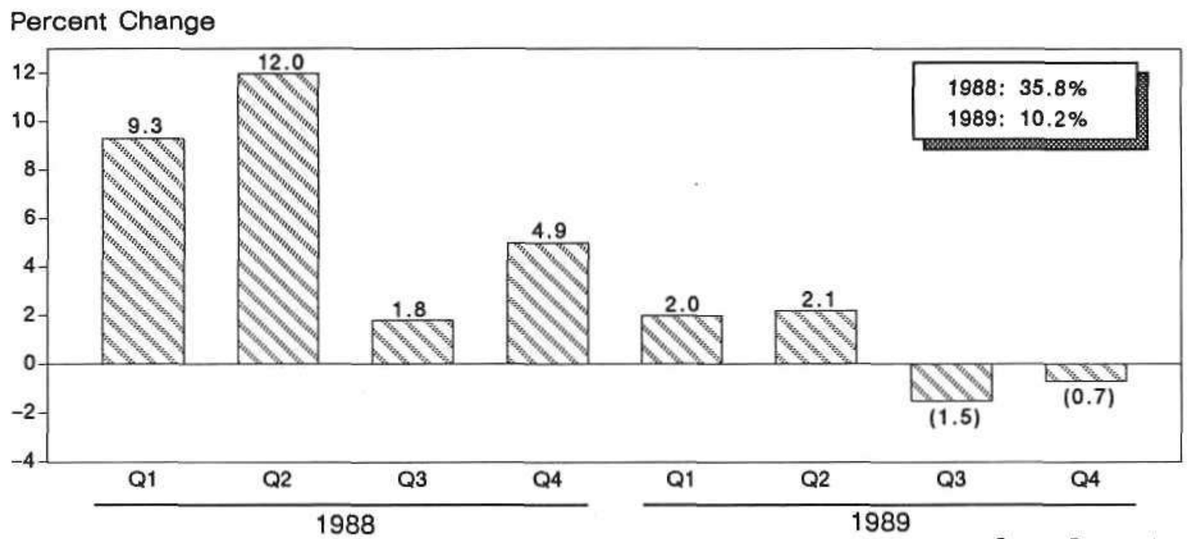
WORLDWIDE SEMICONDUCTOR INDUSTRY UPDATE: WHEN WILL THE DOWNTURN HIT?

SUMMARY

The year 1988 has been a booming one for the worldwide semiconductor industry, with estimated total growth of 35.8 percent, continuing the good times of 1987 (a year of 22.8 percent growth). During the third quarter of 1988, bookings began to soften, and many semiconductor manufacturers experienced poorer than usual August bookings. However, the existing backlog, combined with shortages in key product areas—most notably, DRAMs and SRAMs—should keep shipments strong through the end of the year. Dataquest forecasts much slower growth in the first two quarters of 1989. This slow growth will be followed by negative growth in the second half of 1989, as supply catches up with and then exceeds demand and both unit shipments and ASPs fall. The short-term forecast is summarized in Figure 1.

Figure 1

Worldwide Semiconductor Shipment Forecast



Source: Dataquest
October 1988

WORLDWIDE FORECAST

A summary of the worldwide forecast by region is shown in Tables 1 and 2.

Table 1

Estimated Worldwide Semiconductor Market
(Billions of U.S. Dollars)

	1988	1989	1990	1991	1992	1993	CAGR 1988-1993
North America	15.7	17.2	17.5	20.4	24.8	26.7	11.2%
Japan	19.5	21.3	21.5	25.2	30.5	33.3	11.3%
Europe	8.2	8.8	8.8	9.8	11.3	12.5	8.8%
Rest of World	6.1	7.3	7.9	9.9	12.7	14.3	18.4%
Total World	49.5	54.6	55.7	65.3	79.3	86.8	11.9%

Source: Dataquest
October 1988

Table 2

Estimated Worldwide Semiconductor Market
(Percent Change, U.S. Dollars)

	1988	1989	1990	1991	1992	1993
North America	32%	10%	1%	17%	22%	8%
Japan	36%	9%	1%	17%	21%	9%
Europe	29%	7%	0	12%	15%	11%
Rest of World	57%	19%	9%	25%	28%	13%
Total World	36%	10%	2%	17%	22%	10%

Source: Dataquest
October 1988

North America

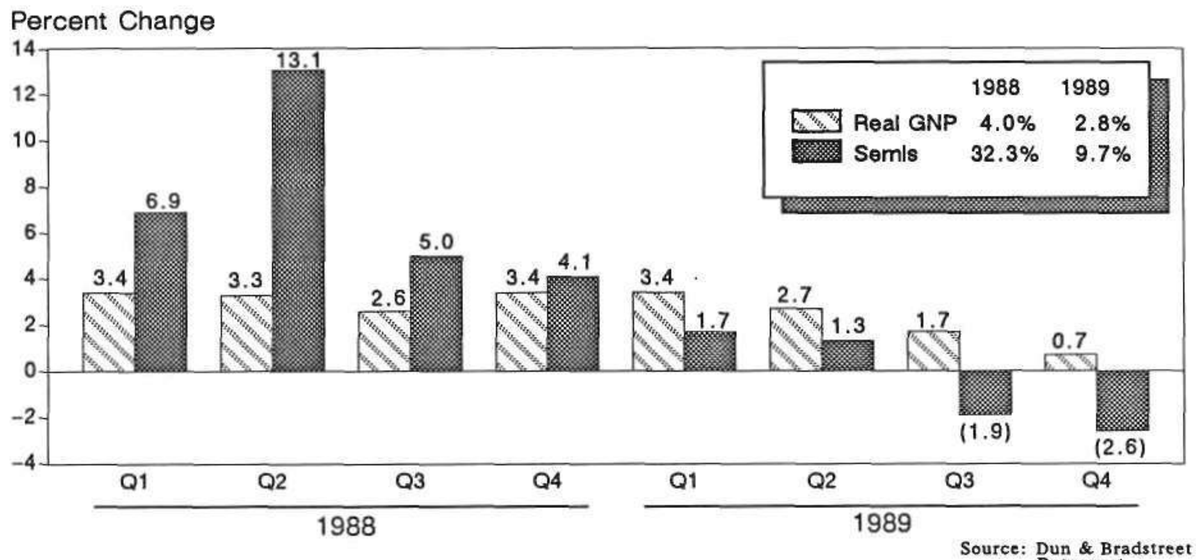
Both in the 1988 to 1989 time frame and over the long term, we believe that North America will be the second slowest growing market after Europe; through 1993, however, it will remain second largest in overall size after Japan. In 1988, North America will account for 31.7 percent of worldwide semiconductor consumption. Although capital spending in North America will increase by some 40.0 percent in 1988, this growth is modest compared with the capacity buildup in 1983 and 1984, which led to the 1985 market glut.

Historical patterns of billings and bookings show that bookings may begin to fall on a 12/12 basis any time now, but billings will not start to decline until 9 to 10 months later (i.e., mid-1989). Semiconductor inventory levels are rising, but they are being held in better check by OEMs than in 1984, due to careful tracking of target and actual inventory levels.

Dun & Bradstreet forecasts show that the U.S. economy will slow in 1989, with real GNP growth of 2.8 percent, versus 4.0 percent growth in 1988. This reduced GNP growth, combined with slower electronic equipment production growth and lowered capital expansion plans, will slow the semiconductor industry as well. We believe that the sluggishness in semiconductors will last through the first half of 1990. Figure 2 compares U.S. GNP growth with North American semiconductor consumption growth.

Figure 2

U.S. Economy versus Semiconductors



Source: Dun & Bradstreet
Dataquest
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Japan

The GNP outlook for Japan is very strong, with growth rates forecast at 4.6 percent for fiscal 1988 and 3.5 percent for fiscal 1989. We expect Japan to be the second fastest growing market after the ROW market, in both the short and long term. We expect prices to remain firm through the second half of this year, with shortages of DRAMs and SRAMs continuing at least until the first quarter of 1989 (one quarter sooner than in the United States). Although Japanese capital spending will grow 56.0 percent in dollar terms in 1988, the yen growth will be significantly lower, at 40.0 percent.

Europe

PCs are the driving factor in European semiconductor growth this year, particularly in MOS microdevices, memory, and bipolar digital logic. The PC build rate has slowed substantially, and bookings are collapsing, except for 1Mb DRAMs. We expect Europe to be the slowest growing market in the long term, and we believe that ROW will surpass Europe in dollar size in 1991.

ROW

The 1988 Seoul Olympics drove 1988 consumer demand worldwide, stimulating the ROW semiconductor market. Currently, PC shipments are slowing because of memory shortages. The telecommunications industry is growing extremely quickly in ROW, but telecommunications is still a small market. We expect the ROW market to be the fastest growing in both the short and long term. ROW will surpass Europe in total dollar consumption in 1991 to become the world's third largest market.

Shipments by Product

Tables 3 and 4 give Dataquest's short- and long-term forecasts, respectively, for the worldwide semiconductor industry. By 1993, we forecast a total market of $86.7 billion. In the long term, the fastest growing products will continue to be MOS ICs. Bipolar memory is forecast to decline steadily through 1993, as BICMOS memory edges it out. Optoelectronics growth will continue to be strong over the long term, as its use in consumer and telecommunications products continues to grow; at the same time, new applications such as medical, dental, machine vision, and submarine communications are proliferating.

Table 3

Estimated Worldwide Semiconductor Shipments (Millions of U.S. Dollars)

	1987	Q1/88	Q2/88	Q3/88	Q4/88	1988	% Chg. 1988
Total Semiconductor	$36,449	$11,112	$12,442	$12,669	$13,286	$49,509	35.8%
Total IC	$28,619	$ 8,718	$ 9,885	$10,128	$10,672	$39,403	37.7%
Bipolar Digital	$ 4,672	$ 1,297	$ 1,359	$ 1,419	$ 1,495	$ 5,570	19.2%
Memory	565	154	163	166	169	652	15.4%
Logic	4,107	1,143	1,196	1,253	1,326	4,918	19.7%
MOS Digital	$16,739	$ 5,385	$ 6,380	$ 6,561	$ 6,924	$25,250	50.8%
Memory	6,019	2,182	2,762	2,785	2,904	10,633	76.7%
Micro	4,770	1,521	1,765	1,813	1,906	7,005	46.9%
Logic	5,950	1,682	1,853	1,963	2,114	7,612	27.9%
Linear	$ 7,208	$ 2,036	$ 2,146	$ 2,148	$ 2,253	$ 8,583	19.1%
Discrete	$ 6,112	$ 1,805	$ 1,918	$ 1,887	$ 1,939	$ 7,549	23.5%
Optoelectronic	$ 1,718	$ 589	$ 639	$ 654	$ 675	$ 2,557	48.8%
Exchange Rate Yen/$	144	128	125	134	134	130	(9.7%)
European Basket/$	1.25	1.17	1.17	1.20	1.20	1.18	(5.6%)

	1988	Q1/89	Q2/89	Q3/89	Q4/89	1989	% Chg. 1989
Total Semiconductor	$49,509	$13,556	$13,843	$13,636	$13,536	$54,571	10.2%
Total IC	$39,403	$10,882	$11,104	$10,917	$10,833	$43,736	11.0%
Bipolar Digital	$ 5,570	$ 1,518	$ 1,519	$ 1,451	$ 1,400	$ 5,888	5.7%
Memory	652	169	161	151	146	627	(3.8%)
Logic	4,918	1,349	1,358	1,300	1,254	5,261	7.0%
MOS Digital	$25,250	$ 7,058	$ 7,209	$ 7,101	$ 7,057	$28,425	12.6%
Memory	10,633	2,950	3,022	2,972	2,953	11,897	11.9%
Micro	7,005	1,944	1,990	1,969	1,959	7,862	12.2%
Logic	7,612	2,164	2,197	2,160	2,145	8,666	13.8%
Linear	$ 8,583	$ 2,306	$ 2,376	$ 2,365	$ 2,376	$ 9,423	9.8%
Discrete	$ 7,549	$ 1,976	$ 2,010	$ 1,996	$ 1,988	$ 7,970	5.6%
Optoelectronic	$ 2,557	$ 698	$ 729	$ 723	$ 715	$ 2,865	12.0%
Exchange Rate Yen/$	130	134	134	134	134	134	3.1%
European Basket/$	1.18	1.20	1.20	1.20	1.20	1.20	1.2%

Source: Dataquest
October 1988

Table 4

Estimated Worldwide Semiconductor Shipments
(Millions of U.S. Dollars)

	1988	1989	1990	1991	1992	1993	CAGR 1988-1993
Total Semiconductor	$49,509	$54,571	$55,600	$65,230	$79,233	$86,730	11.9%
Total IC	$39,403	$43,736	$44,767	$53,295	$65,734	$73,213	13.2%
Bipolar Digital	$ 5,570	$ 5,888	$ 5,878	$ 6,737	$ 7,813	$ 8,509	8.8%
Memory	652	627	606	595	546	530	(4.1%)
Logic	4,918	5,261	5,272	6,142	7,267	7,979	10.2%
MOS Digital	$25,250	$28,425	$29,333	$35,487	$44,610	$49,663	14.5%
Memory	10,633	11,897	12,141	14,762	18,562	20,262	13.8%
Micro	7,005	7,862	7,993	9,800	12,482	13,867	14.6%
Logic	7,612	8,666	9,199	10,925	13,566	15,534	15.3%
Linear	$ 8,583	$ 9,423	$ 9,556	$11,071	$13,311	$15,041	11.9%
Discrete	$ 7,549	$ 7,970	$ 7,917	$ 8,668	$ 9,712	$ 9,254	4.2%
Optoelectronic	$ 2,557	$ 2,865	$ 2,916	$ 3,267	$ 3,787	$ 4,263	10.8%
Exchange Rate Yen/$	130	134	134	134	134	134	
European Basket/$	1.18	1.20	1.20	1.20	1.20	1.20	

Source: Dataquest
October 1988

DATAQUEST CONCLUSIONS

We believe that worldwide semiconductor shipments will slow down through the first half of 1989 and begin to decline slightly in the second half of 1989, continuing into the first half of 1990. However, due to careful OEM management of semiconductor inventory, careful semiconductor manufacturer management of capacity (capacity utilization is at 86 percent in 1988, and we expect it to be a still-healthy 80 percent in 1989 and 78 percent in 1990), and a generally healthy world economy, we forecast the downturn to be modest, particularly in comparison with the 1985 industry depression.

Patricia S. Cox

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THE OMNIBUS TRADE BILL: WHAT IT MEANS TO THE SEMICONDUCTOR INDUSTRY

SUMMARY

The fortunes of U.S. high-technology industries have played no small part in the formulation of U.S. trade policy of late. In the semiconductor industry alone, a number of trade-related issues have combined to elevate chip making concerns to a level of political visibility far beyond what the industry's significance as a generator of revenue and jobs would suggest.

It is therefore not surprising to find a number of measures within the more than 1,000 pages of the Omnibus Trade and Competitiveness Act of 1988 that seem very much directed at high-technology systems and the components that enable them. Potentially, the most significant portions of the bill, with regard to producers and users of semiconductors, deal with the following areas:

- Amendments to Section 301 of the Trade Act of 1974
- The tightening of antidumping regulations
- The strengthening of intellectual property laws
- Restrictions on foreign takeovers of U.S. companies
- The relaxation of high-technology exports

This newsletter reviews the likely industry impact of each of the above aspects of the trade bill, with attention as well to the implications of the Toshiba sanctions to electronics original equipment manufacturers (OEMs).

TRADE: A HIGHER PLACE ON THE NATIONAL AGENDA

The Omnibus Trade and Competitiveness Act of 1988 represents a significant effort by the U.S. government to advance the competitive interests of American industry without resorting to self-defeating, protectionist measures. Clyde Prestowitz, former

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counselor for Japanese affairs to the secretary of commerce, has pointed out that government has typically viewed trade as an activity of the private sector, rather than as a strategic issue. For this reason, past issues of unfair practices by trade partners have at times been subordinated to other political agendas, such as national security concerns.

The trade bill signed by President Reagan breaks with the past by moving authority to respond to unfair trade practices from the president to the U.S. trade representative (USTR). Nevertheless, the bill still allows the president override power if any such response violates the General Agreement on Tariffs and Trade (GATT) or is judged by the president to jeopardize national security or economic interests. As a result, while avoiding the complete tying of the president's hands, the trade bill forces the chief executive to take a position in instances of unfair trade practices, and, to that extent, furthers the decoupling of trade and national security issues.

SECTION 301

The amendments to Section 301 of the Trade Act of 1974 may strengthen the efforts of the Semiconductor Industry Association (SIA) to increase U.S. semiconductor manufacturers' share of the Japanese market. The amendments require that the USTR submit an annual report to Congress on foreign trade practices that adversely affect U.S. commerce. This report must include a list of "priority" foreign countries that maintain unfair trade barriers, which from the SIA's point of view would certainly include Japan.

These amendments, however, do not necessarily mandate retaliatory action in instances where a foreign government tolerates anticompetitive activities by private firms—unless it can be demonstrated that the purchasing practices of these firms are "inconsistent with commercial considerations." This will be the acid test of this portion of the trade bill: proving that trade barriers against U.S. rice are "inconsistent with commercial considerations" is one thing; proving that point with regard to vertically integrated Japanese electronics companies' purchases of foreign semiconductors is another matter altogether. The SIA will therefore have to continue pressing its case that Japan's reluctance to increase its consumption of U.S. chips flies in the face of its own commercial self-interest. It will, however, most certainly have the attention of a more powerful USTR in the process.

DUMPING LAWS

The trade bill allows domestic industries to petition the USTR to request that foreign governments initiate their own antidumping investigations, and to use "constructed values" (similar to the scheme followed for DRAM and EPROM pricing) as the basis for foreign market values (FMVs). As a result, the trade bill is an assurance to the U.S. semiconductor industry that government will address dumping issues <u>before</u> their impact causes the forced withdrawal of U.S. suppliers from a key market.

To guard against "diversionary input dumping," the trade bill broadens the scope of the dumping regulations to cover "downstream products." In the case of semiconductors, this would apply to subsystems or board-level products containing components that have been subject to a dumping or subsidy finding of 15 percent or more in the past five years. To put even more of a bite in the dumping regulations, the trade bill authorizes the Department of Commerce (DOC) to disregard intracompany transfer prices for components and materials used in products subject to any dumping investigation. In addition, measures in the trade bill establish a method for determining whether or not domestic subsidies by foreign governments constitute a dumping violation.

In the case of countries that have been found to be repeated dumping violators, the trade bill requires the DOC to conduct expedited antidumping investigations in the case of "short life cycle" products: products that the International Trade Commission (ITC) "determines (are) likely to become outmoded within four years . . ." One can certainly appreciate the relevance of this measure to new generations of memory products, if not to the chip industry as a whole. The intent of this measure is to ensure that, by the time a dumping investigation concerning an existing generation of a product is concluded, the aggrieved industry has not hopelessly lost market share opportunities to a next-generation device.

Finally, the dumping regulations in the trade bill include a section that requires the ITC to look at the issue of material damage to a domestic industry from a number of factors distinctive to the affected industry, and not solely from the standpoint of business cycles and general competitive conditions. The trade bill even includes a section that requires the ITC to evaluate factors that create the "threat" of material injury, such as the ability of domestic producers to develop subsequent generations of a product, and whether third-country dumping suggests a threat.

In these measures, one sees evidence of lessons learned from the U.S.-Japan Semiconductor Trade Arrangement. The Section 301 violations, the resulting FMVs, and the market gyrations that followed have made government and industry a bit more savvy about the complexities of dumping issues. Elements such as intracompany sales, incorporation of dumped goods into higher-integration products, the effects of government subsidies on cost, and the relationship between distributors and third-country markets must all be taken into account as a part of the FMV equation.

Although the trade bill clearly strengthens antidumping laws to provide deterrents to multiple foreign offenders, the version of the bill signed into law falls short of the measures the SIA would like to have seen included. The SIA had sought to modify trade legislation dating back to 1916 that allows victims of dumping to sue for treble damages if they can prove that a competitor had clearly intended to drive them from a market. The SIA had hoped to modify this law in a way that would have shifted the burden of proof to the defendant in a dumping suit. Under these regulations, third-time dumping offenders would have had to prove that they <u>had not</u> intended to damage a competitor as a result of their pricing strategy or face being barred from participating in that market.

INTELLECTUAL PROPERTY

If you think the industry currently has a growing love affair with litigation, the intellectual property regulations in the trade bill look like the honeymoon hotel. Since the Tariff Act of 1930, victims of unfair acts of competition have been able to obtain exclusion orders from the president, provided they could prove injury or the threat of injury to the ITC along with evidence of intellectual property violation.

The trade bill amends Section 337 of the Tariff Act of 1930 by removing the proof-of-injury requirement. In fact, the amendments minimize the requirements that a petitioner show investments in R&D, plants and equipment, or employment as constituting an industry. Also removed is the requirement that the aggrieved company be efficiently and economically operated. Had these amendments been in force last year, it is conceivable that Intel could have taken its DRAM patent infringement case against Samsung to the ITC in order to block the import of DRAMs from that company. As it was, Intel was able to press only its EPROM case against Samsung, since it was still a manufacturer of those devices.

The trade bill amends patents so that holders of patents on processes by which products are made can sue importers of products from countries where the patents are not protected. Furthermore, if a plaintiff shows that there is a substantial likelihood that such products use the patented process, the burden falls to the defendant to prove that the patented process was not used.

EXPORT CONTROLS

Although the changes to export controls in the trade bill do not appear to have a significant impact on chip producers, the fact that they are aimed at the removal of unnecessary controls should prove a further stimulus to electronics exports. Essentially, the provisions of the trade bill abolish controls on the export of many widely available electronics products to Japan and 14 North Atlantic Treaty Organization Allies—subscribers to COCOM regulations. The Pentagon's role in reviewing export licenses for goods still on the export control list is confined to "national security" concerns, an effort to eliminate the possibility that such approval would be used as a tool of foreign policy.

THE TOSHIBA SANCTIONS

For their role in the supply of specialized milling machines to the Soviet Navy, the trade bill places a three-year moratorium on any U.S. procurement of products and services from Toshiba Machine Company and Kongsberg Trading Company. These measures have no significant impact on the ability of Toshiba's semiconductor operations to supply components to the U.S. market, except in the case of sales to U.S. government agencies. As a whole, Toshiba Corporation is prohibited from providing goods and services to government agencies for a three-year period.

OEMs using Toshiba components in their products are less apt to be sanguine about the ban on Toshiba government sales. What is the effect of the trade bill, for example, on the government sales of a U.S. memory board supplier if the boards use memories from Toshiba, the world's number one producer of 1Mb DRAMs? Fortunately, the trade bill makes exceptions to the ban both in cases of the procurement of defense articles or services and, in the case of "component parts," which it defines as " . . . any article which is not usable for its intended functions without being imbedded in or integrated into any other product and which, if used in production of a finished product, would be substantially transformed in that process."

One question concerning the Toshiba sanctions incorporated in the trade bill is whether or not they will supersede the sterner measures spelled out in the defense appropriations bill for fiscal 1988. These sanctions prohibit the purchase, using Department of Defense (DOD) funds, of any systems in which Toshiba components make up 50 percent or more of the systems' value.

FOREIGN TAKEOVERS

In the past, the president could prevent the acquisition of a U.S. company by a foreign-based firm only if U.S. antitrust laws were violated or if a state of national emergency was declared. The trade bill (as a result of the Exon-Florio Amendment) amends Title VII of the Defense Production Act of 1950, allowing the president to block a foreign takeover if it is determined, upon investigation, that U.S. national security is compromised.

Had the trade bill been in force last year, it is interesting to speculate on whether or not President Reagan would have invoked this power to block Fujitsu's acquisition of Fairchild. It is probably no coincidence that, with the trade bill headed for presidential signature, Gould, Inc., divested itself of its semiconductor operations before completing the arrangements of its acquisition by Nippon Mining Company. In this sense, the effects of this portion of the bill may already have been felt by industry.

TECHNICAL COMPETITIVENESS

A number of trade bill sections deal with the role of government agencies in enhancing the technological prowess and worldwide competitiveness of U.S. high-technology industries. These measures include the creation of a Competitiveness Policy Council (comprising government, business, labor, and academic leaders), and an annual assessment of the impact of the federal budget on the U.S. trade balance.

In addition, the bill renames the National Bureau of Standards, calling it the National Institute of Standards and Technology, and expands its charter to aid in the development of leading-edge technologies such as superconductivity, advanced materials, and biotechnology.

A number of sections pertaining to technological competitiveness deal specifically with the semiconductor industry. These include:

- The creation of the National Advisory Committee on Semiconductors (NACOS), which will monitor the semiconductor industry and recommend a national strategy to promote greater U.S. competitiveness in semiconductors. Members are currently being solicited for this advisory body.

- The creation of the National Critical Materials Council. This council will initially develop a plan for advanced materials research and development.

- The requirement of an annual report to Congress by the Council on Federal Participation in Sematech, updating the progress of the consortium toward its objectives. This report will also identify prospects for the recoupment of federal investments from royalties or fees generated from Sematech technology.

DATAQUEST CONCLUSIONS: THE ROLE OF GOVERNMENT

Several years ago, the semiconductor industry took its case to the federal government in the form of Section 301 dumping allegations against Japanese semiconductor manufacturers. Prior to this, and during the creation of the U.S.-Japan Trade Arrangement, semiconductor business leaders argued before often skeptical legislators that the current trade climate threatened to destroy a key U.S. industry. However one feels about the effectiveness of the arrangement, its eventual creation came too late for a number of U.S. companies.

For the most part, the aspects of the trade bill described in this newsletter remain in keeping with the federal government's traditional trade posture: that of the defender of free trade among U.S. industry and its trading partners. In defining how best to fulfill this role in an increasingly global environment, U.S. trade policy is obviously intent on fostering improved trade conditions for domestic industry without intervening aggressively on behalf of any particular business sector. Nonetheless, in regard to the U.S. high-technology industries, certain aspects of the trade bill define a government role closer to that of coach than referee in the game of international trade and competitiveness.

Most significantly for chipmakers, the trade bill signed by President Reagan marks a departure from the attitude that the woes of the industry were brought upon it solely by some lack of competitive fire. By defining its role in fostering a trade climate more conducive to the success of the U.S. semiconductor industry, government can do much to encourage investments in capacity that systems companies would dearly love to see in the memories area. A proactive role in trade may also ensure that future government measures look less like closing the barn door after the horses have escaped.

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THE THREE FACES OF JAPAN: CONSUMER, PARTNER, COMPETITOR

SUMMARY

During the past decade, Japan's impact on the worldwide semiconductor industry has been characterized in a variety of ways. Japan has been cast as a low-cost, high-reliability source of commodity ICs, a market spoiler, a technology pirate, the driver of leading-edge processes, a strategic partner, and a market prize. For many U.S. companies, alternately understanding the Japanese as consumers, partners, and competitors amid all the current media hyperbole is a difficult exercise.

Dataquest's Japanese Semiconductor Industry Service (JSIS) recently conducted a half-day seminar to provide an update on various aspects of the Japanese semiconductor industry: its markets, manufacturers, and end-use drivers. From this seminar emerged a number of insights regarding the Japanese semiconductor industry. Among these were the following:

- From a $132 billion figure in 1988, the production value of Japan's electronics equipment is forecast to reach nearly $190 billion by 1992. Dataquest believes that the if-sold value of these goods will surpass the U.S. electronics industry at this time.

- Having become the world's largest semiconductor market in 1986, Japan's consumption of devices by 1991 will exceed $21 billion.

- In 1980, the number of semiconductor alliances entered into by Japanese suppliers could have been counted on one hand. In 1986 alone, Japanese semiconductor agreements numbered more than 100.

- Through the Neural Computer Project undertaken by Japan's Ministry of International Trade and Industry (MITI), current research is paving the way for a massively parallel computer using neural networks and/or biodevices. Dataquest expects stunning breakthroughs in system and chip architectures stemming from this program and others in the 1990s.

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This newsletter distills a number of recent Dataquest research efforts in order to characterize the Japanese semiconductor industry as a device consumer, a strategic alliance partner, and a growing competitive force worldwide.

JAPAN THE CONSUMER

In 1987, yen-based Japanese electronic equipment production was nearly flat, with negative growth rates in the industrial and consumer electronics segments. Despite the continued appreciation of the yen, however, Japan's electronic equipment industry is currently in recovery, with 15 percent growth in yen and 27 percent growth in dollars forecast for 1988. Dataquest expects this recovery to last until mid-1989.

The macroeconomic factors behind this growth are easy enough to understand—Japan's GNP growth for 1987 is expected to be 4 percent. What is more significant is that export-oriented Japan is being spurred by increased domestic demand, which contributed to 5 percent of its economic growth in 1987. Dataquest believes that private sector and domestic demand will continue leading the Japanese economy into 1989, with data processing, communications, and industrial electronic equipment output as well as consumer electronics growing.

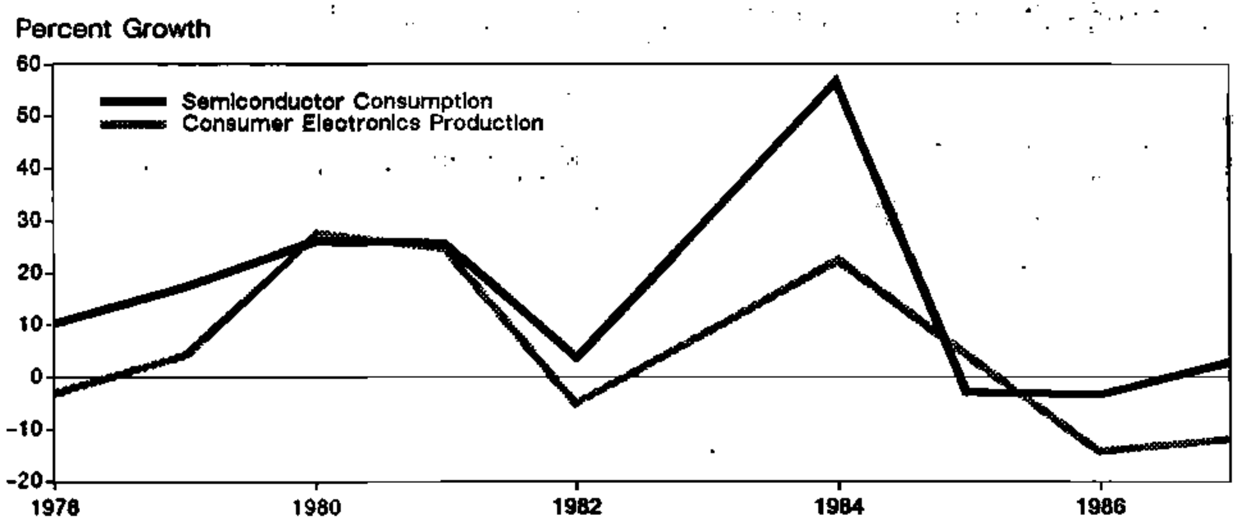
The nature of Japan's electronic equipment industry is changing rapidly. Analysts in Dataquest's Semiconductor User and Applications Group believe that in the period between 1987 and 1991, Japan's personal computer market will double in dollar-based production value, growing at a compound annual rate of 18.4 percent—well over twice that of color TVs and VCRs. By 1991, Dataquest believes that the production value of PCs and mainframe computers in Japan will be roughly equal in dollars to the combined total of its VCR and TV production.

The Japanese consumer electronics industry is no longer the driving force in the Japanese semiconductor market, although it accounted for better than 32 percent of semiconductor consumption in 1987. In fact, as Figure 1 illustrates, semiconductor consumption in the consumer segment has not grown for the past three years. Dataquest estimates that consumer electronics production in Japan will increase by 7.6 percent in 1988. By contrast, however, computer production in Japan grew 15 percent in 1987 and has maintained this strong growth through 1988. The computer/data processing market now accounts for nearly 43 percent of Japan's semiconductor consumption.

With computer manufacturing growing in importance, microprocessor (MPU), controller, and peripheral device consumption will surge. Traditional growth products such as linear ICs and discrete components will grow more slowly due to lower demand for consumer electronics equipment. Table 1 shows Dataquest's near-term analysis of the Japanese semiconductor market by major product area.

Figure 1

Semiconductor Consumption versus Consumer Electronics Production



Source: Dataquest
September 1988

Table 1

Estimated Japanese Semiconductor Consumption (Millions of Dollars)

	1987	1988	1989
Total Semiconductor	14,329	19,149	21,141
Total IC	11,006	14,986	16,634
Bipolar Digital	1,491	1,981	2,148
Memory	183	299	323
Logic	1,308	1,682	1,825
MOS	6,327	8,979	10,211
Memory	2,311	3,633	4,355
Microdevice	1,732	2,442	2,706
Logic	2,284	2,904	3,150
Linear	3,188	4,026	4,275
Discrete	2,424	3,043	3,266
Optoelectronic	899	1,120	1,241
Exchange Rate (¥ per $1)	130	125	124

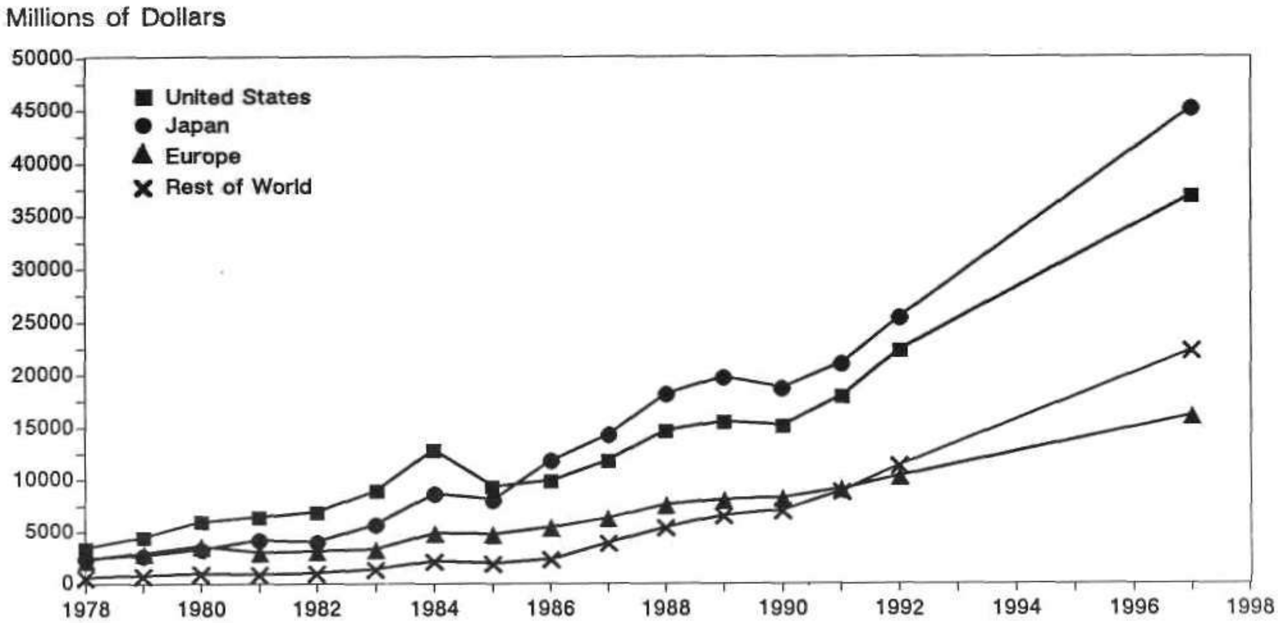
Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
September 1988

W.E. Davis, vice president of the Semiconductor Industry Association (SIA), recently noted that Japan and the Pacific Rim will account for two-thirds of the world's semiconductor consumption by the year 2000. Figure 2 compares regional consumption for the world, illustrating the fact that not only has Japan become the world's largest consumer of semiconductor devices since 1986, but that it will continue to outpace all other world markets for the foreseeable future.

Figure 2

Estimated Semiconductor Consumption by Region



Source: Dataquest September 1988

In light of Japan's changing semiconductor market, Dataquest believes that the best potential for increased penetration by foreign suppliers will be in the following product areas:

- 32-bit microprocessors, RISC, and SPARC architectures
- Digital signal processing (DSP)
- Complex standard cells and software
- High-performance bipolar devices

- Video digital-to-analog converters
- Analog devices

JAPAN THE PARTNER

Since 1980, Dataquest has recorded more than 350 strategic alliances between Japanese semiconductor producers and other Japanese or foreign companies. In the early 1980s, agreements generally involved one-way licensing or second-sourcing of U.S. microprocessors and ASICs and joint developments between U.S. and Japanese equipment makers. In most cases, these agreements were signed during the 1983-to-1984 boom years because of inadequate U.S. fab capacity and marketing presence in Japan. Several agreements ended up in court during the 1985 downturn as some of the Japanese partners began competing for a shrinking market.

Like the semiconductor market itself, the nature of Japanese alliances has been changing. More recent Japanese semiconductor alliances have become more sophisticated and varied, reflecting the shift of Japanese companies into application-specific memories, high-end microprocessors, smart cards, signal processors, CAD tools, power MOSFETs, and other emerging areas. CAD tools and software constituted a particularly hot alliance area in 1987, with Fujitsu, Hitachi, and Toshiba actively entering agreements to bolster their CAD capabilities in the fiercely competitive ASIC market. Table 2 lists these alliances.

Table 2

Japanese Semiconductor CAD Tool Alliances in 1987

Japanese Company	Partner	Product
Toshiba	SDA Systems	ASICs CAD software
Nippon Steel	Sun Microsystems	CAD workstations
Fujitsu Facom	Nippondenso (Japan)	Analog IC CAD system
Fujitsu	Tektronix	Gate array workstation
NEC/Fujitsu/Hitachi/ Toshiba/Mitsubishi	SDA Systems	ASICs CAD software
Tokyo Electron	Sun Microsystems	CAD OEM agreement
Seiko Instruments	Tangent Systems	CAD software
Toshiba	Viewlogic Systems	PC-based CAE software
Hitachi/Toshiba	FutureNet	Simulation library
Toshiba	Tangent Systems	Channelless array CAD

Source: Dataquest
September 1988

JAPAN THE COMPETITOR

Where Japan has been frustrated in its alliance efforts, most notably in obtaining 32-bit microprocessor technology from U.S. companies, it has turned inward. No better example of this exists than the TRON (The Real-time Operating Nucleus) Project. Starting out with a man-machine interface, TRON has progressed to an operating system followed by a microprocessor architecture. The TRON concept has now developed along several application areas: BTRON for personal computers, CTRON for mainframes, and ITRON for industrial applications. In January of this year, the "Gmicro Group," a chip technology committee made up of Fujitsu, Hitachi, and Mitsubishi Electric, announced that it had successfully developed a 32-bit microprocessor and three models of peripheral chips based on TRON technology. Hitachi, under whose auspices the 32-bit MPU was developed, is expected to begin volume production of the device, the GMICRO0200, in the fall of this year.

Table 3 provides a list of the major Japanese companies involved in the various TRON committees and reveals the extent of their unity in creating an industry standard, multiapplication computing engine. This show of unity compares favorably (for the Japanese) with the fractiousness of the U.S. microprocessor market. Those who view TRON as an attempt by Japanese companies to go head-to-head with Intel or Motorola in the microprocessor arena miss the point. Japan simply does not want to be dependent on the United States for the microprocessor technology that will define its future electronics systems.

Table 3

TRON Project Organization

	ITRON Technology Committee	BTRON Technology Committee	CTRON Technology Committee	Chip Technology Committee
Hitachi	O	O	O	X
Fujitsu	O	O	O	X
Mitsubishi	O	O	O	X
Toshiba		O	O	O
NEC	O	O	O	
Matsushita		O		O
Oki		O	O	O
NTT			O	

O = Under development
X = Gmicro family

Source: Dataquest
September 1988

The increased efforts at consensus between U.S. chip manufacturers, represented by the SIA, and chip users, represented by the American Electronics Association (AEA), acknowledge the recognition by both industries that Japan's greatest threat as a chip competitor will ultimately come about through its success in systems. Conversely, its greatest threat as a competitor in the systems arena will come about through its success in higher-integration chips such as ASICs and MPUs and advances in materials and interconnect technology.

While Japan's impact on the U.S. data processing market has up until now been most visible in the laptop PC segment, Dataquest expects to see a future increase in the export of office automation and personal communications products from Japanese companies that made their initial inroads into the U.S. market through consumer electronics. Examples of such horizon products include:

- Home control systems
- Auto navigation systems
- Built-in phone/fax systems for autos
- Memo-to-text and graphics electronic tablets for rapid production of hard copy and transparent overheads
- "PC watches" for internal office communications
- Videophone PCs
- Electronic shopping systems

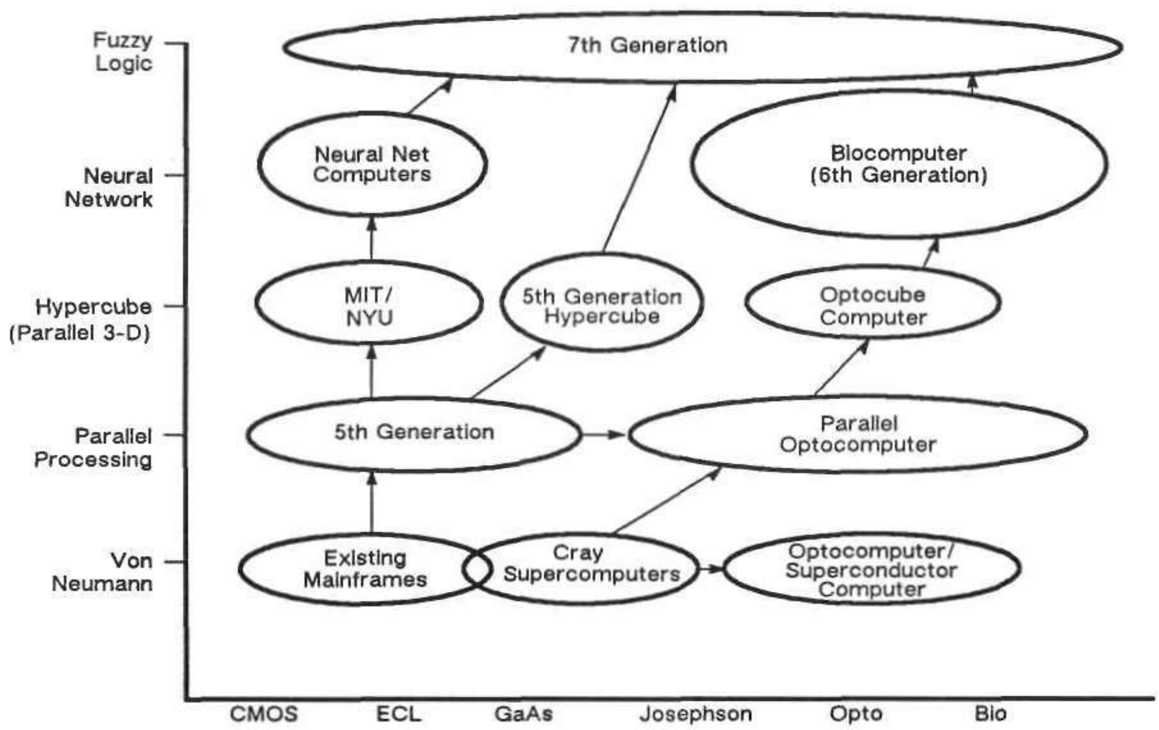
To support products such as these, component manufacturers will have to meet technology requirements in a number of areas. These will include 2-D and 3-D megabit memories (video and voice storage), specialized 32-bit MPUs (video and voice processing, parallel processing), optoelectronic ICs (semiconductor laser controllers and optical computing), and superconductors (ultrasupercomputing interconnection). Needless to say, the implementation of these technologies to systems solutions will require continued advances in submicron manufacturing, ASIC design, packaging, and interconnect techniques.

Looking beyond the office automation/data processing market as a driver of semiconductor technology, MITI and other Japanese government agencies have begun laying the foundations for next-generation computing in the 1990s and beyond. MITI recently announced the funding of a nine-year Neural Computer Project to begin in April 1989. The purpose of this project is to develop neural network systems and devices capable of massive parallel processing and "fuzzy" logic recognition. Dataquest believes that neural network technology will be the basis for breakthroughs in sophisticated ISDN voice, image, and pattern recognition computing and language translation.

MITI also expects the Neural Computer Project to complement its work on parallel processing and language translation currently under way in its Fifth-Generation Computer Project. Dataquest has observed intense research activity in Japan focusing on neural networks and fuzzy logic since the first IEEE Neural Network Conference in San Diego in June 1987. To place current Japanese computer projects in perspective, analysts in Dataquest's Japanese Semiconductor Industry Service have developed a technology road map for future computing systems, as shown in Figure 3. Today, existing mainframes and supercomputers have limited computing performance. Future computers will employ optical switches to link with optical communications and video systems, and hypercube architecture will be used for various technologies. In MITI's Biocomputer Project, neural network and bioelectronic research are converging.

Figure 3

Future Computing Trends



Source: Dataquest
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DATAQUEST CONCLUSIONS

In support of its current and future systems demands, the Japanese semiconductor industry has entered into a new era. The industry of pre-1985 Japan was marked by commodity ICs, microprocessor licensing and second-source deals, and DRAM dominance. The post-1985 Japanese semiconductor industry is witnessing the development of ASICs and CAD software, proprietary microprocessors (TRON and RISC), and an increasing interest in specialty memories.

In the battle to keep the U.S. semiconductor industry a world-class competitor, domestic chip producers are engaged in a number of major skirmishes: dumping prevention, increased access to the Japanese market, more effective protection of intellectual property, and the use of consortia to improve manufacturing technology. The U.S. could conceivably win all of these battles, however, and still lose the war. As James Smaha, the head of National Semiconductor's components division, has put it, "application drives specification." If Japan ultimately sets the pace for future electronics systems, it will be in the position of defining component product standards. In such an environment, the U.S. chip industry will have to choose between adhering to such standards and accepting the role of follower rather than leader or fighting against them and risking isolation and irrelevance.

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Dataquest
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Research *Bulletin*

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HARRIS CORPORATION TO ACQUIRE GE SOLID STATE

Since GE's acquisition of RCA in mid-1986, there has been much speculation regarding its intentions in the merchant semiconductor market. Over the past year, the company frequently intimated its willingness to sell its semiconductor business. These rumors were put to bed, with the August 15 announcement of an agreement for Harris Corporation to acquire GE Solid State.

Specific details of the agreement have not been released. However, it was announced that GE's dedicated facility, the Microelectronics Center in Research Triangle Park, North Carolina, will be excluded from the deal, along with certain other military semiconductor operations that were acquired from RCA and are part of GE's aerospace business.

Harris

Dataquest estimates that Harris' 1987 semiconductor revenue remained essentially flat at $268 million. Semiconductor revenue represented 13 percent of the company's total revenue for calendar year 1987. If GE Solid State's 1987 semiconductor revenue were added to this, the percentage would jump to about 38 percent of total company revenue, giving the combined entity a number-16 ranking worldwide.

Profiles of the companies' respective participation in the semiconductor market are quite different, based on 1987 semiconductor revenue.

What Do the Numbers Mean?

Three primary areas—military, linear, and standard logic—seem to emerge as the significant items in this proposed transaction. Harris' main strength within the semiconductor market stems from its position in the military market segment where it is one of the leading suppliers. Sources at GE claim that the GE/Harris businesses are very complementary from a military perspective. The venture probably would rank Harris as one of the top two suppliers to the military market. National Semiconductor, the current leader, had estimated 1987 military revenue of $250 million. The deal also would result in the consolidated supply of super radiation-hardened devices by Harris, already a leading supplier.

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Harris concentrates its linear business on amplifiers, whereas GE distributes its linear products fairly evenly over the areas of amplifiers, interface, data conversion, consumer, and other linear products. More than one-fourth of GE Solid State's semiconductor revenue is derived from sales of discrete products, while Harris has no presence in this market. Often this product area is considered a good source of steady revenue, so it may be Harris' intention to benefit from GE's established position in this market.

GE's solid standard logic business, which it inherited from RCA, would be another area of appeal to Harris. GE Solid State ranked among the top 10 standard logic suppliers in 1987, with revenue of $110 million, and was the leading MOS logic supplier to the military market. We note that Harris pulled out of the bipolar gate array market in 1987, but the companies' combined MOS gate array revenue would move Harris up toward a top-10 spot. However, the more significant development would occur with respect to cell-based ICs: Revenue amalgamation, viewed in terms of 1987 revenue, would place the company as the second target supplier worldwide. Although Harris currently participates in the MOS PLD market, it does not do so to any great extent, and it retreated from the bipolar PLD market in 1985.

Why the Merger?

One has to wonder about Harris' objectives in undertaking this acquisition. Harris certainly would expand its presence in the semiconductor market, but more importantly, would expand its presence in the military semiconductor market. Harris reported fiscal 1988 sales and earnings showing a fourth-quarter decline in sales of 4 percent, to $538.4 million, and a 93 percent decline in income to $1.8 million. Sales were flat at $2.1 billion, and without the adoption of FAS No. 96 to offset a $33.1 million charge for asset revaluations and restructuring costs, the company would have reported a 23 percent decline in income for fiscal 1988, as opposed to the reported 19 percent increase.

From GE's perspective, its semiconductor operations did not fit into its long-term strategy of focusing on jet engines and major household appliances—markets where it is a leading supplier. This view is consistent with the company-stated goal of remaining among the top two suppliers in the markets that it serves. GE's semiconductor operations constituted one of the company's smaller support operations. Apparently, GE had decided that it needed only research, design, and limited manufacturing capability to support its aerospace and medical equipment businesses. GE's acquisition of RCA presented the challenge of integrating both captive and merchant operations. However, morale at GE, and more particularly at RCA, suffered somewhat as a result of the takeover.

Now Harris will face the challenge of integrating GE Solid State to its semiconductor sector reporting to Vice President Jon Cornell. Negotiations are not expected to be completed until year end. Many questions are still outstanding, such as: What are the implications of this transaction for GE's gate array agreement with VLSI Technology and for the agreement to cooperate with IBM on ASICs and power BICMOS products?

Patricia Galligan

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Research Bulletin

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CAN CALIFORNIA MICRO DEVICES INJECT NEW LIFE INTO AMI?

Gould Inc. and California Micro Devices Corp. (CMD) have signed a definitive agreement whereby CMD will purchase Gould's Semiconductor Division, the former American Microsystems Inc. (AMI). CMD will acquire all of the ongoing semiconductor operations of AMI at the approximate cost of $70 million in cash. This acquisition includes the name; a 310,000-square-foot wafer fab in Pocatello, Idaho; a 64,000-square-foot test and assembly facility in the Philippines; AMI's ASIC design software; and a total worldwide work force of approximately 1,500 employees.

According to Dataquest market share figures, Gould/AMI's 1987 semiconductor revenue totaled $100 million, while CMD's revenue for the same fiscal year was approximately $10 million. During this period, CMD acquired the Microcircuits Division of GTE Communications, which would have doubled its fiscal 1987 sales figure. In the case of both CMD and AMI, application-specific IC (ASIC) related business accounted for the majority of 1987 revenue. Table 1 provides a breakout of the ASIC revenue for AMI and CMD.

Table 1

CMD/AMI ASIC Revenue Analysis
Fiscal 1987
(Thousands of Dollars)

	Gate Array	Cell-Based IC	Other	Total
CMD	$ 4,000	$ 2,000	$ 4,000	$ 10,000
GTE	1,000	0	7,000	8,000
AMI	6,000	20,000	74,000	100,000
Total	$11,000	$22,000	$85,000	
Combined CMD/AMI ASIC Revenue				$118,000

Source: Dataquest
August 1988

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Although the full-custom design and foundry work have produced a significant portion of AMI's total semiconductor revenue, the preceding table reveals that cell-based ICs (CBICs) comprise the single largest ASIC segment of the combined CMD/AMI. Dataquest's market share figures indicate that the total CBIC revenue of the two companies puts them among the world's top ten CBIC suppliers.

There are a number of promising aspects regarding a combined CMD/AMI. AMI should benefit from a management team (Chan M. Desaigoudar, chairman, chief executive officer; Handel H. Jones, president, chief operating officer) with a more focused approach to the semiconductor market than that of more diversified Gould. Under Messrs. Desaigoudar and Jones, CMD has given a good accounting of itself. During a period of industry recession in 1985 and 1986, CMD's revenue grew by 45 percent. Although it had fiscal 1987 revenue growth of only 3 percent, the company increased its gross margin to nearly 49 percent and concluded the acquisition of GTE's semiconductor division.

Besides its management strengths, CMD presents a compelling mix of technologies. Starting out as a supplier of thin-film components in 1976, CMD created its ASIC division in 1983. With the introduction two years later of a proprietary, high-density, ultrastable thin-film material (SX), the company became capable of integrating the two technologies. In 1987, approximately 40 percent of CMD's ASIC designs utilized on-board, thin-film components, representing a high-margin product line for military markets. The company also has a development contract from a major computer manufacturer to provide prototypes of an ink-jet color printhead with approximately 50 jets.

Once the AMI acquisition is approved, CMD will find itself propelled into the ranks of the top 40 semiconductor companies of the world (based on 1987 market share data). The challenge will be one of marketing this newfound muscle. The nature of CMD's products and technology have placed it in the low-volume, high-margin world of military niche markets. This contrasts with the majority of AMI's business in commercial data processing and communications segments.

To swallow an entity that went nowhere in 1987, the team of Desaigoudar and Jones will have to take on additional debt during a period of business conditions that Dataquest believes have crested. CMD will then have to demonstrate the same propensity for profit in a market more competitive and less familiar than those in which it has demonstrated its strengths. The fact remains, however, that CMD has gotten where it is today by virtue of sound management and gutsy moves—attributes that its management team will now apply to a greatly expanded potential.

Michael J. Boss

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FLYING HIGH IN SEMICONDUCTORS: BUCKLE UP FOR DESCENT

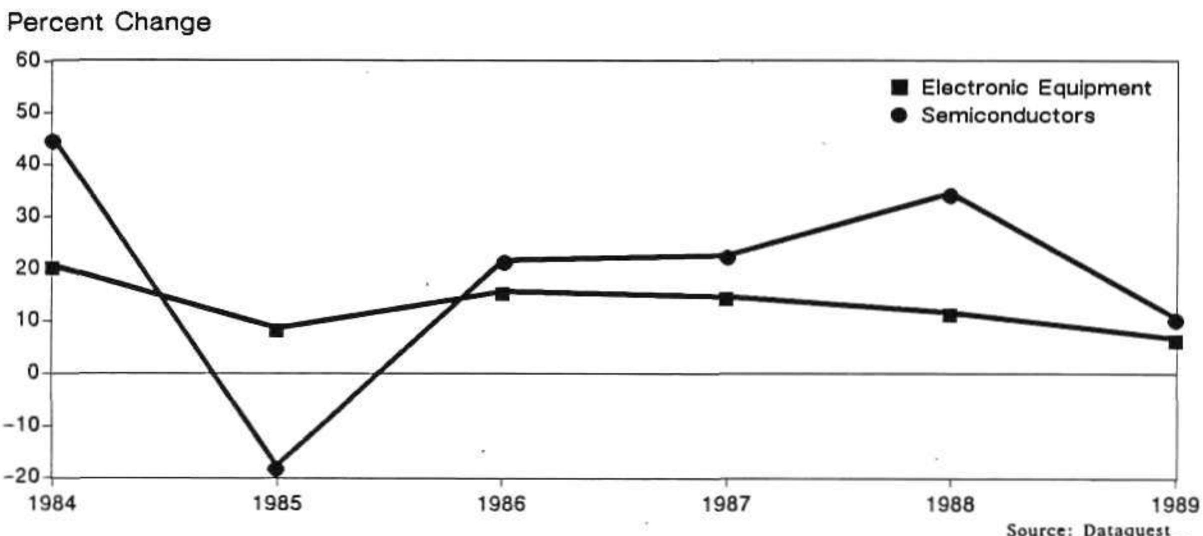
SUMMARY

The recovery in the worldwide semiconductor market that began in early 1987 has turned into a boom in the sizzling summer of 1988. Unlike the rampant double-ordering and inventory accumulation that characterized the euphoria of 1984, however, the current market conditions are unbalanced only in selected product areas, most notably in memory chips. The cycle of chip shortages, firming prices, and capacity build-up is following a healthier pace in the current recovery. Smarting from the scars of a devastating market collapse in 1985, semiconductor vendors approached this recovery with wise caution, suggesting that the industry is coming of age.

At a 35 percent growth rate in 1988, the worldwide semiconductor industry is now growing at about two to three times the pace of growth in electronic equipment production, as shown in Figure 1. Surprisingly, the multiple in 1984 was in the same

Figure 1

**Estimated Worldwide Annual Growth Rate
Electronic Equipment versus Semiconductors**



Source: Dataquest
August 1988

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range, but somewhat closer to two. While the growth in PCs, workstations, and technical computers fuels the semiconductor recovery, these segments are now growing at modest sustainable rates, unlike the skyrocketing pace of 1983 and 1984. We anticipate a deceleration in electronic equipment production from 12 percent growth in 1988 to 7 percent growth in 1989. What does this mean for semiconductors? Cautious industry leaders should now buckle up for descent to a modest growth of only 11 percent in 1989 in the world semiconductor market.

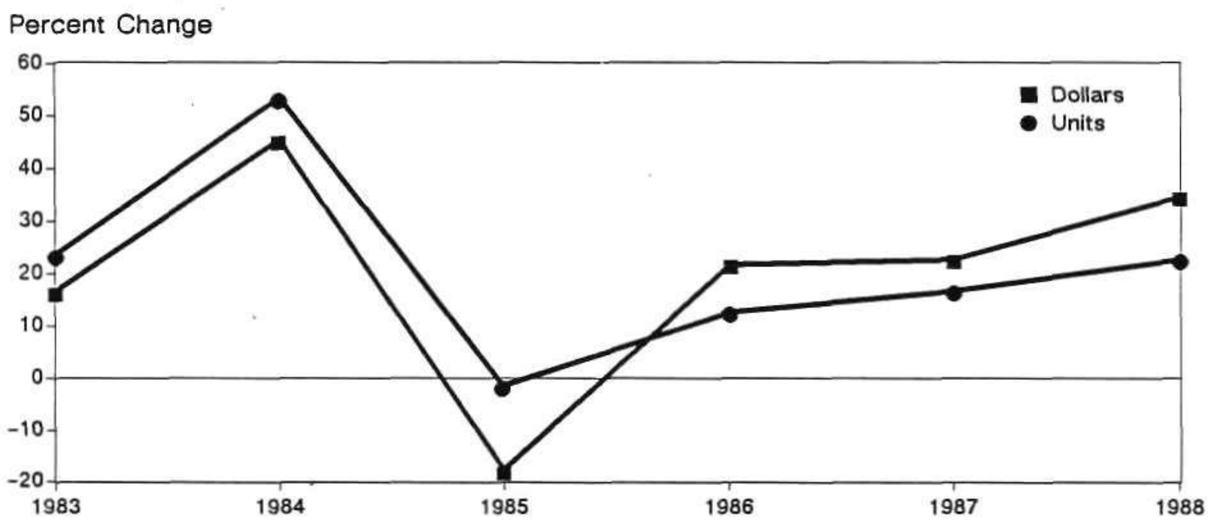
COMPONENTS OF GROWTH

Dataquest estimates the size of a market as the total available market (TAM) for merchant shipments. It is important to note that TAM consists of demand for consumption and inventory buildup in the various stages of procurement and manufacturing flow. Also note that in times of shortages, demand for consumption may exceed TAM due to inventory depletions.

The growth in the world semiconductor market expressed in U.S. dollars is a composite of changes in volume (TAM in units) and average selling price (ASP). The comparison of volume growth and dollar growth shown in Figures 2 and 3 sheds some light on the current state-of-the-world semiconductor and IC markets. To understand the difference between volume growth and dollar growth, let us explore the components that influence semiconductor ASP.

Figure 2

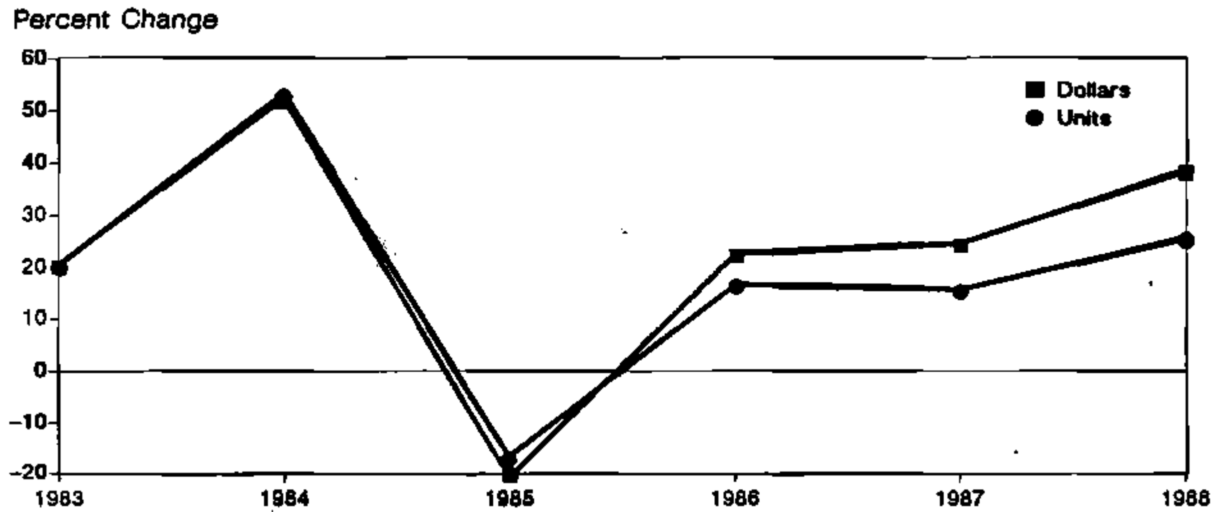
Estimated Worldwide Semiconductor Market
Dollars versus Units



Source: Dataquest
August 1988

Figure 3

Estimated Worldwide IC Market
Dollars versus Units



Source: Dataquest
August 1988

Components of ASP Change

Perhaps the most obvious component of semiconductor ASP change is the effect of the supply and demand situation and the learning curves for individual products on market price movements.

A second component of ASP change is the effect of swings in currency exchange rates to the U.S. dollar in a global product market. For example, the dollar value of the Japanese semiconductor market is affected significantly by the rising yen.

A third interesting component of semiconductor ASP change is the effect of the continuing movement to a higher integration, higher unit value, product mix. As segments of the semiconductor industry churn out more bits in fewer packaged units valued at higher prices, there is significant upward pressure on ASP. Examples of these higher integration trends include denser memories, higher functionality in microcomponents, and the displacement of standard logic by ASIC. Nonrecurring engineering expenses (NRE) associated with ASIC designs also have a front-loading effect on ASP.

The data in Figure 2 raise the spectre of inflationary growth, suggesting that prices could soften considerably when demand slackens. After factoring out the effects of exchange rate swings, the combined effect of price and mix changes on ASP is shifting from a negative 4 percent in 1987 to a positive 4 percent in 1988 as shown in Table 1.

Table 1

Estimated Worldwide Semiconductor Market
(Percent Change)

	1987	1988
In Dollars	23%	35%
In Units	-17	-23
Difference	6%	12%
Exchange Rate Effect	-10	- 8
Price plus Mix Effect	(4%)	4%

Source: Dataquest
August 1988

DATAQUEST'S FORECAST

We are often asked the following question: How can the worldwide semiconductor industry sustain a 13 to 15 percent long-term growth rate when the undelying electronic equipment industry has a long-term growth rate of only 9 to 11 percent? The answer to this question lies in the effect of the value added by innovation, related to the "pervasiveness" of semiconductors. As semiconductor vendors push the frontiers of technology to support and sometimes drive innovation in electronic equipment application markets, more value is transferred into silicon. Leading-edge electronic products pay a premium for the silicon content to buy into the new technologies early. This continuous infusion of new technologies and applications accounts for about a 4 percentage point spread between the long-term growth rates in electronics and semiconductors.

Dataquest estimates that the worldwide semiconductor market should boom at a 35 percent rate in 1988, as shown in Tables 2 and 3. We anticipate that a deceleration in electronic equipment demand should soften semiconductor prices by mid-1989, causing the worldwide semiconductor market to slow to a modest 11 percent growth in 1989. Dataquest's semiconductor forecast through 1993 will be presented on October 17 at the Semiconductor Industry Conference in San Diego.

Joseph Borgia

Table 2

Estimated Worldwide Semiconductor Market
(Billions of U.S. Dollars)

Regions	1987	1988 Q1	1988 Q2	1988 Q3	1988 Q4	1988	CAGR 1987-1988
North America	$11.9	$3.45	$3.85	$4.09	$4.28	$15.7	32.0%
Japan	14.3	4.38	4.75	4.96	5.07	19.1	33.6%
Europe	6.4	1.97	2.14	2.15	2.21	8.5	33.2%
Rest of World	3.9	1.32	1.50	1.60	1.67	6.1	56.1%
Total World	$36.5	$11.1	$12.2	$12.8	$13.3	$49.4	35.4%
Exchange Rates							
Yen/US$	144	128	125	125	125	126	
European Basket/$	125	117	117	117	117	117	

Regions	1988	1988 Q1	1988 Q2	1988 Q3	1988 Q4	1989	CAGR 1988-1989
North America	$15.7	$4.39	$4.43	$4.35	$4.18	$17.4	10.8%
Japan	19.1	5.17	5.30	5.37	5.30	21.1	10.4%
Europe	8.5	2.25	2.31	2.22	2.25	9.0	6.6%
Rest of World	6.1	1.75	1.78	1.79	1.79	7.1	16.9%
Total World	$49.4	$13.6	$13.8	$13.7	$13.5	$54.6	10.7%

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
August 1988

Table 3

Estimated Worldwide Semiconductor Shipments
(Millions of U.S. Dollars)

Regions	1987	1988 Q1	1988 Q2	1988 Q3	1988 Q4	1988	CAGR 1987-1988
Total Semiconductor	$36,449	$11,112	$12,225	$12,791	$13,234	$49,362	35.4%
Total IC	$28,619	$ 8,821	$ 9,800	$10,325	$10,747	$39,693	38.7%
Bipolar Digital	4,672	1,297	1,394	1,464	1,524	$ 5,679	21.6%
Memory	565	154	174	183	192	703	24.4%
Logic	4,107	1,143	1,220	1,281	1,332	4,976	21.2%
MOS Digital	$16,739	$ 5,385	$ 6,150	$ 6,539	$ 6,851	$24,925	48.9%
Memory	6,019	2,182	2,565	2,776	2,905	10,428	73.3%
Micro	4,770	1,521	1,771	1,850	1,910	7,052	47.8%
Logic	5,950	1,682	1,814	1,913	2,036	7,445	25.1%
Linear	$ 7,208	$ 2,139	$ 2,256	$ 2,322	$ 2,372	$ 9,089	26.1%
Discrete	$ 6,112	$ 1,805	$ 1,907	$ 1,930	$ 1,944	$ 7,586	24.1%
Optoelectronic	$ 1,718	486	518	536	543	$ 2,083	21.2%
Exchange Rate Yen US$	144	128	125	125	125	126	(12.5%)
European Basket US$	125	117	117	117	117	117	(6.4%)

(Continued)

Table 3 (Continued)

Estimated Worldwide Semiconductor Shipments
(Millions of U.S. Dollars)

Regions	1988	1989 Q1	1989 Q2	1989 Q3	1989 Q4	1989	CAGR 1988-1989
Total Semiconductor	$49,362	$13,558	$13,824	$13,727	$13,521	$54,629	10.7%
Total IC	$39,693	$11,020	$11,236	$11,139	$10,960	$44,354	11.7%
Bipolar Digital	$ 5,679	$ 1,557	$ 1,569	$ 1,504	$ 1,443	$ 6,073	6.9%
Memory	703	190	189	181	176	736	4.7%
Logic	4,976	1,367	1,380	1,323	1,267	5,337	7.3%
MOS Digital	$24,925	$ 7,042	$ 7,196	$ 7,171	$ 7,064	$28,472	14.2%
Memory	10,428	3,001	3,083	3,082	3,017	12,183	16.8%
Micro	7,052	1,953	2,005	2,005	1,989	7,951	12.7%
Logic	7,445	2,088	2,108	2,084	2,058	8,338	12.0%
Linear	$ 9,089	$ 2,421	$ 2,471	$ 2,464	$ 2,453	$ 9,809	7.9%
Discrete	$ 7,586	$ 1,981	$ 2,015	$ 2,020	$ 2,000	$ 8,016	5.7%
Optoelectronic	$ 2,083	$ 557	$ 573	$ 568	$ 561	$ 2,259	8.4%
Exchange Rate Yen US$	126	126	126	126	126	126	0
European Basket US$	117	117	117	117	117	117	0

Source: Dataquest
August 1988

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TI: VERTICAL INTEGRATION U.S.-STYLE

SUMMARY

As the furor over chip dumping subsides, the United States is beginning to realize that the vertical integration of Japanese electronics companies is as much responsible for their worldwide success as their forward pricing strategies. Furthermore, there is a growing realization that in an era of application-driven design, vertical integration between systems and components yields benefits as substantial as the fostering of economies-of-scale manufacturing.

With the exception of Texas Instruments (TI), the U.S. semiconductor industry, at least in the merchant arena, is not marked by vertical integration. This newsletter analyzes TI and provides an update on the company's current semiconductor strategies from the standpoint of vertical integration, which Dataquest characterizes as follows:

- Synergy between systems and components
- Forward-looking R&D investments to support the systems and components
- Successful commercialization of technology
- Manufacturing excellence
- International marketing presence

TI FINANCIAL UPDATE

Recovery in 1987

TI experienced a strengthening in its main businesses--semiconductors and defense systems--in 1987. The company also invested in knowledge-based systems, industrial automation, and computer-aided software engineering to increase productivity. TI took a major realignment step by selling its majority interest in Geophysical Service, Inc. (GSI). This consolidation was undertaken to drive TI's total business mix toward a higher

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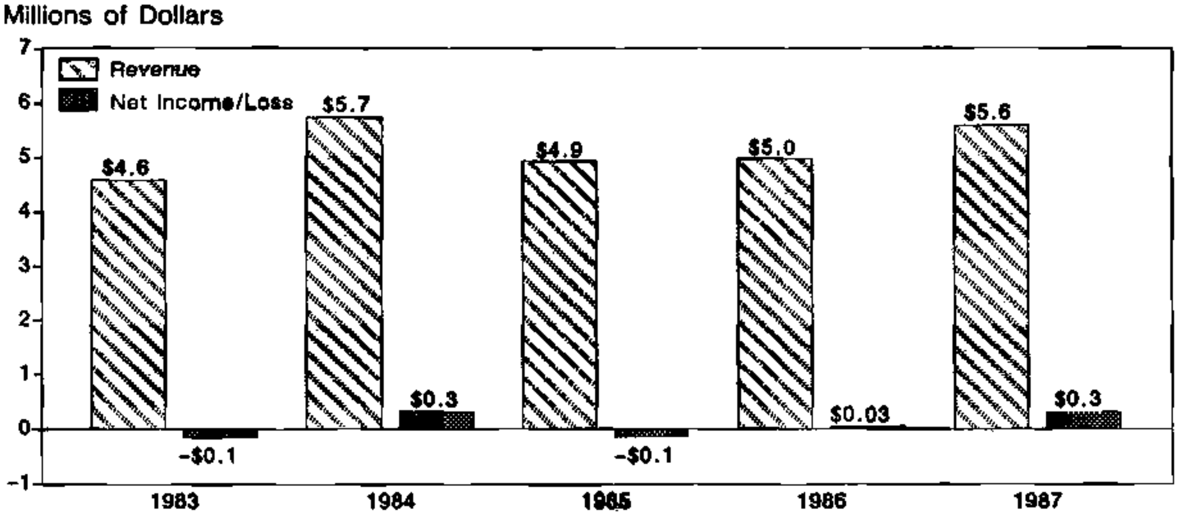
content of proprietary systems and software. Improvement continued in the company's financial performance in 1987, as shown in Figure 1. Revenue totaled $5.6 billion, an increase of 12 percent over 1986. Net income was $309 million, up substantially from $29 million in the prior year. TI continues to defend its investment in intellectual property vigorously, as is apparent from the DRAM litigation, which resulted in adding $191 million of royalty income to the company's net income figure.

Figure 1

TI Revenue/Income
1983–1987



Source: Texas Instruments Annual Report

Positive Outlook for 1988

TI's total order backlog reached record levels in the first quarter of 1988, amounting to $5 billion. First quarter 1988 revenue was approximately $1.5 billion, up 15 percent from the corresponding period in 1987, but down from the prior quarter. Reasons contributing to this decline from the fourth quarter were TI's sale of GSI, the timing of defense electronic shipments, and the seasonal decline in consumer electronics. Semiconductor demand continued to strengthen, however. Other income for the first quarter included $52 million of royalty income from the settlement of the DRAM patent litigation, including royalties from another company not listed in that litigation. Royalty income will be less significant in the second quarter.

The company's overall outlook for 1988 is positive. TI has reaped financial benefits from the DRAM shortage situation. Semiconductor bookings are being driven by PCs and electronic workstations (EWs). TI expects worldwide semiconductor growth of 25 percent and U.S. growth of 20 percent in 1988, basically consistent with Dataquest forecasts.

Capital Spending and R&D Increases

Total company capital expenditure is forecast to increase more than 30 percent in 1988, as shown in Table 1, and will primarily support the company's semiconductor operations and defense business. In the semiconductor area, capital expenditure will be largely for equipment to outfit new front-end operations. Capital expenditure on equipment for 1Mb DRAM capacity has been approved for both TI's Miho, Japan, and Dallas, Texas, fabs. Currently, TI is in volume production of 256K DRAMs at its DMOS IV facility in Dallas and is producing 1Mb DRAMs at its Miho fab. In the latter half of 1988, 256K DRAM production at Dallas is expected to transition over to 1Mb devices. TI's R&D spending in 1988 is expected to grow 5 percent, again reflecting large investments in semiconductor products, particularly systems-level products.

Table 1

Texas Instruments
Estimated Semiconductor Capital and R&D Expenditure
(Millions of Dollars)

Texas Instruments	1983	1984	1985	1986	1987	1988	Change 1987-1988
S/C Revenue	$1,638	$2,484	$1,742	$1,781	$2,127	N/A	
Capital Expenditures	$ 478	$ 722	$ 515	$ 447	$ 459	$600	30.7%
S/C Capital Expenditures	$ 232	$ 472	$ 281	$ 213	$ 231	$360	55.8%
Capital as a % of S/C Revenue	14.2%	19.0%	16.1%	12.0%	10.9%	N/A	
R&D	$ 301	$ 367	$ 402	$ 406	$ 428	$450	5.1%
S/C R&D	$ 163	$ 195	$ 214	$ 256	$ 270	$295	9.3%
R&D as a % of S/C Revenue	10.0%	7.9%	12.3%	14.4%	12.7%	N/A	

N/A = Not Available

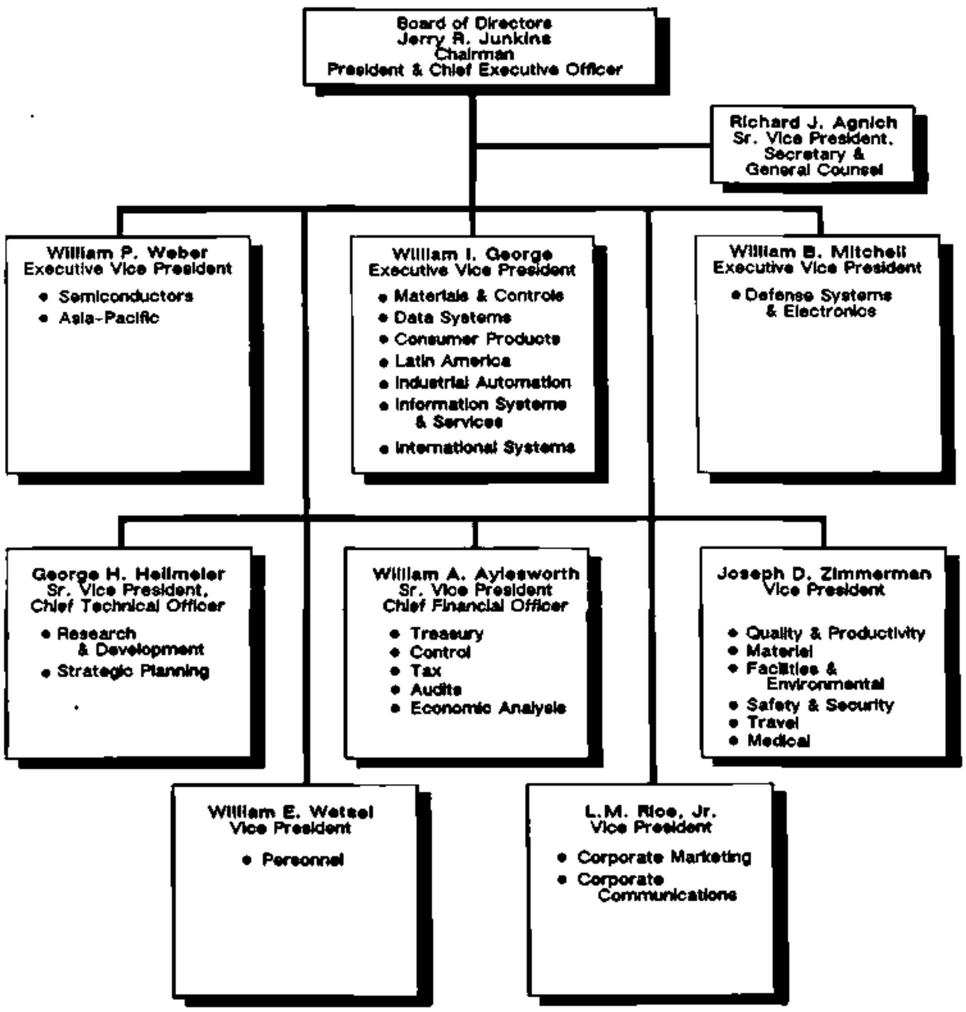
Source: Texas Instruments, Inc.
Dataquest
August 1988

MANAGEMENT

It was announced at TI's Annual Shareholder's meeting that Mark Sheppard Jr. would be stepping down as Chairman of the Board after 40 years at the helm of Texas Instruments. His announced successor, Jerry Junkins, has been operating as the company's president since the departure of Fred Bucy in 1985. This restructuring of management is reflected in the organization chart shown in Figure 2. Prior to the changeover of presidents in 1985, TI had suffered from an industry perception of being overly introspective. This attitude, however, appears to be changing under the new management. Nowhere is this change more evident than in the company's newly developed interest in strategic alliances, which is in sharp contrast to its former custom of going it alone. This greater openness of management philosophy is viewed as a positive development.

Figure 2

Texas Instruments, Inc.
Organization Chart



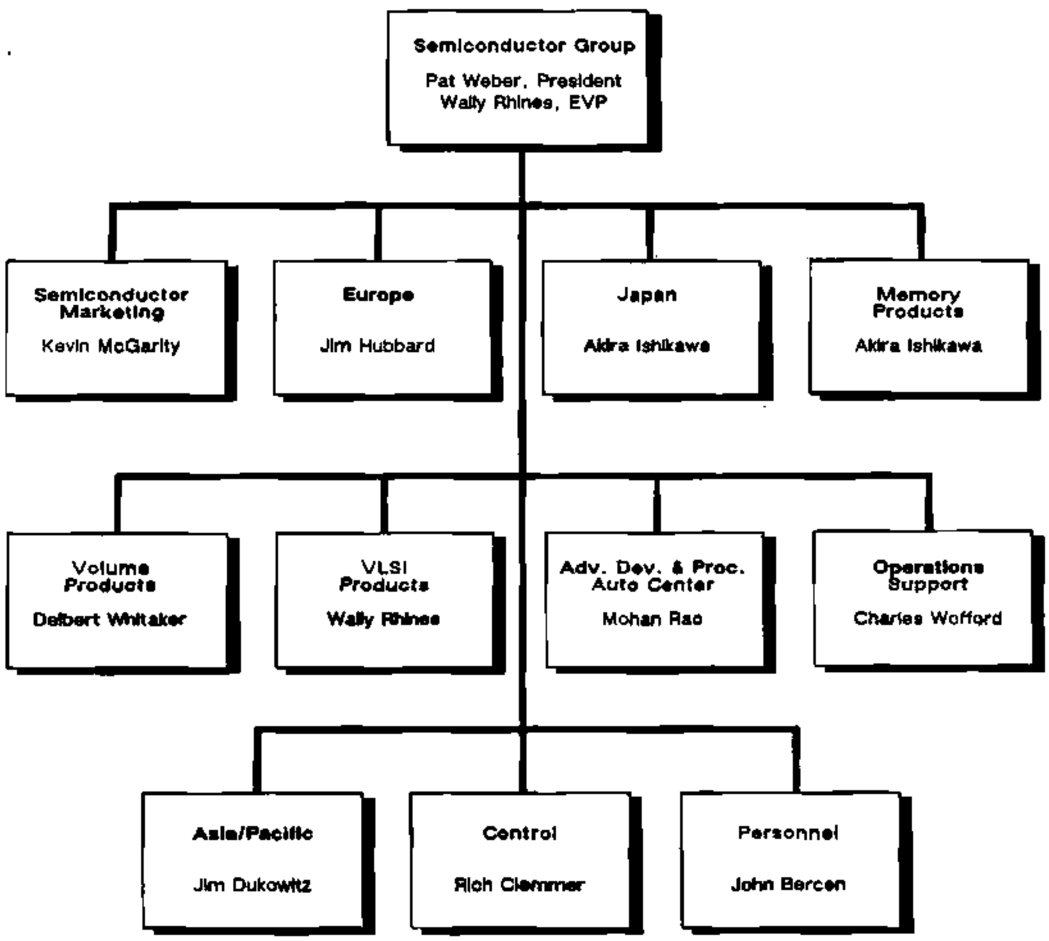
Source: Texas Instruments Inc.

Semiconductor Group Organization

TI changes in management over the past few years were made with a view to honing its structure to better compete in a more global marketplace. Effective January 1987, William "Pat" Weber, formerly in charge of corporate development, became president of the Semiconductor Group, replacing William Sick, Jr. A newly established position of creating alliances and cooperative agreements and raising TI's visibility in the Asia-Pacific region was filled by William Sick until his departure from TI. Mr. Sick handled the formative period of this program during a turbulent time while the search for a home for Sematech was under way and there was ongoing litigation between TI and some Far East companies. Since Mr. Sick's departure from TI, this area of responsibility resides within the office of the president, which is occupied by Pat Weber and Wally Rhines, as shown in Figure 3. In June 1986, the company's memory operations were reorganized under Akira Ishikawa; he is responsible for operations in Japan as well as worldwide memory operations, reporting to Pat Weber.

Figure 3

Texas Instruments, Inc.
Semiconductor Group Organization Chart



Source: Texas Instruments Inc.

Two key indicators can be used to measure the effectiveness of management: long-term planning and leadership. The challenge that TI management has defined for itself is to compete with well-financed vertically integrated Far East manufacturers in an increasingly global market.

VERTICAL INTEGRATION

Synergy between Systems and Components

TI believes that AI and industrial automation can support much more business and thus strengthen systems capability throughout the company. TI views itself as a pioneer in AI/speech/factory automation/CAD technology. It contends that there is an emergence of the concept of "hypermedia," where text, speech, images, and graphics converge. TI intends to be a leading supplier of productivity solutions through investment in three key areas:

- Knowledge-based systems (AI)
- Industrial automation
- Computer-aided software engineering

TI traditionally has been strong in AI hardware and development tools, and recently has augmented its position through an agreement with Apple Computer that is aimed at delivering AI capability to desktop computers.

By acquiring Rexnord's control and industrial systems division and the company's own product development, TI is becoming a full-range supplier of factory automation systems (Rexnord is a wholly owned subsidiary of Banner Industries, a supplier of aviation replacement parts as well as a diverse line of pumps and other mechanical and electronic parts and systems for the industrial market.) The following two Rexnord product lines were of particular interest to TI:

- The D/3 system is a distributed process control system that offers advanced, integrated batch capabilities aimed at medium-size to large businesses and complements TI's own TRISTAR system, which is aimed at small to medium-size businesses.
- The other product line, the S/3 system, is a supervisory control and data acquisition product for geographically distributed business operations.

TI is pursuing a market opportunity in software development that will reduce development time and cost. The company will be marketing a new product—Information Engineering Facility—that will allow system developers to analyze problems and design software using simple graphical diagrams to generate computer programs.

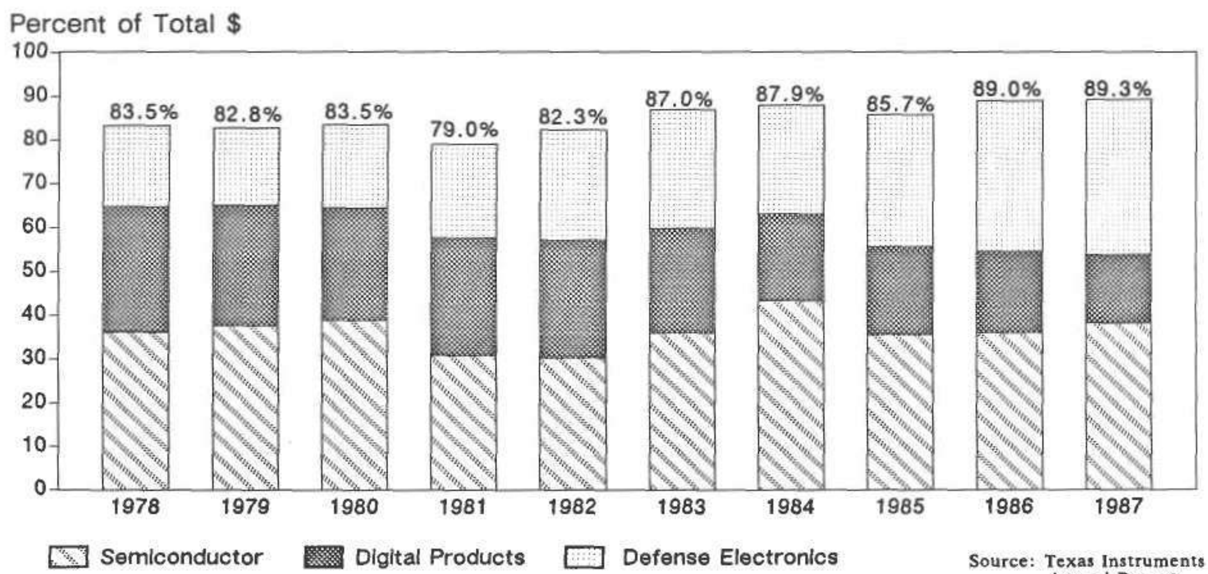
For the merging of silicon and systems to be successful, integration of the two is key. TI has recognized this and has established a business objective that builds on the synergy between its semiconductor and defense electronics business. Figure 4 shows how semiconductor and defense business revenue has been gaining as a percent of TI's total revenue for many years now. R&D expenditure will focus on a higher level of systems capability, primarily in VLSI, defense electronics, artificial intelligence (AI), and industrial automation technology.

TI believes that AI and industrial automation will strengthen systems capability throughout the company. The company's strategies to address this challenge include the following:

- Increasing design automation to shorten time to market and achieve lower costs
- Maintaining manufacturing process leadership through focused R&D investment and aggressive moves into new technologies
- Developing closer customer relationships
- Penetrating the components market in the product areas where TI can provide system-level solutions, as follows:
  - ASICs (application-specific integrated circuits)
  - Application processors
  - Advanced linear devices
  - Military semiconductors
  - VLSI logic

Figure 4

Semiconductors, Digital Products, and Defense Revenue
(Percent of Total Business)



Source: Texas Instruments Annual Report

The System is the Chip

The rapidly evolving pace of technology and accelerating product life cycles are forcing companies to speed up their decision-making process, respond to new markets more quickly, and introduce products much faster. If ASICs—or CSICs (customer-specific ICs) in this case--become the new technology driver, value-added design will move closer to the user and the need for closer customer-vendor relationships will become more critical. In this environment, a company can introduce higher value-added products through the application of better technology. New products and short runs will drive the manufacturer's speed, flexibility, and assembly. Companies will only be considered "global" when they can manufacture, market, and design products anywhere in the world. Although TI has made its money in the standard logic business, a "sunset" product segment, its manufacturing capabilities, customer service emphasis/sales support, and standard product dominance in the logic area put the company in a very strong position in the applications-specific era. It is this focus on applications that reflects TI's forward-looking approach.

Application Processors

TI is the leading supplier of single-chip digital signal processors (DSPs). According to Dataquest estimates, 1987 revenue in this market amounted to $98 million, with TI by far the dominant supplier at approximately 45 percent market share. Originally, DSP devices were conceived to support complex speech and telecommunication applications, but they are finding their way into markets such as active suspension systems for automobiles, which is potentially a very significant market opportunity. A key feature of TI's success in this market was its commitment of the resources to provide an extensive infrastructure to support the needs of its customers.

TI has employed a heavily modular design approach in its recently announced configurable MCU family, the TMS370, so that this high-performance 8-bit MCU is reconfigurable to include such on-chip options as EEPROM and A/D converters. Because of features such as more on-chip functions, speed (the device has a 20-MHz clock), fabrication in 1.6-micron CMOS for low power consumption, and a host of development support tools, this product family has the potential to raise TI's standing in the MCU world, where its TMS1000 was once the industry leader.

In the graphics arena, TI's 34010 32-bit MPU, which focuses on graphics applications, has been well received. TI claims 750 design wins for the product. According to Dataquest estimates, approximately 100,000 units were shipped in 1987.

TI's IC design methodology is to use a standard process and design rules, which are stored electronically in TI's library. Not only can this decrease design cycle time by 75 percent, it also allows customers to access designs. In ASICs, TI's standard cell library offers 1-micron feature sizes in CMOS technology. Its LinASIC library contains 30 analog cells and 300 digital cells in CMOS and allows a combination of analog and digital circuits on one chip.

TECHNOLOGY

TI emphasizes enabling technologies. In this respect its military focus is important in advancing technology, and TI participates in GaAs and the government-funded MIMIC (monolithic millimeter wave/microwave IC) Program and VHSIC (very-high-speed IC) Program. In order to contend with what TI terms the 1-micron barrier, the company moved to a CMOS process technology and opted to employ a trench capacitor approach for production of the 1-Mbit DRAM. TI's 1Mb CMOS DRAM process is called EPIC 1. Because trench capacitors have a large surface area as opposed to the planar approach, TI decided to move to a 3-D approach at the 1Mb level. So far only one other company has taken this approach. The company adopted a phased approach to production of the 4Mb DRAM, so in addition to the trench capacitor, both 4Mb and 16Mb DRAMs will have trench transistors. By using a proprietary self-contained unit photolithographic work cell, TI achieves operation at Class 1 levels with robotic handling of the wafers as well as shortened process time.

The company's bipolar focus is its ExCL bipolar transistor, which offers high performance and self alignment. Another process, EPIC-B, combines TI's ExCL bipolar process with its EPIC CMOS process to create a BICMOS process. This process allows CMOS design library compatibility in order to combine CMOS and bipolar. Because of the importance of BICMOS as an emerging technology, TI is trying to leverage multilevel metal from bipolar into CMOS.

Future Technology Trends

TI's approach to VLSI divides into four main areas: advanced materials and device structures; interface technology; data/knowledge technology; and mass storage. The company participates in the first three elements of this four-prong plan through the following approaches:

- Technology
  - VLSI for scaling
  - Double- and triple-level metal
  - CMOS processes for SRAMs, gate arrays, MPUs, and logic
  - GaAs for niche markets
  - Multimaterial chips for performance
  - Focal plane array technology
- Manufacturing and assembly
  - Excimer laser lithography to operate at 0.6 microns
  - Laser direct-slice write systems
  - Flexible manufacturing and assembly

- 3–D packaging
- Ability to add incremental capacity

- Design
  - Object–oriented design to combine 500K to 1M transistor design in 3 to 6 months

MANUFACTURING: A CORNERSTONE

Although other U.S. manufacturers chose to abandon the DRAM market, TI deemed its participation in this market strategic. As well as being high–performance devices, DRAMs constitute both a technology and manufacturing driver for the company's semiconductor products. From a market standpoint, DRAMs drive volume, price, quality, and reliability. In terms of manufacturing expertise, DRAMs are clearly a primary driver for the following areas:

- Technology
- Manufacturing
- Particle reduction
- Equipment
- Diagnostic tools

The key elements of TI's manufacturing are as follows:

- Leading–edge process technology (see the Technology section of this newsletter)
- High yields and reliability
- Automation and accountability

High Yields and Reliability

TI's reputation ranks it as one of the preeminent manufacturers in the United States. The company offers high–quality, high–volume, and high–yield manufacturing capability. Compared with the other major U.S. suppliers, our data show that TI has the highest revenue per square inch of silicon. Furthermore, in terms of revenue per square inch of silicon, the U.S. semiconductor manufacturers, overall, are ahead of the Japanese. (This may, however, indicate that the Japanese companies use more test wafers to qualify their manufacturing process than U.S. companies.)

When the disquieting news began to emerge in the early 1980s that the quality and reliability of Japanese-manufactured devices exceeded that of their U.S. competitors, the U.S. manufacturers began to focus on Japanese manufacturing procedures as the means by which to learn how to improve their own standards. Because of the importance accorded by Japanese semiconductor manufacturers to manufacturing, TI measures itself against the Japanese. Memory processes, TI's acknowledged manufacturing driver, are generally brought up first at Miho, Japan, and then transferred to Dallas, its U.S. counterpart. According to TI, the yields and costs at the two plants are now comparable.

Automation and Accountability

TI has an innovative approach to equipment assembly. The company's PAC group (Process Automation Control) builds much of TI's equipment needs, such as etchers and E-beams. TI is very interested in automation and its implementation has forced the company to study how a facility actually runs. Automation is a priority investment for TI and requires a management with vision to commit the sizable upfront investment to put such resources in place.

TI's WIP (work in process) tracking system is unique and demonstrates almost unparalleled customer service. This extensive computer system, which was internally developed and operates on TI hardware, is used to track devices through the assembly cycle offshore. The system tracks all device locations through the assembly cycle and provides TI with current status, yield information, and detailed records for product accountability. Even though a process currently may be within specifications, an elementary expert network and statistical quality control system can be used to determine if a process is trending out of specifications.

Customers are even able to place orders directly with the FAM (Flexible Assembly Module) computer system. With vendor consolidation occurring among its customers, TI wished to ensure that it would be chosen as the primary supplier. FAM was developed to guarantee 100 percent on-time delivery. FAM was started in late 1983/early 1984 to develop cost-competitive onshore assembly versus low-labor-cost offshore assembly. Should a yield problem from an offshore assembly location indicate the possibility that an on-time delivery might not be met, the information would be transmitted to the FAM system, which would flag the appropriate wafers from inventory in Sherman, Texas, to enter the assembly cycle. By this means, products can generally be assembled in about a week or two. Communication between the companies' customers and suppliers can be effected electronically, and the WIP can be accessed by customers to get updated information on their orders.

ALLIANCES

Nowhere is TI's change in philosophy more in evidence than in the area of alliances. The company has come to the realization that its "loner" mentality is no longer appropriate. Consequently, it has entered into an increasing number of agreements with other semiconductor suppliers and customers in the past few years.

The adversarial, contractual relationships of merchant semiconductor companies has tended to promote fragmentation and instability in the industry. Cooperation between buyers and sellers of products all along the chain of supply has become essential and the concept of "virtual vertical integration" has come into vogue. Its advocates urge that product development alliances be extended into joint-manufacturing agreements, long-term purchase contracts, and other relationships that help justify capacity expansions. As an example, TI is helping Hyundai of Korea bring up DRAM manufacturing capability and will use the company as a source of foundry production. The appeal of such a strategy is that it provides a means for U.S. companies to preserve their innovative and competitive nature while working toward greater long-term planning and cooperation.

MARKETING: AN INTERNATIONAL PRESENCE

TI first applied to MITI for permission to establish a wholly owned subsidiary in Japan in January 1964; permission was finally granted in May 1968. TI managed to use to its advantage the fact that the Japanese needed a license from TI for access to Jack Kilby's IC patent in exchange for TI eventually owning a manufacturing facility in Japan. Initially, TI started up in Japan as an equally financed joint venture with Sony. As agreed, after three years Sony withdrew from the arrangement and the corporation became wholly owned by TI. Although it was several years before TI was granted permission to set up a facility in Japan, it was worth the effort and TI claims to be doing well there. Table 2 shows the results of TI and Motorola having invested very early (in the 1960s and early 1970s) in markets outside of the United States. Of the three companies in Table 2, TI has been the most successful because it was the first to establish factories in regional markets. In fact, the company has done so well that more than half of this business is non-United States. For about 10 years, TI was the only U.S. semiconductor company with a manufacturing facility in Japan. Where it has achieved excellent penetration, especially in the memory and standard cell markets. TI has been able to capitalize on its experience in the Japanese market in order to maintain its presence in the memory market. TI moved from being the sixth largest DRAM supplier worldwide in 1986 to being ranked fourth worldwide in 1987, as shown in Figure 5.

Since manufacturing where the market is located is a key feature of TI's strategy, it is not surprising that the company is an international semiconductor manufacturer in terms of fab locations. Outside of the United States, TI's production capability is in the United Kingdom, West Germany, and Japan—a total of seven fabs. TI has just received approval from the Korean government for a wholly owned operation in that country. Motorola, TI's largest U.S. competitor, also has seven overseas fabs. NEC operates just two non-Japan-based manufacturing facilities—one in Scotland and one in the United States.

Table 2

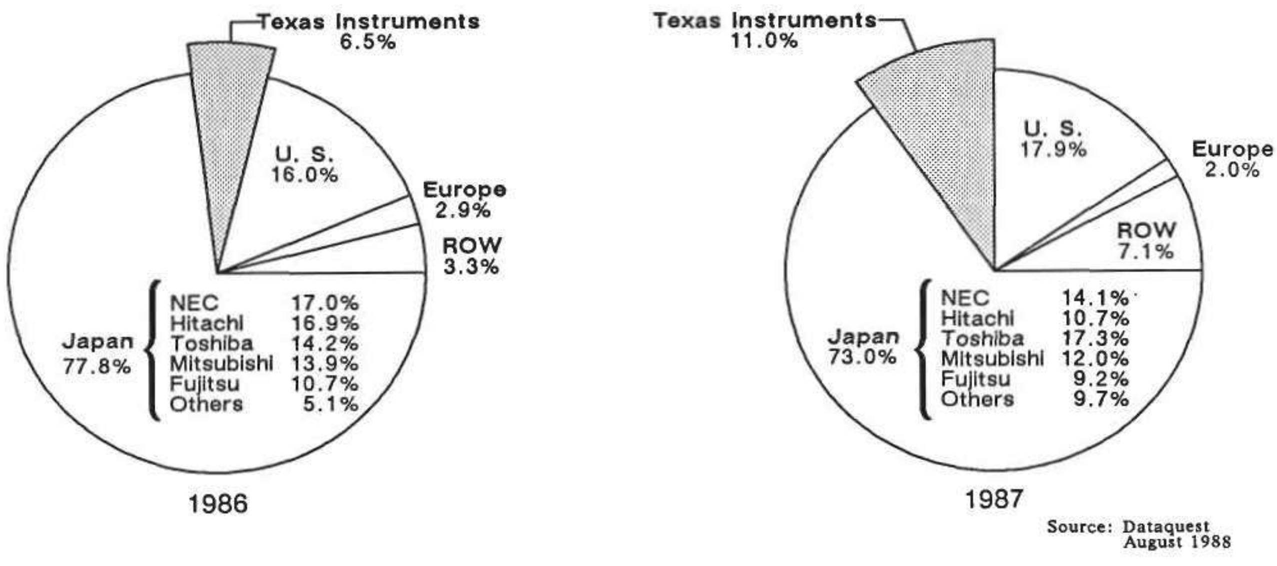
Total Semiconductor Business
Estimated 1987 Regional Share

	NEC		Motorola		Texas Instruments	
	Revenue	Regional Share	Revenue	Regional Share	Revenue	Regional Share
United States	$ 335	10.1%	$1,542	62.9%	$1,036	48.7%
Japan	2,449	73.7	170	6.9	403	18.9%
Europe	255	7.7	478	19.5	492	23.1%
ROW	286	8.6	260	10.6	196	9.2%
Total	$3,325	100.0%	$2,450	100.0%	$2,127	100.0%

Source: Texas Instruments, Inc.
Dataquest
August 1988

Figure 5

Top Six Worldwide DRAM Suppliers
1986 and 1987
(Dollarized Unit Shares)



Source: Dataquest
August 1988

DATAQUEST ANALYSIS

The semiconductor industry is undergoing massive restructuring. The nature of global competition is changing, not just for U.S. semiconductor suppliers, but also for the Japanese suppliers and the "Four Tigers" (South Korea, Taiwan, Hong Kong, and Singapore). Being a world-class electronics company that can think, communicate, and act globally, implies more than just an operational perspective. It requires a long-range outlook and in-depth knowledge of customers and markets.

Our research leads us to conclude that TI differs from its major Far Eastern competitors. Two main points of contrast are that TI is driven by its components business rather than by its systems business, and it has been more selective about the type of business it targets. The company's thrust is to be a leading supplier of semiconductors and a leading supplier to the military market. For many of its Far Eastern competitors, semiconductor components are a much less prominent piece of their overall business. By contrast, TI's semiconductor operations are based not on its internal requirements, which it nonetheless supports, but on its fundamental objective to become the leading component supplier to the U.S. market, as well as a major global player. So, although TI is not vertically integrated in the same fashion or to the same degree as many of these competitors, it represents a good example of vertical integration U.S.-style, and its semiconductor business represents a firm foundation on which to build or support other business activities.

TI is committed to making investments of strategic importance from a corporate view, thus enhancing its ability to maximize the synergy generated by the many constituents of its business. TI's choice of investment contends that, contrary to popular belief, we are now in the information age. We are, in fact, data rich but information poor. Dataquest believes that TI exhibits the strengths necessary to compete with other vertically integrated competitors worldwide, and that in response to the changing nature of global competition, the company has planned well and invested wisely for the shape of things to come.

Patricia A. Galligan

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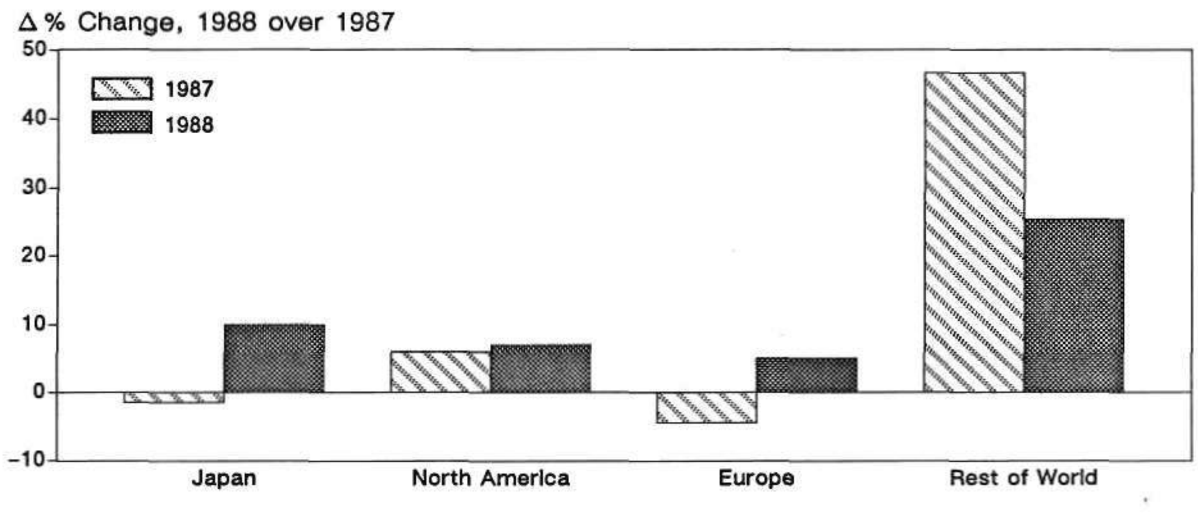
THE SUN CONTINUES TO RISE IN ASIA

SUMMARY

In his opening comments at a half-day seminar sponsored by Dataquest's ASETS (Asian Semiconductor and Electronics Technology Service) in June, Gene Norrett, Corporate Vice President and General Manager of Dataquest's Components Division, explained why the region designated ROW (Rest of World) is generating so much interest. A quick look at Figure 1 shows why attention is now focusing on the significant market opportunity represented by the ROW region. Many factors are contributing to the phenomenal growth being witnessed in the Asia/Pacific region, and these issues were discussed in detail at the seminar. This newsletter will highlight and summarize some of the most important issues.

Figure 1

Estimated 1988 Worldwide Electronics Markets



Note: Japan and Europe are in local currency to reflect appreciation of yen and ECU.

Source: Dataquest
July 1988

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THE SPEECHES

In terms of the share of production, the Four Tigers—South Korea, Taiwan, Hong Kong, and Singapore—and China represent about 80 percent of ROW electronics production. ROW production was valued at US$94 billion in 1987, accounting for approximately 14 percent of worldwide production. Semiconductor consumption in the region is also growing in leaps and bounds as shown in Table 1.

Table 1

Estimated Worldwide Semiconductor Consumption March 1988 Percent Change, U.S. Dollars

	1987	1988	1989
North America	19%	24%	6%
Japan	21%	27%	9%
Europe	16%	20%	6%
ROW	67%	39%	22%
Total World	23%	26%	9%

Source: Dataquest July 1988

Issues

The key influences that will positively affect the Asia/Pacific market in 1988 were identified as follows:

- Government support
- GNP growth
- Yen appreciation
- Local demand
- Capital spending
- Manufacturing moving offshore to Asia
- Partnerships/alliances
- Technology perception

The Four Tiger governments are making concerted efforts to orchestrate their industry development in order to become a major force in the semiconductor market of the future. To promote economic growth, South Korea and Taiwan have long pursued a vigorous export policy. Some of the region's large vertically integrated electronics conglomerates are flexing their industrial muscle and targeting what ASETS Director Tom Wang refers to as the four Cs: consumer, computer, communications, and components (semiconductors).

The GNP

Last year, the South Korean, Taiwanese, and Hong Kong economies grew in double digits, although growth is expected to slow in the future. Dataquest research analyst Terrance Birkholz said that this compared favorably with the 2.9 percent growth of the U.S. economy and the 3.2 percent growth of the Japanese economy. A key contributing factor to this growth was that these are export-driven economies, and half of their exports have been to the United States where the economy has experienced continuous growth over the past six years. None of the Four Tiger currencies have appreciated against the U.S. dollar as much as has the Japanese yen.

Electronics: Data Processing Leads the Way

Electronics production in the ROW area grew a vigorous 46.7 percent in 1987 compared with 15.1 percent growth (dollar denominated growth) in Japan and 6.5 percent growth in the United States. Production in the region is expected to grow 25.4 percent in 1988. The data processing and consumer application markets comprise both the largest portion of the market and the fastest-growing segments. Data processing equipment, of which personal computers and related equipment represent a substantial portion, and consumer electronics have dominated Asia/Pacific's electronics industry in the recent past and will continue to do so during the forecast period. These two application segments accounted for 82 percent of the region's electronics production in 1987. Dataquest forecasts that ROW data processing applications will grow 27.9 percent in 1988 and consumer applications will grow 27.3 percent.

Of the Four Tigers, South Korea has posted the fastest growth in electronics production since 1982. The country's comparative advantage in electronics is due to consumer products such as color televisions and VTRs, which represented more than half of its total consumer electronics production. Taiwan, which experienced approximately 52 percent growth in electronics in 1987, derives its comparative advantage from data processing equipment production.

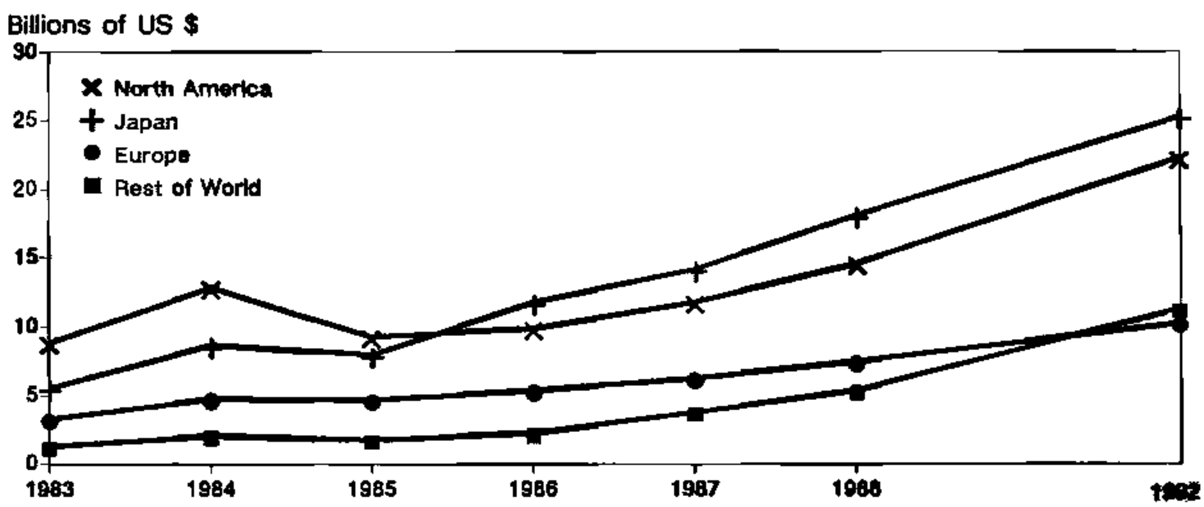
This theme was taken up again by another speaker later in the course of the seminar when Dr. Chintay Shih, Vice President and General Director of ERSO (Electronics Research and Service Organization), Taiwan, talked about the opportunities for PS/2-compatible systems in Asia Pacific countries. According to Dr. Shih, Taiwan led the Four Tigers in supplying personal computers in 1987, with an estimated export value of US$760 million.

Semiconductors Follow Suit

What does this all mean for semiconductors, Mr. Birkholz queried? He explained that as electronic equipment production goes, so goes semiconductor consumption. The ROW posted phenomenal consumption growth of 66.8 percent in 1987. Currently, the region consumes $3.9 billion in semiconductors, or 10.7 percent of the total semiconductor market. As can be seen in Figure 2, the rapid consumption growth rate being exhibited by the region will cause the countries to overtake Europe in 1992 as the third largest consumer of semiconductors. With the data processing and consumer electronics sectors setting the pace in terms of growth and production level, the same driving forces apply to semiconductor consumption, as shown in Figure 3. When combined, these two application markets represented 77.6 percent of total ROW semiconductor consumption in 1987.

Figure 2

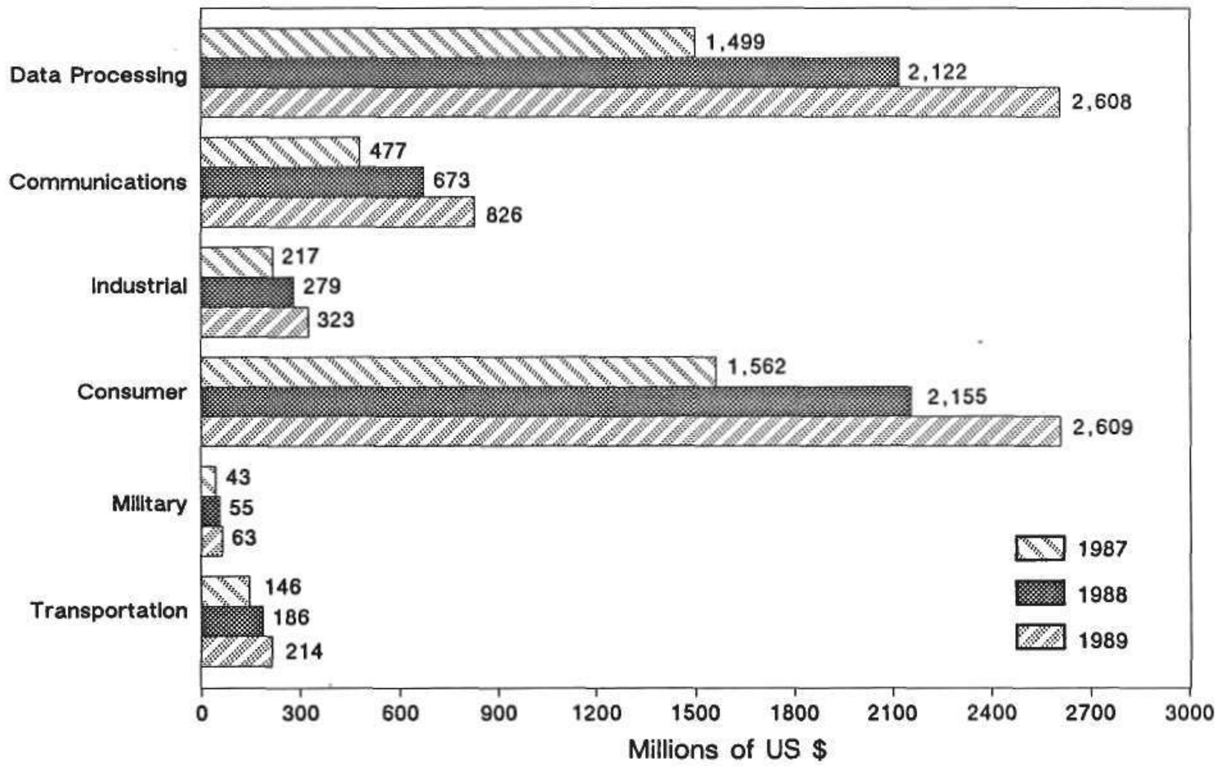
Estimated Worldwide Semiconductor Consumption by Region



Source: Dataquest July 1988

Figure 3

Estimated 1987 ROW Semiconductor Consumption by Application Market



Source: Dataquest
July 1988

The growth in these application markets translates into high growth in memories, microcomponents, logic, and linear ICs. South Korean semiconductor companies are expanding their production capacity or have plans to expand fab plants in order to become significant producers of DRAM memories. As the major South Korean chip makers gear up for more production, opportunities increase for semiconductor equipment manufacturers to supply this market. However, according to guest speaker Iksu Kim, Director Strategic Marketing, Semiconductor Division, Hyundai Electronics America, the U.S. equipment manufacturers are finding tough competition from Japanese equipment suppliers. He contended that this is a major opportunity for the U.S. suppliers that will have to become more aggressive to participate in this major growth market.

Asia: An Ally?

Move to Offshore Manufacturing

Dr. David Lam's presentation drew from his own personal experiences with Lam Research, which he founded, and with Link Technologies, where he is Chairman and CEO. Dr. Lam discussed the many reasons that companies still find it an attractive proposition to move manufacturing offshore. He cited savings in direct labor, in parts, and in overhead expenses as the usual justifications for moving to offshore manufacturing. Other important considerations are the high productivity rate in Asia, the availability of technical expertise, and proximity to the market. Although there are still costs associated with such a venture, often they do not offset the benefits. Where the product design is not proprietary, companies often find it is advantageous to leverage offshore manufacturing.

Some long-term issues also are at stake. The Hong Kong dollar is still tied to the U.S. dollar, which maintains its competitive edge. China represents a huge untapped market and as the country opens up, Hong Kong is moving in for assembly and production of labor-intensive goods. An interesting speech by Ye Zhongling, research professor in the Ministry of Electronics Industry, China, went on to substantiate the extent to which China represents a huge, untapped market. For example, of the approximately 112 million television sets in use in China, 80 percent are black-and-white units. About one person in ten of the Chinese population has a television set. Demand for color television sets is acute, Mr. Zhongling said, and domestic production was apparently able to supply only 65 percent of the demand in 1987. The country's production of 1.35 million semiconductor devices in 1987 pales in comparison to estimated worldwide production of almost 100 billion semiconductor devices.

South Korea's technology primarily has been purchased rather than developed by indigenous manufacturers. This means that not only are there extensive relationships between South Korean companies and U.S. semiconductor companies, but also that as the country strives to bridge the gap between proprietary process technology and design and purchased technological capability, opportunities will arise for mutually beneficial future alliances.

DATAQUEST'S CONCLUSIONS

Opportunities exist for U.S. companies to make alliances with Asia/Pacific companies, and the United States should seriously consider allying itself with the region against its real competitor, Japan. However, there are some current negative issues that should be kept in mind, such as:

- Currency value appreciation
- Protectionism
- Competition from non-newly industrialized countries (NICs)
- U.S.-dependent industry

Asia/Pacific is one of the most dynamic and important high-technology areas in the world today, and its influence on the worldwide semiconductor industry is increasing.

Patricia Galligan

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DRAM AVAILABILITY IMPACT ON DEPENDENT ICs AND SYSTEMS

SUMMARY

This newsletter reviews the current DRAM shortage, the direct and indirect impact on IC purchases dependent on DRAMs, and the long-term implications for end-use system competitiveness. We will also review the future supply lines of these critical components and note possible alternatives available to prevent such shortages in the future.

CURRENT STATUS

For at least six months now, DRAM availability (or lack thereof) has been bemoaned to the extent that many buyers with contracts have been forced to go to the spot market in order to secure adequate supplies. The cause of the current problem dates back to the measures MITI reluctantly took during the first quarter of 1987. These measures were so successful that by the end of 1987 the reduced supply of key DRAMs had the AEA and the DOC demanding that MITI "advise" increased production. Production advisories were raised in December of last year that would allow market demand to determine production rates.

The opening of production to demand forces did not result in immediate supply increases. Despite shifts in existing capacity to the 1Mb part and lower than anticipated overall yields for this part, the net supply of both 256K and 1Mb DRAMs increased only slightly during the first quarter of 1988, as shown in Figure 1. This supply shortfall in the face of steady demand drove prices rapidly upward during this time period, as seen in Figure 2. Current DRAM prices remain at this elevated level and are not expected to come down until the late third quarter, when the combination of increased wafer starts and higher device yields will begin to make a dent in the pent-up demand for 1Mb parts. The 256K DRAM supply is not expected to increase, as most vendors focus on the newer, more profitable 1Mb part. The amount of demand shifted to the 1Mb part relieving pressure on 256K supplies is expected to be balanced by decreases in 256K capacity.

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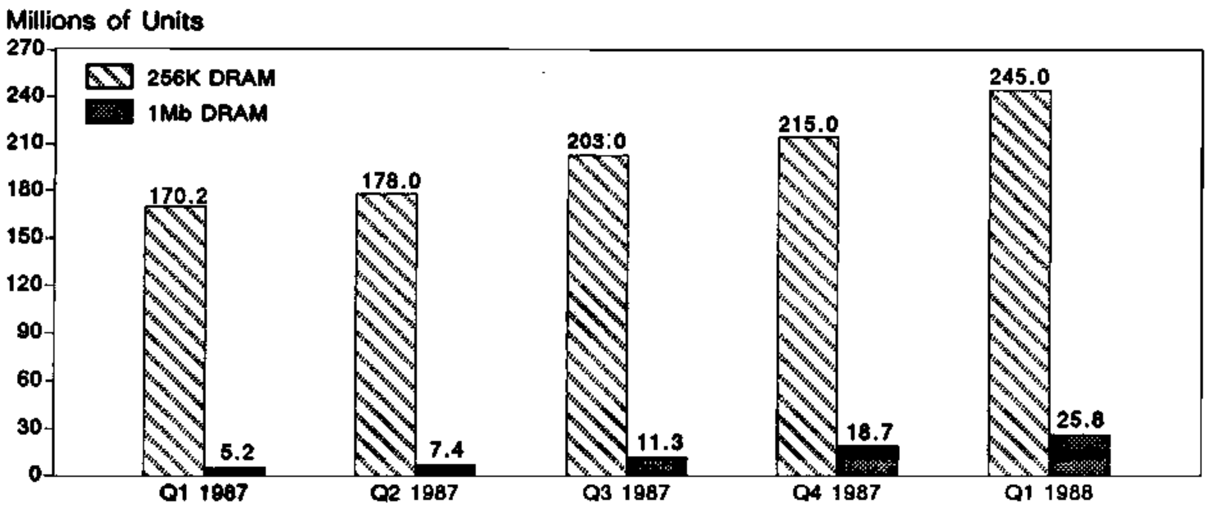
Figure 1

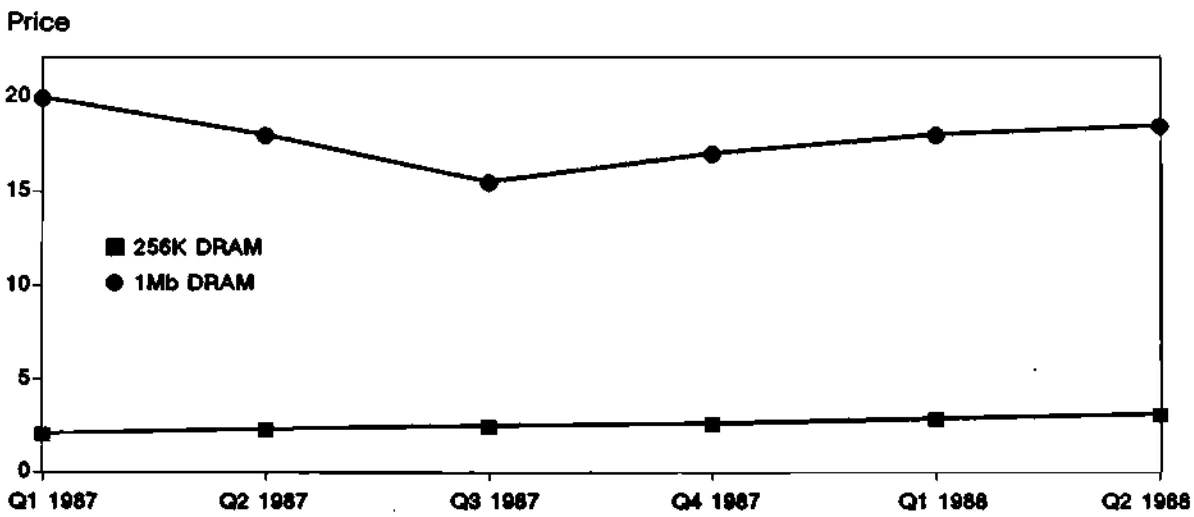
Worldwide DRAM Shipments—256K and 1Mb (Millions of Units)



Source: Dataquest June 1988

Figure 2

U.S. DRAM Contract Pricing—$256K and 1Mb (Millions of Units)



Source: Dataquest June 1988

DRAM SHORTAGE FALLOUT

Semiconductors

Besides the direct shortage of DRAMs crimping end-user supply lines, SRAMs and Video RAMs have also been directly affected. This situation is due to the similar processes utilized by the three devices and the current higher profits derived from DRAM shipments. The result of decreased SRAM and Video RAM supplies have raised prices for these parts, thus raising their respective profits. As supplies of DRAMs increase, thereby reducing their respective prices and profits, manufacturing is expected to migrate back to SRAM and Video RAM production, increasing supplies and tempering prices. This migration is expected to occur during the mid to late 1989 time frame.

Two semiconductor product groups that have been indirectly affected by this situation are the slow-speed (6 to 8 MHz) microprocessors and some standard logic families (i.e., LS, HC, ALS). These parts have had relatively less demand compared with overall semiconductor sales growth. This situation implies that once DRAM supplies improve, these product prices will also begin to firm up as a result of higher demand.

Systems

Although the DRAM crisis has affected all users of these parts, not all users have been equally affected. Generally, large users that have good communications with their vendors have weathered the storm better than smaller users or those that have been opportunistic in their past procurement practices. The current shortage has caused much turmoil for small companies that depend on state-of-the-art, high-speed memory parts for their systems to successfully compete in the marketplace.

Another subtle effect of the DRAM shortage is the shortage of exported surface-mount packages for these parts. Taken in aggregate, the overall lack of SMT devices has forced many system manufacturers to delay new product introductions, retrofit their new board designs, or stay with older board designs. Either way, an otherwise competitive edge is foregone because of a lack of supply. SOJ package capacity increases are expected to alleviate this situation as the volume of 1Mb DRAMs increases, starting later this year.

FUTURE DRAM SUPPLIES

The majority of DRAM supplies in the future will continue to be primarily Japanese owned. However, the actual sourcing/manufacturing of these parts will be spread more evenly on a regional basis in response to demand and the currently strong yen, making Japanese capital investment affordable. This increase in regional supply will help to alleviate regional supply bottlenecks and potential political market share problems. Table 1 shows the current regional 1Mb DRAM merchant market fab location and ownership percentages and their estimated regional percentages in 1990.

Tabel 1

Regional 1Mb DRAM Merchant Market Fabrication Capacity

Region	1988	Percent Japanese Owned	1990	Percent Japanese Owned
U.S.	3%	0	9%	0
Japan	92	93%	67	94%
Europe	3	40%	9	33%
ROW	2	0	15	0
Worldwide Total	100%		100%	

Source: Dataquest July 1988

Another trend that may have unanticipated side effects is the increased interest by large system manufacturers in adding captive fabrication capacity. For companies with means, the option to internally source key semiconductor components has always been a double-edged decision. In high-demand periods, internal capacity often requires merchant market supplementation at higher than captive transfer cost-based prices, whereas in slow periods, external purchases are reduced and market prices may be lower than captive transfer prices. Over the long term, internal sourcing has provided a technological edge and steady supply of key components for companies that have chosen this option. The requirement of a steady supply of high-quality components from internal sources is being countered with the increasing cost of making state of the art semiconductors (i.e., fab equipment, clean rooms, etc.), now reaching the $100 million range.

DATAQUEST ANALYSIS

The current shortage of key memory components can be seen as a blessing in disguise. To the extent that the prolonged delivery of key components has extended and perhaps mollified the traditional boom/bust electronics cycle, long-term procurement strategies have become more prevalent to the benefit of the electronics industry. The regional DRAM supply-demand imbalance is being addressed by the major suppliers at the demand of users. It remains to be seen if the merchant market suppliers can forge long-term arrangements with their key accounts to provide a stable supply of high-quality next-generation products that will forestall captive semiconductor manufacturing. By stressing the need for regional vendor support, users become less dependent on the regional "sole-sourcing" type of phenomena that often precedes competitive disadvantage.

Some users share costs for capital equipment that is predominantly utilized by a user's specific parts (i.e., special surface-mount handling machines, high-speed testers, etc.). This, in effect, guarantees capacity for users and lowers capital expenditures for vendors. In this way, users know that they have a viable supply of parts because they helped pay for the capacity, and vendors can enter new areas of business with reduced risk because of lower equipment costs.

The DRAM shortage will correct itself within the next six to nine months. The challenge for users of these strategic components is to plan procurement strategies that ensure adequate future supplies at a reasonable price. Although it is currently a sellers' market, users that have put into place a rational method of forecasting and have gained credibility with vendors will ride out future economic cycles better than competitors that do not.

Mark Giudici

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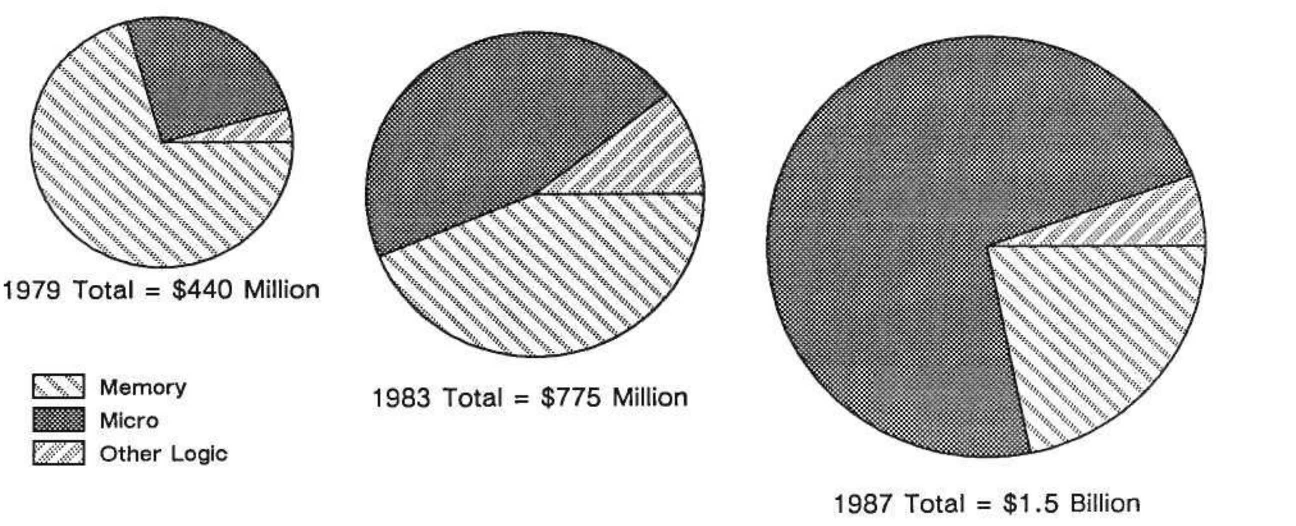
INTEL TURNS TWENTY: IS THERE LIFE AFTER DOS?

SUMMARY

The past 20 years for Intel Corporation have been characterized by technological leadership and product innovation. During this period, however, the company has changed dramatically in scope and structure. A quick look at Figure 1 reveals the changes that Intel has experienced in terms of product mix—changes wrought by a watershed event in the history of Intel and the entire semiconductor industry: the development of the personal computer market.

Figure 1

Intel's Semiconductor Revenue by Product Category



Source: Dataquest
May 1988

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From its position today of worldwide microcomponent preeminence, Intel is now formulating its strategy for a future that looks very different from the past—a future in which the company will face increasing challenges to its market share in standard microprocessor platforms, and in which the ownership of the DOS market may not imply the same rewards as it has in the past.

This newsletter provides an update on Intel through a summary of the following factors:

- Current financial standing
- Capital spending plans and changes in production capabilities
- Positioning in key product areas

More importantly, this newsletter looks at some significant challenges that face Intel in the rapidly changing microcomponent market and at ways in which the company is addressing these challenges. Some of the information was obtained at the company's recent shareholders' meeting in Albuquerque, New Mexico.

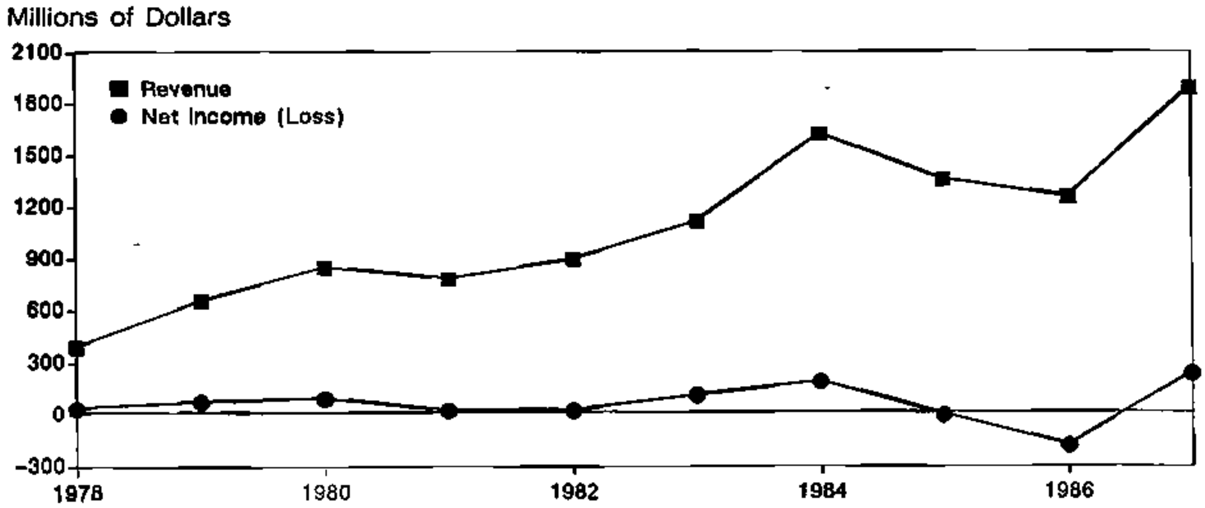
FINANCIAL SUMMARY

Having just weathered two difficult years, Intel is enjoying the fruits of a very bountiful 1987. Financial results for 1987 marked the fifth year in a row the company reported net revenue of more than $1 billion as shown in Figure 2. With 1987 total net revenue of $1.907 billion, Intel is now poised on the brink of the $2 billion mark. The company's 1987 semiconductor revenue of $1.5 billion ranked it as the eighth largest semiconductor supplier in the world.

Intel's business continues to accelerate. With record revenue of $636 million for the most recent quarter ended in March 1988, the year ahead promises to be a banner one. Revenue per employee for 1987 was $100,000, and first quarter 1988 results put this figure at $132,000. (Between 1978 and 1986, Intel's revenue per employee averaged $55,000.)

Figure 2

Intel's Net Revenue and Net Income (Loss)
10–Year History



Source: Intel Corporation

CAPITAL SPENDING PLANS

Over the past 10 years, Intel's R&D expenditures have consistently been more than 10 percent of revenue. Capital expenditure in 1987 was approximately $302 million, almost double the amount in 1986. Capital expenditure in 1988 is pegged at $450 million, which will put this investment above 1984's record spending of $388.5 million for the first time.

Intel's pioneering effort to facilitize Fab 7 in Rio Rancho (Albuquerque), New Mexico, as the world's first 6–inch fab was an expensive activity. The selection of Albuquerque for the annual shareholders' meeting was significant. It is not only the site of Fab 7, now the company's largest silicon–producing fab, but is also the location of its newest fab, Fab 9.1, which is on the verge of producing the lucrative 80386 microprocessors.

Current investments are directed at upgrading Fab 7 and completing Fab 9.1, the first module of Fab 9. At the annual shareholders' meeting, the company announced that it has approved plans to complete work on the next module at Fab 9, Fab 9.2. Thus, 1989 is expected to be another big year for capital investment. Fab 9.2 is estimated to require $95 million to cover facility and equipment costs and is expected to be complete and producing by the end of 1989.

PRODUCTION PLANS

Each of the four modules at Fab 9 will comprise 25,000 square feet of Class 1 clean room. The phased–capacity approach promulgated by Intel means that a module a year could be added over the next few years. The equipment in Fab 9.1 has been qualified for production and is expected to be running at volume levels by late this year. The target by the end of the year is about 800 wafer starts per week, less than one-third of the final target when the fab is fully facilitized. The process for producing the 80386 has been fully characterized and debugged at Fab 4 in Aloha, Oregon, where there is a duplicate model of Fab 9.1.

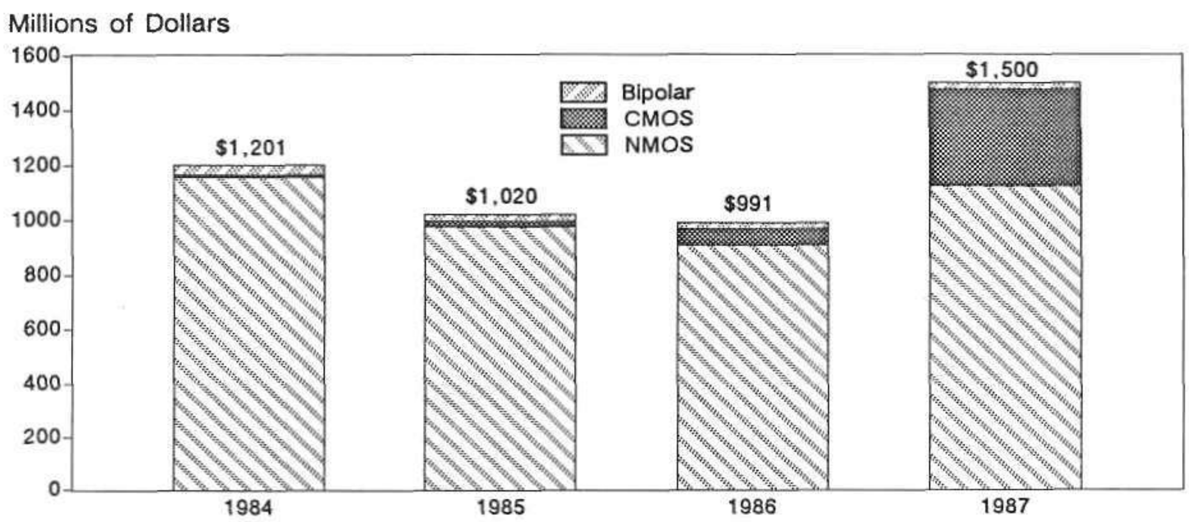
Currently, Fab 7 at Albuquerque accounts for 25 percent of Intel's total silicon output. It has 36,000 square feet of Class 10 clean room and boasts 1-micron CMOS technology. Revenue based on CMOS products only became a significant contributor to Intel's business in 1987, as illustrated by Figure 3.

About 75 to 80 percent of Intel's production capacity is at the 1.5-micron feature size, less than 5 percent is at 1 micron, and the remainder is at 2 microns or greater. Future generations of technology will be developed at the company's Development Center in Santa Clara now under construction.

Intel's manufacturing focus emphasizes total quality control. One element of this effort to achieve greater reliability and productivity is the implementation of integrated automation solutions. The importance being accorded to statistical process control at Intel signals a change in attitude for the company and is an indicator that it is working towards its goal of being a world-class manufacturer.

Figure 3

Intel's Estimated Semiconductor Revenue Based on Process Technology (1984–1987)



Source: Dataquest May 1988

KEY PRODUCT AREAS

Microcomponents—Still the Leader

Intel continues to be the world's leading supplier of microcomponents. Revenue from Intel's microcomponents business is estimated to be $1,098 million for 1987, reflecting growth of approximately 75 percent over the prior year. Its nearest competitor, NEC, has 1987 estimated microcomponent revenue of $629 million, which is equal to Intel's 1986 microcomponent revenue. Figure 4 shows Intel's market share in microcomponents over the past nine years.

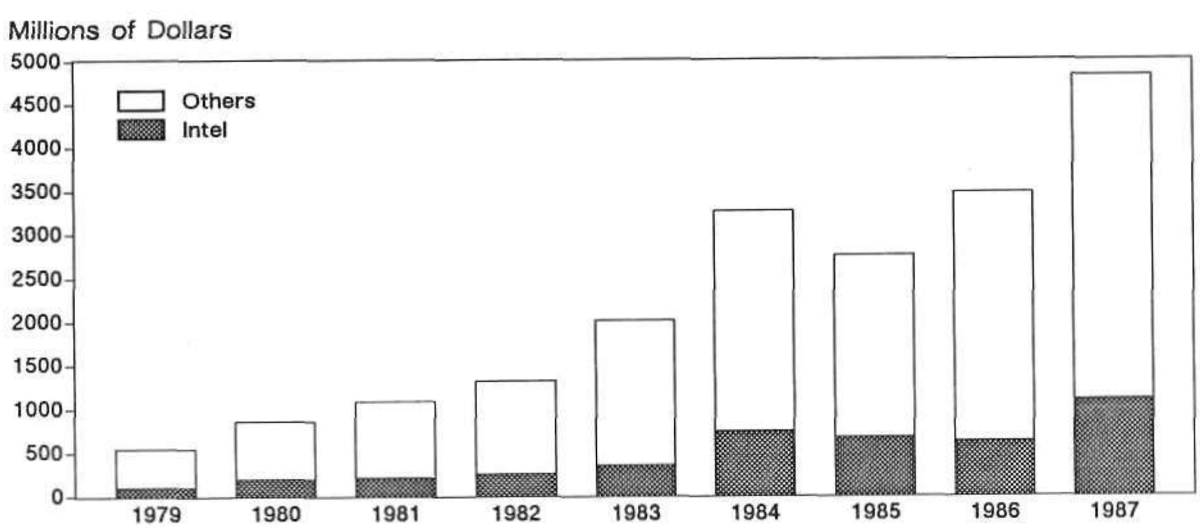
To generate growth in 1988, the company plans to increase the pace of its product introductions, and continue its efforts to become more streamlined and automated. New product announcements in 1988 will include six new 32-bit microprocessors (MPUs), four of which have already been unveiled. One more of these is due in the summer, and the last one is anticipated in the fall.

Intel plans three strategic thrusts that relate to the microcomponent portion of its business. The targets of these thrusts are:

- Embedded control
- Super chip sets
- Computer platforms (systems perspective)

Figure 4

Intel's Share of Total Worldwide Microcomponent Market



Source: Dataquest
May 1988

The targeting of these segments is predicated on Intel's extremely strong position in microcomponents. The 80286 has become a real workhorse of the personal computer (PC) industry. Intel's fortunes have been tied to the fate of the PC to the point that none of its traditional competitors has the same stake in the PC market as Intel does. According to Dataquest estimates, Intel shipped 4.7 million units in 1987, or approximately 60 percent of the total 80286 market. According to the company, shipment volumes are still holding up, and in fact, shipments in the first quarter of 1988 were as high as they had ever been. Figure 5 provides Dataquest's PC forecast, highlighting the proportions of the PC market that we expect to be claimed by the 80286 and the 80386.

Microprocessors: Life After DOS?

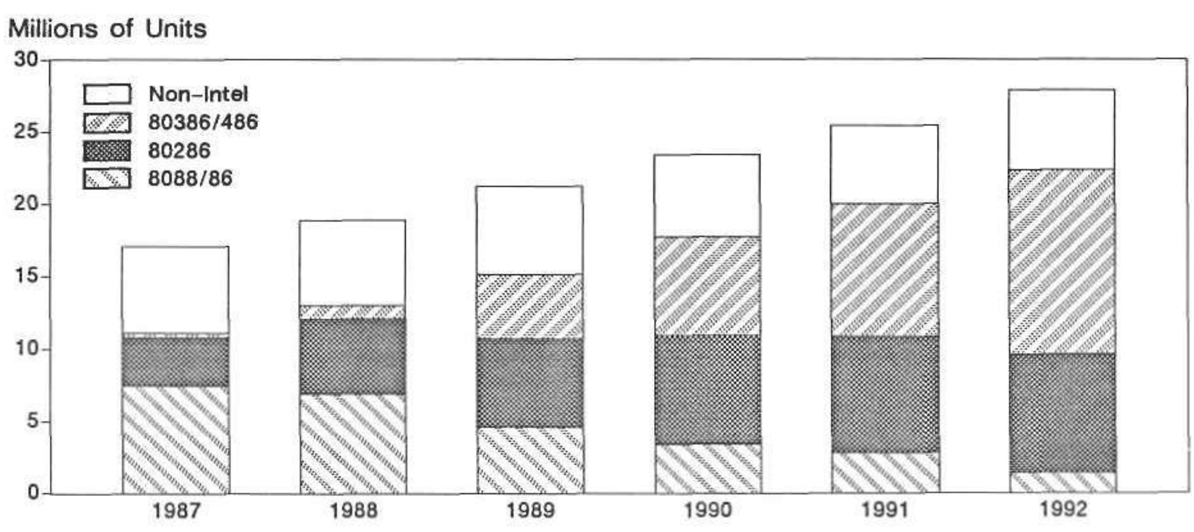
With four new 32-bit microcomponent products and two more major announcements to be made this year, how far can Intel take this architecture and still add value?

IBM's future architectural plans will certainly impact Intel's future microprocessor development strategy. Currently, it is widely claimed that IBM is not manufacturing the 80386, and its agreement with Intel requires that it buy the lion's share of its 80386 needs from Intel. However, IBM does have rights to modify the 80386 core. IBM's desire to defend its market share position from the clone makers might create a dilemma for Intel. If a modified 80386 chip were proprietary to IBM, this might impact the future 80486, which Intel would presumably wish to sell to as wide a market as possible. Intel sources claim that the 80486 is not slated for introduction this year.

This is part of the larger question that Intel faces in looking forward; namely, is there life after DOS and what does it look like? Of growing interest, therefore, is the emergence of software emulation products that allow DOS applications to run on previously non-DOS-compatible platforms. With these products, users can make their system selections based on need without sacrificing DOS compatibility.

Figure 5

Five-Year Worldwide PC Shipment Forecast



Source: Dataquest
May 1988

This trend takes on increased importance in the nebulous and merging world of PC-meets-workstation. Dataquest observes that technical workstation technology is destined to decline in price to the PC range within approximately three years. Moreover, if one considers what Intel's competition is doing, we see a host of companies lining up for the most part along RISC-based architectural platforms that offer a standard operating system environment such as UNIX. In the past, the necessity of DOS compatibility benefited Intel by keeping systems engineers on an upward migration path from one generation of Intel MPU to the next. Current trends in the high-end PC/workstation market would make the question of upward architectural compatibility a moot point, in light of increasing software independence of hardware.

Intel could effectively respond to the frantic ongoing RISC activity in the marketplace by leapfrogging the competition with a performance solution. This could mean exploring options such as BICMOS or ECL implementations of products. Additionally, we believe that the company's experience in the systems side of the business could also stand it in good stead.

Leveraging Its Strengths. Clearly in the DOS-based world, Intel has the advantage, not just because DOS is a standard for PCs, but also because the PC market is a volume market. Although this market has become more volatile than it used to be, we expect that Intel will continue to reap dividends from it in the future. Intel believes that it can achieve increased levels of penetration in both the domestic and international PC markets.

Intel president Andrew Grove promotes the notion of the "Volkscomputer." He has indicated a desire to achieve in the computer world what was achieved by the Volkswagen (car of the people) in the automotive world—a machine for the masses. With pricing for the 80286 in the $25-$45 range and for the 80386 in the $250 to $300 range, the company certainly has a wide variety of product prices. In fact, it needs more products at different price points in its MPU product portfolio if it intends to be the instigator of the "Volkscomputer." Development of the "PC-as-commodity" market relies heavily on Intel's approach, and the current pricing of the 80386 does not support such a strategy. With limited second-sourcing on the 80286, none for the 80386 (and possibly likewise for future product introductions), Intel has nimbly sidestepped the issue of having to choose between market share and profits.

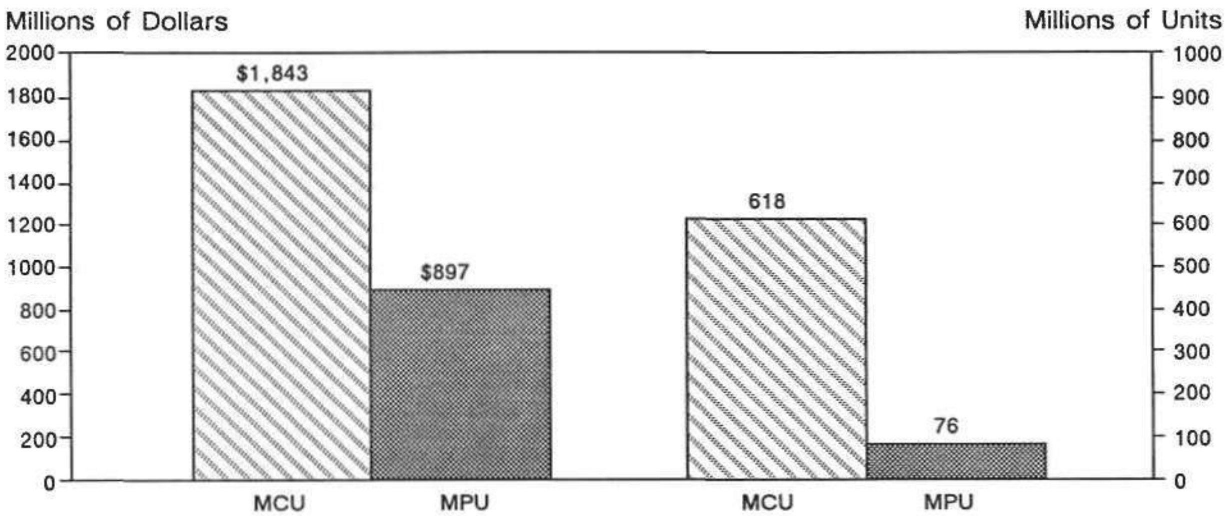
Microcontrollers—A New Strategic Significance

Intel has seen both the boom and the bust sides of the PC market. Realizing that so many of its eggs are in an increasingly volatile basket, the company has recently been emphasizing the embedded controller market. Although, seemingly less visible, this market is much larger than the reprogrammable market. The relative sizes of these two markets are compared in Figure 6.

Intel has spawned architectural standards in the microcontroller (MCU) market. However, its second sources have often surpassed it in the marketplace by delivering more cost-effective products. Apparently, this was not initially disconcerting to Intel, as it simply moved on to the next-generation product, which commanded higher ASPs. What became evident though, was that this strategy essentially limited Intel's growth by ignoring large chunks of business. Intel's participation in the 8048 market, as shown in Figure 7, illustrates this point.

Figure 6

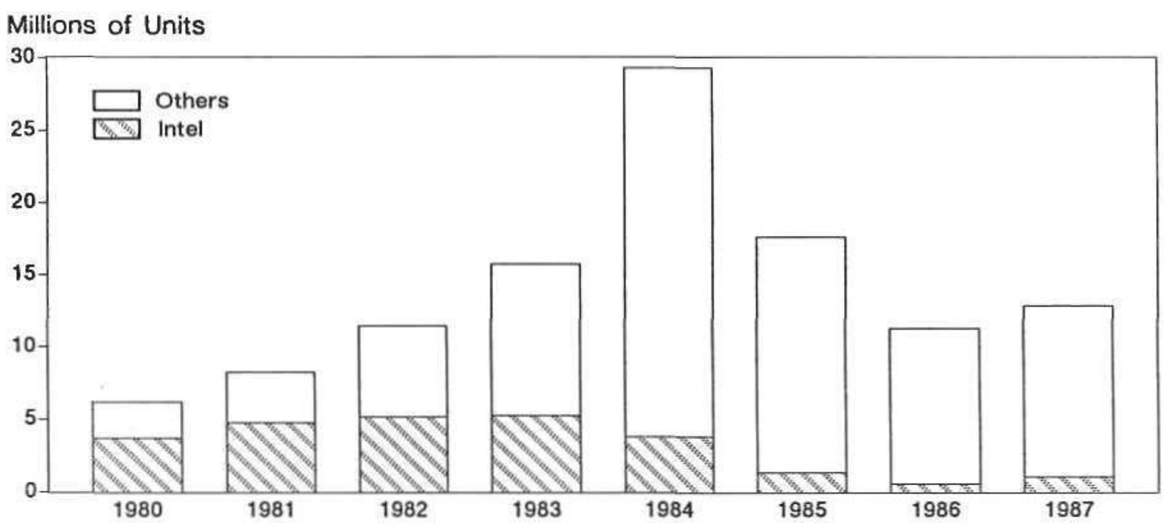
1987 MPU/MCU Comparison



Source: Dataquest
May 1988

Figure 7

Intel's Share of 8048 Market versus Competitors' Share (1980–1987)



Source: Dataquest
May 1988

The 8-bit MCU market is in a high-growth phase. Although two-thirds of the shipments are still in NMOS, Japanese suppliers now dominate the growing CMOS 8-bit MCU market segment. MCU devices can have very long product life cycles, as is evidenced by the continuing large sales of 4-bit microcontrollers.

To succeed in the MCU market, manufacturing capability is key. Embedded control design wins are usually extremely cost sensitive. Hence, Intel's objective of increasing its penetration in this market segment necessitates very strong manufacturing capability. To this end, the company did decide to subcontract out production of some of its 8048/8049 production to a low-cost Korean supplier.

Besides lowering costs, another component of Intel's MCU strategy emphasizes the targeting of specific applications. Because of this, a microcontroller design win often dictates a close supplier/vendor relationship. As an example, development of the 8096 emerged from the company's relationship with Ford, Intel's second largest customer.

Another trend in MCUs has become evident—powerful microprocessors with even greater on-chip functionality, such as the 80186, are penetrating sophisticated nonreprogrammable applications. To carry this to its next logical step, microprocessor and microcontroller cores can be made more application-specific depending on the choice of on-board functions. We now see a proliferation of products based on this approach. In April, Intel introduced three devices based on a 32-bit core architecture; known as the 80960 series, which incorporates RISC design techniques; and the 80376 embedded processor, a non-DOS-compatible derivative of the Intel 386 microprocessor.

We now see emerging from Intel a multitiered strategy that differentiates on one level between DOS and non-DOS applications. This differentiation is borne out organizationally in that Intel's non-DOS products are gathered under the designation ECO or Embedded Control Operations. This represents a stronger emphasis on Intel's part to diversify away from its traditional image of dependency on the PC market. Within the embedded control area there is further stratification of MCUs that target different types of activities described as system control (an 80286 controlling an 8096 and 80186), data control (an 80186 with on-chip peripherals to speed up data handling), and event control (an 8096 doing real-time control).

Simultaneously then, Intel is putting in place the resources to serve a high-volume, cost-conscious market while providing MCU-based products offering greater functionality. In the MPU arena, the complete solution usually takes the form of chip sets. It is equally clear that a complete solution approach in MCUs is also needed. We expect to see this from Intel as it concentrates on delivering solutions.

Microperipherals—The Weaker Link

The enormous success of the PC market engendered a market opportunity, quickly capitalized on by companies such as Chips and Technologies, which offered chip sets for standard PC configurations. Intel was slow to react to emerging trends in the chip set business. So lucrative is the microperipheral (MPR) segment that the prevailing wisdom advises giving away the CPU to get the peripheral business that goes with it.

One would have expected that no company could have had been better placed than Intel to exploit the MPR market or better placed to reap the benefits of the synergy between MPU and MPR product offerings. Peripherals offer great potential for value-added product differentiation. Intel did secure a second-source agreement with

ZyMOS for its 80286 AT-compatible chip set, and subsequently announced its intention to enter the market with its own Micro Channel-compatible chip set. These are steps in the right direction, and from Intel's stated intentions, we expect the company to place greater emphasis on this market segment in the future. Dataquest analysts speculate that Intel may leverage its strength in MPUs to increase its MPR business by seeking additional opportunities to promote sales of these products together in the future.

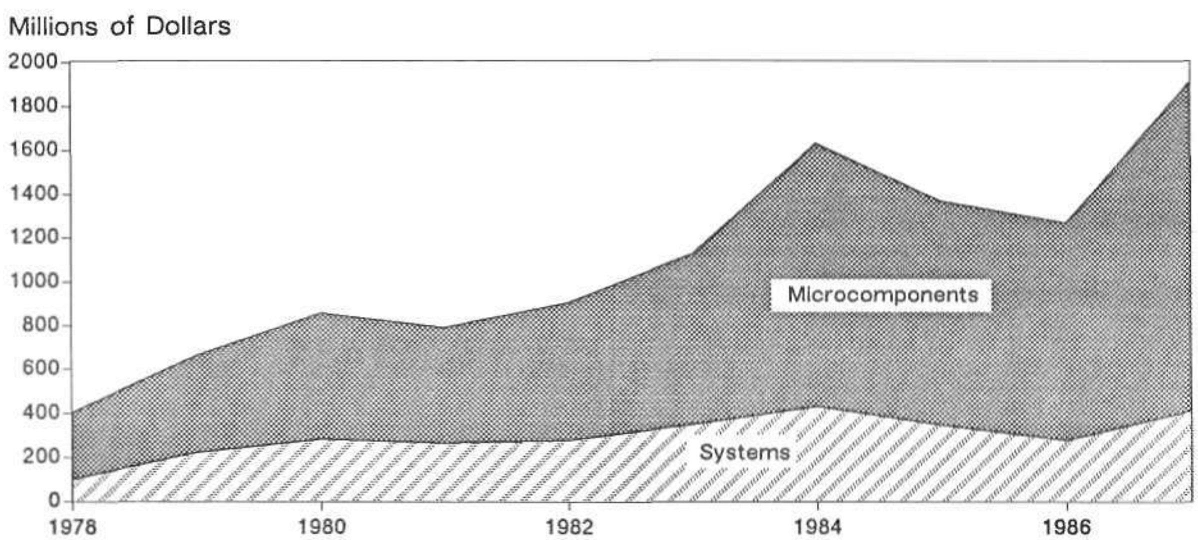
Systems—Increased Forward Integration

Intel's systems business operates with a very low profile, but with sales of almost half a billion dollars the business is of growing significance. Tribute was perhaps paid to this fact by announcing at the shareholders' meeting that Les Vadasz, senior vice president and general manager of the Systems Group, had been appointed to the Board of Directors. Figure 8 illustrates estimated systems revenue as a proportion of total company revenue. Because of this division's potential to impact future microprocessor decision making, it can be expected to play a more visible role in the company's future direction. Intel intends to grow this piece of the business so that by 1992, it will comprise about 50 percent of the company's total revenue.

As a delivery vehicle for Intel's chip technology and as a generator of value-added systems solutions, there is considerable synergy between the Microprocessor Components Division and the OEM Platforms Operation, as the Intel Systems Group is now called.

Figure 8

Intel's Estimated System versus Microcomponent Revenue



Source: Dataquest
May 1988

Memories—From DRAMs to Flash

Intel, which started out by producing memories, phased out of the DRAM portion of this market in 1986 and currently entertains no further DRAM aspirations.

What DRAM business it does participate in is generated by agreements with companies such as Micron Technology and Samsung to package and resell its memory parts. Intel's memory business is mostly in EPROMs; Dataquest estimates that the company's 1987 EPROM market share amounted to approximately 20 percent of the total, making it the leading supplier of these devices.

Intel announced two flash EPROM devices in April, a 64K and a 256K device that permit rapid bulk erase in 2 to 5 seconds, in contrast to the 15 to 20 minutes required to erase conventional EPROMs. This is an emerging area that is receiving attention from a number of vendors. Although, Intel does participate slightly in the EEPROM market, its product is based on technology from Xicor, so it is not clear at this point to what extent the company intends to offer E^2 memory capability as part of a value-added proprietary product.

ASICs

Since Jack Carsten, who headed Intel's ASIC efforts, left the company in early 1988, this area has been undergoing major reorganization. At the shareholders' meeting, Mr. Grove commented that growth in this business has been reasonable, but not as much as hoped for. Even that assessment may have been optimistic. It seems likely that the heavy demand Intel is experiencing for its standard products has had the effect of detracting from the ASIC effort, which is a very different business requiring more hand-holding and a longer gestation period before results can be seen. In light of the organizational volatility, the company may be reevaluating its strategy in ASICs, and it is possible that we could see a shifting of focus and direction within a year.

Intel's "official" entry into ASICs, through its 1986 gate array agreement with IBM, addresses one aspect of the ASIC phenomenon: logic consolidation. From the standpoint of systems integration, a higher value-added approach, Intel's MCU strategy is clearly "application specific"—a strategy that will be implemented through new generations of standard products. Dataquest believes that the extent to which Intel can harness ASIC technology to drive this thrust will be crucial to its success in the microcomponents area.

DATAQUEST CONCLUSIONS

As part of its annual meeting in Albuquerque on April 20, Intel included a brief retrospective of its 20 years in the semiconductor business. A series of slides flashed through the impressive careers of the company's founders: Robert Noyce, Gordon Moore, and Andrew Grove—a leadership nucleus that remains in place to this day.

Intel's renowned technological expertise has given it a major stake in one of the most phenomenal markets in the electronics industry: the personal computer. Intel must now address a future in which DOS compatibility may no longer be the only game in town, and in which new microprocessor architectures challenge its industry-standard products.

In facing these challenges, Intel's success equation demands that the company execute a cohesive strategy that meshes its core CPU product offering with peripheral products, addresses end-user requirements, and delivers a cost-competitive product. To achieve these ends Intel is stressing the following corporate goals:

- Continued extension of architectural and technological leadership
- Improved vendor status
- Achievement of world class manufacturer status
- Greater focus on employees

Given the enormity of its capital, technological, manufacturing, and human resources, Dataquest believes that Intel has the wherewithal to rise to these challenges, without overreaching itself.

Patricia Galligan

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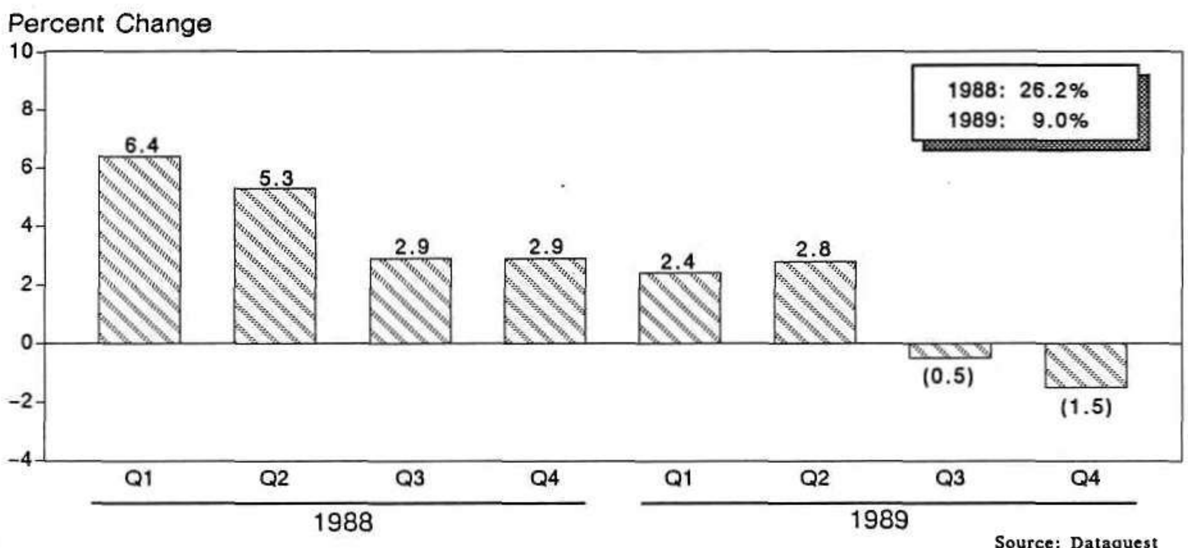
SEMICONDUCTOR RECOVERY GATHERS MOMENTUM

SUMMARY

The recovery in the worldwide semiconductor market should be stronger in 1988, as the Japanese and European markets continue to recover following the lead of the North American and Rest of World markets. Dataquest forecasts that the worldwide semiconductor market will grow 26 percent in 1988, stacked on top of the 23 percent growth in 1987. The bookings momentum and the shortages in leading-edge products suggest that the strength in shipments should continue through the first half of 1989. The Dataquest world semiconductor forecast is summarized in Figure 1 and Tables 1 and 2.

Figure 1

World Semiconductor Forecast



Source: Dataquest
May 1988

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

Table 1

Estimated World Semiconductor Market
(Billions of U.S. Dollars)

	1987	1988	1989	1990	1991	1992	CAGR 1987-1992
North America	11.9	14.7	15.6	15.2	18.0	22.3	13.5%
Japan	14.3	18.2	19.9	18.8	21.1	25.4	12.1%
Europe	6.4	7.6	8.1	8.3	9.2	10.4	10.3%
Rest of World	3.9	5.5	6.6	7.1	8.9	11.4	23.6%
Total World	36.5	46.0	50.2	49.4	57.2	69.5	13.8%

Table 2

Estimated World Semiconductor Market
(Percent Change, U.S. Dollars)

	1987	1988	1989	1990	1991	1992
North America	19%	24%	6%	(2%)	18%	24%
Japan	21%	27%	9%	(5%)	12%	21%
Europe	16%	20%	6%	2%	10%	13%
Rest of World	67%	39%	22%	7%	26%	28%
Total World	23%	26%	9%	(2%)	16%	22%

Source: Dataquest
May 1988

The short-term outlook is very strong, in spite of shortages in memory chips and increasing demand for high-end microprocessors and ASIC devices consumed in the production of data processing equipment. Overall capacity utilization is estimated to be 82 percent by the end of 1988, up from 78 percent in 1987. Capacity is tight for the leading-edge products, with capacity utilization in excess of 90 percent for the finer geometries in the 1.5-micron range. Capital spending is expected to rise 40 percent in 1988 in both the United States and Japan.

As new plants are brought on stream, capacity utilization for high-integration devices should ease a bit later this year. High-end microprocessors should soon cease to be supply limited, but microprocessor demand in 1988 is constrained by memory shortages. Although we expect demand to exceed supply for DRAMs in 1988, we expect supply to catch up in 1989 as a result of increased capacity and improved yields for 1Mb DRAMs, putting downward pressure on prices.

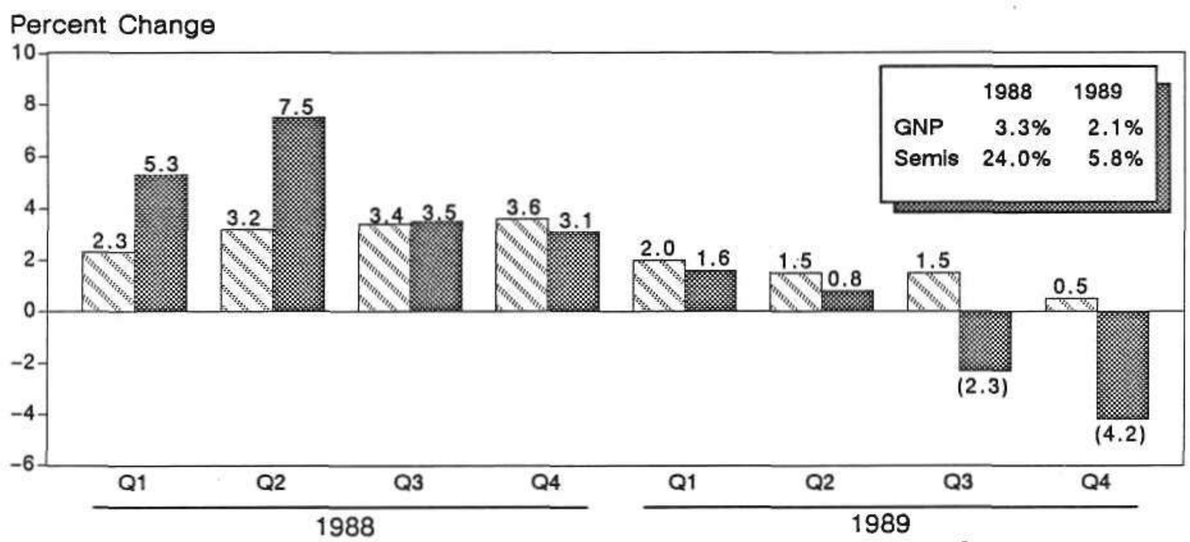
NORTH AMERICAN SEMICONDUCTOR MARKET

In the North American Semiconductor market, the strength in bookings continued in the first quarter of 1988 as confirmed by the SIA reports of robust book-to-bill ratios in the 1.15 to 1.17 range. The bookings and billings levels are now in striking range of beating the records set in 1984. The broad-based strength in data processing equipment production is driving the semiconductor demand, and demand for PCs, technical computers, and business computers continues to be strong. The resulting shortages in memory chips and high-end micros have put upward pressure on prices. Supporting the health of the industry, Dataquest's Semiconductor Application Markets (SAM) service surveys suggest that end-user inventories of semiconductors are below their target levels. Dataquest projects that the North American semiconductor market will grow 24 percent in 1988.

A mild chip recession is anticipated by mid-1989, coincident with a mild recession in the U.S. economy (see Figure 2). As the growth in U.S. real GNP slows from 3.3 percent in 1988 to 2.1 percent in 1989, worldwide electronic equipment production is expected to slow down. In particular, U.S. computer and data processing equipment production is expected to slow down from a 10.0 percent pace in 1988 to an 8.0 percent pace in 1989 and a 6.0 percent pace in 1990 (see Figure 3).

Figure 2

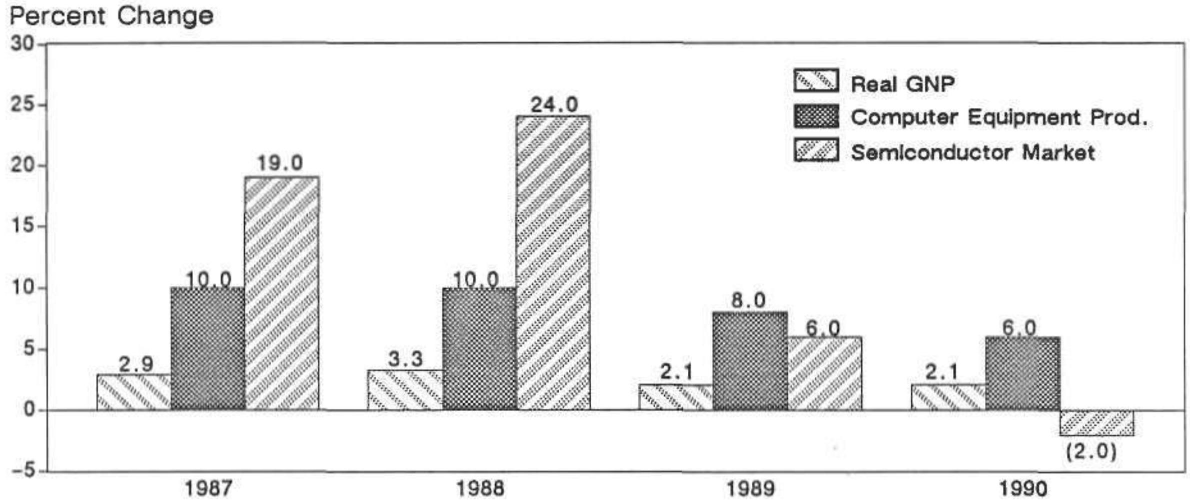
U.S. Economy versus Semiconductors



Source: Dun & Bradstreet
Dataquest
May 1988

Figure 3

U.S. Economy versus Equipment versus Semiconductors



Source: Dun & Bradstreet
Dataquest
May 1988

The chip recession is signaled by a virtually flat semiconductor market forecast for the second quarter of 1989 in North America. This should be followed by four to five quarters of mild contraction spanning the second half of 1989 and the first half of 1990, resulting in an annual growth of 5.8 percent in 1989 and a decline of 2.2 percent in 1990 in the North American semiconductor market.

The stagger chart shown in Table 3 compares our current forecast to our prior forecasts. A significant change from our prior forecast is the timing of the next chip recession. Some of the strength in 1988 is now anticipated to spill over into early 1989 because of the memory shortage. The mild downturn is now projected to span second half of 1989 and first half of 1990.

Table 3

North American Semiconductor Market
Stagger Chart
(Percent Change, U.S. Dollars)

Forecast Date	1987	1988	1989	1990
October 1986	12%	30%	(5%)	11%
January 1987	13%	23%	(5%)	11%
April 1987	15%	22%	(0%)	12%
July 1987	18%	22%	(1%)	12%
October 1987	21%	20%	(2%)	13%
January 1988		21%	(1%)	14%
April 1988		24%	6%	(2%)

Source: Dataquest
May 1988

The North American product detail forecasts are shown in Tables 4 and 5. MOS memory is the fastest growing product area in the North American market, growing 49.0 percent in 1988. MOS logic (including ASICs) and MOS microcomponents are also strong, growing 32.0 percent and 29.0 percent, respectively. The long-term forecast is for a robust 13.5 percent compound annual growth rate (CAGR) from 1987 through 1992 for the North American semiconductor market. MOS memory leads with 20.4 percent CAGR, followed by MOS logic with 17.0 percent CAGR and MOS microcomponents with 14.4 percent CAGR. High-end microprocessors and denser memories push up the average selling price of these high-integration devices. The replacement of discrete devices and standard logic by ASICs transfers value from board real-estate and wire traces to ICs. Bipolar memory is a declining market because the proportion of TTL PROMs getting replaced by MOS EPROMs and EEPROMs outpaces the growth in the high-speed ECL RAM market. Linear (analog) ICs are strong, with 11.2 percent CAGR due to fast-growing segments such as linear arrays and telecom ICs.

Table 4

Estimated Semiconductor Shipments to North America by Quarter (Millions of Dollars)

	1987	Q1/88	Q2/88	Q3/88	Q4/88	1988	Percent Change 1987-1988
Total Semiconductor	$11,869	$3,395	$3,651	$3,779	$3,895	$14,720	24.0%
Total IC	9,991	2,908	3,140	3,264	3,370	12,682	26.9%
Bipolar Digital	2,072	510	561	590	608	2,269	9.5%
Memory	279	65	72	76	84	297	6.5%
Logic	1,793	445	489	514	524	1,972	10.0%
MOS Digital	6,128	1,928	2,086	2,171	2,239	8,424	37.5%
Memory	2,347	815	862	892	916	3,485	48.5%
Micro	1,817	533	584	609	623	2,349	29.3%
Logic	1,964	580	640	670	700	2,590	31.9%
Linear	1,791	470	493	503	523	1,989	11.1%
Discrete	1,442	377	396	396	404	1,573	9.1%
Optoelectronic	436	110	115	119	121	465	6.7%

	1988	Q1/89	Q2/89	Q3/89	Q4/89	1989	Percent Change 1988-1989
Total Semiconductor	$14,720	$3,956	$3,988	$3,898	$3,734	$15,576	5.8%
Total IC	12,682	3,424	3,453	3,377	3,240	13,494	6.4%
Bipolar Digital	2,269	616	617	587	555	2,375	4.7%
Memory	297	82	77	72	70	301	1.3%
Logic	1,972	534	540	515	485	2,074	5.2%
MOS Digital	8,424	2,275	2,303	2,273	2,187	9,038	7.3%
Memory	3,485	941	950	935	895	3,721	6.8%
Micro	2,349	632	633	623	612	2,500	6.4%
Logic	2,590	702	720	715	680	2,817	8.8%
Linear	1,989	533	533	517	498	2,081	4.6%
Discrete	1,573	408	409	397	373	1,587	0.9%
Optoelectronic	465	124	126	124	121	495	6.5%

Source: Dataquest May 1988

Table 5

Estimated Semiconductor Shipments to North America by Year (Millions of U.S. Dollars)

	1987	1988	1989	1990	1991	1992	CAGR 1987-1992
Total Semiconductor	$11,869	$14,720	$15,576	$15,236	$17,993	$22,355	13.5%
Total IC	9,991	12,682	13,494	13,079	15,655	19,762	14.6%
Bipolar							
Digital	2,072	2,269	2,375	2,245	2,528	2,924	7.1%
Memory	279	297	301	291	275	265	(1.0%)
Logic	1,793	1,972	2,074	1,954	2,253	2,659	8.2%
MOS Digital	6,128	8,424	9,038	8,664	10,582	13,794	17.6%
Memory	2,347	3,485	3,721	3,499	4,287	5,936	20.4%
Micro	1,817	2,349	2,500	2,375	2,890	3,558	14.4%
Logic	1,964	2,590	2,817	2,790	3,405	4,300	17.0%
Linear	1,791	1,989	2,081	2,170	2,545	3,044	11.2%
Discrete	1,442	1,573	1,587	1,642	1,753	1,904	5.7%
Optoelectronic	436	465	495	515	585	689	9.6%

Source: Dataquest
May 1988

WORLDWIDE SEMICONDUCTOR MARKET

The Japanese semiconductor market experienced slow growth of only 4 percent in 1987 measured in yen, although the yen appreciation translated this to 21 percent growth measured in U.S. dollars. The Japanese market is now projected to recover in 1988 to 15 percent growth measured in yen. At a constant exchange rate of 130 yen to the U.S. dollar, compared with the 1987 rate of 144 yen, this translates to 27 percent growth measured in U.S. dollars. Despite the slowdown in consumer electronics production in Japan for export to the United States due to the yen appreciation, semiconductor consumption in Japan is shifting more and more into the telecom and data processing application markets. Electronic equipment production in Japan is expected to grow 7 percent in 1988.

Real GDP growth in Japan is expected to slow from 3 percent in 1988 and 1989 to 2 percent in 1990. A slow third quarter in 1989 signals the chip recession in Japan. This should be followed by three to four quarters of mild decline, resulting in an annual growth of 9 percent in 1989 and a mild decline of 4 percent in 1990 in the Japanese semiconductor market.

The European semiconductor market declined 1 percent in 1987, measured in local currency, though this translates to 16 percent growth when measured in U.S. dollars. The European market is now projected to recover to 12 percent growth in 1988, measured in local currency. At a constant exchange rate of 117 European Basket Currency Units, compared with the 1987 rate of 125 Units, this translates to 20 percent growth measured in U.S. dollars. Though European electronic equipment production continues to stagnate with only 5 percent growth expected in 1988, semiconductor demand is spurred by growth in selected areas such as PCs, workstations, and telephones. In addition to the production increase of such U.S. computer companies as Digital Equipment, Hewlett-Packard, and IBM, some Japanese electronics manufacturers are opening facilities in Europe to be closer to the markets they serve. The long-term projection is for continued modest growth in the European semiconductor market with the usual summer doldrums. The outlook is for 6 percent growth in 1989, slowing to 2 percent growth in 1990.

The Rest of World (ROW) semiconductor market, including the Asia/Pacific region (Korea, Taiwan, Singapore, Hong Kong, China) boomed in 1987, growing a whopping 67 percent. We expect this growth to "moderate" to 39 percent in 1988 in this fastest-growing region of the world. While the 1987 growth came from relocation of electronic equipment production by U.S. companies, this trend has slowed considerably. However, Japanese electronics manufacturers are now reported to be relocating plants to Asia/Pacific, sustaining growth in the region. As the U.S. economy slows, the growth in the ROW semiconductor market should flatten during the second half of 1989. The long-term outlook is for growth slowing to 22 percent in 1989 and 7 percent in 1990 in the ROW semiconductor market. As we move into the 1990s, semiconductor consumption in the ROW region should be sustained more and more by electronic equipment produced for local consumption in potentially vast markets such as China. Dataquest estimates that the ROW semiconductor market will surpass the European market in size by 1992, accounting for more than 16 percent of worldwide semiconductor consumption (see Figure 4).

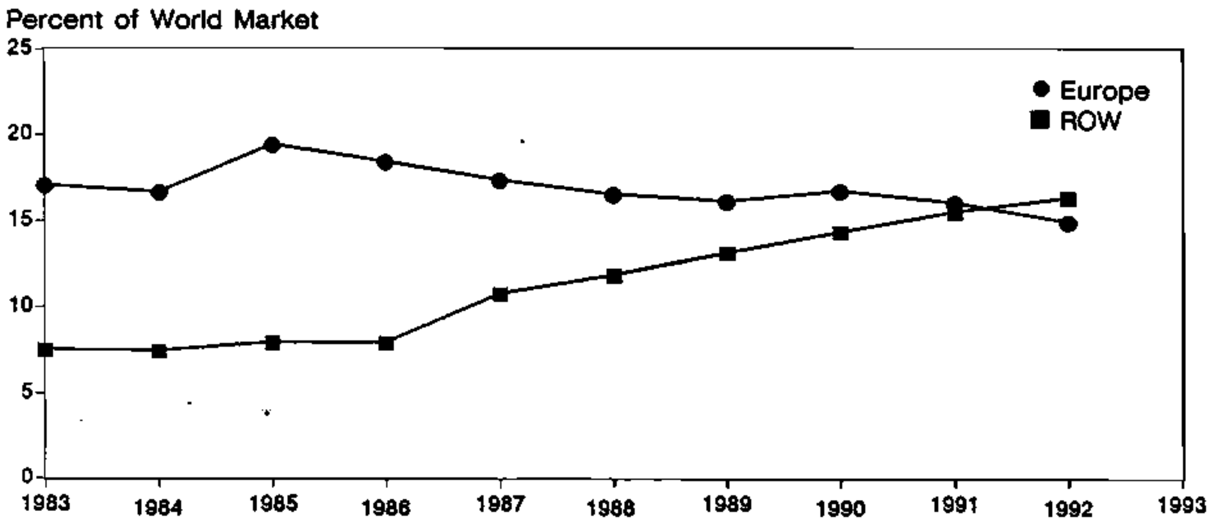
The Worldwide semiconductor shipment forecasts are shown in Tables 6 and 7. The relative product trends are similar to the North American market. MOS memory leads the pack with 42.0 percent growth in 1988, followed by MOS logic growing 33.0 percent and MOS microcomponents growing 28.0 percent. Linear (analog) ICs and optoelectronic devices will grow 20.0 percent, faster than the North American pace, with Japanese and ROW markets contributing to the growth. The long-term outlook is for a strong 13.8 percent CAGR for the world semiconductor market from 1987 through 1992. MOS memory leads with 17.7 percent CAGR, followed by MOS logic with 17.3 percent CAGR, MOS microcomponents with 14.3 percent CAGR, and linear with 13.3 percent CAGR. Optoelectronics will grow at 11.7 percent CAGR because of fast-growing segments such as laser devices used in compact discs (CDs), charge-coupled device (CCD) sensors used in imaging, and fiber-optic couplers used in telecommunications.

In summary, Dataquest forecasts the world semiconductor market to grow 26.0 percent in 1988, measured in U.S. dollars. Due to the cyclical downturn caused by slowing demand and capacity buildup, growth should decelerate to 9.0 percent in 1989, followed by a mild 1.5 percent decline in 1990. The industry should then enter the recovery cycle, topping 22.0 percent growth by 1992.

Joseph Borgia

Figure 4

Semiconductor Markets:
The Emergence of Rest of World



Source: Dataquest
May 1988

Table 6

Estimated Worldwide Semiconductor Shipments (Millions of U.S. Dollars)

	1987	Q1/88	Q2/88	Q3/88	Q4/88	1988	Percent Change 1988
Total Semiconductor	$36,498	$10,831	$11,404	$11,736	$12,077	$46,048	26.2%
Total IC	28,668	8,602	9,098	9,399	9,707	36,806	28.4%
Bipolar Digital	4,672	1,263	1,364	1,424	1,480	5,531	18.4%
Memory	565	143	153	158	167	621	9.9%
Logic	4,107	1,120	1,211	1,266	1,313	4,910	19.6%
MOS Digital	16,788	5,285	5,580	5,783	5,973	22,621	34.7%
Memory	6,019	1,999	2,099	2,184	2,246	8,528	41.7%
Micro	4,819	1,435	1,531	1,579	1,609	6,154	27.7%
Logic	5,950	1,851	1,950	2,020	2,118	7,939	33.4%
Linear	7,208	2,054	2,154	2,192	2,254	8,654	20.1%
Discrete	6,112	1,734	1,797	1,814	1,840	7,185	17.6%
Optoelectronic	1,718	495	509	523	530	2,057	19.7%
Exchange Rate Yen/$	144	130	130	130	130	130	(9.7%)
European Basket/$	125	117	117	117	117	117	(6.4%)

	1988	Q1/89	Q2/89	Q3/89	Q4/89	1989	Percent Change 1989
Total Semiconductor	$46,048	$12,368	$12,713	$12,649	$12,464	$50,194	9.0%
Total IC	36,806	9,960	10,241	10,181	10,019	40,401	9.8%
Bipolar Digital	5,531	1,506	1,526	1,469	1,400	5,901	6.7%
Memory	621	165	164	156	151	636	2.4%
Logic	4,910	1,341	1,362	1,313	1,249	5,265	7.2%
MOS Digital	22,621	6,139	6,332	6,339	6,263	25,073	10.8%
Memory	8,528	2,332	2,421	2,425	2,405	9,583	12.4%
Micro	6,154	1,643	1,697	1,704	1,699	6,743	9.6%
Logic	7,939	2,164	2,214	2,210	2,159	8,747	10.2%
Linear	8,654	2,315	2,383	2,373	2,356	9,427	8.9%
Discrete	7,185	1,864	1,911	1,907	1,891	7,573	5.4%
Optoelectronic	2,057	544	561	561	554	2,220	7.9%
Exchange Rate Yen/$	130	130	130	130	130	130	0
European Basket/$	117	117	117	117	117	117	0

Source: Dataquest
May 1988

Table 7

Estimated Worldwide Semiconductor Shipments (Millions of U.S. Dollars)

	1987	1988	1989	1990	1991	1992	CAGR 1987-1992
Total Semiconductor	$36,498	$45,343	$49,564	$49,032	$56,695	$68,868	13.5%
Total IC	28,668	36,192	39,815	39,270	45,916	56,698	14.6%
Bipolar							
Digital	4,672	5,467	5,834	5,665	6,430	7,506	9.9%
Memory	565	621	636	613	578	534	(1.1%)
Logic	4,107	4,846	5,198	5,052	5,852	6,972	11.2%
MOS Digital	16,788	22,185	24,671	23,914	28,184	35,602	16.2%
Memory	6,019	8,405	9,474	8,882	10,229	13,457	17.5%
Micro	4,819	6,045	6,647	6,545	7,676	9,307	14.1%
Logic	5,950	7,735	8,550	8,487	10,279	12,838	16.6%
Linear	7,208	8,540	9,310	9,691	11,302	13,590	13.5%
Discrete	6,112	7,116	7,546	7,526	8,246	9,228	8.6%
Optoelectronic	1,718	2,035	2,203	2,236	2,533	2,942	11.4%
Exchange Rate Yen/$	144	130	130	130	130	130	
European Basket/$	125	117	117	117	117	117	

Source: Dataquest
May 1988

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Research *Newsletter*

SIS Code: 1988 Newsletters: March
1988-9

MOTOROLA'S 88000 RISC MPU: A SUN SPARC KILLER?

SUMMARY

On February 17, Motorola advanced yet another step in processor technology, releasing a first look at its rumored RISC microprocessor, the 88000. Dataquest believes that this announcement could have serious implications for the Sun Microsystems-originated SPARC architecture among others.

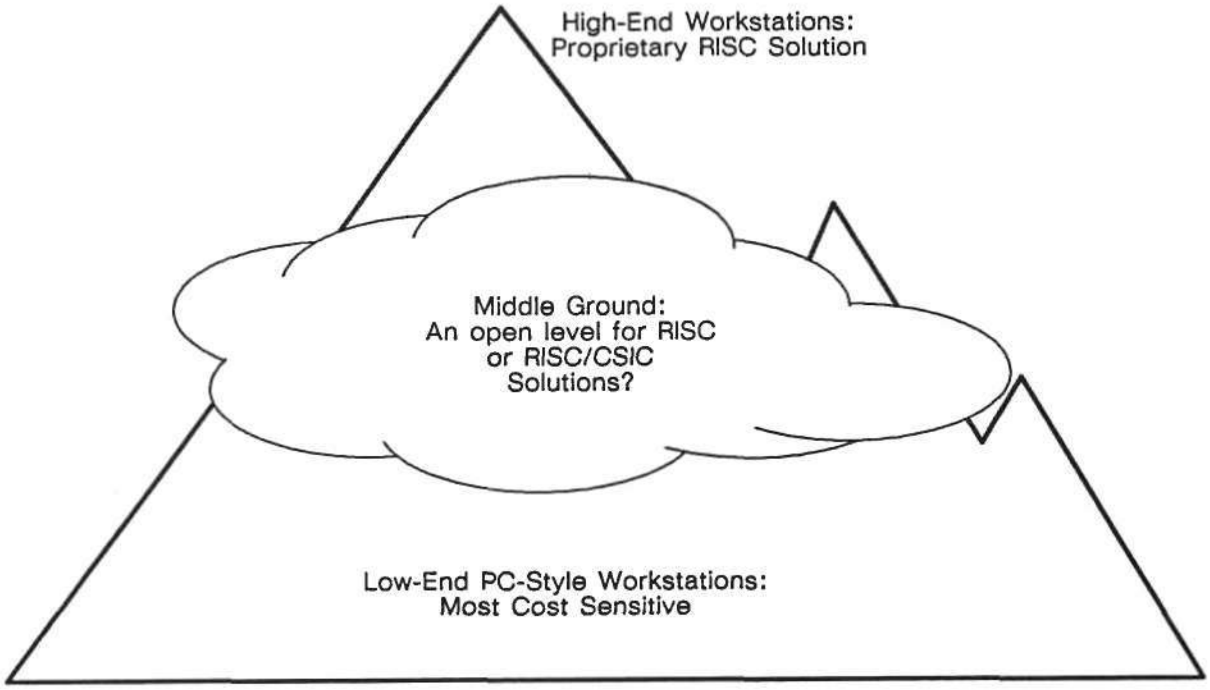
Motorola's presence is expected to legitimize the RISC market. This will clearly change the market share potential of the current participants. Motorola recognizes the need to protect its leadership position in the 32-bit market, and it is willing to outspend its competition to the tune of $20 million this year to achieve that goal. Motorola has also been able to maintain software compatibility with its existing 680x0 family. This will make it easy for present customers to convert to the 88000 if they wish, a definite competitive advantage. Furthermore, the 88000 appears technically superior because the floating-point unit is incorporated on the integer unit for the fastest possible calculations.

All these factors make Motorola a formidable challenge. As can be seen from Figure 1, Motorola must be careful in positioning the 88000, as the top and bottom levels of the technical computing market may be locked into existing solutions.

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398, (408) 437-8000, Telex 171973, Fax (408) 437-0292

Figure 1

A View of the Workstation Market



Source: Dataquest
March 1988

HAS MOTOROLA CREATED A WINNER?

Motorola's 88000 is actually a three-chip set built in a 1.5-micron double-metal, double-poly HCMOS process. These devices are scalable down to 0.8-micron technology as required. Emerging from this development effort is a 17-mips RISC architecture that is capable of reaching 50 mips in aggressive parallel processor designs.

Motorola has chosen to integrate the integer execution unit and the floating-point execution unit on the same chip. Two companion memory management/cache chips, one for instructions and one for data, complete the device set. This arrangement is called a Harvard-style parallel design. The CPU also features a scoreboarding technique to referee the use of its 32 32-bit registers. Without the scoreboarding approach, a much larger set, such as the 192 registers in Advanced Micro Devices' 29000 RISC processor, would be needed.

DATAQUEST ANALYSIS

The Questions

Motorola's entry into the RISC market prompts the following questions.

Why Would Motorola Enter an Already Crowded Marketplace?

The 88000 is not a late entry as many believe. Motorola has been gestating this product for about two years. Perhaps the need to establish the 68030 initially delayed the introduction of the 88000. Motorola has a very large investment in the microprocessor business and a substantial customer allegience. No doubt Motorola's decision to go ahead with the 88000 now, so soon after the release of the 68030, reflects the fervor generated by RISC processor announcements, especially in light of MIPS' R2000 and Sun's SPARC.

How Does Motorola Compare with the Other RISC Suppliers?

Motorola has a much larger presence in the merchant MPU market than any of the other RISC vendors. To date, the only other substantial microcomponent companies marketing a RISC processor are AMD (Am29000) and Fujitsu (SPARC). The balance of the participants consists of either systems companies where the RISC concept grew from a system-level need or smaller semiconductor companies second-sourcing an original architecture.

The stakes for Motorola are much larger. Currently, Motorola and Intel each control approximately 40 percent of the 32-bit MPU market. But Motorola's position in the scientific and technical portion of the market is more vulnerable to attack than Intel's IBM PC-based position. Motorola must quickly quell the onslaught of these RISC processors to successfully defend its leadership position.

Motorola has the ability to make finanical investments commensurate with its leadership position. Reportedly, it will spend roughly $20 million in 1988 on RISC development exclusive of process development.

How Does the 88000 Product Compare with Other RISC Devices?

All evidence points to the fact that Motorola has done its homework, and the 88000 concept is a very good one.

To begin with, the 88000 has integrated the integer execution unit and the floating-point unit. This is the only merchant RISC MPU of this design. Also, the memory management unit and caching scheme is integrated into two devices—no extra controllers are required. The 88000 has one of the highest mips ratings at 17 working VAX mips. A last, but very important point, is that the 88000 is source-code compatible with the existing 680x0 processor family. This gives Motorola an edge because a total reinvestment on the part of the customer is not required.

Where Will the 88000 Reside in the Applications Arena?

Dataquest believes that many of the RISC applications will be in the embedded-controller market such as high-speed peripherals. However, in the technical computing and workstation market, where the need for RISC was first conceived, the following three primary strata are emerging.

- The very high-end segment, where systems suppliers will continue to use proprietary RISC solutions

- The larger middle segment where a product such as the 88000 would most likely find a home—it is in this area, where semicustom solutions may not be as cost-effective, that Motorola's 88000 will be the most successful.

- The cost-sensitive low-end PC-type workstation designs probably using the 80386 and 680x0 processors—the key questions here are:

  - How much will this low-end workstation market infringe on the midrange product?

  - Will the workstation market continue to support three levels of product?

The Bottom Line

The answers to the preceding questions indicate that Motorola is a definite threat to the existing RISC MPU market. It must, however, be selective in positioning the 88000, since it is virtually impossible to be all things to all people.

(RISC technology is covered in greater detail as a part of the Semiconductor Industry Service Microcomponent segment.)

Brand A. Parks

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Research Newsletter

SIS Code: 1988 Newsletters: March
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SEMICONDUCTOR TECHNOLOGY LIMITS AND OPPORTUNITIES

INTRODUCTION

The present era has been described by various people as the age of miniaturization, the space age, or the computer age. Often there are references to the information explosion that has flooded our lives with paper, this newsletter being no exception. The fusion of communications and computer systems, which is made possible by the transistor, the planar processing of integrated circuits, gigahertz transmission and reception, and software evolution, has set the stage for continuing worldwide economic growth, improvements in productivity, and new highs in standards of living.

Nineteen eighty-seven was a time of reflection for many in the semiconductor industry, marking the 40th anniversary of the invention of the transistor. Some of the papers presented at Dataquest's SIS conference in Phoenix last October examined long-term trends in semiconductor technology. In his presentation, Dr. James D. Meindl coined the phrase "gigascale integration" and joined the list of those who have predicted the emergence, before the end of this century, of chips containing 1 billion or more transistors each. Others, including Dr. Gordon Moore and Jack Kilby, cautioned against trend extrapolation by linear regression.

This newsletter examines the limits imposed and the opportunities provided by semiconductor technology in its continuing role as a vehicle of change, and it explores some of the issues to be dealt with by this industry as it approaches the next decade.

ANALYSIS OF SEMICONDUCTOR TECHNOLOGY PROGRESS

Factors affecting semiconductor technology's rate of progress include environment, lithography science, the availability of technical talent, materials, processing knowledge, device physics, circuit and logic functions, system architecture, and the evolution of applications science. Many years ago, Dr. Moore observed that semiconductor memory density approximately doubled each year; others have observed a decrease in this rate in recent years and expect further decreases in the future (refer to Figure 1). For example, at the October Dataquest SIS conference, Mr. Kilby commented that a straight-line extrapolation of density to the year 2027 would suggest a range of 100 billion to 10 trillion transistors on 12-inch square chips at a cost of $3.00 per chip, clearly an impossible situation.

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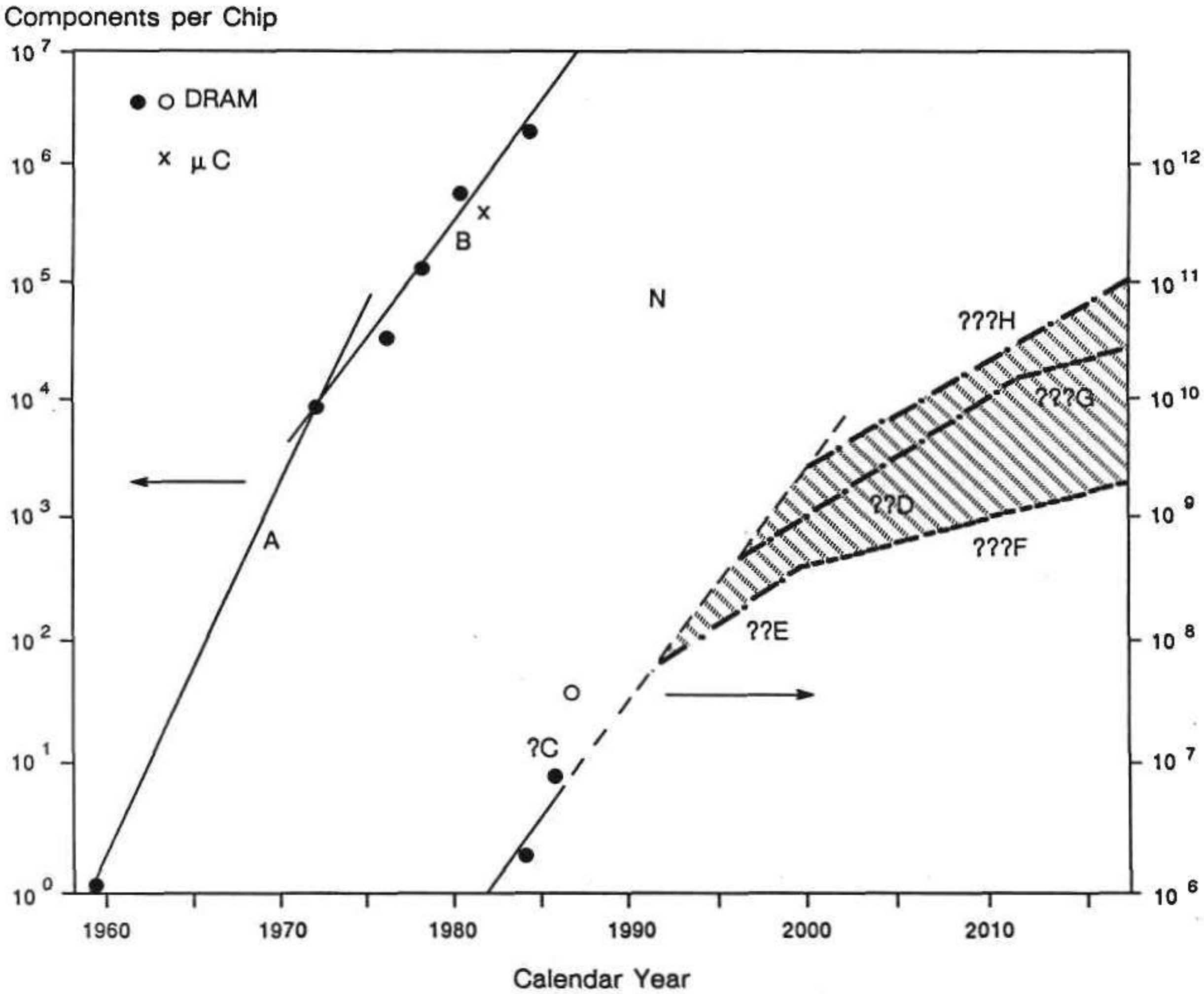
Figure 1

Circuit Density Trends



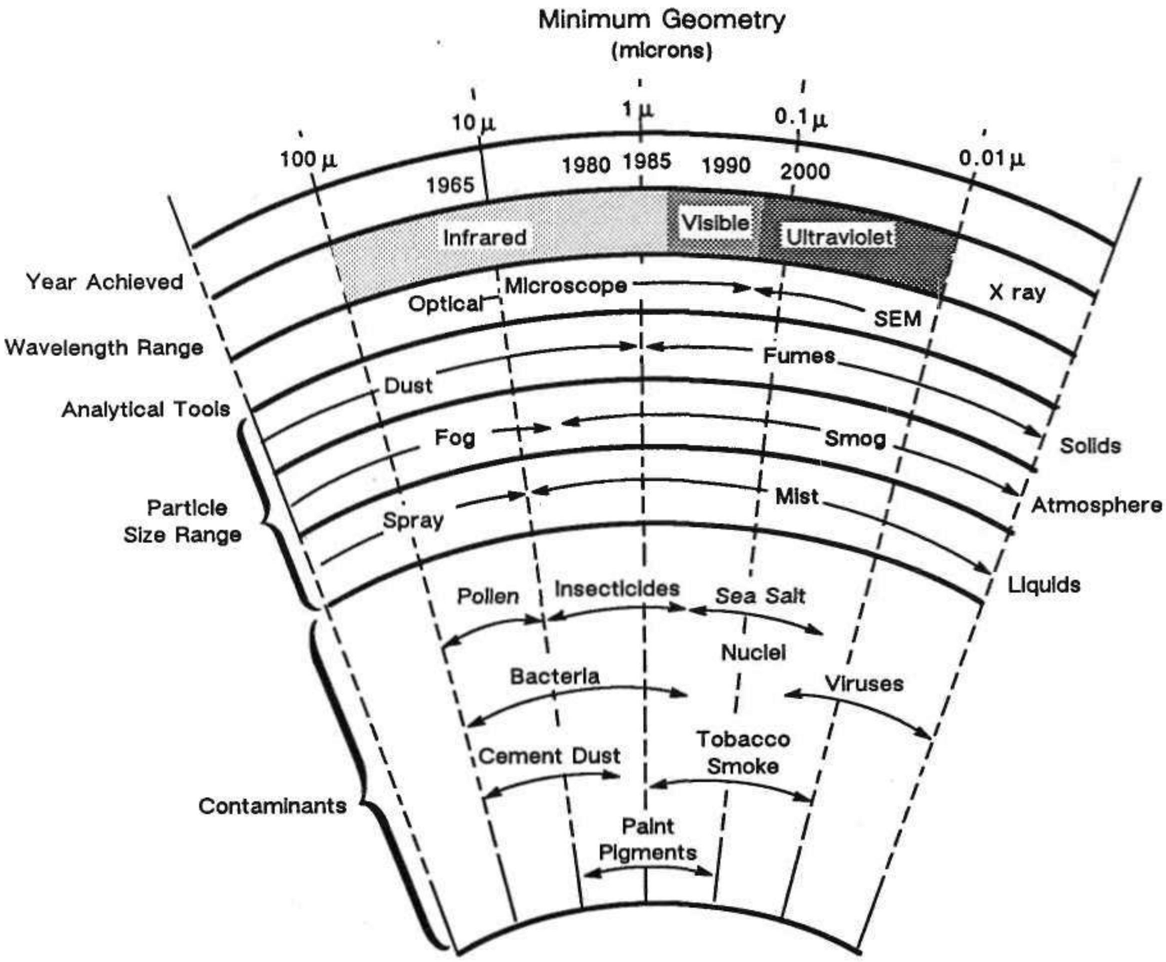
Source: Dataquest
March 1988

Environment

Perhaps the biggest environmental obstacle to semiconductor development is contamination. During early semiconductor history, contaminants included cosmetics, coal and insecticide dusts, bacteria, cement dust, and various metallurgical dusts. By the late 1970s, as minimum geometries decreased below 3 microns (u), problem contaminants included those listed above plus paint pigments, atmospheric smog, and many atmospheric dusts (see Figure 2).

Figure 2

Lithography Trends and Issues



Source: Aztek Associates

As geometries decrease to the 1u range and smaller, tobacco smoke (1.0u), oil and rosin smokes (1.0u), and sea salt nuclei (0.5u) become serious threats to quality. Fortunately, most viruses range in size below 0.05u and may not represent a major problem before the mid-1990s. The cost and ability to detect and remove these contaminants from the semiconductor manufacturing environment are significant limitations on the rate of future progress.

For more than two years, some Japanese IC manufacturers have required clean-room facilities capable of removing 0.1u and larger particles to class-10 level. At least one facility constructed in 1987 is operating at class-1 level.

Lithography Science

As geometries progress below the visible spectrum, photolithography becomes inadequate for masking. Stepper equipment available in 1987 from Canon, Nikon, and Zeiss operates at G-line (436nm) wavelength and allows 0.8u resolution in a production environment. I-line (365nm) equipment appears useful to 0.5u resolution and is becoming available. Krypton fluoride excimer laser-based systems operating at 249nm (short ultraviolet) wavelength may extend design rule limits below 0.3u, adequate for silicon but marginal for leading-edge GaAs into the 1990s. Laser sources (argon fluoride) operable at 193nm are now available and may be used before synchrotron sources become necessary.

Each step in the above-described progression implies major investments in money, time, and manpower to accomplish factory upgrading. One industry source has described the key to success as the ability to become the last company to change over (to the latest version of the latest equipment) before the marketplace for a generation of products becomes the growth limiter.

Availability of Technical Talent

Although the myth of a shortage of engineers persists, it is believed that this will never be a long-term problem. To date, it appears that every temporary shortage of technical talent has been resolved by more efficient assignment and management of resources, including increased automation of repetitive tasks. This trend is expected to continue.

Materials

For more than 20 years, the preferred starting materials (crystals sliced into wafers) for active circuits have been silicon for relatively low-cost electronic circuits and GaAs for superior performance and for photonic emitters. Each of these has unique properties that make it appropriate for classes of problems (see Table 1). The recent activity in GaAs-on-Si wafer technology offers the hope of combining the best of both worlds onto single substrates.

Silicon proponents argue that, at the limit, complementary circuit forms of GaAs do not offer a major speed advantage due to the similarity of GaAs's hole mobility with that of silicon. Further, they argue that thermal conductivity will eventually present a problem; the higher speed-power product of GaAs makes this a questionable argument.

Table 1

Comparison of GaAs and Si

Property	GaAs	Si
Relative Dielectric Constant	12.9	11.7
Energy Gap (eV)	1.42	1.12
Intrinsic Carrier Concentration (cm^{-3})	1.79×10^6	1.45×10^{10}
Linear Coefficient of Thermal Expansion ($^oC^{-1}$)	6.86×10^{-6}	5.8×10^{-6}
Minority Carrier Lifetime (s)	10^{-8}	2.5×10^{-3}
Mobility (cm^2/V-s)		
Electrons	8,500	1,500
Holes	400	450
Resistivity (ohms-cm)		
Electrons	0.02	0.08
Holes	0.25	0.11
Semi-Insulating ($10^7 cm^{-3}$ Doping)	10^7-10^9	10^3-10^5
Thermal Conductivity (W/cm-^oC)	0.46	1.5
Saturated Electron Velocity (cm/s)	1.3×10^7	-

Source: Dataquest
March 1988

Processing Knowledge

The information explosion has contributed much to the knowledge base for semiconductor processing. Most technical universities are actively engaged in semiconductor research; thousands of papers are published each year, discussing the various aspects of semiconductor processing. The "publish or perish" syndrome prevails here, particularly regarding compound semiconductors. However, there is a negative side: Turnaround time is always critical, and data overload can choke the staff of a small organization. The issue here is how to manage process technology research effectively and maintain organizational focus, without loss of momentum.

Device Physics and Scaling Effects

Silicon device technology has evolved into field-effect devices for medium performance through VLSI density at low cost, and bipolar devices, particularly ECL, for high performance at the expense of cost and density. GaAs device evolution appears to be accelerating, with depletion mode (D) and enhancement/depletion mode metal electrode semiconductor field-effect transistor (E/D-MESFET) devices now the logic workhorses, and with high electron mobility transistor (HEMT), complementary heterostructure field-effect transistor (C-HFET), and various bipolar approaches in rapid development. Although proponents of each of the device technologies often forecast the demise of the others, Dataquest believes that each will serve significant areas of applications.

Eventually, scaling dictates a decrease in circuit supply voltage, which alone is a very expensive consideration among suppliers and users alike. Other adverse effects of scaling result from the introduction of thermal problems and unacceptably high variations in parameters such as threshhold range, gain, noise immunity, and others. With every advance in lithography, CAD/CAE tools are frequently revised, as geometry shrinkage and resultant scaling affect circuit-model parameters.

Functional Blocks

At the chip level, the design of efficient functional blocks remains a problem that requires the ongoing expenditure of large amounts of precious R&D resources. The use of CAD/CAE tools has made possible the continuing rapid advancement in functional block design; future progress will depend on the availability of much more powerful workstations and software packages than those in use today.

System Architecture

At the system level, silicon has replaced copper as the material of choice for very high-speed (above 1 GHz) interconnections, for many reasons. These include:

- Enhanced security against "tapping"
- Reduced cable costs
- Lower line losses and less power consumption
- Freedom from disturbance by external electromagnetic sources
- Relative immunity to cross talk
- Unidirectional signal flow; minimum reflection problems
- Elimination of ground loops and offset voltages
- Data transmission rates in excess of 4 GHz
- Simplified signal multiplexing
- Reduced electrical hazards—no arcing or sparking
- Resistance to harsh environment
- Less cross-sectional area and weight and more ruggedness than electrical cable

The replacement of copper with silicon has profound implications on the form factor of future systems; start-up opportunities may evolve in this area.

The displacement of both copper and silicon with microwave and infrared transmission links will further impact systems architecture. For example, development of a miniature "satcom" type of PC/smart-terminal-interconnection approach, using a ceiling-mounted microwave transceiver and local microwave up-down links at each desktop station in an office complex, has been under way for more than two years. Other applications of microwave technology to the interconnect problem are expected.

Modeling of a new chip technology at the system level is still in infancy, although progress is being made. An excellent example of an attempt to develop more useful methodologies in this area is the SUSPENS system model recently described by Dr. Meindl. The model takes into account chip technology, architecture and integration level, module technology, and system architecture and size through the use of 26 parameters. The model allows addressing such issues as determining the impact of a proposed chip technology on overall system performance.

In the 1980s, there has been progress toward developing figures of merit for various semiconductor families such as CMOS, ECL, and E/D-MESFET (see Table 2). One approach under consideration accounts for minimum geometries, gate delay, gate power, and other parameters to allow direct comparison of competing device technologies. Such schemes often provoke discussions at technical conferences, with such conclusions as "0.6u CMOS requires more power than similar ECL at high duty cycle." However, such figures of merit apparently have not received widespread acceptance; the speed-power product remains the one most frequently used.

Table 2

Comparison of Si CMOS, Si ECL, GaAs E/D-MESFET, and GaAs ECL digICs

Parameter	Si CMOS	Si ECL	GaAs E/D	GaAs ECL
Gate Speed (ps) (Loaded)	1,000	350	200	50
Power/Internal Gate (uW)	5,000*	1,000	200*	1,000
Minimum Feature Size (u)	1.2	1.2	1.2	1.2
Circuit Layers	9	13	7	11
Voltages (V)	5	-3.5;+2	1.5**	1.5**
Density (Internal Gates/Die) at 1W Maximum	200	1,000	5,000	1,000

*Power is a function of electron mobility and duty cycle. The example assumes 20 percent duty cycle. CMOS achieves much higher gate counts in practice because the circuits operate at much lower duty cycles in typical applications.

**GaAs needs ECL or CMOS voltage(s) if interface compatibility to one or both circuit forms is required.

Source: Dataquest
March 1988

Evolution of Applications Science

Perhaps the biggest issues facing many semiconductor suppliers are the related questions, "Which future products should be developed?" and "What should be their specifications?" The dilemma appears to be the opposite of that of the Renaissance; rather than a shortage of practical solutions, we have a shortage of legitimate problems. This is a strong sign of a maturing industry; only due diligence to the cause of applications development will prevent premature aging.

A specific case in point is the issue of automotive safety enhancement. This opportunity can be addressed on at least two fronts with existing semiconductor technology: for collision avoidance and for engine start-up or brake release protection against drunk drivers. These applications would open tens to hundreds of millions of new sockets to GaAs linear and CMOS digital ICs. To date, no semiconductor supplier's or electronic equipment supplier's marketing department is known to be dealing with the political hurdles that must be overcome to create an environment of acceptance. Defense contractors have been good at attacking similar problems for years, but none have applied this expertise to the automotive safety application.

DATAQUEST SUMMARY AND CONCLUSIONS

It is relatively easy to envision semiconductor technology limits. Clearly, Dr. Moore's observation of density progression will not hold into the indefinite future; he recently commented that continued growth of the semiconductor industry at historic rates would result in shipments exceeding the collective GNP of all countries by the year 2010.

Although limits are easy to envision, one should be careful to analyze the perceptions for logical flaws. For example, optical lithography obviously cannot function much below the visible spectrum, but many alternatives are available. Although the physical law governing the speed of light cannot be repealed, particles other than electrons and photons are yet to be well understood. Also, indium phosphide (InP) is an example of an infant technology that may extend the range of choices for semiconductor implementation.

In summary, the semiconductor industry has an exciting decade ahead, as opportunities are developed by testing the limits of the technology in materials, equipment, devices, processes, and new applications.

Gene Miles

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Research *Bulletin*

SIS Code: 1988 Newsletters: February
1988–7

THE QUICKENING PACE OF DRAM SHORTAGES AND RISING PRICES

In September 1987, Dataquest predicted higher 1988 DRAM prices in a research bulletin entitled "Higher DRAM Prices Forecast: The Politics of Pricing." The 256K DRAM prices were projected to hit $3.00 by the end of 1988, and 1Mb DRAM prices were expected to decline at a very slow rate.

The price forecasts drew justifiable skepticism. By the end of 1987, the foreign market values (FMVs) of both 256K and 1Mb DRAMs dropped substantially below market prices. MITI effectively lifted the production constraints and allowed higher levels than manufacturers could reasonably match. There were no reports of rampant production line stoppages due to the DRAM storage. DRAM vendors announced aggressive 1Mb DRAM production plans.

Fears of 256K DRAM shortage were also relieved. Texas Instruments announced a foundry agreement with Hyundai. Micron Technology boosted its capacity with a successful die shrink program.

However, in January DRAM users were greeted with sudden changes in the DRAM market.

- The 256K DRAM shortage became a greater problem than the 1Mb DRAM deficit. Unauthorized distribution channels currently sell at $4.00 to $6.00. Certain manufacturers raised their prices to about $3.50 for standard speeds and packages. Others now carry $4.00 prices in their backlogs.
- Once a growing pipeline, the 1Mb DRAM supply via unauthorized channels tightened, raising prices in these channels to about $30.00 to $40.00. Dataquest believes that many DRAM users depend on these channels for upsides and variations in their purchasing requirements.
- The European and Asian markets are desperate in their 256K DRAM needs. Dataquest heard that U.K. Prime Minister Margaret Thatcher recently sent a letter to Japanese Prime Minister Noboru Takeshita concerning the damage that DRAM shortages are wreaking on her country's electronics industry.

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POTENTIAL CAUSES

From our investigation and observations, Dataquest believes that the following are the probable causes of recent events.

- Japanese manufacturers recently finalized their fiscal 1988 budgets. Dataquest believes that DRAM users have discovered that the production plans remain conservative and will not meet their projected demand requirements. Many manufacturers have indicated that they are booked through the third quarter of 1988.

- There are reports that in January, MITI further tightened DRAM exports by unauthorized distribution channels such as some Japanese sales representatives and trading companies. There are very limited noncaptive 1Mb DRAM applications in Japan at present. Dataquest believes that this situation is causing the Japanese distribution channels to seek business abroad. These distribution channels are reputable companies and are not to be mistaken for the suitcase brigades.

- The 1Mb DRAM yields still are not performing to plan for many companies, especially those employing trench cells. While there are legitimate technical difficulties, Dataquest believes that the political umbrella--the trade agreement and MITI initiatives--has lessened competitive intensity and the drive to improve costs and yields.

- Tragedy also contributed to the January demand shortage. In late December, a severe earthquake reportedly damaged Hitachi's Mobara plant, a major 1Mb DRAM producer. Although the extent of the damage cannot be ascertained, Dataquest believes that at least January availability was affected. The Taiwan market suffered a major blow, with the theft of NT$ 50 million worth of 256K DRAMs from the Taipei airport.

1988 OUTLOOK

Dataquest expects the high third-channel prices to have a short-lived effect. Eventually, the DRAMs will find the appropriate channel, which, in this case, should be the manufacturers' legitimate overseas operations.

However, DRAM users should brace themselves for gradually increasing 256K DRAM prices and only slight decreases in 1Mb DRAM prices in the United States. Levels of 256K DRAM production continue to decrease. With the conservative investment status in the industry, many manufacturers are transforming their 256K DRAM production areas into the 1Mb DRAM production sites. On the other hand, 1Mb DRAM availability is not likely to grow substantially, as manufacturers still struggle with their yields.

DATAQUEST ANALYSIS

Dataquest sees little relief this year in DRAM availability, as long as product demand remains robust. DRAM users must contend with four factors that will greatly limit availability.

- DRAM producers remain skeptical about the demand requirements and booking rates of their customers. Many still recall the 1985 "nightmare" and cringe at the thought of reliving it.

- Political intervention by MITI and the U.S. Department of Commerce has limited competition and, with it, the urge to improve yields and capacity rapidly.

- U.S. manufacturers can provide a semblance of 1Mb DRAM competition but hesitate to do so because of technical problems and the alluring profits of the 256K DRAM market.

- The SIA and MITI may lock horns again soon over the Japanese market access issue and the imposition of new trade sanctions. Hidden agendas and plans of action may once more disrupt the DRAM marketplace.

Manufacturers maintain control of their destinies only within a confined space. The boundaries of this space are clearly determined by governmental agencies. Within the confined space, these manufacturers face great uncertainty concerning future demand and a fluctuating exchange rate.

Victor de Dios

Dataquest

Conference Schedule

1988

Semiconductor Users/Semiconductor Application Markets	February 22–23	Westin St. Francis Hotel San Francisco, California
Computer Products	March 1	Hotel Inter-Continental New York City, New York
	March 4	Back Bay Hilton Boston, Massachusetts
	March 7	Santa Clara Doubletree Inn Santa Clara, California
Copying and Duplicating	March 7–9	The Pointe at Squaw Peak Phoenix, Arizona
Imaging Supplies	March 9–10	The Pointe at Squaw Peak Phoenix, Arizona
Telecommunications	March 21–23	Hyatt Regency Monterey Monterey, California
Electronic Printer	April 5–7	Hyatt Regency Monterey Monterey, California
Imaging Supplies	April 7–8	Hyatt Regency Monterey Monterey, California
Japanese Semiconductor	April 11–12	Century Hyatt Hotel Tokyo, Japan
Computer Storage	April 18–20	Santa Clara Marriott Santa Clara, California
Color Conference	May 2–3	Hyatt Regency Cambridge Cambridge, Massachusetts
European Semiconductor	June 8–10	Gleneagles Hotel Auchterarder, Scotland
Display Terminals/Graphics and Imaging	June 13–15	Hyatt Regency Monterey Monterey, California
Electronic Publishing	June 16–17	Silverado Country Club Napa, California
European Copying and Duplicating	June 29–July 1	Bristol Hotel Kempinski Berlin, West Germany
Financial Services	August 28–30	Silverado Country Club Napa, California
Western European Printer	September 7–9	Hilton International Wien Vienna, Austria
Manufacturing Automation/CAD/CAM	September 12–15	Hyatt Regency Monterey Monterey, California
Personal Computer	September 21–23	Silverado Country Club Napa, California

(Continued)

Information Systems	September 30–October 7	Tokyo American Club Tokyo, Japan
Technical Computer	October 5–7	San Diego Princess San Diego, California
Semiconductor	October 17–19	San Diego Princess San Diego, California
European Telecommunications	October 19–21	Hilton International Brussels Brussels, Belgium
Office Equipment Dealer/ Electronic Typewriter	November 2–4	Hyatt Regency Cambridge Cambridge, Massachusetts
Asian Semiconductor and and Electronics Technology	November 7–8	Seoul, Korea
Industrial Automation	November 30–December 2	Palace Hotel Madrid, Spain

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GATE ARRAYS: AN INTENSE BATTLEGROUND

LSI Logic battled the Japanese giants to maintain its number one position in 1987 worldwide MOS gate arrays, hard pressed by NEC, Toshiba, and Fujitsu. (See Table 1.) CMOS gate array prices continue to be slashed as suppliers bid for market share. Pricing on 2-micron CMOS arrays with densities ranging from 500 to 8,000 gates went from between .2 and .3 cents per gate in late 1986, to between .1 and .2 cents per gate in late 1987.

During 1987, the worldwide gate array market grew 27.8 percent compared to 1986, while U.S. companies grew 24.2 percent and Japanese companies grew 32.4 percent. Japanese companies now own 50.1 percent of the total worldwide gate array market, while U.S. companies own 40.6 percent. Japanese companies tend to be vertically integrated and use their internal consumption to drive their products down the learning curve and cut the overhead costs.

Table 1

Estimated Worldwide MOS Gate Array
Shipment Revenue
(Millions of Dollars)

1986 Rank	1987 Rank	Company	1986 Revenue	1987 Revenue	Percent Change
1	1	LSI Logic	$192.0	$251.0	30.7%
2	2	NEC	$158.0	$206.0	30.4%
4	3	Toshiba	$116.0	$174.0	50.0%
3	4	Fujitsu	$120.0	$156.0	30.0%
5	5	Oki	$ 48.0	$ 67.0	39.6%
7	6	Seiko/S-MOS	$ 30.3	$ 52.5	73.3%
6	7	National/Fairchild	$ 31.5	$ 43.9	39.4%
8	8	Honeywell	$ 27.0	$ 39.1	44.8%
10	9	SGS/Thomson	$ 20.3	$ 28.0	37.9%
9	10	GE/RCA	$ 26.8	$ 27.0	0.7%

Source: Dataquest
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On the gate array market battleground, companies compete with software, design expertise, manufacturing, and service. VLSI Technology found the right formula for CMOS gate arrays and went from number 32 worldwide in 1986 with $5.5 million, to number 11 in 1987 with $25.0 million.

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Table 2 shows the 1987 top ten worldwide bipolar gate array suppliers and their revenue.

Table 2

Estimated Worldwide Bipolar Gate Array Shipment Revenue (Millions of Dollars)

1986 Rank	1987 Rank	Company	1986 Revenue	1987 Revenue	Percent Change
1	1	Fujitsu	$170.0	$201.0	18.2%
2	2	Motorola	$ 82.6	$ 93.0	12.6%
3	3	NEC	$ 69.0	$ 84.0	21.7%
4	4	Plessey/Ferranti	$ 59.6	$ 60.0	0.7%
7	5	Hitachi	$ 34.0	$ 51.0	50.0%
5	6	Honeywell	$ 45.0	$ 47.0	4.4%
6	7	National/Fairchild	$ 37.0	$ 40.2	8.6%
9	8	AMCC	$ 19.0	$ 27.0	42.1%
8	9	Raytheon	$ 22.0	$ 26.5	20.5%
11	10	Exar	$ 15.0	$ 17.8	18.7%

During 1987, the worldwide MOS gate array market increased 35.3 percent, while the ECL gate array market grew 27.1 percent. Worldwide TTL gate array revenue peaked during 1986 and fell 4 percent during 1987. Table 3 shows Dataquest's 1988 forecast for MOS, bipolar, and BICMOS gate arrays.

BICMOS gate arrays will take market share from both the ECL and CMOS gate array markets. Dataquest forecasts and supplier shipment revenue include NRE, production, and sales to internal divisions. Gate array design methodology not only will be used to design single-user ASICs, it will be used to generate standard products that have been excluded from the forecast. The expected 1989 recession has been programmed into our semiconductor forecasts.

This research bulletin will be followed by a comprehensive gate array newsletter in the near future.

Bryan Lewis

Table 3

Estimated Worldwide Gate Array Consumption by Technology (Millions of Dollars)

	1985	1986	1987	1988	1989	1990	1991	1992
Total	$1,279.3	$1,768.1	$2,268.4	$2,883.6	$3,184.5	$4,006.5	$5,034.3	$6,323.8
Total MOS	718.3	1,092.6	1,478.3	1,935.3	2,126.9	2,678.9	3,355.8	4,159.6
Total Bipolar	556.0	657.5	759.1	889.5	954.5	1,126.6	1,326.8	1,566.2
Total BICMOS	5.0	18.0	31.0	58.8	103.1	201.0	351.7	598.0

Source: Dataquest
February 1988

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SEMATECH GOES TO AUSTIN—WHAT'S NEXT?

SUMMARY

During the month of January, Sematech made two key announcements concerning what it plans to produce and where it plans to produce it. The details of these announcements are are follows:

- On January 6, Sematech's board of directors unanimously approved Austin, Texas, as the site for the first U.S. semiconductor manufacturing consortium. In so doing, the board ended months of intense speculation concerning Sematech's intended location.

- On January 26, Sematech announced its manufacturing demonstration vehicles (MDVs). The devices that Sematech has chosen to produce, high-density DRAMs and fast SRAMs, are based on processes being donated by member corporations AT&T and IBM.

This newsletter, produced jointly by Dataquest's Semiconductor Industry Service (SIS) and Semiconductor Equipment and Materials Service (SEMS), looks at the following issues that have arisen in the wake of these recent Sematech announcements:

- The significance of the Austin site as an infrastructure serving the goals of the Sematech program

- The manufacturing choices now confronting Sematech as it undertakes its charter to restore the U.S. semiconductor industry to world class manufacturing competitiveness

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SITE SELECTION CRITERIA

The responsibility for choosing a Sematech location fell to a site selection committee headed by Sanford L. Kane, vice president of industry operations for IBM's General Technology Division. In a document sent to participants in the site proposal process, Mr. Kane's committee outlined the site selection criteria. The stated criteria included the following:

- A 100,000- to 200,000-square-foot facility, preferably with existing clean room capability, that could be occupied by the fourth quarter of 1987
- At least 30 to 35 acres of property to accommodate a future facility
- Proximity to universities with which the site could maintain a "proposed ongoing relationship"
- Support from state and local governments in the form of financial and other incentives
- A quality of life for Sematech personnel that would take into account the cost and availability of housing, traffic congestion, and climate

WHY AUSTIN?

At first glance, Austin, Texas, seems to be overshadowed by some of its competitors in key criterion areas:

Funding

The University of Texas, Austin, pledged $50 million to purchase and retrofit a facility formerly owned by Data General. With the addition of other incentives offered by the university and state and local governments, the total funding offered by Texas came to an estimated $68 million. In comparison, Massachusetts had proposed a financial package valued at nearly $400 million, with Arizona, California, and New York offering financial incentives in the neighborhood of $100 million or more.

Facilities

While the former Data General building that will serve as Sematech's manufacturing facility meets the site selection requirements for immediate and expandable space, it lacks one significant feature: a clean room. Acceptance of the Massachusetts bid, on the other hand, would have given Sematech immediate access to the Massachusetts Microelectronics Center, located in Westboro, which is situated on 36 acres of land and includes an IC fab facility. The Arizona bid would have given Sematech the headquarters and wafer fab sites formerly belonging to SGS, with rent subsidized by bond money.

University Research Relationships

The close working relationship that Sematech will have with the University of Texas, Austin, is already evident from the fact that the university itself is funding Sematech's fab requirements. In addition, the university is allowing Sematech access to its Cray supercomputer and will build a permanent headquarters for the consortium at its Balcones Research Center.

Other site proposals, however, included highly attractive associations with university research programs. Arizona offered support valued at nearly $160 million from its state university system. New York's proposal would have given Sematech a complex of facilities at the Rensselaer Polytechnic Institute, making available its Centers for Integrated Electronics and Industrial Innovation. Also participating would have been the Rochester Institute of Technology, the semiconductor laboratory of Cornell University, Massachusetts Institute of Technology, and Carnegie Mellon Institute.

INFRASTRUCTURE WINS

With its choice of Austin, Texas, the Sematech site selection committee believes that it has chosen an infrastructure that will further the consortium's goal. As expressed by Sematech Board Chairman Charlie Sporck, that goal is to "ensure the domestic semiconductor industry's future competitiveness." Although some of the components of this infrastructure may not shine as brightly as those offered by competing states, Austin certainly touches all the bases: strong ties with a major university program, proximity to the Microelectronics and Computer Corporation (MCC), an aggressive program aimed at retrofitting the Data General facility for wafer processing by the end of this year, a centralized location, and an environment that is increasingly attracting technology industries.

However effectively other site proposals addressed these same infrastructure elements, the Austin site adds two others that make it unique:

- The close involvement of government at local, state, and federal levels
- The presence of leading-edge semiconductor manufacturing capacity

For an organization that clearly sees its mission in the context of a nationwide initiative to restore the United States to the front ranks of world class manufacturing, these elements could very well have tipped the scales in Austin's favor. A closer look at these elements follows.

Government Partnering

Texas politicians at the state and local levels are being credited with a masterful performance in putting together the Austin site proposal. When faced with the obvious disadvantage of a facility that lacked a clean room, Texas officials responded with a thorough and demanding clean room construction schedule. Then, they built a model clean room at the Data General site through the cooperation of a consultant and donations from equipment suppliers.

The support shown for Sematech at the state and local levels in Texas was mirrored at the federal level by the efforts of U.S. Representative J.J. Pickle, a senior member of the House Ways and Means Committee, and House Speaker James Wright. Sematech leaders have cited the efforts of these two Texas politicians in the saving of Sematech's $100 million federal grant from budget cutting.

Some of the losing states in the site selection contest have suggested that the choice of Austin may be as much a tribute to political clout as to the intrinsic advantages of the site itself. The fact remains, however, that in order to be successful, Sematech will depend on a partnering relationship with government. Texas has clearly demonstrated its intention, at all political levels, to support the Sematech program.

Where the Manufacturers Are

Dataquest's Semiconductor Equipment and Materials Service (SEMS) maintains a detailed data base on semiconductor manufacturers in North America. Much of the information that follows has been derived from the surveys and research that support the fab data base. A top-level view of the SEMS data base suggests that, from the standpoint of the regional dispersion of semiconductor manufacturing capacity, locating Sematech in the central region of North America makes sense. Looking at the wafer fab locations of the 10 largest U.S.-owned semiconductor manufacturers, most of whom are participating in Sematech, a regional profile appears in Table 1.

Table 1

Regional Dispersion of Semiconductor Fab Sites Among the Ten Major Sematech Participants

Company	Western	Central	Eastern
AMD	X	X	
AT&T			X
GE	X		X
Harris			X
HP	X	X	
IBM			X
Intel	X	X	
Motorola		X	
National	X	X	X
TI	-	X	-
Total	5	6	5

Note: The above table does not represent the actual number of facilities that a company has in a geographic region, but whether or not it has some manufacturing presence there.

Source: Dataquest February 1988

Quoting Charlie Sporck, Sematech's "product" is "...manufacturing knowledge. This cannot be expressed as a single deliverable product, process, statement, or strategy." Because of Sematech's charter to further production-worthy semiconductor processes, locating in a state with a high-volume, leading-edge manufacturing base makes sense. Moreover, in terms of current, equipment-limited, semiconductor manufacturing capacity, Texas leads all other North American states.

Texas: Home of Leading Edge Capacity

Although California boasts the largest number of production-based fab lines currently operating in North America (97 of 255 fab locations), the fab lines in California have approximately half of the average start capacity of their Texas counterparts. In addition, 38 percent of today's 150mm and 200mm wafer capacity is in Texas.

This suggests that if someone wants to develop a start-up and a process technology, California is the place to go. If, however, a company wants to bring up volume production, it should be aware that a large portion is outside California—and most is in Texas. This difference in infrastructure of this activity is not lost on semiconductor manufacturers, as is evident in recent moves to Texas by VLSI Technology and Cypress Semiconductor. In fact, California has seen almost every major semiconductor company move its manufacturing eastward, as new capacity was required. Looking ahead, Dataquest believes that while California will continue to support more wafer fab lines during the 1990s, Texas is expected to have the highest capacity in North America.

WHAT NEXT FOR SEMATECH?

With its manufacturing site selected, Sematech is now faced with rolling up its sleeves and producing. Since the announcement of its formation in early 1987, the member companies of Sematech have held ongoing workshops to hammer out the consortium's objectives. Among the issues that have been settled are the following:

- Sematech will manufacture both DRAMs and fast SRAMs. Member company IBM will donate its 0.8-micron, 4Mb DRAM process to Sematech, while AT&T will contribute its 0.7-micron, 64K fast SRAM process based on the six-transistor cell.

- The processes are CMOS based.

- Sematech will begin its fab operations by early 1989.

- Sematech will be using equipment geared for high-volume production, but on a smaller manufacturing scale.

- Working devices produced by Sematech will be destroyed rather than sold. This will keep Sematech focused on the manufacturing demonstration vehicles (MDVs) that it is developing, rather than on making shipment commitments.

PRODUCING 16Mb SRAMS/64Mb DRAMS

In predicting just what type of MDVs Sematech will deliver, two points are important to note. The first is that, at present, 256K SRAMs (four-transistor cell) and 1Mb DRAMs, utilizing 1.0- to 1.2-micron processes, are the current technology drivers. The second is that, in 1989, Sematech will start out with 0.8- and 0.7-micron technologies that will be six months to one year ahead of the merchant semiconductor market. Dataquest is assuming that Sematech is serious about its avowed goal of achieving world class semiconductor manufacturing leadership within five years. Based on this assumption, Dataquest believes that by early 1994, Sematech expects to deliver the equivalent of a 16Mb SRAM (four-transistor cell) and 64Mb DRAM to its members, using a 0.35-micron CMOS process.

If Sematech is able to hit this assumed target, it could give its members a lead of one to one and one-half years ahead of the rest of the merchant semiconductor industry's predicted introductions of these devices. Dataquest does not expect the merchant semiconductor industry to be reasonably comfortable with 0.8-micron processes until 1990, and even then, these processes are not expected to be mainstream. Excluding the possible impact of Sematech, the merchant semiconductor industry is not expected to become equally comfortable with 0.5-micron processes until 1993, and with 0.35-micron processes until 1996.

SRAM/DRAM Pros and Cons

With Sematech's choice of both SRAMs and DRAMs as the MDVs, the pros and cons of both MDV choices are listed below.

DRAMs—The Pros

- IBM has contributed a 4Mb DRAM, plus all the manufacturing and engineering support that is necessary for a rapid and efficient technology transfer.
- IBM's DRAM uses a modular process architecture, which allows the construction of SRAMs or logic chips with only minor changes to the process sequence.
- DRAMs are proven as complex technology drivers.
- DRAMs are very high-volume products.
- DRAMs are conducive to very large wafer sizes.
- Some merchant semiconductor DRAM-technology expertise still remains in North America.

DRAMs—The Cons

- Limited DRAM capacity is left in North America.
- Possible limitations of technology transfer arise from IBM's proprietary photoresist technologies.

Fast SRAMs—The Pros

- AT&T has contributed a 64K SRAM using a six-transistor cell design.
- AT&T's SRAM is built with a process technology designed for making circuits such as logic chips, microprocessors, and ASICs.
- More fast SRAM expertise in North America is available to Sematech for the development and execution of the technology.
- AT&T's SRAM process sequence is shorter than IBM's DRAM process sequence and will, therefore, produce working silicon demonstration units first.

Fast SRAMs—The Cons

- Fast SRAMs do not drive the largest wafer sizes for the following two reasons:
  - The uniformity of the process across the wafer is critical to achieving uniform yields of the fastest SRAMs. Since one wafer can yield various classes of SRAMs, these uniformity issues are better addressed on smaller wafers. As wafer sizes get larger, process uniformity across the wafer is degraded.
  - The fast SRAM market is not a high-volume market and, therefore, is not conducive to the largest wafer sizes.

When looking at these issues, the best product for Sematech appears to be the DRAM. The DRAM is a high-volume, large-wafer technology driver, and some good on-shore expertise is available. With the additional selection of fast SRAMs, Sematech is working to meet the diversified needs of its 13 member companies. Sematech appears to have made the most logical choices concerning the types of devices it will develop and deliver.

WAFER SIZE

A number of important manufacturing decisions still face Sematech. Probably the most important near-term decision Sematech must make is whether to run 125mm, 150mm, or 200mm wafers initially. Sematech must also plan which wafer size it will use to deliver products to its member companies.

The processes offered to Sematech by AT&T and IBM are based on 125mm wafers. While there is a mixed bag of issues regarding wafer size, one thing is obvious: Sematech cannot expect to deliver a leading-edge process based on 125mm wafers when 150mm and 200mm wafers will, respectively, be the mainstream and leading-edge wafer sizes in 1994.

Wafer Size Pros and Cons

The following are the pros and cons that Sematech must resolve regarding the wafer size that it will begin with and the wafer size it will eventually deliver its MDVs on.

The Pros of 125mm Wafers

- 125mm wafers would allow for the quickest start with established 0.7- and 0.8-micron processes.
- Sematech could immediately begin to smooth out its fab operations with a well-understood wafer size.
- The industry as a whole is far along the learning curve with 125mm wafers.

The Cons of 125mm Wafers

- 125mm wafers are too small to be competitive in the 1994 time frame.
- Starting with this size will add one or possibly two necessary jumps in wafer size for Sematech during the next five years.

The Pros of 150mm Wafers

- The product could be delivered in 1994, at which time 150mm wafers will be mainstream.
- The industry has gained a fairly good understanding of 150mm wafer technology.

The Cons of 150mm Wafers

- No 150mm wafer processes have been offered to Sematech.
- If a 150mm wafer process is delivered in 1994, some companies (certainly IBM) will have to bear the expense and risk of bringing the process up to a 200mm process. At that time, there will be approximately 20 to 25 large 200mm fabs in North America.

The Pros of 200mm Wafers

- IBM could offer its 200mm process soon.
- This size would be difficult to start out with but could offer the most reward in 1994.
- It is easier to downsize from 200mm wafers to 150mm wafers than it is to jump up from 150mm to 200mm wafers.

The Cons of 200mm Wafers

- No 200mm wafer processes are currently offered to Sematech.
- The 200mm wafer size would be a difficult size to start with in 1989.

- Some companies will not have 200mm wafer processes and will, therefore, have to downsize the process to 150mm, thereby adding cost and time.
- Some semiconductor equipment is not yet ready for 200mm wafer processing.

CONCLUSIONS

With a facility and products selected, a new sense of urgency now accompanies the manufacturing decisions facing Sematech. Based on the information concerning wafer size, the most likely scenario for Sematech could be any one of the following three:

- Starting out with the established 125mm wafer processes and enlist the help of IBM to make one jump up to 200mm wafers
- Starting out with 150mm wafers during 1989 and shift to 200mm wafers by 1991
- Starting out with 200mm wafers during 1989, assuming that IBM offers its 200mm wafer process and that the process is mature enough to be delivered

Michael J. Boss
Mark T. Reagan

Dataquest

Conference Schedule

1988

Semiconductor Users/Semiconductor Application Markets	February 22-23	Westin St. Francis Hotel San Francisco, California
Computer Products	March 1	Hotel Inter-Continental New York City, New York
	March 4	Back Bay Hilton Boston, Massachusetts
	March 7	Santa Clara Doubletree Inn Santa Clara, California
Copying and Duplicating	March 7-9	The Pointe at Squaw Peak Phoenix, Arizona
Imaging Supplies	March 9-10	The Pointe at Squaw Peak Phoenix, Arizona
Telecommunications	March 21-23	Hyatt Regency Monterey Monterey, California
Electronic Printer	April 5-7	Hyatt Regency Monterey Monterey, California
Imaging Supplies	April 7-8	Hyatt Regency Monterey Monterey, California
Japanese Semiconductor	April 11-12	Century Hyatt Hotel Tokyo, Japan
Computer Storage	April 18-20	Santa Clara Marriott Santa Clara, California
Color Conference	May 2-3	Hyatt Regency Cambridge Cambridge, Massachusetts
European Semiconductor	June 8-10	Gleneagles Hotel Auchterarder, Scotland
Display Terminals/Graphics and Imaging	June 13-15	Hyatt Regency Monterey Monterey, California
Electronic Publishing	June 16-17	Silverado Country Club Napa, California
European Copying and Duplicating	June 29-July 1	Bristol Hotel Kempinski Berlin, West Germany
Financial Services	August 28-30	Silverado Country Club Napa, California
Western European Printer	September 7-9	Hilton International Wien Vienna, Austria
Manufacturing Automation/CAD/CAM	September 12-15	Hyatt Regency Monterey Monterey, California
Personal Computer	September 21-23	Silverado Country Club Napa, California

(Continued)

Information Systems	September 30–October 7	Tokyo American Club Tokyo, Japan
Technical Computer	October 5–7	San Diego Princess San Diego, California
Semiconductor	October 17–19	San Diego Princess San Diego, California
European Telecommunications	October 19–21	Hilton International Brussels Brussels, Belgium
Office Equipment Dealer/ Electronic Typewriter	November 2–4	Hyatt Regency Cambridge Cambridge, Massachusetts
Asian Semiconductor and and Electronics Technology	November 7–8	Seoul, Korea
Industrial Automation	November 30–December 2	Palace Hotel Madrid, Spain

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SEMICONDUCTOR OUTLOOK REMAINS HEALTHY

At the Dataquest Semiconductor Conference on October 19, we presented our outlook projecting 24 percent growth for the 1988 worldwide semiconductor market. The worldwide stock market crash that began the same day has prompted us to reevaluate our assumptions and monitor the market for any change in conditions. Although we have not yet found signs of any major revisions in business plans resulting from the crash, the continued decline of the U.S. dollar against the Japanese yen points to slower growth in electronic equipment production and semiconductor consumption in Japan and the Asia-Pacific area where the electronics exports to the United States are sourced. The semiconductor outlook for Europe is lower due to the weakness of their telecom sector.

With the continued recovery in the North American market, the current outlook for the world semiconductor market is for a 21 percent growth, from $38 billion in 1987 to $46 billion in 1988, as shown in Tables 1 and 2. Our revised quarterly industry forecast for the 1988 world semiconductor market for 1988 is shown in Table 3.

Table 1

Estimated Worldwide Semiconductor Market
(Percent Change in U.S. Dollars)

		1988				
	1987	Q1	Q2	Q3	Q4	1988
Japan	19.4%	1.3%	3.3%	3.0%	2.3%	20.7%
North America	21.4%	5.2%	5.6%	2.0%	2.1%	21.1%
Europe	12.2%	5.4%	5.3%	2.3%	4.0%	14.0%
Rest of World	62.1%	6.9%	9.9%	6.2%	5.1%	31.5%
Total Worldwide	22.8%	3.9%	5.2%	3.0%	2.9%	21.1%
Japan (in Yen)	2.9%	1.3%	3.3%	3.0%	2.3%	13.2%
Europe (in ECU)	(3.4%)	5.4%	5.3%	2.3%	4.0%	8.7%

Source: Dataquest
January 1988

Table 2

Estimated Worldwide Semiconductor Market
(Billions of U.S. Dollars)

		1988				
	1987	Q1	Q2	Q3	Q4	1988
Japan	$14.8	$ 4.3	$ 4.4	$ 4.5	$ 4.6	$17.8
North America	12.4	3.6	3.7	3.8	3.9	15.0
Europe	6.2	1.6	1.8	1.8	1.9	7.1
Rest of World	4.7	1.4	1.5	1.6	1.7	6.2
Total Worldwide	$38.1	$10.9	$11.4	$11.7	$12.1	$46.1
Exchange Rates						
Japan (Yen/$)	144	135	135	135	135	135
Europe (ECU/$)	126	120	120	120	120	120

Source: Dataquest
January 1988

Table 3

Estimated Worldwide Semiconductor Shipments
(Millions of U.S. Dollars)

		1987					% Change
	1986	Q1	Q2	Q3	Q4	1987	1987
Total Semiconductor	$31,009	8,330	9,371	9,931	10,439	$38,071	22.8%
Total IC	$23,601	6,401	7,263	7,817	8,243	$29,724	25.9%
Bipolar Digital	$ 4,321	1,130	1,250	1,237	1,184	$ 4,801	11.1%
Memory	675	176	179	174	166	695	3.0%
Logic	3,646	954	1,071	1,063	1,018	4,106	12.6%
MOS Digital	$13,064	3,651	4,196	4,696	5,108	$17,651	35.1%
Memory	4,338	1,158	1,313	1,528	1,809	5,808	33.9%
Micro	3,661	1,016	1,171	1,300	1,367	4,854	32.6%
Logic	5,065	1,477	1,712	1,868	1,932	6,989	38.0%
Linear	$ 6,216	1,620	1,817	1,884	1,951	$ 7,272	17.0%
Discrete	$ 5,818	1,519	1,651	1,664	1,727	$ 6,561	12.8%
Optoelectronic	$ 1,590	410	457	450	469	$ 1,786	12.3%
Exchange Rate (Yen/$)	167	153	142	147	135	144	(13.8%)
Exchange Rate (ECU/$)	146	129	126	128	120	126	(13.6%)

(Continued)

Table 3 (Continued)

Estimated Worldwide Semiconductor Shipments
(Millions of U.S. Dollars)

	1987	1988 Q1	1988 Q2	1988 Q3	1988 Q4	1988	% Change 1988
Total Semiconductor	$38,071	10,845	11,410	11,752	12,092	$46,099	21.1%
Total IC	$29,724	8,593	9,082	9,373	9,685	$36,733	23.6%
Bipolar Digital	$ 4,801	1,216	1,269	1,312	1,382	$ 5,179	7.9%
Memory	695	172	182	191	198	743	6.9%
Logic	4,106	1,044	1,087	1,121	1,184	4,436	8.0%
MOS Digital	$17,651	5,365	5,670	5,841	6,017	$22,893	29.7%
Memory	5,808	1,947	2,081	2,116	2,154	8,298	42.9%
Micro	4,854	1,413	1,486	1,529	1,547	5,975	23.1%
Logic	6,989	2,005	2,103	2,196	2,316	8,620	23.3%
Linear	$ 7,272	2,012	2,143	2,220	2,286	$ 8,661	19.1%
Discrete	$ 6,561	1,771	1,826	1,853	1,873	$ 7,323	11.6%
Optoelectronic	$ 1,786	481	502	526	534	$ 2,043	14.4%
Exchange Rate (Yen/$)	144	135	135	135	135	135	(6.3%)
Exchange Rate (ECU/$)	126	120	120	120	120	120	(4.8%)

Source: Dataquest
January 1988

ANALYSIS

A survey of leading economists projects 1988 gross national product (GNP) growth at least one full percentage point lower than the precrash estimates for both the United States and Japan. The Dun & Bradstreet chief economist Joe Duncan in particular has lowered his estimate of 1988 real GNP growth in the United States from 3.3 percent to 2.8 percent. Dataquest's own estimate for real gross domestic product (GDP) growth in Japan is for a mild acceleration from 2.5 percent in 1987 to 3.0 percent in 1988, contrasted with our previous estimate of 4.0 percent. The yen appreciation lowers the prospects for Japanese electronics exports to the United States. The European economy should continue to languish at 2 percent growth in 1988.

Dataquest projects that U.S. electronic equipment production will grow 6 to 7 percent in 1988. We now expect the U.S. computer and office equipment production to recover to 10 percent growth and communications equipment production to grow 7 percent in 1988. While the demand should continue to exceed supply in the leading-edge products such as 1Mb DRAMs and high-end microprocessors, we should begin to see softening demand and price erosion for commodity products by the second half of 1988.

The strength of the recovery in computer equipment production should carry the North American semiconductor consumption during the first half of 1988. The growth should slow during the second half, however, resulting in an overall 21 percent growth in 1988, about the same as in 1987.

Japanese electronic equipment production should grow only 6 to 7 percent in 1988, lower than our earlier estimate of 10 percent. While we expect the telecom sector to continue to be strong locally, the sharp yen appreciation to the ¥125 level should limit equipment exports and production. The net result is a 13 percent growth in the Japanese semiconductor market measured in yen, or 21 percent measured in U.S. dollars.

Electronic equipment production in Europe is expected to be very soft, with only 3 to 5 percent growth in 1988. This lowers the European semiconductor market growth rate to only 9 percent in 1988 measured in local currency, or 14 percent measured in U.S. dollars.

The Rest of World market, including the Asia-Pacific area, is very sensitive to the U.S. economy, and we anticipate a slower pace of growth compared with the boom in 1987. The up side is that the Korean Olympics should bolster local demand.

Thus, Dataquest is projecting a healthy outlook for the worldwide semiconductor market with 21 percent growth in 1988. We expect the recovery in the North American market to continue through the first half of 1988 while the Japanese and European semiconductor markets recover from the 1987 slump.

Joseph Borgia
Stan Bruederle

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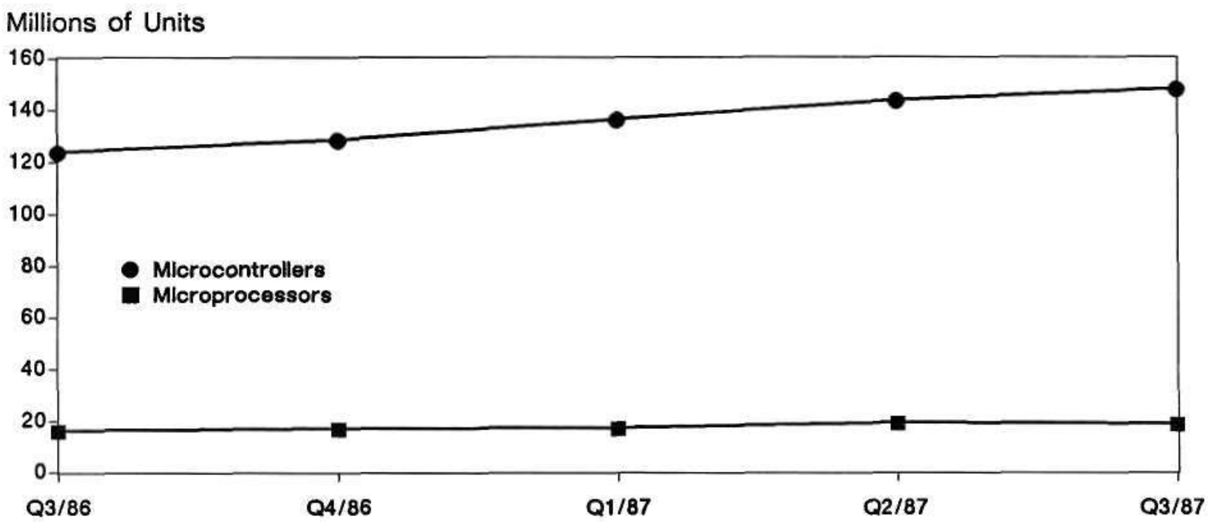
MICROPROCESSOR/MICROCONTROLLER SHIPMENT UPDATE
THIRD QUARTER 1987

SUMMARY

For the seventh consecutive quarter, estimated shipments of all microcontroller devices were up as shown in Figure 1. Shipments of microcontrollers experienced a growth rate of just more than 3 percent, representing a unit increase of 4.3 million.

Figure 1

Microcontroller and Microprocessor Unit Shipments
Third Quarter 1986 through Third Quarter 1987
(Millions of Units)



Source: Dataquest
January 1988

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During the third quarter of 1987, worldwide microprocessor (MPU) unit shipments declined slightly by approximately 2 percent from the previous quarter. This resulted primarily from a 4.7 percent decrease in 8-bit microprocessors, as shown in Table 1.

Table 1

Total Microprocessor Unit Shipments by Word Length (Thousands of Units)

	Q2/87		Q3/87		Percent
		Percentage of		Percentage of	Growth
MPU	Units	Shipments	Units	Shipments	Q2 to Q3
8-Bit	13,917	71.9%	13,263	70.0%	(4.7%)
16-Bit	5,120	26.5	5,231	27.6	2.2%
Others	315	1.6	446	2.4	41.6%
Totals	19,352	100.0%	18,940	100.0%	(2.1%)

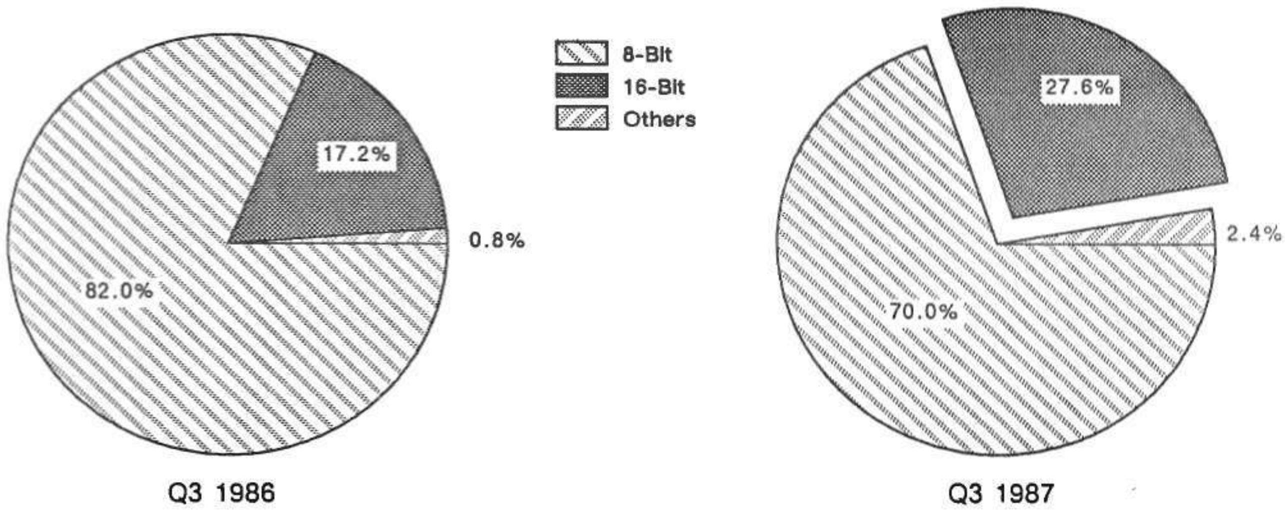
Source: Dataquest
January 1988

MICROPROCESSOR COMMENTARY

In keeping with the alternating increase/decrease pattern exhibited over the past six quarters, shipments of 8-bit MPUs declined 4.7 percent from the second quarter. Shipments of 16-bit MPUs, however, continued to increase as they have every quarter since the beginning of 1986, although at a slower rate in the current quarter. Increased shipments of 16-bit MPUs have affected the 8-bit to 16-bit MPU ratio by increasing 16-bit MPUs as a percentage of the total. Figure 2 compares the third quarter of 1987 with the same quarter of 1986. Also in the third quarter, for the first time we see the continued strong rate of increase in 32-bit MPUs starting to translate into larger market share. This stems largely from the entry of the 80386 into high-volume production for the first time.

Figure 2

Microprocessor Word Length as a Percentage of Total Shipments



Source: Dataquest
January 1988

8–Bit MPU Shipments Down 4.7 Percent

With the exception of the Z80 family of devices, 8–bit MPUs across the board experienced a decline in shipments. Table 2 ranks the major 8–bit MPUs for the third quarter of 1987 and indicates percent growth for the quarter.

Table 2

8–Bit Microprocessor Shipments (Thousands of Units)

	Q2/87		Q3/87		Percent Growth
Device	Units	Percentage of Shipments	Units	Percentage of Shipments	Q2 to Q3
Z80	5,713	41.0%	5,861	44.2%	2.6%
8085	2,126	15.3	1,999	15.1	(6.0%)
8088/V20	2,073	14.9	1,695	12.8	(18.2%)
6802	1,111	8.0	1,027	7.7	(7.6%)
6809	976	7.0	870	6.6	(10.9%)
Others	1,918	13.8	1,811	13.6	(5.6%)
Total	13,917	100.0%	13,263	100.0%	(4.7%)

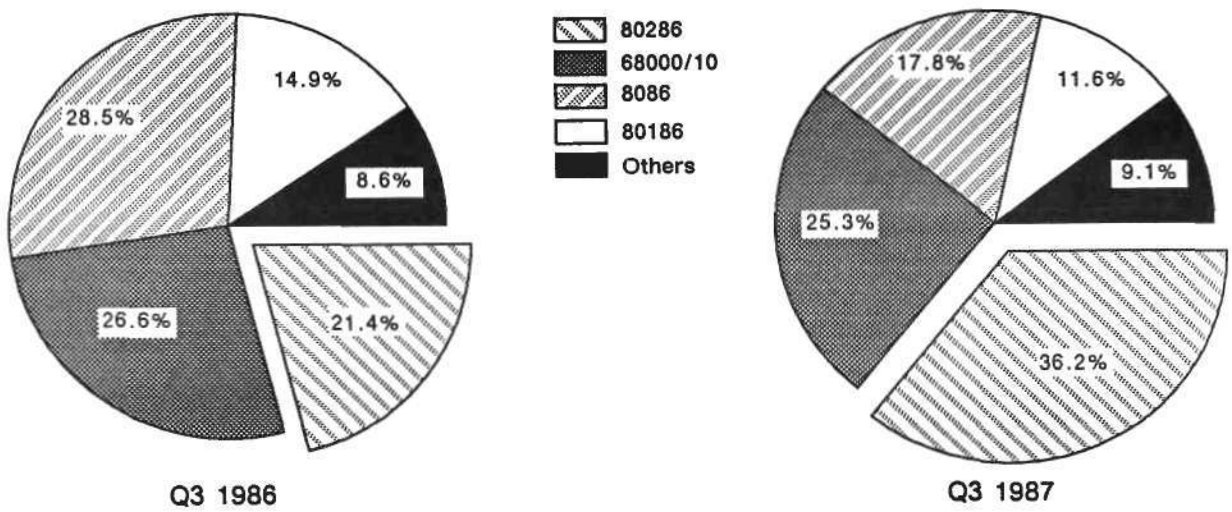
Source: Dataquest
January 1988

16–Bit MPU Shipments Keep Going Up

The rate of growth for shipments of 16–bit MPUs slowed in the third quarter of 1987 to just more than 2 percent. As shown in Figure 3, the 80286, the leading 16–bit MPU, has significantly increased its market share since third quarter 1986 to command more than 36 percent of the market in the third quarter of 1987. In Table 3, third quarter 1987 shipments of the leading 16–bit MPUs are compared with the previous quarter's shipments.

Figure 3

Estimated Market Share by Product for 16–Bit MPUs



Source: Dataquest
January 1988

Table 3

Leading 16-Bit MPU Shipments (Thousands of Units)

Device	Q2/87 Units	Q2/87 Percentage of Shipments	Q3/87 Units	Q3/87 Percentage of Shipments	Percent Growth Q2 to Q3
80286	1,870	36.5%	1,893	36.2%	1.2%
68000/10	1,293	25.3	1,323.5	25.3	2.4%
8086/V30	885	17.3	931.5	17.8	5.3%
80186	571	11.1	606	11.6	6.1%
Z8000	252	4.9	241	4.6	(4.4%)
32016	96	1.9	99	1.9	3.1%
Others	153	3.0	137	2.6	(10.5%)
Total	5,120	100.0%	5,231	100.0%	2.2%

Source: Dataquest
January 1988

Small Changes in Regional Shipment Distribution

Table 4 shows the market share changes in 8- and 16-bit MPU shipments (not consumption) by geographical region. The data for 8-bit MPU market share indicates only marginal changes in the third quarter of 1987 from the prior quarter. Japanese and U.S. suppliers stand neck-and-neck in this segment of the market. However, in the 16-bit MPU market, the U.S. share has increased in the two most recent quarters to the current level of 78 percent market share.

Table 4

Market Share by Region for 8- and 16-Bit Microprocessor Shipments

Device	Region	Q3/86	Q4/86	Q1/87	Q2/87	Q3/87
8-bit MPUs	United States	40.9%	41.3%	43.8%	40.6%	41.3%
	Japan	46.1	44.3	42.3	41.6	41.7
	Europe	13.0	14.4	13.9	17.8	17.0
	Total	100.0%	100.0%	100.0%	100.0%	100.0%
16-bit MPUs	United States	71.8%	74.9%	73.1%	76.0%	78.0%
	Japan	18.5	18.3	14.8	13.3	13.2
	Europe	9.7	6.8	12.1	10.7	8.8
	Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Dataquest
January 1988

MICROCONTROLLER COMMENTARY

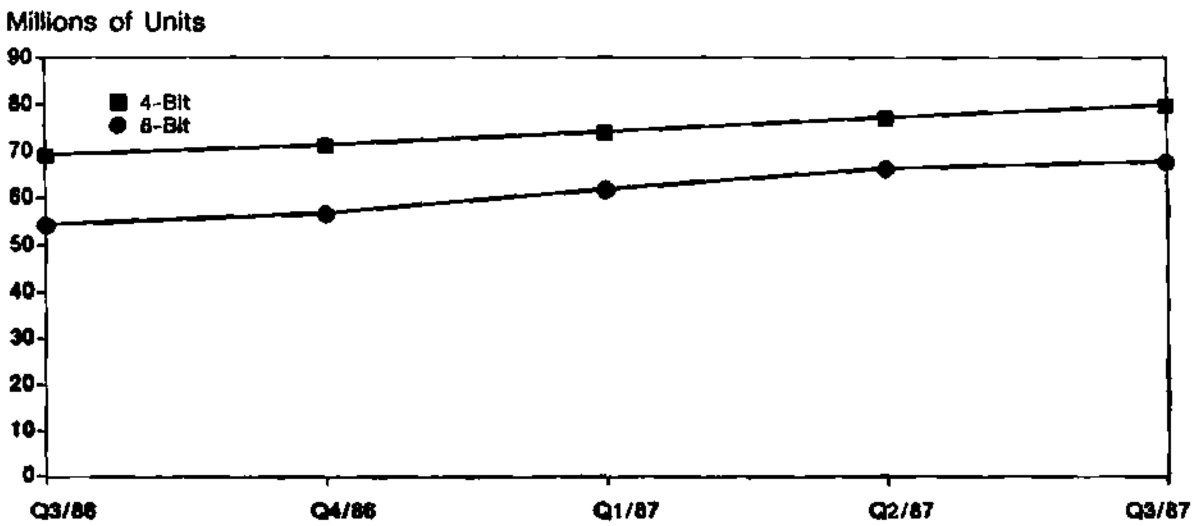
Shipments of 4-bit microcontrollers (MCUs) continue to lead 8-bit MCU shipments by a reasonably constant ratio. Figure 4 shows estimated shipments of 4- and 8-bit MCUs for the most recent five quarters. Both 4- and 8-bit MCUs grew in the third quarter of 1987 over the second quarter of 1987 but at a slower pace. Overall growth for this market segment was 3 percent, as shown in Table 5.

Among the leading 8-bit MCUs, the 8049 and 8051 devices displayed the highest growth. In each case we are seeing strong increases in shipments of the CMOS version of the device, as well as good growth for the NMOS parts. Table 6 shows the changes in estimated shipments of leading 8-bit microcontrollers in the third quarter of 1987 from second quarter 1987.

Japanese suppliers continue to dominate the 4-bit MCU market, whereas in the 8-bit MCU arena, the market share of the U.S. and Japanese suppliers is not as skewed. Here both regions are evenly balanced in terms of market share, although the Japanese tend to retain a slight lead. Table 7 shows the market share changes in shipments (not consumption) by geographical region for 4- and 8-bit MCUs from the third quarter of 1986 through the third quarter of 1987.

Figure 4

4- and 8-Bit MCU Unit Shipments
Third Quarter 1986 through Third Quarter 1987
(Millions of Units)



Source: Dataquest
January 1988

Table 5

Total Microcontroller Unit Shipments by Word Length
(Thousands of Units)

	Q2/87		Q3/87		Percent
		Percentage of		Percentage of	Growth
Device	Units	Shipments	Units	Shipments	Q2 to Q3
4-bit	77,341	53.7%	80,215	54.1%	3.7%
8-bit	66,581	46.2	68,012	45.8	2.2%
16-bit	102	0.1	142	0.1	39.2%
Total	144,024	100.0%	148,369	100.0%	3.0%

Source: Dataquest
January 1988

Table 6

Leading 8-Bit Microcontroller Shipments
(Thousands of Units)

	Q2/87		Q3/87		Percent
		Percentage of		Percentage of	Growth
Device	Units	Shipments	Units	Shipments	Q2 to Q3
6805	9,805	14.7%	9,859	14.5%	0.6%
8049	8,474	12.7	9,197	13.5	8.5%
8051	6,832	10.3	7,421	10.9	8.6%
8048	3,618	5.4	3,408	5.0	(5.8%)
Others	37,852	56.9	38,127	56.1	0.7%
Totals	66,581	100.0%	68,012	100.0%	2.2%

Source: Dataquest
January 1988

Table 7

Market Share by Region for 4- and 8-Bit Microcontroller Shipments

Device	Region	Q3/86	Q4/86	Q1/87	Q2/87	Q3/87
4-bit	United States	18.0%	19.9%	17.7%	17.0%	15.0%
	Japan	79.6	77.6	79.8	80.6	82.6
	Europe	2.4	2.5	2.5	2.4	2.4
	Total	100.0%	100.0%	100.0%	100.0%	100.0%
8-bit	United States	37.3%	39.8%	40.2%	41.1%	41.5%
	Japan	46.2	43.5	44.5	43.9	44.1
	Europe	16.5	16.7	15.3	15.0	14.4
	Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Dataquest
January 1988

NMOS VERSUS CMOS

The ratio between NMOS and CMOS shipments for 8-bit MPUs and 8-bit MCUs is similar. Table 8 shows that the market share for CMOS 8-bit MCUs has remained remarkably constant over the past three quarters. In the 8-bit MPU segment, however, there has been a slow but steady increase in the CMOS share of shipments over the same period. During third quarter 1987, Japanese suppliers accounted for more than 77 percent of all 8-bit CMOS MCU shipments and approximately 57 percent of all 8-bit CMOS MPU shipments.

Table 8

Market Share by Technology for 8-Bit MCU/MPU Shipments

Device	Technology	Q3/86	Q4/86	Q1/87	Q2/87	Q3/87
8-Bit MCU	CMOS	27.1%	29.0%	30.3%	31.9%	31.8%
	NMOS	72.9	71.0	69.7	68.1	68.2
	Total	100.0%	100.0%	100.0%	100.0%	100.0%
8-Bit MPU	CMOS	25.3%	26.2%	25.7%	26.0%	28.9%
	NMOS	74.7	73.8	74.3	74.0	71.1
	Total	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Dataquest
January 1988

DATAQUEST ANALYSIS

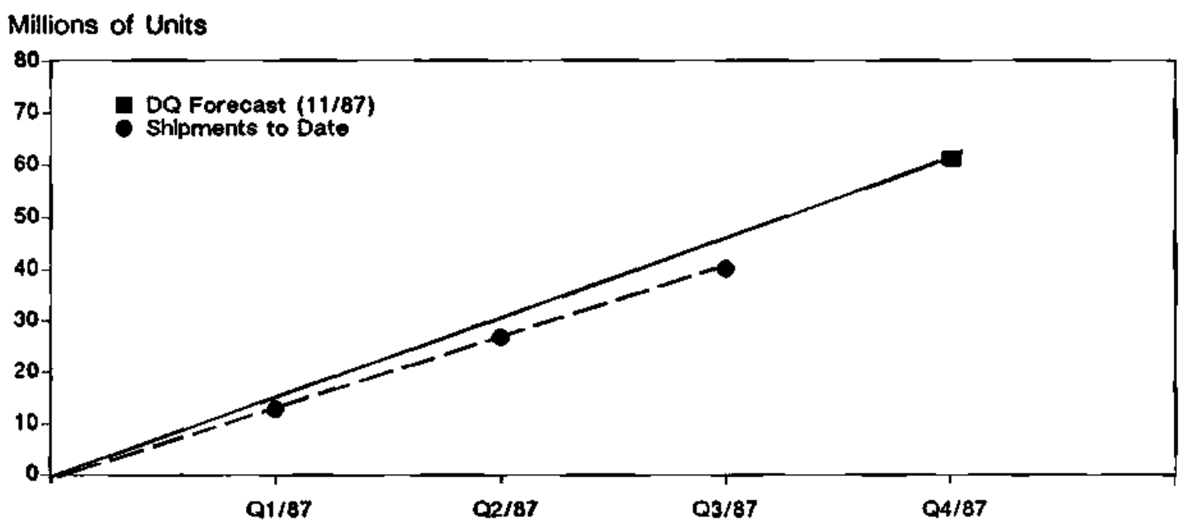
How does the quarterly data compare to our forecast?

A key indicator of the health of a particular market is how the quarterly shipments compare to the forecast. Figures 5 through 8 track the cumulative shipments to date of the four major microcomponent product categories against the current Dataquest forecast. We are using the forecast generated in October as our reference. It would appear from the graphs for 8- and 16-bit MPUs that there is a more rapid transition from 8- to 16-bit MPUs, which accounts for the overestimation of 8-bit MPUs and underestimation of 16-bit MPUs in the forecast. Four-bit MCUs are substantially correct but the forecast with respect to 8-bit MCUs continues to demonstrate a noticeable overestimation of this market segment.

Patricia A. Galligan
Alice K. Leeper

Figure 5

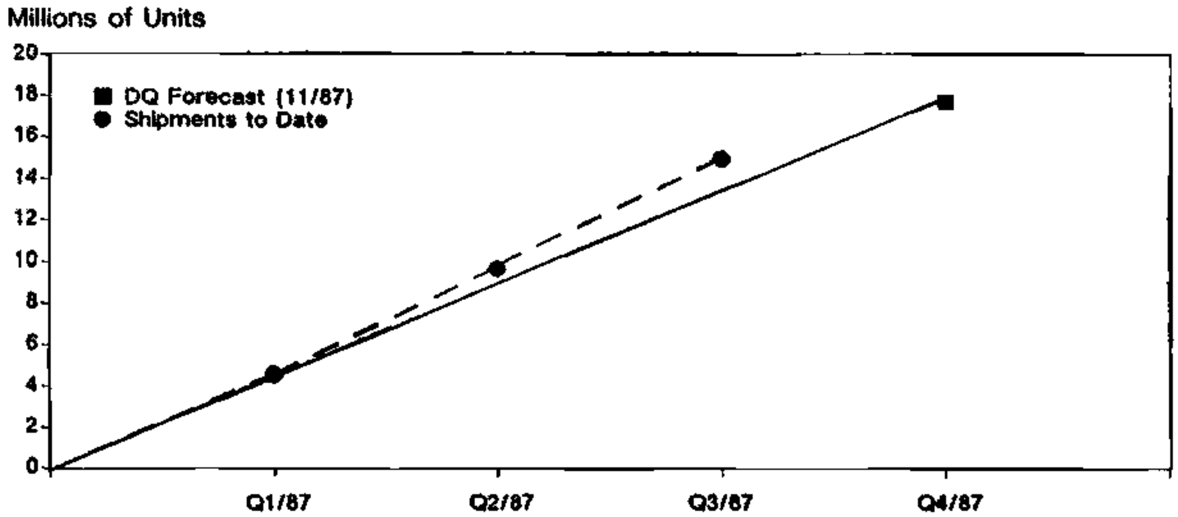
8-Bit Microprocessors
Cumulative Shipments to Date
(Millions of Units)



Source: Dataquest
January 1988

Figure 6

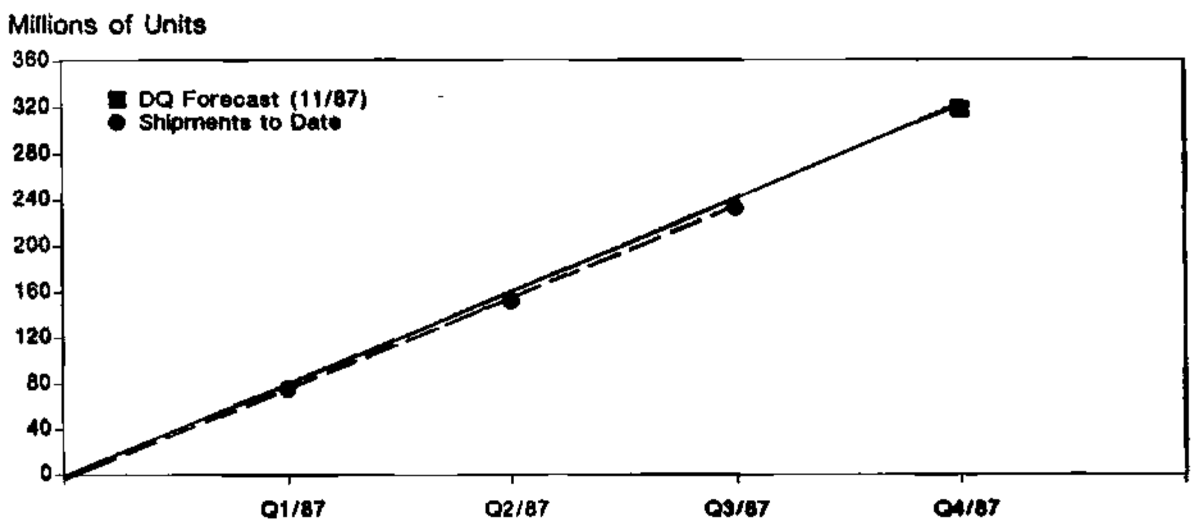
16-Bit Microprocessors Cumulative Shipments to Date (Millions of Units)



Source: Dataquest
January 1988

Figure 7

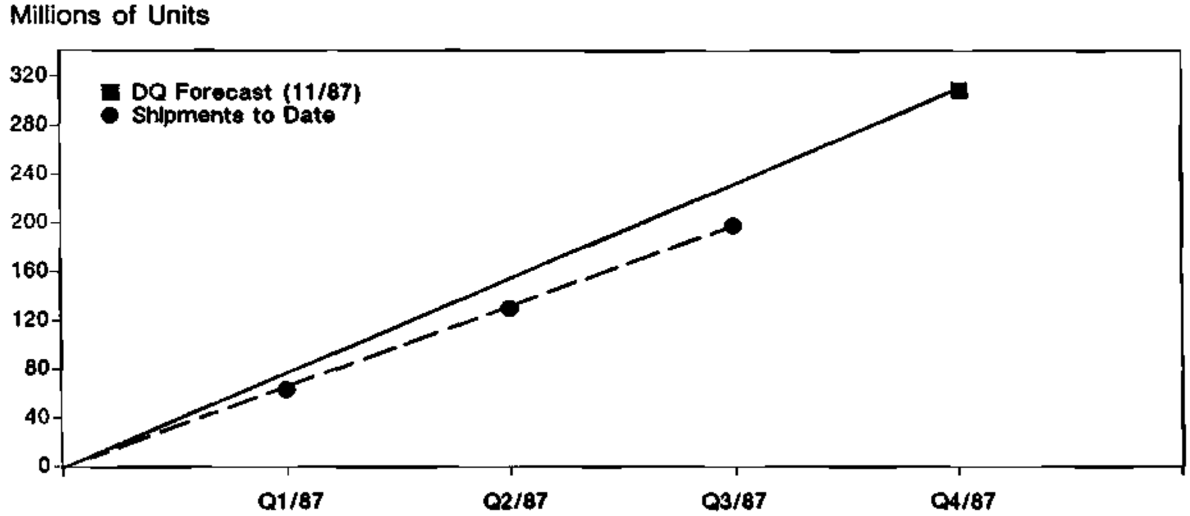
4-Bit Microcontrollers Cumulative Shipments to Date (Millions of Units)



Source: Dataquest
January 1988

Figure 8

8-Bit Microcontrollers
Cumulative Shipments to Date
(Millions of Units)



Source: Dataquest
January 1988

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FERRAM: THE MEMORY THE MARKET ALWAYS WANTED

SUMMARY

The ferroelectric RAM, or FERRAM, memory technology provides all the performance features that the market wants. It is nonvolatile, radiation hard, compatible with MOS, GaAs, and bipolar processing, and offers fast read and write together with longterm data storage in the absence of applied power. If there are no unforeseen technical glitches, FERRAMs should have significant memory market impact.

This newsletter uses a learning curve analysis to forecast the FERRAM market for the next five years. During this period, the FERRAM will compete primarily with EEPROMS, reaching total sales of an estimated $350 million in 1992.

Ferroelectric technology is not new, but two start-up companies, Krysalis and Ramtron, have applied the technology in a novel way. This newsletter describes the technology and provides brief profiles of both companies.

THE MEMORY HIERARCHY

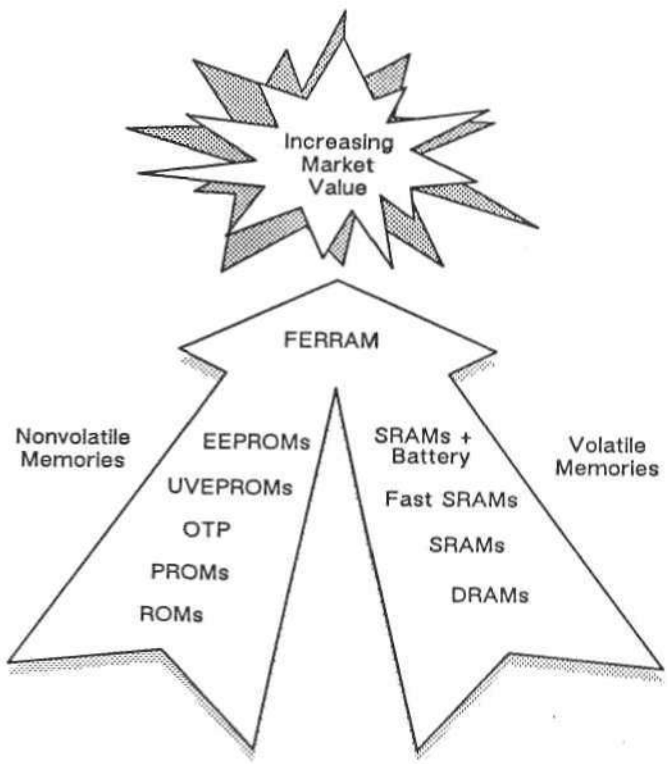
Today, many technologies are used to supply the needs of the memory market. No one technology supplies all needs, and as a result, market niches exist that are supplied by specialized memories. The FERRAM promises to be the one technology for all applications, since it combines fast read and write with nonvolatility. In spite of this promise, FERRAMs are new and must compete with existing technologies that have been in manufacture for some time and are well down the learning curve. For most memories, learning curves are such that the selling price is multiplied by a factor of 60 percent to 80 percent every time the cumulative volume doubles. For this reason, a memory manufactured in high volume is likely to have a much lower selling price than a low-volume memory.

FERRAM memories are currently in the embryonic stage—manufacturing volumes are essentially nil. The key question is whether the FERRAM can capture enough of some memory market segment to begin proceeding down its own learning curve.

The memory hierarchy is shown graphically in Figure 1. Here, memory technologies are shown in ascending order of performance. Note that this figure divides the memory market into its two segments: volatile and nonvolatile. FERRAM is shown at the intersection of the two segments because it satisfies the needs of both.

Figure 1

The Memory Hierarchy



Source: Dataquest
January 1988

The feature content of the various technologies in the nonvolatile hierarchy can be described as follows:

- ROM: Read only
- OTP/PROM: Read only, write once
- UVEPROM: Read only, write once, UV erase
- EEPROM: Read fast, write slowly
- FERRAM: Read fast, write fast, extended wear–out

Each member of the hierarchy has a significant advantage over the inferior technology. OTPs and bipolar PROMs can be programmed by the user; ROMs can be programmed only by the manufacturer. EPROMs can be erased and reprogrammed; OTPs and PROMs can be programmed only once. EEPROMs can be electrically erased so that they can be used in applications that require in-socket reprogramming; EPROMs cannot. FERRAMs are superior to EEPROMs because they have fast write and can be rewritten many more times than EEPROMs before they wear out.

The feature content of the various technologies in the volatile hierarchy can be described as follows:

- DRAM: Slow, needs refresh
- SRAM: Faster, no refresh
- Fast SRAM: Faster still, no refresh
- SRAM and Battery: All SRAM features plus battery backup
- FERRAM: All SRAM features, nonvolatile without battery

As with the nonvolatile hierarchy, each member of this hierarchy has significant advantages over the inferior technology. SRAMs tend to be faster then DRAMs and need no refresh. Fast SRAMs have a speed advantage over SRAMs. SRAMs with battery backup should have all the performance of the best SRAM and offer data storage during power outage as well; although they have gained wide acceptance, many users are suspicious of battery reliability. FERRAMs are superior to SRAMs with batteries because users are likely to prefer nonvolatility that can be accomplished without a battery.

It is significant that the FERRAM is at the top of both memory hierarchies from a feature point of view. If it could be manufactured for a low enough price, it would undoubtedly replace all the market segments in both hierarchies.

Table 1 shows estimated 1989 bit prices and bit shipments for memories in the nonvolatile hierarchy. Note that the most desirable memories have the highest bit prices, whereas the lowest-priced memories have the highest bit volumes. The OTP is an exception to this rule since it has lower bit shipments than UVEPROM; because it is an exception, it is gaining market share from UVEPROM. This will be further explained in the next section.

Table 1

Estimated Nonvolatile Memory Market Highlights, 1989

Type	Bit Price (Millicents)	Bit Shipments (Billions)	Market (Millions of Dollars)
EEPROM	12.80	3,360	$ 429
UVEPROM	0.97	112,932	1,097
OTP	0.61	20,897	128
ROM	0.37	132,710	493
Total			$2,147

Source: Dataquest
January 1988

Table 2 shows estimated 1989 bit prices and bit shipments for memories in the volatile hierarchy. In this hierarchy, the most desirable memories have the highest prices and lowest bit shipments as would be expected.

Table 2

1989 Volatile Memory Market Highlights

Type	Bit Price (Millicents)	Bit Shipments (Billions)	Market (Millions of Dollars)
Fast SRAM	5.85	8,955	$ 524
SRAM	0.98	42,992	422
DRAM	0.35	887,279	3,110
Total			$4,056

Source: Dataquest
January 1988

HIERARCHICAL CANNIBALISM

Hierarchical cannibalism occurs when one memory technology usurps the market of a technology next to it in the hierarchy. Currently, this is occurring as OTP replaces UVEPROM. In the late '70s, cannibalism occurred when bipolar PROMs replaced bipolar ROMs. Today, there are no bipolar ROMs in the marketplace.

This section describes the circumstances under which cannibalism is likely to occur. Most of the discussion is based on learning curve theory; it tends to overlook factors that might be important in a more detailed analysis. Such factors might include the strategies of different participants in the market, their financial strength, or their marketing prowess.

A comparison of relative price and relative market share of various technologies is given in Figure 2. Here, data is plotted for technologies that are next to each other in the memory hierarchy. The ratio of the bit shipments of these paired technologies is given on the horizontal axis and the ratio of their bit prices is given on the vertical axis. Paired memory technologies are indicated on the figure. For instance, the point EEPROM/UVEPROM illustrates the relative situation between these two technologies.

Two things are of special interest in Figure 2. First, the slope of the trend envelope is such that the relative prices decrease about 20 percent every time the relative volume doubles. This seems to be related to the 80 percent learning curve that is exhibited by most memory technologies. Second, the lower part of the envelope passes through bit parity when the superior technology is at a 40 percent price premium. At the upper side of the envelope, this premium expands to more than 300 percent. This spread in price premium is a measure of the relative superiority of one technology over another. All the market estimates for FERRAM in this newsletter assume the more conservative price premium of 40 percent at bit parity.

As Figure 2 shows, the only two paired technologies jockeying for market position are UVEPROM and OTP. In recent years, the price of OTP has been declining more rapidly than that of UVEPROM. As a result, OTP bit shipments have been increasing more rapidly than UVEPROM bit shipments; this drives the bit ratio of the UVEPROM down as compared with OTP, causing the data points to migrate in the manner shown from 1984 to 1987.

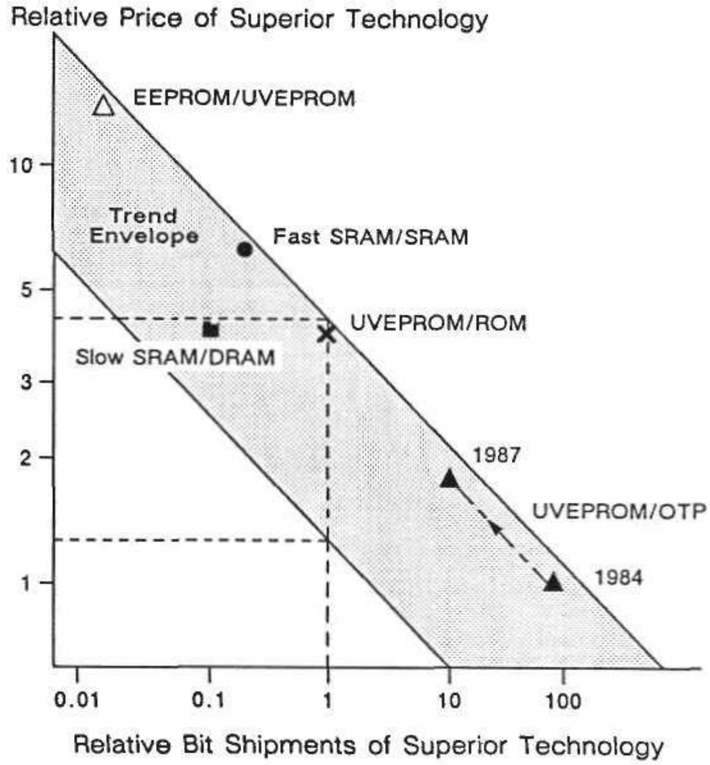
Why is it that cannibalism is occurring in the case of UVEPROM/OTP? Table 3 provides the answer to that question. In the period 1984-1989, OTP increased in bit shipments by 98.11 to 1, while UVEPROM increased in bit shipments by only 8.88 to 1. In other words, OTP decreased more in selling price because it increased relative bit shipments much more than UVEPROM.

Cannibalism occurs when a new technology (e.g., OTP) is introduced near price parity with an older technology (e.g., UVEPROM), but at much lower bit shipments. In this situation, the new technology need garner only a small fraction of the bit shipments of the older technology to double and redouble its bit shipments. The new technology can thus run rapidly down its learning curve and lower its relative price substantially, until eventually it captures the bulk of the market from the older technology.

Why are the other technologies in Figure 2 not cannibalistic? They are simply too far apart in price for cannibalism to occur. To put it more precisely, they are priced so that little change in relative bit shipments is likely. That is why movement is observed only for the pair UVEPROM/OTP. This pair plotted near the parity price point in Figure 2 in 1984. If technologies are far apart in price, they can be thought of as occupying separate, defensible market niches. In this situation, users buy the superior technology only when it is absolutely required, and relative bit prices can be quite high. However, when relative bit prices approach parity, users will use the superior memory even when they do not absolutely need the extra features so long as the premium paid is not too great.

Figure 2

Relative Market Share of Competing Memory Technologies (1987 Data, unless Indicated)



Source: Dataquest
January 1988

Table 3

Comparison of UVEPROM and OTP

Type	1989 Bits/1984 Bits	1989 Price/1984 Price
UVEPROM	8.88	0.105
OTP	98.11	0.064

Source: Dataquest
January 1988

FERRAM MARKET SHARE ESTIMATES

Dataquest's estimates for the FERRAM make the following assumptions:

- The FERRAM can be introduced at a bit price near that of EEPROM.
- Early shipments are limited by market dynamics.
  - The time required to educate the market
  - The time required to build shipments
- The FERRAM takes market only from EEPROM.
- FERRAM technology is used only to store data when power is off.
- FERRAM pricing follows a 60 percent learning curve.

All of these assumptions are conservative. FERRAM prices near those of SRAMs should be possible, since FERRAMs can be built using an SRAM process with only three additional mask layers.

It is assumed that FERRAM will take market share only from EEPROM. It is possible that FERRAM can gain additional market share from other memories such as bubble memories and SRAMs.

It is assumed that FERRAM technology is used to store data only when power is turned off. A circuit to accomplish this with SRAM technology can easily be built by adding only the aforementioned three mask layers. In this case, the FERRAM is cycled only when the power is turned off. The wear-out mechanism in FERRAM is good for at least 10 to a factor of 10 cycles, which provides memory life in excess of 10,000 years if power is cycled twice a day.

There is also a good possibility that the wear-out could be extended to 10 to a factor of 15 cycles. This would make it possible to cycle the FERRAM every time the memory is read without wear-out occurring. As a result, FERRAM could achieve something close to SRAM performance using a single-transistor FERRAM cell. This technology would be much less expensive than the SRAM technology assumed in Dataquest's forecast.

A 60 percent learning curve is assumed. Since the FERRAM will be introduced at a premium to EEPROM prices (which are assumed to be 12.8 millicents per bit in 1989, as shown in Table 1) but built with SRAM technology (.98 millicents per bit in 1989 as Table 2 shows), this entire premium is used to pay for the three extra FERRAM masking layers. All other things being equal, the premium should be proportional only to the number of mask layers. This means a premium of 3/13 equals 23 percent if there are 13 SRAM layers and 3 FERRAM mask layers. Thus, it is reasonable to assume that FERRAM prices proceed along a 60 percent learning curve rather than the 80 percent learning curve typical for most memories, since all the learning can be focused on only the three extra mask layers.

Both vendors project that in the future, FERRAMs will need only one additional mask layer. This would make the above assumptions even more conservative.

Figure 3 gives Dataquest's estimates for FERRAM and EEPROM bit prices for the period 1988 through 1992. FERRAM prices are kept relatively high through the beginning of this period because shipments are limited mostly by market dynamics rather than relative price.

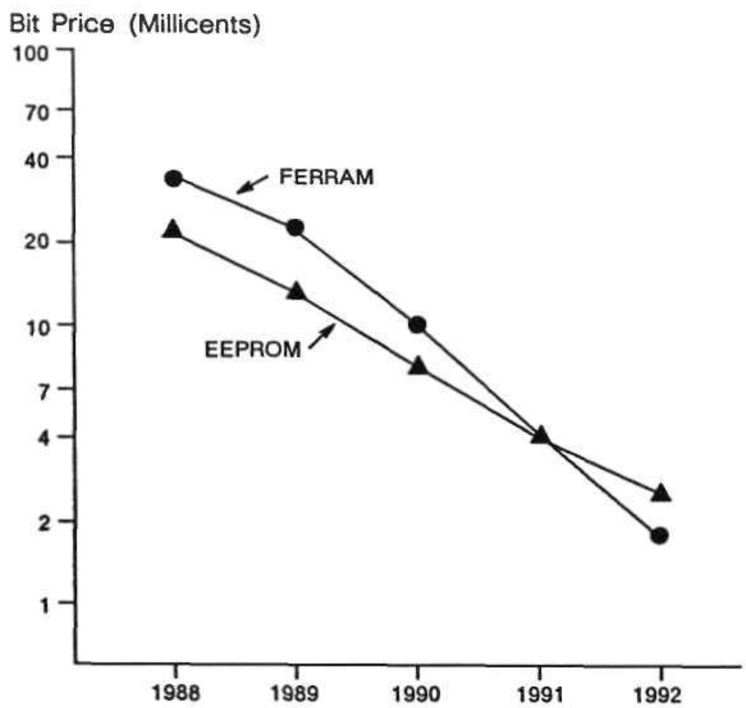
Figure 4 gives the relative dollar shipments of FERRAM and EEPROM. In this figure, the hollow bars indicate the EEPROM shipments before FERRAM, whereas the shaded areas indicate EEPROM shipments after FERRAM. Note the significant impact that FERRAM has in 1991 and 1992.

Dataquest's scenario that accompanies this forecast assumes the most complex part is a 256K FERRAM in 1988, with shipments of this device ramping in 1989. Introduction of a 1-megabit FERRAM using a single-transistor cell is assumed in 1990. If this part is not introduced, however, the forecast of Figure 4 would be little changed.

Dataquest also anticipates that a 4-megabit FERRAM will be introduced sometime in the early to mid -1990s. This part should be very interesting, because there is a good chance that it may be easier to build than a 4-megabit DRAM. This is possible because the ferroelectric capacitors used in FERRAMs have dielectric constants hundreds of times higher than silicon dioxide. This means that a storage capacitor can easily be built without resorting to the need for the trench capacitors currently contemplated for that generation of DRAM.

Figure 3

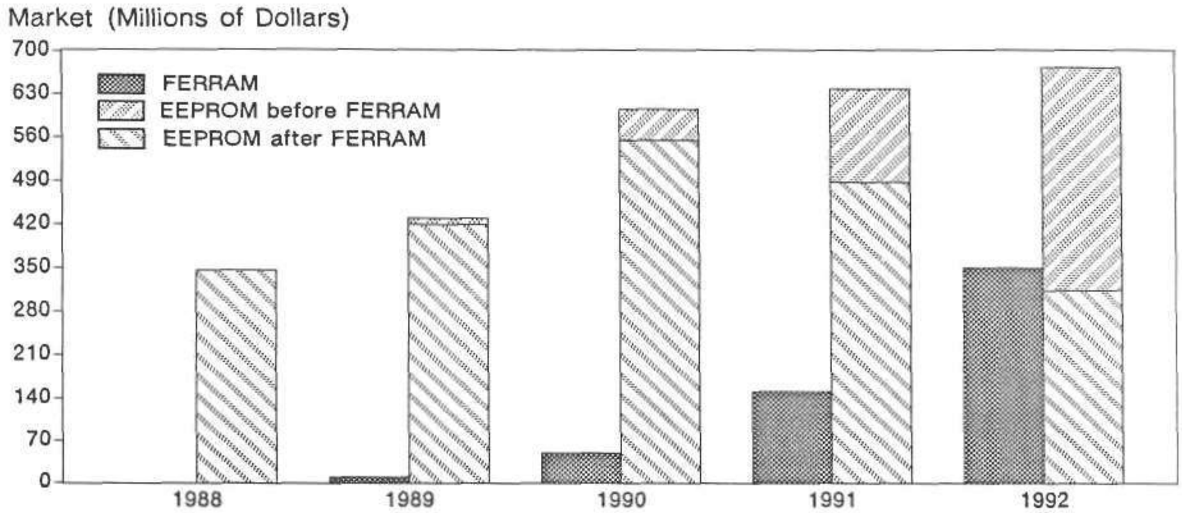
Forecast EEPROM and FERRAM Bit Prices



Source: Dataquest
January 1988

Figure 4

Forecast EEPROM and FERRAM Markets



Source: Dataquest
January 1988

TECHNOLOGY

Ferroelectric technology has been around for some time. Thirty years ago, ferroelectric technology was being considered as an alternative to magnetic core technology. That line of research was abandoned for many reasons. Important among these was the fact that ferroelectric memories could not be addressed by a combination of voltages on the row and column lines in the same way that magnetic memories could be addressed by coincident row and column currents.

Later, a great deal of research was done on ferroelectrics because of the other properties of these materials. Among other things, ferroelectric materials exhibit an index of refraction that can be controlled by an applied voltage. This makes them useful for modulating beams of light.

Ferroelectric materials are also often piezoelectric. Some attempts to use these materials have floundered because the piezoelectric effect caused them to flex mechanically and eventually fatigue.

Today, hundreds or even thousands of ferroelectric materials are known. These all have different properties, and only a few are suitable for semiconductor applications.

The current breakthrough in ferroelectric memories seems to be due to several factors. First, several groups realized that a ferroelectric device could be addressed using semiconductor technology rather than coincident voltages. This greatly relieved constraints on the ferroelectric material.

Secondly, two companies began working with a ferroelectric material that is effectively a ceramic. With proper processing, this material is robust and compatible with semiconductor processing.

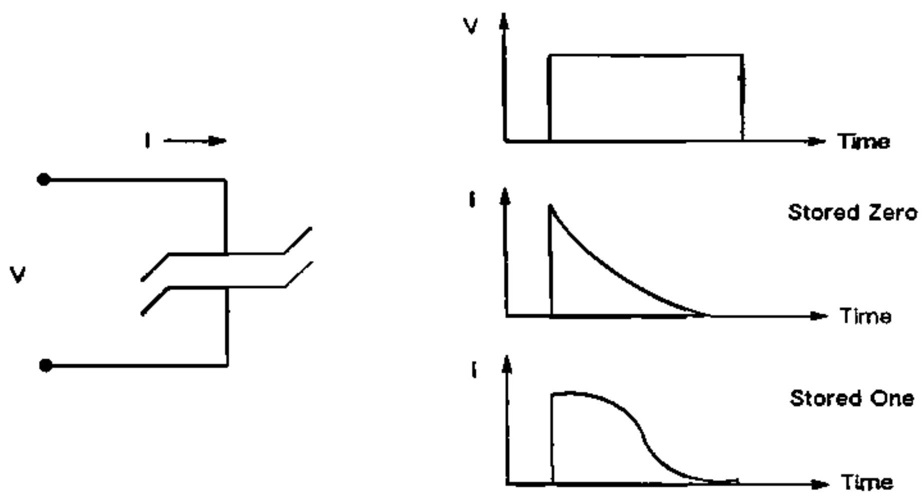
Finally, deposition techniques have advanced to the point where it is possible to reliably deposit reproducible thin films of this material. Deposition is still somewhat tricky because the exact mixture of elements must be maintained or the material will not exhibit ferroelectric properties.

When a ferroelectric material is used as the dielectric in a capacitor, it exhibits some interesting properties. As the capacitor is charged, the bipolar (+ on one end, – on the other) molecules in the ferroelectric material align themselves with the electric field. If the capacitor is discharged, these molecules stay aligned. If a subsequent voltage is applied in a direction opposite to the first voltage, these molecules have to realign themselves in the opposite direction, and a high current flows. If, on the other hand, the second voltage is applied in the same direction as the first, only a small current flows since the bipolar molecules are already aligned in that direction.

This is illustrated in Figure 5, where a voltage is applied to a ferroelectric capacitor. If a zero is stored in the capacitor, its molecules are already aligned in the same direction as the applied voltage. If, on the other hand, a one is stored, the molecules are aligned in the opposite direction, and a higher current flows.

Figure 5

Memory in a Ferroelectric Capacitor



Source: Dataquest
January 1988

These capacitors can be used in conjunction with conventional memory circuits. In an SRAM, one capacitor is attached to each side of each memory flip-flop when the power to the chip begins to go off. One side of the flip-flop is high, and this side causes that memory capacitor to polarize. The other memory capacitor does not polarize because that side of the flip-flop is low. When the power is turned back on, less current will flow in the polarized capacitor than in the capacitor tied to the other side of the flip-flop. This will cause the flip-flop to return to its original state.

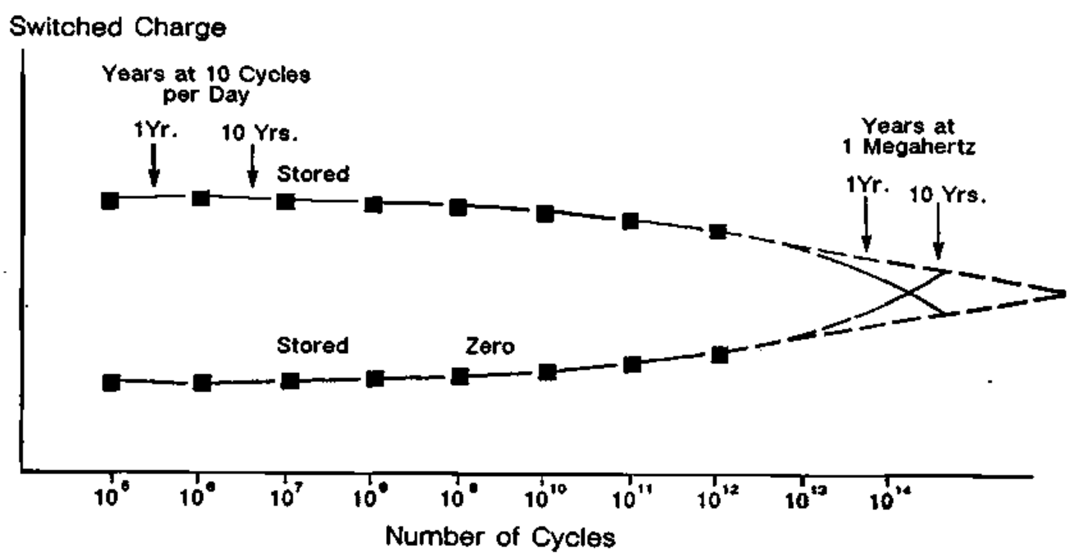
Alternatively, a ferroelectric capacitor can be used as the storage capacitor in a DRAM. This capacitor is alternately charged and discharged every time a bit is read, just like in a conventional DRAM. However, data storage in the DRAM is permanent because the polarization of the ferroelectric capacitor stores the data when the power to the chip is turned off.

Ferroelectric capacitors also have an advantage in DRAM circuits because they have several hundred times as much capacitance per square micron as the silicon dioxide capacitors now used in today's DRAMs. This means that a smaller capacitor will generate a much higher output voltage. Conceivably, ferroelectric capacitors could eliminate the need for trench capacitors in the 4-megabit DRAM while simultaneously providing nonvolatility as an added bonus.

Figure 6 shows the way that the ability of a ferroelectric capacitor to store charge deteriorates as the memory is cycled. Initially, the charge stored for a one is 1.5 to 2.0 times as great as the charge stored for a zero. As the capacitor is read and rewritten, there is a tendency for some of the bipolar molecules to become "stuck" so that they no longer turn around when a reverse voltage is applied. This reduces the ratio of the amount of charge stored for a one and a zero, gradually causing the capacitor to be useless after repeated cyclings.

Figure 6

Endurance Testing of FERRAMs



Source: Dataquest
January 1988

Currently, 10 to the 10th power cycles have been achieved, and one vendor is claiming 10 to the 14th cycles. If the SRAM technology is used and the ferroelectric capacitors are cycled only when power to the memory is lost, 10 to the 10th cycles is far more than adequate. On the other hand, if the DRAM circuit is used, a 10-year life would require 10 to the 14th cycles if the memory cycle is 1 microsecond and 10 to the 15th cycles if the memory cycles in 100 nanoseconds. This may be achieved in the near future, since progress in improving this wear-out has been rapid so far.

For comparison, the number of cycles achieved by EEPROMs before wear-out is 10 to the fifth or less. Ferroelectric capacitors are already far superior. In addition, the ferroelectric capacitor seems able to retain its memory in the presence of radiation, a fact of interest to the military.

Ferroelectric capacitors have also been tested to see how long they retain data when they are stored without being cycled. Current data suggests that long-term storage does not present a problem. This conclusion is based on the fact that no measurable deterioration is seen in a period of months.

Ferroelectric capacitors are compatible with MOS processes, so it appears likely that they would also be compatible with GaAs and bipolar processing. This should offer some interesting product opportunities, since no nonvolatile memory is available in either of these technologies.

COMPANIES

Two companies, Krysalis and Ramtron, are currently in the start-up phase of FERRAMS production. Krysalis is located in Albuquerque, New Mexico. The firm has had two infusions of capital and has produced a 512-bit sample memory. It is working on 16-Kbit and 256-Kbit memories. Krysalis has recently installed a processing area for adding the extra ferroelectric layers to base wafers produced in a foundry.

Ramtron is located in Colorado Springs, Colorado. Its early ferroelectric work was done at the University of Colorado, and the ferroelectric layers are still being applied in the university wafer fab. Ramtron has just finished a 256-bit device and is working on both 16K and a 256K devices. Initial financing for Ramtron came from a venture capital firm in Australia. Recently, a license was negotiated with an Australian semiconductor start-up.

Both firms appear to be using the same ferroelectric material, though it appears that they apply it in a different manner. Both are actively adding to their patent portfolios and both plan to pursue an active licensing program for this technology.

DATAQUEST CONCLUSIONS

Dataquest believes that FERRAMs represent a significant new memory technology. If unforeseen production or reliability problems do not crop up, FERRAMs should garner a growing share of the memory market. This share is may grow dramatically in the next five years if the FERRAM technology achieves its anticipated cost and technology developments. Beyond that, FERRAMs could continue gaining share as they begin to take market share from SRAMs. Our most optimistic scenario suggests that FERRAMs are the technology of choice at the 4-megabit DRAM level. This would result in FERRAM achieving a significant share of the entire memory market.

Howard Z. Bogert

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1987 PRELIMINARY MARKET SHARE
BROAD BASED RECOVERY IN SEMICONDUCTORS

Preliminary estimates of the worldwide semiconductor market indicate a 24.3 percent expansion of the revenue base of the top 100 vendors, from $29.4 billion in 1986 to $36.6 billion in 1987. A comparison of the 1986 and 1987 revenue bases of semiconductor companies is shown by region in Table 1. The continued decline of the U.S. dollar against the Japanese yen and the European currencies has a significant first-order impact on the valuation of revenue. The second- and third-order effects of the devaluation of the dollar should cause changes in cost structure, prices, and the competitive dynamics in the worldwide market.

Table 1

**Worldwide Semiconductor Market
Revenue of Top 100 Companies
(Billions of U.S. Dollars)**

Regional Companies	1986	1987	Percent Change
Japanese Companies	$14.0	$17.8	27.2%
North American Companies	11.7	14.2	21.7%
European Companies	3.3	4.0	20.8%
Rest of World Companies	0.4	0.6	63.9%
Total	$29.4	$36.6	24.3%
Exchange Rates			
Japanese Yen/US$	167.0	144.0	(13.8%)
Europe: ECU/US$	145.9	125.3	(14.1%)

Source: Dataquest
January 1988

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Japanese companies continued to gain share of the worldwide semiconductor market, as shown in Table 2.

The revenue bases and growth rates of the top 100 companies are shown by product area in Table 3. Since the top 100 semiconductor companies account for more than 99 percent of world semiconductor revenue, we will use their combined revenue as an estimate of the total market. The top 50 major semiconductor suppliers worldwide are ranked by product area in Tables 4 through 19.

Table 2

Worldwide Semiconductor Market
(Percentage of Market Share)

Regional Companies	1984	1985	1986	1987
Japanese Companies	40%	42%	46%	48%
North American Companies	48	45	42	39
European Companies	11	12	11	11
Rest of World Companies	1	1	2	2
Total	100%	100%	100%	100%

Source: Dataquest
January 1988

Table 3

Worldwide Semiconductor Market
Revenue Base of Top 100 Companies
(Billions of U.S. Dollars)

Product	1986	1987	Percent Change
Total Semiconductor	$29.4	$36.6	24.3%
IC	$22.6	$28.7	26.8%
Bipolar Digital	$ 4.3	$ 4.7	9.7%
Bipolar Memory	$ 0.6	$ 0.7	5.6%
Bipolar Logic	$ 3.7	$ 4.0	10.4%
Standard Logic	$ 2.3	$ 2.4	3.9%
ASIC	$ 1.4	$ 1.6	21.7%
MOS Digital	$12.6	$17.1	36.3%
MOS Memory	$ 4.5	$ 5.8	29.6%
MOS Micro	$ 3.4	$ 5.1	49.6%
MOS Logic	$ 4.7	$ 6.2	32.9%
Standard Logic	$ 1.6	$ 1.8	12.5%
ASIC	$ 3.1	$ 4.4	43.2%
Linear	$ 5.7	$ 6.9	18.7%
Discrete	$ 5.3	$ 6.2	15.9%
Optoelectronic	$ 1.5	$ 1.7	16.6%

Source: Dataquest
January 1988

SEMICONDUCTOR MARKET SHARE

NEC continued to lead the semiconductor market with revenue exceeding $3 billion in 1987. Toshiba continued to grow faster than the market, displacing Hitachi from second to third place. Motorola and Texas Instruments remained in the top 5, with revenue exceeding $2 billion each. Intel advanced three notches, to eighth place in the top 10, growing twice as fast as the total semiconductor market (see Table 4 and Figures 1 and 2). The combined entity of National/Fairchild ranked 11th. The combined entity of AMD/MMI ranked 12th and was expected to break the billion-dollar barrier for the first time in 1987.

Table 4

Preliminary Worldwide Semiconductor Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	NEC	$ 2,638	$ 3,193	21.0%
3	2	Toshiba	$ 2,276	$ 2,939	29.1%
2	3	Hitachi	$ 2,307	$ 2,781	20.5%
4	4	Motorola	$ 2,025	$ 2,450	21.0%
5	5	Texas Instruments	$ 1,781	$ 2,125	19.3%
6	6	Fujitsu	$ 1,365	$ 1,899	39.1%
8	7	Philips-Signetics	$ 1,258	$ 1,597	26.9%
11	8	Intel	$ 991	$ 1,500	51.4%
10	9	Mitsubishi	$ 1,136	$ 1,481	30.4%
9	10	Matsushita	$ 1,206	$ 1,479	22.6%
7	11	National/Fairchild	$ 1,365	$ 1,431	4.8%
12	12	AMD/MMI	$ 838	$ 1,015	21.1%
13	13	SGS Thomson	$ 806	$ 850	5.5%
14	14	Sanyo	$ 615	$ 786	27.8%
18	15	Oki	$ 438	$ 651	48.6%
17	16	Siemens	$ 442	$ 595	34.6%
19	17	Sharp	$ 433	$ 594	37.2%
16	18	Sony	$ 458	$ 555	21.2%
15	19	GE Solid State	$ 509	$ 554	8.8%
20	20	Rohm	$ 377	$ 480	27.3%
21	21	ITT	$ 312	$ 357	14.4%
30	22	Samsung	$ 170	$ 316	85.9%
25	23	Sanken	$ 224	$ 294	31.3%
22	24	Harris	$ 260	$ 277	6.5%
23	25	Analog Device	$ 243	$ 274	12.8%

(Continued)

Table 4 (Continued)

Preliminary Worldwide Semiconductor Market Share Rankings
(Millions of Dollars)

24	26	General Instrument	$ 236	$ 274	16.1%
29	27	LSI Logic	$ 194	$ 260	34.0%
26	28	Telefunken Electronic	$ 219	$ 258	17.8%
28	29	Fuji Electric	$ 205	$ 248	21.0%
27	30	Hewlett-Packard	$ 217	$ 240	10.6%
31	31	Seiko Epson	$ 165	$ 211	27.9%
32	32	Honeywell	$ 157	$ 176	12.1%
34	33	International Rectifier	$ 145	$ 172	18.6%
38	34	VLSI Technology	$ 112	$ 170	51.8%
33	35	Gould AMI Semiconductors	$ 155	$ 155	0.0%
44	36	New JRC	$ 92	$ 141	53.3%
36	37	Plessey	$ 112	$ 128	14.3%
35	38	Sprague	$ 122	$ 124	1.6%
41	39	Burr-Brown	$ 98	$ 120	22.4%
39	40	TRW	$ 105	$ 116	10.5%
56	41	Micron Technology	$ 63	$ 115	82.5%
37	42	Siliconix	$ 112	$ 115	2.7%
43	43	NCR	$ 94	$ 114	21.3%
65	44	Chips & Technologies	$ 41	$ 112	173.2%
40	45	Powerex	$ 99	$ 106	7.1%
42	46	Ferranti	$ 96	$ 100	4.2%
51	47	Integrated Device Technology	$ 72	$ 98	36.1%
54	48	Rockwell	$ 65	$ 95	46.2%
47	49	Inmos	$ 80	$ 91	13.8%
53	50	United Microelectronics	$ 69	$ 90	30.4%
		Total Market Estimate	$29,380	$36,570	24.3%

Source: Dataquest
January 1988

Figure 1

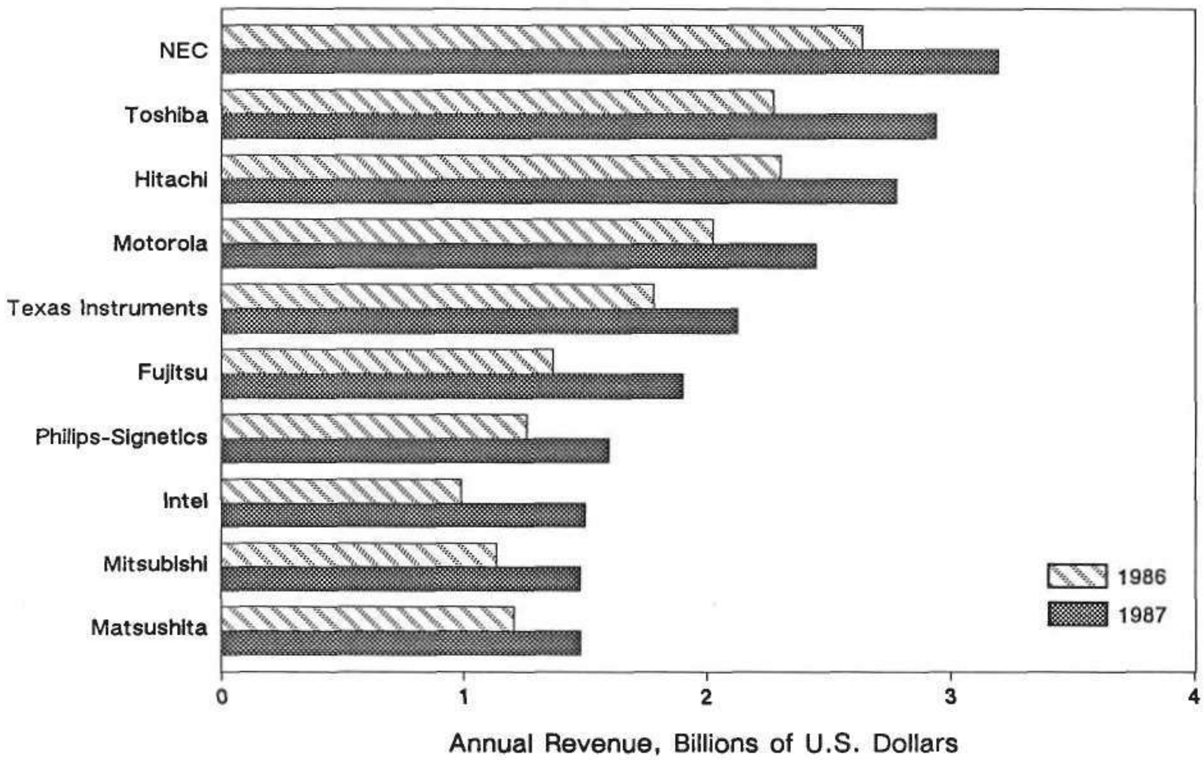
Top 10 Worldwide Semiconductor Manufacturers for 1987

Company	1986 Rank	1987 Rank		1986 Sales	1987 Sales
				(Millions of Dollars)	
NEC	1	1		2,638	3,193
Toshiba	3	2		2,276	2,939
Hitachi	2	3		2,307	2,781
Motorola	4	4		2,025	2,450
Texas Instruments	5	5		1,781	2,125
Fujitsu	6	6		1,365	1,899
Philips-Signetics	8	7		1,258	1,597
Intel	11	8		991	1,500
Mitsubishi	10	9		1,136	1,481
Matsushita	9	10		1,206	1,479

Source: Dataquest
January 1988

Figure 2

Worldwide Semiconductor Market Share
Top 10 Companies



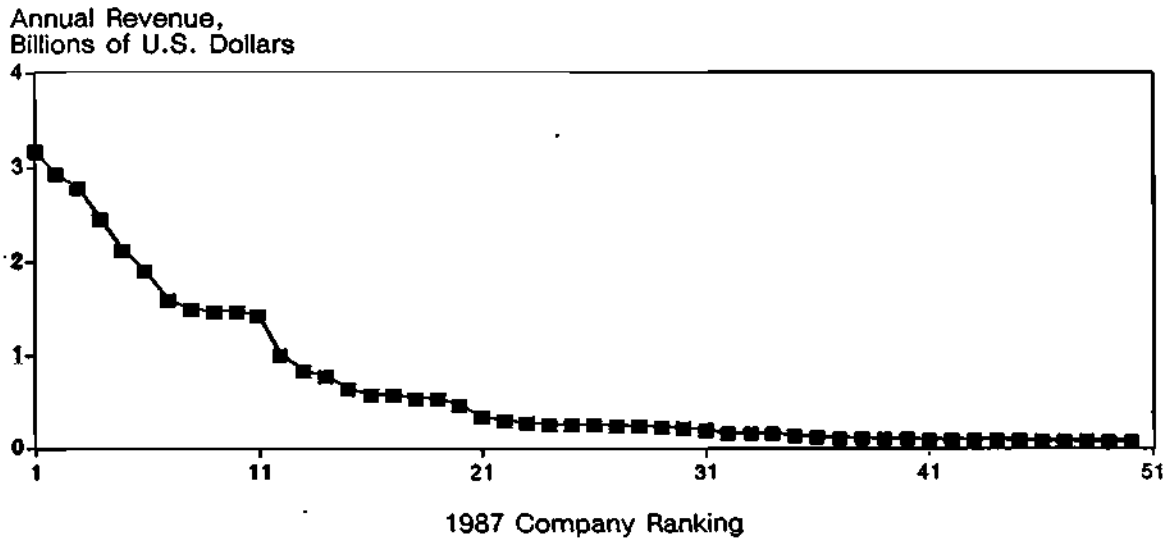
Source: Dataquest
January 1988

The high-fliers among the top 50 include Fujitsu, ranked 6th and growing at 39.1 percent; Intel, ranked 8th and growing at 51.4 percent; Oki, ranked 15th and growing at 48.6 percent; Samsung of Korea, ranked 22nd and growing at 85.9 percent; Micron Technology, ranked 41st and growing at 82.5 percent; and Chips & Technologies, ranked 44th and growing at 173.2 percent. These companies focused on high-growth product areas such as MOS micros, ASICs, and memories. Chips & Technologies, Integrated Device Technology, Micron Technology, New Japan Radio Company (JRC), Rockwell, and United Microelectronics of Korea were new entrants to the top 50.

The revenue base of the semiconductor suppliers decreased rapidly with decreasing market share ranking (see Figure 3). The worldwide semiconductor industry remained concentrated, with the top 5 gaining 37 percent share of the market, the top 10 gaining 59 percent share, and the top 50 gaining 94 percent share.

Figure 3

Worldwide Semiconductor Market Share
Concentration of Top 50



Source: Dataquest
January 1988

IC Market Share

While NEC and Hitachi held the top two places in the IC market, Toshiba displaced the erstwhile leader, Texas Instruments (ranked number one in 1985), from third place. The rankings of all the top 50 contenders in the worldwide IC market are listed in Table 5. The top 4 exceeded $2 billion each in IC revenue. The top 5 IC makers held 37 percent share, and the top 10 held 63 percent share of the worldwide IC market.

The big movers include Sharp, which advanced 4 positions to rank 16th; Samsung, which advanced 7 positions to rank 20th; Sanken, which advanced 4 positions to rank 31st; Micron Technology, which advanced 15 positions to rank 32nd; and Chips & Technologies, which advanced 21 positions to rank 34th.

Table 5

Preliminary Worldwide IC Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	NEC	$ 2,154	$ 2,630	22.1%
2	2	Hitachi	$ 1,771	$ 2,169	22.5%
4	3	Toshiba	$ 1,610	$ 2,161	34.2%
3	4	Texas Instruments	$ 1,689	$ 2,022	19.7%
5	5	Motorola	$ 1,403	$ 1,774	26.4%
7	6	Fujitsu	$ 1,250	$ 1,758	40.6%
8	7	Intel	$ 991	$ 1,500	51.4%
6	8	National/Fairchild	$ 1,298	$ 1,354	4.3%
10	9	Mitsubishi	$ 891	$ 1,197	34.3%
9	10	Philips-Signetics	$ 942	$ 1,176	24.8%
12	11	Matsushita	$ 802	$ 1,047	30.5%
11	12	AMD/MMI	$ 838	$ 1,015	21.1%
13	13	SGS Thomson	$ 589	$ 640	8.7%
14	14	Oki	$ 414	$ 619	49.5%
15	15	Sanyo	$ 407	$ 491	20.6%
20	16	Sharp	$ 236	$ 371	57.2%
16	17	GE Solid State	$ 338	$ 367	8.6%
17	18	Sony	$ 281	$ 345	22.8%
21	19	Siemens	$ 230	$ 330	43.5%
27	20	Samsung	$ 145	$ 284	95.9%
18	21	Harris	$ 260	$ 277	6.5%
19	22	Analog Devices	$ 243	$ 274	12.8%
22	23	LSI Logic	$ 194	$ 260	34.0%
24	24	Seiko Epson	$ 165	$ 211	27.9%
23	25	ITT	$ 168	$ 197	17.3%
25	26	Rohm	$ 161	$ 195	21.1%
29	27	VLSI Technology	$ 112	$ 170	51.8%
26	28	Gould AMI Semiconductors	$ 155	$ 155	0.0%
28	29	Honeywell	$ 122	$ 146	19.7%
31	30	Burr-Brown	$ 98	$ 120	22.4%
35	31	Sanken	$ 81	$ 119	46.9%
47	32	Micron Technology	$ 63	$ 115	82.5%
33	33	NCR	$ 94	$ 114	21.3%
55	34	Chips & Technologies	$ 41	$ 112	173.2%
32	35	Plessey	$ 96	$ 111	15.6%

(Continued)

Table 5 (Continued)

Preliminary Worldwide IC Market Share Rankings
(Millions of Dollars)

39	36	New JRC	$ 76	$ 108	42.1%
30	37	Sprague	$ 108	$ 106	(1.9%)
43	38	Integrated Device Technology	$ 72	$ 98	36.1%
34	39	General Instrument	$ 82	$ 95	15.9%
46	40	Rockwell	$ 65	$ 95	46.2%
37	41	Telefunken Electronic	$ 79	$ 95	20.3%
36	42	Inmos	$ 80	$ 91	13.8%
45	43	United Microelectronics	$ 69	$ 90	30.4%
40	44	Silicon Systems	$ 75	$ 88	17.3%
41	45	Zilog	$ 74	$ 88	18.9%
52	46	Cypress Semiconductor	$ 50	$ 79	58.0%
38	47	Ferranti	$ 78	$ 78	0.0%
44	48	Raytheon	$ 69	$ 77	11.6%
42	49	Precision Monolithics	$ 73	$ 71	(2.7%)
51	50	Western Digital	$ 53	$ 70	32.1%
		Total Market Estimate	$22,580	$28,670	26.8%

Source: Dataquest
January 1988

Bipolar Digital Market Share

While Texas Instruments continued to lead the bipolar digital market, AMD/MMI claimed the second position. Fujitsu moved up a rung on the ladder to third place. National/Fairchild claimed fourth place, easing Motorola into fifth place and Philips–Signetics into sixth place. The rankings of the top 25 companies in the worldwide bipolar digital market are shown in Table 6. This industry is concentrated, with the top 5 suppliers holding 63 percent share and the top 10 suppliers holding 89 percent share of the world bipolar digital market.

Table 6

Preliminary Worldwide Bipolar Digital Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Texas Instruments	$ 826	$ 908	9.9%
3	2	AMD/MMI	$ 488	$ 552	13.1%
4	3	Fujitsu	$ 396	$ 533	34.6%
2	4	National/Fairchild	$ 521	$ 476	(8.6%)
5	5	Motorola	$ 393	$ 429	9.2%
6	6	Philips-Signetics	$ 360	$ 415	15.3%
7	7	Hitachi	$ 339	$ 410	20.9%
8	8	NEC	$ 176	$ 197	11.9%
9	9	Mitsubishi	$ 134	$ 125	(6.7%)
10	10	Toshiba	$ 129	$ 125	(3.1%)
11	11	Honeywell	$ 86	$ 76	(11.6%)
14	12	Raytheon	$ 42	$ 51	21.4%
15	13	Siemens	$ 39	$ 37	(5.1%)
13	14	Ferranti	$ 44	$ 35	(20.5%)
17	15	Plessey	$ 32	$ 35	9.4%
12	16	Harris	$ 45	$ 32	(28.9%)
18	17	Oki	$ 29	$ 32	10.3%
19	18	Matsushita	$ 28	$ 31	10.7%
22	19	AMCC	$ 20	$ 28	40.0%
20	20	Sanyo	$ 23	$ 26	13.0%
24	21	Chips & Technologies	$ 10	$ 24	140.0%
23	22	Gold Star	$ 14	$ 22	57.1%
21	23	Intel	$ 21	$ 22	4.8%
16	24	SGS Thomson	$ 34	$ 17	(50.0%)
25	25	VTC	$ 10	$ 14	40.0%
		Total Market Estimate	$4,270	$4,680	9.7%

Source: Dataquest
January 1988

Bipolar Memory Market Share

Fujitsu was the clear leader in the bipolar memory market, outgrowing rivals at nearly four times the pace of the industry growth. AMD/MMI (in second place) showed declining revenue, while Hitachi (in third place) grew nearly three times as fast as the industry. Captive demand for mainframe memories contributed significantly to the success of Fujitsu and Hitachi. This industry is the smallest and most concentrated segment of the semiconductor industry, with the top 5 companies holding 79 percent share and the top 10 holding 97 percent share of the world bipolar memory market. The top 10 companies in the worldwide bipolar memory market are ranked in Table 7.

Table 7

Preliminary Worldwide Bipolar Memory Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Fujitsu	$145	$178	22.8%
2	2	AMD/MMI	$135	$132	(2.2%)
3	3	Hitachi	$ 80	$ 92	15.0%
6	4	Texas Instruments	$ 48	$ 54	12.5%
4	5	Philips-Signetics	$ 58	$ 52	(10.3%)
5	6	National/Fairchild	$ 48	$ 47	(2.1%)
7	7	NEC	$ 32	$ 35	9.4%
10	8	Raytheon	$ 10	$ 14	40.0%
9	9	Motorola	$ 11	$ 10	(9.1%)
8	10	Harris	$ 23	$ 8	(65.2%)
		Total Market Estimate	$610	$640	5.6%

Source: Dataquest
January 1988

Bipolar Logic Market

While Texas Instruments continued to lead the bipolar logic market, National/Fairchild and AMD/MMI claimed the next two positions, easing Motorola into fourth place and Philips-Signetics into fifth place. This industry is concentrated, with the top 5 suppliers holding 63 percent share and the top 10 suppliers holding 89 percent share of the world bipolar logic market. The ranking of the top 25 companies in the worldwide bipolar logic marked are shown in Table 8. The picture is somewhat different in the standard logic and ASIC segments of this market.

Table 8

Preliminary Worldwide Bipolar Logic Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Texas Instruments	$ 778	$ 854	9.8%
2	2	National/Fairchild	$ 473	$ 429	(9.3%)
4	3	AMD/MMI	$ 353	$ 420	19.0%
3	4	Motorola	$ 382	$ 419	9.7%
5	5	Philips-Signetics	$ 302	$ 363	20.2%
7	6	Fujitsu	$ 251	$ 355	41.4%
6	7	Hitachi	$ 259	$ 318	22.8%
8	8	NEC	$ 144	$ 162	12.5%
9	9	Mitsubishi	$ 134	$ 125	(6.7%)
10	10	Toshiba	$ 129	$ 125	(3.1%)
11	11	Honeywell	$ 86	$ 76	(11.6%)
14	12	Raytheon	$ 32	$ 37	15.6%
12	13	Ferranti	$ 44	$ 35	(20.5%)
13	14	Plessey	$ 32	$ 35	9.4%
16	15	Oki	$ 29	$ 32	10.3%
17	16	Matsushita	$ 28	$ 31	10.7%
15	17	Siemens	$ 32	$ 30	(6.3%)
22	18	AMCC	$ 20	$ 28	40.0%
19	19	Sanyo	$ 23	$ 26	13.0%
24	20	Chips & Technologies	$ 10	$ 24	140.0%
20	21	Harris	$ 22	$ 24	9.1%
23	22	Gold Star	$ 14	$ 22	57.1%
21	23	Intel	$ 21	$ 22	4.8%
25	24	VTC	$ 10	$ 14	40.0%
18	25	SGS Thomson	$ 28	$ 10	(64.3%)
		Total Market Estimate	$3,660	$4,040	10.4%

Source: Dataquest
January 1988

Bipolar Standard Logic Market

Though Texas Instruments continued to hold a dominant 30 percent share of the bipolar standard logic market, it grew much slower than the industry. National/Fairchild, in second place, saw its revenue decline in this market. Philips-Signetics gained share, growing much faster than the industry, displacing Motorola from third place to fourth. Hitachi displaced AMD/MMI from fifth place to sixth. The top 5 suppliers held 76 percent share, and the top 10 held 92 percent share of the worldwide bipolar standard logic market. The top 19 competitors in this market, and their market share rankings are shown in Table 9.

Table 9

Preliminary Worldwide Bipolar Standard Logic Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Texas Instruments	$ 709	$ 726	2.4%
2	2	National/Fairchild	$ 423	$ 367	(13.2%)
4	3	Philips-Signetics	$ 211	$ 295	39.8%
3	4	Motorola	$ 235	$ 254	8.1%
6	5	Hitachi	$ 154	$ 188	22.1%
5	6	AMD/MMI	$ 181	$ 185	2.2%
7	7	Fujitsu	$ 75	$ 65	(13.3%)
8	8	Mitsubishi	$ 74	$ 59	(20.0%)
9	9	NEC	$ 43	$ 45	4.7%
10	10	Plessey	$ 25	$ 25	0.0%
18	11	Chip & Technologies	$ 10	$ 24	140.0%
12	12	Harris	$ 22	$ 24	9.1%
13	13	Intel	$ 21	$ 22	4.8%
19	14	Oki	$ 10	$ 22	120.0%
16	15	Gold Star	$ 13	$ 20	53.8%
14	16	Siemens	$ 21	$ 16	(23.8%)
20	17	VTC	$ 10	$ 14	40.0%
17	18	Raytheon	$ 12	$ 13	8.3%
11	19	Honeywell	$ 23	$ 10	(56.5%)
		Total Market Estimate	$2,320	$2,410	3.9%

Source: Dataquest
January 1988

Bipolar ASIC Market

Fujitsu held first place in the bipolar ASIC market, growing about three times as fast as the industry. AMD/MMI, in second place, grew almost twice as fast as the industry, while third-ranked Motorola grew slower than the industry. Texas Instruments made a significant move in this market, advancing three places to the fifth ranking, while growing more than four times as fast as the industry. The market in this industry is concentrated, with the top 5 suppliers holding 57 percent share and the top 10 suppliers holding 85 percent share of the world bipolar ASIC market. The top 19 companies in the bipolar ASIC market are ranked in Table 10.

Table 10

Preliminary Worldwide Bipolar ASIC Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Fujitsu	$ 176	$ 290	64.8%
2	2	AMD/MMI	$ 172	$ 235	36.6%
3	3	Motorola	$ 147	$ 165	12.2%
5	4	Hitachi	$ 105	$ 130	23.8%
8	5	Texas Instruments	$ 69	$ 128	85.5%
6	6	NEC	$ 101	$ 117	15.8%
4	7	Toshiba	$ 121	$ 116	(4.1%)
7	8	Philips-Signetics	$ 91	$ 68	(25.3%)
9	9	Honeywell	$ 63	$ 66	4.8%
10	10	Mitsubishi	$ 60	$ 66	10.0%
11	11	National/Fairchild	$ 50	$ 62	24.0%
12	12	Ferranti	$ 44	$ 35	(20.5%)
15	13	AMCC	$ 20	$ 28	40.0%
13	14	Sanyo	$ 23	$ 26	13.0%
16	15	Raytheon	$ 20	$ 24	20.0%
14	16	Matsushita	$ 21	$ 23	9.5%
18	17	Siemens	$ 11	$ 14	27.3%
17	18	Oki	$ 19	$ 10	(47.4%)
20	19	Plessey	$ 7	$ 10	42.9%
		Total Market Estimate	$1,340	$1,630	21.7%

Source: Dataquest
January 1988

MOS Market Share

NEC held first place in the world MOS market, with more than $2 billion in MOS revenue. Toshiba and Intel advanced to the second and third places, respectively, displacing Hitachi from second to fourth place. This is a less-concentrated segment of the semiconductor industry, with the top 5 holding 44 percent share and the top 10 holding 66 percent share of the world MOS market. Several high-fliers in the semiconductor industry focus on the MOS market segment. The rankings of the top 50 companies in this segment are listed in Table 11.

Table 11

Preliminary Worldwide MOS Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	NEC	$ 1,615	$ 2,009	24.4%
3	2	Toshiba	$ 1,106	$ 1,579	42.8%
4	3	Intel	$ 970	$ 1,478	52.4%
2	4	Hitachi	$ 1,167	$ 1,461	25.2%
5	5	Fujitsu	$ 779	$ 1,088	39.7%
6	6	Motorola	$ 728	$ 1,006	38.2%
7	7	Mitsubishi	$ 562	$ 795	41.5%
8	8	Texas Instruments	$ 511	$ 728	42.5%
9	9	Matsushita	$ 387	$ 591	52.7%
10	10	Oki	$ 371	$ 566	52.6%
13	11	AMD/MMI	$ 279	$ 393	40.9%
14	12	National/Fairchild	$ 275	$ 347	26.2%
12	13	Philips-Signetics	$ 302	$ 338	11.9%
11	14	SGS Thomson	$ 322	$ 336	4.3%
17	15	Sharp	$ 193	$ 317	64.2%
16	16	LSI Logic	$ 194	$ 260	34.0%
15	17	GE Solid State	$ 211	$ 236	11.8%
20	18	Samsung	$ 117	$ 234	100.0%
19	19	Seiko Epson	$ 147	$ 199	35.4%
23	20	Siemens	$ 109	$ 173	58.7%
22	21	VLSI Technology	$ 112	$ 170	51.8%
18	22	Gould AMI Semiconductor	$ 155	$ 155	0.0
24	23	ITT	$ 107	$ 146	36.4%
21	24	Sony	$ 114	$ 146	28.1%
27	25	Sanyo	$ 88	$ 119	35.2%

(Continued)

Table 11 (Continued)

Preliminary Worldwide MOS Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
34	26	Micron Technology	$ 63	$ 115	82.5%
26	27	NCR	$ 94	$ 114	21.3%
25	28	Harris	$ 102	$ 107	4.9%
30	29	Integrated Device Tech.	$ 72	$ 98	36.1%
33	30	Rockwell	$ 65	$ 95	46.2%
28	31	Inmos	$ 80	$ 91	13.8%
31	32	United Microelectronics	$ 69	$ 90	30.4%
46	33	Chips & Technologies	$ 31	$ 88	183.9%
29	34	Zilog	$ 74	$ 88	18.9%
38	35	Cypress Semiconductor	$ 50	$ 79	58.0%
32	36	General Instrument	$ 67	$ 78	16.4%
43	37	Honeywell	$ 36	$ 70	94.4%
37	38	Western Digital	$ 53	$ 70	32.1%
36	39	Ricoh	$ 55	$ 65	18.2%
40	40	Xicor	$ 41	$ 59	43.9%
35	41	Standard Microsystems	$ 56	$ 56	0.0
45	42	Seeq	$ 32	$ 50	56.3%
42	43	Plessey	$ 37	$ 43	16.2%
47	44	IMP	$ 31	$ 42	35.5%
39	45	Matra-Harris	$ 44	$ 42	(4.5%)
50	46	Hyundai	$ 21	$ 40	90.5%
41	47	Hughes	$ 38	$ 39	2.6%
66	48	Mietec	$ 10	$ 32	220.0%
56	49	Zymos	$ 18	$ 30	66.7%
85	50	AMS	0	$ 29	N/A
		Total Market Estimate	$12,560	$17,140	36.3%

N/A = Not Available

Source: Dataquest
January 1988

MOS Memory Market Share

Japanese suppliers retained the top five places in the MOS memory market, with no change in rankings. Hitachi led the market, despite a decline in revenue. NEC, in second place, also grew slower than the market, while Fujitsu, Toshiba, and Mitsubishi outgrew the market. Texas Instruments moved past Intel to claim sixth place. The high-fliers include Oki, ranked 8th and growing at 114 percent; Samsung, ranked 9th and growing at 148 percent; Sharp, ranked 11th and growing at 140 percent; and Micron Technology, ranked 12th and growing at 82.5 percent. The top 37 companies and their rankings in this market are listed in Table 12. The industry is somewhat concentrated, with the top 5 suppliers holding 56 percent share and the top 10 suppliers holding 77 percent share of the worldwide MOS memory market.

Table 12

Preliminary Worldwide MOS Memory Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Hitachi	$ 814	$ 764	(6.1%)
2	2	NEC	$ 586	$ 707	20.6%
3	3	Fujitsu	$ 485	$ 689	42.1%
4	4	Toshiba	$ 455	$ 646	42.0%
5	5	Mitsubishi	$ 304	$ 461	51.6%
7	6	Texas Instruments	$ 286	$ 405	41.6%
6	7	Intel	$ 298	$ 329	10.4%
9	8	Oki	$ 90	$ 193	114.4%
13	9	Samsung	$ 65	$ 161	147.7%
8	10	AMD/MMI	$ 124	$ 142	14.5%
16	11	Sharp	$ 55	$ 132	140.0%
15	12	Micron Technology	$ 63	$ 115	82.5%
11	13	Matsushita	$ 70	$ 91	30.0%
17	14	Motorola	$ 51	$ 86	68.6%
14	15	Integrated Device Tech.	$ 64	$ 85	32.8%
10	16	SGS Thomson	$ 88	$ 84	(4.5%)
19	17	Seiko Epson	$ 44	$ 69	56.8%
21	18	National/Fairchild	$ 41	$ 65	58.5%
18	19	Cypress Semiconductor	$ 45	$ 63	40.0%
22	20	Xicor	$ 41	$ 59	43.9%

(Continued)

Table 12 (Continued)

Preliminary Worldwide MOS Memory Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
25	21	Siemens	$ 31	$ 57	83.9%
24	22	Sony	$ 39	$ 49	25.6%
20	23	General Instrument	$ 41	$ 47	14.6%
12	24	Inmos	$ 69	$ 43	(37.7%)
26	25	Seeq	$ 27	$ 42	55.6%
23	26	Harris	$ 40	$ 39	(2.5%)
40	27	Hyundai	$ 4	$ 30	650.0%
28	28	VLSI Technology	$ 24	$ 23	(4.2%)
32	29	Philips-Signetics	$ 13	$ 19	46.2%
27	30	GE Solid State	$ 24	$ 18	(25.0%)
31	31	Ricoh	$ 16	$ 18	12.5%
30	32	Matra-Harris	$ 18	$ 16	(11.1%)
39	33	Waferscale	$ 5	$ 12	140.0%
33	34	Gould AMI Semiconductors	$ 11	$ 11	0.0
34	35	STC	$ 10	$ 11	10.0%
29	36	NCR	$ 19	$ 10	(47.4%)
42	37	Vitelic	$ 4	$ 10	150.0%
		Total Market Estimate	$4,510	$5,840	29.6%

Source: Dataquest
January 1988

MOS Micro Market Share

The five top-ranked companies in the MOS micro market remained stable, with Intel leading the pack and growing at a 75 percent clip. Second-place NEC grew slower than the industry, while third-place Motorola grew faster. Hitachi, in fourth place, outpaced the top three companies, growing at 79 percent. The top 34 contenders in this market and their market share rankings are listed in Table 13. While the MOS micro market was the fastest growing segment of the semiconductor market, nearly 50 percent growth in 1987, this industry is also somewhat concentrated, with the top 5 suppliers holding 57 percent share and the top 10 suppliers holding 76 percent share of the world MOS micro market.

Table 13

Preliminary Worldwide MOS Micro Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Intel	$ 628	~~$1,098~~ 1089	74.8%
2	2	NEC	$ 490	$ 629	28.4%
3	3	Motorola	$ 342	$ 539	57.6%
4	4	Hitachi	$ 240	$ 429	78.8%
5	5	Mitsubishi	$ 208	$ 274	31.7%
6	6	Toshiba	$ 181	$ 264	45.9%
7	7	Matsushita	$ 167	$ 202	21.0%
9	8	AMD/MMI	$ 94	$ 171	81.9%
8	9	Fujitsu	$ 120	$ 146	21.7%
11	10	Texas Instruments	$ 92	$ 139	51.1%
10	11	SGS Thomson	$ 92	$ 110	19.6%
14	12	Oki	$ 68	$ 101	48.5%
12	13	Philips-Signetics	$ 77	$ 99	28.6%
21	14	Chips & Technologies	$ 31	$ 88	183.9%
13	15	Zilog	$ 74	$ ~~88~~ 78	18.9%
16	16	National/Fairchild	$ 48	$ 74	54.2%
15	17	Western Digital	$ 50	$ 63	26.0%
17	18	Sanyo	$ 44	$ 57	29.5%
30	19	Inmos	$ 11	$ 48	336.4%
23	20	Sharp	$ 26	$ 48	84.6%
20	21	Rockwell	$ 40	$ 44	10.0%
26	22	Siemens	$ 17	$ 44	158.8%
18	23	Harris	$ 42	$ 43	2.4%
19	24	Standard Microsystems	$ 42	$ 42	0.0
22	25	GE Solid State	$ 27	$ 28	3.7%

(Continued)

Table 13 (Continued)

Preliminary Worldwide MOS Micro Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
25	26	United Microelectronics	$ 18	$ 26	44.4%
27	27	Sony	$ 17	$ 22	29.4%
29	28	ITT	$ 13	$ 21	61.5%
28	29	Weitek	$ 17	$ 20	17.6%
24	30	Matra-Harris	$ 18	$ 19	5.6%
98	31	VLSI Technology	0	$ 18	N/A
31	32	Ricoh	$ 11	$ 14	27.3%
32	33	General Instrument	$ 10	$ 12	20.0%
33	34	NCR	$ 10	$ 10	0.0
		Total Market Estimate	$3,400	$5,100	49.6%

N/A = Not Available

Source: Dataquest
January 1988

MOS Logic Market Share

The top three companies in the MOS logic market remained stable, with second-place Toshiba coming close to first-place, NEC and Motorola remaining third. Matsushita advanced six notches to fourth place, and Hitachi advanced eight notches to sixth place. The rankings of the top 50 companies in this market are listed in Table 14. This industry is less concentrated, with the top 5 suppliers holding 37 percent share and the top 10 suppliers holding 57 percent share of the MOS logic market. MOS logic market includes MOS standard logic and MOS ASIC markets.

Table 14

Preliminary Worldwide MOS Logic Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	NEC	$ 539	$ 673	24.9%
2	2	Toshiba	$ 470	$ 669	42.3%
3	3	Motorola	$ 335	$ 381	13.7%
10	4	Matsushita	$ 150	$ 298	98.7%
4	5	Oki	$ 213	$ 272	27.7%

(Continued)

Table 14 (Continued)

Preliminary Worldwide MOS Logic Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
14	6	Hitachi	$ 113	$ 268	137.2%
6	7	LSI Logic	$ 194	$ 260	34.0%
8	8	Fujitsu	$ 174	$ 253	45.4%
5	9	Philips-Signetics	$ 212	$ 220	3.8%
7	10	National/Fairchild	$ 186	$ 208	11.8%
9	11	GE Solid State	$ 160	$ 190	18.8%
13	12	Texas Instruments	$ 133	$ 184	38.3%
11	13	SGS Thomson	$ 142	$ 142	0.0
12	14	Gould AMI Semiconductors	$ 138	$ 139	0.7%
15	15	Sharp	$ 112	$ 137	22.3%
16	16	Seiko Epson	$ 103	$ 130	26.2%
18	17	VLSI Technology	$ 88	$ 129	46.6%
17	18	ITT	$ 94	$ 125	33.0%
19	19	NCR	$ 65	$ 94	44.6%
20	20	AMD/MMI	$ 61	$ 80	31.1%
22	21	Sony	$ 58	$ 75	29.3%
21	22	Siemens	$ 61	$ 72	18.0%
31	23	Honeywell	$ 29	$ 70	141.4%
23	24	Samsung	$ 52	$ 65	25.0%
24	25	Mitsubishi	$ 50	$ 60	20.0%
25	26	United Microelectronics	$ 46	$ 59	28.3%
27	27	Sanyo	$ 39	$ 54	38.5%
26	28	Intel	$ 44	$ 51	15.9%
34	29	Rockwell	$ 24	$ 51	112.5%
28	30	Plessey	$ 37	$ 43	16.2%
30	31	IMP	$ 31	$ 42	35.5%
29	32	Hughes	$ 34	$ 35	2.9%
33	33	Ricoh	$ 28	$ 33	17.9%
52	34	Mietec	$ 10	$ 32	220.0%
78	35	AMS	0	$ 27	N/A
35	36	ASEA-BBC	$ 22	$ 26	18.2%
36	37	Harris	$ 20	$ 25	25.0%
38	38	Telefunken Electronic	$ 18	$ 25	38.9%
39	39	Zymos	$ 18	$ 25	38.9%
46	40	Altera	$ 12	$ 23	91.7%

(Continued)

Table 14 (Continued)

Preliminary Worldwide MOS Logic Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
43	41	ERSO	$ 15	$ 22	46.7%
32	42	Eurosil	$ 28	$ 22	(21.4%)
37	43	Micro Power Systems	$ 20	$ 20	0.0
41	44	General Instrument	$ 16	$ 19	18.8%
66	45	Gold Star	$ 4	$ 19	375.0%
42	46	Sprague	$ 16	$ 17	6.3%
49	47	VTC	$ 11	$ 17	54.5%
61	48	Cypress Semiconductor	$ 5	$ 16	220.0%
56	49	Fuji Electric	$ 7	$ 15	114.3%
45	50	Standard Microsystems	$ 14	$ 14	0.0
		Total Market Estimate	$4,650	$6,200	32.9%

N/A = Not Available

Source: Dataquest
January 1988

MOS Standard Logic Market Share

Motorola led the MOS standard logic market, followed by Philips-Signetics. Toshiba displaced a stagnant National/Fairchild from third place. The top 27 companies in this market are ranked in Table 15. The industry is concentrated, with the top 5 suppliers holding 54 percent share and the top 10 suppliers holding 74 percent share of the world MOS standard logic market.

Table 15

Preliminary Worldwide MOS Standard Logic Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Motorola	$ 278	$ 310	11.5%
2	2	Philips-Signetics	$ 203	$ 204	0.5%
4	3	Toshiba	$ 133	$ 160	20.3%
3	4	National/Fairchild	$ 154	$ 154	0.0
5	5	GE Solid State	$ 102	$ 118	15.7%

(Continued)

Table 15 (Continued)

Preliminary Worldwide MOS Standard Logic Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
7	6	NEC	$ 69	$ 83	20.3%
8	7	AMD/MMI	$ 55	$ 73	32.7%
10	8	Texas Instruments	$ 51	$ 70	37.3%
9	9	Samsung	$ 52	$ 65	25.0%
14	10	Rockwell	$ 24	$ 51	112.5%
11	11	United Microelectronics	$ 41	$ 48	17.1%
13	12	Siemens	$ 25	$ 40	60.0%
15	13	Hitachi	$ 22	$ 28	27.3%
12	14	Oki	$ 25	$ 28	12.0%
21	15	Matsushita	$ 14	$ 27	92.9%
6	16	SGS Thomson	$ 78	$ 25	(67.9%)
17	17	ITT	$ 20	$ 23	15.0%
23	18	NCR	$ 12	$ 22	83.3%
19	19	Plessey	$ 20	$ 21	5.0%
18	20	Micro Power Systems	$ 20	$ 20	0.0
16	21	Intel	$ 21	$ 19	(9.5%)
24	22	VTC	$ 11	$ 17	54.5%
22	23	Standard Microsystems	$ 14	$ 14	0.0
38	24	New JRC	$ 3	$ 13	333.3%
27	25	Telefunken Electronic	$ 9	$ 13	44.4%
36	26	Fujitsu	$ 4	$ 10	150.0%
26	27	Supertex	$ 9	$ 10	11.1%
		Total Market Estimate	$1,550	$1,750	12.5%

Source: Dataquest
January 1988

MOS ASIC Market Share

NEC led the MOS ASIC market, chased by fast-growing Toshiba. Matsushita advanced past LSI Logic, Oki, and Fujitsu to third place. The high-fliers include Hitachi, ranked 8th and growing at 164 percent; SGS Thomson, ranked 12th and growing at 83 percent; and Honeywell, ranked 19th and growing at 141 percent. The top 50 contenders in this market are ranked in Table 16. The market share in this industry is less concentrated, with the top 5 suppliers holding 42 percent share and the top 10 suppliers holding 62 percent share of the world MOS ASIC market.

Table 16

Preliminary Worldwide MOS ASIC Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	NEC	$ 470	$ 590	25.5%
2	2	Toshiba	$ 337	$ 509	51.0%
6	3	Matsushita	$ 136	$ 271	99.3%
3	4	LSI Logic	$ 194	$ 260	34.0%
4	5	Oki	$ 188	$ 244	29.8%
5	6	Fujitsu	$ 170	$ 243	42.9%
10	7	Hitachi	$ 91	$ 240	163.7%
8	8	Sharp	$ 112	$ 137	22.3%
7	9	Gould AMI Semiconductors	$ 131	$ 132	0.8%
9	10	Seiko Epson	$ 103	$ 130	26.2%
11	11	VLSI Technology	$ 88	$ 129	46.6%
14	12	SGS Thomson	$ 64	$ 117	82.8%
12	13	Texas Instruments	$ 82	$ 114	39.0%
13	14	ITT	$ 74	$ 102	37.8%
16	15	Sony	$ 58	$ 75	29.3%
15	16	GE Solid State	$ 58	$ 72	24.1%
18	17	NCR	$ 53	$ 72	35.8%
17	18	Motorola	$ 57	$ 71	24.6%
25	19	Honeywell	$ 29	$ 70	141.4%
23	20	National/Fairchild	$ 32	$ 54	68.8%
19	21	Mitsubishi	$ 43	$ 51	18.6%
22	22	Sanyo	$ 33	$ 47	42.4%
24	23	IMP	$ 31	$ 42	35.5%
21	24	Hughes	$ 34	$ 35	2.9%
27	25	Ricoh	$ 28	$ 33	17.9%

(Continued)

Table 16 (Continued)

Preliminary Worldwide MOS ASIC Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
28	26	Intel	$ 23	$ 32	39.1%
40	27	Mietec	$ 10	$ 32	220.0%
20	28	Siemens	$ 36	$ 32	(11.1%)
67	29	AMS	$ 0	$ 27	N/A
29	30	ASEA-BBC	$ 22	$ 26	18.2%
30	31	Harris	$ 20	$ 25	25.0%
31	32	Zymos	$ 18	$ 25	38.9%
34	33	Altera	$ 12	$ 23	91.7%
26	34	Eurosil	$ 28	$ 22	(21.4%)
32	35	Plessey	$ 17	$ 22	29.4%
33	36	General Instrument	$ 16	$ 19	18.8%
51	37	Cypress Semiconductor	$ 5	$ 16	220.0%
55	38	Gold Star	$ 4	$ 16	300.0%
42	39	Philips-Signetics	$ 9	$ 16	77.8%
37	40	ERSO	$ 10	$ 14	40.0%
44	41	Fuji Electric	$ 7	$ 14	100.0%
53	42	Sierra Semiconductor	$ 5	$ 14	180.0%
38	43	Ferranti	$ 10	$ 12	20.0%
35	44	IMI	$ 12	$ 12	0.0
43	45	Telefunken Electronic	$ 9	$ 12	33.3%
41	46	Sprague	$ 10	$ 11	10.0%
54	47	United Microelectronics	$ 5	$ 11	120.0%
36	48	Universal	$ 11	$ 11	0.0
57	49	Xilinx	$ 4	$ 11	175.0%
39	50	Holt	$ 10	$ 10	0.0
		Total Market Estimate	$3,100	$4,450	43.2%

N/A = Not Available

Source: Dataquest
January 1988

Linear Market Share

National/Fairchild regained the leadership position in the linear market for National. Toshiba displaced the erstwhile leader Matsushita, which dropped to third place. Philips-Signetics advanced three notches to fifth place, growing nearly three times as fast as the industry. The top 50 companies in this market are ranked in Table 17. This industry is the least concentrated segment of the semiconductor industry, with the top 5 suppliers holding 33 percent share and the top 10 suppliers holding 58 percent share of the worldwide linear market.

Table 17

Preliminary Worldwide Linear Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	National/Fairchild	$ 502	$ 531	5.8%
3	2	Toshiba	$ 375	$ 457	21.9%
2	3	Matsushita	$ 387	$ 425	9.8%
4	4	NEC	$ 363	$ 424	16.8%
8	5	Philips-Signetics	$ 280	$ 423	51.1%
5	6	Texas Instruments	$ 352	$ 386	9.7%
6	7	Sanyo	$ 296	$ 346	16.9%
7	8	Motorola	$ 282	$ 339	20.2%
9	9	Hitachi	$ 265	$ 298	12.5%
11	10	SGS Thomson	$ 233	$ 287	23.2%
12	11	Mitsubishi	$ 195	$ 277	42.1%
10	12	Analog Devices	$ 243	$ 274	12.8%
13	13	Sony	$ 167	$ 199	19.2%
14	14	Rohm	$ 153	$ 182	19.0%
16	15	Harris	$ 113	$ 138	22.1%
21	16	Fujitsu	$ 75	$ 137	82.7%
15	17	GE Solid State	$ 127	$ 131	3.1%
17	18	Burr-Brown	$ 98	$ 120	22.4%
19	19	Siemens	$ 82	$ 120	46.3%
20	20	Sanken	$ 81	$ 119	46.9%
24	21	New JRC	$ 72	$ 95	31.9%
18	22	Sprague	$ 85	$ 89	4.7%
22	23	Silicon Systems	$ 75	$ 88	17.3%
23	24	Precision Monolithics	$ 73	$ 71	(2.7%)
25	25	AMD/MMI	$ 71	$ 70	(1.4%)

(Continued)

Table 17 (Continued)

Preliminary Worldwide Linear Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
27	26	Telefunken Electronic	$ 61	$ 70	14.8%
28	27	Siliconix	$ 59	$ 61	3.4%
29	28	Sharp	$ 43	$ 54	25.6%
26	29	ITT	$ 61	$ 51	(16.4%)
34	30	Samsung	$ 28	$ 50	78.6%
33	31	Linear Technology	$ 29	$ 44	51.7%
31	32	Mitel	$ 33	$ 39	18.2%
30	33	Exar/Exel	$ 36	$ 38	5.6%
35	34	Plessey	$ 27	$ 33	22.2%
38	35	Ferranti	$ 24	$ 31	29.2%
37	36	Fuji Electric	$ 26	$ 27	3.8%
32	37	Gold Star	$ 30	$ 26	(13.3%)
39	38	Cherry Semiconductor	$ 19	$ 25	31.6%
36	39	Raytheon	$ 27	$ 25	(7.4%)
43	40	Unitrode	$ 16	$ 23	43.8%
47	41	Oki	$ 14	$ 21	50.0%
50	42	KEC	$ 10	$ 20	100.0%
41	43	TRW	$ 18	$ 18	0.0
45	44	General Instrument	$ 15	$ 17	13.3%
42	45	Interdesign	$ 17	$ 17	0.0
49	46	Solitron	$ 12	$ 13	8.3%
48	47	Teledyne	$ 13	$ 13	0.0
40	48	Seiko Epson	$ 18	$ 12	(33.3%)
44	49	VTC	$ 16	$ 12	(25.0%)
51	50	Micro Power Systems	$ 10	$ 10	0.0
		Total Market Estimate	$5,750	$6,850	18.7%

Source: Dataquest
January 1988

Discrete Market Share

The five top-ranked companies in the discrete market remained stable, with second-place Toshiba almost catching up with the leader, Motorola. The top 40 companies in this market are ranked in Table 18. The industry is fairly concentrated, with the top 5 suppliers holding 45 percent share and the top 10 suppliers holding 64 percent share of the worldwide discrete market.

Table 18

Preliminary Worldwide Discrete Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Motorola	$ 604	$ 652	7.9%
2	2	Toshiba	$ 557	$ 650	16.7%
3	3	Hitachi	$ 476	$ 544	14.3%
4	4	NEC	$ 439	$ 512	16.6%
5	5	Philips-Signetics	$ 288	$ 388	34.7%
6	6	Matsushita	$ 278	$ 271	(2.5%)
7	7	Mitsubishi	$ 216	$ 260	20.4%
10	8	Rohm	$ 160	$ 220	37.5%
11	9	Sanyo	$ 159	$ 210	32.1%
9	10	Fuji Electric	$ 163	$ 202	23.9%
8	11	SGS Thomson	$ 209	$ 200	(4.3%)
12	12	International Rectifier	$ 145	$ 172	18.6%
16	13	Siemens	$ 126	$ 169	34.1%
15	14	Sanken	$ 133	$ 162	21.8%
13	15	ITT	$ 144	$ 160	11.1%
14	16	GE Solid State	$ 139	$ 150	7.9%
17	17	General Instrument	$ 115	$ 134	16.5%
18	18	Powerex	$ 99	$ 106	7.1%
19	19	Telefunken Electronic	$ 82	$ 97	18.3%
20	20	Semikron	$ 72	$ 79	9.7%
23	21	National/Fairchild	$ 61	$ 75	23.0%
22	22	Sony	$ 62	$ 72	16.1%
25	23	Fujitsu	$ 53	$ 70	32.1%
24	24	Texas Instruments	$ 58	$ 64	10.3%
29	25	KEC	$ 38	$ 55	44.7%
26	26	Hewlett-Packard	$ 51	$ 54	5.9%
27	27	Siliconix	$ 51	$ 52	2.0%
30	28	ASEA-BBC	$ 36	$ 50	38.9%
28	29	TRW	$ 43	$ 49	14.0%
21	30	Unitrode	$ 66	$ 46	(30.3%)

(Continued)

Table 18 (Continued)

Preliminary Worldwide Discrete Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
31	31	Solitron	$ 30	$ 34	13.3%
32	32	Samsung	$ 25	$ 32	28.0%
33	33	Ferranti	$ 18	$ 22	22.2%
41	34	New JRC	$ 7	$ 21	200.0%
35	35	TAG	$ 18	$ 21	16.7%
36	36	VQSI (Varo)	$ 17	$ 21	23.5%
34	37	MEDL	$ 18	$ 20	11.1%
38	38	Sprague	$ 14	$ 18	28.6%
39	39	Acrian	$ 13	$ 15	15.4%
37	40	Raytheon	$ 15	$ 12	(20.0%)
		Total Market Estimate	$5,320	$6,180	15.9%

Source: Dataquest
January 1988

Optoelectronics Market Share

The top five companies in the optoelectronics market remained stable, with Sharp leading the market. Sanyo advanced four notches to seventh place. Table 19 lists the rankings of the top 25 contenders in this market. The industry is somewhat concentrated, with the top 5 suppliers holding 49 percent share and the top 10 suppliers holding 72 percent share of the worldwide optoelectronics market.

Table 19

Preliminary Worldwide Opto Market Share Rankings
(Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Sharp	$ 197	$ 223	13.2%
2	2	Hewlett-Packard	$ 166	$ 186	12.0%
3	3	Matsushita	$ 126	$ 161	27.8%
4	4	Sony	$ 115	$ 138	20.0%
5	5	Toshiba	$ 109	$ 128	17.4%
6	6	Siemens	$ 86	$ 96	11.6%
11	7	Sanyo	$ 49	$ 85	73.5%
7	8	Fujitsu	$ 62	$ 71	14.5%
8	9	Hitachi	$ 60	$ 68	13.3%
9	10	Telefunken Electronic	$ 58	$ 66	13.8%
10	11	Rohm	$ 56	$ 65	16.1%
12	12	NEC	$ 45	$ 51	13.3%
13	13	General Instrument	$ 39	$ 45	15.4%
14	14	TRW	$ 38	$ 43	13.2%
16	15	Texas Instruments	$ 34	$ 39	14.7%
17	16	GE Solid State	$ 32	$ 37	15.6%
19	17	Philips-Signetics	$ 28	$ 33	17.9%
15	18	Honeywell	$ 35	$ 30	(14.3%)
21	19	Oki	$ 18	$ 25	38.9%
18	20	Mitsubishi	$ 29	$ 24	(17.2%)
20	21	Motorola	$ 18	$ 24	33.3%
22	22	Plessey	$ 16	$ 17	6.3%
23	23	Sanken	$ 10	$ 13	30.0%
24	24	New JRC	$ 9	$ 12	33.3%
25	25	SGS Thomson	$ 8	$ 10	25.0%
		Total Market Estimate	$1,480	$1,720	16.6%

Source: Dataquest
January 1988

NORTH AMERICAN MARKET SUMMARY

The market share rankings in the North American semiconductor and IC markets are shown in Tables 20 and 21. Market share data in the regional markets by detailed product category is available from Dataquest Components Division Services. Japanese market data is available from the JSIS, European market data is available from the ESIS, North American market data is available from the SIS, and Rest of World market data is available from the ASETS.

Preliminary estimates of the North American market revenue indicate that the semiconductor market grew 20 percent, from $9.8 billion in 1986 to $11.8 billion in 1987. The North American IC market grew 21 percent, from $8.3 billion in 1986 to $10.1 billion in 1987.

The top five companies in the North American semiconductor market are all U.S. companies. Motorola remained the clear leader in the North American market. Texas Instruments retained second place, while Intel displaced National/Fairchild from third place. AMD/MMI retained fifth place. Toshiba advanced three notches to sixth place, growing at almost three times the industry growth rate. Hitachi dropped three notches to 9th place, with declining North American revenue. The concentration of the North American industry is comparable to the worldwide industry with the top 5 holding 43 percent share and the top 10 holding 59 percent share.

The top five contenders in the North American IC market are the same as the top five in the semiconductor market. Toshiba gained share and Hitachi lost share in the North American IC market.

Table 20

Preliminary North American Semiconductor Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Motorola	$1,309	$ 1,584	21.0%
2	2	Texas Instruments	$ 845	$ 980	16.0%
4	3	Intel	$ 629	$ 910	44.7%
3	4	National/Fairchild	$ 832	$ 848	1.9%
5	5	AMD/MMI	$ 515	$ 613	19.0%
9	6	Toshiba	$ 294	$ 464	57.8%
7	7	Philips-Signetics	$ 341	$ 372	9.1%
8	8	GE Solid State	$ 339	$ 367	8.3%
6	9	Hitachi	$ 398	$ 365	(8.3%)
11	10	Fujitsu	$ 251	$ 347	38.2%

(Continued)

Table 20 (Continued)

Preliminary North American Semiconductor Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
10	11	NEC	$ 260	$ 335	28.8%
13	12	Hewlett-Packard	$ 217	$ 240	10.6%
12	13	Harris	$ 222	$ 236	6.3%
14	14	SGS Thomson	$ 169	$ 208	23.1%
15	15	LSI Logic	$ 162	$ 206	27.2%
22	16	Oki	$ 101	$ 168	66.3%
20	17	Mitsubishi	$ 114	$ 160	40.4%
16	18	Honeywell	$ 139	$ 158	13.7%
17	19	Analog Devices	$ 136	$ 151	11.0%
24	20	VLSI Technology	$ 96	$ 143	49.0%
18	21	General Instrument	$ 126	$ 138	9.5%
21	22	International Rectifier	$ 103	$ 125	21.4%
19	23	Gould AMI Semiconductors	$ 117	$ 123	5.1%
26	24	NCR	$ 94	$ 109	16.0%
25	25	TRW	$ 95	$ 100	5.3%
23	26	Sprague	$ 99	$ 98	(1.0%)
33	27	Samsung	$ 59	$ 96	62.7%
37	28	Micron Technology	$ 51	$ 94	84.3%
27	29	Powerex	$ 81	$ 86	6.2%
31	30	Raytheon	$ 63	$ 76	20.6%
34	31	Integrated Device Technology	$ 57	$ 74	29.8%
30	32	ITT	$ 63	$ 70	11.1%
46	33	Chips & Technologies	$ 36	$ 69	91.7%
41	34	Cypress Semiconductor	$ 44	$ 67	52.3%
40	35	Rockwell	$ 47	$ 65	38.3%
32	36	Inmos	$ 61	$ 64	4.9%
29	37	Siliconix	$ 66	$ 64	(3.0%)
38	38	Siemens	$ 49	$ 59	20.4%
28	39	Unitrode	$ 67	$ 53	(20.9%)
36	40	Zilog	$ 52	$ 53	1.9%
39	41	Precision Monolithics	$ 48	$ 46	(4.2%)
42	42	Standard Microsystems	$ 43	$ 43	0.0
44	43	VTC	$ 37	$ 43	16.2%
51	44	Xicor	$ 30	$ 43	43.3%
45	45	Burr-Brown	$ 36	$ 42	16.7%

(Continued)

Table 20 (Continued)

Preliminary North American Semiconductor Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
57	46	Seeq	$ 27	$ 41	51.9%
43	47	Solitron	$ 37	$ 41	10.8%
50	48	Seiko Epson	$ 31	$ 40	29.0%
35	49	Silicon Systems	$ 54	$ 40	(25.9%)
47	50	Hughes	$ 36	$ 39	8.3%
		Total Market Estimate	$9,800	$11,800	19.8%

Source: Dataquest
January 1988

Table 21

Preliminary North American IC Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
1	1	Motorola	$ 910	$ 1,125	23.6%
2	2	Texas Instruments	$ 800	$ 931	16.4%
4	3	Intel	$ 629	$ 910	44.7%
3	4	National/Fairchild	$ 796	$ 807	1.4%
5	5	AMD/MMI	$ 515	$ 613	19.0%
9	6	Toshiba	$ 252	$ 395	56.7%
8	7	Philips-Signetics	$ 325	$ 371	14.2%
7	8	GE Solid State	$ 339	$ 367	8.3%
10	9	NEC	$ 251	$ 326	29.9%
6	10	Hitachi	$ 356	$ 320	(10.1%)
11	11	Fujitsu	$ 230	$ 312	35.7%
12	12	Harris	$ 222	$ 236	6.3%
13	13	LSI Logic	$ 162	$ 206	27.2%
19	14	Oki	$ 101	$ 168	66.3%
15	15	SGS Thomson	$ 128	$ 156	21.9%

(Continued)

Table 21 (Continued)

Preliminary North American IC Market Share Rankings (Millions of Dollars)

1986 Rank	1987 Rank		1986 Revenue	1987 Revenue	Percent Change
14	16	Analog Devices	$ 136	$ 151	11.0%
17	17	Mitsubishi	$ 105	$ 150	42.9%
20	18	VLSI Technology	$ 96	$ 143	49.0%
18	19	Honeywell	$ 104	$ 128	23.1%
16	20	Gould AMI Semiconductors	$ 117	$ 123	5.1%
21	21	NCR	$ 94	$ 109	16.0%
25	22	Samsung	$ 57	$ 95	66.7%
28	23	Micron Technology	$ 51	$ 94	84.3%
22	24	Sprague	$ 85	$ 80	(5.9%)
24	25	Integrated Device Technology	$ 57	$ 74	29.8%
38	26	Chips & Technologies	$ 36	$ 69	91.7%
32	27	Cypress Semiconductor	$ 44	$ 67	52.3%
31	28	Rockwell	$ 47	$ 65	38.3%
23	29	Inmos	$ 61	$ 64	4.9%
29	30	Raytheon	$ 49	$ 59	20.4%
27	31	Zilog	$ 52	$ 53	1.9%
33	32	General Instrument	$ 43	$ 47	9.3%
30	33	Precision Monolithics	$ 48	$ 46	(4.2%)
34	34	Standard Microsystems	$ 43	$ 43	0.0
36	35	VTC	$ 37	$ 43	16.2%
44	36	Xicor	$ 30	$ 43	43.3%
37	37	Burr-Brown	$ 36	$ 42	16.7%
48	38	Seeq	$ 27	$ 41	51.9%
43	39	Seiko Epson	$ 31	$ 40	29.0%
26	40	Silicon Systems	$ 54	$ 40	(25.9%)
35	41	Siliconix	$ 39	$ 40	2.6%
39	42	Hughes	$ 36	$ 39	8.3%
42	43	ITT	$ 32	$ 39	21.9%
40	44	Western Digital	$ 34	$ 39	14.7%
45	45	Gold Star	$ 29	$ 34	17.2%
47	46	IMP	$ 28	$ 34	21.4%
41	47	Exar/Exel	$ 32	$ 32	0.0
54	48	Linear Technology	$ 20	$ 30	50.0%
46	49	Interdesign	$ 29	$ 29	0.0
56	50	AMCC	$ 19	$ 28	47.4%
		Total Market Estimate	$8,300	$10,100	21.2%

Source: Dataquest
January 1988

DATAQUEST ANALYSIS

The combined revenue of the worldwide semiconductor suppliers grew 24 percent, to $36.6 billion in 1987. The Asia-Pacific companies fared the best, growing at 64 percent. The Japanese companies grew 27 percent, while the North American and European companies grew about 21 percent each.

While interpreting the revenue growth, the weary reader should bear in mind that we are measuring the worldwide market in terms of the declining U.S. dollar. The dollar declined about 14 percent against the Japanese yen and the European currencies in 1987. Insomuch as the Japanese companies depend on their local market for about 75 percent of their semiconductor revenue, and the European companies depend on their local market for about 67 percent of their revenue, the real market positions for the Japanese and European companies are overstated by using the declining dollar as the unit of measure.

Joseph Borgia

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DRAM ALLIANCE: THE UNITED STATES TALKS, THE BRITISH ACT

SUMMARY

While American systems companies continue to debate the pros and cons of forming alliances that will assure their supply of critical memory devices, the British have taken action. Amstrad plc, a fast-growing maker of personal computers and home entertainment products based in Brentwood, England, agreed on October 3 to make a $75 million equity investment in Micron Technology Inc. of Boise, Idaho. The deal will allow Micron to accelerate its development of new facilities that will at least double its manufacturing capacity in DRAM and other memory products. As part of the agreement, Amstrad will receive an option to buy up to approximately 9 percent of Micron's semiconductor production over the next three years.

MICRON'S ALLIANCE STRATEGY

Micron Technology, one of only three United States-based semiconductor manufacturers still producing DRAMs, has made no secret of its interest in lining up alliance partners to help fund expansion, develop new products, and enhance its marketing clout. Micron used funding from Digital Equipment Corporation to develop video RAM (VRAM) technology, which is now its fastest-growing product area. Earlier this year, Micron gave Intel Corporation a warrant to buy 600,000 shares of its stock for approximately $11.6 million in return for an agreement to market Micron products through Intel's sales network.

In joining forces with Amstrad, Micron hopes to achieve multiple objectives. Most important initially is the infusion of cash, which may allow the company to cut as much as a year from its two-year plan to build and equip a 100,000-square-foot wafer fabrication plant and a 250,000-square-foot assembly and test building. Investment in the new facilities will increase from a planned $180 million to $250 million, according to Micron.

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The three-year purchase agreement also encourages Micron to accelerate its expansion plans. Although Amstrad is not required to take all of the production it is entitled to buy under the agreement, it already accounts for approximately 9 percent of Micron's sales and still needs additional memory supply. Micron clearly expects the relationship to tighten as the company tries to improve its penetration of the European market.

WHAT DOES AMSTRAD GAIN?

Founded by chairman and managing director Alan Sugar in 1968, Amstrad has about doubled its sales every year since 1980. It crossed the $1 billion mark in the year ended last June. Personal and home computers, word processors, and software account for about three-quarters of Amstrad's sales volume. Company officials claim that the recent DRAM shortage has cut Amstrad's shipments by 10,000 to 30,000 units per month.

The agreement provides Amstrad with assured access to memory products that could be worth more than $50 million per year when Micron's new production facility comes on stream next year. Unlike the 20-plus Micron customers who recently signed two-year noncancellable DRAM supply contracts, Amstrad does not have to commit to a fixed delivery schedule. In addition to negotiating prices on a quarterly basis, Amstrad is able to start with a ceiling price that is based on the weighted average of all other noncancellable contracts for the previous 90 days.

The investment also gives Mr. Sugar a seat on Micron's board and, presumably, some say in future product and marketing decisions. Micron officials stress, however, that the deal will not reduce product allocations to present customers. Under terms of the agreement, Amstrad has a claim on no more than 9.03 percent of any Micron part type. This will prevent Amstrad from using its position to monopolize Micron's output of high-performance devices or others in short supply.

DATAQUEST ANALYSIS

The era of "virtual vertical integration," in which producers and users of critical technology components join forces, has clearly arrived. Assuming that it receives government approval, this agreement provides an excellent example of the benefits to both sides that can flow from such alliances. Dataquest has heard credible rumors that one Japanese chipmaker is floating a business plan to the investment community that would fund a wafer fab jointly owned by itself and several U.S. computer manufacturers.

The irony in all this is that, with the Micron/Amstrad alliance, we have a U.S. semiconductor company reserving a significant share of its much-needed capacity for an aggressive European company, while other rumors suggest a somewhat similar arrangement between U.S. systems manufacturers and a Japanese semiconductor supplier. The Amstrad/Micron arrangement should be a clear signal to U.S. systems and device companies that the alliance dance has started, and it is time to choose partners.

John W. Wilson
Michael J. Boss

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Research Newsletter

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THE 4Mb HURDLE

SUMMARY

The 4Mb DRAM market offers both opportunity and challenge. Unlike any previous generation, the 4Mb DRAM promises to be an overwhelming technical hurdle that threatens to change the competitive rules, business practices, and pricing trends of the DRAM industry. Manufacturers will need to deal with the uncertainty of three-dimensional memory cells, escalating costs of production facilities, and the complexities of 8-inch wafers.

Also unlike any previous generation, the 4Mb DRAM will open doors to new applications beyond traditional computer main memory. Opportunities in solid-state disk drives, graphics and imaging, fax machines, laser printers, digital copiers, and telephone sets will become more visible in the next decade.

MARKET FORECAST

Dataquest estimates that the 4Mb DRAM market will grow as sluggishly as the 1Mb DRAM market did in its early years but for different reasons. A combination of political and technical factors hampered the growth of the 1Mb DRAM, with the political influences bearing a greater weight. Technical factors will play a greater role in the 4Mb DRAM case, however. Figure 1 and Table 1 show Dataquest's forecast for 4Mb DRAMs.

The prices of 4Mb DRAMs are expected to decline at a slower rate because of the higher expected cost. Dataquest does not expect the slope of the 4Mb DRAM cost learning curve to approximate the 1Mb DRAM slope until the 3-D cell and the 8-inch wafer obstacles are fully overcome.

The result is that the 1Mb DRAM life cycle is projected to be longer and to peak at a higher rate until the 4Mb DRAM issues are resolved. Eventually, the 4Mb DRAM market is projected to peak at a much higher level than that of the 1Mb DRAM because of the new applications that will develop in the next decade.

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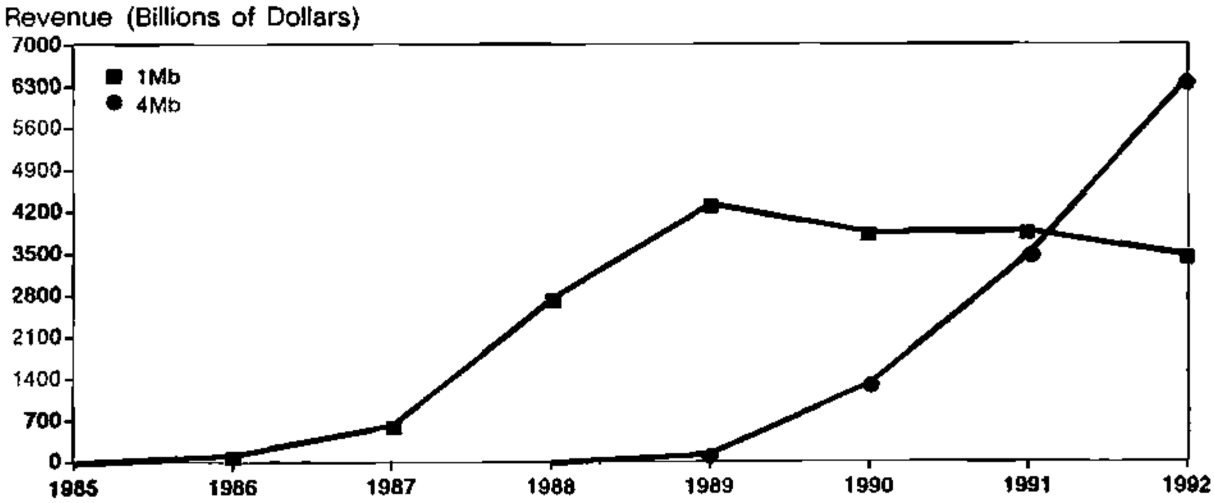
Figure 1

4Mb and 1Mb DRAM Revenue Forecast



0001639-1

Source: Dataquest
November 1988

Table 1

4Mb DRAM Forecast

	1988	1989	1990	1991	1992
Revenue ($M)	$ 5	$ 148	$1,338	$3,517	$6,485
Units (M)	0	2.2	43.2	204.9	560.0
Average Selling Price	$217.50	$67.09	$30.98	$17.16	$11.58

Source: Dataquest
November 1988

MARKET STATUS

Only a few manufacturers are in the early sampling stages for 4Mb DRAMs. Hitachi and Toshiba distributed limited amounts of engineering samples to their major customers as far back as December 1987. Since then, NEC and Texas Instruments also have shown preliminary samples.

NEC and Mitsubishi already have announced the locations where they plan to be manufacturing their versions of the 4Mb DRAM. NEC will be starting production in January at its Yamaguchi plant, and then supplementing shipments with product from its fab in Hiroshima by 1991. Mitsubishi will construct a new facility in Saijo for production starting in 1990. Mitsubishi plans to start sampling early next year with product from its Kochi plant.

Dataquest believes that Hitachi and Toshiba are currently the major contenders for the 4Mb DRAM lead. Matsushita appears to have a convincing 4Mb design, but the company still needs to prove its CMOS process first and will more likely produce DRAMs to support its consumer division initially.

Hitachi has an advantage because it has chosen a more conservative approach—the stacked memory cell—and it is certainly a company that has the financial clout to handle the higher plant investments. Toshiba, on the other hand, has opted for the trench cell. This company has accumulated significant profits because of its 1Mb DRAM lead, and these profits can be reinvested in the next generation. Should Toshiba be successful, it will be an industry first to have the same company lead in succeeding DRAM generations.

Furthermore, there is no lack of interest among the other manufacturers. Table 2 presents a comparison of ISSCC 4Mb DRAM reports showing a large number of companies that are planning to engage in this market.

Table 2

4Mb DRAM ISSCC Reports

	Design Rule	Process Technology	Cell Type	Cell Size (mm^2)	Chip Size (mm^2)	ISSCC Year	Notes
Hitachi	0.8	CMOS	Stacked	14.74	110.9	1987	
Mitsubishi	0.8	CMOS	Trench	10.9	72.3	1987	
Toshiba	0.9	CMOS	Trench	13.8	111.2	1987	Redundancy
Matsushita	0.8	CMOS	Trench	8.0	67.1	1987	Redundancy
NEC	0.8	NMOS	Trench	10.6	99.2	1986	
Fujitsu	0.7	CMOS	Stacked	7.5	63.7	1987	Redundancy
Texas Instruments	1.0	CMOS	Trench	8.9	100.0	1986	
Siemens	0.9	CMOS	Trench	10.6	91.3	1988	Redundancy
IBM	0.8	CMOS	Trench	11.0	78.0	1987	

Source: Dataquest
November 1988

MAJOR 4Mb DRAM ISSUES

The future success of the 4Mb DRAM manufacturers will be determined by the following issues:

- Three-dimensional cell approach
- Higher capital investment
- Eight-inch wafers
- Political intervention

Three-Dimensional Cell Approach

The three-dimensional cell approaches are prerequisites to a cost-efficient 4Mb DRAM. These approaches are far from being completely developed, however. Despite the fact that they have chosen one approach versus the others in their ISSCC papers, DRAM manufacturers are invariably pursuing at least three simultaneous 4Mb DRAM R&D efforts: trench cell, stacked cell, or a combination of both.

Committing everything to one approach creates too much risk. Many 1Mb DRAM manufacturers almost missed the boat by jumping to a trench capacitor cell early in the game, and they have learned their lesson. It is likely that manufacturers will shift approaches as they encounter breakthroughs in their research; for example:

- A manufacturer can first introduce a stacked cell DRAM while continuing to pursue development of a trench cell that will yield an even smaller die. Eventually, the company will introduce the trench version. The advantage is that the company derives high early revenue from the stacked version, allowing it time to develop the trench cell.

- A company can introduce a trench version with considerable redundancy to improve overall manufacturing yields. Eventually, as the trench approach is perfected, the redundancy can be reduced in stages. The advantage is that the company focuses on only one approach and learns from actual trench experience in a production environment.

Eventually, most manufacturers will want to end up with a workable trench cell because this approach best minimizes die size.

Higher Capital Investment

So far, most of the 1Mb DRAMs produced still come from converted 256K DRAM production lines. Only a few new fabrication plants for 1Mb to 4Mb DRAMs are being built, although this number is expected to accelerate beginning next year. These new plants are estimated to cost approximately $150 million. Eventually, companies will have to consider building the next generation fab—a 0.8- to 0.5-micron, 8-inch wafer fab—that can produce 4Mb as well as 16Mb DRAMs. These are currently estimated to cost about $400 million. DRAM manufacturers will take longer making these next capital spending decisions, not only because of the magnitude of the investment but also because of the fear of building excessive capacity.

Eight-Inch Wafers

Dataquest believes that the 4Mb DRAM eventually will have to be built on 8-inch wafer lines as these become more viable. The 4Mb DRAM cost curve will not approximate the 1Mb DRAM curve unless 8-inch wafers are used. In Japan, the viability of high-volume, 8-inch wafer production lines is expected to occur no earlier than the end of 1990. Currently, only IBM has an 8-inch wafer line producing 1Mb and 4Mb DRAMs. Sematech, the manufacturing development consortium located in Austin, Texas, has plans to pursue this approach.

Political Intervention

A risk is that the foreign market values (FMVs) and the terms of the U.S.-Japan semiconductor trade agreement could affect the production ramp and pricing of 4Mb DRAMs the way that they constrained 1Mb DRAMs. However, the American Electronics Association (AEA) is endeavoring to change some of the details of the agreement to better encourage manufacturers to expand 4Mb DRAM capacity.

4Mb DRAM OPPORTUNITIES

In the next decade, the 4Mb DRAM will encounter a market composed of new applications, including the following:

- Solid-state disk drives replacing some of the market traditionally held by magnetic media
- Graphic memory for computers resembling the industry's boundless need for main memory (Graphic memory requirements increase substantially with increasing screen size, resolution, and features.)
- Frame memory requirements for laser printers, digital copiers, and digital facsimile machines
- Frame and line memory for enhanced-definition television (EDTV) and high-definition television (HDTV) and corresponding peripherals such as video cassette recorders
- Telephone message sending and recording applications where one 4Mb DRAM can hold up to two and a half minutes of a voice message (Toshiba has incorporated 1Mb DRAMs in some of its most advanced telephone sets.)

These applications will increase bit consumption by orders of magnitude, but they will require aggressive pricing because of the cost sensitivity of these types of systems.

DATAQUEST OUTLOOK

Dataquest believes that the events and issues surrounding the 4Mb DRAM will affect the DRAM market in the following ways:

- The 4Mb DRAM will be a relatively expensive DRAM in the first two to three years of its product life.

- The production ramp of 4Mb DRAMs will be slower because of the technical problems and high capital investment required.

- As a result, the 1Mb DRAM life will be longer and its peak displaced by at least a year.

- The 1Mb DRAM eventually will incorporate several of the breakthroughs in 4Mb DRAM development to reduce its cost beyond the limits of planar technology.

- The 4Mb DRAM market will pick up rapidly with the implementation of 8-inch wafers and the emergence of new applications in the next decade.

Despite the expected changes, it is not likely that the competitive intensity in the DRAM market will change. New applications for 4Mb DRAMs will require low cost and plentiful capacity, which historically have been the major competitive drivers in DRAMs.

With all the uncertainty surrounding it, the 4Mb DRAM promises to be a turning point in DRAM history. Dataquest believes that manufacturers and users alike will need to take a closer look at their plans to adequately prepare for the changes that the future may bring.

Victor de Dios
Bart Ladd

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Research *Bulletin*

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AGGRESSIVE START-UPS SPAWN NEW COMPANIES

Many believe that start-up companies serve only one purpose—to be acquired. However, some of the recently formed start-ups are actively making acquisitions and spawning new start-ups. This newsletter describes the acquisitions and equity investments by these aggressive new companies. The information is based on research contained in a new Dataquest directory entitled Decade of Semiconductor Companies—1988 Edition.

Significantly, start-up companies have spawned six enterprises, five of them semiconductor companies. They are Aspen Semiconductor Corporation, G-2 Incorporated, Inter-Act Corporation, Multichip Technology Incorporated, Nihon Semiconductor Corporation, and Chartered Semiconductor Corporation. Cypress Semiconductor provided first-round financing for two of the new companies—Aspen Semiconductor and Multichip Technology. Aspen Semiconductor will develop and market ultrahigh-speed ECL ICs, and Multichip Technology will manufacture high-density memory modules using surface-mount packaging technology. Inter-Act, in which LSI Logic has a 66 percent interest, will develop and market an integrated software and hardware development system for the MIL-STD-1750 embedded system marketplace. The complete list of equity investments is shown in Table 1.

Table 1

New Company Formations/Equity Investments by Start-Up Companies

Investor Company	Invested Company	Year of Investment
Cypress Semiconductor	Aspen Semiconductor (100%)	1987
Cypress Semiconductor	Multichip Technology (100%)	1988
LSI Logic	G-2 Incorporated (100%)	1987
LSI Logic	STC (semi. div.) (>50%)	1984
LSI Logic	Nihon LSI Logic K.K. (100%)	1984
LSI Logic	Nihon Semiconductor (55%)	1985
LSI Logic	LSI Logic (Canada)	1987
LSI Logic	Video Seven (20%)	1987
LSI Logic	Master Images (20%)	1986
LSI Logic	Inter-Act Corporation (66%)	1987
Micron Technology	Barvon Research (16%)	1985
Micron Technology	Standard Microsystems	1988
Sierra Semiconductor	Chartered Semiconductor (17%)	1987

Source: Dataquest
June 1988

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Start-ups also have acquired 12 companies, as shown in Table 2. California Micro Devices (CMD) has been most active, acquiring Micro Innovators in 1983, merging Custom MOS Arrays in 1986, and acquiring the GTE Microcircuits Division in 1987. The acquisition of GTE Microcircuits adds new microcomponent and telecom IC products to CMD's existing thin film and ASIC capability.

In contrast, 13 start-ups have been acquired as listed in Table 3.

Table 2

Acquisitions by Start-Ups

Start-Up Company	Acquired Company	Year Acquired
Acrian	Communication Transistor	1982
Austek	Silicon Macrosystems	1986
Brooktree	Manx Engineering	1987
California Micro Devices	Micro Innovators	1983
California Micro Devices	Custom MOS Arrays	1986
California Micro Devices	GTE Microcircuits	1987
Calmos Systems	Siltronics (bipolar IC line)	1988
European Silicon Structures	Lattice Logic	1987
European Silicon Structures	Best	1987
MemTech	Materials Progress (crystal div.)	1987
Microwave Technology	Monolithic Microsystems	1987
VLSI Technology	Visic	1986

Table 3

Start-Ups That Have Been Acquired/Merged

Start-Up Company (Date Formed)	Acquired By	Year Acquired
Array Technology (1982)	Imperial Chemical Industries	1986
Custom MOS Arrays (1982)	California Micro Devices	1986
Exel Microelectronics (1983)	Exar Integrated Circuits	1986
Inmos (1987)	Thorn EMI	1984
Spectrum Microchip (Insouth)	Fairchild Communications	1983
Integ. Power Semiconductor (1984)	Seagate Technology	1987
Panatech Semiconductor (1981)	Ricoh	1987
Signal Processor (1981)	Analog Devices	1983
Silicon Macrosystems (1984)	Austek Microsystems	1986
Vatic (1983)	Thomson-Mostek	1986
Visic (1983)	VLSI Technology	1986
VTC (1984)	Control Data Corporation	1987
ZyMOS (1978)	Daewoo Corporation	1986

Source: Dataquest
June 1988

DATAQUEST CONCLUSIONS

Start-ups are not the easy pickings for long-established companies that some believe. The acquisitions and equity investments by these aggressive young companies serve a variety of purposes, including expansion of product and marketing horizons. These are a few of the ways start-ups are adding the muscle needed to compete in worldwide markets. More and more, start-ups are becoming companies to watch out for!

Penny Sur

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Research *Bulletin*

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WHO WILL WIN THE ASIC BUSINESS?

Two fascinating questions were asked to the panel members during a panel session at the Custom Integrated Circuit Conference (CICC) in Rochester, New York, on May 18: (1) Who will win the ASIC business? and (2) What factors will determine the winners? The panel consisted of: Wayne Spence from Texas Instruments, Tom Reynolds from Sierra Semiconductor, David Sear from Fujitsu, Rick Rasmussen from LSI Logic, Dick Jacobs from AT&T, Doug Fairbairn from VLSI Technology, and Jack Carsten (formerly the head of Intel's ASIC group) from U.S. Venture Partners.

The panel session quickly turned into a debate that contrasted the assets and liabilities of large, traditional standard products suppliers that have entered the ASIC business and the key attributes of the focused ASIC suppliers. The consensus was that integrated CAD tools are the number-one ingredients for success. Supplier strategies were discussed, including one-stop shopping, product differentiation, and alliances.

TRADITIONAL VERSUS FOCUSED ASIC SUPPLIERS

The large, traditional semiconductor suppliers started the session by pointing out their assets: deep pockets, marketing infrastructure, access to leading-edge technology and manufacturing, and, above all, their large standard product offerings, which can be converted into cell libraries. The focused ASIC suppliers were quick to point out the liabilities of the traditional suppliers: rigid procedures, poor integration of CAD and silicon, fab allocation issues, conflicts between standard product divisions and ASIC divisions, and the many problems associated with converting the standard products into a common process for the library.

The focused ASIC suppliers felt that they would win the ASIC business because they possess the following attributes: high integration of CAD and silicon, the ability to react quickly to market changes, a focus on service, and a long track record in low-volume production manufacturing. Their major liability was stated to be cash flow, as it is hard for these suppliers with smaller budgets to outrun the giants.

Major Success Factors

Almost all the panelists agreed that the winners will be separated from the losers by how they handle the following issues:

- CAD tools
- Libraries
- Service
- Manufacturing
- Packaging
- Test

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Comprehensive, user-friendly CAD tools were stated as the most important ingredients in the ASIC business, because without them, it does not matter what else the supplier has. The next important ingredients are rich, dedicated libraries focused on end-use applications (communications, data processing, etc.). Service, as defined by one of the panelists, means short cycle times, quality, reliability, and personal involvement with each customer by providing weekly updates. Manufacturing was ranked fourth by many on the panel, because they can buy outside manufacturing in the form of foundry services. Test and packaging require major investments and have become the battlegrounds that determine the winners in the high-complexity market (greater than 20,000 gates).

Strategies

Based on observations of Dataquest analysts and CICC panel members, a wide variety of penetration strategies is chosen by suppliers, depending on their size, strengths, and financial resources.

Most of the traditional semiconductor suppliers are offering one-stop shopping to their customers. One-stop shopping means providing a full range of technologies, ASIC products, and standard products for their customers. This strategy requires very deep pockets.

Product differentiation is a common strategy for small suppliers. This means not trying to do everything for everyone, but rather, focusing on niche markets with targeted products. One panel member stated that while this strategy may require only a minimum investment, it can be risky, because a large supplier may enter the market and squash the small supplier "like a giant stepping on an ant."

Forming alliances has become critical for ASIC suppliers to cope with the high investment costs required in process technology, manufacturing, test, and packaging.

DATAQUEST CONCLUSIONS

Dataquest believes that the early ASIC leaders, as well as the patient, broad-based traditional semiconductor suppliers, will dominate the market. We estimate that in excess of 75 percent of the 1992 worldwide ASIC market will be owned by 10 suppliers. The winners will have made major investments or formed alliances for integrated CAD tools, libraries, manufacturing, test, and packaging. Providing outstanding service is extremely important. Other requirements for being a top-10 ASIC supplier are success in economies-of-scale manufacturing and a worldwide presence. Dataquest advises the small suppliers to avoid the mainstream and focus on providing system solutions (libraries and system design expertise) to defined end-user markets where they can bring something to the market that the large suppliers do not have. Each supplier must decide which role to play: to be a major supplier or to become a niche supplier. Each role requires a completely different set of resources, strategies, and technologies.

Bryan Lewis

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Research *Newsletter*

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PLDs: HAPPY DAYS ARE HERE AGAIN!!

A RED–HOT 1987!

Last year was a banner year for programmable logic devices (PLDs). Total PLD shipments in 1987 amounted to $441.7 million. Between 1986 and 1987, the PLD market grew by a sizzling $134.5 million, a whopping 43.8 percent increase over 1986 shipments. This comes on the heels of a not–so–shabby $71.9 million, or 30.6 percent, increase in 1986. And if that is not enough, Dataquest projects that 1988, in true semiconductor feast–or–famine tradition, will be an even better year than 1987. In 1988, Dataquest expects total PLD shipments to soar to $707.4 million, which represents an impressive 60.2 percent increase ($265.7 million) over 1987 revenue. As recently as 1985, the total PLD market was $235.3 million. So, what is fueling this red–hot PLD activity? Figure 1 gives a historical perspective of the driving forces behind PLDs, and the following events show the vitality of this market:

- Faster microprocessors demand faster PLDs. With blazing–fast 20–MHz 68020s and 80386s being designed into PS/2s, workstations, instruments, printers, etc., high–performance PLDs are suddenly in demand almost everywhere to speed up support logic. Fast microprocessors require fast support logic; otherwise, all that CPU crunching power is wasted. From all accounts, the computer segment is leading the charge on PLDs.

- In 1987, CMOS revenue doubled to $73.8 million. From a barely perceptible 4.3 percent market share in 1985, CMOS now accounts for 16.7 percent of the market. Of this, EPLDs account for 11.5 percent; EEPLDs, 2.7 percent; and SRAMs, 2.4 percent. High–performance, low–power CMOS PLDs have opened up new markets in telecom, laptop computers, and consumer electronics, markets that were previously not within the domain of PLDs.

- The logic cell array (LCA) device from Xilinx took off in a big way in 1987. From essentially zero revenue in 1986, total LCA revenue jumped to $11 million in 1987. With its flexible architecture, low power consumption, and reconfigurability, the device is ideal for prototyping new designs. Because any pin on the device can be an input or output pin, this device is a distinct departure from traditional PLD architectures that typically are limited in the number of input and output pins.

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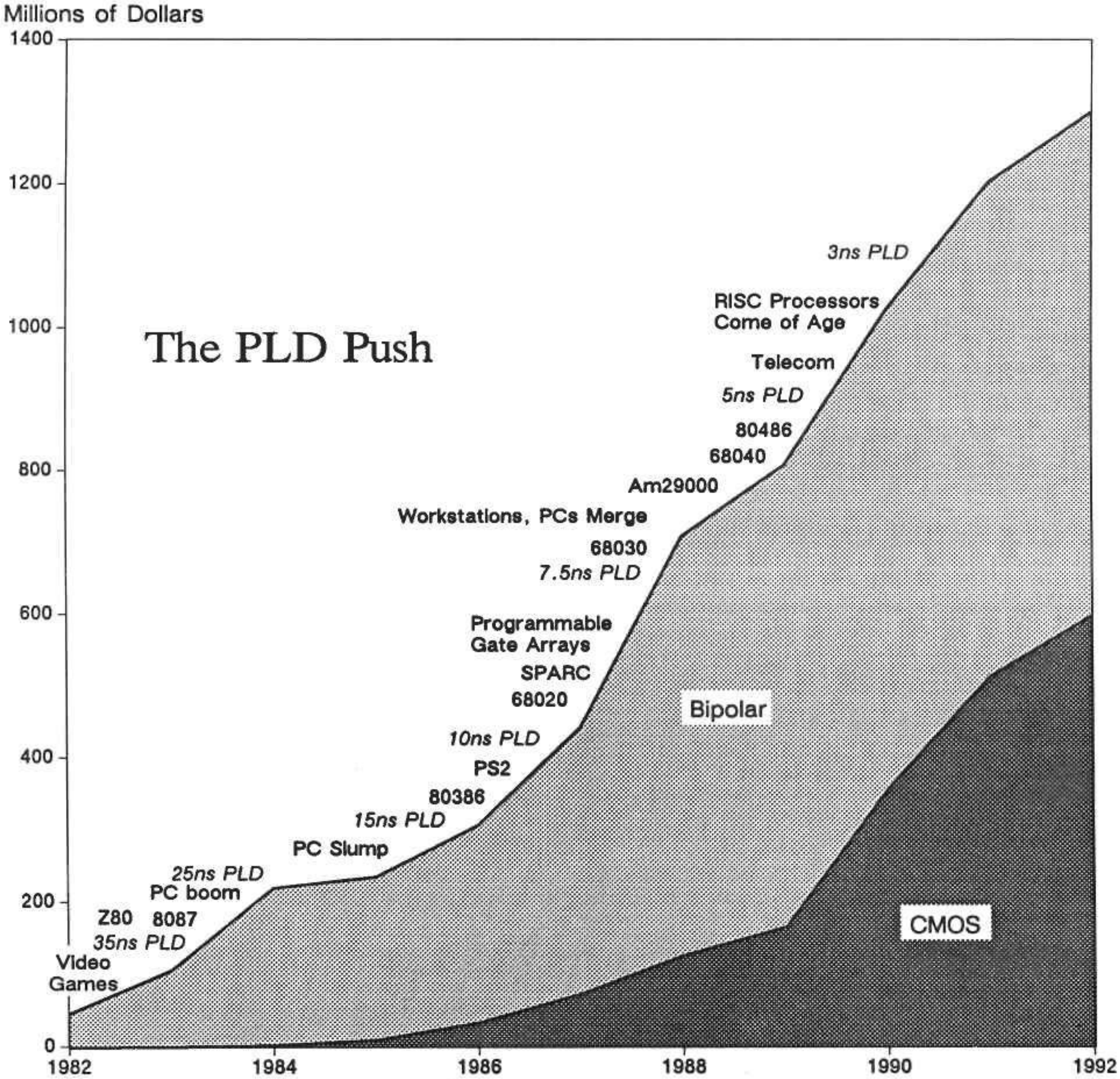
- With product life cycles shortening unrelentlessly, systems designers must live with compressed design cycles that allow them only one or two iterations to fix any design errors that they subsequently uncover. Today's turnaround times for gate array or cell-based designs are excellent, but still not good enough for these designers. For them, PLDs take the risk out of a "RISC-ky" or "RISC-less" design.

Figure 1

A Historical Perspective on PLDs (Millions of Dollars)



Source: Dataquest April 1988

WHO'S HOT, WHO'S NOT

The Bipolar Folks

In a memorable year marked by crashing stock markets and earth-shattering revelations by defrocked ministers, the PLD world in 1987 had its share of upheavals. Most notably, the stunning acquisition of MMI by AMD must stand out as the PLD event of the year. The acquisition of Fairchild by National is also noteworthy, but its impact on the PLD market is limited. The AMD/MMI union results in a behemoth that controls 53.9 percent of the market, down slightly from the 56.0 percent that the two controlled in 1986.

Looking at the union with a jaundiced eye and with the benefit of a bit of hindsight, with the PLD market sizzling, one wonders whether MMI might have been the acquirer instead of the acquiree, had the acquisition not taken place for another year. Be that as it may, the marriage has produced some benefits: the MMI subsidiary should benefit from AMD's strength in process technology and state-of-the-art fab facilities, while MMI can offer AMD PLD folks some lessons in how to compete in the PLD arena. The more than $100 million dowry from MMI probably did not hurt either.

TI turned in a stellar performance for 1987, essentially doubling its revenue for the year. Much of the increase is due to 10ns PLD business that TI captured due to a manufacturing hiccup MMI suffered in midyear.

Total 1987 PLD revenue for Signetics dropped slightly. Recognizing its dependence on bipolar technology, the company is slowly shifting over to CMOS as the technology of choice. In particular, its FPLS family is vulnerable to CMOS look-alikes from the competition.

The CMOS Folks

Lattice Semiconductor rose like a phoenix from the ashes of bankruptcy in 1987. Along the way, it entered into marriages of convenience with MMI, National, Gould, and SGS/Thomson, licensing to them the EEPLD technology that is its bread and butter. We also expect the number of EEPLD suppliers to expand in 1988 with entry of International CMOS Technology and Gould.

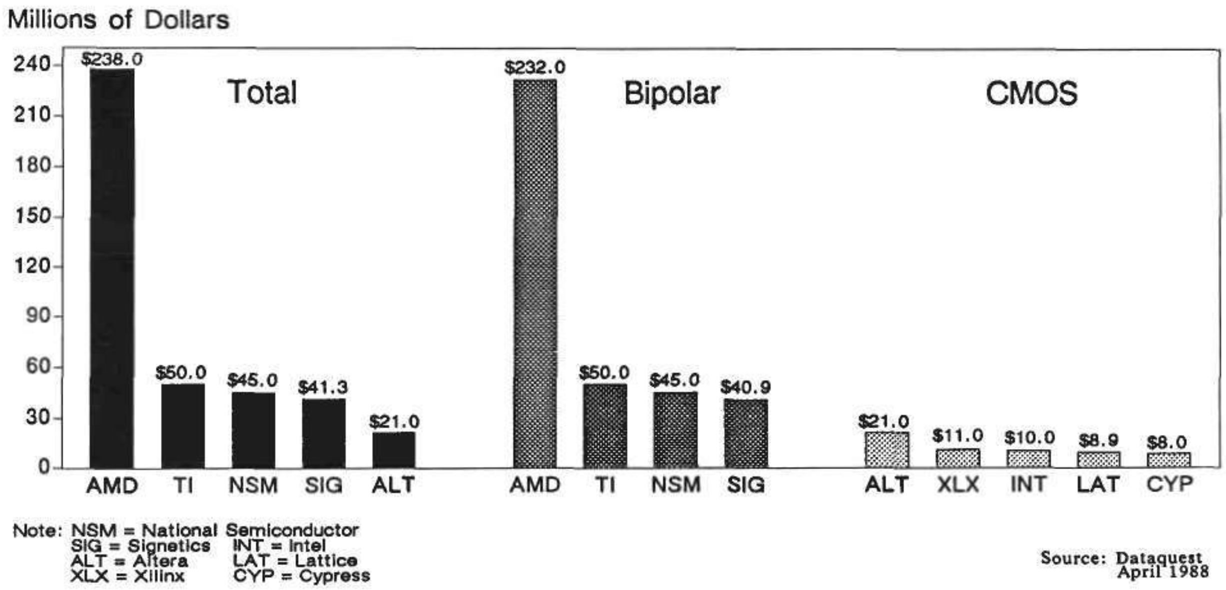
In 1987, Altera, Cypress, and Intel all benefited from their technological leadership in CMOS. If it can put its financial troubles to rest, Lattice is poised to make a very strong comeback. In their performance, Lattice's EE products effectively compete almost lockstep with high-performance bipolar offerings.

WHO'S NUMBER ONE?

AMD/MMI is number one, with a commanding 53.9 percent market share. Its next three rivals, TI (11.3 percent), National (10.2 percent), and Signetics (9.3 percent) are not even close. Altera is a distant fourth, with only 4.8 percent of the market (see Figure 2).

Figure 2

Estimated PLD Market Share
(Millions of Dollars)



For bipolar PLDs, AMD/MMI's dominance is even more imposing—63.0 percent. TI is number two, followed by National and Signetics. Interestingly, in the CMOS realm, not only is there no dominant supplier, but also a different set of players. In the ranking sweepstakes, the order is Altera (28.5 percent), Xilinx (14.9 percent), Intel (13.6 percent), Lattice (12.1 percent), and Cypress (10.8 percent).

PLD FORECAST

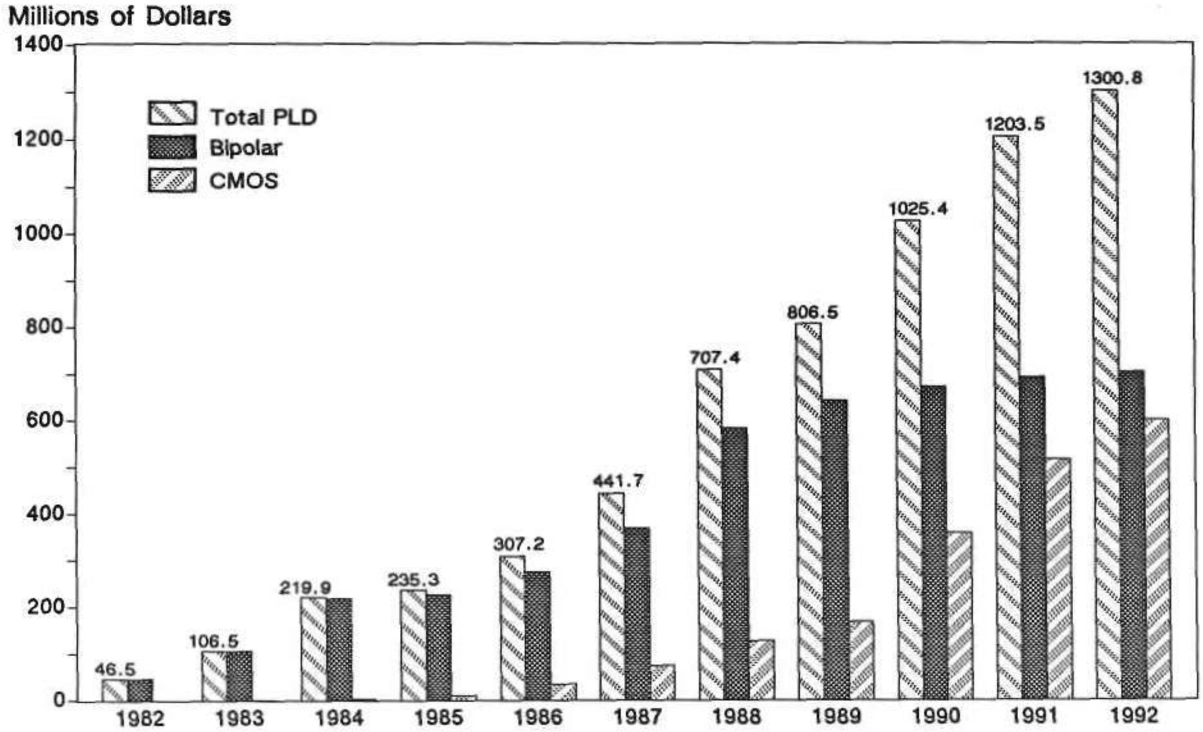
Dataquest projects that the PLD market will grow to $1.3 billion by 1992 at a compound annual growth rate (CAGR) of 25.9 percent. We believe that there will be strong growth for bipolar PLDs but that the growth for CMOS will even be stronger. Figure 3 provides details of the five-year forecast, and Figure 4 gives a geographical breakdown of 1987 consumption.

Dataquest believes the market is dividing into three segments:

- High-performance PLDs
- Low-power PLDs
- Low-cost PLDs

Figure 3

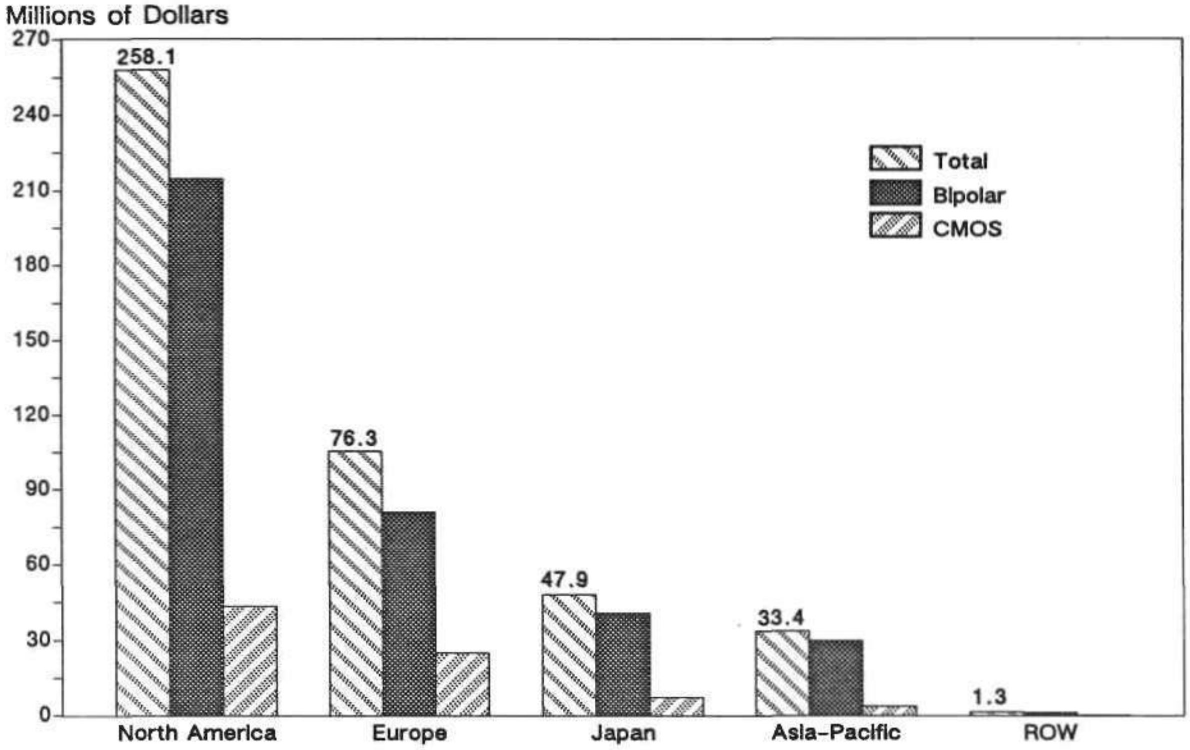
PLD Five-Year History and Forecast (Millions of Dollars)



Source: Dataquest April 1988

Figure 4

Estimated 1987 PLD Consumption by Region
(Millions of Dollars)



Source: Dataquest
April 1988

High-Performance PLDs

Bipolar is not dead. Reports of its demise are greatly exaggerated. Indeed, AMD/MMI is reportedly sampling 7.5ns TTL PLDs already, and circuit simulations on their oxide-isolated process indicate that a 5.0ns device is feasible. Moreover, in the next year, Dataquest expects propagation delays for ECL PLDs to drop to 3.0ns from the current 6.0ns. To keep things in perspective, advances in line geometries that benefit CMOS also benefit bipolar devices.

As minisupercomputers impinge upon the workstation world, and as workstations impinge upon the PC world, the battle over mips, Whetstones, and LINPACKs will intensify. Performance plus time-to-market pressures will force systems houses to look to PLDs as the solution to their design problems. These considerations will fuel the growth of high-performance PLDs through the rest of the '80s.

Low-Power PLDs

CMOS PLD performance lies on the outer fringes of high-performance bipolar PLDs. However, miserly, low-power CMOS opens up applications markets not previously available to PLDs before. Already, the announcement of 9,000-gate LCAs from Xilinx has stirred considerable interest in the engineering community, and the recently announced part from Actel has peaked interest. Nonetheless, PLD users are still looking for the Holy Grail of PLDs: a true programmable gate array. Such a device would have 2,000 to 15,000 gates, be low power and easy to use, have fast propagation delays, be flexible, and, most importantly, low cost. Dataquest believes that CMOS will eventually account for close to half of all PLD shipments.

Low-Cost PLDs

Older PLDs, in the 25ns to 35ns category, are fast becoming the commodity segment of the market. Prices for such PLDs dropped below $1.00 in 1987. At such prices, PLDs are starting to cannibalize the standard logic market. Also, MMI has spread the PLD gospel far and wide to the point where several community colleges now teach PLD design techniques to their electronics classes. Today, it may be easier to design with a PLD rather than a standard logic part. The designer needs to stock fewer parts and needs fewer data books.

WHAT LIES AHEAD

Emerging Technologies

Expect more programmable gate array offerings. This is a market opportunity too obvious to ignore. Two problems need to be addressed:

- How to make the design tools low-cost and easy to use
- How to make a low-cost, high-performance product that is price-performance competitive with gate arrays

PLDs are the offspring of PROMs. Any technology advance in memory devices eventually trickles down to PLDs. The "flash" EEPROM cell is one development that may promise faster, smaller, and cheaper PLD devices. Now that technology has reached the shores of PLD-land, any technological advances that result in smaller EEPROMs should also result in smaller PLDs.

Increased Competition

With PLDs well on their way to becoming a billion dollar market, the question is whether or not the PLD market will go the way of the PROM market. It is also too lucrative a market for foreign semiconductor vendors to ignore. Japanese companies certainly have fusible link technology and, through technology exchange agreements, so do the Koreans. In looking at the roster of PLD suppliers, the foreign semiconductor companies are conspicuous by their absence.

Application-Specific PLDs

Traditionally, a PLD is characterized by the existence of an AND-OR matrix within the device. Altera's EP family, Intel's 5AC312, and Excel's ERASIC device are essentially variations on a theme. As PLD vendors struggle to differentiate their offerings from those of their competitors, they are defining products that are optimized and targeted for a specific application. These are devices such as BUSTER (Altera), 5CBIC (Intel), and PLX300 (PLX) for bus interfaces; PROSE (AMD/MMI) and SAM (Altera) for sequencing; and, EPB2001 (Altera) for IBM PS/2 microchannel interfaces. The activity in this area will increase.

DATAQUEST CONCLUSIONS

In 1987, the PLD industry was robust. Moreover, the outlook for 1988 is rosier than it has ever been before. For PLD vendors, the products are in place; the capacity is in place, and the demand is out there. If the DRAM shortage does not bring systems houses to their knees, the only thing that PLD vendors have to do is go home and count the money.

C.B. Lee
Andy Prophet

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Research Newsletter

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DATAQUEST DSP OPINION: CONDITIONS FOR SURVIVAL IN THE GENERAL-PURPOSE DSP MARKETPLACE

SUMMARY

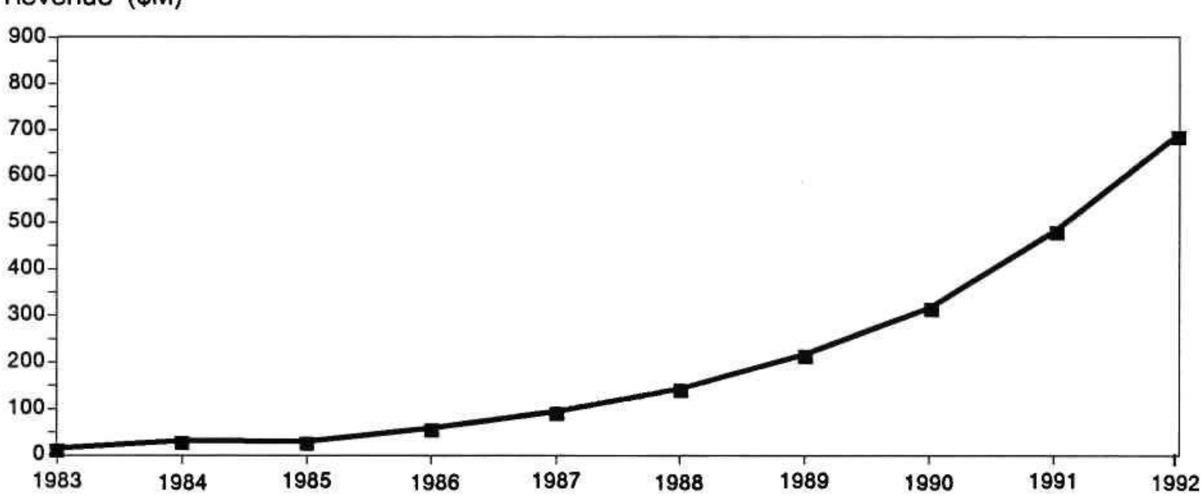
The digital signal processing (DSP) marketplace is partitioned by Dataquest into the following four different integrated circuit product areas:

- General-purpose DSP microprocessors (DSMPUs)
- Microprogrammable DSP (MPDSP)
- Special-function DSP (SFDSP)
- Application-specific DSP (ASDSP)

Certainly the most visible of these product categories through the middle portion of the 1980s has been DSMPUs. Revenue has blossomed from roughly $18 million in 1983 to nearly $100 million in 1987, as shown in Figure 1. Dataquest expects DSMPU revenue to accelerate rapidly past revenue for the relatively flat MPDSP market during calendar year 1989. DSMPU revenue growth is expected to slow only minimally to about 47 percent from the 53 percent compounded growth it experienced from 1983 through 1987.

Figure 1

Historical and Anticipated Revenue Growth for DSP Microprocessors from 1983 through 1992



Source: Dataquest
August 1988

Although such growth potential presents many opportunities for new entrants to service this market, there are also plenty of risks involved. The remainder of this newsletter examines some of the issues important to the market success of general-purpose DSP microprocessor architectures.

STATE OF THE ART

A minimum of 13 different manufacturers have introduced families of proprietary DSMPU architectures. Although each processor family has architectural characteristics that certainly help distinguish it from competitive products, these features often introduce incremental advantages to designers of DSP systems. Illustrating this point, three key DSP benchmarks are shown in Table 1 for four of the new floating-point DSP processors introduced recently by AT&T, Motorola, Texas Instruments, and Zoran.

Table 1

Comparative Benchmarks for Four Recently Introduced DSP Microprocessors*

Company	FIR Filter (per tap)	IIR Filter (2nd-order biquad)	1K Complex FFT (radix-2 with bit reversal)
AT&T DSP-32C	80ns	400ns	3.2ms
Motorola 96000	75ns	375ns	2.45ms
TI TMS320C30	60ns	360ns	4.12ms
Zoran ZR34325	80ns	400ns	1.7ms

*Performance benchmarks obtained from manufacturers

Source: Dataquest
August 1988

As observed, the benchmarks indicating device performance are reasonably similar. Of course, additional subtleties introduced by the architectures will affect other signal processing operations. Generally, however, each of these processors can be used effectively to solve a wide range of problems.

NECESSARY (BUT NOT NECESSARILY SUFFICIENT) CONDITIONS FOR SUCCESS

Dataquest believes that the long-term success of these architectures ultimately will be determined by the product support provided by the manufacturer to the customer. Support in this case refers to:

- Training, education, and applications assistance
- Hardware and software development tools including simulators, assemblers, compilers, and emulators
- Software libraries

DSP microprocessors require an even larger investment in customer development assistance than do conventional microprocessors.

Training and Education

The required base knowledge by designers of DSP systems is quite high. The traditional skill of microprocessor system design is essential, coupled with a knowledge of digital signal processing theory, hardware, and software design techniques. The number of designers possessing both backgrounds is relatively few. In order for semiconductor companies to be successful in propagating and expanding their digital signal processing products, they must help provide the appropriate training and education for their customers.

Development Tools

As the architectures of many DSP products on the market are maturing, designers of DSP systems are demanding more sophisticated hardware and software development tools. These tools, analogous to those available for traditional microprocessor systems, include C compilers and hardware emulators. DSP algorithm purists rightfully claim that compilers generate less efficient code than can be generated by hand coding coupled with an assembler. However, as the complexity of the software effort for DSP systems increases, the traditional reasons for using high-level languages becomes ever more important for DSP systems.

Additional tools also are important for DSP systems including software simulators and development boards. These tools allow designers of DSP systems to develop and debug many of their software algorithms prior to actually building a piece of hardware.

Software Libraries

DSP systems often require lengthy hardware and software development cycles. However, shared by many systems are a few "key" DSP algorithms that are easily identified, such as fast Fourier transforms, finite-impulse response, and infinite-impulse response filters. Manufacturers can greatly aid the software effort of their customers by publishing "standard" DSP algorithm code in readily available libraries. Observing the large amount of software available for Texas Instruments DSP processors provide testimonial to the importance of libraries.

As happened in the microprocessor marketplace in the early 1980s, and for similar reasons, Dataquest expects the number of true winners in the DSMPU marketplace—as judged by unit and revenue growth—to be limited to three or four. Other minor players may exist but will be limited largely to specialty applications on the fringes of the mainstream DSMPU marketplace.

The fallout in suppliers to the DSMPU market already has begun to occur. Probably the most notable has been National Semiconductor's exit from the market in 1987. Zoran Corporation has not exited the DSP business, but it is refocusing its strategy after never having achieved the revenue growth expected after its visible market entry in 1986.

DATAQUEST CONCLUSIONS

It is important for DSMPU manufacturers to remember that a product is not simply a device, such as a DSP processor, but rather a complete package purchased by the customer. This package includes tangibles such as the device, development tools, software libraries, and applications assistance; it also includes intangibles such as the reputation and stability of the manufacturer.

Dataquest expects the fallout among general-purpose DSP microprocessor manufacturers to accelerate over the next two years. Adoption and implementation of the stated support requirements are not sufficient to guarantee success; they are necessary conditions for manufacturers to be considered among the contenders for success.

David M. Taylor

Dataquest
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Research Newsletter

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THE FINAL FRONTIER IN VOICEBAND MODEMS

SUMMARY

Fueled by advances in semiconductor digital signal processing (DSP) architectures, the final frontier in voiceband modems is now beginning to unfold. This frontier provides transmission rates of 9,600 bits per second (bps) over the standard switched telephone network. The 9,600-bps transmission rate approaches the theoretical maximum information rate achievable over the limited bandwidth of the telephone network, effectively prohibiting significantly higher modem data rates. Higher transmission rates eventually will occur, but are most likely to use future digital networks such as the Integrated Services Digital Network (ISDN).

Transmission speeds of switched-network modems have evolved rapidly in the last ten years, moving from the primitive acoustically coupled 300-bps modem boxes that dominated the market through the 1970s, to the sophisticated direct-connect 9,600-bps modems now beginning to appear. It is interesting to note that the "bits-per-second" rating for modem transmission speed has roughly doubled every two years, nearly keeping pace with the more widely watched indicator representing the increase in capacity of dynamic random-access memory (DRAM) chips.

A number of incompatible techniques currently exist for 9,600-bps modem transmission over the switched telephone network. This problem is often encountered when new, higher-speed modems are introduced. Clearly the leading contender to ultimately dominate the personal computer marketplace at 9,600 bps is the V.32, which was defined by the Consultative Committee for International Telephony and Telegraphy (CCITT).

BACKGROUND

Modem technology has evolved swiftly since the Federal Communications Commission (FCC) ruled in 1978 that any manufacturer could apply for registration to connect its communications equipment directly to the telephone network. Until that time, acoustically coupled 300-bps Bell 103 modems dominated the market for more than 20 years. After this important FCC decision, 1,200-bps Bell 212A modems requiring direct connection began to gain in popularity.

Beginning in 1982, a number of major semiconductor companies (including Advanced Micro Devices, Motorola, National Semiconductor, and Texas Instruments) began supplying single-chip 300-bps modems. Most design approaches at that time relied on an integrated analog design combined with switched capacitor filter technology. AMD was a leading innovator by building a true digital signal processing architecture that included both analog-to-digital and digital-to-analog converters on its chip, all optimized to solve the modem function.

These new devices significantly drove down prices of low-speed box modems, giving additional life (albeit short) to the low-speed modem market. These same devices also allowed for the birth of the embedded personal computer modem.

The semiconductor content of 1,200-bps Bell 212A modems evolved a bit differently. Many of the same semiconductor companies that competed in the 300-bps marketplace also introduced single-chip Bell 212A modems beginning in 1984. However, the early 1980s also saw the introduction of the first single-chip digital signal processors. Texas Instruments ultimately abandoned its single-chip Bell 212A modem in favor of implementing the modem function on its general-purpose TMS32010 DSP microprocessor. Thus began the trend that is still important in today's higher-speed modem technology. Modems that operate at 2,400 bps (and higher speeds) require digital signal processing approaches to implement sophisticated functions such as adaptive equalizers (to correct for telephone line distortions) and echo cancelers. In fact, the modem marketplace is still the single largest consumer of DSP microprocessors.

To have broad appeal, high-speed modems must also support the popular slower standards: V.22bis at 2,400 bps, Bell 212A at 1,200 bps, and Bell 103 at 300 bps. This is cost-effectively implemented in firmware on a DSP microprocessor. The interest in modems that support multiple standards extends both to leased-lines that have dial-up standards as a backup and to fax modem standards for the electronic office.

At least nine manufacturers currently supply 2,400-bps V.22bis chip sets. Interestingly enough, only one of these chip sets—the K224 from Silicon Systems, Inc.—is a single-chip solution combining all of the analog and digital processing on one device. The K224 is currently being sampled. The other chip sets are built around ROM-coded, DSP microprocessors. TI's DSP2400 uses a TMS32011, Telebit's T24 uses a TMS320C10, and VLSI Technology's chip set uses an ASIC version of Intel's 8096. Silicon Systems also has a chip-set (2404) solution using a ROM-coded version of the NEC 7720. Competition here is pushing prices down to $25 in quantities of 10,000 for a chip-set solution. This is within $10 of a 1,200-bps, Bell 212A solution.

To complete the modem chip set (except for the SSI K224 product) an additional one to three parts are necessary to implement the front-end and back-end analog processing. TI adds a preprogrammed TMS7042 plus two analog front-end chips (a 29C19 codec plus an SC11005 filter) to the TMS32011. Telebit adds a preprogrammed 80C51 and an Oki analog front-end chip (the 6950B). VLSI Technology adds its own analog part (the VL7C224A). Silicon Systems adds its own 73M214 front end to the 2404.

DATAQUEST ANALYSIS OF 9,600-bps MODEMS

The 9,600-bps marketplace is currently dominated by modems obeying the CCITT V.29 half-duplex specification. The original V.29 modems were used on leased telephone lines, but more recently have been used on the switched network as well. The largest application for this modem is in facsimile machines where the bulk of the data transmission is unidirectional. Dataquest estimates that the total number of 9,600-bps modems shipped in 1987 was about 3 million, with approximately 80 percent of these in fax machines. Only about 1 percent of the total shipments were dial-up modems. The remaining modems were used in 4-wire and other dedicated applications.

The requirements of personal computer users, though, differ from those of dedicated fax machine users. Personal computer users require bidirectional data transmission, although not necessarily simultaneously. This characteristic implies that a simpler half-duplex modem is really all that PC users require.

However, Dataquest believes that history will again repeat itself as it did in the early 1980s when the full-duplex Bell 212A modem gained nearly exclusive market dominance over the less-expensive, half-duplex Bell 202 modems for personal computer applications. Dataquest expects the more-complicated CCITT V.32 modem specification to win easily in the 9,600-bps personal computer marketplace over simpler rival modem specifications. The reasons for this are as follows:

- The CCITT V.32 9,600-bps modem specification has been ratified internationally.
- The availability of low-cost V.32 chip-sets can and will impose standards.
- Full-duplex data transmission protocols between modems are easier to implement (and standardize) than the line-turnaround required for half-duplex transmission.
- Most incompatible V.32 modems will talk only with identical modems from the same manufacturer.

It is important to understand, though, that alternative 9,600-bps modem standards (primarily V.29) will not disappear. They will remain important for specific applications because of their inherently simpler operation and lower cost. However, their future growth rate is expected to be much lower than that of V.32 modems.

CCITT V.32 Modem Specification

Implementation requirements for the CCITT V.32 modem specification are certainly the most sophisticated yet to be introduced for telephony modems. It allows 9,600-bps full-duplex transmission over the switched telephone network. The entire telephone bandwidth is used simultaneously for both the transmit and receive channels. This differs from all other full-duplex modems, which use a frequency-division technique; i.e., the transmit and receive channels split the available 3-kHz bandwidth in half, so there is (in theory) no interference between channels.

In order for V.32 modems to use the entire telephone bandwidth simultaneously for both transmission and reception, they employ echo cancelers in the receiver to eliminate:

- The crosstalk caused by the local transmitter
- The far-end echo caused by impedance mismatches in the telephone network

Also used is a sophisticated data-encoding technique called trellis coding, which embeds error correction capability in the modulation. Trellis-coding techniques provide an approximate 3dB signal-to-noise (SNR) performance improvement. It is the incorporation of the echo-canceling and trellis-coding techniques that make building V.32 modems more expensive.

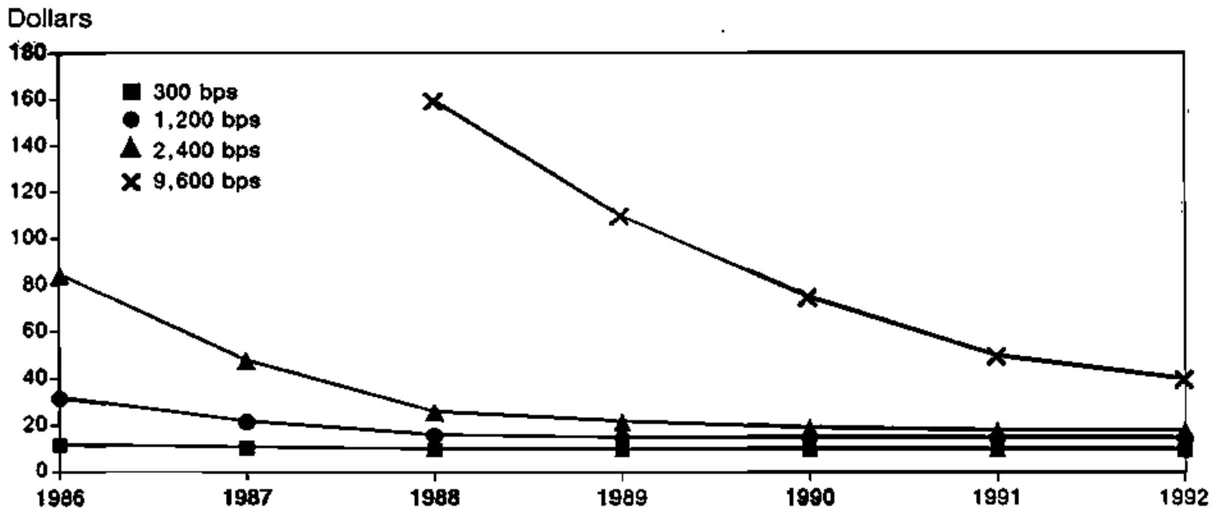
V.32 Chip Sets

V.32 chip sets that are low enough in cost to allow 9,600-bps modems to compete in the personal computer market will appear beginning in 1988. The most competitive of these will comprise two $15 to $25 DSP microprocessors, one $6 to $10 analog front end, a $4 to $15 single-chip microcontroller, and $5 to $8 worth of static RAM. These sets will cause retail prices of 9,600-bps modems to drop precipitously from their current range of $1,500 to $1,800, to less than $300 by 1992 for plug-in modem cards--the price of current 2,400-bps modems. Currently, the major semiconductor companies that have announced products for the V.32 modem marketplace include Rockwell and SGS/Thomson. A third company, Phylon Communications, while not a semiconductor company, has announced a V.32 modem module, which is expected to directly compete with the chip-set solutions being introduced by semiconductor companies.

Figure 1 illustrates the historical and projected future pricing of modem chip sets (in volume) versus time for four different transmission rates. In this case, the chip set refers only to the data pump; e.g., the specific modem function. Not included are costs of the telephone line interface nor intelligent-modem features such as auto-dialing. Note that the dramatic decline in projected prices for 9,600-bps chip sets between 1988 and 1992 follows a trend similar to the one expected for V.22bis modems between 1986 and 1990.

Figure 1

Volume Selling Prices of Modem Data Pump Chip Sets



Source: Dataquest June 1988

Rockwell

Rockwell is the major high-speed manufacturer of modem chip sets. It was the first company to offer a 2,400-bps V.22bis chip set: the R2424. Rockwell advertises that it has shipped over 1 million V.22bis sets. Dataquest estimates that Rockwell controls nearly 50 percent of this market. Dataquest also estimates that Rockwell chip sets are being used in approximately 90 percent of the V.29 modems in production.

In 1987, Rockwell introduced the R9696DP, a V.32 module solution. It is the only V.32 solution currently available to OEMs, although shipments to date have been relatively small. The R9696DP consists of five processor chips—three proprietary DSP microprocessors, a DSP echo canceler chip, and an analog front end chip—all on a 12-square-inch board. Initially, Rockwell should do well selling this board to high-end modem manufacturers, who will add value such as "intelligent" features to the module. Its current price of $350 in quantities of 1,000 is expected to spur growth for the PC marketplace. Dataquest expects this price to drop as competition increases.

SGS/Thomson

SGS/Thomson's first V.32 offering will be a six-chip set, to be priced at $150 in quantities of 10,000. It consists of three of SGS/Thomson's 68930 DSP microprocessors (one for transmission, one for reception, one for echo canceling), two analog front-end ICs, and a clock generator. In May, SGS/Thomson released the chip set, which uses external ROMs. Samples of its internally ROM-coded devices are scheduled for the fourth quarter of 1988. A CMOS version of its DSP microprocessor is expected to be available in the third quarter. Porting the modem firmware to the CMOS parts should follow by October. SGS/Thomson will also sell its echo canceler chip and analog front ends individually.

Phylon Communications

Also of significance is a new product from Phylon Communications, of Santa Clara, California. The PHY-96 is a V.32 modem module designed as a direct functional, physical, and electrical replacement for the Rockwell V.32 module. It reportedly goes beyond Rockwell's capabilities by also including V.22bis, Bell 212A, V.22, Bell 103, and V.21 modem standards as part of the module. The module uses two DSP microprocessors plus a two-chip analog front end to implement all of the modem signal processing operations. Phylon expects to begin production shipments in the third quarter of 1988.

Other 9,600-bps Standards: The Electronic Tower of Babel

A number of box modem manufacturers are promoting their own 9,600 bps (and higher) standards, most of which are incompatible with the others. Some of them may even be technically superior to the V.32 although this point is arguable. However, once V.32 chip sets are in production, Dataquest expects that volumes will grow, prices will fall, and alternative solutions will diminish. One can recall the failure of Racal-Vadic's proprietary pre-Bell-212A 1,200-bps modem, which was acknowledged by the technical community to be superior in performance to the Bell 212A. It failed due in large part to the creation of a de facto standard by the major communications company in the world--AT&T--which preempted Racal-Vadic's superior implementation.

Telebit

The Telebit Trailblazer is currently the most technically advanced voiceband modem. It transmits and receives data in the frequency domain using fast Fourier transform (FFT) techniques in order to take full advantage of the bandwidth and signal-to-noise characteristics present in a telephone connection. It adapts to the telephone line it is using and packetizes the information it has to transmit.

In Telebit's zealousness to keep its competitive edge, the company kept its admittedly unique technology too proprietary just as 9,600-bps modem standards were evolving. It is the timing on just that kind of decision which can spell success or disaster for a young company. In the case of modems, where standards are ever-important, Telebit was not quick enough to license its technology to others. Had it done so, Telebit might have had more influence in the evolution of the 9,600-bps modem standard.

One caveat remains for the Telebit implementation: A current proposal in front of CCITT Study Group XVII includes the Telebit multicarrier approach as an alternative to V.32. However, the chances of this approach gaining wide acceptance in the marketplace over the V.32 are slim indeed. Telebit's current installed base is approximately 20,000 units, whereas it is reasonable to anticipate the U.S. market to be using 200,000 V.32 chip sets annually by 1990.

Pseudo-V.32 Implementations

The concept behind pseudo-V.32 implementations is to use the V.32 modulation at half duplex, not supporting true full-duplex transmission. Hence, when data are to go in the other direction, the line must be "turned around." In order to simulate full-duplex transmission, buffering of data occurs on the side that is not currently transmitting. The advantage to this approach is the elimination of the echo canceler required in the receive path of true full-duplex V.32 modems. The echo canceler is undoubtedly the most sophisticated part of the signal processing chain. Unfortunately, most pseudo-V.32 implementations are incompatible between different manufacturers.

Hayes is certainly one of the champions of pseudo-V.32 modems. It claims that its line turnaround is very fast and transparent to the user. U.S. Robotics was the first company to introduce a pseudo-V.32 modem. Its method, which is incompatible with that of Hayes, uses an asymmetrical technique that combines a 9,600-bps forward channel and a 300-bps back channel. Still other 9,600-bps approaches are also competing in the marketplace. For example, Microcom and Racal-Vadic use half-duplex V.29 modulation.

However, Concord Data Systems recently performed detailed tests on all of the existing 9,600-bps approaches and presented the results to CCITT Study Group XVII. The results indicate that under all test conditions, V.32-compliant modems perform better than any of the other V.29 or multicarrier half-duplex modulation techniques.

Dataquest expects many of the modem companies now providing modems that are incompatible with V.32 to begin offering V.32-compliant solutions combined with their existing incompatible solution. In other words, a company might package its existing incompatible modem in the same box with a new entry into the V.32 market. This keeps these companies from alienating their existing installed bases while also addressing the mainstream V.32 market.

High-Speed Networks Should Encourage Growth of High-Speed Modems

The proliferation of digital ISDN and Ethernet networks may actually encourage the growth of high-speed modems. After all, even a 9,600-bps modem is slow compared to 56-Kbps ISDN or 10-Mbps Ethernet. It is generally acknowledged that both ISDN and Ethernet will exist in the office environment long before they invade the general switched network. While office workers will be able to communicate within a given plant location at ISDN or Ethernet rates, communication outside that location will still require the use of the switched network. Dataquest believes that the high rates at which these networks transmit data will demand that switched-network transmission rates increase to 9,600 bps.

Public data networks are both an indicator and an influence on the direction in which switched-network modems are headed. Tymnet, one of the largest public data networks, started using Concord Data Systems V.32 modems about three months ago. Similarly, Dow Jones Retrieval Service has been using Concord's V.32 for almost two years.

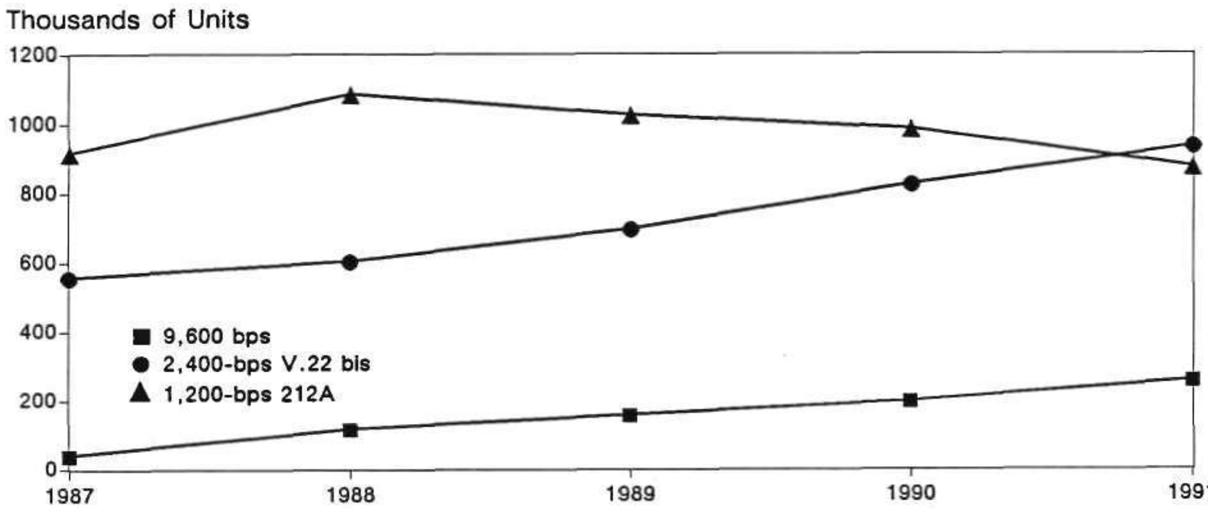
Compuserve has entered into a joint venture with Hayes to provide 9,600-bps service using the Hayes V-Series 9,600-bps modems. The service is expected to be operable within a few months. However, this Hayes modem is not V.32 compatible (as described earlier). It is clearly an attempt by Hayes to use its clout in the modem business to create a de facto standard using its noncompatible V.32 modem. It will be interesting to see how events evolve for both Hayes and Compuserve as they appear to be bucking what seems to be a growing tide toward adherence to the V.32 standard.

V.32 MODEM MARKET FORECASTS

Figure 2 illustrates Dataquest's projections for the growth of the dial-up modem marketplace. The curve for 9,600-bps includes both the V.32 and the pseudo-V.32 modems that are incompatible with the specification. Of the estimated 43,000 9,600-bps dial-up modems shipped worldwide in 1987, less than 10 percent were V.32-compliant. However, Dataquest estimates that by 1990, nearly 90 percent of the estimated 200,000 units shipped will be V.32-compliant.

Figure 2

Estimated Worldwide Market for Dial-Up Telephone Modems



Source: Dataquest
June 1988

DATAQUEST CONCLUSIONS

The 2,400-bps V.22bis modems are now mass-market items, due in large part to the low-cost DSP semiconductor chip sets used to build them. A modem that is faster, downward compatible, and has a small price premium will displace lower-speed modems. One can no longer find advertisements for 300-bps-only modems in personal computer magazines. They have gone the way of the 16K dynamic RAM.

Dataquest believes that market forces are beginning to encourage 9,600-bps modem transmission rates over the switched-telephone network. The question is no longer "if" but "when" V.32 modems will exceed V.22bis modems in production volume for personal computer applications. V.32 implementation issues are technically complex, but curiously enough, the effort required is largely for algorithms and software, not hardware. The final implementations will probably make almost exclusive use of single-chip digital signal processors programmed for the V.32 function. Dataquest expects many of the semiconductor companies to begin selling their own (or somebody else's) DSP microprocessors as V.32 modem chips. There is plenty of incentive for manufacturers to do this, as the modem market is extremely large. It is likely that nearly 200,000 V.32 units will be shipped in 1990.

While the market for V.32 modems will be quite large, Dataquest does not expect V.32 modems to be the only 9,600-bps modems in production. Other standards such as V.29 will also be used, but mainly for specific applications such as facsimile.

(Statistical support for this newsletter was provided by Larry Cynar of Dataquest's Telecommunications Industry Service.)

David M. Taylor

Dataquest

a company of
The Dun & Bradstreet Corporation

June 3, 1988

Dear Client:

Digital signal processing (DSP) promises to be one of the significant technologies of the 1990s. Already, DSP applications have emerged as consumers of substantial numbers of integrated circuits, particularly in the communications and military market segments. Dataquest estimates that 36 million DSP integrated circuits were consumed in 1987 alone, with worldwide consumption forecast to exceed 87 million units in 1990.

Dataquest has recognized this growing market with the addition of the Digital Signal Processing Segment as an option to the Semiconductor Industry Service. This segment provides the data and analysis necessary for timely assessment of new product and market opportunities, user issues, threats from emerging technologies, and changing strategies to keep you competitive in this rapidly expanding market.

To service this multidimensional area adequately, we have hired an industry expert with more than seven years of semiconductor DSP experience. David Taylor brings four years of DSP design experience plus three years of DSP marketing experience to Dataquest. The early part of his career was spent at Advanced Micro Devices, where he was the architect of a number of different telecommunications products, including single-chip DSP modems that are still in production. More recently, David spent three years as technical marketing manager at Zoran Corporation, a DSP semiconductor start-up.

As an introduction to this new segment, I have included some of David's recent work, including an outline of the DSP notebook, a list of some of the topics to be covered in upcoming newsletters, and also his first newsletter, which reviews the recent International Conference on Acoustics, Speech, and Signal Processing (ICASSP) held in New York City. If you would like additional information on the Digital Signal Processing Segment option, please feel free to give either your Dataquest account manager or David a call directly.

Sincerely,

Mel Thomsen
Director
Semiconductor Industry Service

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Digital Signal Processing Segment

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Dataquest

Semiconductor Industry Service

Digital Signal Processing Segment

Vital information for marketing and product managers, strategic planners, and marketing analysts in the semiconductor industry

Overview

Dataquest's Semiconductor Industry Service (SIS) provides research and analyses on the markets, products, companies, technologies, and legal and geopolitical trends of the semiconductor industry.

SIS offers detailed information and in-depth analyses in the following service segments: Digital Signal Processing, Microcomponents, ASIC and Standard Logic, Gallium Arsenide, and Memory. In addition, a semiconductor industry overview segment—Products, Markets, and Technology—is available as an alternative.

The Digital Signal Processing Segment supplies in-depth, detailed information on DSP microprocessors, DSP building blocks, application-specific DSP ICs, and special-function DSP ICs.

Who Needs the Service?

The Digital Signal Processing Segment is designed and organized for those involved in:

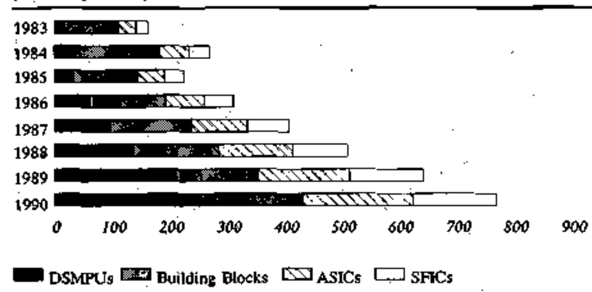
- Sales and marketing management
- Strategic planning
- Product and technology development
- Competitive analyses
- International marketing management
- IC purchasing and commodity planning

Key Benefits

The Digital Signal Processing Segment offers research and decision support to help you:

- Analyze market potential
- Understand supply/demand dynamics
- Analyze user applications and environments
- Develop new products
- Implement and execute tactical plans
- Analyze competitive strategies and product offerings
- Develop long-term, strategic goals

Worldwide DSP Revenue Forecast by Product Category
(Millions of Dollars)



The SIS staff leverages its industry experience and research by drawing on the expertise and resources of Dataquest's other semiconductor services. These services include the following:

- Semiconductor User Information Service
- Semiconductor Equipment and Materials Service
- Japanese Semiconductor Industry Service
- European Semiconductor Industry Service
- Asian Semiconductor and Electronics Technology Service
- Semiconductor Application Markets

This cross-industry, cross-regional perspective provides clients with a thorough understanding of the forces and issues affecting the semiconductor industry and the digital signal processing market.

Digital Signal Processing Segment Research Coverage

The DSP Segment covers the following areas:

Product coverage

- DSP microprocessors
- DSP building blocks
  - — Microprogrammable (bit slices)
  - — Multipliers
  - — Digital filters
- Application-specific DSP ICs
  - — Gate arrays
  - — Cell-based ICs
- Special-function DSP ICs
  - — Speech
  - — Telecommunications

(over)

Digital Signal Processing Segment Research Coverage (Cont.)

Market analyses

- ASP trends
- Regional consumption
- End-use market consumption
- Five-year history
- Five-year forecast

Competitive analyses

- Market shares
- Product positioning
- Suppliers
- Distribution channels
- Captive manufacturing

Product analyses

- Market shares
- Product comparisons
- Pricing
- Life cycles
- Design wins

End-user coverage

- Data processing
- Communication
- Industrial
- Consumer
- Transportation
- Military

Geographic coverage

- North America
- Europe
- Japan
- Rest of World

Applications and technology focus

- Major applications
- Emerging markets and applications
- Emerging trends and technologies
- Packaging issues

Vendor profiles

- Financial
- Product/productions strategies
- Alliances

Dataquest provides research and decision support to SIS clients under its comprehensive Industry Service program. Elements of this program include:

Data Base Notebooks These notebooks constitute detailed, frequently updated reference sources on the semiconductor industry. The notebooks are conveniently sectioned, indexed, and cross-referenced for easy use.

Inquiry Privilege This feature provides clients with a personalized source of data and opinions on the service topics most relevant to them. Inquiries can be made in person or by telephone, telex, or facsimile.

Research Bulletins These publications provide a continual flow of timely information and Dataquest analyses on major industry events and issues.

Industry Conference An annual conference brings industry participants together to review the state of the semiconductor industry and to discuss the major issues in an open forum.

On-Line Access Clients are provided with 24-hour access to frequently updated SIS data bases and to the *DQ Monday Report*. This report contains bimonthly analyses of worldwide and regional pricing trends for 25 major semiconductor products and weekly updates of news affecting the semiconductor industry. In addition, clients may also use on-line access for electronic inquiry privileges and immediate availability of SIS research bulletins.

Research Library Clients have access to Dataquest's extensive libraries should they wish to perform independent research.

Custom Consulting Dataquest's senior staff is available to conduct custom research for clients on an *ad hoc* basis.

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Research Newsletter

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PERSPECTIVE ON ICASSP '88

INTRODUCTION

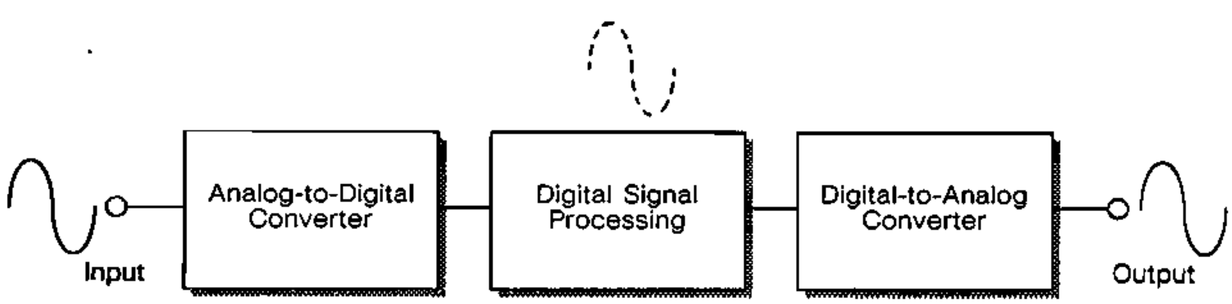
The thirteenth annual International Conference on Acoustics, Speech, and Signal Processing (ICASSP) hosted by the IEEE was held at the New York Hilton from April 11 through April 14, 1988. This year boasted the largest ICASSP attendance ever, with 46 exhibitors, 1,950 attendees, and more than 700 presentations.

The main focus of ICASSP since the first conference in 1976 has been to provide a forum where academic advancements in digital signal processing (DSP) technology can be presented and discussed. ICASSP has remained true to its technical charter through the years, even with the recent inclusion of exhibitor booths in the early 1980s. It remains the premier industry conference dealing with general topics in digital signal processing.

As the name "digital signal processing" implies, DSP is a technology used for processing signals digitally. These digital signals are often acquired from analog signals by using an analog-to-digital converter, as illustrated in Figure 1. The output of DSP systems is sometimes converted back into an analog form by using a digital-to-analog converter, also shown in Figure 1. The processing of these digital signals between the data converters is broadly categorized as digital signal processing.

Figure 1

A Generic Digital Signal Processing System



Source: Dataquest May 1988

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

The size of the transaction volumes from ICASSP '88 is testimony to the largely infinite amount of digital processing that can be performed on signals. This year's transactions consist of nearly 3,000 pages in five volumes that total seven inches in thickness.

ICASSP EVOLUTION

The IEEE Acoustics, Speech, and Signal Processing (ASSP) society of today evolved from the old IEEE Audio and Electroacoustics society. The first ICASSP conference was held in 1976 and consisted of more than 200 papers presented and 600 participants.

Both the attendance and the number of presentations at ICASSP have more than tripled since the first conference. Additionally, a number of other conferences focus on other areas in which DSP is significant, such as applications and VLSI implementations. (As an example of DSP proliferation at other conferences, please refer to April 1988 SIS Research Newsletter number GA4/DS2, entitled "DSP Evolution Evident at 35th ISSCC." It highlights the fact that about 30 percent of the papers presented at the February 1988 ISSCC conference described semiconductor devices oriented toward digital signal processing.)

In recent years, ICASSP has taken on an additional dimension with the inclusion in the early 1980s of exhibits by a variety of semiconductor, hardware, software, systems, and publishing vendors. Products from these companies are targeted at a variety of people in the DSP community: research engineers, systems and algorithm engineers, hardware designers, and software designers. The addition of exhibits adds a level of maturity and credibility to the conference (and the industry) that should continue to build over the next decade.

THE SESSIONS

Presentation sessions were organized into seven broad categories, as follows:

- Digital Signal Processing
- Spectral Estimation and Modeling
- Speech Processing: Coding, Analysis, Synthesis, and Recognition
- Multidimensional Signal Processing
- VLSI for Signal Processing
- Underwater Acoustic Signal Processing
- Audio and Electroacoustics

The following paragraphs will examine special topics and applications of interest in some of these categories from a variety of the sessions. Future newsletters will go into additional detail on these and other issues.

Speech Processing

The speech processing category boasted the largest number of sessions (14) and presentations (178). This is not a new trend, as all aspects of speech processing have received tremendous amounts of research over the years. In fact, five to eight years ago, most of the major U.S. semiconductor companies had engineering organizations designing VLSI products for speech processing, including Advanced Micro Devices, General Instrument, Motorola, National Semiconductor, and Texas Instruments. In all cases, the VLSI activities at these companies have been disbanded. It is fair to say that Texas Instruments still supports speech from an applications standpoint, but the hardware implementation of speech algorithms is almost exclusively done using general-purpose digital signal processors such as the TMS320—not using custom VLSI. In many cases, the speech groups from these companies were redirected into more general digital signal processing organizations.

Audio and Electroacoustics

The smallest category was Audio and Electroacoustics, with only 3 sessions and 32 presentations. In Dataquest's opinion, however, one of these sessions was one of the most interesting at the conference. It discussed (in part) hearing and speech aids for the handicapped.

As an introduction, according to the Ear Research Institute in Southern California, there are 2 million people in the United States who either are totally deaf or lack the ability to detect speech without aid. External-aid techniques in the form of either electrical stimulation of the cochlea by implanted electrodes or tactile cutaneous stimulation are often used in order to simulate hearing for the deaf. Another 12 million "hearing-impaired" individuals, who suffer from serious hearing loss, often are treated using conventional analog hearing aids. A number of different digital signal processing techniques are being developed to aid both groups of people, providing a level of hearing quality not achievable today using analog technology. Seven papers were presented at ICASSP discussing a variety of these techniques.

VLSI

The second smallest presentation category was that of VLSI signal processing implementations, containing 4 sessions and 54 papers. A related session entitled "Hardware and Software in Signal Processing" was actually in another category, but it will also be counted here because it is related to the VLSI category. This session added another 20 papers.

Papers on VLSI focused largely on hardware architectures designed to solve a variety of signal processing problems. Of special note were products that either are available now or will soon be from a variety of different semiconductor manufacturers. A summary of these follows.

LSI Logic described a set of four chips optimized for high-performance signal processing applications with data sampling rates greater than 5 MHz, such as image and radar processing. One of the processors is a 64-tap transversal filter (MFIR) containing 64 8x8 multipliers on one die. This device can operate as a one-dimensional 64-tap filter or can be reconfigured to operate as an 8x8 two-dimensional filter. A second device in the set is a 64-tap rank-value filter (RVF) that can also operate in both one and two dimensions. Common operations with the RVF are minimum, median, and maximum value filtering. A third device in the set is a binary filter and template matcher (BFIR). It is optimized to perform 1-bit filtering, morphology, and template matching. The final device in the set is a video shift register that will hold 4K 8-bit pixels. The lengths (in pixels) of the video lines are configurable from as few as 8 pixels per line up to 4,000 pixels per line. This device is configurable also as a two-dimensional array of pixel buffers to work with the other devices in the family.

Honeywell described a chip set (processor plus controller) with an architecture optimized for high-throughput fast Fourier transforms (FFTs). The processor is able to process data at up to 500 million arithmetic operations per second. The worst-case performance benchmark for a 1K complex FFT is 204.8 microseconds. Using different memory configurations and cascading multiple processors, this execution time can be reduced to 20.48 microseconds.

AT&T presented the architecture for its new 25-mflops DSP-32C general-purpose floating-point digital signal processor. It is an extension to the architecture of the company's DSP-32, which has been in production for more than a year. Because the DSP-32C has been previously announced, it will not be described in detail here.

Zoran Corporation presented the architecture of its new floating-point vector signal processor. This processor differs from many general-purpose digital signal processors in the way it handles data. Most processors operate on single data samples in each instruction. The vector processor is optimized to operate on multiple data samples in each instruction, which is achieved by use of a "high-level" instruction set that is microcoded into the processor. Its instruction set resembles that of an array processor. For instance, single-instruction commands exist in the processor to do finite-impulse response (FIR) filtering as well as fast Fourier transforms (FFTs). This architecture allows very high performance when the function desired is already microcoded into the device. The processor tends to be less efficient if the desired function is not already microcoded into the processor.

A very important issue for designers building systems using digital signal processors is one of software development support. In many ways, the issues facing software developers for DSP systems parallel those facing microprocessor system developers. Early generations of DSP processors required that users program them at the level of assembly code (analogous to the way early microprocessors were programmed). Programming at this level is tedious when dealing with sophisticated algorithms. On the other hand, assembly coding of algorithms also provides the highest level of performance, important in most DSP applications. For programmers, the ideal solution to this dichotomy is to have available optimized high-level language (such as C or FORTRAN) compilers that translate code efficiently to the instruction set of the DSP microprocessor.

Recent generations of DSP microprocessors have been introduced with C compilers to help solve these programming problems. A number of papers were presented describing C compilers optimized for DSP microprocessors, including papers by Texas Instruments and AT&T for their new processors.

Image Compression

Another prominent topic spread through a number of different sessions dealt with algorithm and architecture implementations of the discrete cosine transform (DCT). This mathematical transform is usually implemented in two dimensions as part of the signal processing chain for compressing images. Image compression promises to be an exciting area in the next few years as we begin handling and transmitting images (pictures) using our personal computers and the telephone network. Already a number of companies are selling commercial products that transmit images over a standard telephone network. AT&T's original introduction of the picture-phone was only 20 years too early!

For example, a good-quality color photograph stored on a computer hard disk without compression can take 3 Mbytes or more. The transmission of this image using a standard 2,400-bps modem would take 10,000 seconds—nearly three hours! Fortunately, compression techniques such as cosine transforms can help reduce the storage or transmission time requirements of an image by a factor of 10 to 50, depending on the resulting quality desired. Thus, nearly three hours of transmission time can be reduced to about three minutes.

THE EXHIBITORS

This year's ICASSP drew 46 exhibitors, more than have attended the conference at any time in the past. Most of the major U.S. DSP semiconductor manufacturers were present, including Analog Devices, AT&T, Microchip Technologies, Motorola, and Texas Instruments. (Microchip Technologies is the newly named company spun off recently from General Instrument's microelectronics division.) The two most prominent exhibitors at the show were Texas Instruments and Motorola, both of whom had large booths directly in the center of the exhibition area. Both of these companies also had evening presentation sessions to discuss their recently announced 32-bit floating-point DSP microprocessors.

In addition, Texas Instruments (TI) also had the die of its floating-point TMS320C30 on display under a microscope. The die contains some 700,000 transistors and is more than 500 mils on a side in a 1-micron CMOS technology. Observing the die through the microscope, one can see the impressive functional modularity designed into the die layout. Each of the functional blocks appears on the die much as one might draw a block diagram of the architecture on a piece of paper. The obvious implication of this organization is the ability to customize the product for targeted application areas (or customers) by adding or deleting unique functional blocks. The architecture supports this concept with what TI calls its "peripheral bus."

TI announced that the TMS320C30 functional blocks will be available to customers as standard cells in the future. It also announced that the TMS32010 architecture will be available in the next year as an ASIC core.

The Motorola booth display was effective also. A number of Motorola's existing and potential customers were given space in the booth to demonstrate current and future products using Motorola's DSP processors. The company's third-party developers also were present, demonstrating hardware and software development tools.

A number of independent hardware and software development companies were present with a plethora of tools to aid the designer. Most of these companies are small, with a limited ability to market and distribute their products. Some of these companies are trying to make arrangements with the main DSP semiconductor manufacturers for distribution of their products. Although considerable opportunities exist for third-party development tools, many seem to be "me-too" kinds of products. For instance, about six different small companies were displaying various versions of filter design programs. Each product had its own small uniqueness relative to the others, but they were all created to solve the same basic problem, that of designing FIR and infinite-impulse response (IIR) filters. It seems likely that many of these companies will not be able to survive the intense competition without finding a unique market position or distribution channel.

One impressive development tool was displayed by a small company called MicroWorkshop, located in Bohemia, New York. This company has a Microsoft Windows-based development tool for the 32010 DSP microprocessor. It combines truly easy-to-use text editor, assembler, signal editing, debug, and board driver software with a hardware development board for the processor, all of which runs on a PC. The board contains a 32-MHz DSP-320C10 built by Microchip Technologies of Chandler, Arizona. MicroWorkshop promises additional development tools for other processors in the future.

DATAQUEST CONCLUSIONS

A tremendous number of interesting topics were discussed, presented, and further advanced at this year's ICASSP. The vast majority of ICASSP presentations are generated in universities and research laboratories from around the world, however, and are oriented toward the academic community; most will never have the ability to directly affect our lives. To this end, most will never see ultimate implementation in hardware. Nevertheless, it is through forums of this nature that we obtain insight into future directions for theoretical work, applications, algorithms, and VLSI architectures that will ultimately affect all of us. Future newsletters will address many of these topics in greater detail.

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Research Newsletter

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DSP EVOLUTION EVIDENT AT 35TH ISSCC

SUMMARY

The International Solid State Circuits Conference (ISSCC), held February 17 through 19, 1988, in San Francisco, celebrated its 35th year of reporting continuing progress in semiconductor technology. One hundred papers by more than 600 industry and academic participants emphasized the rapid rate of evolution of IC functions. Significantly, a record 30 percent of these were specifically oriented to digital signal processing (DSP) chips, and another 50 percent described general-purpose functions that are directly usable in DSP applications.

Dataquest broadly categorizes DSP IC functions as signal processing, graphics generation, image processing, and scientific computing products. This newsletter examines major ISSCC presentations in each of these areas, then discusses their impact on trends in products, technology, and applications.

ANALYSIS AND DISCUSSION

Since the first 4-bit microprocessor of 1970, microprocessor chips have evolved to 32-bit word length, CMOS and GaAs processing, <1-micron design rules, clock rates beyond 30 MHz, and throughputs measured in tens to hundreds of mops. Where appropriate, on-board EPROM or EEPROM is used for microcontrol storage. The DSP functions presented at this conference represent a continuation of this progress.

Some of the major developments discussed at the conference are summarized in Table 1. All of the devices shown use CMOS processing, with transistor counts as high as 368,000. All incorporate two-layer metal and/or double-poly interconnections for efficient use of chip area. Minimum geometries are on the order of 0.8 to 2.0 microns. Power dissipation for each of the two largest functions is 4 watts.

Table 1

1988 ISSCC—Major Silicon DSP Chips

Characteristic	Company: Hitachi	Matsushita	National	NTT	Toshiba	VITI
Function	Video signal processing	3-D hidden surface processing	Video signal processing	Geometric mapping processing	Graphics processing	Parallel image processing
Gate Count	9,000	N/A	N/A	105,000	N/A	50,000
Transistor Count	36,000	330,000	40,000	N/A	368,000	200,000
Process	CMOS	Twin-tub CMOS	CMOS, 2L poly	CMOS	Twin-tub CMOS	CMOS
Minimum Feature Size (u)	1.0	1.2	2.0	1.2	0.8	2.0
Metal	2L Al	2L	N/A	2L	2L	2L
Die Size (cm^2)	6.8 x 5.5	11.1 x 11.5	7.0 x 5.5	14.5 x 14.5	10.9 x 12.2	11.7 x 10.7
Clock Rate	N/A	20 MHz	27 MHz	50 MHz	40 MHz	N/A
Performance	50 mips	N/A	N/A	N/A	40M pixels/s	114 mops
Pinouts (S + P)	80	57 + 7	37 + 3	280	144	119 + 30
Package	N/A	N/A	DIP	PIP	Ceramic FP	PGA
Voltage(s)	+5V	+5V	+5V, -5V	+5V	+5V	V_{DD}, V_{SS}
Power Consumption	N/A	4W	500mW	4W	800mW	N/A
Remarks		256-pixel processing	Maximum rate--30 MHz			12 transistors per register bit

N/A = Not Available

Source: Aztek Associates

Signal Processing Products

Companies and other organizations presenting information on developments in signal processing products include AT&T Bell Laboratories, Fujitsu, General Electric, Hitachi, Matsushita, National Semiconductor, NEC, Philips, Siemens, and Stanford University. Notable are the AT&T communications signal processing chips, the 4Gb/s optical repeater by Fujitsu, and Sony's CMOS thermal printer head LSI logic/driver chip containing 11,448 transistors and parallel heating elements.

Numerous improvements in A/D and D/A conversion were evident. Philips and others continue to advance the state of the art of audio signal processing using digital techniques. Several telecommunications functions were presented, including an echo canceller and switching functions including cross-point switches. These are included in Table 2.

Table 2

1988 ISSCC Developments in Signal Processing Chips

Company	Chip Developments
AT&T Bell Labs	45-MHz P/FLL (phase/frequency-locked loop) timing recovery circuit, 146Mb/s time/space switch, 64 x 17 nonblocking cross-point switch, 2-GHz CMOS dual-modulus prescaler
Catholic University (Leuven, Belgium)	Micropower monolithic data acquisition
Fujitsu Opto Systems Lab	4Gb/s repeater chip set
General Electric	A mixed A/D chip for phased array single processing
Hitachi	Voice-band DSP chip with A/D and D/A, 10Mb/s link-level CMOS processor
Matsushita ERL	GaAs programmable timer with 125ps resolution
National Semiconductor	33Mb/s data-synchronizing phase-locked loop (PLL)
NEC, BSR (Newton, Massachusetts)	18-bit oversampling A/D converter for digital audio
Philips	Stereo 16-bit CMOS D/A for digital audio, algorithmic 15-bit CMOS D/A converter

(Continued)

Table 2 (Continued)

1988 ISSCC Developments in Signal Processing Chips

Company	Chip Developments
Siemens	2u CMOS equalizer for quadriture amplitude modulation (QAM) digital radio, self-calibrating 16-bit CMOS A/D converter
Sony	Thermal printer head with CMOS logic and drivers
Stanford University	Asynchronous multiplexer for biotelemetry
University of California at Berkeley ERL	250 Mbit/s CMOS cross-point switch

Source: Dataquest
April 1988

Graphics-Generation Products

Charge-coupled device (CCD) chips topped the list of graphics-generation functions discussed at the 1988 ISSCC. The largest of these, a 2 million-pixel chip by Toshiba, is organized in high-definition television (HDTV) format, 1,920 horizontal by 1,036 vertical pixels, allowing a 9:16 aspect ratio. The unit cell measures 7.3 x 7.6 microns, with a charge-handling capacity of 200,000 electrons per picture element. At F11 illumination, a signal current of 300nA has been obtained.

Texas Instruments' 128Kx8 video RAM allows storage and manipulation of 256 individual colors or shades of gray at standard HDTV resolution and frequency. Philips engineers have developed a 835Kb video serial memory and a 400K-pixel CCD imager, both aimed at HDTV. Table 3 summarizes the graphics-generation product developments.

Table 3

1988 ISSCC Developments in Graphics-Generation Functions

Company	Chip Developments
Philips	835-Kbit video serial memory (VSM), 400K-pixel CCD imager
Sony	Comb filter
Texas Instruments	128Kx8, 70-MHz video RAM
Toshiba	2M-pixel CCD imager

Source: Dataquest
April 1988

Image Processing Products

Video signal processing (VSP) functions have evolved to include 3-D manipulation and elimination of hidden areas from processed images. Matsushita presented an approach to this problem that incorporates a skewed systolic architecture fabricated on a $11.1 \times 11.5mm^2$ die containing 330,000 transistors. This chip is detailed in Table 1.

Significant developments were described by the France's National Telecommunications Center, General Electric, Hitachi Central Research Laboratories, Matsushita Central Research Laboratories, Nippon Telegraph and Telephone, Toshiba, and Visual Information Technology, Inc. (VITI). The parallel image processor (PIP) chip by VITI is a graphics computer incorporating the properties of two-dimensional DSP of pixel data, pixel enhancement, and interactive processing rates. Performance of 50 mips is achieved in CMOS with relatively conservative design rules of 2 microns. VITI's chip is detailed in Table 1. Table 4 is a summary of image processing product developments presented at the conference.

Table 4

1988 ISSCC Developments in Image Processing

Company	Chip Developments
French Government	27-MHz D/A VSP
General Electric	10-MHz ICs for graphics processing designed on a silicon compiler
Hitachi CRL	20ns CMOS DSP core for VSP
Matsushita CRL	Hidden surface processor
NTT	50-MHz CMOS geometrical mapping processor
Toshiba	32-bit 3-D graphics processor with 10M-pixels/s Gouraud shading, 40M-pixels/s graphics processor
VITI	PIP chip

Source: Dataquest
April 1988

Scientific Computing Products

Table 5 identifies the major developments in scientific computing products described by LSI Logic's Stanford Research Laboratory, Rockwell, a Stanford team, and Texas Instruments.

Table 5

1988 ISSCC Developments in Scientific Computing Chips

Company	Chip Developments
LSI Logic SRL	30-mflops, 32-bit CMOS floating point processor
Rockwell	150-mops GaAs 8-bit slice
Stanford University	Pipeline 64x64 array multiplexer
Texas Instruments	200-mips GaAs 32-bit microprocessor

Source: Dataquest
April 1988

Technology Trends

While CMOS processing at 0.8- to 2.0-micron geometries represents the present "workhorse" technology, advances in silicon emitter-coupled logic (ECL) and GaAs processing were visible in the presentations. The yield data for GaAs devices at LSI density levels indicate significant improvements during the last 12 to 18 months. Dataquest believes that more applications will shift toward GaAs as speed becomes a larger factor in new applications. Table 6 compares two approaches to DSP using GaAs hardware developed by Rockwell and Texas Instruments.

Table 6

GaAs Microprocessor IC Comparison

Characteristic	Company Rockwell Design	 Texas Instruments/CDC Design
Function	150 mops 8-bit ALU (1,750 type)	32-bit RISC microprocessor
Architecture	3-bus bit slice (expandable to 16 bits)	6-stage pipeline
Performance	150 mops	200 mips
Operations	Add, subtract, modified Booth multiply, divide, bit operations	4 address modes, 16 ALU and 5 control instructions, 10 memory instructions
Power (Watts)	Low--4.2, high--9.2	Estimated 20 maximum
Die Size--mm	4.9 x 3.9	7.6 x 7.6
Chip Complexity	9,400 transistors, 3,000 diodes	12,872 gates (typical gate is 1 transistor and 5 resistors)
I/Os: Signal + Power/Gnd	64 + 29	256 + 70
Process	1.0u GaAs D-MESFET	1.5u GaAs HBT
Logic Form	Buffered FET logic (BFL)	I^2L (modified RTL)
Cell Speed/Power	120ps/1.6mW (register)	160ps/2mW (gate)
Yield Data	18 percent	Experienced 2 percent, projected 8 percent

Source: Aztek Associates

Product Trends

The development of several VSP devices by ISSCC participants is an indication of an emerging product area for chips oriented toward solving the unique problems incurred in high-definition video system designs. A similar evolution is occurring in voice-processing hardware. An estimated 50 other papers described DRAMs and SRAMs, microprocessors, and other DSP-related functions. These gave evidence of trends toward continuing increase in SRAM, DRAM, and DSP function densities and speeds with accompanying decreases in power per bit.

Application Trends

Enhancing human interface with systems is a major new thrust in semiconductor applications. The main focus of this year's ISSCC developments in chip architectures is toward improving the human-system interface. This was portrayed by the focus of many papers on voice and graphics communication and processing. HDTV is a major application addressed by many chip suppliers, followed by optical communications and massive main memories. Dataquest expects many product announcements in these applications areas in the near future.

DATAQUEST CONCLUSIONS

The IC world is rapidly evolving toward submicron processing of chips ranging above 1 million transistors in complexity (silicon CMOS), with GaAs now within a factor of 16 in complexity and 4 to 5 times faster in speed. The competing technologies are causing a proliferation of application-specific DSP designs. Dataquest expects DSP functions to play an increasingly important role in IC suppliers' product portfolios for at least the next two to three years. Realignments among IC competitors are expected as these developments accelerate the obsolescence of many existing products.

Gene Miles

Dataquest
a company of The Dun & Bradstreet Corporation

Research Newsletter

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NEW FLOATING-POINT DSP PRODUCTS THREATEN TI'S LEAD

SUMMARY

With the 1983 introduction of its first digital signal processing product, the TMS32010, Texas Instruments (TI) established a seemingly unshakeable lead in the emerging digital signal processing (DSP) market. Today, the heavy investments made by TI and others in educating the technical community to the wonders of DSP are paying off. DSP product use is becoming more pervasive. In addition, DSP product technology is currently evolving from 16-bit integer products to high-performance 32-bit floating-point products. As highlighted in Table 1, 1988 will be a banner year for DSP microprocessor (DSMPU) product introductions.

Table 1

A Sampling of High-Performance DSMPU Products

Company	Product	Expected Availability	Description
AT&T	DSP32	Available now	32-bit Floating Point
	DSP32C	Q2 1988	32-bit Floating Point
Fujitsu	MB86232	Q1 1988	32-bit Floating Point
	MB86220	Q3 1988	24-bit Floating Point
Motorola	DSP56000	Available now	24-bit Integer
NEC	uPD77230	Available now	32-bit Floating Point
	uPD77220	Q2 1988	24-bit Integer
Oki	M6992	Available now	22-bit Floating Point
	M699210	Q1 1988	22-bit Floating Point
TI	TMS320C30	Q2 1988	32-bit Floating Point
Zoran	VSP325	Q3 1988	32-bit Floating Point

Source: Dataquest
February 1988

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What does this mean for Texas Instruments? It means that, for the first time, TI may not be alone with the latest technology in the DSP market. TI's TMS320C30 will most certainly experience heavy competition from this new crop of products and the competitors that TI faces are not new to this market, either. These vendors are all on their second- or third-generation DSP products.

In the last five years, TI has built a strong customer-support structure. If the TMS320C30 can be delivered close to its targeted introduction date and for its projected price, TI shouldn't lose much ground at the high end of the DSP market. However, the new midrange 22- and 24-bit products, which promise 32-bit floating-point performance at 16-bit integer prices, do pose a threat in such emerging new DSP markets as digital audio.

MARKET OUTLOOK

A half dozen vendors are trying to get a jump on Texas Instruments and stake out some high ground in the digital signal processing market. Their products fall into the following two broad categories:

- High-performance 32-bit floating-point DSMPUs
- Midrange 22- and 24-bit floating-point DSMPUs

First, there are 32-bit floating-point superchips that will compete with TI's announced TMS320C30. These DSMPUs are some of the most powerful silicon yet produced. They can multiply two numbers as fast as a Weitek arithmetic processor, have more transistors than Intel's 80386, and will replace some building block systems with a single chip.

Secondly, there is emerging a class of 22- and 24-bit floating-point DSMPUs that promise floating-point capability at the price of midrange, 16-bit integer DSP chips. Also not to be overlooked in this category are the 24-bit integer processors from Motorola and NEC. These products, while lacking floating-point capability, do offer the customer another 8 bits of dynamic range to play with.

Floating-point processors can be both easier to use and more powerful than fixed-point processors—a great combination! All this activity in floating-point products raises two interesting market-related questions:

- How fast will customers move to these parts?
- How will they affect TI's dominance of the DSP market?

In this newsletter, we will examine the products listed in Table 1 with respect to their market potential and probable effect on Texas Instruments' lead in this market. Located at the end of this newsletter, Table 2 compares and contrasts the features of each product reviewed.

High-End Market Prognosis

The new 32-bit floating-point products will find their first uses in applications that currently are implemented by building blocks (i.e., high-performance bit slices and multipliers). These areas are:

- High-end graphics
- Imaging
- Array processors
- Military systems

These applications are more driven by performance than by cost. Thus, a $300 or $400 DSP product may well provide a cost-effective solution. Because performance is what counts in these areas, the competition is just getting started for the 32-bit floating-point market. Products with sub-100-nanosecond cycle times—such as those from AT&T, Fujitsu, and Texas Instruments—look like contenders.

While this market may be bounded by building block applications in the short term, one would be foolish to expect that to last. Forces that will help move these products into a broad spectrum of applications include:

- Price reductions
- Availability of C compilers
- An increase in customer awareness of product capabilities

The bright spot for TI's competitors is that engineers now using building blocks are perhaps the most sophisticated consumers of DSP products. They will tend to choose DSP products mainly because of performance, and they will be less influenced by TI's imposing presence and customer-support structure.

Market Participants

AT&T. AT&T's second-generation 32-bit floating-point DSP product, the DSP32C, appears competitive from a hardware standpoint; it is twice as fast as its predecessor. AT&T's earlier product and NEC's initial 32-bit product, the uPD77230, are both too slow in comparison with the newer products and limited in external memory addressing capability.

Perhaps more importantly, AT&T is providing serious software support to its new product. The DSP32C's 32-bit arithmetic unit is limited to floating-point operations, however, while the Fujitsu and Texas Instruments products can also perform 32-bit fixed-point adds, subtracts, and logical operations.

Fujitsu. Fujitsu's MB86232 will likely be the first of this new generation of products. This product and the Zoran VSP325 are the only devices that directly handle the IEEE 754 single-precision floating-point format. Additionally, the MB86232 has highly parallel memory addressing. A big "if" is whether or not Fujitsu can overcome the somewhat stereotypical Japanese company's weakness in supporting complicated processors.

Texas Instruments. Texas Instruments clearly has the lead in the DSMPU market today. Its latest product, the TMS320C30, should be as fast as the competitors' chips with more on-chip memory. Additionally, TI's software experience and extensive customer-support network will work to the company's advantage.

It is probably realistic to assume that the high-end 32-bit market will develop slowly. And, as stated earlier, if the TMS320C30 can maintain its targeted introduction date and projected price, TI shouldn't lose much ground in this market. The only question concerns how imposing TI's lead will be. However, should the introduction date slip appreciably, TI may find itself sharing more of the market than it had expected or wanted.

Zoran. Zoran's VSP325, like its 16-bit predecessor, is hardwired to perform DSP functions. This gives the VSP325 the highest performance available for applications that it fits, but this also narrows its appeal quite a bit. However, because the 32-bit DSMPU market is a performance-driven market, Zoran has a chance to do better than it did in the 16-bit DSMPU market.

High-End Pricing

Initial samples of some of these 32-bit floating-point DSMPUs may cost more than $1,000 apiece, which is a serious price for an integrated circuit. Prices are expected to drop below $500 each (in 1K quantities) before the end of the year—still a significant price!

Midrange Market Prognosis

The threat to Texas Instruments' market domination comes not so much from the flagship 32-bit products as it does from the new 22- and 24-bit floating-point products, such as those from Fujitsu and Oki. If these products can be delivered for the price of midrange 16-bit integer DSMPUs, they pose a very attractive option. Even with a qualitatively more advanced architecture and a superior price/performance ratio, however, strong customer support and an assertive selling effort will be needed to capitalize on this opportunity. Figure 1 illustrates the potential DSP opportunities in consumer electronic products that could fuel the development of a midrange DSP market.

Figure 1

DSP Opportunities in Consumer Products

*Refers to improved-definition (IDTV), extended-definition (EDTV), and high-definition television (HDTV) standards.

** Pulse code modulated.

Source: Dataquest February 1988

Market Participants

Fujitsu. Fujitsu's 24-bit floating-point product, the MB86220, has the potential to be very successful. Its projected pricing is extremely competitive. In addition, its word size and format are excellent for digital audio applications. Digital audio may become the largest application for midrange DSP products, as design wins in consumer applications mean big volumes.

Motorola. Motorola's DSP56000 is a 24-bit integer device. Although it doesn't have the convenience of a floating-point device, its ALU is 8 bits wider than other integer DSMPUs. This translates roughly to an additional 48db of dynamic range. The DSP56000 also rates as one of the fastest of the midrange products. Another plus for the product is that people are comfortable buying advanced processors from Motorola. Comfort is a big factor in the DSP market—a market dominated by Texas Instruments.

NEC. NEC's uPD77230 is a bit schizophrenic. It simply does not have the raw speed of the newer 32-bit parts. Its relatively low price, however, makes it a viable alternative for midrange applications. Another big plus for the product is that it is available now. Die shrinks with resultant increases in clock speed could even make the uPD77230 more competitive at the high end. Not to be ignored, of course, is NEC's position as the number two market leader behind Texas Instruments.

NEC will soon spin off a lower-cost 24-bit integer version of this chip. The new product, the uPD77220, will be upwardly compatible with the uPD77230. Ironically, although floating-point products should make development less complicated, NEC feels that customers are still just learning about floating point. This attitude further illustrates the amount of education and selling required for DSP products.

Oki. Oki's 22-bit M699210 is an upgrade and die shrink of its M6992. It is a 1.5-micron CMOS full-custom design. The M6992 was a 2.0-micron standard cell design. The die-size reduction offered by the full-custom design should move Oki's pricing further down the learning curve, and Oki is supplying good software tools. The company believes that engineers who have had to implement products based on the fixed-point TMS320 family are good candidates for their floating-point devices.

Midrange Pricing

Existing midrange products, such as TI's TMS320C25 and NEC's uPD77230, are currently priced at slightly more than $100 each in 1K quantities. To be competitive in the midrange market, prices need to drop below $50 (for moderate quantities) by the end of the year.

DATAQUEST ANALYSIS

The Rationale for Floating Point

Telecommunications has been the single largest market for DSMPUs to date. These applications are well served by the 16-bit integer products. Additionally, most DSP applications require interface to the real world through A/D and D/A converters, which are normally 8 to 16 bits in resolution. So the question is: Do customers really want or need floating-point digital signal processors?

The answer is "yes" in a surprisingly high percentage of applications. A key point is that each calculation results in an increased number of bits in the output. The more calculations, the larger the resultant word. Rounding of the results to fit a 16-bit word leads to loss of resolution. In highly iterative algorithms, this round-off error can be quite large.

Seemingly innocuous applications can quickly outgrow a 16-bit word. For example, suppose you wish to design a digital equalizer to work with a compact disc (CD) player. Compact disc players use a 16-bit data word. At first glance, a 16-bit integer DSP chip may seem a good match.

The natural way to implement a digital equalizer is by doing a fast Fourier transform (FFT), modifying the spectrum the way you want, and then doing an inverse FFT. An FFT can grow as much as one bit per stage; however, and we have to remember that for an equalizer, the more bands the better. Thus, for a 256-band equalizer, the growth could be as much as 9 bits. That means that the equalizer needs at least a 25-bit integer DSP chip in order to ensure maximum resolution. And, because people are fanatic about audio quality, they will want those bits.

Applications that require two-dimensional FFTs, such as medical imaging, robotics, or video data compression, experience bit growth in both the row and the column FFT results. So an N x N transform will have twice the bit growth of a length N transform. Therefore, even 8-bit video signals could benefit from using floating-point DSMPUs.

Even if resolution is not a problem, fixed-point programs usually require some software scaling and checking for overflow. This additional code can be quite substantial. It slows down program execution, and programmers would be quite happy not to have to do it. Because DSP algorithms are often developed on computers that use floating-point arithmetic, the need for scaling and overflow checking can be an unpleasant surprise. Floating-point DSMPUs handle these issues automatically, shortening algorithm development time.

The Threat to TI's Lead

Texas Instruments enjoys a dominant position in the DSP market—a position in which the company has invested heavily. However, it is facing more competition than ever before. Today's competition is seasoned, having encountered TI's immense third-party software/hardware vendor network and customer-support structure in the past. While TI is still recognized as the leader in customer support, the level of customer support offered by other DSP vendors has improved with each succeeding generation of products.

As software and hardware support lessens as an issue, the technical merits of a product and the price/performance ratio become more important. At the high end of the DSP market, TI's TMS320C30 compares very favorably with its competition. It is expected to be one of the fastest products available, in addition to having more on-chip memory than any of its competitors (see Table 2). Furthermore, the TMS320C30 is software compatible with its predecessors in the TMS320 family. The TMS320C30 will not be the first 32-bit floating-point DSMPU to be available; nevertheless, if its targeted introduction date doesn't slip appreciably, TI should maintain its impressive grasp of the high-end DSP market.

TI is vulnerable, however, in the new developing midrange market. Their current products address the high-end 32-bit floating-point and low-end 16-bit integer markets. TI doesn't have a midrange product similar in price/performance to those of Fujitsu and Oki. If a midrange market such as digital audio develops, TI will be out in the cold on two counts. The first factor is that the company lacks a midrange product. The second factor is that such a market will be heavily influenced by Japanese consumer product manufacturers.

Alice K. Leeper

Table 2

DSMPU Product Comparison

Supplier:	AT&T	AT&T	Fujitsu	Fujitsu
Part:	DSP32	DSP32C	86232	86220
Word:	32 FP	32 FP	32 FP	24 FP
Word Format:	24E8	24E8	24E8	18E6
Cycle Time:	160ns	80ns	75ns (2 mac)	80ns
Clock:	25 MHz	50 MHz	40 MHz	25 MHz
Internal RAM:	512 x 32 x 2	512 x 32 x 3	512 x 32	256 x 24 x 2
External Data RAM:	14K x 32	4M x 32	1M x 32	64K x 24
Internal Program ROM:	512 x 32	1K x 32	1K x 32	2K x 30
Internal Data ROM:	Shared	Shared	Shared	Shared
External Program Memory	Shared	Shared	64K x 32	4K x 30
Wait States:	-	Yes	Yes	-
DMA:	PIO	PIO	Yes	External
Accumulators:	4 x 40	4 x 40	2 x 40	1 x 24
PIO:	1 x 8	1 x 16	1 x 32	1 x 8
SIO:	1	1	2	1
1K Complex FFT:	14ms	4ms	N/A	N/A
Process:	1.5 NMOS	0.75 CMOS	1.3 CMOS	1.3 CMOS
Package:	40 DIP 100 PGA	133 PGA -	208 PGA -	135 PGA 80 FPT
Estimated 1K Price:	$170	$300	$500	$30

(Continued)

Table 2 (Continued)

DSMPU Product Comparison

Supplier:	Motorola	NEC	NEC	Oki
Part:	56000	77230	77220	6992
Word:	24 Int	32 FP	24 Int	22 FP
Word Format:	N/M	24E8	N/M	16E6
Cycle Time:	75ns	150ns	122ns	100ns
Clock:	26.7 MHz	13.3 MHz	16.4 MHz	40 MHz
Internal RAM:	256 x 24 x 2	512 x 32 x 2	256 x 24 x 2	128 x 22 x 2
External Data RAM:	64K x 24 x 2	8K x 32	8K x 24	64K x 22
Internal Program ROM:	2K x 24	2K x 32	2K x 32	1K x 32
Internal Data ROM:	256 x 24 x 2	1K x 32	1K x 24	Shared
External Program Memory	64K x 24	4K x 32	4K x 32	64K x 32
Wait States:	Yes	No	No	No
DMA:	No	No	No	External
Accumulators:	2 x 56	8 x 55	8 x 47	2 x 22
PIO:	1 x 8	Shared	Shared	Shared
SIO:	2	1	1	-
1K Complex FFT:	2.6ms	12.5ms	10ms	7ms
Process:	1.5 CMOS	1.75 CMOS	1.75 CMOS	2.0 CMOS
Package:	88 PGA 88 SLAM	68 PGA	68 PGA 68 PLCC	132 PGA -
Estimated 1K Price:	$120	$115	$70	$165

(Continued)

Table 2 (Continued)

DSMPU Product Comparison

Supplier:	Oki	TI	Zoran
Part:	699210	320C30	VSP325
Word:	22 FP	32 FP	32 FP
Word Format:	16E6	24E8	24E8
Cycle Time:	100ns	60ns	80ns
Clock:	40 MHz	33 MHz	25 MHz
Internal RAM:	256 x 22 x 2	1K x 32 x 2	64 x 32 x 2
External Data RAM:	64K x 22	16M x 32 8K x 32	64M x 32
Internal Program ROM:	2K x 32	4K x 32	-
Internal Data ROM:	Shared	Shared	1K x 32 x 2
External Program Memory	Shared	Shared	Shared
Wait States:	Yes	Yes	Yes
DMA:	External	Yes	External
Accumulators:	2 x 22	8 x 40	2 x 32
PIO:	Shared	Shared	Shared
SIO:	-	2	-
1K Complex FFT:	7ms	3ms	1.7ms
Process:	1.5 CMOS	1.0 CMOS	1.5 CMOS
Package:	84 PLCC 100 Flat	180 PGA 100 PGA	84PGA -
Estimated 1K Price:	$80	$400	$395

N/A = Not Available
N/M = Not Meaningful

Notes: Fastest parts are shown. FFT benchmarks are not consistent as to radix 2 or radix 4, including or not including bit reversal, including or not including data transfer onto and off chip. Price is estimated only.

Source: Dataquest
February 1988

Dataquest
a company of The Dun & Bradstreet Corporation

Research Newsletter

SIS Code: SIS/DSP Newsletters: February 1988-1

NEW FLOATING-POINT DSP PRODUCTS THREATEN TI'S LEAD

SUMMARY

With the 1983 introduction of its first digital signal processing product, the TMS32010, Texas Instruments (TI) established a seemingly unshakeable lead in the emerging digital signal processing (DSP) market. Today, the heavy investments made by TI and others in educating the technical community to the wonders of DSP are paying off. DSP product use is becoming more pervasive. In addition, DSP product technology is currently evolving from 16-bit integer products to high-performance 32-bit floating-point products. As highlighted in Table 1, 1988 will be a banner year for DSP microprocessor (DSMPU) product introductions.

Table 1

A Sampling of High-Performance DSMPU Products

Company	Product	Expected Availability	Description
AT&T	DSP32	Available now	32-bit Floating Point
	DSP32C	Q2 1988	32-bit Floating Point
Fujitsu	MB86232	Q1 1988	32-bit Floating Point
	MB86220	Q3 1988	24-bit Floating Point
Motorola	DSP56000	Available now	24-bit Integer
NEC	uPD77230	Available now	32-bit Floating Point
	uPD77220	Q2 1988	24-bit Integer
Oki	M6992	Available now	22-bit Floating Point
	M699210	Q1 1988	22-bit Floating Point
TI	TMS320C30	Q2 1988	32-bit Floating Point
Zoran	VSP325	Q3 1988	32-bit Floating Point

Source: Dataquest
February 1988

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398, (408) 437-8000, Telex 171973, Fax (408) 437-0292

What does this mean for Texas Instruments? It means that, for the first time, TI may not be alone with the latest technology in the DSP market. TI's TMS320C30 will most certainly experience heavy competition from this new crop of products and the competitors that TI faces are not new to this market, either. These vendors are all on their second- or third-generation DSP products.

In the last five years, TI has built a strong customer-support structure. If the TMS320C30 can be delivered close to its targeted introduction date and for its projected price, TI shouldn't lose much ground at the high end of the DSP market. However, the new midrange 22- and 24-bit products, which promise 32-bit floating-point performance at 16-bit integer prices, do pose a threat in such emerging new DSP markets as digital audio.

MARKET OUTLOOK

A half dozen vendors are trying to get a jump on Texas Instruments and stake out some high ground in the digital signal processing market. Their products fall into the following two broad categories:

- High-performance 32-bit floating-point DSMPUs
- Midrange 22- and 24-bit floating-point DSMPUs

First, there are 32-bit floating-point superchips that will compete with TI's announced TMS320C30. These DSMPUs are some of the most powerful silicon yet produced. They can multiply two numbers as fast as a Weitek arithmetic processor, have more transistors than Intel's 80386, and will replace some building block systems with a single chip.

Secondly, there is emerging a class of 22- and 24-bit floating-point DSMPUs that promise floating-point capability at the price of midrange, 16-bit integer DSP chips. Also not to be overlooked in this category are the 24-bit integer processors from Motorola and NEC. These products, while lacking floating-point capability, do offer the customer another 8 bits of dynamic range to play with.

Floating-point processors can be both easier to use and more powerful than fixed-point processors—a great combination! All this activity in floating-point products raises two interesting market-related questions:

- How fast will customers move to these parts?
- How will they affect TI's dominance of the DSP market?

In this newsletter, we will examine the products listed in Table 1 with respect to their market potential and probable effect on Texas Instruments' lead in this market. Located at the end of this newsletter, Table 2 compares and contrasts the features of each product reviewed.

High–End Market Prognosis

The new 32-bit floating-point products will find their first uses in applications that currently are implemented by building blocks (i.e., high-performance bit slices and multipliers). These areas are:

- High–end graphics
- Imaging
- Array processors
- Military systems

These applications are more driven by performance than by cost. Thus, a $300 or $400 DSP product may well provide a cost-effective solution. Because performance is what counts in these areas, the competition is just getting started for the 32-bit floating-point market. Products with sub-100-nanosecond cycle times—such as those from AT&T, Fujitsu, and Texas Instruments—look like contenders.

While this market may be bounded by building block applications in the short term, one would be foolish to expect that to last. Forces that will help move these products into a broad spectrum of applications include:

- Price reductions
- Availability of C compilers
- An increase in customer awareness of product capabilities

The bright spot for TI's competitors is that engineers now using building blocks are perhaps the most sophisticated consumers of DSP products. They will tend to choose DSP products mainly because of performance, and they will be less influenced by TI's imposing presence and customer-support structure.

Market Participants

AT&T. AT&T's second-generation 32-bit floating-point DSP product, the DSP32C, appears competitive from a hardware standpoint; it is twice as fast as its predecessor. AT&T's earlier product and NEC's initial 32-bit product, the uPD77230, are both too slow in comparison with the newer products and limited in external memory addressing capability.

Perhaps more importantly, AT&T is providing serious software support to its new product. The DSP32C's 32-bit arithmetic unit is limited to floating-point operations, however, while the Fujitsu and Texas Instruments products can also perform 32-bit fixed-point adds, subtracts, and logical operations.

Fujitsu. Fujitsu's MB86232 will likely be the first of this new generation of products. This product and the Zoran VSP325 are the only devices that directly handle the IEEE 754 single-precision floating-point format. Additionally, the MB86232 has highly parallel memory addressing. A big "if" is whether or not Fujitsu can overcome the somewhat stereotypical Japanese company's weakness in supporting complicated processors.

Texas Instruments. Texas Instruments clearly has the lead in the DSMPU market today. Its latest product, the TMS320C30, should be as fast as the competitors' chips with more on-chip memory. Additionally, TI's software experience and extensive customer-support network will work to the company's advantage.

It is probably realistic to assume that the high-end 32-bit market will develop slowly. And, as stated earlier, if the TMS320C30 can maintain its targeted introduction date and projected price, TI shouldn't lose much ground in this market. The only question concerns how imposing TI's lead will be. However, should the introduction date slip appreciably, TI may find itself sharing more of the market than it had expected or wanted.

Zoran. Zoran's VSP325, like its 16-bit predecessor, is hardwired to perform DSP functions. This gives the VSP325 the highest performance available for applications that it fits, but this also narrows its appeal quite a bit. However, because the 32-bit DSMPU market is a performance-driven market, Zoran has a chance to do better than it did in the 16-bit DSMPU market.

High-End Pricing

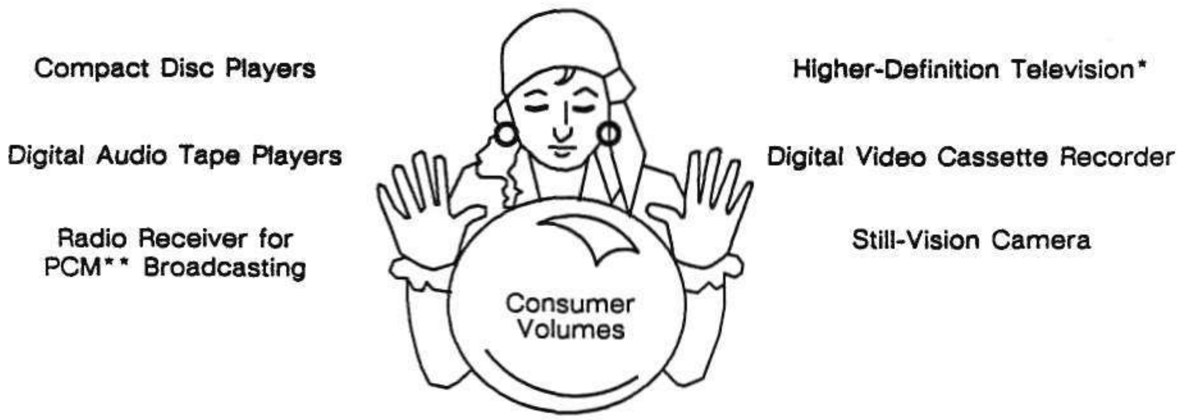
Initial samples of some of these 32-bit floating-point DSMPUs may cost more than $1,000 apiece, which is a serious price for an integrated circuit. Prices are expected to drop below $500 each (in 1K quantities) before the end of the year—still a significant price!

Midrange Market Prognosis

The threat to Texas Instruments' market domination comes not so much from the flagship 32-bit products as it does from the new 22- and 24-bit floating-point products, such as those from Fujitsu and Oki. If these products can be delivered for the price of midrange 16-bit integer DSMPUs, they pose a very attractive option. Even with a qualitatively more advanced architecture and a superior price/performance ratio, however, strong customer support and an assertive selling effort will be needed to capitalize on this opportunity. Figure 1 illustrates the potential DSP opportunities in consumer electronic products that could fuel the development of a midrange DSP market.

Figure 1

DSP Opportunities in Consumer Products



*Refers to improved-definition (IDTV), extended-definition (EDTV), and high-definition television (HDTV) standards.

** Pulse code modulated.

Source: Dataquest
February 1988

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Alice K. Leeper

Table 2

DSMPU Product Comparison

Supplier:	AT&T	AT&T	Fujitsu	Fujitsu
Part:	DSP32	DSP32C	86232	86220
Word:	32 FP	32 FP	32 FP	24 FP
Word Format:	24E8	24E8	24E8	18E6
Cycle Time:	160ns	80ns	75ns (2 mac)	80ns
Clock:	25 MHz	50 MHz	40 MHz	25 MHz
Internal RAM:	512 x 32 x 2	512 x 32 x 3	512 x 32	256 x 24 x 2
External Data RAM:	14K x 32	4M x 32	1M x 32	64K x 24
Internal Program ROM:	512 x 32	1K x 32	1K x 32	2K x 30
Internal Data ROM:	Shared	Shared	Shared	Shared
External Program Memory	Shared	Shared	64K x 32	4K x 30
Wait States:	-	Yes	Yes	-
DMA:	PIO	PIO	Yes	External
Accumulators:	4 x 40	4 x 40	2 x 40	1 x 24
PIO:	1 x 8	1 x 16	1 x 32	1 x 8
SIO:	1	1	2	1
1K Complex FFT:	14ms	4ms	N/A	N/A
Process:	1.5 NMOS	0.75 CMOS	1.3 CMOS	1.3 CMOS
Package:	40 DIP 100 PGA	133 PGA -	208 PGA -	135 PGA 80 FPT
Estimated 1K Price:	$170	$300	$500	$30

(Continued)

Table 2 (Continued)

DSMPU Product Comparison

Supplier:	Motorola	NEC	NEC	Oki
Part:	56000	77230	77220	6992
Word:	24 Int	32 FP	24 Int	22 FP
Word Format:	N/M	24E8	N/M	16E6
Cycle Time:	75ns	150ns	122ns	100ns
Clock:	26.7 MHz	13.3 MHz	16.4 MHz	40 MHz
Internal RAM:	256 x 24 x 2	512 x 32 x 2	256 x 24 x 2	128 x 22 x 2
External Data RAM:	64K x 24 x 2	8K x 32	8K x 24	64K x 22
Internal Program ROM:	2K x 24	2K x 32	2K x 32	1K x 32
Internal Data ROM:	256 x 24 x 2	1K x 32	1K x 24	Shared
External Program Memory	64K x 24	4K x 32	4K x 32	64K x 32
Wait States:	Yes	No	No	No
DMA:	No	No	No	External
Accumulators:	2 x 56	8 x 55	8 x 47	2 x 22
PIO:	1 x 8	Shared	Shared	Shared
SIO:	2	1	1	-
1K Complex FFT:	2.6ms	12.5ms	10ms	7ms
Process:	1.5 CMOS	1.75 CMOS	1.75 CMOS	2.0 CMOS
Package:	88 PGA 88 SLAM	68 PGA	68 PGA 68 PLCC	132 PGA -
Estimated 1K Price:	$120	$115	$70	$165

(Continued)

Table 2 (Continued)

DSMPU Product Comparison

Supplier:	Oki	TI	Zoran
Part:	699210	320C30	VSP325
Word:	22 FP	32 FP	32 FP
Word Format:	16E6	24E8	24E8
Cycle Time:	100ns	60ns	80ns
Clock:	40 MHz	33 MHz	25 MHz
Internal RAM:	256 x 22 x 2	1K x 32 x 2	64 x 32 x 2
External Data RAM:	64K x 22	16M x 32 8K x 32	64M x 32
Internal Program ROM:	2K x 32	4K x 32	-
Internal Data ROM:	Shared	Shared	1K x 32 x 2
External Program Memory	Shared	Shared	Shared
Wait States:	Yes	Yes	Yes
DMA:	External	Yes	External
Accumulators:	2 x 22	8 x 40	2 x 32
PIO:	Shared	Shared	Shared
SIO:	-	2	-
1K Complex FFT:	7ms	3ms	1.7ms
Process:	1.5 CMOS	1.0 CMOS	1.5 CMOS
Package:	84 PLCC 100 Flat	180 PGA 100 PGA	84PGA -
Estimated 1K Price:	$80	$400	$395

N/A = Not Available
N/M = Not Meaningful

Notes: Fastest parts are shown. FFT benchmarks are not consistent as to radix 2 or radix 4, including or not including bit reversal, including or not including data transfer onto and off chip. Price is estimated only.

Source: Dataquest
February 1988

Dataquest
a company of
The Dun & Bradstreet Corporation

Research Newsletter

SIS Code: MC3 1988 Newsletters: April
0000046

NATIONAL'S NEW PRINTER PROCESSOR: A TASK SOLUTION ENGINE

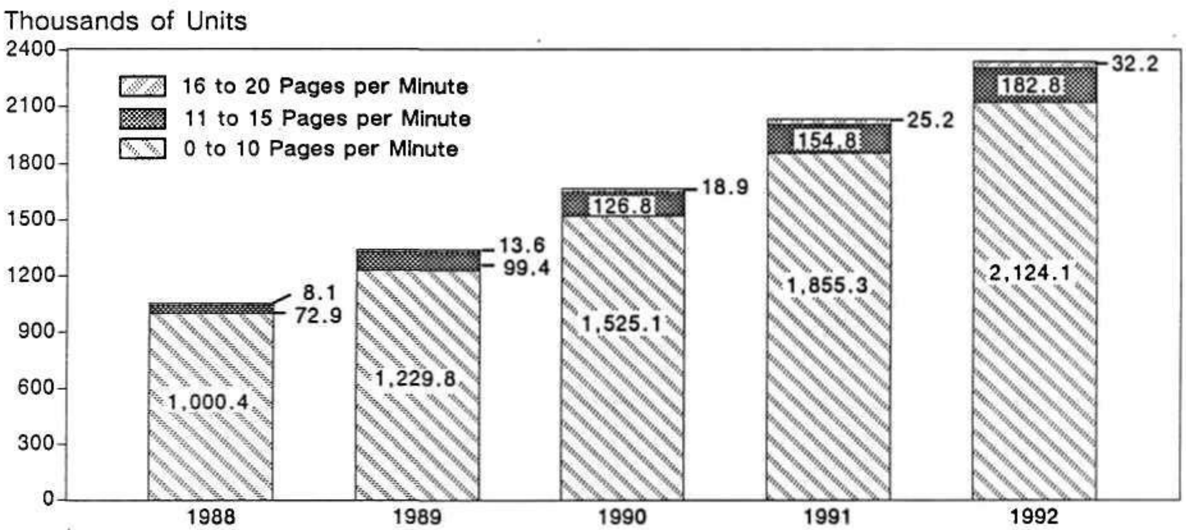
SUMMARY

On March 17, National Semiconductor announced the NS32CG16 printer/display microprocessor. The NS32CG16 is derived from National's Series 32000 family of 32-bit microprocessors. Dataquest believes that this trend toward specialized processing engines will escalate as applications demand more specific features. This is especially true as the processor/controller boundary fades away.

Regarding the 0- to 20-page-per-minute (ppm) page printer and other imaging peripherals as well, this tailored processor promises to keep equipment manufacturers' profits alive while maintaining an execution performance comparable with that of more expensive, high-end processors. Figure 1 illustrates the potential market size in units for these processors.

Figure 1

Worldwide Page Printer Shipment Forecast



Source: Dataquest
April 1988

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WHAT IS A PRINTER/DISPLAY PROCESSOR?

A printer/display processor is a type of task solution engine. Dataquest defines this term as a computing engine, be it a processor or controller, resolved for a given class of tasks. Dataquest also believes that the boundary between microprocessors and microcontrollers is disintegrating as applications change form. As this phenomenon occurs, more of the powerful processor architectures will infiltrate dedicated control applications. The difference becomes a personality change to an engine, tailoring it for a unique processing job.

Design tool advancements and architectural flexibility permit the specialization of a processor's nature in terms of its computing resources. As an example, the NS32CG16 is an architectural variation of National's existing 32-bit, Series 32000 microprocessor family. Clearly, a trend is in place for further processor products to be focused on a specific task through "special training."

Why Develop a Specialized Processor?

As National is indicating in its marketing campaign, existing high-end microprocessors in standard form may simply be too expensive for more cost-sensitive applications.

A possible solution? Take an established processor architecture, add just the right instructions and application-dedicated features for the task at hand, and sell it as a task solution engine. Excellent idea.

The Technical Rationale: Clear-Cut Speed

Regardless of the printing technology used, there exists a distinct need to keep the page output in unison with the data output of the image processor. Electronic printer engines--such as laser printer engines--can lay down thousands of characters, or millions of dots for graphics, per second.

The controlling processor must be able to decode incoming data for printing, execute the page layout code in memory, and then feed the printing engine quickly enough to create an unbroken page image.

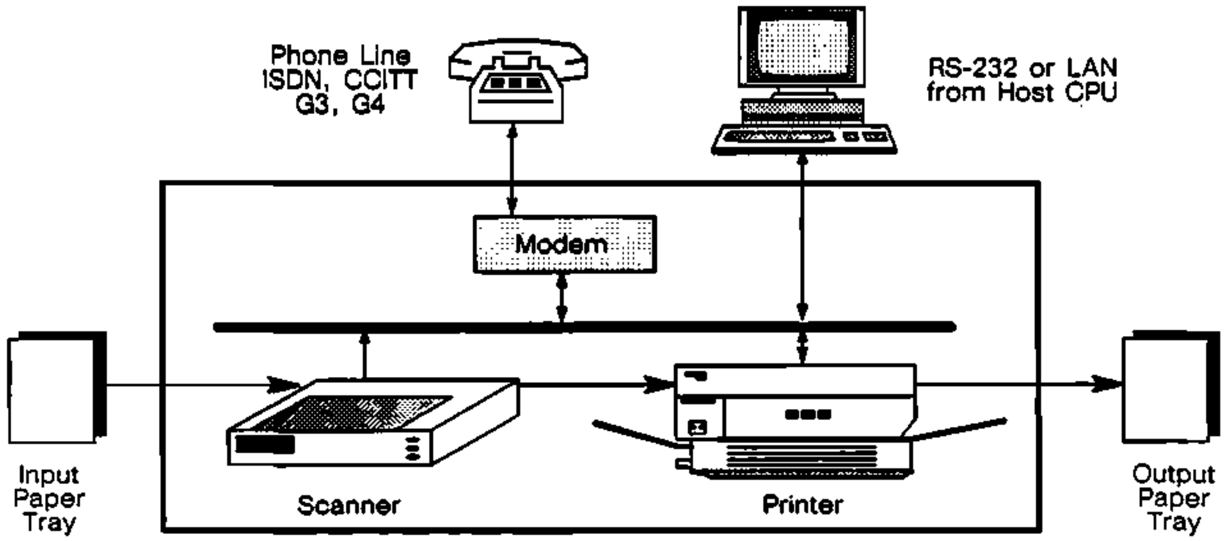
Figure 2 indicates the typical imaging and communications hardware blocks that an integrated imaging peripheral might contain. Within this "system" is the need for the cost-effective specialized processor.

To meet this need, National's NS32CG16 is:

- Designed for page-oriented printing technologies
- Designed for use with low-cost DRAM devices
- Compatible with other Series 32000 processors
- Priced inexpensively in relation to alternative processor solutions

Figure 2

An Integrated Imaging Peripheral



Source: National Semiconductor

A Case of Joint Development

National arrived at this architectural solution after working closely with Canon of Japan and several other major printer manufacturers to better understand their unique problems and needs. Here is a case in point in which joint development between supplier and customer was the answer to a question of applicability, resulting in success for both parties. Dataquest believes that more tailored processing solutions will emerge as specific market leaders, especially in high-volume equipment areas, draw upon knowledgeable semiconductor suppliers for help.

PRINTER PRODUCT POSITIONING

Nearly all current page printer models use a Motorola MC68000 microprocessor as the heart of their controller design. The combination of its relatively low cost, typically about $10 in reasonable quantities, and inherent architecture provide the platform to design a moderately powerful controller commensurate with the needs of the rapidly expanding, less than 10-ppm page printer market. The great majority of these units are being sold for less than $2,000, and the outlook is for price versus performance points to continue downward during the next few years, as shown in Table 1.

While there are printers that currently use more powerful microprocessors than the ubiquitous 68000, relatively few printer vendors or end users, can justify a product containing a Motorola MC68020 or an Intel i80386 with costs in excess of $200 each. Selling in the $25 to $35 range, the NS32CG16 provides printer performance closer to what is achievable with a 68020, at a price nearer the price of the 68000.

Table 1

North American, 0– to 10–ppm, Page, Nonimpact, Plain Paper (PNPP) Printer Forecast

	1987	1988	1989	1990	1991	1992
Units(K)	609.0	1,000.4	1,229.8	1,525.1	1,855.3	2,124.1
ASP($K)	2.7	2.5	2.4	2.2	2.0	1.9
Revenue($M)	1,644.3	2,539.0	2,928.1	3,224.8	3,771.9	4,037.9

Source: Dataquest
April 1988

The NS32CG16 promises performance that should satisfy the needs of printers with throughputs of up to 20 ppm at a resolution of 300 dots per inch (dpi). Its scalable architecture will allow very fast BITBLT operations through an optional DP8510 BITBLT processing unit, as well as fast PostScript outline font calculations by supporting the NS32081 and NS32381 Floating Point Units. In addition, a wide selection of NS32CG16 peripheral chips will support EPROM, EEPROM, UART, DMA, and interfaces including RS–232, Centronics, AppleTalk, IBM LAN, 3270, Ethernet, Cheapernet, and Starlan.

The NS32CG16 has been configured to operate with the slower and less costly 120 to 150ns DRAMs. Further, National Semiconductor claims that controller performance can be up to six times faster than that of a comparable controller with a 68000 design, for approximately only twice the cost.

DATAQUEST ANALYSIS

National Semiconductor has apparently done an excellent job of analyzing the total market and identifying specific high–volume applications, such as page printers, then committing to understanding the requirements of the leading vendors and developing a cost–effective solution not available elsewhere. The NS32CG16 is poised for acceptance not only by the page printer vendors, but also by the high–performance ink jet and serial, impact, dot matrix printer vendors that are increasingly duplicating the functions of the page printers at lower price points and with enticingly higher potential volumes. In addition, as the distinction between printer, plotter, and facsimile output continues to become less and less, the total market for microprocessors, such as the NS32CG16, will undoubtedly grow even more.

Similarly, the image–processing requirements for scanners and computer/terminal displays continue to increase in complexity. As these systems begin to resemble their hard–copy brethren in more detail, the potential for the NS32CG16 becomes even brighter.

Assemble an Awareness

Performance–conscious, yet cost–conscious, printer engine suppliers should be aware of the alternatives available to them as more sophisticated control electronics—such as the NS32CG16 printer processor—emerge. In a similar manner, semiconductor manufacturers seeking to enter a targeted market, such as integrated imaging systems, should work closely with selected customers on development. Dataquest believes that a win–win market is ultimately the best solution.

Brand A. Parks
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Research Newsletter

SIS Code: GA3/MC2 1988 Newsletters: March

32-BIT GaAs RISC uP DEBUTS AT 35th ISSCC

INTRODUCTION

The International Solid State Circuits Conference (ISSCC), held February 17 through 19, 1988, in San Francisco, celebrated its 35th year of reporting continuing progress in semiconductor technology. One hundred papers, coauthored by more than 600 engineers and scientists, and 10 informal discussion sessions enlightened a record audience. This newsletter summarizes the reported progress in GaAs technology and provides additional information on progress in silicon technology for comparison purposes.

PROGRESS IN GaAs TECHNOLOGY

The most significant GaAs development discussed at ISSCC was Texas Instruments' 32-bit GaAs RISC (reduced instruction set architecture) microprocessor. This session was attended by more than 1,000 persons. Other developments in compound semiconductor technology included Rockwell's 150-mops (millions of operations per second) GaAs ALU (arithmetic logic unit), Hughes' 25-GHz frequency dividers using 0.2u design rules and InP wafers, Fujitsu's HEMT data register, Matsushita's 125ps-resolution programmable delay timer, and a 26dB wideband D-MESFET amplifier. One of the evening sessions was devoted to the never-ending discussion of GaAs versus silicon for high-speed analog ICs.

TI Builds 32-Bit RISC Chip

A GaAs RISC-architecture 32-bit microprocessor chip, described by Texas Instruments (TI), represents the most complex logic IC reported to date by the compound IC industry. The chip contains 12,872 bipolar gates implemented in HI^2L (heterojunction integrated injection logic) circuitry, which is a form of RTL (resistor-transistor logic). The initial design, based on 2u-gate and 8u-metal-pitch rules, resulted in a chip size of 445 x 415 mils. TI has demonstrated the device at a 1-GHz clock rate and up to SDI radiation levels. The chip is functional at power supply levels from 1.5 to 4.0 volts; nominal operation is expected at 2.5 volts.

TI used SPICE and other CAD tools to develop the chip family. Some of the models were developed at the company's Bedford, England, design facility. Many of the CAD tools, such as the autorouter, were adapted directly from VHSIC CAD software.

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A redesigned version is to be complete in June 1988; it will use 1.5u gates and 2.5u-wide, 2.5u-spaced two-layer metal to achieve 160ns gate speeds on a 300 x 300 mil^2 die. Performance of 200 mips is expected, limited primarily because the critical CPU path consists of 30 gate levels. TI has achieved 250ps gate delays at 2mW/gate with the 2u process. Yield of 2 percent per lot of 100 chips was experienced. Projected yield for the 1.5u version is 8 percent, based on test array runs made to date.

The chip is intended to function as part of a microcomputer containing two cache memories, two MMUs, and a processor board interface. The system can be expanded with as many as six floating-point coprocessors. TI performed the work jointly with Control Data Corporation (CDC) under a DARPA contract, partially supported by TI and CDC funding. McDonnell Douglas is a competitor on the program.

Rockwell ALU Performs at 150 mops

Rockwell International Corporation presented results of its development of an 8-bit-slice ALU architecture. The IC contains 9,400 transistors and 3,010 diodes comprising BFL (buffered FET logic) gates. The chips are fabricated with 1u D-MESFET, non-self-aligned, ion-implanted technology. Die size is 4.9 x 3.9 mm^2 with 4u-pitch first-layer metal and 6u-pitch second-layer metal. At 9.2 watts P_D, the ALU performs add instructions in 6.6ns.

The chip includes a 31-word, 8-bit register file. A three-bus architecture was used to enhance logic efficiency. Hardwired algorithms include modified Booth multiplier, nonresidual divider, and variable bit-length operations. Single-step shifters (left and right 1, 2, 4, 8) were used instead of a barrel-shifter, for reduced complexity.

The present chip design is sensitive to V_{DD} supply variations; this parameter is presently set at -2.5 -0.1, +0.5 volts. Within this limit, yields have been very good at 18 percent for 150-mops devices and 22 percent for the low-power version. Table 1 summarizes the major characteristics of the Rockwell design and provides important data for comparative analysis of the Rockwell and TI/CDC chips.

Table 1

GaAs Microprocessor IC Comparison

Characteristic	Rockwell Design	TI/CDC Design
Function	8-bit ALU (1750A type)	32-bit RISC uP
Architecture	3-bus bit slice (expandable to 16 bits)	6-stage pipeline
Performance	150 mops	200 mips

(Continued)

Table 1 (Continued)

GaAs Microprocessor IC Comparison

Characteristic	Rockwell Design	TI/CDC Design
Operations	Add, subtr., mod. Booth multiply, divide, bit operations	4 address modes, 16 ALU and 5 control instructions, 10 memory instructions
Power (Watts)	4.2 (low), 9.2 (high)	Estimated 20 max.
Voltage(s)	V_{DD}=+2.5, V_{SS}=-2.0, V_{ref}=-0.1 volts	V_{CC}=+2.5±1.0 volts
Die size	193 x 154 mils 4.9 x 3.9 mm	300 x 300 mils 7.6 x 7.6 mm
Chip complexity	9,400 transistors, 3,000 diodes	12,872 gates (typical gate is 1 transistor and 5 resistors)
I/Os	64 (signal) 29 (power/ground)	256 (signal) 70 (power/ground)
Process	GaAs D-MESFET	GaAs HBT
Min. feature size	1.0u	1.5u
Metal width/spacing	2u/2u (1st layer) 3u/3u (2nd layer)	2.5u/2.5u (1st layer) 2.5u/2.5u (2nd layer)
Logic form	BFL	I^2L (modified RTL)
Cell speed (type)	120ps (register)	160ps (gate)
Cell power	1.6mW	2mW
Yield data	18 percent	Experienced 2 percent, projected 8 percent
Minimum system	Must add controller, RAM	Must add MMU, 1K cache ICs
Other	5-xstr/3-diode cells	Critical path--30 gates; Ti/Pt/Au Schottky metal

Source: Aztek Associates

Hughes Develops 0.2u HEMT, 25-GHz Dividers

Hughes Research Laboratories has developed a 0.2u modulation-doped AlInAs/GaInAs process, which enables it to demonstrate BFL and CEL frequency dividers at 25 GHz. Table 2 compares the two approaches.

Table 2

Hughes InP HEMT Frequency Dividers

Logic Type	Speed	Power
BFL (buffered FET logic)	25.2 GHz	450mW
CEL (capacitor enhanced logic)	25.4 GHz	63.8mW

Source: Dataquest
March 1988

The epitaxial process developed by Hughes includes the following layers, starting with the substrate and building to the top:

- InP substrate
- AlInAs buffer layer
- 80nm GaInAs channel layer
- 2nm undoped AlInAs spacer
- n^+ 1nm doped AlInAs donor layer
- 20nm undoped AlInAs Schottky layer
- n^+ GaAlAs contact layer

Fujitsu HEMT Register Uses 0.5u Geometries

Fujitsu Laboratories Ltd. has developed a 36-bit (4x9) register IC using high electron mobility transistor (HEMT) structures and 0.5u minimum geometries. The metal pitch is 4u, with 2u width and 2u spacing. The HEMT layers are grown by MBE, and e-beam lithography is used. Transistor cutoff frequency is 31 GHz. Unloaded gate delay is 19ps at room temperature; average gate delay is 43ps (ring oscillator) and 86ps for a fan-in = 3, fan-out = 3, 1mm interconnection load. The 6.1 x 6.2 mm^2, 1137-gate chip is ECL compatible. Power dissipation is more than 4 watts. This development is part of the Japan National Research and Development Program on Scientific Computing Systems.

Matsushita's Programmable Timer Has 125ps Resolution

Using non-self-aligned 1u GaAs MESFET processing, Matsushita Electronics Research Laboratory has demonstrated an ECL-compatible programmable timer with 125ps resolution and ±125ps linearity. The die includes a 7-bit digital-to-analog converter (DAC), comparators, flip-flop, and current switches. Power dissipation of the $3.3 \times 3.65\ mm^2$ chip is 0.9 watts.

Wideband Amplifier Features 26dB Gain at 2.5 GHz

The University of California, Los Angeles, reported developing a high-performance amplifier, supported by TriQuint Semiconductor Corporation. This amplifier has 26dB gain, 6.5dB noise figure, 3.2-GHz bandwidth and 10-dBm saturation power. The $1mm^2$ die dissipates 850mW.

PROGRESS IN SILICON TECHNOLOGY

Ninety-five percent of the papers at this conference were devoted to silicon technology. The major topics included:

- High-speed circuits, data recovery, microprocessors
- Analog devices and techniques, including A/D conversion
- Video signal processors
- CCD and sensors
- Telecom circuits
- ASICs, including gate arrays
- DRAMs, SRAMs, and nonvolatile memories

Although GaAs and InP devices dominated the high-speed results presented at ISSCC, significant progress was reported by Fujitsu, General Electric (GE), LSI Logic, and others. Fujitsu described a 4-GHz optical repeater chip set. LSI Logic presented a 30-mflops, 32-bit CMOS floating-point processor design. GE described its 40MHz, 32-bit CPU chip with instruction cache.

Hitachi, National Semiconductor, and TI each described BICMOS 256Kbit ECL SRAMs. The Hitachi and TI parts feature 8ns address access times; the National design has 12ns access time. Three of the papers featured 16Mb DRAMs. These three papers were presented by employees of Japanese companies—Hitachi, Mitsubishi, and Toshiba. Some of the RAM designs are oriented toward video and graphics signal processing applications.

A paper authored by Lattice Semiconductor engineers described a 9ns CMOS EEPLD (electrically eraseable programmable logic device). The architecture includes an industry-standard eight-input programmable AND array and a fixed OR array of eight product terms. The eight I/Os are also individually programmable.

Video signal sensor presentations included a paper by Toshiba devoted to a CCD image sensor for HDTV applications. The imager contains two million pixels in a 1,920 (horizontal) x 1,036 (vertical) configuration, on a 14 x 7.8mm die (adaptable to one-inch optical format). The charge readout frequency is 74.25 MHz, in the proposed HDTV format. Demonstrated sensitivity is 210nA/lux, several times that of conventional TV CCDs.

A novel solution to the difficult problem of integrating CMOS transistors onto a thermal printer head was described by Sony Corporation. The solution involves a line-type chip measuring 27 x 4mm. It contains 11,448 CMOS transistors and 216 heating-element dots (density 8 dots/mm), and it uses doped polysilicon as the heating element material.

Regarding IC device feature sizes, the environment will soon become a submicron world. While GaAs has set the pace, silicon suppliers are quick to take advantage of emerging production technology. This is, of course, essential for the production of leading-edge, high-density chips; this fact was underscored by many companies' presentations.

SUMMARY AND CONCLUSIONS

The 1988 ISSCC emphasized the continuation of intense competition in the IC industry, with advances reported across the entire range of chip functions. The mainstream is shifting rapidly to submicron geometries. A new variable to competition is evident with the arrival of practical GaAs LSI chips. The designers of the next round of personal computers and workstations have an unprecedented array of devices from which to choose, as does the entire range of electronics equipment houses.

GaAs LSI is here; the reproducibility of 8-bit ALUs and 32-bit microprocessors has been demonstrated. Suppliers of leading-edge-performance systems would do well to rethink their hardware and marketing strategies, based on what their competitors are now capable of offering to the world's markets.

Gene Miles

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Research Newsletter

SIS Code: SIS/MCU Newsletters: January 1988-1

RISC ARCHITECTURE: A PROCESSING PANACEA OR A COMPETITIVE MARKET MEASURE

INTRODUCTION

Since the beginning of the computing era, man has pursued the ideal of the fastest processing machine. Many seem to believe that the answer to this pursuit is reduced-instruction-set computing (RISC) architecture. Today, two schools of thought exist on whether RISC or complex-instruction-set-computing (CISC) is the solution to the quest. Probably, a suitable coexistence is the best answer.

This newsletter will define RISC, outline the market participants and products, submit a user perspective, and provide a market forecast.

WHAT IS RISC?

The definition of RISC lends itself to the tenet that simpler is better. By design, not only is the instruction set reduced, but so is the complexity of the control logic and of other internal facilities. In accordance with that belief, RISC machines have architectures that are typically hardwire controlled rather than microcoded. They perform simple loading and storing operations via a very fast set of on-chip registers, using a sophisticated memory hierarchy to maintain efficiency.

The current objective of RISC is to execute one instruction per clock cycle in a sustained manner. As technology progresses, this rate could be reduced to one instruction per partial cycle or even multiple instructions per cycle.

Also, it has been determined that about 80 percent of an average computational task is performed by 20 percent of the instruction set. This statistic formed the foundation of a simplified instruction set with the goal of reducing the number of clock cycles per instruction executed.

The Technical Aspects

Performance is clearly the key in virtually all semiconductor devices. Moreover, in RISC designs, this has never been more true. Effective processing speed, as measured in millions of instructions per second (mips), is the yardstick by which true performance is measured. However, the cost of those desired mips is becoming the next largest parameter for a selection decision.

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The following architectural aspects form the basis of a RISC design:

- Registers
- Cache
- Pipeline
- Floating-point unit

Registers

All computing engines have a register set. However, in a RISC design, the registers are key to extremely quick data handling. The software parameters that would normally be in system memory until needed are now kept in the fast-register array for accelerated access. These fast registers must be capable of holding variable-length operands as large as the maximum word length (typically 32 bits), and they also must be of sufficient quantity to make context switching and exchanges efficient. In the current RISC engines, this quantity could be from 27 to more than 190 individual register locations.

Cache

Earlier, in the section describing the RISC definition, the concept of sophisticated memory hierarchies was mentioned. Critical to this issue is cache implementation.

A highly efficient caching scheme is mandatory. It could make or break the overall design, due to the role it plays in increasing processing speed. Cache, therefore, should have the following attributes:

- High-speed SRAM (25ns or less)
- Easy access (dual-port design)
- Flexible coherency scheme (maximum hit rate)

A nascent trend in microprocessor engines is toward providing separate instruction and data caches combined with on-chip memory management. Virtual-to-physical address translation is typically a time-consuming activity; therefore, it is highly desirable to pipeline this process to reduce any system access delays.

Pipeline

The instruction pipeline plays a vital role in ensuring instruction execution speed. Multistage pipelines (most are fourstage) must now be more than just queues. Built-in intelligence is necessary to limit or eliminate stalls.

The predictability of an operation, as determined by an optimizing compiler, results in a more efficient instruction stream for the pipeline to handle. Because some operations may indeed take more than one cycle, the pipeline mechanism must be able to do the following:

- Arbitrate program branches
- Manage temporary holding of a datum for a subsequent operation

Floating-Point Unit

In RISC engines, as in conventional microprocessors, the floating-point unit (FPU) for high-level arithmetic functions is typically a separate device. However, unlike conventional CISC designs, the interface and, therefore, operation of the floating-point unit with the integer CPU must be different. There can be little if no delay in execution. Ideally, overlapped floating-point operations within the FPU should occur, and the results should be delivered in a transparent manner for use by the integer CPU. The FPU might also require its own direct access to the caches to facilitate data availability.

WHAT PRODUCTS ARE AVAILABLE AND FROM WHOM?

Currently, several companies produce a RISC or RISC-like microprocessor engine. The implementations vary, but the general theme remains the same. Table 1 lists the current market participants and their announced products.

Table 1

RISC Microprocessor Suppliers and Products

Company	Product
Acorn Ltd.	ARM
AMD	Am29000
BIT	SPARC* version (ECL)
Cypress	SPARC version (CMOS)
Fujitsu	MB86900 (SPARC)
IDT	R2000 second source
INMOS	T414, T800
Integraph	C300 (Clipper)
LSI Logic	R2000 second source
MIPS Computer Systems	R2000
Motorola	Name not announced
Performance	R2000 second source
VLSI Technology Inc.	VL86C010 (ARM)

*SPARC is a design originated by Sun Microsystems

Source: Dataquest
January 1988

Many of the suppliers listed in Table 1 are alternative sources of original designs from a few select companies. Dataquest believes that more original designs will be released to the merchant market over the next couple of years. However, partnerships are now being formed to build needed support.

SYSTEM DESIGN/APPLICATIONS

Simply stated, the movement toward RISC designs has been prompted by the basic need for the accelerated processing of data. Companies involved in designing systems or peripherals have recognized the benefit of using RISC as the computing engine, but they have implemented this in various ways. Table 2 shows several system manufacturers and their design approaches.

Table 2

System Designs Using RISC Architectures

Company	RISC Method
AT&T	Merchant MPU (SPARC)
Celerity Computing	Discrete design
Edge Computers	Discrete design
Hewlett-Packard	Proprietary MPU
IBM	Proprietary MPU
MIPS Computer Systems	R2000
Prime Computer	Merchant MPU (R2000)
Pyramid Systems	Discrete design
Ridge Computers	Discrete design
Silicon Graphics	Merchant MPU (R2000)
Sun Microsystems	SPARC
Xerox	Merchant MPU (SPARC)

Source: Dataquest
January 1988

As noted in Table 2, many systems manufacturers have their own approaches, either via in-house microprocessor designs or perhaps by implementing ASIC versions (discrete). What this may imply is that not all of the traditional computing applications are ready for merchant RISC microprocessor solutions.

It is highly probable that even as more merchant RISC devices are introduced to the market, some, if not many, systems suppliers will still choose to implement their own designs to fit very specific requirements.

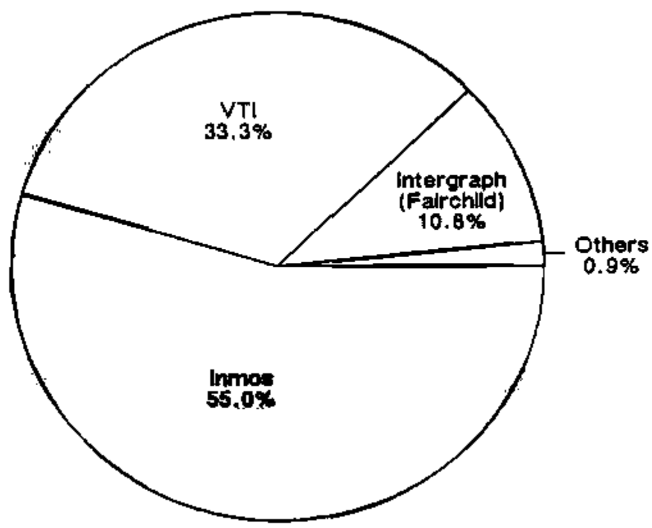
This might suggest that other applications are better suited to the merchant RISC devices. These applications, such as high-speed disk drives, graphics, communication, and even signal processing, could be in the peripherals area.

RISC FORECAST

Dataquest estimates that RISC processors accounted for approximately 60,000 units shipped in 1987, or almost 4 percent of the total 32-bit microprocessor market. Figure 1 shows Dataquest's estimated market share for the three primary suppliers of commercial RISC microprocessors in 1987.

Figure 1

Estimated 1987 RISC Unit Market Share

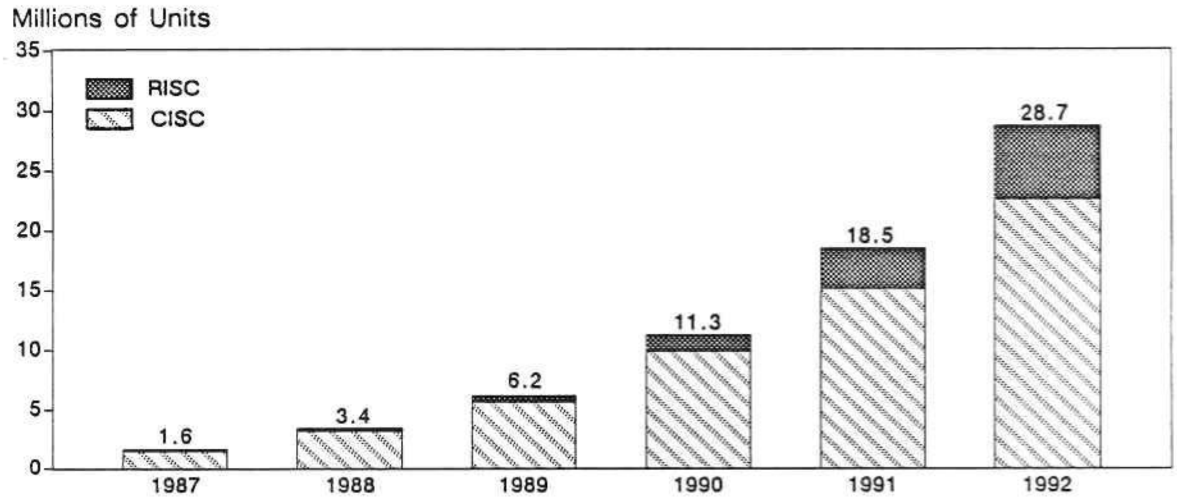


Source: Dataquest
January 1988

With the number of RISC designs being introduced, Dataquest expects shipments of RISC processors to increase rapidly from 1987 through 1992, growing at a compound annual growth rate (CAGR) of 151.4 percent, which is faster than that of CISC processors. Dataquest forecasts that by 1992, RISC processors will account for 21.0 percent of all 32-bit processors shipped (see Figure 2), and 29.0 percent of all 32-bit processor revenue (see Figure 3). However, this rapid growth should begin to slow as the market matures.

Figure 2

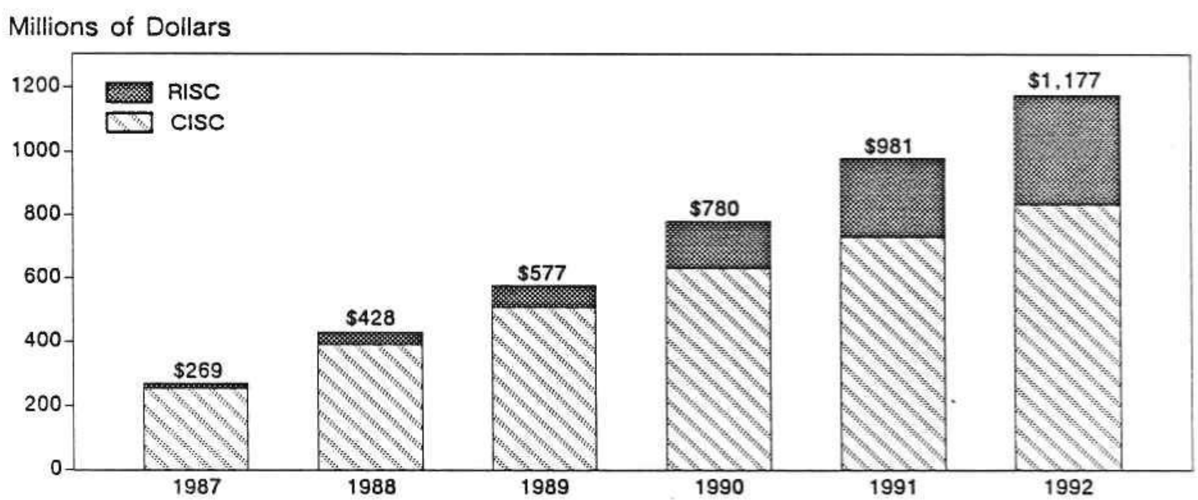
32–Bit Microprocessor Shipment Forecast



Source: Dataquest
January 1988

Figure 3

32–Bit Microprocessor Revenue Forecast



Source: Dataquest
January 1988

DATAQUEST ANALYSIS

All evidence points to the fact that RISC, as a discipline, clearly has a place in the computing market, but it may not be an end-all for architectural evolution. CISC is far from a fading breed. There are many ways to enhance performance, and specific aspects of RISC are clearly applicable to CISC speed enhancement. Hence, Dataquest believes that the two approaches can coexist and perhaps contribute to the evolution of monolithic microprocessors from the TTL logic replacements that they once were to the more sophisticated computers-on-a-chip that they might eventually become.

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Research *Bulletin*

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DRAM ALLIANCE: THE UNITED STATES TALKS, THE BRITISH ACT

SUMMARY

While American systems companies continue to debate the pros and cons of forming alliances that will assure their supply of critical memory devices, the British have taken action. Amstrad plc, a fast-growing maker of personal computers and home entertainment products based in Brentwood, England, agreed on October 3 to make a $75 million equity investment in Micron Technology Inc. of Boise, Idaho. The deal will allow Micron to accelerate its development of new facilities that will at least double its manufacturing capacity in DRAM and other memory products. As part of the agreement, Amstrad will receive an option to buy up to approximately 9 percent of Micron's semiconductor production over the next three years.

MICRON'S ALLIANCE STRATEGY

Micron Technology, one of only three United States-based semiconductor manufacturers still producing DRAMs, has made no secret of its interest in lining up alliance partners to help fund expansion, develop new products, and enhance its marketing clout. Micron used funding from Digital Equipment Corporation to develop video RAM (VRAM) technology, which is now its fastest-growing product area. Earlier this year, Micron gave Intel Corporation a warrant to buy 600,000 shares of its stock for approximately $11.6 million in return for an agreement to market Micron products through Intel's sales network.

In joining forces with Amstrad, Micron hopes to achieve multiple objectives. Most important initially is the infusion of cash, which may allow the company to cut as much as a year from its two-year plan to build and equip a 100,000-square-foot wafer fabrication plant and a 250,000-square-foot assembly and test building. Investment in the new facilities will increase from a planned $180 million to $250 million, according to Micron.

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The three-year purchase agreement also encourages Micron to accelerate its expansion plans. Although Amstrad is not required to take all of the production it is entitled to buy under the agreement, it already accounts for approximately 9 percent of Micron's sales and still needs additional memory supply. Micron clearly expects the relationship to tighten as the company tries to improve its penetration of the European market.

WHAT DOES AMSTRAD GAIN?

Founded by chairman and managing director Alan Sugar in 1968, Amstrad has about doubled its sales every year since 1980. It crossed the $1 billion mark in the year ended last June. Personal and home computers, word processors, and software account for about three-quarters of Amstrad's sales volume. Company officials claim that the recent DRAM shortage has cut Amstrad's shipments by 10,000 to 30,000 units per month.

The agreement provides Amstrad with assured access to memory products that could be worth more than $50 million per year when Micron's new production facility comes on stream next year. Unlike the 20-plus Micron customers who recently signed two-year noncancellable DRAM supply contracts, Amstrad does not have to commit to a fixed delivery schedule. In addition to negotiating prices on a quarterly basis, Amstrad is able to start with a ceiling price that is based on the weighted average of all other noncancellable contracts for the previous 90 days.

The investment also gives Mr. Sugar a seat on Micron's board and, presumably, some say in future product and marketing decisions. Micron officials stress, however, that the deal will not reduce product allocations to present customers. Under terms of the agreement, Amstrad has a claim on no more than 9.03 percent of any Micron part type. This will prevent Amstrad from using its position to monopolize Micron's output of high-performance devices or others in short supply.

DATAQUEST ANALYSIS

The era of "virtual vertical integration," in which producers and users of critical technology components join forces, has clearly arrived. Assuming that it receives government approval, this agreement provides an excellent example of the benefits to both sides that can flow from such alliances. Dataquest has heard credible rumors that one Japanese chipmaker is floating a business plan to the investment community that would fund a wafer fab jointly owned by itself and several U.S. computer manufacturers.

The irony in all this is that, with the Micron/Amstrad alliance, we have a U.S. semiconductor company reserving a significant share of its much-needed capacity for an aggressive European company, while other rumors suggest a somewhat similar arrangement between U.S. systems manufacturers and a Japanese semiconductor supplier. The Amstrad/Micron arrangement should be a clear signal to U.S. systems and device companies that the alliance dance has started, and it is time to choose partners.

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Research *Newsletter*

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THE 4Mb HURDLE

SUMMARY

The 4Mb DRAM market offers both opportunity and challenge. Unlike any previous generation, the 4Mb DRAM promises to be an overwhelming technical hurdle that threatens to change the competitive rules, business practices, and pricing trends of the DRAM industry. Manufacturers will need to deal with the uncertainty of three-dimensional memory cells, escalating costs of production facilities, and the complexities of 8-inch wafers.

Also unlike any previous generation, the 4Mb DRAM will open doors to new applications beyond traditional computer main memory. Opportunities in solid-state disk drives, graphics and imaging, fax machines, laser printers, digital copiers, and telephone sets will become more visible in the next decade.

MARKET FORECAST

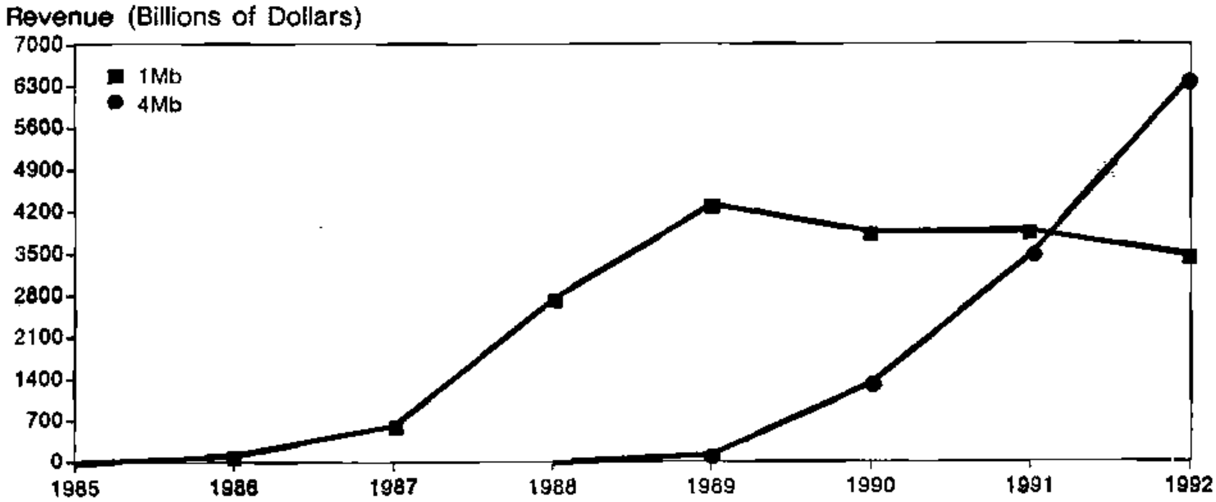
Dataquest estimates that the 4Mb DRAM market will grow as sluggishly as the 1Mb DRAM market did in its early years but for different reasons. A combination of political and technical factors hampered the growth of the 1Mb DRAM, with the political influences bearing a greater weight. Technical factors will play a greater role in the 4Mb DRAM case, however. Figure 1 and Table 1 show Dataquest's forecast for 4Mb DRAMs.

The prices of 4Mb DRAMs are expected to decline at a slower rate because of the higher expected cost. Dataquest does not expect the slope of the 4Mb DRAM cost learning curve to approximate the 1Mb DRAM slope until the 3-D cell and the 8-inch wafer obstacles are fully overcome.

The result is that the 1Mb DRAM life cycle is projected to be longer and to peak at a higher rate until the 4Mb DRAM issues are resolved. Eventually, the 4Mb DRAM market is projected to peak at a much higher level than that of the 1Mb DRAM because of the new applications that will develop in the next decade.

Figure 1

4Mb and 1Mb DRAM Revenue Forecast



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Source: Dataquest
November 1988

Table 1

4Mb DRAM Forecast

	1988	1989	1990	1991	1992
Revenue ($M)	$ 5	$ 148	$1,338	$3,517	$6,485
Units (M)	0	2.2	43.2	204.9	560.0
Average Selling Price	$217.50	$67.09	$30.98	$17.16	$11.58

Source: Dataquest
November 1988

MARKET STATUS

Only a few manufacturers are in the early sampling stages for 4Mb DRAMs. Hitachi and Toshiba distributed limited amounts of engineering samples to their major customers as far back as December 1987. Since then, NEC and Texas Instruments also have shown preliminary samples.

NEC and Mitsubishi already have announced the locations where they plan to be manufacturing their versions of the 4Mb DRAM. NEC will be starting production in January at its Yamaguchi plant, and then supplementing shipments with product from its fab in Hiroshima by 1991. Mitsubishi will construct a new facility in Saijo for production starting in 1990. Mitsubishi plans to start sampling early next year with product from its Kochi plant.

Dataquest believes that Hitachi and Toshiba are currently the major contenders for the 4Mb DRAM lead. Matsushita appears to have a convincing 4Mb design, but the company still needs to prove its CMOS process first and will more likely produce DRAMs to support its consumer division initially.

Hitachi has an advantage because it has chosen a more conservative approach—the stacked memory cell—and it is certainly a company that has the financial clout to handle the higher plant investments. Toshiba, on the other hand, has opted for the trench cell. This company has accumulated significant profits because of its 1Mb DRAM lead, and these profits can be reinvested in the next generation. Should Toshiba be successful, it will be an industry first to have the same company lead in succeeding DRAM generations.

Furthermore, there is no lack of interest among the other manufacturers. Table 2 presents a comparison of ISSCC 4Mb DRAM reports showing a large number of companies that are planning to engage in this market.

Table 2

4Mb DRAM ISSCC Reports

	Design Rule	Process Technology	Cell Type	Cell Size (mm^2)	Chip Size (mm^2)	ISSCC Year	Notes
Hitachi	0.8	CMOS	Stacked	14.74	110.9	1987	
Mitsubishi	0.8	CMOS	Trench	10.9	72.3	1987	
Toshiba	0.9	CMOS	Trench	13.8	111.2	1987	Redundancy
Matsushita	0.8	CMOS	Trench	8.0	67.1	1987	Redundancy
NEC	0.8	NMOS	Trench	10.6	99.2	1986	
Fujitsu	0.7	CMOS	Stacked	7.5	63.7	1987	Redundancy
Texas Instruments	1.0	CMOS	Trench	8.9	100.0	1986	
Siemens	0.9	CMOS	Trench	10.6	91.3	1988	Redundancy
IBM	0.8	CMOS	Trench	11.0	78.0	1987	

Source: Dataquest
November 1988

MAJOR 4Mb DRAM ISSUES

The future success of the 4Mb DRAM manufacturers will be determined by the following issues:

- Three-dimensional cell approach
- Higher capital investment
- Eight-inch wafers
- Political intervention

Three-Dimensional Cell Approach

The three-dimensional cell approaches are prerequisites to a cost-efficient 4Mb DRAM. These approaches are far from being completely developed, however. Despite the fact that they have chosen one approach versus the others in their ISSCC papers, DRAM manufacturers are invariably pursuing at least three simultaneous 4Mb DRAM R&D efforts: trench cell, stacked cell, or a combination of both.

Committing everything to one approach creates too much risk. Many 1Mb DRAM manufacturers almost missed the boat by jumping to a trench capacitor cell early in the game, and they have learned their lesson. It is likely that manufacturers will shift approaches as they encounter breakthroughs in their research; for example:

- A manufacturer can first introduce a stacked cell DRAM while continuing to pursue development of a trench cell that will yield an even smaller die. Eventually, the company will introduce the trench version. The advantage is that the company derives high early revenue from the stacked version, allowing it time to develop the trench cell.
- A company can introduce a trench version with considerable redundancy to improve overall manufacturing yields. Eventually, as the trench approach is perfected, the redundancy can be reduced in stages. The advantage is that the company focuses on only one approach and learns from actual trench experience in a production environment.

Eventually, most manufacturers will want to end up with a workable trench cell because this approach best minimizes die size.

Higher Capital Investment

So far, most of the 1Mb DRAMs produced still come from converted 256K DRAM production lines. Only a few new fabrication plants for 1Mb to 4Mb DRAMs are being built, although this number is expected to accelerate beginning next year. These new plants are estimated to cost approximately $150 million. Eventually, companies will have to consider building the next generation fab—a 0.8- to 0.5-micron, 8-inch wafer fab—that can produce 4Mb as well as 16Mb DRAMs. These are currently estimated to cost about $400 million. DRAM manufacturers will take longer making these next capital spending decisions, not only because of the magnitude of the investment but also because of the fear of building excessive capacity.

Eight-Inch Wafers

Dataquest believes that the 4Mb DRAM eventually will have to be built on 8-inch wafer lines as these become more viable. The 4Mb DRAM cost curve will not approximate the 1Mb DRAM curve unless 8-inch wafers are used. In Japan, the viability of high-volume, 8-inch wafer production lines is expected to occur no earlier than the end of 1990. Currently, only IBM has an 8-inch wafer line producing 1Mb and 4Mb DRAMs. Sematech, the manufacturing development consortium located in Austin, Texas, has plans to pursue this approach.

Political Intervention

A risk is that the foreign market values (FMVs) and the terms of the U.S.-Japan semiconductor trade agreement could affect the production ramp and pricing of 4Mb DRAMs the way that they constrained 1Mb DRAMs. However, the American Electronics Association (AEA) is endeavoring to change some of the details of the agreement to better encourage manufacturers to expand 4Mb DRAM capacity.

4Mb DRAM OPPORTUNITIES

In the next decade, the 4Mb DRAM will encounter a market composed of new applications, including the following:

- Solid-state disk drives replacing some of the market traditionally held by magnetic media
- Graphic memory for computers resembling the industry's boundless need for main memory (Graphic memory requirements increase substantially with increasing screen size, resolution, and features.)
- Frame memory requirements for laser printers, digital copiers, and digital facsimile machines
- Frame and line memory for enhanced-definition television (EDTV) and high-definition television (HDTV) and corresponding peripherals such as video cassette recorders
- Telephone message sending and recording applications where one 4Mb DRAM can hold up to two and a half minutes of a voice message (Toshiba has incorporated 1Mb DRAMs in some of its most advanced telephone sets.)

These applications will increase bit consumption by orders of magnitude, but they will require aggressive pricing because of the cost sensitivity of these types of systems.

DATAQUEST OUTLOOK

Dataquest believes that the events and issues surrounding the 4Mb DRAM will affect the DRAM market in the following ways:

- The 4Mb DRAM will be a relatively expensive DRAM in the first two to three years of its product life.

- The production ramp of 4Mb DRAMs will be slower because of the technical problems and high capital investment required.

- As a result, the 1Mb DRAM life will be longer and its peak displaced by at least a year.

- The 1Mb DRAM eventually will incorporate several of the breakthroughs in 4Mb DRAM development to reduce its cost beyond the limits of planar technology.

- The 4Mb DRAM market will pick up rapidly with the implementation of 8-inch wafers and the emergence of new applications in the next decade.

Despite the expected changes, it is not likely that the competitive intensity in the DRAM market will change. New applications for 4Mb DRAMs will require low cost and plentiful capacity, which historically have been the major competitive drivers in DRAMs.

With all the uncertainty surrounding it, the 4Mb DRAM promises to be a turning point in DRAM history. Dataquest believes that manufacturers and users alike will need to take a closer look at their plans to adequately prepare for the changes that the future may bring.

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Research Newsletter

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SIS MEMORY QUARTERLY EVENTS NEWSLETTER
August 1988

This is the third newsletter issued by the SIS Memory Products Group. It contains a synopsis of detailed memory product news events gathered from the trade press and company releases over the past three months (April, May, and June). SIS assumes no responsibility for the accuracy of their contents.

The following is a key to the publications reviewed during research, which are included in this issue:

Company News Release	CNR	Electronic Design	ED
EDN	EDN	Electronic Engineering Times	EET

The new products for the third quarter of 1988 are as follows:

Company	Density	Speed
DRAM Developments		
Ampex	512K, 1Mb	350, 550ns
Toshiba	1Mb	70, 80, or 100ns
	1Mb	70, 80, or 100ns
SRAM Developments		
Hitachi	1Mb	70 to 120ns
	64K	15 or 20ns
IDT	2Mb, 512K	30 to 70ns
Intel	64K	35ns
Motorola	64K	25, 35, 45ns
	16K	25, 35ns
National	64K	25 to 35ns
Sharp	256K	35, 45ns
Toshiba	1Mb	70, 85, or 100ns
	64K	20, 25, or 35ns
	64K, 72K	20, 25, or 35ns

(Continued)

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Company	Density	Speed
ECL I/O-Level RAM Developments		
NEC	4K	5 to 7ns

Company	Density	Type	Speed
Nonvolatile Developments			
Advanced Micro Devices	256K	EPROM	90, 100, 120, 150ns
	1Mb	EPROM	170, 100, 250, 300ns
Atmel	256K	EEPROM	70ns
	1Mb	EEPROM	120ns
GigaBit	4K	ROM	1.5ns
Intel	64K, 256K	Flash	150 to 170ns
Mitsubishi	1Mb	OTP	200ns
National		EEPROM	
NEC	2Mb	EPROM	150 to 200ns
Seeq	512K	Flash	200ns
Sierra	32x8	EEPROM	
Toshiba	1Mb	EPROM	200 to 250ns
	256K	EPROM	70 to 85ns
	256K	Flash	170, 200, 250ns
Specialty Memories			
IDT	256x9	FIFO	25ns
	256K	Dual-Port	55, 60, 70, 90ns
Saratoga	64x9, 64x5	FIFO	30, 40 MHz
Toshiba	1Mb	Field Mem.	30ns

DRAM DEVELOPMENTS

Ampex

Ampex has introduced two new memory modules targeted for the military market: the MESA DRAM module with storage of either 512K or 1Mb of 16-bit words and the MESA 128 core memory module at 128Kx18 bits. The DRAM module access and cycle times are 350ns and 550ns. (CNR, May 27, 1988)

Toshiba

A series of 1Mb DRAM memories has been introduced by Toshiba. Organized 1Mx1, the TC511000AP/AJ/AZ offers fast page mode while the TC511001AP/AJ/AZ and TC511002AP/AJ/AZ offer nibble and static column mode, respectively. The TC514256AP/AJ/AZ and TC514258AP/AJ/AZ, organized 256Kx4, offer fast page and static column mode, respectively. The series has access times of 70, 80, or 100ns, and packages are available in standard 20-pin plastic dual-in-line (DIP), plastic small-outline J-lead (SOJ), and plastic ZIP. (CNR, March 28, 1988)

A new 1Mb DRAM memory from Toshiba offers a write-per-bit capability for selective data masking. Organized 256Kx4, the TC514266AP/AJ/AZ and TC514268AP/AJ/AZ have fast page and static column mode, respectively, and access times of 70, 80, or 100ns. Packaging consists of a standard 20-pin plastic DIP, plastic SOJ, and plastic ZIP. (CNR, March 28, 1988)

SRAM DEVELOPMENTS

Hitachi

Hitachi introduced the HM628128, a 1Mb SRAM packaged in a 32-pin plastic DIP or a 32-pin plastic surface-mount package. The part is available in four speeds—70, 85, 100, and 120ns. (CNR, June 23, 1988)

Hitachi announced a new family of 64Kb BICMOS SRAMs. Both the HM6787HP-15, organized 64Kx1, and the HM6788HP-15, organized 16Kx4, are available in 22-pin plastic DIP. The HM6789HJP-15 is organized 16Kx4, has an additional output enable, and is available in a 24-pin plastic SOJ. Access times are 15 or 20ns for all three parts. (CNR, June 23, 1988; ED, June 23, 1988, pg. 23)

Integrated Device Technology

Recently introduced by Integrated Device Technology were two 32-bit wide CMOS static RAM modules: the IDT7M4017, a 2Mb SRAM, offered in a 60-pin, 600-mil-wide sidebraze DIP, with access times of 45 to 70ns; and the IDT7MC4032, a 512K SRAM, available in an 88-pin dual ceramic single-in-line package (SIP), with access times of 30, 35, and 45ns versions. (CNR, May 2, 1988)

Intel

Intel announced that the M51C98 64Kb SRAM is Intel's first JAN QPL device to meet VHSIC Phase I criteria. The 1um CMOS part is organized 16Kx4 and has an access time of 35ns. (CNR, June 8, 1988)

Motorola

Motorola has announced two new CMOS static RAMs, all of which are available in surface-mount, SOJ packages. The MCM6264J, organized 8Kx8 bits, has 35 and 45ns access times and comes in a 400-mil package; the 16Kx4 MCM6290J has 25, 30, and 35ns speeds and comes in a 300-mil package. The 25 and 35ns 4Kx4-bit MCM6268 will also be available in a 300-mil 24-pin SOJ. (EDN, June 23, 1988, pg. 227)

National Semiconductor

National Semiconductor has introduced new 64K CMOS SRAMs with TTL-compatible I/O and the option of a low-voltage and a data-retention version. The NM1600/1601 (64Kx1) and the NM1620/1621 (16Kx4) are both available in a 300-mil, 22-pin ceramic or plastic DIP and a 22-pin LCC package. The NM1624/1625 16Kx4 offer an additional output enable and are available in a 300-mil, 24-pin ceramic or plastic DIP and a 28-pin LCC package. All parts have 25 and 35ns access times. (CNR, June 8, 1988)

Sharp

Sharp introduced the LH52252 CMOS static RAM. The part is organized 64Kx4 bits, is available in 35 and 45ns versions, and comes in a 24-pin 300-mil DIP. (EDN, June 23, 1988, pg. 233-234)

Toshiba

Toshiba has introduced the TC551001P/F. The 1Mb static RAM is organized 128Kx8 and is available in either a 32-pin, 600-mil plastic DIP or a 450-mil SOIC. Access times are 70, 85, or 100ns. (CNR, May 6, 1988)

Available from Toshiba are the TC55416P/J and the TC55417P/J 64K CMOS static RAMs with access times of 20, 25, or 35ns. These parts are organized 16Kx4. The TC55416 is available in 22-pin DIP and SOJ, while the TC55417 comes in a 24-pin package because of its additional output enable. (CNR, April 25, 1988)

Toshiba has made available 64K and 72K CMOS static RAMs with access times of 20, 25, and 35ns. The new parts, the TC5588P/J and the TC5589P/J, are organized 8Kx8 and 8Kx9, respectively. Packaging is a standard 28-pin, 300-mil-wide plastic DIP or a 28-pin SOJ. (CNR, May 6, 1988)

ECL I/O-LEVEL RAM DEVELOPMENTS

NEC

NEC has introduced two new 4Kb ECL RAMs, the uPB10474A and the uPB100474A. The parts are organized 1Kx4 and are available in 10K or 100K ECL interface levels. They have access times of 5 to 7ns and are packaged in both 24-pin ceramic DIP and 24-pin ceramic Quad flat packages. (EDN, June 23, 1988, pg. 47)

NONVOLATILE DEVELOPMENTS

Advanced Micro Devices

Advanced Micro Devices has introduced two high-speed, high-density CMOS EPROM parts. The Am27C256 is organized 32Kx8 and has a 28-pin JEDEC-approved CERDIP with access times of 90, 100, 1220, or 150ns. The Am27C010 is organized 128Kx8, is packaged in a 32-pin DIP or an LCC, and has access times of 170, 100, 250, and 300ns. (EET, June 20, 1988, pg. 76)

Atmel

Atmel has introduced a 1-micron 256K EEPROM, the AT28HC256, with circuits in double-layer metal and with access times of 70ns. The company also is offering a 1Mb module (AT28MC010) with access times of 120ns. The 256K is available in a 28-pin CERDIP or a 32-pin LCC. The 1Mb module is available in a 32-pin DIP module. (EET, May 16, 1988, pg. 53)

GigaBit Logic

GigaBit Logic has announced a GaAs ROM. It is an ECL-compatible part (10GM048) organized 512x8, accesses data in 1.5ns, and dissipates 2.0W. (EET, May 9, 1988, pg. 2)

Intel

Intel has introduced three new Flash EPROMs: the 28-pin 27F64 and 27F256 with access times of 170ns, and the 32-pin 28F256 with access times of 150ns. (EET, April 18, 1988, pg. 99)

Mitsubishi

Mitsubishi has introduced three new 1Mb OTP ROMs. Two of the parts, the M5M27C100, which is ROM compatible, and the M5M27C101, are organized 128Kx8 and are available in 32-pin plastic DIP, PLCC, and SOP. The M5M27C102, organized 64Kx16, is available in a 40-pin plastic DIP and a 44-pin PLCC. (CNR, June 9, 1988)

National Semiconductor

National Semiconductor has introduced three new low-density EEPROMs: the NMC98C10, the NMC98C20, and the NMC98C40. They are available in the standard 300-mil, 18-pin plastic DIP package. (CNR, April 19, 1988)

NEC

Just launched by NEC is the PD27C2001D, a 2-Mbit CMOS EPROM. The part, organized 256Kx8, has access times of 150 to 200ns, and is packaged in 32-pin, 600-mil CERDIP with JEDEC standard pinout. (EDN, June 23, 1988, pg. 46)

Seeq

Seeq introduced a new generation of high-density, FLASH-type EEPROMs. The 512Kb 48F512 offers high-density in-circuit programmability combined with surface-mount packaging. Typical access time is 200ns. The part is available in ceramic and plastic surface-mount packages, as well as both plastic and ceramic 32-pin JEDEC format DIPs. (CNR, April 4, 1988)

Sierra Semiconductor

Sierra Semiconductor announced the SC22100, a 32x8-bit EEPROM with 1 million write/erase cycles and 25-year data retention. The part is housed in an 18-pin dual in-line package (DIP). (CNR, June 27, 1988)

Toshiba

Toshiba has introduced two 1Mb OTP ROMs, the TC541000P and the TC541001P, both of which have access times of 200 and 250ns. The TC541000P comes in the JEDEC standard pinout and the TC541001P is ROM compatible. The parts are organized 128Kx8 and are available in 32-pin plastic DIP. (CNR, May 9, 1988)

Toshiba has made available the TC571024, a 1Mb EPROM, organized 64Kx16 with an access time of 150ns. The part is available in the JEDEC standard 40-pin package. (CNR, May 9, 1988)

Toshiba has started marketing two new 256K EPROMs with access times of 70 to 85ns. The parts, the TC57H256D-70 and TC57H256D-85, are organized 32Kx8 and are available in standard 28-pin ceramic DIP. (CNR, June 17, 1988)

Toshiba is marketing a new CMOS 256K "flash" EEPROM, the TC58257AP/AF, organized 32Kx8. The TC58257AP is available in 28-pin plastic DIP and the TC58257AF comes in a 28-pin plastic flat package (SOIC). Access times are 170, 200, and 250ns for each package. (CNR, June 17, 1988)

SPECIALTY MEMORIES

Integrated Device Technology

Integrated Device Technology (IDT) announced a 256x9 CMOS FIFO. The part, the IDT7200, features 25ns access times and is available in a 28-pin 300-mil THINDIP, a 32-pin plastic leaded chip carrier (PLCC), and a 32-pin ceramic leadless chip carrier (CLCC). (CNR, May 2, 1988)

IDT has introduced a 256Kb, high-speed CMOS dual-port SRAM module, the IDT7M137. The part is organized 32Kx8, is manufactured in a 58-pin DIP, and has access times of 55, 60, 70, and 90ns. (CNR, May 2, 1988)

Saratoga Semiconductor

Saratoga Semiconductor has introduced the BICMOS 50-MHz SSL7409S and the 40-MHz cascadable SSL7409C, both organized 64x9 and packaged in 28-pin side-brazed and plastic DIPs and 28-pad LCCs. Another set of BICMOS FIFOs, the 30-MHz SSL7413S and 40-MHz cascadable SSL7413C, are organized 64x5 and packaged in 22-pin plastic DIPs. (EET, April 18, 1988, pg. 100; EDN, June 23, 1988, pg. 230)

Toshiba

Toshiba announced a 1Mb CMOS field memory, the TC521000P, which is suited to video applications. The part features a 256Kx4 DRAM memory array, has a serial cycle time of 30ns, and is available in a 40-pin, 600-mil plastic DIP package. (CNR, March 28, 1988)

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Research Newsletter

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SIS MEMORY QUARTERLY EVENTS NEWSLETTER
May 1988

This is the second newsletter issued by the SIS Memory Product Group. It contains a synopsis of detailed memory product news events gathered from the trade press and company releases over the past three months (January, February, March). SIS assumes no responsibility for the accuracy of their contents.

The following is a key to the publications reviewed during research and included in this issue:

Advanced Technology	AT	Electronic Engineering Times	EET
Company News Release	CNR	Engineering Times	ET
EDN	EDN		

Below are listed new products for the second quarter of 1988:

Company	Density	Speed
DRAM DEVELOPMENTS		
Motorola	1Mb	85ns
Texas Instruments	1Mb	100, 120ns
Vitelic	256K	70, 80, 100, 120ns
SRAM DEVELOPMENTS		
Electronic Design	256K	35, 45, 55ns
Electronic Design	1Mb	60, 70ns
GE Solid State	256K	100ns
Hitachi	64K	15, 20ns
ILC Data	1Mb	100ns
Inova	1Mb	45ns
Int. Device Technology	1Mb	45ns

(Continued)

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Company	Density	Speed
SRAM DEVELOPMENTS (Continued)		
IDT	512K	45, 55, 70ns
IDT	64K	35ns
Motorola	256K	85, 100, 120ns
Saratoga Semiconductor	64K	20 to 45ns
ECL I/O LEVEL RAM DEVELOPMENTS		
Fujitsu	256K, 64K	15ns
Fujitsu	4K, 16K	9, 13ns
IDT	64K	15ns
National	256K	15, 18ns
NEC	16K	10, 15ns
Vitesse	1K	3ns
NONVOLATILE DEVELOPMENTS		
Fujitsu	256K	100, 120ns
Toshiba	512K	250ns
IDT	16K	55ns
AMD	64K	35ns
Fujitsu	4K, 8K, 16K	20, 25ns
Macronix	16K to 1Mb	
Krysalis	16K	100, 200ns
SPECIALTY MEMORIES		
IDT	4K	25ns
IDT	64x4, 64x5	10 to 35MHz
Saratoga Semiconductor	64x9, 64x5	15 to 50MHz
Texas Instruments	9K	35 to 50ns
Saratoga Semiconductor	16K	15, 25, 35ns
Texas Instruments	16K	25, 35ns
Mitsubishi	32KB, 128KB, 512KB	

DRAM DEVELOPMENTS

Motorola

Motorola has introduced the MCM511000P85/001P/002P, a page/nibble/static column 1-Mbit x1 DRAM and the MCM514256P85/258P, a page/static column mode 256Kx4 DRAM. The chips are packaged 300-mil wide plastic DIP, and have an address access time of 85ns. (EET, January 18, 1988, pg. 66)

Texas Instruments

At ISSCC, Texas Instruments presented its 1Mb Video RAM. The TMS44C251 will have access times of 100 and 120ns. TI will begin general sampling its 256Kx4 VRAMs in 400-mil, 28-pin packages by the end of March, and samples in ZIP packages will be available late in the third quarter. (EET, February 15, 1988, pg. 1)

Vitelic

Vitelic has made available new high-speed, low-power 256K DRAM memory devices, with access times of 70, 80, 100, and 120ns. The parts are the V53C256 and V53C258, 256Kx1 devices that offer fast page mode and static column functionality and come in 16-pin DIP, 16-pin ZIP, and 18-lead PLCC. (CNR, January 18, 1988)

SRAM DEVELOPMENTS

Electronic Designs

Electronic Designs introduced three new military 256K SRAMs: the EDI81256C, organized 256Kx1, the EDI8464C, organized 64Kx4, and the EDI8832C, organized 32Kx8 bits, with access times ranging from 35 to 55ns. Packaging for the x1 and x4, is 24-pin DIP or 28-pin LCC, and x8, is 28-pin DIP or 32-pin LCC. (EET, January 18, 1988, pg. 66)

Electronic Designs has also introduced the EDI8M1664C, a high speed 64Kx16 CMOS static RAM module. It consists of four 32Kx8 CMOS static RAMs in leadless chip carriers surface-mounted onto a multilayered ceramic substrate. The part is a 40-pin, 600 mil wide DIP, uses JEDEC standard footprint and pinout, and is available with access times of 60 and 70ns. (CNR, February 11, 1988)

GE Solid State

GE Solid State offers a 32Kx8 high-rel SRAM with 100ns access time at 25°. The device will operate over the full military temperature range and is available in a 28-terminal DIL package. (EET, March 28, 1988, pg. 64)

Hitachi

Using its HiBiCMOS process, Hitachi has increased the speed of its x1 and x4 64K-bit TTL I/O SRAM product line. The 64Kx1 has a 15-20ns access time, and it comes in a 300-mil, 22-pin DIP, with a power dissipation of 280 mW. (ET, February 15, 1988, pg. 49)

ILC Data Device

The MEM-84000 is a hybrid 1-Mbit MIL SRAM introduced by ILC Data Device. Its features include 100ns access time, 64Kx16-bit organization, and use of four TTL-compatible 32Kx8 RAMs, external decoding, and a 46-pin hermetic flatback. (EET, January 25, 1988, pg. 105)

Inova

Inova has made available the S128K8, a high performance 1M-bit SRAM, organized as 128Kx8-bit bytes. The part has advanced 4T CMOS technology, JEDEC standard pinout, has access time of 45ns, and comes in ceramic DIP. (CNR, March, 1988)

Integrated Device Technology

The IDT8M824S45 and IDT8M624S45 are fast 1-Mbit modules from Integrated Device Technology. Organized 128Kx8 and 64Kx16, these devices are JEDEC-compatible and feature 45ns access times. They consist of four 32Kx8-bit SRAMs. (EET, January 25, 1988, pg. 105)

Also released by IDT is a CMOS 512K synchronous RAM module, the IDT7MP6025. The module is organized 64Kx8, is available in 45, 55, or 75ns cycle times, and features a plastic SIP. (EET, January 25, 1988, pg. 105)

Recently, IDT introduced the IDT71502, a 4Kx16 CMOS SRAM with high-speed registers at the RAM outputs, and IDT's Serial Protocol Channel™. The part is a multifunctional, user-configurable device that features 35ns address access time. It is available in a 48-pin plastic and side-brazed DIP and a 52-pin plastic PLCC. (CNR, March 21, 1988)

Motorola

Available from Motorola is the MCM60256, a 32Kx8-bit CMOS SRAM. The part has access times of 85, 100 or 120ns, comes in a standard or low-power version, and is packaged in a 28-pin DIP. (EET, January 18, 1988, pg. 66)

Saratoga Semiconductor

Saratoga Semiconductor has introduced two new 64K TTL SRAMs, having 20, 25, 35, or 45ns speeds with x8 and x4 organizations. (EET, January 11, 1988, pg. 15)

ECL I/O LEVEL RAM DEVELOPMENTS

Fujitsu

Fujitsu introduced a series of ECL I/O BiCMOS RAMs: the MBM10C500 is a 10K series ECL compatible 256Kx1 RAM; the MBM100C500 is 100K series ECL compatible. The parts feature access times of 15ns. The 256Kx1 devices are packaged in a 300-mil wide, 24-pin, JEDEC approved DIP and 24-pin, JEDEC approved flatpack. The Company also introduced four other BiCMOS devices. These parts are organized 16Kx4 and 64Kx1 with 10K and 100K ECL I/O levels and feature access times of 15ns. (CNR, February 18, 1988)

Also offered by Fujitsu is a synchronous memory circuit called a STRAM (self-timed RAM). The devices are available in 4K and 16K-bit densities. The MBM10476LL-9 and MBM100476LL-9 are organized as 1Kx4 bits and the MBM10486LL-13 and MBM100486LL-13 are organized as 4Kx4, with cycle times of 9 and 13ns and address access times of 7 and 10ns. These devices come in 400-mil 28-pin side-brazed CERDIP and Tape Automated Bonding (TAB) packages. (EET, February 22, 1988, pg. 38)

Integrated Device Technology

The first in a series of BiCEMOS™ products, introduced by Integrated Device Technology, is a 64Kx1 ECL I/O static RAM that features a fast 15ns access time. The part (IDT100490) is as fast as ECL bipolar products and has 70 percent less power consumption. It is packaged in a 22-pin plastic and side-braze DIP and a 24-pin SOIC. (CNR, February 8, 1988)

National Semiconductor

A new high-performance 256K fast static RAM (FSRAM) has been made available by National Semiconductor. Designated the NM5100, the device is organized as 256Kx1 bit and is 10K or 100K I/O compatible. It is offered in 15 and 18ns, 24-pin, 400-mil ceramic DIP or in ceramic flatpack. (CNR, February 15, 1988)

NEC Electronics

NEC Electronics' newest 16K ECL RAM family can be ordered with 10 or 15ns access times at 10K or 100K level interface, and in a 16Kx1 (uPB10480D and uPB100480D) or 4Kx4 (uPB10484D and uPB100484D) configuration. The 16Kx1 is available in 20-pin ceramic DIPs and the 4Kx4 configuration is available in 28-pin ceramic DIPs. (CNR, January 22, 1988)

Vitesse

Vitesse has released an ECL I/O-compatible GaAs RAM with an access time of 3ns. The part, designated VS12G422E, is organized 256x4, and is pin-compatible with existing ECL RAM products. It is also radiation hard and has 24-pin compatible DIP. (EET, January 25, 1988, pg. 105)

NONVOLATILE DEVELOPMENTS

Fujitsu

A high-speed 256K-bit CMOS EPROM has been released by Fujitsu. The MBM27C256H, organized 32Kx8 bits, features access times of 100 or 120ns, and comes in a 28-pin ceramic DIP or 32-pad LCC. (EET, February 15, pg. 52)

Toshiba

Released by Toshiba is a 512K one-time programmable (OTP) EPROM (TMM24512P). The device, organized 64Kx8 bits, features an access time of 250ns, and is packaged in a 28-pin plastic DIP. (EET, January 18, 1988, pg. 66)

Integrated Device Technology

Available from Integrated Device Technology are two 16K CMOS EEPROM parts with a serial access scheme and a 55ns read access time. The IDT78C16 comes in a 24-pin, 300-mil CERDIP; 24-pin 600-mil CERDIP; or 32-pin LCC package. The IDT78C18 features a 28-pin, 300-mil side-brazed DIP and 32-pin LCC package. (EDN, January, 1988, pg. 29)

Advanced Micro Devices

Introduced by Advanced Micro Devices is the Am27C49, a high-speed CMOS 8Kx8 PROM. It features 35ns access time and power consumption of only 450mW. (AT, March, 1988, pg. 2)

Fujitsu

Fujitsu's MB7226 512x8, MB7232 1Kx8, and MB7238 2Kx8, are fast registered PROMs, featuring access times of 20 and 25ns, 24-pin CERDIP, ceramic flat pack or 28-pin LCC. (EET, February 8, 1988, pg. 59)

Macronix

Orbit Semiconductor and Macronix have signed a foundry pact for production of quick-turn mask ROMs and telecommunication ICs. ROM densities range from 16K-bits to 1-Mbit. (EET, March 14, 1988, pg. 18)

Krysalis

The Krysalis K22C16 UniRAM is a 16K bit non-volatile memory organized 2Kx8 bits. The uniRAM (Universal Random Access Memory) device is fabricated with CMOS ferroelectric technology and offers read and write cycles times of 100 to 200ns. It comes in JEDEC standard packages, pinouts, and functions. (CNR, February 1988)

SPECIALTY MEMORIES

Integrated Device Technology

Recently announced by IDT is a 512x9 CMOS FIFO part, the IDT7201, that features 25ns access times. It is available in a 28-pin, 300-mil wide THINDIP package, a standard 28-pin 600-mil plastic and CERDIP package, a 28-pin flatpack and 32-bit PLCC and CLCC. (CNR, January 11, 1988)

Upgrades of five IDT devices in the 64x4 and 64x5 FIFO family were announced with the IDT72401/02/03/04 having speeds varying from 10 to 35 MHz and the IDT72413 in 25 and 35MHz versions. They all use high-speed CEMOS™ technology. Package options include plastic DIPs, CERDIPS, SOICs, and LCCs. (CNR, March 14, 1988)

Saratoga Semiconductor

Saratoga Semiconductor announced two new products, SSL7409, a 64x9 at 40 to 50 MHz, and SSL7413, a 64x5 at 15 to 50 MHz, both high-speed BiCMOS FIFO memories. The parts are available in 22- and 28-pin side-brazed and 300-mil DIP, plastic dips and 28-pad LCC. (CNR, March 15, 1988)

Texas Instruments

Texas Instruments has released its first FIFO based on its proprietary CMOS Epic technology. The SN74ACT7202 is a functional replacement for Integrated Device Technology's IDT7202S/L. The buffer is organized 1Kx9, has access times of 35ns to 50ns, and comes in 28-pin plastic DIP. (CNR, January 4, 1988, pg. 55)

Saratoga Semiconductor

Two devices (SSL4180 and SSL4181) are a new family of high performance BiCMOS cache-tag RAMs that have been introduced by Saratoga Semiconductor. Having 15, 25, and 35ns address compare access times, they are the fastest available tag RAMs to date. Both are organized 4Kx4 and feature 300 mil wide 22-pin dual in-line packages (DIPs). (CNR, January 20, 1988)

Texas Instruments

TI has also made available 2K-word by 8-bit cache address comparators. It is designated the SN74ACT2152 and SN74ACT2154, has a maximum address-to-match delay of 25 or 35ns, and its parts are supplied in 28-pin plastic DIPs and 28-pin plastic-leaded chip carriers (PLCCs). (CNR, February 3, 1988)

Mitsubishi

Mitsubishi announced three types of memory card (Melcards) are available in 8- and 16-bit data widths: SRAM (32K to 512K bytes); OTPROM 32K to 512K bytes) and mask ROM (128K to 2M bytes). The packages are designed to be used with a 60-pin, 2-piece connector or a 50-pin card-edge connector. (CNR, February 29, 1988)

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FERRAM: THE MEMORY THE MARKET ALWAYS WANTED

SUMMARY

The ferroelectric RAM, or FERRAM, memory technology provides all the performance features that the market wants. It is nonvolatile, radiation hard, compatible with MOS, GaAs, and bipolar processing, and offers fast read and write together with longterm data storage in the absence of applied power. If there are no unforeseen technical glitches, FERRAMs should have significant memory market impact.

This newsletter uses a learning curve analysis to forecast the FERRAM market for the next five years. During this period, the FERRAM will compete primarily with EEPROMS, reaching total sales of an estimated $350 million in 1992.

Ferroelectric technology is not new, but two start-up companies, Krysalis and Ramtron, have applied the technology in a novel way. This newsletter describes the technology and provides brief profiles of both companies.

THE MEMORY HIERARCHY

Today, many technologies are used to supply the needs of the memory market. No one technology supplies all needs, and as a result, market niches exist that are supplied by specialized memories. The FERRAM promises to be the one technology for all applications, since it combines fast read and write with nonvolatility. In spite of this promise, FERRAMs are new and must compete with existing technologies that have been in manufacture for some time and are well down the learning curve. For most memories, learning curves are such that the selling price is multiplied by a factor of 60 percent to 80 percent every time the cumulative volume doubles. For this reason, a memory manufactured in high volume is likely to have a much lower selling price than a low-volume memory.

FERRAM memories are currently in the embryonic stage—manufacturing volumes are essentially nil. The key question is whether the FERRAM can capture enough of some memory market segment to begin proceeding down its own learning curve.

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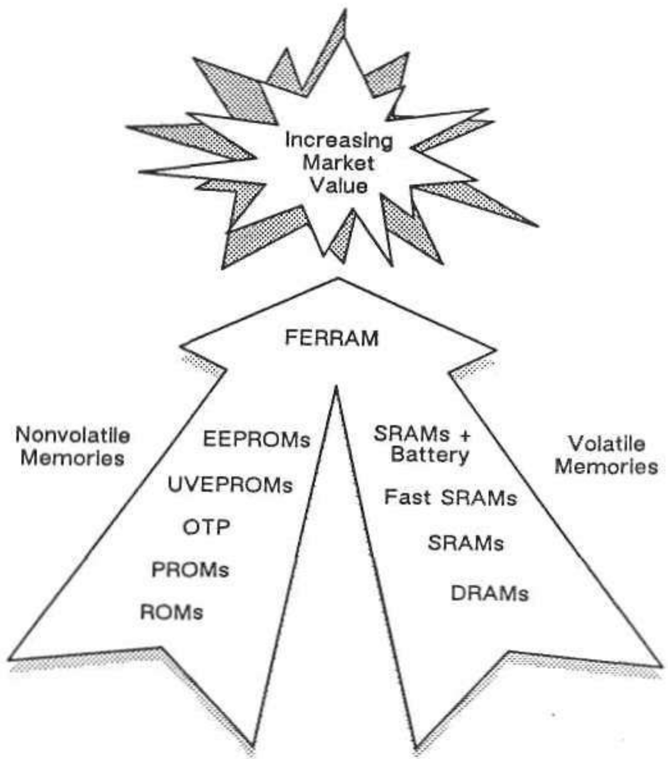
The memory hierarchy is shown graphically in Figure 1. Here, memory technologies are shown in ascending order of performance. Note that this figure divides the memory market into its two segments: volatile and nonvolatile. FERRAM is shown at the intersection of the two segments because it satisfies the needs of both.

Figure 1

The Memory Hierarchy



Source: Dataquest
January 1988

The feature content of the various technologies in the nonvolatile hierarchy can be described as follows:

- ROM: Read only
- OTP/PROM: Read only, write once
- UVEPROM: Read only, write once, UV erase
- EEPROM: Read fast, write slowly
- FERRAM: Read fast, write fast, extended wear-out

Each member of the hierarchy has a significant advantage over the inferior technology. OTPs and bipolar PROMs can be programmed by the user; ROMs can be programmed only by the manufacturer. EPROMs can be erased and reprogrammed; OTPs and PROMs can be programmed only once. EEPROMs can be electrically erased so that they can be used in applications that require in-socket reprogramming; EPROMs cannot. FERRAMs are superior to EEPROMs because they have fast write and can be rewritten many more times than EEPROMs before they wear out.

The feature content of the various technologies in the volatile hierarchy can be described as follows:

- DRAM: Slow, needs refresh
- SRAM: Faster, no refresh
- Fast SRAM: Faster still, no refresh
- SRAM and Battery: All SRAM features plus battery backup
- FERRAM: All SRAM features, nonvolatile without battery

As with the nonvolatile hierarchy, each member of this hierarchy has significant advantages over the inferior technology. SRAMs tend to be faster then DRAMs and need no refresh. Fast SRAMs have a speed advantage over SRAMs. SRAMs with battery backup should have all the performance of the best SRAM and offer data storage during power outage as well; although they have gained wide acceptance, many users are suspicious of battery reliability. FERRAMs are superior to SRAMs with batteries because users are likely to prefer nonvolatility that can be accomplished without a battery.

It is significant that the FERRAM is at the top of both memory hierarchies from a feature point of view. If it could be manufactured for a low enough price, it would undoubtedly replace all the market segments in both hierarchies.

Table 1 shows estimated 1989 bit prices and bit shipments for memories in the nonvolatile hierarchy. Note that the most desirable memories have the highest bit prices, whereas the lowest-priced memories have the highest bit volumes. The OTP is an exception to this rule since it has lower bit shipments than UVEPROM; because it is an exception, it is gaining market share from UVEPROM. This will be further explained in the next section.

Table 1

Estimated Nonvolatile Memory Market Highlights, 1989

Type	Bit Price (Millicents)	Bit Shipments (Billions)	Market (Millions of Dollars)
EEPROM	12.80	3,360	$ 429
UVEPROM	0.97	112,932	1,097
OTP	0.61	20,897	128
ROM	0.37	132,710	493
Total			$2,147

Source: Dataquest
January 1988

Table 2 shows estimated 1989 bit prices and bit shipments for memories in the volatile hierarchy. In this hierarchy, the most desirable memories have the highest prices and lowest bit shipments as would be expected.

Table 2

1989 Volatile Memory Market Highlights

Type	Bit Price (Millicents)	Bit Shipments (Billions)	Market (Millions of Dollars)
Fast SRAM	5.85	8,955	$ 524
SRAM	0.98	42,992	422
DRAM	0.35	887,279	3,110
Total			$4,056

Source: Dataquest
January 1988

HIERARCHICAL CANNIBALISM

Hierarchical cannibalism occurs when one memory technology usurps the market of a technology next to it in the hierarchy. Currently, this is occurring as OTP replaces UVEPROM. In the late '70s, cannibalism occurred when bipolar PROMs replaced bipolar ROMs. Today, there are no bipolar ROMs in the marketplace.

This section describes the circumstances under which cannibalism is likely to occur. Most of the discussion is based on learning curve theory; it tends to overlook factors that might be important in a more detailed analysis. Such factors might include the strategies of different participants in the market, their financial strength, or their marketing prowess.

A comparison of relative price and relative market share of various technologies is given in Figure 2. Here, data is plotted for technologies that are next to each other in the memory hierarchy. The ratio of the bit shipments of these paired technologies is given on the horizontal axis and the ratio of their bit prices is given on the vertical axis. Paired memory technologies are indicated on the figure. For instance, the point EEPROM/UVEPROM illustrates the relative situation between these two technologies.

Two things are of special interest in Figure 2. First, the slope of the trend envelope is such that the relative prices decrease about 20 percent every time the relative volume doubles. This seems to be related to the 80 percent learning curve that is exhibited by most memory technologies. Second, the lower part of the envelope passes through bit parity when the superior technology is at a 40 percent price premium. At the upper side of the envelope, this premium expands to more than 300 percent. This spread in price premium is a measure of the relative superiority of one technology over another. All the market estimates for FERRAM in this newsletter assume the more conservative price premium of 40 percent at bit parity.

As Figure 2 shows, the only two paired technologies jockeying for market position are UVEPROM and OTP. In recent years, the price of OTP has been declining more rapidly than that of UVEPROM. As a result, OTP bit shipments have been increasing more rapidly than UVEPROM bit shipments; this drives the bit ratio of the UVEPROM down as compared with OTP, causing the data points to migrate in the manner shown from 1984 to 1987.

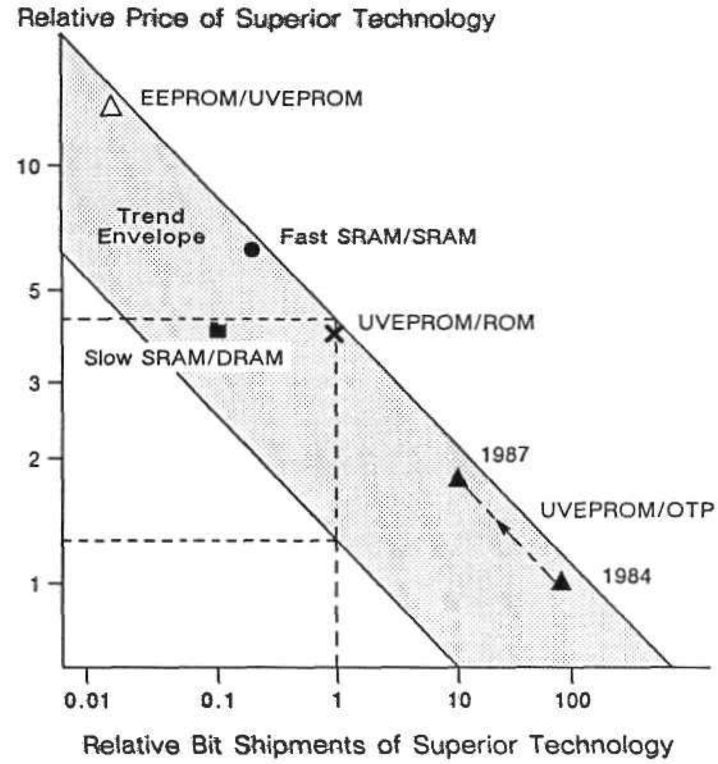
Why is it that cannibalism is occurring in the case of UVEPROM/OTP? Table 3 provides the answer to that question. In the period 1984-1989, OTP increased in bit shipments by 98.11 to 1, while UVEPROM increased in bit shipments by only 8.88 to 1. In other words, OTP decreased more in selling price because it increased relative bit shipments much more than UVEPROM.

Cannibalism occurs when a new technology (e.g., OTP) is introduced near price parity with an older technology (e.g., UVEPROM), but at much lower bit shipments. In this situation, the new technology need garner only a small fraction of the bit shipments of the older technology to double and redouble its bit shipments. The new technology can thus run rapidly down its learning curve and lower its relative price substantially, until eventually it captures the bulk of the market from the older technology.

Why are the other technologies in Figure 2 not cannibalistic? They are simply too far apart in price for cannibalism to occur. To put it more precisely, they are priced so that little change in relative bit shipments is likely. That is why movement is observed only for the pair UVEPROM/OTP. This pair plotted near the parity price point in Figure 2 in 1984. If technologies are far apart in price, they can be thought of as occupying separate, defensible market niches. In this situation, users buy the superior technology only when it is absolutely required, and relative bit prices can be quite high. However, when relative bit prices approach parity, users will use the superior memory even when they do not absolutely need the extra features so long as the premium paid is not too great.

Figure 2

Relative Market Share of Competing Memory Technologies (1987 Data, unless Indicated)



Source: Dataquest
January 1988

Table 3

Comparison of UVEPROM and OTP

Type	1989 Bits/1984 Bits	1989 Price/1984 Price
UVEPROM	8.88	0.105
OTP	98.11	0.064

Source: Dataquest
January 1988

FERRAM MARKET SHARE ESTIMATES

Dataquest's estimates for the FERRAM make the following assumptions:

- The FERRAM can be introduced at a bit price near that of EEPROM.
- Early shipments are limited by market dynamics.
  - The time required to educate the market
  - The time required to build shipments
- The FERRAM takes market only from EEPROM.
- FERRAM technology is used only to store data when power is off.
- FERRAM pricing follows a 60 percent learning curve.

All of these assumptions are conservative. FERRAM prices near those of SRAMs should be possible, since FERRAMs can be built using an SRAM process with only three additional mask layers.

It is assumed that FERRAM will take market share only from EEPROM. It is possible that FERRAM can gain additional market share from other memories such as bubble memories and SRAMs.

It is assumed that FERRAM technology is used to store data only when power is turned off. A circuit to accomplish this with SRAM technology can easily be built by adding only the aforementioned three mask layers. In this case, the FERRAM is cycled only when the power is turned off. The wear-out mechanism in FERRAM is good for at least 10 to a factor of 10 cycles, which provides memory life in excess of 10,000 years if power is cycled twice a day.

There is also a good possibility that the wear-out could be extended to 10 to a factor of 15 cycles. This would make it possible to cycle the FERRAM every time the memory is read without wear-out occurring. As a result, FERRAM could achieve something close to SRAM performance using a single-transistor FERRAM cell. This technology would be much less expensive than the SRAM technology assumed in Dataquest's forecast.

A 60 percent learning curve is assumed. Since the FERRAM will be introduced at a premium to EEPROM prices (which are assumed to be 12.8 millicents per bit in 1989, as shown in Table 1) but built with SRAM technology (.98 millicents per bit in 1989 as Table 2 shows), this entire premium is used to pay for the three extra FERRAM masking layers. All other things being equal, the premium should be proportional only to the number of mask layers. This means a premium of 3/13 equals 23 percent if there are 13 SRAM layers and 3 FERRAM mask layers. Thus, it is reasonable to assume that FERRAM prices proceed along a 60 percent learning curve rather than the 80 percent learning curve typical for most memories, since all the learning can be focused on only the three extra mask layers.

Both vendors project that in the future, FERRAMs will need only one additional mask layer. This would make the above assumptions even more conservative.

Figure 3 gives Dataquest's estimates for FERRAM and EEPROM bit prices for the period 1988 through 1992. FERRAM prices are kept relatively high through the beginning of this period because shipments are limited mostly by market dynamics rather than relative price.

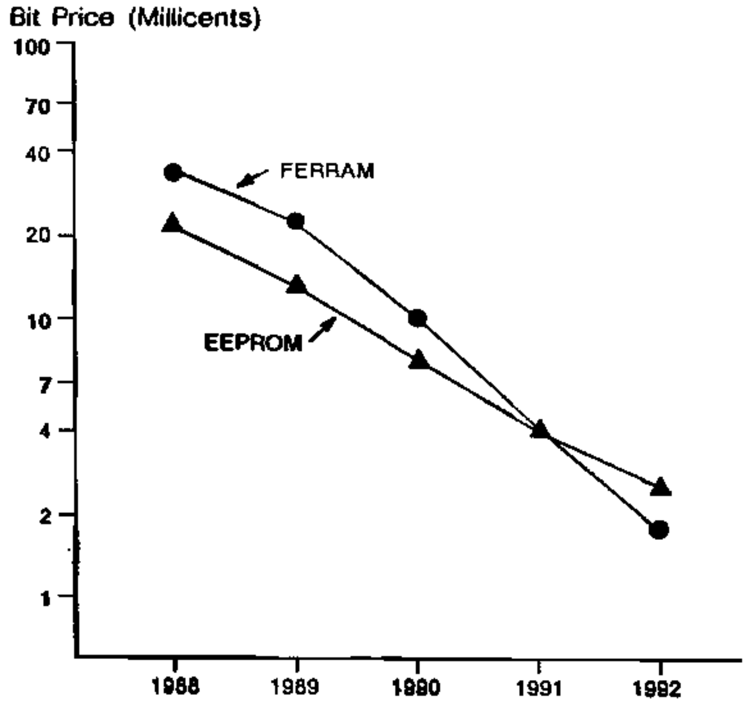
Figure 4 gives the relative dollar shipments of FERRAM and EEPROM. In this figure, the hollow bars indicate the EEPROM shipments before FERRAM, whereas the shaded areas indicate EEPROM shipments after FERRAM. Note the significant impact that FERRAM has in 1991 and 1992.

Dataquest's scenario that accompanies this forecast assumes the most complex part is a 256K FERRAM in 1988, with shipments of this device ramping in 1989. Introduction of a 1-megabit FERRAM using a single-transistor cell is assumed in 1990. If this part is not introduced, however, the forecast of Figure 4 would be little changed.

Dataquest also anticipates that a 4-megabit FERRAM will be introduced sometime in the early to mid -1990s. This part should be very interesting, because there is a good chance that it may be easier to build than a 4-megabit DRAM. This is possible because the ferroelectric capacitors used in FERRAMs have dielectric constants hundreds of times higher than silicon dioxide. This means that a storage capacitor can easily be built without resorting to the need for the trench capacitors currently contemplated for that generation of DRAM.

Figure 3

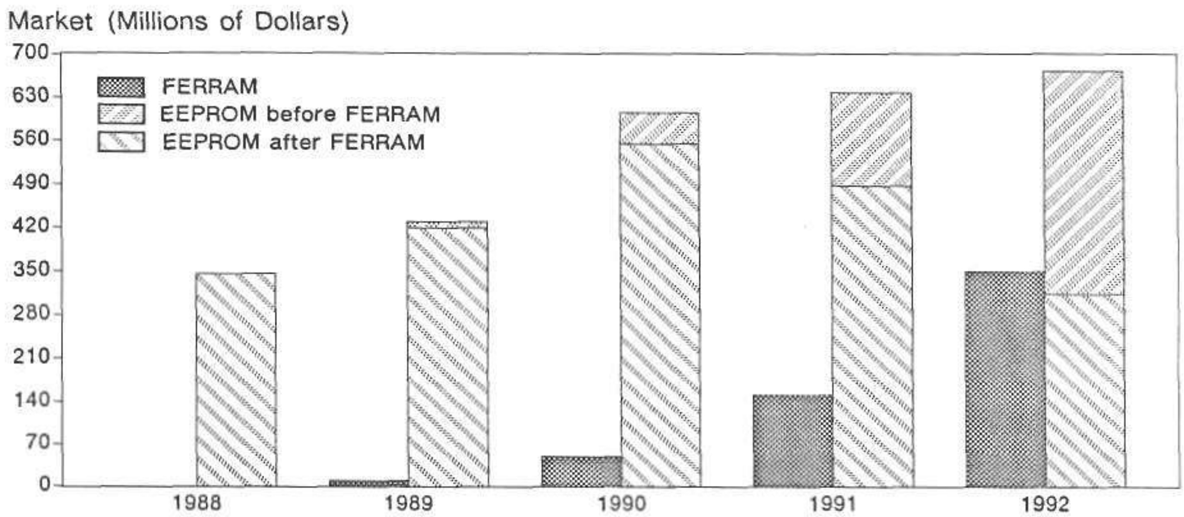
Forecast EEPROM and FERRAM Bit Prices



Source: Dataquest
January 1988

Figure 4

Forecast EEPROM and FERRAM Markets



Source: Dataquest
January 1988

TECHNOLOGY

Ferroelectric technology has been around for some time. Thirty years ago, ferroelectric technology was being considered as an alternative to magnetic core technology. That line of research was abandoned for many reasons. Important among these was the fact that ferroelectric memories could not be addressed by a combination of voltages on the row and column lines in the same way that magnetic memories could be addressed by coincident row and column currents.

Later, a great deal of research was done on ferroelectrics because of the other properties of these materials. Among other things, ferroelectric materials exhibit an index of refraction that can be controlled by an applied voltage. This makes them useful for modulating beams of light.

Ferroelectric materials are also often piezoelectric. Some attempts to use these materials have floundered because the piezoelectric effect caused them to flex mechanically and eventually fatigue.

Today, hundreds or even thousands of ferroelectric materials are known. These all have different properties, and only a few are suitable for semiconductor applications.

The current breakthrough in ferroelectric memories seems to be due to several factors. First, several groups realized that a ferroelectric device could be addressed using semiconductor technology rather than coincident voltages. This greatly relieved constraints on the ferroelectric material.

Secondly, two companies began working with a ferroelectric material that is effectively a ceramic. With proper processing, this material is robust and compatible with semiconductor processing.

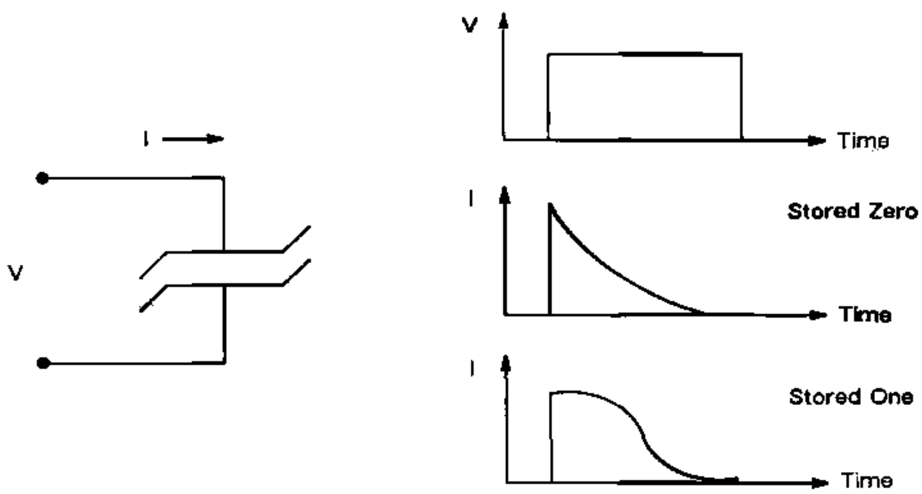
Finally, deposition techniques have advanced to the point where it is possible to reliably deposit reproducible thin films of this material. Deposition is still somewhat tricky because the exact mixture of elements must be maintained or the material will not exhibit ferroelectric properties.

When a ferroelectric material is used as the dielectric in a capacitor, it exhibits some interesting properties. As the capacitor is charged, the bipolar (+ on one end, - on the other) molecules in the ferroelectric material align themselves with the electric field. If the capacitor is discharged, these molecules stay aligned. If a subsequent voltage is applied in a direction opposite to the first voltage, these molecules have to realign themselves in the opposite direction, and a high current flows. If, on the other hand, the second voltage is applied in the same direction as the first, only a small current flows since the bipolar molecules are already aligned in that direction.

This is illustrated in Figure 5, where a voltage is applied to a ferroelectric capacitor. If a zero is stored in the capacitor, its molecules are already aligned in the same direction as the applied voltage. If, on the other hand, a one is stored, the molecules are aligned in the opposite direction, and a higher current flows.

Figure 5

Memory in a Ferroelectric Capacitor



Source: Dataquest
January 1988

These capacitors can be used in conjunction with conventional memory circuits. In an SRAM, one capacitor is attached to each side of each memory flip-flop when the power to the chip begins to go off. One side of the flip-flop is high, and this side causes that memory capacitor to polarize. The other memory capacitor does not polarize because that side of the flip-flop is low. When the power is turned back on, less current will flow in the polarized capacitor than in the capacitor tied to the other side of the flip-flop. This will cause the flip-flop to return to its original state.

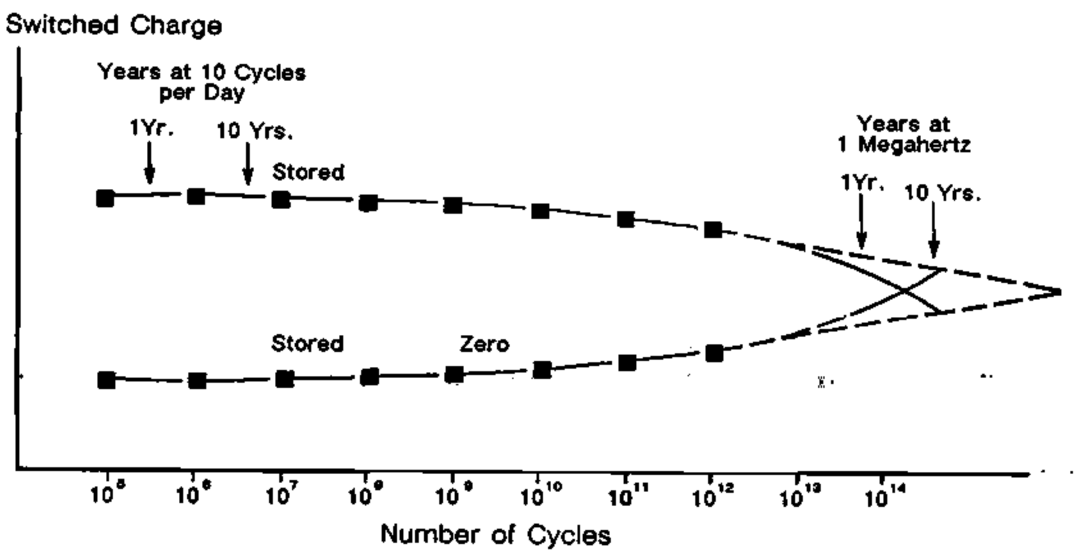
Alternatively, a ferroelectric capacitor can be used as the storage capacitor in a DRAM. This capacitor is alternately charged and discharged every time a bit is read, just like in a conventional DRAM. However, data storage in the DRAM is permanent because the polarization of the ferroelectric capacitor stores the data when the power to the chip is turned off.

Ferroelectric capacitors also have an advantage in DRAM circuits because they have several hundred times as much capacitance per square micron as the silicon dioxide capacitors now used in today's DRAMs. This means that a smaller capacitor will generate a much higher output voltage. Conceivably, ferroelectric capacitors could eliminate the need for trench capacitors in the 4-megabit DRAM while simultaneously providing nonvolatility as an added bonus.

Figure 6 shows the way that the ability of a ferroelectric capacitor to store charge deteriorates as the memory is cycled. Initially, the charge stored for a one is 1.5 to 2.0 times as great as the charge stored for a zero. As the capacitor is read and rewritten, there is a tendency for some of the bipolar molecules to become "stuck" so that they no longer turn around when a reverse voltage is applied. This reduces the ratio of the amount of charge stored for a one and a zero, gradually causing the capacitor to be useless after repeated cyclings.

Figure 6

Endurance Testing of FERRAMs



Source: Dataquest
January 1988

Currently, 10 to the 10th power cycles have been achieved, and one vendor is claiming 10 to the 14th cycles. If the SRAM technology is used and the ferroelectric capacitors are cycled only when power to the memory is lost, 10 to the 10th cycles is far more than adequate. On the other hand, if the DRAM circuit is used, a 10-year life would require 10 to the 14th cycles if the memory cycle is 1 microsecond and 10 to the 15th cycles if the memory cycles in 100 nanoseconds. This may be achieved in the near future, since progress in improving this wear-out has been rapid so far.

For comparison, the number of cycles achieved by EEPROMs before wear-out is 10 to the fifth or less. Ferroelectric capacitors are already far superior. In addition, the ferroelectric capacitor seems able to retain its memory in the presence of radiation, a fact of interest to the military.

Ferroelectric capacitors have also been tested to see how long they retain data when they are stored without being cycled. Current data suggests that long-term storage does not present a problem. This conclusion is based on the fact that no measurable deterioration is seen in a period of months.

Ferroelectric capacitors are compatible with MOS processes, so it appears likely that they would also be compatible with GaAs and bipolar processing. This should offer some interesting product opportunities, since no nonvolatile memory is available in either of these technologies.

COMPANIES

Two companies, Krysalis and Ramtron, are currently in the start-up phase of FERRAMS production. Krysalis is located in Albuquerque, New Mexico. The firm has had two infusions of capital and has produced a 512-bit sample memory. It is working on 16-Kbit and 256-Kbit memories. Krysalis has recently installed a processing area for adding the extra ferroelectric layers to base wafers produced in a foundry.

Ramtron is located in Colorado Springs, Colorado. Its early ferroelectric work was done at the University of Colorado, and the ferroelectric layers are still being applied in the university wafer fab. Ramtron has just finished a 256-bit device and is working on both 16K and a 256K devices. Initial financing for Ramtron came from a venture capital firm in Australia. Recently, a license was negotiated with an Australian semiconductor start-up.

Both firms appear to be using the same ferroelectric material, though it appears that they apply it in a different manner. Both are actively adding to their patent portfolios and both plan to pursue an active licensing program for this technology.

DATAQUEST CONCLUSIONS

Dataquest believes that FERRAMs represent a significant new memory technology. If unforeseen production or reliability problems do not crop up, FERRAMs should garner a growing share of the memory market. This share is may grow dramatically in the next five years if the FERRAM technology achieves its anticipated cost and technology developments. Beyond that, FERRAMs could continue gaining share as they begin to take market share from SRAMs. Our most optimistic scenario suggests that FERRAMs are the technology of choice at the 4-megabit DRAM level. This would result in FERRAM achieving a significant share of the entire memory market.

Howard Z. Bogert

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Research *Newsletter*

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SIS MEMORY QUARTERLY EVENTS NEWSLETTER
January 1988

Because of the need for detailed memory product information, the SIS Memory Product Group will issue a quarterly events newsletter containing a synopsis of news events gathered from the trade press and company releases over a three-month period. This issue marks our first such newsletter. This newsletter summarizes events that occurred during the last quarter (October, November, December) of 1987. The SIS Memory Group does no analysis of the news items and assumes no responsibility for the accuracy of their contents. Information is abstracted and cross-referenced by company name, Dataquest classification, source, and date. Clients who require additional information may take advantage of their inquiry privileges and call the SIS MOS Memory product research staff.

The following is a key to the publications reviewed during research and included in this issue:

Company News Release	CNR	Electronic Engineering Times	EET
Business Wire	BW	Electronic News	EN
Electronic Business	EB	Journal of Electronic Engineering	JEE
Electronic Buyers' News	EBN	San Jose Mercury News	SJM

MOS DRAM DEVELOPMENTS

Motorola

Motorola's Memory Products Division announced that it was expanding its DRAM product offerings by adding two new high-speed 1-Mbit CMOS DRAM products. The two new DRAMs are available in 1Mx1 and 256Kx4 configurations. Initially, the products will be packaged in 300-mil wide plastic DIPs (dual in-line packages), with SOJ (small outline J-lead) packages available during the second quarter of 1988. (CNR, 12/7/87, pg. 29)

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398, (408) 437-8000, Telex 171973, Fax (408) 437-0292

Texas Instruments

Texas Instruments added three 64Kx4 NMOS DRAMs to its Military Product list. The three parts, numbered SMJ4464-12JDS, SMJ4464-15JDS, and SMJ4464-20JDS, are MIL-STD-883 qualified and have average access speeds of 120ns to 200ns over the -55 degree to 110 degree C temperature range. (CNR, 10/87, Vol.4, Iss.9)

Toshiba

Toshiba America added two new ZIP (zig-zag in-line package) 1-Mbit DRAMs to its product portfolio in 1987. The new CMOS DRAMs, numbered TC511000Z and TC514256Z, are offered in 1Mx1 and 256Kx4 configurations, with 85ns, 100ns, and 120ns access speeds available. (CNR, 11/17/87, pg. 29)

MOS SRAM DEVELOPMENTS

Electronic Designs (EDI)

EDI has received DESC (Defense Electronic Supply Center) approval on its EDH8808, 8Kx8 SRAM module, military drawing reference 5962-85525. This 64K device is available in 55, 70, 100, 120, and 150ns speeds. (CNR, 10/26/87)

Fujitsu

Fujitsu has announced development of an HEMT (high-electron mobility transistor) 4K SRAM with a 0.5ns access time. The device consists of four 1-Kbit memory cell blocks in a 1Kx4 configuration. (JEE, 11/87, pg. 26)

Integrated Device Technology (IDT)

IDT has introduced its new IDT7MP6025, 512K CMOS synchronous RAM module, which has the potential of replacing 15 standard ICs and offers a 7 to 1 density improvement over equivalent through-hole devices. The new device is available in a 64Kx8 configuration with 45, 55, and 75ns speeds available. The device is expandable to 16- or 32-bit word widths and is fully testable at the module level. The device is packaged in an FR4 plastic SIP module. (CNR, 12/17/87)

IDT has also introduced two JEDEC-compatible 1-Mbit SRAM modules, with access speeds faster than 50ns. The modules are available in 128Kx8 (IDT8M824S45), and 64Kx16 (IDT8M624S45) configurations. IDT believes that these new modules can provide a 4 to 1 space reduction over other 256K SRAMs. The products are offered in a side-braze module with LCCs or SOICs. (CNR, 12/17/87)

Motorola

Motorola has introduced its new MCM60256, 32Kx8 CMOS SRAM product. The 256K device can achieve speeds of 85ns, 100ns, and 120ns, and is available in the standard 28-pin, 600-mil DIP package. (CNR, 12/7/87)

Texas Instruments

Texas Instruments is sampling its 16Kx1 (SMJ61CD16), and a 4Kx4 (SMJ64C16), CMOS SRAM products for its military line. These devices, processed to MIL-STD-883C, Class B standards, are part of TI's SRAM product offering that will eventually include the 256K density. These devices are expected to meet access speeds of 25ns to 35ns over the military temperature range, and will be available in side-braze ceramic DIPs and LCCs. (CNR, November/December 1987)

Toshiba

Toshiba recently announced that it was sampling the new 1-Mbit CMOS virtually static RAM (VSRAM). This device integrates 1-Mbit CMOS DRAM technology with full on-chip refresh circuitry, but functions like an SRAM. Toshiba believes that the TC518128P device can be used as a direct replacement for a 1-Mbit SRAM, or it can also be used in a pseudo-SRAM (PSRAM) mode, requiring external refresh timing. Access time for the SRAM averages 100ns, or 120ns in the PSRAM mode. The new VSRAM is packaged in a 32-pin plastic DIP, and is pin compatible with the JEDEC-standard 1-Mbit SRAM. (EET, 11/9/87, pg. 56)

MOS EPROM DEVELOPMENTS

Microchip Technology

Microchip Technology, previously known as General Instruments, Microelectronics Division, has introduced a new high-speed 64K CMOS EPROM with access speeds of 45, 55, and 70ns. The 8Kx8 density-labeled 27HC64 is being offered in both a 28-pin CERDIP and a 32-pin LCC package. (EET, 10/5/87, pg. 94)

Mitsubishi

Mitsubishi continues to add to its OTP (one-time programmable) product offerings with its latest developments of the 128K, 256K, and 512K densities. Access time for all three devices averages 250ns.
(CNR 12/87)

Toshiba

Toshiba has announced a 64Kx8, 250ns OTP EPROM that is programmable with Data I/O's quick-pulse algorithm. The product is being offered in a standard 28-pin plastic DIP, with a 250ns access speed. (CNR, 12/4/87)

MOS ROM DEVELOPMENTS

Sharp

Sharp has recently introduced its new 150ns, 2-Mbit CMOS ROM. The LH532300 device is organized in a 256Kx8 configuration and is packaged in a 32-pin DIP. (JEE, 11/87, pg. 66)

MOS EEPROM DEVELOPMENTS

Catalyst Semiconductor

Catalyst has announced its further entry into the EEPROM arena with two new 16K CMOS EEPROM devices. The CAT28C16A and CAT28C17A devices are organized in 2Kx8 configurations, with expected access times of 150ns. The 16A device is available in a 24-pin CERDIP or plastic DIP and 32-pin PLCC, while the 17A version is available in a 28-pin CERDIP or plastic DIP and a 32-pin PLCC. (EET, 11/9/87, pg. 62)

Integrated Device Technology (IDT)

IDT has joined the EEPROM competition with its entry of two new 16K CMOS EEPROM products. Labeled IDT78C16 and IDT78C18, the devices can achieve access speeds of 55ns and offer Serial Protocol Channel (SPC is a trademark of IDT). This SPC feature allows rewrites to occur serially, via its SPC pin set, thus eliminating on-board microprocessor interaction in control/store operations. The pin set consists of four pins that allow read and write functions to be serially performed. This feature not only benefits customers that require infrequent programming, it also benefits those customers with remote programming applications. The C16 version is pin- and function-compatible with other 16K EEPROMs currently on the market, and is available in a 24-pin 300mil CERDIP, a 24-pin 600mil CERDIP, and a 32-pin LCC package. The C18 version is available in a 28-pin 300-mil side-braze DIP or a 32-pin LCC package. (CNR 11/4/87)

Seeq Technology

Seeq has recently introduced its MM28C1024/B, the new 1-Mbit CMOS EEPROM module. The device is organized in a 128Kx8 configuration using four 28C256 EEPROMs in LCC packages that are mounted on a ceramic co-fired substrate, and has a decoder chip and a decoupling capacitor. The new device is available in a 32-lead JEDEC standard side-braze package and will be pin-compatible to the future monolithic 1-Mbit versions. (CNR, 10/12/87)

Xicor, Inc.

Xicor has announced a 1-Mbit EEPROM module by packing four, 256K CMOS devices on a piggyback 32-pin DIP. The device is organized in a 128Kx8 configuration, and is offered with 250ns and 300ns access speeds. (EET, 10/19/87, pg. 8)

Xicor has also announced that it has started shipping its X24C16 16K CMOS EEPROM. This 16K serial device is organized as eight 256x8 pages, and is available in an 8-pin miniDIP package. This device is also fully compatible with Xicor's 2K and 4K serial EEPROMs, and features a serial interface and software protocol allowing operation on a two-wire bus. (CNR, 11/7/87)

BICMOS DEVELOPMENTS

Saratoga Semiconductor

Saratoga Semiconductor continues to break the speed barriers with its speed upgrades for its family of 64K TTL BICMOS SRAMs. These devices are organized in 16Kx4 configurations, with access speeds achieving 20ns. While the products initially have been introduced in DIP-type packages for sampling, surface-mount package options will be made available in 1988. (CNR, 11/13/87)

Saratoga Semiconductor also announced upgrades to four products in its 4K ECL BICMOS SRAM line. The new 4K upgrades can now achieve 8ns and 10ns access times. Initially introduced in DIP packages, these new products will be offered in ceramic LCCs and flat packages. (CNR, 12/8/87)

SPECIALTY MEMORY DEVELOPMENTS

Toshiba

Toshiba has recently announced sampling of two new 1-Mbit CMOS video RAMs. Labeled TC524256 and TC524257, these new products are multiport memories that have a 256Kx4 DRAM port combined with a 512Kx4 serial access memory. The RAM port operates as a conventional DRAM. The devices are available in 100ns and 120ns, with 400-mil 28-pin plastic DIP, SOJ, or ZIP package styles. (JEE, 11/87, pg. 28)

BIPOLAR MEMORY DEVELOPMENTS

National Semiconductor

National recently added a new 16-Kbit registered TTL PROM to its family of bipolar memory products. Labeled DM7787SR191 (synchronous) and DM778SR193 (asynchronous), the device is organized in a 2Kx8 configuration. National is offering the device in either a 24-pin ceramic or plastic DIP, or a 28-pin PLCC. (CNR, 11/12/87)

OTHER MEMORY DEVELOPMENTS

Vitesse Semiconductor

Vitesse has recently announced development of a 1K GaAs SRAM with an access speed that can achieve 3ns. The new ECL-compatible part, labeled VS12G422E, is organized in a 256 x 4 configuration, uses the standard ECL 4.5V power supply, and is designed to meet the -55 degree to 125 degree C military temperature range. Vitesse will sample the product during the first quarter of 1988, with volume production expected to occur during the second half of 1988. (EET, 12/21/87, pg. 32)

MEMORY APPLICATION DEVELOPMENTS

Mitsubishi

Mitsubishi has intensified its participation in the memory card business by announcing its next-generation Melcards. Mitsubishi's Melcards are available with SRAM from 32 Kbytes to 512 Kbytes of memory, with OTP ROM from 32 Kbytes to 512 Kbytes of memory, and with ROM from 128 Kbytes to 2 Mbytes of memory. Mitsubishi's Melcard memory capacity can be upgraded from its current 2 Mbytes maximum to 8 Mbytes in the future. The cards are designed to be used with either a 60-pin, two-piece connector, or a 50-pin card-edge connector. Mitsubishi incorporates its very small outline package (VSOP) in the Melcard. The VSOP is approximately two-and-one-half times smaller than standard surface-mount device packages. This smaller size allows 16 memory ICs plus interface circuitry to be mounted on a card that is only 3.4mm thick. (CNR 10/12/87)

Toshiba

Toshiba is entering the memory card business with its introduction of the 768 EMS memory card. The 768 card has been made available for the T1000 portable computer for memory expansion from 512 Kbytes to 1.2 Mbytes. The new memory card can be used as a memory expansion card or configured as a battery-backed RAM disk with up to 720 Kbytes of memory. (BW, 11/23/87)

Mary A. Olsson

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Research *Newsletter*

SIS Code: PM6 1988 Newsletters: November
0001633

ASIC MIDYEAR UPDATE

Dataquest has incorporated the latest industry trends in producing a new application-specific integrated circuit (ASIC) forecast. In 1987, ASICs accounted for 59.1 percent of the worldwide logic market. By 1992, we now estimate that ASICs will be a $13.5 billion market, accounting for 66.5 percent of the worldwide logic market. As this growth indicates, ASICs are transforming the IC industry.

Prevailing trends incorporated in the new ASIC forecast include:

- Standard logic to ASICs—ASICs continue to impact the mature bipolar standard logic families such as LSTTL. We believe that there is an unrelenting migration of applications moving from standard logic to ASICs.
- PLDs—CMOS PLDs continue to gain popularity from suppliers and users. There are now 19 CMOS PLD suppliers. While CMOS PLDs only accounted for 18.7 percent of the 1987 PLD market, they are expected to account for 50.0 percent of the 1992 PLD market.
- BICMOS ASICs—Seven suppliers have now entered the BICMOS ASIC market, so we are forecasting both BICMOS gate arrays and BICMOS CBICs.
- Slowdown in 1990—Analysis of the forces at work in the global electronics industry lead us to conclude that ASICs will experience a slowdown in 1990.

Table 1 shows the total ASIC consumption forecast segmented by product and technology. Dataquest forecasts include NRE, device production, CAD software, and intracompany sales (internal sales). Dataquest forecasts do not include captive manufacturing by companies such as Digital Equipment, IBM, and Unisys that do not sell semiconductors to the merchant market.

Table 1

Estimated Worldwide ASIC Consumption (Millions of Dollars)

	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 1987-1992
Total Application-Specific	4,065.5	4,923.6	5,943.9	7,267.4	8,259.7	9,199.2	11,139.3	13,531.1	17.9%
MOS	3,130.0	3,778.4	4,537.9	5,462.8	6,117.9	6,858.8	8,307.0	10,007.0	17.1%
Bipolar	930.5	1,127.2	1,375.0	1,744.8	2,033.7	2,120.4	2,429.6	2,801.1	15.3%
BICMOS	5.0	18.0	31.0	59.8	108.1	220.0	402.7	723.0	87.7%
Gate Arrays	1,284.3	1,783.1	2,288.3	2,909.2	3,601.5	4,028.4	5,051.6	6,323.1	22.5%
MOS	718.3	1,092.6	1,478.2	1,935.3	2,436.2	2,677.5	3,353.2	4,156.6	23.0%
Bipolar	561.0	672.5	779.1	915.1	1,062.2	1,149.9	1,346.7	1,568.5	15.0%
BICMOS	5.0	18.0	31.0	58.8	103.1	201.0	351.7	598.0	80.7%
Programmable Logic	234.8	305.7	452.6	699.4	910.7	913.0	1,135.2	1,384.1	25.1%
MOS	9.8	32.3	84.7	156.0	274.6	336.3	511.2	689.1	52.1%
Bipolar	225.0	273.4	367.9	543.4	636.1	576.7	624.0	695.0	13.6%
Cell-Based ICs	484.8	674.4	919.4	1,263.7	1,542.6	2,109.7	2,836.8	3,736.3	32.4%
MOS	471.7	640.3	859.1	1,171.0	1,426.6	1,943.8	2,598.4	3,372.4	31.5%
Bipolar	13.1	34.1	60.3	91.7	111.0	146.9	187.4	238.9	31.7%
BICMOS	0	0	0	1.0	5.0	19.0	51.0	125.0	-
Full Custom	2,061.6	2,160.4	2,283.6	2,395.1	2,204.9	2,148.1	2,115.7	2,087.6	(1.8%)

Source: Dataquest
November 1988

During early 1987, Dataquest had forecast the ASIC market to reach $6 billion. The 1987 year-end historical shipment data indicate that it was a $5.9 billion market.

Gate arrays became the largest ASIC market during 1987. Dataquest believes that gate arrays will be the dominant design methodology through 1992. High-complexity CMOS array designs (greater than 20,000 gates) and high-complexity ECL array designs (greater than 10,000 gates) are experiencing major growth. CMOS CBICs are narrowing the gap on CMOS gate arrays, but will not catch them by 1992. There are an increasing number of CBIC designs with compilable cells and megacells that provide increased functionality over and above that of gate arrays.

There are now more than 100 worldwide merchant ASIC suppliers. The ASIC market has grown from infancy to $5.9 billion in 10 years. ASICs have now matured, and we believe that they will play the leading role in the future electronics industry. Applications for ASICs are pervasive, ranging from talking toy bears to the world's fastest and most powerful computers.

Bryan Lewis
Andy Prophet

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Research *Bulletin*

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0001247

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Programmable Logic	234.8	305.7	452.6	699.4	910.7	913.0	1,135.2	1,384.1	25.1%
MOS	9.8	32.3	84.7	156.0	274.6	336.3	511.2	689.1	52.1%
Bipolar	225.0	273.4	367.9	543.4	636.1	576.7	624.0	695.0	13.6%
Cell-Based ICs	484.8	674.4	919.4	1,263.7	1,542.6	2,109.7	2,836.8	3,736.3	32.4%
MOS	471.7	640.3	859.1	1,171.0	1,426.6	1,943.8	2,598.4	3,372.4	31.5%
Bipolar	13.1	34.1	60.3	91.7	111.0	146.9	187.4	238.9	31.7%
BICMOS	0	0	0	1.0	5.0	19.0	51.0	125.0	-
Full Custom	2,061.6	2,160.4	2,283.6	2,395.1	2,204.9	2,148.1	2,115.7	2,087.6	(1.8%)

Source: Dataquest
August 1988

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There are now more than 100 worldwide merchant ASIC suppliers. The ASIC market has grown from infancy to $5.9 billion in 10 years. ASICs have now matured, and we believe that they will play the leading role in the future electronics industry. Applications for ASICs are pervasive, ranging from talking toy bears to the world's fastest and most powerful computers.

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Research *Bulletin*

SIS Code: GA8/AS4 1988 Newsletters: June
0000309

GAZELLE INTRODUCES FIRST PRODUCTION GaAs PLD

On June 10, Gazelle Microcircuits, Inc., announced immediate availability of the IC industry's first GaAs laser-programmable logic device (PLD), the GA22V10. The TTL-compatible device is expected to extend GaAs technology into high-end personal computers and workstations. Gazelle priced the device at $55.00 in 100-piece quantities and has been shipping the product since February.

GaAs technology offers an on-chip speed advantage of three to five times that of silicon technology, which translates to an improvement of at least 25 percent at the TTL system level. TTL interface and power pins assure full compatibility with the most popular microprocessor ICs; memory ICs; and CMOS, NMOS, and Schottky TTL logic families. Thus, the Gazelle product has immediate applicability to a segment of the mainstream multibillion-dollar IC market. Further, the GA22V10 is pin equivalent to its slower silicon counterpart, making available a market by direct substitution. Anticipating rapid demand buildup, Gazelle has entered into a foundry agreement with TriQuint, a subsidiary of Tektronix, Inc. TriQuint is an established volume producer of GaAs ICs, with 4-inch fab capacity.

Gazelle is a Silicon Valley-based start-up cofounded in 1986 by Andy Graham and David MacMillan. Its objective is to design and market high-performance, easily used LSI and VLSI GaAs digICs. The company has $10.5 million in financing; equity investors include Kleiner Perkins Caufield & Byers, Hambrecht & Quist, and others.

DATAQUEST CONCLUSIONS

The Gazelle announcement is another in the recent sequence of GaAs digIC product introductions, closely following those of Ford, GAIN, GigaBit, Vitesse, and others. Dataquest expects an acceleration in the acceptance of GaAs ICs into a broad range of applications including high-volume computers, high-speed testers and instrumentation equipment, communications, and high-performance workstations.

Gene Miles

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Research *Bulletin*

SIS Code: AS3/PM2 1988 Newsletters: May
0000119

WHO WILL WIN THE ASIC BUSINESS?

Two fascinating questions were asked to the panel members during a panel session at the Custom Integrated Circuit Conference (CICC) in Rochester, New York, on May 18: (1) Who will win the ASIC business? and (2) What factors will determine the winners? The panel consisted of: Wayne Spence from Texas Instruments, Tom Reynolds from Sierra Semiconductor, David Sear from Fujitsu, Rick Rasmussen from LSI Logic, Dick Jacobs from AT&T, Doug Fairbairn from VLSI Technology, and Jack Carsten (formerly the head of Intel's ASIC group) from U.S. Venture Partners.

The panel session quickly turned into a debate that contrasted the assets and liabilities of large, traditional standard products suppliers that have entered the ASIC business and the key attributes of the focused ASIC suppliers. The consensus was that integrated CAD tools are the number-one ingredients for success. Supplier strategies were discussed, including one-stop shopping, product differentiation, and alliances.

TRADITIONAL VERSUS FOCUSED ASIC SUPPLIERS

The large, traditional semiconductor suppliers started the session by pointing out their assets: deep pockets, marketing infrastructure, access to leading-edge technology and manufacturing, and, above all, their large standard product offerings, which can be converted into cell libraries. The focused ASIC suppliers were quick to point out the liabilities of the traditional suppliers: rigid procedures, poor integration of CAD and silicon, fab allocation issues, conflicts between standard product divisions and ASIC divisions, and the many problems associated with converting the standard products into a common process for the library.

The focused ASIC suppliers felt that they would win the ASIC business because they possess the following attributes: high integration of CAD and silicon, the ability to react quickly to market changes, a focus on service, and a long track record in low-volume production manufacturing. Their major liability was stated to be cash flow, as it is hard for these suppliers with smaller budgets to outrun the giants.

Major Success Factors

Almost all the panelists agreed that the winners will be separated from the losers by how they handle the following issues:

- CAD tools
- Libraries
- Service
- Manufacturing
- Packaging
- Test

Comprehensive, user-friendly CAD tools were stated as the most important ingredients in the ASIC business, because without them, it does not matter what else the supplier has. The next important ingredients are rich, dedicated libraries focused on end-use applications (communications, data processing, etc.). Service, as defined by one of the panelists, means short cycle times, quality, reliability, and personal involvement with each customer by providing weekly updates. Manufacturing was ranked fourth by many on the panel, because they can buy outside manufacturing in the form of foundry services. Test and packaging require major investments and have become the battlegrounds that determine the winners in the high-complexity market (greater than 20,000 gates).

Strategies

Based on observations of Dataquest analysts and CICC panel members, a wide variety of penetration strategies is chosen by suppliers, depending on their size, strengths, and financial resources.

Most of the traditional semiconductor suppliers are offering one-stop shopping to their customers. One-stop shopping means providing a full range of technologies, ASIC products, and standard products for their customers. This strategy requires very deep pockets.

Product differentiation is a common strategy for small suppliers. This means not trying to do everything for everyone, but rather, focusing on niche markets with targeted products. One panel member stated that while this strategy may require only a minimum investment, it can be risky, because a large supplier may enter the market and squash the small supplier "like a giant stepping on an ant."

Forming alliances has become critical for ASIC suppliers to cope with the high investment costs required in process technology, manufacturing, test, and packaging.

DATAQUEST CONCLUSIONS

Dataquest believes that the early ASIC leaders, as well as the patient, broad-based traditional semiconductor suppliers, will dominate the market. We estimate that in excess of 75 percent of the 1992 worldwide ASIC market will be owned by 10 suppliers. The winners will have made major investments or formed alliances for integrated CAD tools, libraries, manufacturing, test, and packaging. Providing outstanding service is extremely important. Other requirements for being a top-10 ASIC supplier are success in economies-of-scale manufacturing and a worldwide presence. Dataquest advises the small suppliers to avoid the mainstream and focus on providing system solutions (libraries and system design expertise) to defined end-user markets where they can bring something to the market that the large suppliers do not have. Each supplier must decide which role to play: to be a major supplier or to become a niche supplier. Each role requires a completely different set of resources, strategies, and technologies.

Bryan Lewis

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Research Newsletter

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0000088

GATE ARRAY MIDYEAR UPDATE

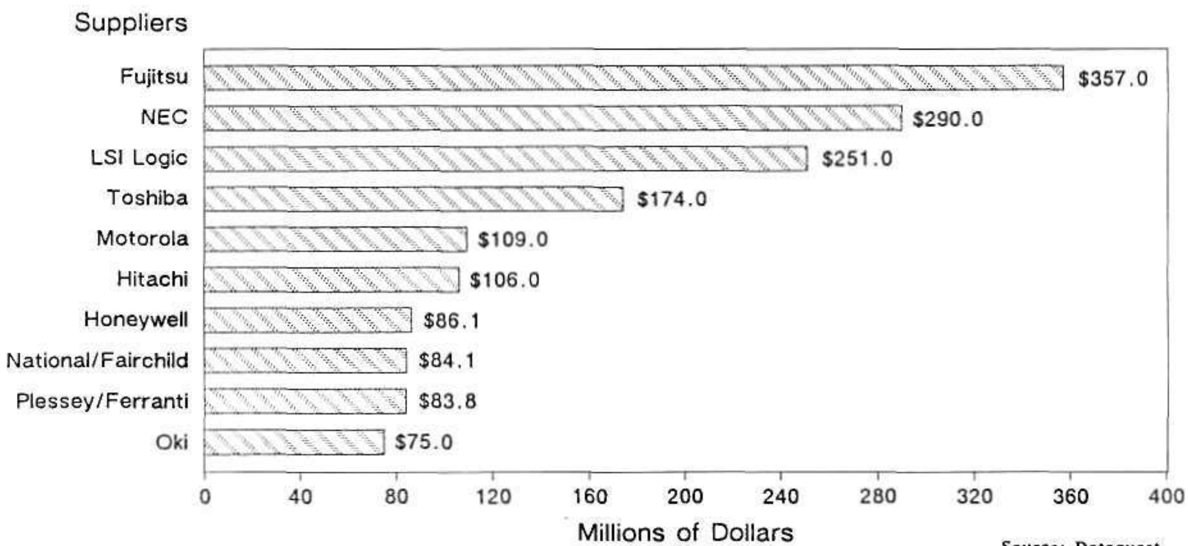
EXECUTIVE SUMMARY

The gate array segment surpassed the full-custom IC segment to become the largest ASIC market during 1987. Dataquest has projected that the $2.3 billion gate array market of 1987 will exceed $6.3 billion by 1992. Pricing on both nonrecurring engineering charges (the cost of designing the chip) as well as device pricing dropped sharply over the past three years, thus increasing their overall cost effectiveness. In excess of 11,600 gate arrays were designed during 1987, and we expect the design starts to grow to 24,040 in 1992. Dataquest believes that in excess of 30 percent of the 1992 MOS North American gate array design starts will be in products that have greater than 20,000 gates.

Figure 1 shows the top 10 worldwide gate array suppliers and their 1987 shipment revenue.

Figure 1

**Top 10 Suppliers
Estimated Worldwide Gate Array Shipments
1987**



Source: Dataquest
May 1988

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398 / (408) 437-8000 / Telex 171973 / Fax (408) 437-0292

Worldwide MOS gate array consumption grew 35.3 percent in 1987 compared with bipolar gate array consumption, which rose 15.9 percent. North American companies shipped 40.2 percent of the total worldwide gate arrays while Japanese companies shipped 50.3 percent. However, 43.8 percent of the Japanese companies' revenue was generated from intracompany sales (sales to internal divisions) while only 5.9 percent of the North American companies' revenue came from intracompany sales. Dataquest's estimates do not include captive manufacturing of the companies that do not sell to the merchant market such as IBM, Unisys, and Digital Equipment.

The key areas addressed in this newsletter include:

- 1987 shipment revenue estimates, by technology
- Technology forecast
- NRE and device pricing
- Design starts
- 1988 and beyond

1987 SHIPMENT REVENUE ESTIMATES

A review of last year's shipment data shows that the ranking did not change significantly, but in terms of gate complexity and mergers among the suppliers, the changes were dramatic.

MOS Gate Arrays

LSI Logic maintained its number one position in MOS gate arrays in 1987, but was hard pressed by NEC, Toshiba, and Fujitsu. NEC and Fujitsu earned a large percentage of their revenue from sales to internal divisions. Dataquest understated NEC's MOS gate array shipment revenue estimate in 1986 because we underestimated its internal sales. We have now revised our estimates to reflect NEC's true position. Toshiba, Oki, Seiko/S-MOS, and National/Fairchild all gained market share by focusing on capturing lower-density designs with high-production volumes.

The race in the MOS gate array world is for complexity first and speed second. LSI Logic has the highest-density gate array announced so far, with 100,000 usable gates. Most of the top 10 suppliers, along with Motorola and VLSI Technology, have joined the race for high-complexity gate arrays and are announcing products with more than 50,000 usable gates and with gate delays as fast as 650 picoseconds.

Of the top 10 MOS suppliers, 6 are Japanese companies, 3 are North American, and 1 is European (see Table 1).

Table 1

Estimated Worldwide MOS Gate Array Shipment Revenue (Millions of Dollars)

Rank 1986	Rank 1987	Company	Revenue 1986	Revenue 1987	Percent Change
1	1	LSI Logic	$192.0	$ 251.0	30.7%
2	2	NEC	158.0	206.0	30.4%
4	3	Toshiba	116.0	174.0	50.0%
3	4	Fujitsu	120.0	156.0	30.0%
5	5	Oki	48.0	67.0	39.6%
6	6	Hitachi	41.2	55.0	33.5%
8	7	Seiko/S-MOS	30.3	52.5	73.3%
7	8	National/Fairchild	31.5	43.9	39.4%
9	9	Honeywell	27.0	39.1	44.8%
11	10	SGS/Thomson	20.3	28.0	37.9%
Total			$784.3	$1,072.5	36.7%

Source: Dataquest
May 1988

Bipolar Gate Arrays

The ECL gate array market is heating up while the TTL array market continues to fade. Supercomputers, mainframes, and some minicomputers consume large quantities of ECL arrays. Fujitsu, Motorola, NEC, Honeywell, National/Fairchild, and Siemens are the key suppliers to the computer manufacturers. The top 10 suppliers shared 85.2 percent of the total 1987 bipolar market.

The race in the bipolar gate array market involves speed first and complexity second. All of the suppliers mentioned above are announcing ECL arrays in the 10,000 gate range with gate delays as fast as 100 picoseconds.

Alliances, mergers, and acquisitions are common in a highly competitive market such as ECL gate arrays. National Semiconductor purchased Fairchild during 1987 while Plessey purchased Ferranti in early 1988. Plessey recently formed an alliance with AMCC to jointly develop high-density ECL arrays.

It is interesting to note that only 3 of the top 10 bipolar gate array suppliers are Japanese companies, 5 are North American, and 2 are European (see Table 2).

Table 2

Estimated Worldwide Bipolar Gate Array Shipment Revenue (Millions of Dollars)

Rank 1986	Rank 1987	Company	Revenue 1986	Revenue 1987	Percent Change
1	1	Fujitsu	$170.0	$201.0	18.2%
2	2	Motorola	82.6	93.0	12.6%
3	3	NEC	69.0	84.0	21.7%
4	4	Plessey/Ferranti	59.6	60.0	0.7%
7	5	Hitachi	34.0	51.0	50.0%
5	6	Honeywell	45.0	47.0	4.4%
6	7	National/Fairchild	37.0	40.2	8.6%
8	8	Siemens	32.0	34.0	6.3%
10	9	AMCC	19.0	27.0	42.1%
9	10	Raytheon	22.0	26.5	20.5%
Total			$570.2	$663.7	16.4%

Source: Dataquest
May 1988

TECHNOLOGY FORECAST

The worldwide gate array market is expected to increase from $2.3 billion in 1987 to $6.3 billion by 1992. Dataquest has projected slower growth for gate arrays in the early 1990s due to the encroachment of PLDs, CBICs, and high-functionality standard products. Dataquest's forecasts and supplier shipment revenue estimates include NRE, device production, CAD software, and intracompany revenue (internal sales). Please note that Dataquest forecasts do not include captive manufacturing of companies that do not sell to the merchant market such as IBM, Unisys, and Digital Equipment.

Dataquest believes that the next recession will not appear until 1990 so we have adjusted the growth rates for that year in the forecast shown in Table 3.

Table 3

Estimated Worldwide Gate Array Consumption by Technology (Millions of Dollars)

	1985	1986	1987	1988	1989	1990	1991	1992
Total	$1,284.3	$1,783.1	$2,288.3	$2,909.2	$3,601.5	$4,028.4	$5,051.6	$6,323.1
Total MOS	$ 718.3	$1,092.6	$1,478.2	$1,935.3	$2,436.2	$2,677.5	$3,353.2	$4,156.6
MOS Digital	706.9	1,081.1	1,465.1	1,919.4	2,418.5	2,660.3	3,333.4	4,133.4
MOS Linear	11.4	11.5	13.1	15.9	17.8	17.2	19.8	23.2
Total Bipolar	$ 561.0	$ 672.5	$ 779.1	$ 915.1	$1,062.2	$1,149.9	$1,346.7	$1,568.5
Bipolar Digital	492.6	606.6	702.1	831.9	974.9	1,065.2	1,258.6	1,477.8
TTL	127.0	144.3	138.3	131.3	123.5	114.8	105.7	97.2
ECL	313.1	395.5	503.5	644.5	800.4	904.5	1,112.5	1,346.2
Other	52.5	66.8	60.3	56.1	51.0	45.9	40.4	34.4
Bipolar Linear	68.4	65.9	77.0	83.2	87.3	84.7	88.1	90.7
Total BICMOS	$ 5.0	$ 18.0	$ 31.0	$ 58.8	$ 103.1	$ 201.0	$ 351.7	$ 598.0

Note: Columns may not add to totals shown because of rounding.

Source: Dataquest
May 1988

MOS digital, ECL, and BICMOS gate arrays are expected to be the highest growth market over the next five years. We expect compound annual growth rates (CAGRs) for MOS digital, ECL, and BICMOS to be of 23.1 percent, 21.7 percent, and 80.7 percent, respectively, for 1987 through 1992. TTL was the first technology used for gate arrays in the mid-1960s; these devices are now being replaced by CMOS, ECL, and BICMOS arrays. We believe that linear arrays will have a modest 4.8 percent CAGR because cell-based ICs (CBICs) are a better solution for mixed linear/digital circuits. Although BICMOS gate arrays represent a relatively small, $31 million market today, which is dominated by Hitachi and NEC internal consumption, BICMOS gate arrays are expected to account for a minimum of 9.5 percent of the total gate array market in 1992.

NRE AND DEVICE PRICING

Gate array pricing continues to be the most competitive aspect of the market.

NRE Pricing

Suppliers are experimenting with different NRE strategies. Some suppliers try to minimize the up-front NRE charge and amortize the cost of the design over production volume. But, this can be risky because 40 to 60 percent of the designs for the industry never go to production. At the other extreme is the supplier that charges NRE and production costs separately, thus making each part self-reliant. Between these extremes are various combinations of NRE and production charges that may not represent the true cost of either part. In today's North American market, most companies are trying to break even on NRE and make money on the silicon.

NRE pricing for low-density CMOS arrays has declined drastically over the last three years. For example, 2,500-gate CMOS devices had a typical NRE charge of $30,000 in 1985, an average NRE charge of $23,000 in late 1986, and a price of less than $15,000 in late 1987. This can be attributed to the competitive environment brought about by the 60 to 70 suppliers offering comparable products.

Device Pricing

The price per device is difficult to estimate because prices vary widely due to technology, gate count, and packaging configuration. Thus, a CMOS 2,500-gate device may sell for as low as $3 in high quantities, while an ECL 2,500-gate device may sell for $170. A better way to monitor gate array pricing is on a price-per-gate basis.

The most popular gate arrays (CMOS, 2,500 gates, die only, in quantities of thousands), took a sharp price-per-gate drop from between $0.01 and $0.012 in 1984 to between $0.002 and $0.004 in 1985, then fell to between $0.002 and $0.003 during 1986. By the end of 1987, pricing per gate was common at $0.001 to $0.002. High-gate-count CMOS devices (those with greater than 20,000 gates) took a smaller drop annually and were running between $0.002 and $0.004 at the end of 1987.

BICMOS gate array pricing in late 1987 was in the $0.009 to $0.011 range and is expected to fall significantly as more suppliers enter the market. The price per gate for ECL gate arrays has taken only an estimated 15 percent drop from last year and currently is running in the $0.04 to $0.05 range.

Price decreases did occur in gate arrays, but not equally across all product lines. Gate array pricing in general has dropped much faster than other ASIC design methodologies, thus making them a more cost-effective solution.

DESIGN STARTS

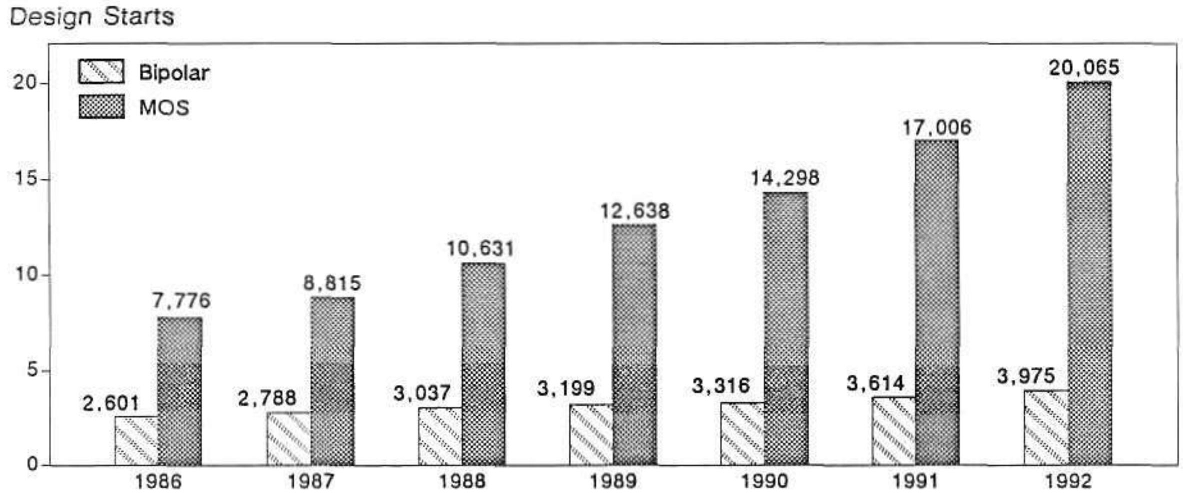
Design starts are a leading indicator of future gate array revenue. Dataquest's analysis indicates that MOS designs captured in 1987 will take an average of six months to a year to reach the production phase. Thus, a high number of designs in 1987 will result in high production revenue in 1988 and 1989. However, the percentage of designs that ultimately reach production can vary widely. Our analysis indicates that the percentage of MOS designs that go to production for the industry ranges from 30 percent during a depressed semiconductor economy to 70 percent in a thriving semiconductor economy.

Figure 2 shows the estimated worldwide gate array design starts by technology for 1986 through 1992.

Only 6.3 percent of the 1987 MOS gate arrays in North America had more than 20,000 gross gates (see Figure 3).

Figure 2

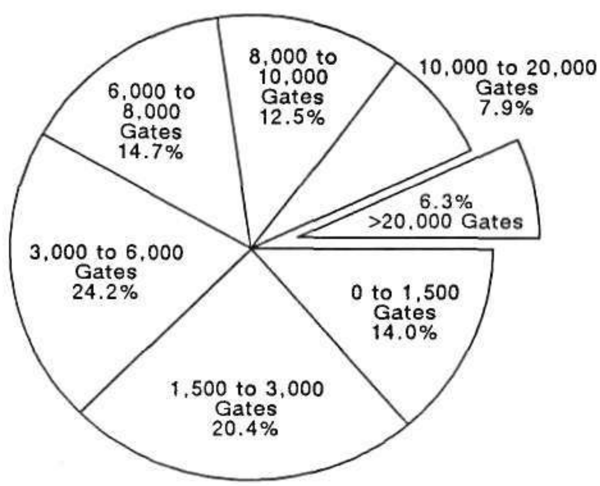
Estimated Worldwide Gate Array Design Starts by Technology 1986–1992



Source: Dataquest May 1988

Figure 3

Estimated North American MOS Gate Array Design Starts by Gate Count 1987



Source: Dataquest May 1988

The majority of the 1987 MOS designs in North America were for personal computers and were in the 3,000 to 6,000 gate range. High-end computers (supercomputers, minicomputers, and workstations) and the military are expected to be the big users of high-density gate arrays. Dataquest believes that the greater than 20,000 gate segment will exceed 30 percent of the market by the end of 1992, while the bulk of the 1992 designs will be in the 10,000 to 20,000 gate range.

1988 AND BEYOND

The total 1988 worldwide gate array market is expected to grow 27.1 percent to $2.9 billion. We expect a 30.9 percent increase in 1988 MOS consumption, a 17.5 percent increase in bipolar consumption, and an 89.7 percent increase in BICMOS consumption.

The 1988 gate array market will be characterized by:

- A major increase in high-complexity CMOS design starts
- RISC-based processors going on-chip
- A proliferation of high-density ECL array announcements
- BICMOS arrays becoming the new frontier

Beyond 1988, watch for the growing encroachment of PLDs, cell-based ICs, and high-functionality standard products.

Bryan G. Lewis

Dataquest
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PLDs: HAPPY DAYS ARE HERE AGAIN!!

A RED-HOT 1987!

Last year was a banner year for programmable logic devices (PLDs). Total PLD shipments in 1987 amounted to $441.7 million. Between 1986 and 1987, the PLD market grew by a sizzling $134.5 million, a whopping 43.8 percent increase over 1986 shipments. This comes on the heels of a not-so-shabby $71.9 million, or 30.6 percent, increase in 1986. And if that is not enough, Dataquest projects that 1988, in true semiconductor feast-or-famine tradition, will be an even better year than 1987. In 1988, Dataquest expects total PLD shipments to soar to $707.4 million, which represents an impressive 60.2 percent increase ($265.7 million) over 1987 revenue. As recently as 1985, the total PLD market was $235.3 million. So, what is fueling this red-hot PLD activity? Figure 1 gives a historical perspective of the driving forces behind PLDs, and the following events show the vitality of this market:

- Faster microprocessors demand faster PLDs. With blazing-fast 20-MHz 68020s and 80386s being designed into PS/2s, workstations, instruments, printers, etc., high-performance PLDs are suddenly in demand almost everywhere to speed up support logic. Fast microprocessors require fast support logic; otherwise, all that CPU crunching power is wasted. From all accounts, the computer segment is leading the charge on PLDs.

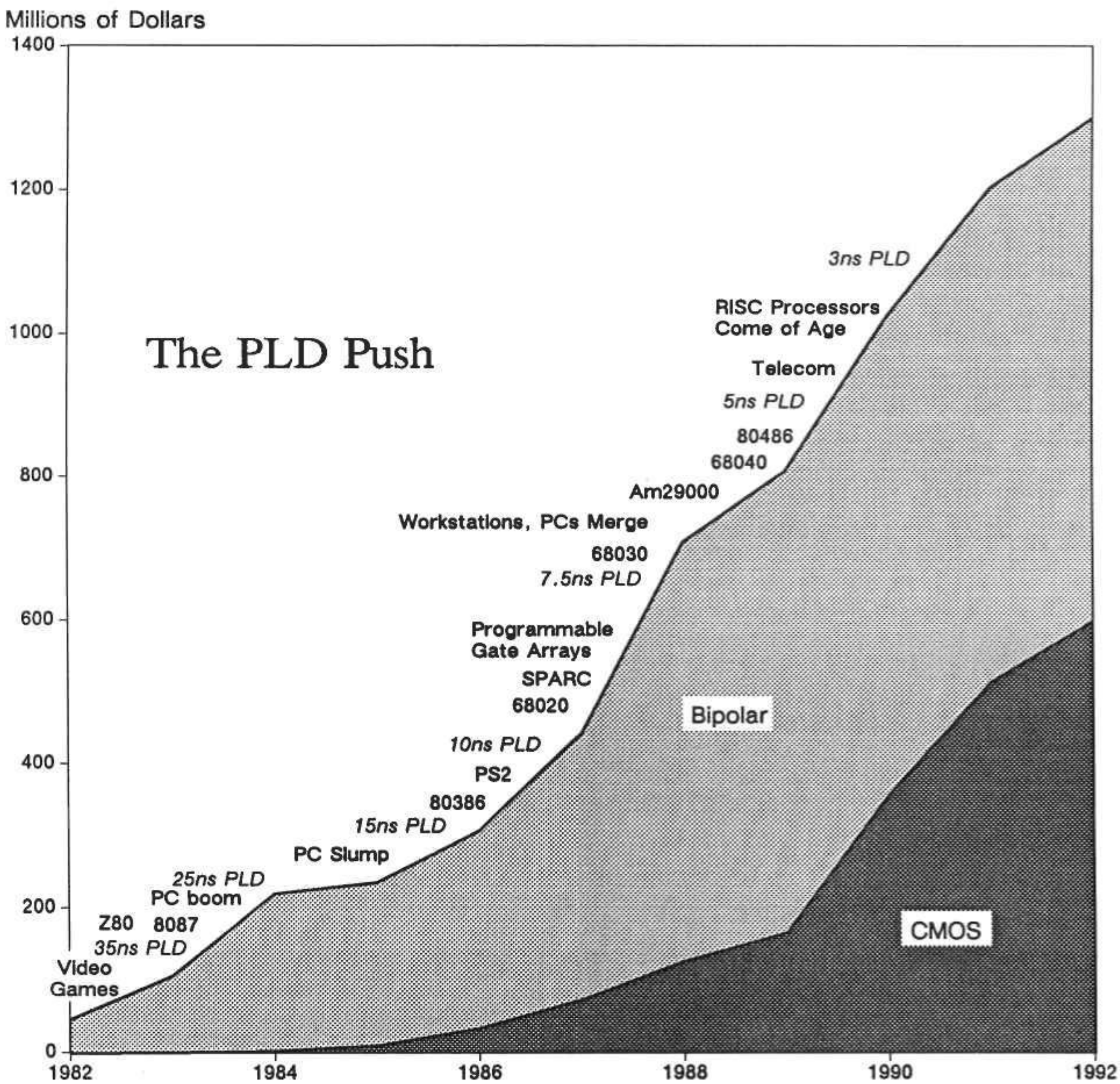
- In 1987, CMOS revenue doubled to $73.8 million. From a barely perceptible 4.3 percent market share in 1985, CMOS now accounts for 16.7 percent of the market. Of this, EPLDs account for 11.5 percent; EEPLDs, 2.7 percent; and SRAMs, 2.4 percent. High-performance, low-power CMOS PLDs have opened up new markets in telecom, laptop computers, and consumer electronics, markets that were previously not within the domain of PLDs.

- The logic cell array (LCA) device from Xilinx took off in a big way in 1987. From essentially zero revenue in 1986, total LCA revenue jumped to $11 million in 1987. With its flexible architecture, low power consumption, and reconfigurability, the device is ideal for prototyping new designs. Because any pin on the device can be an input or output pin, this device is a distinct departure from traditional PLD architectures that typically are limited in the number of input and output pins.

- With product life cycles shortening unrelentlessly, systems designers must live with compressed design cycles that allow them only one or two iterations to fix any design errors that they subsequently uncover. Today's turnaround times for gate array or cell-based designs are excellent, but still not good enough for these designers. For them, PLDs take the risk out of a "RISC-ky" or "RISC-less" design.

Figure 1

A Historical Perspective on PLDs (Millions of Dollars)



Source: Dataquest April 1988

WHO'S HOT, WHO'S NOT

The Bipolar Folks

In a memorable year marked by crashing stock markets and earth-shattering revelations by defrocked ministers, the PLD world in 1987 had its share of upheavals. Most notably, the stunning acquisition of MMI by AMD must stand out as the PLD event of the year. The acquisition of Fairchild by National is also noteworthy, but its impact on the PLD market is limited. The AMD/MMI union results in a behemoth that controls 53.9 percent of the market, down slightly from the 56.0 percent that the two controlled in 1986.

Looking at the union with a jaundiced eye and with the benefit of a bit of hindsight, with the PLD market sizzling, one wonders whether MMI might have been the acquirer instead of the acquiree, had the acquisition not taken place for another year. Be that as it may, the marriage has produced some benefits: the MMI subsidiary should benefit from AMD's strength in process technology and state-of-the-art fab facilities, while MMI can offer AMD PLD folks some lessons in how to compete in the PLD arena. The more than $100 million dowry from MMI probably did not hurt either.

TI turned in a stellar performance for 1987, essentially doubling its revenue for the year. Much of the increase is due to 10ns PLD business that TI captured due to a manufacturing hiccup MMI suffered in midyear.

Total 1987 PLD revenue for Signetics dropped slightly. Recognizing its dependence on bipolar technology, the company is slowly shifting over to CMOS as the technology of choice. In particular, its FPLS family is vulnerable to CMOS look-alikes from the competition.

The CMOS Folks

Lattice Semiconductor rose like a phoenix from the ashes of bankruptcy in 1987. Along the way, it entered into marriages of convenience with MMI, National, Gould, and SGS/Thomson, licensing to them the EEPLD technology that is its bread and butter. We also expect the number of EEPLD suppliers to expand in 1988 with entry of International CMOS Technology and Gould.

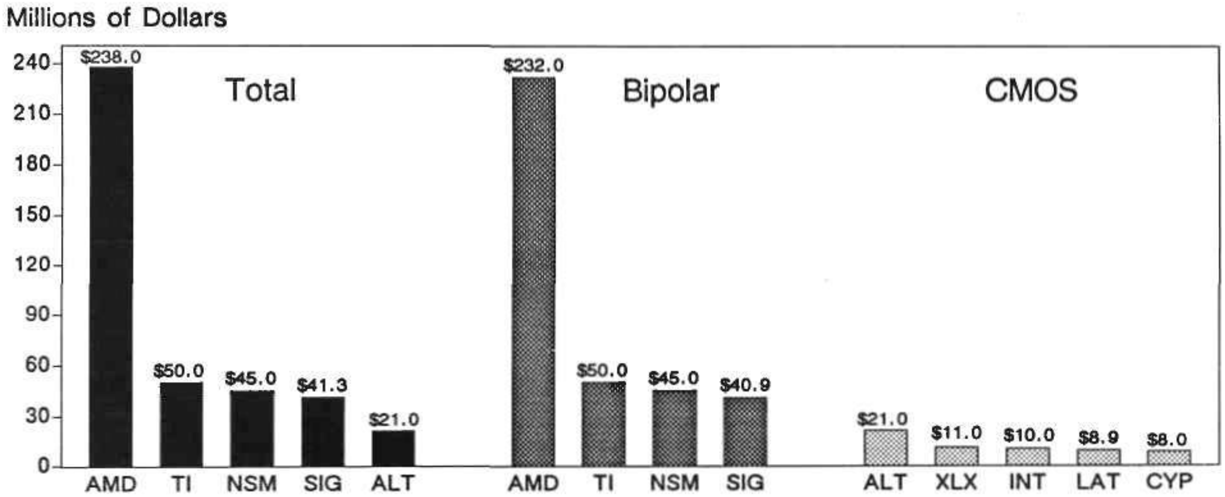
In 1987, Altera, Cypress, and Intel all benefited from their technological leadership in CMOS. If it can put its financial troubles to rest, Lattice is poised to make a very strong comeback. In their performance, Lattice's EE products effectively compete almost lockstep with high-performance bipolar offerings.

WHO'S NUMBER ONE?

AMD/MMI is number one, with a commanding 53.9 percent market share. Its next three rivals, TI (11.3 percent), National (10.2 percent), and Signetics (9.3 percent) are not even close. Altera is a distant fourth, with only 4.8 percent of the market (see Figure 2).

Figure 2

**Estimated PLD Market Share
(Millions of Dollars)**



Note: NSM = National Semiconductor
SIG = Signetics INT = Intel
ALT = Altera LAT = Lattice
XLX = Xilinx CYP = Cypress

Source: Dataquest
April 1988

For bipolar PLDs, AMD/MMI's dominance is even more imposing—63.0 percent. TI is number two, followed by National and Signetics. Interestingly, in the CMOS realm, not only is there no dominant supplier, but also a different set of players. In the ranking sweepstakes, the order is Altera (28.5 percent), Xilinx (14.9 percent), Intel (13.6 percent), Lattice (12.1 percent), and Cypress (10.8 percent).

PLD FORECAST

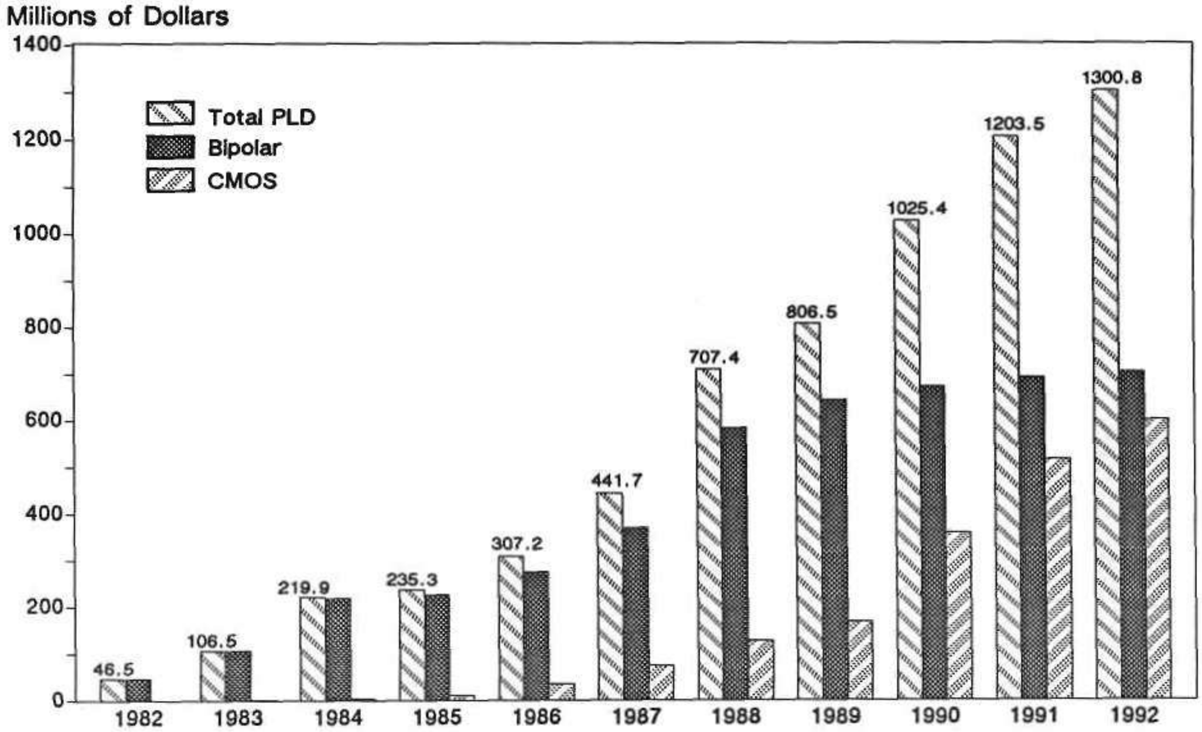
Dataquest projects that the PLD market will grow to $1.3 billion by 1992 at a compound annual growth rate (CAGR) of 25.9 percent. We believe that there will be strong growth for bipolar PLDs but that the growth for CMOS will even be stronger. Figure 3 provides details of the five-year forecast, and Figure 4 gives a geographical breakdown of 1987 consumption.

Dataquest believes the market is dividing into three segments:

- High-performance PLDs
- Low-power PLDs
- Low-cost PLDs

Figure 3

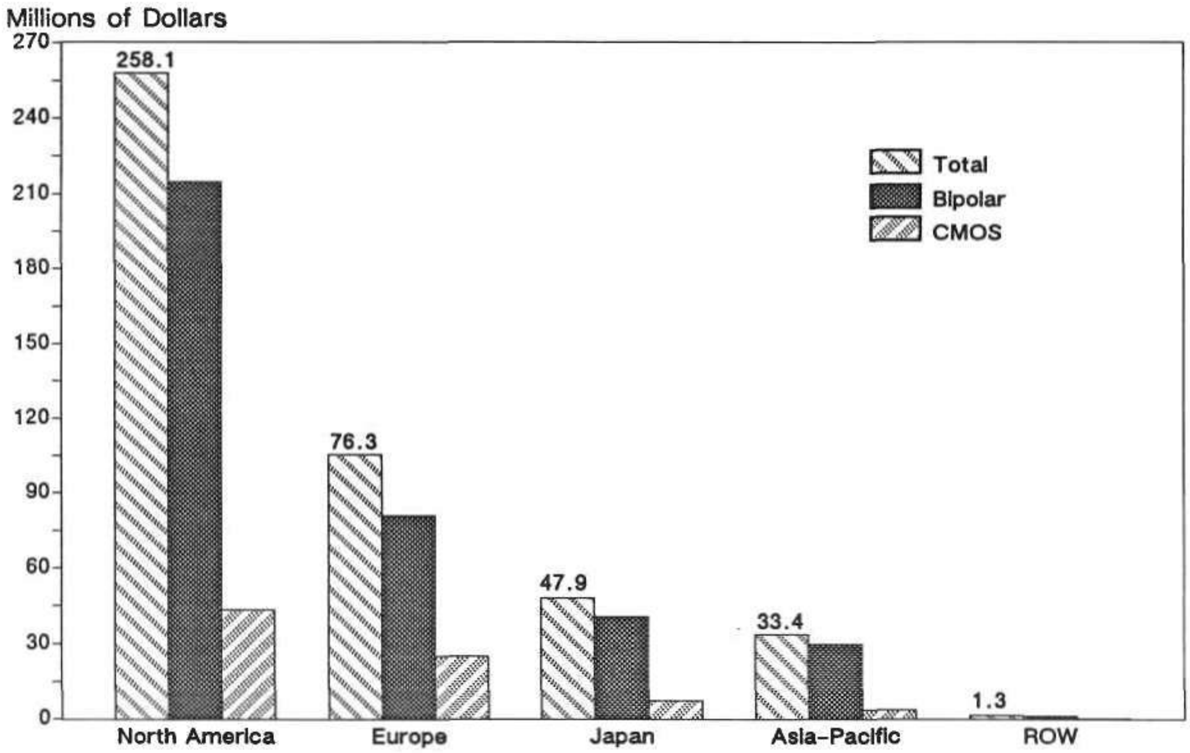
PLD Five-Year History and Forecast
(Millions of Dollars)



Source: Dataquest
April 1988

Figure 4

Estimated 1987 PLD Consumption by Region
(Millions of Dollars)



Source: Dataquest
April 1988

High-Performance PLDs

Bipolar is not dead. Reports of its demise are greatly exaggerated. Indeed, AMD/MMI is reportedly sampling 7.5ns TTL PLDs already, and circuit simulations on their oxide-isolated process indicate that a 5.0ns device is feasible. Moreover, in the next year, Dataquest expects propagation delays for ECL PLDs to drop to 3.0ns from the current 6.0ns. To keep things in perspective, advances in line geometries that benefit CMOS also benefit bipolar devices.

As minisupercomputers impinge upon the workstation world, and as workstations impinge upon the PC world, the battle over mips, Whetstones, and LINPACKs will intensify. Performance plus time-to-market pressures will force systems houses to look to PLDs as the solution to their design problems. These considerations will fuel the growth of high-performance PLDs through the rest of the '80s.

Low-Power PLDs

CMOS PLD performance lies on the outer fringes of high-performance bipolar PLDs. However, miserly, low-power CMOS opens up applications markets not previously available to PLDs before. Already, the announcement of 9,000-gate LCAs from Xilinx has stirred considerable interest in the engineering community, and the recently announced part from Actel has peaked interest. Nonetheless, PLD users are still looking for the Holy Grail of PLDs: a true programmable gate array. Such a device would have 2,000 to 15,000 gates, be low power and easy to use, have fast propagation delays, be flexible, and, most importantly, low cost. Dataquest believes that CMOS will eventually account for close to half of all PLD shipments.

Low-Cost PLDs

Older PLDs, in the 25ns to 35ns category, are fast becoming the commodity segment of the market. Prices for such PLDs dropped below $1.00 in 1987. At such prices, PLDs are starting to cannibalize the standard logic market. Also, MMI has spread the PLD gospel far and wide to the point where several community colleges now teach PLD design techniques to their electronics classes. Today, it may be easier to design with a PLD rather than a standard logic part. The designer needs to stock fewer parts and needs fewer data books.

WHAT LIES AHEAD

Emerging Technologies

Expect more programmable gate array offerings. This is a market opportunity too obvious to ignore. Two problems need to be addressed:

- How to make the design tools low-cost and easy to use
- How to make a low-cost, high-performance product that is price-performance competitive with gate arrays

PLDs are the offspring of PROMs. Any technology advance in memory devices eventually trickles down to PLDs. The "flash" EEPROM cell is one development that may promise faster, smaller, and cheaper PLD devices. Now that technology has reached the shores of PLD-land, any technological advances that result in smaller EEPROMs should also result in smaller PLDs.

Increased Competition

With PLDs well on their way to becoming a billion dollar market, the question is whether or not the PLD market will go the way of the PROM market. It is also too lucrative a market for foreign semiconductor vendors to ignore. Japanese companies certainly have fusible link technology and, through technology exchange agreements, so do the Koreans. In looking at the roster of PLD suppliers, the foreign semiconductor companies are conspicuous by their absence.

Application-Specific PLDs

Traditionally, a PLD is characterized by the existence of an AND-OR matrix within the device. Altera's EP family, Intel's 5AC312, and Excel's ERASIC device are essentially variations on a theme. As PLD vendors struggle to differentiate their offerings from those of their competitors, they are defining products that are optimized and targeted for a specific application. These are devices such as BUSTER (Altera), 5CBIC (Intel), and PLX300 (PLX) for bus interfaces; PROSE (AMD/MMI) and SAM (Altera) for sequencing; and, EPB2001 (Altera) for IBM PS/2 microchannel interfaces. The activity in this area will increase.

DATAQUEST CONCLUSIONS

In 1987, the PLD industry was robust. Moreover, the outlook for 1988 is rosier than it has ever been before. For PLD vendors, the products are in place; the capacity is in place, and the demand is out there. If the DRAM shortage does not bring systems houses to their knees, the only thing that PLD vendors have to do is go home and count the money.

C.B. Lee
Andy Prophet

ANALOG

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Research Newsletter

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ANALOG: "IT'S THE REAL WORLD"

SUMMARY

In a world that has long focused on the digital, it is important to note that analog circuits are a very significant portion of the market, at approximately $7.3 billion, or 20 percent of total semiconductors. Analog circuits are firmly linked to the digital world. These devices translate real-world phenomena such as light, sound, and temperature into digital signals. As digital technology proliferates, so too does analog circuitry by nature of association and the demand for new products and higher-quality signals, speed, and accuracy.

CURRENT MARKET STATUS

The Analog Companies

The analog IC supplier is characterized by three very different profiles—the broad-line supplier, the high-volume-focused supplier, and the niche-market supplier. Of these types of suppliers, large-volume companies such as Motorola, National Semiconductor, and Texas Instruments typically fit the mold of the broad-line supplier. Japanese companies and some European companies generally fit the high-volume-focused supplier mold, with very high volumes noted in the consumer IC sector. The niche-market supplier is often characterized by the small to medium-size sales company. In this category are many United States-based companies that focus on just one or only a few analog product areas.

The ranking of the major analog suppliers changes with the inclusion or exclusion of hybrid circuits. National Semiconductor is the top worldwide supplier of monolithic analog circuits, while NEC holds that position as a supplier of analog circuits, including hybrids. Dataquest's rankings of the top 10 monolithic suppliers and the top 10 total analog suppliers worldwide are shown in Tables 1 and 2.

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Table 1

Top 10 Worldwide Monolithic Analog Suppliers 1987 (Millions of Dollars)

Rank	Company	Sales
1	National	$470
2	Philips	$412
3	Matsushita	$400
4	NEC	$398
5	Texas Instruments	$357
6	Toshiba	$321
7	SGS-Thomson	$260
8	Sony	$243
9	Mitsubishi	$238
10	Analog Devices	$227

Source: Dataquest
September 1988

Table 2

Top 10 Worldwide Total Analog Suppliers, Including Hybrids 1987 (Millions of Dollars)

Rank	Company	Sales
1	NEC	$542
2	National	$495
3	Toshiba	$476
4	Philips	$430
5	Matsushita	$400
6	Texas Instruments	$357
7	Sanyo	$346
8	Motorola	$339
9	Hitachi	$310
10	Mitsubishi	$296

Source: Dataquest
September 1988

The Analog Segments

Dataquest has segmented the worldwide analog markets into several categories, as defined in Table 3.

Table 3

Worldwide Analog Segments
1987
(Millions of Dollars)

Segment	Sales
Monolithic Circuits	$6,165
General-Purpose	
Amplifiers	820
Regulators/References	440
Interface ICs	750
Comparators	235
Data Converters	460
Other Analog ICs	410
Special-Purpose	
Telecom ICs	450
Consumer ICs	2,600
Hybrids	$1,141
Total Analog	$7,306

Source: Dataquest
September 1988

The Regional Analog Markets

Because of the high level of consumer equipment activity in Japan, this region has been a stronghold of circuitry manufactured for consumer goods. Because of their dominance of this equipment, Japanese manufacturers have also dominated the consumer IC market, which has a value of $2.6 billion, or 35.6 percent of the total analog market. Due to such a strong presence in consumer goods and consumer circuits, it is understandable that Japan has the largest consumption of analog circuits, at 43.7 percent.

The European market consumes approximately 17.6 percent of worldwide analog ICs. This market shows a high concentration of consumer, industrial, and communications equipment. As a result, the supplier mix of analog ICs is tailored to the end market. European suppliers have a strong worldwide presence, selling both to their own markets and to markets in other regions.

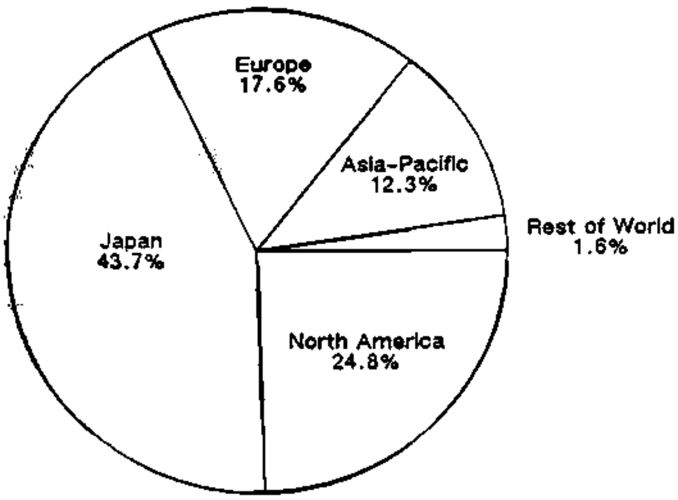
The Asia-Pacific market is similar to the Japanese market in that it is also a large manufacturer of consumer goods. Much of Japan's ubiquity in consumer goods has moved from Japan to Asia as assembly costs have risen in Japan. Asia provides a low-cost manufacturing center for many worldwide equipment companies. While the Asia-Pacific market is not a huge segment, it is growing very rapidly.

In North America, the market is characterized by its breadth of applications. Notable is the military market, which is the largest in the world. From the standpoint of analog products, the industrial sector is very important. It consumes 24.4 percent of all analog circuits sold to North America. The total North American analog market is valued at $1.8 billion, or 24.8 percent of total worldwide consumption.

An illustration of regional analog sales may be seen in Figure 1.

Figure 1

1987 Analog Sales by Region



Total = $7.306 Billion

Source: Dataquest
September 1988

THE ANALOG MARKET FUTURE

Market Trends

The analog market has evolved from functional building block circuits that were very general in application. Over time, many products have become specialized to applications or higher levels of performance. For example, op amps were modified to deal with different frequencies used in audio equipment. We classify these audio-focused amplifiers in the audio segment of consumer ICs. The trend toward specialization continues into system design chips; we expect that many of the circuits presently used as single-function devices will disappear to become portions of complex system-level functions. The system-level configurations available with many telecom circuits illustrate this trend.

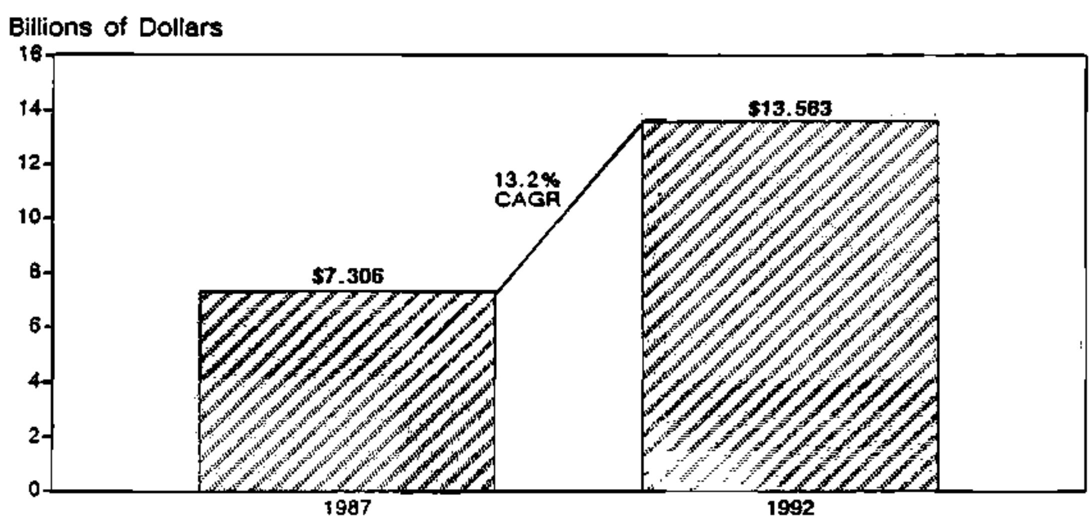
The pace of system level development may also be quickened by expertise developed in the areas of analog ASIC and power IC technology. These manufacturing methods are highly desired by the user environment, so significant resources are being focused on the development of these technologies.

The Analog Forecast

The analog market is expected to grow from its 1987 value of $7.306 billion to $13.563 billion by 1992, as shown in Figure 2. This represents a 13.2 percent compound annual growth rate (CAGR) between 1987 and 1992. It compares with semiconductor growth expectations of 13.8 percent CAGR for the same period. Analog circuits have grown well with the semiconductor market over the years. The market segments that are expected to add extra fuel to analog growth include telecom ICs, regulators, interface ICs, and other analog ICs (including motor control ICs, sensors, timers, signal generation, and phase-locked loop circuits). All of these major segment categories are expected to grow in excess of total analog's 13.2 percent CAGR.

Figure 2

Worldwide Analog IC Forecast
1987 and 1992



Source: Dataquest
September 1988

DATAQUEST CONCLUSIONS

While often overlooked in terms of semiconductor world dynamics, analog products are actually quite dynamic. They continue to hone in on higher and higher levels of performance through design expertise. New products such as mixed-signal circuits, system-level chips and smart power ICs are also rising to the market foreground with new manufacturing technologies available with analog ASICs and power ICs. Some parts of the industry embrace the concept of analog ASICs, which have been extremely popular in the digital world. This technology with sophisticated CAD tools will allow quick design of system-level chips that can mix digital and analog technology. Power ICs are also favored by the industry due to their ability to combine digital control with power handling. Large investments are being made in both of these areas.

Analog has been a sleeping world that has been bypassed by digital technology. However, the time appears ripe for technology advancement in the analog world. It is Dataquest's mission to measure the dynamics occurring in the analog world, and we are now poised to measure this market with our new Analog IC Service.

Barbara Van

The information presented in this newsletter is a summary of some of the information available in Dataquest's new Analog IC Service. More information about our new focus area can be had by contacting Dataquest at (408) 437-8000.

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Research Newsletter

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ASIAN GaAs ACTIVITIES IN 1988

SUMMARY

A recent Dataquest research study examined Asian activities in GaAs and related compound semiconductors in 1988. This newsletter summarizes the results of that study, and examines materials developments, product R&D, applications, and related business activities. Where relevant, space and defense electronics developments are included to add perspective. The study confirmed the increasing pervasiveness of Asian III–V semiconductors into electronics systems. Examples of this pervasiveness include the development by Japanese companies of GaAs ICs and other compound semiconductors for use in VCR/VTR equipment and for fiber–to–home applications.

1988 CHRONOLOGY AND DISCUSSION

The major GaAs and related activities by Asian companies, universities, and other organizations are described by month in the following paragraphs.

January

China's Ministry of Posts and Telecommunications and other agencies are giving strong government support to III–V semiconductor and fiber–optic developments. China's goals are to produce 1,300nm and 1,550nm OEICs using InP and GaAs, with lifetimes of 100,000 hours or more.

Japan's Defense Institute is studying eutectic alloys of GaSb and CrSb grown by the Tammann–Bridgman process; the application was not disclosed. Japan's fiscal 1988 military budget is the first since 1945 to exceed 1 percent of the country's gross national product. The $28.5 billion budget is expected to benefit Mitsubishi, NEC, Toshiba, and others with increased orders for military–range ICs and systems.

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February

Japan's new cruise missiles are using IR image homing and related electronics systems. The Japan Defense Agency plans call for the purchase of 54 launchers and an undisclosed number of missile systems by 1990. Fujitsu is increasing its share of this electronic warfare (EW) business by supplying infrared (IR) seeker electronics jointly with NEC for Kawasaki antitank missile systems.

The Japan Manufacturers' Society of Compound Materials reported Japanese production of III–V wafers in 1987 at ¥20 billion ($157 million). The society predicted 20 percent growth in 1988.

March

Sanyo Electric Company Ltd. announced development of a 0.5-micron gate-length, 12-GHz HEMT by using a g-line stepper, MBE, and ECR plasma CVD. The chip was marketed in Japan starting in April 1988.

DSP chips were among those described by Japanese companies at the recent ISSCC. Although the chips are based on silicon CMOS processes, they are indicators of the desired complexities sought by the manufacturers, all of whom have GaAs process capability.

The Optoelectronic Industry & Technology Development Association of Japan reported that production of the domestic opto industry in 1987 reached ¥1,233 billion ($9.6 billion), up 18 percent over fiscal year 1986 and consisting of the following:

- Optoelectronic components, including lasers and optical fibers—¥371 billion ($2.9 billion) (component ratio 30 percent)

- Optoelectronic equipment, including optical disks—¥707 billion ($5.5 billion) (component ratio 57 percent)

- Optoapplication systems, including optocommunications systems—¥154 billion ($1.2 billion) (component ratio 13 percent)

April

China's drive to become a superpower in the early 21st century involves a mix of geopolitical and commercial goals, including weapons exports. Collaborations with Israel on tank and jet fighter radars, and with Brazil on rocket and satellite technology, are expected to result in a growing demand by China for military ICs. China placed a communication satellite in a geosynchronous orbit earlier this year.

May

Sony reported a GaInAs-based HET (hot electron transistor) design, planned for use in ultrahigh-frequency applications. The chip structure consists of GaInAs and GaAs layers on a GaAs substrate.

Toyota Central R&D Labs has made studies of GaAs/AlGaAs double quantum well heterostructures, which were built using MBE. The hot-electron properties of test devices were evaluated and reported.

June

Hitachi Central Research Labs and Device Development Center developed a buried p-layer structure to enhance immunity of its 1K GaAs SRAM design to soft errors induced by alpha particles. The approach may also lead to much higher levels of integration of GaAs IC designs.

NTT recently reported analysis of the electron velocity overshoot in HBTs. The company expects to use HBTs to achieve operation up to 100 GHz.

Mitsubishi's LSI R&D Laboratory built and tested GaAs HEMTs using 0.25u geometries with beryllium and silicon ion implantation to achieve a 0.68dB noise figure at 12 GHz. The noise figure is below 0.85dB at 18 GHz.

Sharp Corporation increased production of 5.6mm lasers to 1.2 million units per month in June and 1.5 million units per month by year-end to meet the demand for smaller, thinner chips for CD and video disk players.

July

Between 1966 and 1976, the cultural revolution in China halted progress in science and technology; the average age of China's technologists is now 50. China's Research Center for Strategies in Development of Space Technology (under the Commissar of Science, Technology, and Industry for Defense) will lower the age to 40 by the year 2000.

Kokusai Denshin Denwa Co. Ltd.(KDD) ran reliability studies of the Ge APD detectors, InGaAsP/InP lasers, and Si ICs used in repeaters for the KDD OS-280M cable system. The OS-280M will be used in TPC-3, a 9,000km optical submarine cable connecting Japan, Guam, and Hawaii. The ICs met the required failure rate of more than $0.2/10^9$ hours at 45°C T_j at 60 percent confidence. NTT and Fujitsu helped in the tests.

At least four Japanese manufacturers now supply diode lasers for LANs and other fiber-optic communications applications, as shown in Table 1.

Korea's ERTI (Electronics and Telecommunications Research Institute) has purchased a model 450 MOCVD system manufactured by Spire Corporation of Bedford, Massachusetts, for use in developing InGaAs and InGaAs OEICs.

Fujitsu increased its prime military contracts to $187 million in 1987 and booked $32 million more in military subcontracts, moving from thirteenth to eighth place among Japanese defense houses. This includes $100 million for an EW evaluation system. Electronics comprises at least 30 percent of the other contracts, according to Tadaski Takeshima, Fujitsu's deputy GM of defense systems.

Mitsubishi won more than $1 billion in defense procurements in 1987. The company has at least a 70 percent share of the electronic warfare market in Japan, according to Takeshi Abe, deputy GM of Mitsubishi's EP&SG.

Table 1

Japanese Laser Diode Products

Company	Laser Wavelength (nm)	Mode	Package	Comments
Fujitsu	1,300, 1,550	SM	DIP	Developing modules
Hitachi	1,200, 1,300, 1,550	SM, MM	DIP	DFB laser in development
Mitsubishi	1,300	SM, MM	DIP,TO	DFB available
NEC	1,200, 1,300, 1,550	SM, MM	DIP	DFB in development

Note: DIP = dual in-line package, TO = transistor header, SM = single mode, MM = multimode.

Source: Dataquest
December 1988

August

Sumitomo is mass-producing higher-quality, lower-cost 3-inch GaAs wafers, which should result in price decreases. The reductions result from longer boules (yielding 150 wafers each), improved growth-chamber thermal environment, computerized automatic boule diameter control, optimized annealing conditions, and reduced qualification test costs. Sumitomo has improved its vapor-phase epitaxy (VPE) process using new reactor tubes. Reactor gas flow and thermal properties were refined according to computer simulation of the VPE process. These changes should result in major price reductions of Sumitomo epi wafers.

Matsushita has developed InGaAsP/InP multiple quantum well (MQW) planar buried heterostructure (PBH) lasers, using MOCVD process. These lasers have threshold current of 35mA and quantum efficiency of 45 percent.

Japan will spend $7.5 billion on its FSX, a U.S. Air Force F-16 derivative. Deployment is expected by 1997. As many as 170 FSXs are on order. Japan intends to use stealth technology on the FSX. Mitsubishi is the prime contractor and other domestic partners have developed advanced radar, head-up displays, and other avionics for the Japanese Defense Agency's Technical R&D Institute. They do not want U.S. companies to obtain this technology. Traditionally, Japan awards such contracts, including funds for military range ICs, to domestic suppliers.

Researchers at NTT's Applied Electronics Laboratory determined that etch-pit density (EPD) of GaAs-on-Si can be significantly reduced by combining growth interrupt and thermal cycling (in situ TC) with the growth of InGaAs/GaAs superlattices. NTT achieved EPD of $1.4 \times 10^6/cm^2$ in 3.5u GaAs epilayers with this approach. It represented a major gain over the company's prior results.

Japanese companies now marketing GaAs digital ICs (digICs) into the United States include Fujitsu, NEC, and Oki. Fujitsu offers a family of ECL-compatible chips that operate to 6.5 GHz. Oki's products include multiplexers and demultiplexers. NEC, which markets its GaAs products in the United States through California Eastern Labs, has an extensive set of SSI and MSI chips that includes gates, flip-flops, counters, mux/demuxes, and laser drivers.

The major electronics companies and universities in Japan reported results of their R&D activities in GaAs and related materials at the GaAs Materials Conference in Atlanta, Georgia. This information is summarized in Table 2.

Table 2

Recent GaAs Materials Research in Japan

Company	Location	Area(s) of Research
ATR Res Labs	Osaka	Si-doped GaAs
Fujitsu Labs	Atsugi	MOVPE heterostructures, MBE HEMTs, InGaAsP/InP quantum wells
Furukawa Elec. Co. Ltd.	Yokohama	4-in. MLEC GaAs crystal growth
Hitachi Ltd.	Tokyo	Monolayer heterointerfaces
Matsushita Ltd.	Osaka	WSi-gate MESFETs, LDD SiF_3-implanted FETs, MQW integrated laser arrays
Mitsubishi Elec. Corp.	Hyogo	Transverse-junction-stripe (TJS) lasers for OEICs, AlGaAs-on-Si LEDs
NEC	Kanagawa	High-vacuum MBE, AlN-encapsulated GaAs for ion implantation, monolayer epi
NHK	Tokyo	Si-doped GaAs
NTT	Tokyo	FME-grown AlGaAs/GaAs (modified MOCVD)
NTT	Kanagawa	Co-implanted P and Si for improved GaAs LSI yields
Oki Elec. Ind. Co. Ltd.	Tokyo	GaAs-on-Si growth by MOCVD
Sony Corp. Res. Ctr.	Yokohama	AlGaAsP lasers, Si-implanted GaAs
Sumitomo	Yokohama	OMVPE growth of GaInAs on InP
Toshiba Corp.	Kawasaki	30GHz InP power D-MISFETs

University	Location	Area(s) of Research
Hokkaido Univ.	Sapporo	Si-implanted GaAs
Kyoto Univ.	Kyoto	AlGaSb structures
Nippon Inst. of Tech.	Saitama	MBE growth of AlGaAs-on-GaAs, GaAs-on-Si
Tohoku Univ.	Sendai	InSb epi on GaAs
Tokyo Inst. of Tech.	Tokyo	MOMBE growth of C-doped p-GaAs
Tokyo Inst. of Tech.	Yokohama	AlGaSb structures
Univ. of Tokyo	Tokyo	Novel quantum well devices, GaAs-on-Si growth by MOCVD, Er-doped GaAs and InP

Source: Aztek Associates

Hitachi demonstrated a 3-band (VHF/CATV/UHF) GaAs IC tuner for TV/VCR receivers. This project integrates a mixer, oscillators, and IF amplifier, decreasing the size and improving noise properties of the tuner circuit while reducing parts count by 30 percent.

October

Matsushita's Discrete Device Division in Kyoto and R&D Laboratory in Osaka reported developing a GaAs RF amplifier IC for UHF TV/VTR tuner applications in a 6-pin plastic package. The chip reduces the size of the amplifier in the RF tuner by a factor of two and reduces the cost.

NTT achieved 12dB gain with 8.5-GHz bandwidth in an amplifier design using AlGaAs/GaAs ballistic collection transistors (BCTs). NTT has built a CaF_2-gate GaAs MISFET also. CaF_2 deposited by MBE has thickness accuracy of a few monolayers and virtually no contamination.

November

Mitsubishi built a 1Kx4, 7ns GaAs SRAM, which dissipates 850mW using a 1.6V supply. The process was 1.0-micron gate-length E/D DCFL; reported wafer sort yield was 22 percent. Oki described its 1.2-GHz 256-bit GaAs shift register for signal storage applications, and Toshiba reported a 2-GHz 128-bit shift register using 0.5u tungsten-nitride-gate MESFETs.

December

In 1987, six Japanese companies were among the world's top 100 defense electronics suppliers, with two or more of these outranking Motorola, Hewlett-Packard, AT&T, M/A-COM, Zenith, Control Data Corporation, Digital Equipment Corporation, and other major U.S. companies. All six of the Japanese companies have significant GaAs IC and silicon IC capabilities in-house, while many top U.S. suppliers do not. Table 3 presents 1987 performance information on these six companies.

Table 3

Japanese Defense Electronics Company Performance in 1987

Top 100 Rank	Company Name	1987 Def. Elec. Sales ($M)	1987 Total Sales ($M)	Share of Total 1987 Company Sales
34th	Mitsubishi	715	19,321	3.7%
36th	Toshiba	602	30,083	2.0%
42nd	NEC	504	22,915	2.2%
72nd	Fujitsu	183	16,617	1.1%
84th	Oki	136	3,686	3.7%
95th	Hitachi	93	46,281	0.2%

Source: Defense Electronics

Hiroshima University and Matsushita physicists used hydrogen plasma to lower the temperature of cleaning GaAs wafers to 200 to 300°C, as compared with 700 to 1,000°C for previous processes. This allows the MOMBE growth of GaAs-on-Si at 400°C using triethyl gallium (TEGa) and triethyl arsenic (TEAs) without inducing thermal cracking. This development is expected to lead to the 3-D integration of III-V opto devices with silicon VLSI.

DATAQUEST CONCLUSIONS

Asian activities in III-V compound semiconductors are predominantly driven by Japanese efforts to penetrate new markets. The results to date reflect the level and degree of national attention provided by MITI's Optoelectronic Initiative and other initiatives introduced several years ago. Dataquest believes that these programs are starting to pay off, as evidenced by product introductions by almost all of the Japanese companies involved during 1988. We expect more of the same in 1989, as well as more InP-based chips.

We believe that Korea and China will assume increasingly more important roles in compound semiconductor technology in the 1990s. Korea will focus initially on such applications as consumer and automotive electronics, whereas China will continue its push in telecommunications-related device development.

Gene Miles

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Research *Newsletter*

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SYMPOSIUM EMPHASIZES PRACTICALITY OF GaAs ICs

The tenth annual GaAs IC symposium, held in November in Nashville, Tennessee, confirmed the increasing adoption of GaAs ICs into commercial hardware. GaAs digICs are rapidly approaching VLSI density, as demonstrated by GigaBit Logic's introduction of 10,000-gate arrays at less than five cents per gate. Systems containing viable optoelectronic IC (OEIC) chips are moving into volume production at industry giants, such as AT&T, IBM, and Rockwell. Other significant trends that were noted are discussed later in this newsletter.

GaAs ICs RAPIDLY APPROACH VLSI DENSITY

Gigabit Logic (GBL), the leading supplier of GaAs standard cell arrays, broke the VLSI barrier with its new SC10000 family of 50ps (loaded) E/D MESFET standard cells. The cells allow implementation of arrays to 10,000 gates per chip, using three-layer metal with 4um pitch. Cell options allow the user to tailor two-input AND/NAND gates for speeds of 22ps to 64ps (fanout of one) at 8mW to 1mW power; master-slave flip-flops range from 4 GHz and 30mW to 800 MHz and 2.4mW. Power supply and signal I/O options include mixed TTL/CMOS and ECL, if needed. Gate prices are directly competitive with high-end ECL at less than five cents per gate.

Several other presentations discussed chip complexities ranging from 12,000 to more than 250,000 devices per chip. These included a radiation-hardened 16K SRAM containing six-transistor storage cells, and a 32-bit RISC microprocessor, both by McDonnell-Douglas, and 4K SRAMs by GBL and Mitsubishi. The characteristics of the McDonnell-Douglas 32-bit RISC chip compare favorably with earlier devices by Rockwell and the TI-CDC team, as shown in Table 1.

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Table 1

GaAs Microprocessor IC Comparison

Characteristic	McDonnell-Douglas	Rockwell	TI/CDC
Function	32-bit RISC uP	150 mops 8-bit ALU (1750 type)	32-bit RISC uP
Architecture	3-stage pipeline, 3 busses	3-bus slice expands to 16 bits	6-stage pipeline
Performance	60 mips (proj. 100)	150 mops	100 mips (proj. 200)
Operations	ALU includes 32-bit barrel shifter and multiply/divide support	Add, subtract, mod. Booth multiply and divide, bit operations	4 address modes, 16 ALU and 5 control instructions, 10 memory instructions
Power (Watts)	4.7	Low 4.2, high 9.2	Estimated 20 max.
Die Size (mm^2)	8.2 x 11.2 = 91.8	4.9 x 3.9 = 19.1	11.2 x 10.5 = 117.9; proj. 7.6 x 7.6 = 57.8
Chip Complexity	21,606 transistors	9,400 transistors, 3,000 diodes	12,872 gates (typical gate is 1 transistor and 5 resistors)
I/Os: Signal + Pwr/Gnd	130 + 42	64 + 29	171 + 70
Process	Ion-implanted GaAs E-JFET	1.0u GaAs D-MESFET	2u GaAs HBT, proj. 1.5u HBT
Logic Form	DCFL	BFL	I^2L (modified RTL)
Cell Speed/Power	Not available	120ps/1.6mW (reg.)	160ps/2mW (gate)
Yield Data	6 percent	18 percent	Exper. 2 percent, proj. 8 percent

Source: Aztek Associates

TRENDS IN OPTOELECTRONICS

Rockwell's introduction of a two-chip multiplexer/demultiplexer chip set and IBM's transceiver pair, both developed for Gb/s fiber links, underscored the rapid movement of OEICs into production systems. The foundry that supported the Rockwell design is TriQuint. First pass designs were functional, and production lot shipments started more than one year ago. Rockwell is now believed by many to be pressing AT&T for the lead in producing OEICs, having already shipped more than 30,000 sets of mux/demux chips.

Other companies reported that they are making rapid progress in GaAs and related compound semiconductor optoelectronic functions. These included Bell-Northern's monolithic transmitter with on-chip AlGaAs laser, Hitachi's seven-chip set for 2.4 Gb/s links, and devices by NTT and Oki.

PROGRESS IN MMICs

Steady progress in materials, modeling, and circuit development has led to increased availability of low-noise and power amplifiers, up-down converters, oscillators, and other MMIC functions. Companies reporting significant R&D in MMICs include Hewlett-Packard (HP), Matsushita, NEC, Pacific Monolithics, Thomson, TRW, and Varian Associates. Much emphasis was placed on HEMT and HBT structures for enhanced frequency response.

MATERIALS AND MANUFACTURING DEVELOPMENTS

A joint paper by GBL and Kopin Corporation (Taunton, Massachusetts) contends that GaAs-on-silicon will become increasingly viable for the manufacture of digital LSI/VLSI chips. A reliability study by the two companies shows that GaAs-on-Si has no liabilities in terms of parametric instability or catastrophic failure mechanisms. The companies plan further efforts to improve performance, which presently does not match that of devices fabricated on bulk silicon.

The major attraction of GaAs-on-Si with respect to bulk GaAs is substrate cost, which is already 25 to 40 percent lower at 3- to 4-inch wafer levels. At the 6-inch level, bulk GaAs is not yet economically viable, whereas 6-inch GaAs-on-Si volume pricing is in the neighborhood of $350 per wafer, approaching the pricing of 4-inch bulk GaAs wafers.

Additional materials and manufacturing breakthroughs were reported by Anadigics, HP, ITT, Sumitomo, Texas Instruments, and others. Session topics included reliability, packaging, and testing; a paper by TriQuint focused on problems and pitfalls in determining thermo-reliability characteristics of GaAs ICs. Clients interested in these and other details may obtain further information by contacting Dataquest's Client Inquiry Center.

DATAQUEST CONCLUSIONS

While silicon CMOS processing at 0.8- to 2.0-micron geometries represents a present "workhorse" technology, we believe that advances in GaAs ICs are increasingly viable at the high-performance end of the spectrum. Yield data for GaAs devices at LSI/VLSI density levels indicate significant improvements in the last 12 months. Dataquest believes that more applications will shift toward GaAs as speed becomes a more important factor in new systems.

Gene Miles

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Research Newsletter

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FREE-WORLD RESEARCH ADVANCES GaAs MATERIALS STATE OF THE ART

The 15th International Symposium on GaAs and Related Compounds was a clear demonstration of the extensive effort under way to make advances in III-V compound semiconductor technology. The conference emphasized original research activities in MOCVD and MBE growth and characterization of new structures; heteroepitaxy; and FETs, RTDs, and optoelectronic devices. This newsletter summarizes the presentations and tabulates the major efforts reported, both by geographic area and by university or company. Although not discussed herein, Australia and Israel also have university and corporate research activities in this field. A listing of key acronyms is appended to assist those readers relatively unfamiliar with III-V compound semiconductor terminology.

AMERICAN RESEARCH PROGRESS IN III-V COMPOUNDS

Companies in the United States such as Bellcore and AT&T and U.S. universities such as the University of Illinois continue to lead the world in compound semiconductor materials research. Tables 1 and 2 attest to the depth and breadth of these efforts. They present examples of GaAs materials research conducted by companies and universities, respectively, in the United States. In addition to the work tabulated here, significant compound semiconductor materials research is under way in Brazil, Canada, and other countries in the Americas.

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Table 1

Examples of GaAs Materials Research by U.S. Companies

Company	Location	Area(s) of Research
Allied Signal (Bendix)	Columbia, MD	64GHz f_t 0.5u-gate mm-wave HEMTs; InGaAs/InP heterostructure FETs; RIE of sub-u InP, InGaAs & InAlAs; carbon doping of GaAs during MBE
AT&T Bell Labs	Murray Hill, NJ	Delta diffusion in SDHT structures; MOMBE growth of InP and InGaAs; RTTs; MOCVD-grown InP-on-Si
AT&T Bell Labs	Holmdel, NJ	Quantum size and delta dopant diffusion in SDHT structures; GSMBE growth of GaAs
Bellcore	Red Bank, NJ	Epitaxial growth of novel GaAs structures; MBE-grown ZnSe on GaAs wafers; VLE-grown InGaAs/InP QWs; atomic layer epitaxy (ALE); MOCVD growth of buried waveguides; GaAs surface studies; LEC-grown GaInAs crystals; NiAl structures; MSM photodetectors; GaAs/InP OEICs
Ford Aerospace Corp.	Newport Beach, CA	LSI-complexity GaAs-on-Si
Ford Microelectronics	Colorado Springs, CO	MOCVD growth of LSI-density GaAs/Si
GTE Labs	Waltham, MA	OMVPE growth of GaAs/Si
Hughes Research Labs	Malibu, CA	MBE-grown GaInAs/AlInAs HEMTs
IBM TJ Watson Research Center	Yorktown Heights, NY	MBE SQW AlGaAs/GaAs lasers; RTDs
Litton		Dual-gate GaAs MESFETs
Martin-Marietta	Baltimore, MD	MBE growth of superlattices
Motorola, Inc.	Phoenix, AZ	TiPt- and TiPtAu-gate GaAs FETs
Research Triangle Institute	Triangle Park, NC	GaAs DRAM devices; ALE growth of GaAs/InGaAs layers; AlGaAs epitaxy

(Continued)

Table 1 (Continued)

Examples of GaAs Materials Research by U.S. Companies

Company	Location	Area(s) of Research
Spire Corp.	Bedford, MA	MOCVD-grown InP-on-Si
Texas Instruments	Dallas, TX	65 GHz f_{max} GaAs MESFETs; DBRT and RTD structures, cointegration of GaAs MESFET and Si CMOS ICs on Si
TRW	Redondo Beach, CA	DCPBH and p-BC diode lasers
Varian Research Center	Palo Alto, CA	NaS treatment of GaAs surfaces

Source: Aztek Associates

Table 2

Examples of III-V Research by U.S. Universities

University	Location	Area(s) of Research
Arizona State Univ.	Tempe, AZ	Evaluation of passivated GaAs; TiPt- and TiPtAu-gate GaAs FETs; MQWs
California Institute of Technology	Pasadena, CA	GaAs/AlGaAs PNP and NPN HBTs on Si
Cornell Univ.	Ithaca, NY	GaInP/AlInP superlattices; traveling wave MODFETs; MBE-grown SQW AlGaAs/GaAs lasers and waveguides
Colorado State Univ.	Ft. Collins, CO	MBE growth of InGaP/GaAs lasers
MIT	Cambridge, MA	Superlattices
MIT Lincoln Labs	Lexington, MA	ALE growth of GaAs/InGaAs layers

(Continued)

Table 2 (Continued)

Examples of III–V Research by U.S. Universities

University	Location	Area(s) of Research
North Carolina State Univ.	Raleigh, NC	AlAs/GaAs interface studies; growth of GaAs/InGaAs layers by ALE; LCVD
Purdue Univ.	W. Lafayette, IN	GaAs Schottky structures; modeling
Solar Energy Research Institute	Golden, CO	AlGaAs alloys;MOCVD-grown InP-on-Si
Stanford Univ.	Stanford, CA	NaS effects on GaAs; RTDs; MBE GaAs impurities; MBE of AlGaAs/GaAs
UCLA	Los Angeles, CA	MOCVD-grown InP-on-Si
UC Santa Barbara	Santa Barbara, CA	AlGaAs/GaAs MQW structures
Univ. of Colorado	Boulder, CO	Optical switches
Univ. of Illinois	Urbana, Il	Application of IILD in QWHs; MBE GaAs impurities; RIE of sub-u InP, InGaAs, InAlAs; MOCVD LSI GaAs/Si; MBE GaAs/AlGaAs PNP and NPN HBTs on Si; hot-electron diodes
Univ. of Massachusetts	Amherst, MA	MOCVD growth of AlGaAs
Univ. of Maryland	College Park, MD	InP Schottky MESFETs; InGaAs/InP heterostructure FETs
Univ. of Michigan	Ann Arbor, MI	HEMTs; InP; InGaAs/GaAs MQW; etalons
Univ. of New Mexico	Albuquerque, NM	InGaAs/GaAs quantum-well structures
Univ. of Rochester	Rochester, NY	Traveling-wave MODFETs
Univ. of Southern California	Los Angeles, CA	Atomic layer epitaxy (ALE); AlGaAs
Univ. of Utah	Salt Lake City, UT	OMVPE growth of GaP and GaAsP

Source: Aztek Associates

ASIAN RESEARCH PROGRESS IN III–V MATERIALS AND DEVICES

Asian universities and corporations, primarily in Japan, are heavily engaged in studying the state of the art of III–V compound semiconductors. Tables 3 and 4 show recent examples of this work. In addition to the reported activities under way in India, Japan, and the People's Republic of China, companies and universities in Taiwan, Korea, and other Asian countries are involved in the advance of this technology.

Table 3

Examples of GaAs Materials Research by Asian Companies

Company	Location	Area(s) of Research
ATR Research Labs	Osaka	Si-doped GaAs
Fujitsu Labs	Atsugi	MOVPE heterostructures; MBE HEMTs; InGaAsP/InP quantum wells
Furukawa Elec. Co. Ltd.	Yokohama	4-inch MLEC GaAs crystal growth
Hitachi Ltd.	Tokyo	Monolayer heterointerfaces
Matsushita Ltd.	Osaka	WSi-gate MESFETs; LDD SiF_3-implanted FETs; MQW-integrated laser arrays
Mitsubishi Elec. Corp.	Hyogo	Transverse-junction-stripe (TJS) lasers for OEICs; AlGaAs-on-Si LEDs
NEC	Kanagawa	High-vacuum MBE; AlN-encapsulated GaAs for ion implantation, monolayer epi
NHK	Tokyo	Si-doped GaAs
NTT	Tokyo	FME-grown AlGaAs/GaAs (modified MOCVD)
NTT	Kanagawa	Coimplanted P and Si for improved GaAs LSI yields
Oki Elec. Ind. Co. Ltd.	Tokyo	GaAs-on-Si growth by MOCVD
Sony Corp. Research Center	Yokohama	AlGaAsP lasers; Si-implanted GaAs
Sumitomo	Yokohama	OMVPE growth of GaInAs on InP
Toshiba Corp.	Kawasaki	30GHz InP power D-MISFETs

Source: Aztek Associates

Table 4

Examples of Recent III–V Materials Research by Asian Universities

University	Location	Area(s) of Research
Hokkaido Univ.	Sapporo	Si implanted GaAs
Kyoto Univ.	Kyoto	AlGaSb structures
Nippon Institute of Technology	Saitama	MBE growth of AlGaAs-on-GaAs; GaAs-on-Si
Shanghai Institute of Metallurgy	Shanghai	InGaAsP/InP HBTs for optoelectronic switching
Tohoku Univ.	Sendai	InSb epi on GaAs
Tokyo Institute of Technology	Tokyo	MOMBE growth of C-doped p-GaAs
Tokyo Institute of Technology	Yokohama	AlGaSb structures
Univ. of Tokyo	Tokyo	Novel quantum well devices; GaAs-on-Si growth by MOCVD; Er-doped GaAs and InP

Source: Aztek Associates

EUROPEAN RESEARCH PROGRESS IN COMPOUND SEMICONDUCTOR RESEARCH

Every country in West Europe is conducting research to understand and advance compound semiconductor materials, devices, and applications. Tables 5 and 6 summarize the reported results of this research. Additionally, companies and universities in Greece, Ireland, Scotland, Sweden, and other West European countries have ongoing effort in this technology.

Table 5

Examples of GaAs Materials Research by Western European Companies

Company	Location	Area(s) of Research
CNET	Bagneaux, France	AlGaAs/GaAs HBT structures
CNET	Lannion, France	Nondestructive measurement of epi
IBM Research Div.	Zurich, Switzerland	MBE-grown channeled lasers
Philips Research Labs	Surrey, UK	Si-doped MBE GaAs growth
Siemens Research Labs	Princeton, NJ	100 GHz f_T InP MODFETs; AlGaAs quantum-well structures
Thomson-CSF	Orsay, France	Rare-earth-doped MBE AlGaAs/GaAs; GaInP-on-GaAs HEMTs

Source: Aztek Associates

Table 6

Examples of GaAs Materials Research by Western European Universities

University	Location	Area(s) of Research
Heinrich Hertz Inst.	Berlin, FRG	RIE of InGaAsP heterostructures
Tech. Univ. of Berlin	Berlin, FRG	MBE-grown AlGaAs/GaAs QW structures
Univ. of London	London, UK	PECVD and plasma pretreatment of GaAs
Univ. of Lannion	Lannion, France	Nondestructive measurement of epi
Univ. of Paris	Paris, France	Rare-earth-doped AlGaAs-on-GaAs MBE
Univ. of Sheffield	Sheffield, UK	InGaAs/InP MQW structures

Source: Aztek Associates

DATAQUEST CONCLUSIONS

As in high-speed silicon ECL technology, the future success of GaAs and other III-V semiconductors is heavily dependent on continuing evolution and progress in materials and device structures. Today, companies and universities in the United States are the leading innovators in compound semiconductor materials. This leadership will be maintained as long as a critical mass of U.S. companies, government leaders, key academicians, and their respective institutions share the vision that this technology is vital to the national security.

Gene Miles

Appendix

Compound Semiconductor Acronyms

This listing contains acronyms used in this newsletter. A more detailed listing of most of these and other compound semiconductor acronyms appears in Dataquest's GATA notebook, in the section entitled "Glossary."

ALE	Atomic layer epitaxy
AlGaAs	Aluminum gallium arsenide
AlGaAsP	Aluminum gallium arsenide phosphide
AlGaSb	Aluminum gallium selenide
AlInAs	Aluminum indium arsenide
AlN	Aluminum nitride
CMOS	Complementary metal oxide semiconductor
DBRT	Double barrier resonant tunneling
DCPBH	Double channel planar buried heterostructure
D-MISFET	Depletion-mode metal insulator semiconductor FET
DRAM	Dynamic random access memory
Er-doped	Erbium-doped
etalon	A type of optoelectronic device incorporating quarter-wavelength mirrors and an active spacer
FET	Field effect transistor
FME	Flow-rate modulation epitaxy (a modification of MOCVD)
f_t	Cutoff frequency
GaAs	Gallium arsenide
GaAs/InP	Epitaxial GaAs layer on indium phosphide wafer
GaAsP	Gallium arsenide phosphide
GaInP	Gallium indium phosphide
GaP	Gallium phosphide
GaAs-on-Si	Epitaxial GaAs layer on silicon wafer
GaAs/Si	Same as GaAs-on-Si
GaInAs	Gallium indium arsenide
GHz	Gigahertz, or billion cycles per second
GSMBE	Gas source molecular beam epitaxy
HBT	Heterojunction bipolar transistor
HEMT	High-electron mobility transistor (same as SDHT)
IILD	Impurity-induced layer disordering
InAlAs	Indium aluminum arsenide
InGaAs	Indium gallium arsenide
InGaP	Indium gallium phosphide
InP	Indium phosphide
InP-on-Si	Indium phosphide epitaxial layer on silicon wafer
InSb	Indium selenide

(Continued)

Appendix (Continued)

Compound Semiconductor Acronyms

LCVD	Laser-induced chemical vapor deposition
LDD	Lightly doped drain
LEC	Liquid encapsulated Czrochalski
MBE	Molecular beam epitaxy
MESFET	Metal electrode semiconductor field effect transistor
MLEC	Magnetic liquid encapsulated Czrochalski
MOCVD	Metal organic chemical vapor deposition
MODFET	Modulation-doped FET
MOMBE	Metal organic molecular beam epitaxy
MQW	Multiple quantum wellMSM metal semiconductor metal
NaS	Sodium sulfide
NiAl	Nickel aluminum
OEIC	Optoelectronic integrated circuit
OMCVD	(Interchangeable with MOCVD and OMVPE)
OMVPE	Organometallic vapor phase epitaxy (interchangeable with MOCVD and OMCVD)
p-BC	P-type buried crescent (a type of diode developed by TRW)
PECVD	Plasma-etched chemical vapor deposition
PHBT	Photosensitive heterojunction bipolar transistor
QW	Quantum well
QWH	Quantum well heterostructure
RIE	Reactive ion etch
RTD	Resonant tunneling diode
RTT	Resonant tunneling transistor
SDHT	Selectively doped heterojunction transistor (same as HEMT)
SiF_3	Silicon fluoride
SQW	Single quantum well
TiPt	Titanium platinum
TiPtAu	Titanium platinum gold
TJS	Transverse junction stripe
u	Greek letter "mu"; micron (one-millionth of a meter)
VLE	Vapor levitation epitaxy
ZnSe	Zinc selenide

Source: Aztek Associates

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MATERIALS PROGRESS IMPROVES GaAs AFFORDABILITY

SUMMARY

Starting material cost and quality are critical elements in determining GaAs IC pricing and have, until recently, significantly limited acceptance of the technology. Our analysis shows that more than 40 companies have addressed these issues, with innovative approaches that are producing effective results.

Following our GATA newsletter, Code: 1987-5, "III-V Materials—Who's on First?", GaAs-on-silicon has moved from the laboratory to production, and MBE (molecular beam epitaxy) technology has entered the market. Both technologies are competing with existing MOCVD epi technology at the two ends of the cost spectrum; MBE with higher quality at a higher price and GaAs-on-Si at the low-end with a lower price. The net result is increased potential for GaAs IC cost reduction in the near term, making GaAs a more viable replacement technology for many ECL and high-performance TTL functions. MMIC cost improvements are also accelerating, which will spur growth of phased-array radar, GPS receivers, and other hardware requiring linear GaAs ICs. These developments were not unexpected by Dataquest; their effects were factored into the GaAs IC forecast published earlier this year.

DISCUSSION AND ANALYSIS

GaAs Materials Pricing

At present, undoped LEC wafers cost approximately $30 per square inch, or approximately $100 for 2-inch wafers and $225 for 3-inch wafers. Epitaxial wafers cost several times more, depending on quality; MBE wafer costs range to more than $2,000 for 3-inch material. Raw wafer cost improvements, such as those implemented by Sumitomo during 1987, should bring LEC wafer costs down by a factor of two to three, and corresponding reductions in epi wafer pricing should follow as volumes increase. Epi costs are expected to decline further as MOCVD equipment throughputs increase. A wafer cost reduction by a factor of two would favorably impact IC pricing by more than 10 percent.

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The Suppliers

Table 1 provides an update of the product offerings from GaAs and other III-V compound materials suppliers. Since our 1987 newsletter on this subject, several companies have deemphasized GaAs materials; they were replaced by an equal number of new entrants, including GAIN Electronics and MSC (Siemens).

Table 1

III-V Wafer Suppliers and Products

Company	Location	Wafer Sizes (Inches)	III-V Products
Airtron (Litton)	Morris Plains, NJ	2, 2.5, 3	Doped and semi-insulated GaAs wafers
Atomergic Chemetals	Farmingdale, NY	2, 3	GaAs, GaP, InP ingots and wafers; GaAs epi wafers
Bertram Labs	North Branch, NJ	2, 3	HB-grown GaAs wafers
Boliden Finemet	Sweden	2, 3	HPLEC wafers
Cominco Electronic Materials	Trail, BC, Canada	2, 3	GaAs, GaSb, InAs, InSb
Commercial Crystal Labs	Naples, FL	2	GaAs epi wafers
Cryscon	(See text)		
Crystacomm	Mtn. View, CA	2.5	LEC-grown InP wafers
Crystal Specialties	Colorado Spr., CO	2, 3	Epi reactors, wafers
Dowa Mining	Japan	2, 3	GaAs, InP wafers
Epitaxy Materials	Ely, UK	2, 3	GaAs epitaxial wafers
Epitaxx	Princeton, NJ	2, 3	InGaAs epi on InP
Epitronics (Alcan Alum.)	Phoenix, AZ	2, 3	GaAs and AlGaAs epi
Furukawa Electric	Tokyo, Japan	2, 3	GaAs, InP wafers, and GaAs epi wafers

(Continued)

Table 1 (Continued)

III–V Wafer Suppliers and Products

Company	Location	Wafer Sizes (Inches)	III-V Products
GAIN Electronics	Somerville, NJ	3	GaAs MBE epi wafers
Hitachi Cable	Ibaraki, Japan	2, 3, 4	LEC GaAs and InP ingots, wafers, and epi wafers
Hitachi Metals	Hitachi City, Japan	NA	GaAs ingots
ICI Wafer Technology Ltd.	Milton Keynes, UK	2, 3, 4	GaAs and InP wafers, doped and undoped
Iwaki Handotai	Fukushima, Japan	2, 3	LEC GaAs epi wafers
Kopin Corporation	Taunton, MA	2, 3, 4, 6	GaAs-on-Si, GaAs epi wafers, others
M/A-COM	Burlington, MA	2, 2.5, 3	Full range of GaAs ingots, wafers, epi
MSC (Siemens)	Somerset, NJ	2, 3	Multilayer epi
MCP Electronic Metals	Wembley, UK	2, 3	GaAs wafers
Metal Specialties	Fairfield, CT	2, 3	LEC and HB-grown GaAs, GaP, GaSb, InAs, InP, and InSb wafers
Meteaux Speciaux	Moutiers, France	2	LEC InP ingots and wafers
Mitsubishi Metal	Omiya, Japan	2, 3	HB, LEC GaAs wafers
MMK	Tokyo, Japan	2, 3, 4	GaAs and GaP wafers
Morgan Semi.(Ethyl)	Garland, TX	2, 3	GaAs MOCVD epi wafers
Nippon Mining	Tokyo, Japan	3	InP ingots, wafers; GaAs and CdTe ingots
OMVPE Technologies	St. Laurent, Canada	2, 3	GaAs OMVPE epi wafers
Picogiga	Les Ulis, France	2, 3	GaAs MBE epi wafers

(Continued)

Table 1 (Continued)

III–V Wafer Suppliers and Products

Company	Location	Wafer Sizes (Inches)	III-V Products
Preussag	Gossiar, W.Germany	2, 3, 4	GaAs wafers
Raytheon	Bedford, MA	2, 3	LEC, HB GaAs wafers
Showa Denko	Tokyo, Japan	2, 3	MLEC InP wafers; GaAs and GaP NDF wafers
Siemens Opto Division	Cupertino, CA	1.6 to 3	HB-grown GaAs wafers
Spectrum Technology	Holliston, MA	2, 3, 4	GaAs wafers
Spire Corporation	Bedford, MA	2, 3	GaAs and AlGaAs epi wafers and systems
Sumitomo Electric	Hyogo, Japan	2, 3, 4	GaAs, GaP, GaSb, InP, InSb, and InAs ingots and wafers; GaAs epi wafers
United Epitaxial Technologies	Beaverton, OR	2, 3	MOCVD-grown GaAs and InP epi wafers
Wacker	Burghausen, Germany	2, 3	GaAs wafers: semi-insulating and doped

Sources: Aztek Associates
Dataquest
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Airtron (Litton)

Airtron became a division of Litton Industries in 1958. The company specializes in a variety of oxide, fluoride, and semiconductor materials. Its 5,500–square–foot GaAs crystal growth and wafer production area incorporates state–of–the–art equipment and procedures. Wafer flatness is controlled within 5 microns.

Atomergic Chemetals

Atomergic Chemetals supplies prototype volumes of a wide range of III–V compound materials. The company supports custom requirements for its products, which include ingots, undoped and doped wafers, and epitaxial wafers. Atomergic Chemetals offers both single–crystal and polycrystalene materials, grown by zone refined, HB, GF, and LEC methods.

Bertram Laboratories Incorporated (Chemetal AG)

Bertram Laboratories is backed by Chemetal AG of Frankfurt, West Germany. Bertram supplies HB-produced crystals and GaAs wafers.

Boliden Finemet

Boliden Finemet supplies 2- and 3-inch GaAs wafers produced from high-pressure-grown LEC crystals.

Cominco Electronic Materials

Cominco supplies of III-V and II-VI compound semiconductor raw materials and wafers. The company has more than 25 years of experience in crystal growth. Cominco operates a sales facility in Spokane, Washington, to facilitate access to the U.S. marketplace. In addition to the III-V compound wafers listed in Table 1, Cominco offers II-VI wafers including CdTe, HgTe, and CdHgTe.

Commercial Crystal Labs

Commercial Crystal Labs focuses primarily on low-volume, R & D applications. The company expects to add 3-inch wafer capability by late 1988.

Cryscon

In October 1986, Alcan announced its decision to sell Cryscon and to expand Epitronics, another Alcan subsidiary. Cryscon is no longer in operation in Phoenix, Arizona; according to an industry source the company may be restarting with backing by U.K. investors.

Crystacomm

Crystacomm is working only with InP at present; no GaAs activity is under way.

Crystal Specialties International (CSI)

CSI is a division of Akzo Electronic Materials, which is a joint venture of Akzo N.V. (65 percent) and Kollmorgen Corporation (35 percent). CSI's Materials Division is located in Colorado Springs, Colorado; and its Equipment Division is based in Portland, Oregon. The company offers semiconducting p- and n-type wafers, semi-insulating Cr doped and undoped wafers, and all shapes and sizes of polycrystalline material.

Dowa Mining

Dowa Mining produces HB-grown polycrystalline InP, and GaAs and InP wafers.

Epitaxy Materials Ltd. (EML)

Originally located in Cambridge, the United Kingdom, EML recently moved to Ely, near Peterborough. The company claims to be the largest MOCVD epi GaAs wafer supplier in Western Europe. EML has two epi reactors on-line and expects to expand its business base worldwide.

Epitaxx

Founded in 1984, manufactures epi wafers and semiconductors including diodes, in its 10,000-square-foot plant. The company has capacity for growing AlGaAs epi onto InP wafers. Epitaxx recently was awarded a NASA contract for developing advanced InGaAs photodetectors. The company reportedly became profitable in 1986.

Epitronics (Alcan)

Founded in 1984 by Dr. Robert L. Adams, Epitronics is a subsidiary of Alcan Aluminum Corporation. By late 1987, the company had five MOCVD reactors and one LPE system in operation. Epitronics offers GaAs and AlGaAs epitaxial services to the merchant market.

Furukawa Electric

A leading Japanese supplier of fiber-optic cable, Furukawa also offers laser chips, compound semiconductor wafers, and epi substrates. The company's new facility in Iwaki doubled its previous GaP ingot capacity to 200 kilograms per month.

GAIN Electronics

GAIN supplies GaAs digital gate arrays and other IC products to the merchant market. The company developed state-of-the-art MBE epitaxy capability in a class 10 facility and began offering this service to the marketplace in late 1987. GAIN's GaAs epi sales are expected to exceed $1 million in 1988.

Hitachi Cable

Hitachi Cable has invested ¥2 billion in developing III-V materials capability. It plans to increase its sales in 1988 to more than ¥3 billion, including the addition of InP wafers and MOCVD epi wafers to its existing III-V semiconductor materials family. The company expects to increase the epi component of its business to 40 percent of the total by 1989, focusing on the thin-layer segment of the market.

Hitachi Metals

Hitachi Metals supplies GaAs ingots grown by the LEC method, primarily to the Japanese marketplace.

ICI Wafer Technology

ICI, formed in 1985 by the acquisition of Metals Research of Melbourn, Cambridgeshire, United Kingdom, is a subsidiary of Imperial Chemical Industries PLC. Its staff includes many former employees of Cambridge Instruments, the leading maker of III-V crystal pullers. ICI produces GaAs ingots capable of yielding more than 200 3-inch wafers each, and has developed 4-inch ingot and wafer capability. GaAs wafer products include semi-insulating (undoped) and silicon-doped through 4-inch diameter. InP products include undoped, tin-doped, sulfur-doped DF (dislocation-free), and iron-doped semi-insulating—all 2-inch diameter.

Iwaki Handotai

Iwaki Handotai is a joint venture of SEH and Furukawa Mining. The company markets GaAs epi wafers produced from internally manufactured wafers. Iwaki Handotai has an installed base of at least six crystal pullers for GaAs ingot production.

Kopin Corporation

Kopin, a start-up company founded in 1985, specializes in GaAs epitaxial layers on silicon wafers and other engineered wafer products. The company began shipping 2-, 3- and 4-inch wafers in 1987, and displayed a 6-inch GaAs-on-Si wafer at a recent microwave technology conference in New York. Kopin is the leader in this technology. The company recently announced aggressive pricing for 2- and 3-inch GaAs MOCVD epi substrates, confirming its readiness for large-volume production orders.

M/A-COM

M/A-COM, a long-time supplier of GaAs discrete and MMIC chips, offers a full spectrum of GaAs ingots and wafers to the semiconductor industry. Its two bulk GaAs material operations, at Burlington, Massachusetts, and at Metuchen, New Jersey, are fully equipped, crystal-growing, evaluation, slicing, and polishing facilities. Crystal growth methods at M/A-COM include Horizontal Bridgman (HB), gradient-freeze (GF), and LEC. Si, Te, Zn, Cd, or Cr doping are available.

MCP Electronic Materials

MCP supplies both III-V and II-VI compound semiconductor materials. It has approximately 65 employees, of whom more than 50 are scientists or engineers.

Metal Specialties

Metal Specialties, a manufacturer of HB and LEC wafers, offers a wide range of III-V compound wafers including compounds of gallium and of indium.

Meteaux Speciaux

Meteaux Speciaux began production of LEC-grown InP ingots and wafers in mid-1987.

Microwave Semiconductor Corporation (MSC) (Siemens)

MSC supplies GaAs and silicon discretes and ICs for microwave applications. Since early 1987, the company has offered OMVPE (MOCVD) epi services. MCI offers standard buffer layers of 3 to 5 microns ±10 percent and active and contact layers of 0.1 to 1.0 microns ±10 percent, with tighter tolerances available on special request.

Mitsubishi Metal

Mitsubishi Metal produces HB- and LEC-grown GaAs wafers at its wafer plant. The company started sample shipments of GaAs epi wafers to the U.S. market in early 1987. It plans to focus on 2- and 3-inch NDF GaAs wafers. Mitsubishi's capacity exceeded the equivalent of 10,000 2-inch GaAs wafers per month in early 1987.

Mitsubishi-Monsanto Kokusai (MMK)

MMK is the second-largest GaAs wafer supplier. The company introduced polished wafers of unprecedented uniformity in 1987. MMK claims that these products have impurity levels ten times lower than any other commercially available GaAs polished wafers, which enables the IC manufacturer to achieve heretofore unattainable yields on ion-implant processing.

Morgan Semiconductor (Ethyl Corporation)

In 1986, Morgan Semiconductor, a division of Ethyl Corporation, began shipping 2- and 3-inch GaAs MOCVD epi wafers, sliced from internally grown, medium-pressure LEC ingots. The MPLEC method reportedly allows long crystal growth, thus improving yield and reducing wafer cost over the HPLEC method used by other suppliers. Morgan was using six crystal pullers as of late 1986. The company offers a video tape that describes crystal growth, wafer cutting, polishing, and test operations.

Nippon Mining

Nippon Mining, a dominant producer of high-purity indium, was the first Japanese producer of 3-inch NDF wafers. A subsidiary, NIMIC, markets the company's III-V and II-VI products in the United States. Nippon Mining is entering the InP solar cell market, and claims it can produce InP cells at a lower cost than that of GaAs solar cells.

Les Technologies OMVPE

OMVPE Technologies Inc., a start-up company, was reorganized in 1987 to concentrate its efforts on development of a high-quality MOCVD epitaxial process. The company has been shipping prototype quantities for more than a year, and is increasing its production of a wide range of epitaxial wafers and epitaxial services for commercial and military users.

Picogiga

Picogiga, a 1985 start-up company, supplies MBE wafers and services, worldwide. The company is actively pursuing opportunities on the DoD MIMIC program. While the company's products are priced relatively higher than OMVPE (MOCVD) wafers, Picogiga claims that this premium is offset by the superior quality of its MBE processing that results in higher chip yields.

Preussag

A major mining company and supplier of high-purity gallium material, Preussag has spent more than $30 million to develop GaAs wafer capability. Wafer production is expected in 1989.

Raytheon

Raytheon is a large supplier of electronics components, systems, equipment, and services to military and commercial markets. The company also manufactures GaAs wafers and GaAs epi wafers for discrete and IC production.

Showa Denko

Showa Denko was the first company in Japan to produce MLEC-grown InP wafers. The company sampled reduced-defect GaAs wafers in mid-1985. Showa Denko supplies a range of III-V wafers including GaAs, InP, and GaP.

Siemens Opto Division

Siemens Opto Division, formerly Litronix, produces 1.6- to 3-inch HB-grown wafers.

Spectrum Technology

Spectrum Technology, a subsidiary of NERCO Advanced Materials, Inc. (part of the PacifiCorp group), has a 25,000-square-foot plant at its headquarters. The company offers both high- and low-pressure LEC growth of GaAs wafers. Spectrum claims to be the largest supplier of 4-inch GaAs wafers.

Spire

Spire supplies compound semiconductor epitaxial equipment, materials and processing, and test and engineering services. Spire experienced sales of $11.3 million in 1987, down 10 percent from 1986. The company signed an agreement with Sumitomo in 1987 that specifies development of the market for GaAs epi wafers in Japan. Under the agreement, Spire grows GaAs epi on Sumitomo GaAs wafers, and Sumitomo markets the epi wafers in Japan.

Sumitomo Electric

Sumitomo Electric, a $3.6 billion electronics company, enjoys a 30 percent share of the compound semiconductor market. The company began developing GaAs and other compound semiconductor materials in 1962.

Sumitomo recently instituted major cost reductions in the manufacture of GaAs wafers that have not yet been fully reflected in the company's product pricing. The improved production processes include increased boule length, improved diameter control, greater yield of wafers per unit boule length, and decreased test costs. These improvements pose a potential major threat to at least some of Sumitomo's competitors.

Sumitomo Electric sells compound semiconductor materials to Bulgaria, Poland, and the U.S.S.R. To date, this activity has not resulted in any open expression of concern by the U.S. Department of Defense.

United Epitaxial Technologies (UET)

UET, an Oregon-based start-up, is developing advanced compound semiconductor technology and materials. The firm uses MOCVD to produce binary, ternary, and quaternary epitaxial layers on GaAs and InP wafers. Dopants include Be, Zn, Si, and Se. Layer thicknesses range from 200 angstroms to 10 microns, with standard tolerances of less than 4 percent for 2-inch material and 6 percent for 3-inch material.

Wacker Chemtronic GmbH

Wacker is a major supplier of silicon and GaAs wafers to the worldwide market. The company offers a range of 2- and 3-inch single crystals and GaAs wafers in various crystal orientations, both semi-insulating and doped.

DATAQUEST ANALYSIS

The III–V compound semiconductor materials marketplace is supported by a broad range of increasingly capable suppliers, each dedicated to continual improvement of its products and services. Material quality, quantity, and yields are constantly refined, although these improvements do not necessarily appear in the form of price reductions to GaAs semiconductor manufacturers. In some cases, this causes suppliers to hold GaAs chip pricing at artificially high levels.

There is some evidence to suggest that Japanese suppliers of compound semiconductor materials have manipulated the market, both for raw materials such as indium and for wafers such as NDF 2-inch GaAs wafers. Dataquest expects that the increasing competition will reduce the tendency of these suppliers toward holding prices at artificially high levels. This is important to the GaAs chip suppliers who must achieve lower unit costs to accelerate development of their end markets, and, it should ultimately benefit the entire industry.

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IEEE SYMPOSIA AND EXHIBITS HIGHLIGHT PROGRESS IN MICROWAVES

SUMMARY

"Microwaves—Past, Present, and Future" was the theme of this year's IEEE International Microwave Symposium, held in New York City from May 25 through May 27. Attendance exceeded 1,900 persons, and the exhibits were viewed by approximately 6,500. The conference was preceded by workshops on May 23 and by the IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium on May 24 and 25, attended by more than 1,000 professionals.

Exhibits from approximately 250 companies enhanced the events. This newsletter examines important innovations presented or exhibited by program participants, and reviews related developments considered to be of interest to many of Dataquest's clients.

DISCUSSION AND ANALYSIS

Thirty-five papers were presented at the monolithic circuits symposium, which was focused on circuit and chip technology, applications including fiber optics, and producibility. The 219 microwave symposium papers covered discrete and IC components to above 90-GHz operating frequency; waveguides, antennas, and other components; high-frequency superconductors; and communications, radar, and other applications. Special seminars addressed foundry issues, GPS (global positioning satellite) applications, and other topics of major current interest. Disappointing to many attendees was Avantek's late withdrawal from the exhibits.

New Product Concepts

Examples of the new products of interest to many Dataquest clients include a range of ICs, large GaAs-on-Si wafers, new GaAs epi wafer and IC foundry capabilities in Europe, and GaAs MBE (molecular-beam epitaxy) wafer services. Table 1 summarizes many of the IC product concepts presented or displayed at the conference.

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Table 1

1988 MTT-S Microwave/MM-Wave Product Concepts

Company	Product Concept
Alpha/Aerojet/ GAMMA Monolithics	Monolithic Ka-band VCO (voltage-controlled oscillator)
ANADIGICs	7 Gb/s decision circuit IC
ATR (Osaka)	Broadband active inductor
COMSAT Labs	60-GHz MMIC LNAs
Ford/COMSAT Labs/ Pacific Monolithics	ASMMIC (Application-specific MMIC) cell library
GAMMA Monolithics	35-GHz MMIC LNA
General Electric	Wideband MMIC variable gain amplifiers
Hughes Aircraft	V-band MMIC transmit-receive switch
ITT	MMIC IF upconverter
LEP/TRT (France)	MMIC for FM continuous wave radars
Matsushita	15-GHz single-stage divider
Mitsubishi	HEMT fabricated with focused ion beam lithography
NEC Corporation	9.5-GHz prescaler
NTT	Uniplanar MMICs
Pacific Monolithics	6- to 18-GHz MMIC amplifiers
Raytheon	14- to 37-GHz power amplifier MM-wave monolithic IMPATT VCO 3-bit K/Ka-band MMIC phase shifter
Texas Instruments	0.5- to 4-GHz true logarithmic amplifier 60-GHz CW IMPATT oscillator X-band monolithic LNA 3-watt X-band variable gain amplifier Ka-band monolithic power amplifier modules X- and Ka-band MMIC variable attenuation limiters

(Continued)

Table 1 (Continued)

1988 MTT-S Microwave/MM-Wave Product Concepts

Company	Product Concept
TRW Inc.	GaAs HBT log IF amplifier Q-band monolithic 3-stage amplifier
Westinghouse	6- to 18-GHz analog phase shifter
Varian	MMIC Ka-band HEMT LNA

Source: Aztek Assoc.

MMIC Spurs IC Developments

Eliot D. Cohen, of the Office of the Secretary of Defense, presented the status of the MIMIC initiative and described the Phase 1 awards of more than $250 million to be shared among four industry teams. He stated that the present capacity demand estimate is for 700 to 1,000 4-inch wafers per week by the mid-1990s to satisfy the projected MIMIC uses. This figure could increase substantially as new defense needs emerge. The DOD expects to make additional funding available for technology projects such as direct-write E-beam and MOMBE systems developments.

As shown in Table 1, several companies—including COMSAT Labs, GAMMA Monolithics, and Texas Instruments—have developed millimeter-wave IC chips. The functions now available in IC form include logarithmic amplifiers, low-noise amplifiers operating to 60-GHz frequency, and MMIC voltage controlled oscillators from several sources of supply. Dataquest expects these trends to continue, as the U.S. DOD MIMIC Initiative moves into Phase 1.

Progress in Substrate Materials

Kopin Corporation displayed a 6-inch diameter GaAs-on-silicon wafer, the largest available to date. Although this wafer exceeds the useful size for many GaAs IC manufacturers, it is an excellent demonstration of capability; most GaAs epi suppliers have problems with uniformity on 3-inch wafers. The company indicated that it has announced aggressive MOCVD epitaxial GaAs-on-GaAs substrate pricing for 2-inch and 3-inch material, confirming its readiness for production orders.

Ford Microelectronics has fabricated its 504-gate GaAs gate array on a GaAs-on-Si substrate, with test results confirming acceptable circuit performance. Ford grows its own GaAs epi layers on silicon wafers.

Picogiga (Les Ulis, France) and GAIN Electronics (Somerville, NJ) exhibited GaAs MBE wafer processing services. The company was formed to specialize in epi services, and it has targeted the GaAs MBE marketplace. Picogiga hopes to sell its products into the MIMIC program. GAIN is vertically integrated, supplying GaAs digICs as well as epi wafer services. The proponents of MBE claim that the improved quality of the process results in higher IC yields, offsetting the currently higher cost of MBE (compared with MOCVD or OMVPE) processing.

Thomson Develops GaAs Cell Libraries and DigICs

Thomson has developed MMIC analog/linear and fully ECL-compatible GaAs digIC cell libraries, but it would not specify when its foundry services will be available outside of France on a merchant basis. Thomson's digIC cell set is based on BFL (buffered FET logic) circuitry. Typical speed-power characteristics are 80ps delay and 5mW power consumption for an inverter with fan-in and fan-out of one. Delay at the same power level increases to 120ps for a two-input NOR-gate with fan-out of two.

Thomson has also developed a family of GaAs SSI and MSI digICs. The company described the use of these devices in signal-processing applications such as deceptive jammers, FFT butterfly with multipliers, digital fiber-optic links, code generators, and convolvers.

Other GaAs Device Activities in Europe

The Swiss Federal Institute of Technology presented an overview of recent activities in GaAs MESFETs, HEMTs, and GaInAs J-FETs by Siemens and others. Comparison tests indicate that GaInAs J-FET technology may be superior to GaAs MESFET technology at 1u geometries.

AEG described the employment of 50- to 60-GHz frequencies for satellite up-links in military applications. AEG also described the use of 94-GHz radar for battlefield and terrain mapping and 61-GHz sensors for vehicular-traffic applications.

The Next MTT-S

The 1989 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symposium will be held June 12 and 13, 1989. The 1989 IEEE International Microwave Symposium will be held June 13 through 15, 1989. Both meetings will be in Long Beach, California. As usual, the program will be supplemented with exhibits, one-day courses, and other special activities. The deadline for proposed papers for either event is December 12, 1988.

DATAQUEST CONCLUSIONS

The microwave industry is experiencing maturation of the discrete and hybrid businesses; the IC segment is growing from a $100 million base and has started to threaten some of the more mature products. Major breakthroughs in materials are a significant factor, as evidenced by the increasing availability of large-diameter, high-quality substrates.

European companies are making significant progress in the microwave field, applying this technology to both military and commercial hardware. The operating frequency of such hardware ranges to 94 GHz.

The microwave/millimeter-wave industry will continue to experience innovations in hardware concepts as IC technology moves further into the mainstream of microwave applications. Global positioning satellite hardware systems and subsystems, such as emergency-location devices and survey equipment, are excellent examples of this pervasiveness.

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GAZELLE INTRODUCES FIRST PRODUCTION GaAs PLD

On June 10, Gazelle Microcircuits, Inc., announced immediate availability of the IC industry's first GaAs laser-programmable logic device (PLD), the GA22V10. The TTL-compatible device is expected to extend GaAs technology into high-end personal computers and workstations. Gazelle priced the device at $55.00 in 100-piece quantities and has been shipping the product since February.

GaAs technology offers an on-chip speed advantage of three to five times that of silicon technology, which translates to an improvement of at least 25 percent at the TTL system level. TTL interface and power pins assure full compatibility with the most popular microprocessor ICs; memory ICs; and CMOS, NMOS, and Schottky TTL logic families. Thus, the Gazelle product has immediate applicability to a segment of the mainstream multibillion-dollar IC market. Further, the GA22V10 is pin equivalent to its slower silicon counterpart, making available a market by direct substitution. Anticipating rapid demand buildup, Gazelle has entered into a foundry agreement with TriQuint, a subsidiary of Tektronix, Inc. TriQuint is an established volume producer of GaAs ICs, with 4-inch fab capacity.

Gazelle is a Silicon Valley-based start-up cofounded in 1986 by Andy Graham and David MacMillan. Its objective is to design and market high-performance, easily used LSI and VLSI GaAs digICs. The company has $10.5 million in financing; equity investors include Kleiner Perkins Caufield & Byers, Hambrecht & Quist, and others.

DATAQUEST CONCLUSIONS

The Gazelle announcement is another in the recent sequence of GaAs digIC product introductions, closely following those of Ford, GAIN, GigaBit, Vitesse, and others. Dataquest expects an acceleration in the acceptance of GaAs ICs into a broad range of applications including high-volume computers, high-speed testers and instrumentation equipment, communications, and high-performance workstations.

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DOD MIMIC PROGRAM ADVANCES INTO PHASE 1

The U.S. Department of Defense (DOD) has awarded four Phase 1 contracts under the MMIC (Microwave/Millimeter Wave Monolithic Integrated Circuits) program. The seven-year, $500 million program is funded for $46 million in the current fiscal year. Phase 0, the definition phase, ended in January; it involved 48 companies and studies of 50 applications. Many Phase 0 participants are subcontractors on Phase 1. Prime contractors and related information are shown in Table 1. Phase 1 teams include the following:

- AT&T, E-Systems, Hercules (Sperry Clearwater division), M/A-COM, Cascade Microtech, and Harris Microwave supporting Hughes/GE
- Three divisions of ITT, Harris GSD, Pacific Monolithics, Alpha Industries, SRI, and Watkins-Johnson supporting ITT/Martin Marietta
- Aerojet General, Consilium, Compact, General Dynamics, Litton Airtron, Magnavox, Norden, and Teledyne supporting Raytheon/TI
- General Dynamics, Honeywell, and Kodak supporting TRW

The DOD expects to make additional funding available for technology projects such as direct-write E-beam and MOMBE systems developments. Eliot D. Cohen, of the Office of the Secretary of Defense, stated to an audience at the MTT that the present demand estimate is 700 to 1,000 4-inch wafers per week by the mid-1990s to satisfy the currently projected MMIC uses. This figure could increase substantially as new defense needs emerge.

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Table 1

MMIC Phase 1 Summary

Prime Contractors	Award ($M)	Service Branch	Freq. Range Upper Limit	Technologies	Applications
Hughes/GE	50	Air Force	To 30 GHz	MESFET, HEMT	Radar
ITT/Martin Marietta	49	Army	Above 30 GHz	SAGFET	Communications, Smart munitions
Raytheon/TI	68	Navy	To 30 GHz	MESFET	Electronic warfare
TRW	58	Army	Above 30 GHz	MESFET, HBT, HEMT	Electronic warfare, Smart munitions

Source: U.S. DOD

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GaAs FOUNDRIES INCREASE FREQUENCY OF RESPONSE

SUMMARY

GaAs foundry activities intensified during the last year, as commercial usage of digICs and MMICs gained market momentum, and as the United States Department of Defense's MIMIC program evolved through Phase 0 and into Phase 1. Newcomers in this year's summary include COMSAT Labs, Raytheon, Sanders Associates (Lockheed), and Varian Associates. This newsletter analyzes the available GaAs foundry services and tabulates the companies, locations, contacts, plant capacities, processes, and other useful data. Significant improvement occurred in the foundries' responsiveness to customers' orders, as processes were debugged and yield enhancements were made.

ANALYSIS AND DISCUSSION

At least 21 GaAs foundries now serve the free world marketplace. Thomson-CSF is expected to join the ranks in the near future. Japan's candidates include at least four of the major silicon suppliers, a situation very different from that in the United States. Since early 1987, processes have advanced below 0.5u at several facilities to support microwave performance demands. Table 1 summarizes the GaAs process and product offerings available at press time.

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Table 1

Merchant Market GaAs Foundries

Company	Process	Product	Comments
Adams-Russell	0.5u D-MESFET	MMICs	Multiproject wafers
ANADIGICS	0.5u D-MESFET	MMICs, digICs	Multiproject wafers
Avantek	0.5u MESFET	MMICs	150,000-square-foot facility
COMSAT Labs	0.5u MESFET	MMICs	To 60 GHz
Ford Micro	0.5u, 1.4u E-/D-MESFET	MMICs, digICs	500 wafers/week
GAIN	E-/D-MESFET, SDHT	DigICs	7,000-gate array, MBE wafers
GigaBit Logic	D-MESFET	DigICs	Extensive macrocell library
Harris Micro	1u, 0.5u MESFET	MMICs, digICs	Cell library
Honeywell			Relocated to Minneapolis, MN
ITT GTC	0.4u, 0.5u D-, E-/ D-MESFET	MMICs, digICs	Superior temperature test capacity
M/A-COM	0.8u, 0.5u, 0.25u	MMICs	Decreased production
MSC	0.5u	MMICs	To 25 GHz
Plessey 3-5	0.7u D-MESFET	MMICs	Emphasis on quality control
Raytheon	0.5u, 0.25u D-MESFET	MMICs	Foundry under construction
Rockwell	D-MESFET, HEMT	DigICs	250 3-inch wafers/ shift/week
Sanders	0.5u, 0.25u	MMICs	To 40+ GHz
Tachonics	0.5u, 0.25u E-/D-MESFET	MMICs, digICs	Alternative source to GigaBit Logic

(Continued)

Table 1 (Continued)

Merchant Market GaAs Foundries

Company	Process	Product	Comments
TI MMCD	0.5u D-MESFET	MMICs	Three process profiles
TriQuint	0.7u, 0.5u E-/D-MESFET	DigICs, MMICs	Multiproject wafers
Varian	0.25u HEMT	MMICs	To 40 GHz
Vitesse Semi	1.2u E-/D-MESFET	DigICs	Technology exchange with AMD

Source: Aztek Assoc.

Analog/Linear GaAs Foundries

Microwave, millimeter wave, and other analog functions represent a continuing opportunity for many GaAs foundries. Because unique specifications are usually imposed by each customer and each application, and because the NRE costs are significant, the responsive foundry has an opportunity to support repeat business. Most foundries are continuing to develop and implement ASIC capabilities in response to specific market needs.

Increasing availability of 3-inch MOCVD and MBE wafers with improved defect densities, coupled with enhanced modeling of GaAs functions on relatively inexpensive workstations, has caused a rapid migration toward monolithic ASIC solutions to multifunctional microwave design problems. As is the case in silicon technology, GaAs ASICs often provide the most cost-effective approach for both customer and supplier.

Several companies have offered GaAs ASIC support via foundry services, and the list is growing. Major MMIC ASIC foundries, locations, and contacts are summarized in Table 2, and the capabilities of these foundries are listed in Table 3.

Similar to integrated circuits in the GaAs analog/linear world, GaAs application-specific digital integrated circuits (ASIC digICs) offer a relatively attractive means of evolving system designs from silicon to GaAs. Several companies, including recent start-ups, have mounted substantial foundry programs to support GaAs ASICs. Table 4 lists locations and contacts for merchant market foundries in the United States and in Western Europe offering GaAs digIC services in early 1988. There were no announced merchant GaAs digIC foundries in Japan at press time.

Table 2

Analog/Linear GaAs Foundry Contacts

Company/Location	Phone	Foundry Contact
Adams-Russell Burlington, MA	(617) 273-5830	Bryan Reardon Marketing director
ANADIGICS Warren, NJ	(201) 668-5000	Michael Gagnon Director, marketing & sales
Avantek Santa Clara, CA	(408) 727-0700	Peter Manno Marketing director
COMSAT Labs Clarksburg, MD	(301) 428-4000	Dr. Ho Chung Huang Executive director, Micro Division
Ford Micro Colorado Springs, CO	(303) 528-7660	Charlotte Diener Marketing manager
Harris Milpitas, CA	(408) 433-2222	Jim Klug Program director
ITT GTC Roanoke, VA	(703) 563-3912	Joe Girzyb Project manager
M/A-COM Lowell, MA	(617) 937-2800	Larry Ward Marketing director
MSC Somerset, NJ	(201) 563-6300	Bruce Hoffman Product marketing manager
Plessey 3-5 Towcester, United Kingdom	(0327) 51871	Jim Arnold Applications executive
Sanders Nashua, NH	(603) 885-1054	Dr. John Heaton Manager, Adv. Micro Ctr.
Tachonics Plainsboro, NJ	(609) 275-2705	Kevin Townsend Sales manager
TI MMCD Dallas, TX	(214) 995-3043	Ray Toole Operations manager
TriQuint Beaverton, OR	(503) 644-3535	Dr. Ajit Rode VP, foundry products
Varian Associates Santa Clara, CA	(408) 562-2834	Michael Kopek III-V sales manager

Source: Aztek Assoc.

Table 3

Analog/Linear GaAs Foundry Capabilities

Company	Wafer Size (Inches)	Capacity (Starts/Wk.)	Turnaround Time (Weeks)	Services	NRE Costs ($K)
Adams-Russell	2, 3	100	12	RF probing	$45/4 wafers
ANADIGICS	3	200	8	Training	$15 to $50
Avantek	2, 3	270	N/A	Die bank	N/A
COMSAT Labs	2, 3	20	16	HEMT process	N/A
Ford Micro	3	500	10	RF probing	N/A
Harris	2, 3	100	14	100% visuals	$25 to $100
ITT GTC	3	100	9	Ion implant	$68
M/A-COM	2, 3	N/A	N/A	N/A	N/A
MSC	2, 3	180	6	RF probing	$25/design, $42/production run
Plessey 3-5	2	100	8-12	Strict QC	$48 plus $6.5/wafer
Sanders	2, 3	50-125	14	RF probing	$9/4 wafers, plus mask charges
Tachonics	3	300	8	Ion implant	$45
TI MMCD	3	60	12	E-beam	$69.5
TriQuint	3	250	10	Multiproject	$50 to $90
Varian Associates	2, 3	N/A	16	E-beam, HEMT	$40 first wafer, $15 next 10 wafers

N/A = Not Available

Source: Aztek Assoc.

Table 4

GaAs DigIC Foundry Contacts

Company/Locations	Phone	Foundry Contact
ANADIGICS Warren, NJ	(201) 668-5000	Michael Gagnon Director, marketing & sales
Ford Micro Colorado Springs, CO	(303) 528-7660	Charlotte Diener Marketing manager
GAIN Somerville, NJ	(201) 526-7111	Glen Martini Marketing manager
GigaBit Logic Newbury Park, CA	(805) 499-0610	Tony Conoscenti Product marketing engineer
Harris Milpitas, CA	(408) 433-2222	Jim Klug Program director
Honeywell Minneapolis, MN	(612) 887-4047	Dr. Richard Cirillo Program manager
ITT GTC Roanoke, VA	(703) 563-3912	Joe Girzyb Project manager
Plessey 3-5 Towcester, United Kingdom	(0327) 51871	Jim Arnold Applications executive
Rockwell Anaheim, CA	(714) 762-4074	Phil Dee Marketing manager
Tachonics Plainsboro, NJ	(609) 275-2705	Kevin Townsend Sales manager
TriQuint Beaverton, OR	(503) 644-3535	Dr. Ajit Rode Vice president, foundry products
Vitesse Semi Camarillo, CA	(805) 388-3700	Tom Dugan Marketing vice president

Source: Aztek Assoc.

TriQuint and others are marketing multiuser prototype wafer programs that allow several customers to design devices according to the respective suppliers' ground rules and receive the first prototype devices from wafers fabricated during a single run. To accomplish this, the vendor assigns standardized reticle areas (e.g., 80 mils x 80 mils) for chip locations so that several customers' chips can be interspersed on the same wafer. This represents a major breakthrough in economies of scale in developing GaAs devices. Cost reduction for the user can be as much as 80 percent per wafer run.

GigaBit Logic has experienced particularly impressive foundry yields on the Cray-3 GaAs ASIC program. Yields of the cell-based MSI-density chips have continued to advance well beyond 50 percent for several months. As a result, the Cray-4 machine is expected to advance to E/D gate arrays or CBICs of at least a 2,000-gate density.

Table 5 summarizes digIC foundry data including wafer sizes, plant capacities, turnaround times, services, and NRE charges.

Table 5

GaAs digIC Foundry Capabilities

Company	Wafer Size (Inches)	Capacity (Starts/Wk.)	Turnaround Time (Weeks)	Services	NRE Costs ($K)
ANADIGICS	3	200	8	Training	$15 to $50
Ford Micro	3	500	10	RF probing	N/A
GAIN	3	300	12	SDHT process	N/A
GigaBit Logic	3	N/A	6-8	100% speed testing	$35 to $48 depending on process
Harris	2, 3	100	14	100% visuals	$25 to $100
Honeywell	N/A	N/A	N/A	N/A	Deemphasizing foundry activity
ITT GTC	3	100	9	Ion implant	$60
Plessey 3-5	2	100	8-12	Strict QC	$48, plus $6.5/wafer
Tachonics	3	300	8	Ion implant	$45
TriQuint	3	250	10	Multiproject	$50 to $90
Vitesse	3	N/A	3	E/D process	N/A

N/A = Not Available

Source: Aztek Assoc.

DATAQUEST CONCLUSIONS

GaAs IC users may now select from more than 20 foundries in establishing sources of supply. Of these, 15 are analog/linear houses, and 12 supply to the digIC marketplace. The majority of these suppliers now sustain production of 3-inch, nearly defect-free wafers, supported with increasingly capable wafer test, assembly, and final test facilities. Some have developed novel cost-reduction methods such as the multiuser wafer concept. Ample capacity is in place, making GaAs ICs better bargains now than ever before. With hundreds of metal-mask variations of chip designs now available to the individual user, the equipment designer can no longer afford to ignore the potential of GaAs devices for enhanced system performance.

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ICs LEAD FORECAST GROWTH OF GALLIUM ARSENIDE

SUMMARY

The worldwide market for GaAs semiconductors exceeded $2.2 billion in 1987. Although discrete optoelectronic and other discrete devices accounted for more than 88 percent of total shipments, GaAs ICs made up more than 23 percent of the $281 million total market growth compared with the 1986 market figures.

DATAQUEST ANALYSIS

For several years, market figures for the GaAs semiconductor industry have been a source of confusion for many observers. This is due in large part to overly optimistic business plans, "bottom-up" forecasting methodology, and a long progression of poor yields and non-worst-case designs. Since 1986, many of the industry participants have attacked these problems, and progress is evident. Our forecast includes a number of cross-checks of shipments history in an attempt to remove the "advancing hockey stick" phenomenon evident in some projections of this industry.

Table 1 is a summary of Dataquest's forecast of worldwide GaAs semiconductor market consumption through 1992. The overall market is expected to exceed a compound annual growth rate (CAGR) of 15 percent. This will be driven primarily by the emerging markets for linear, digital, and optoelectronic ICs, although discrete opto-electronics will continue to account for the majority of shipments through 1992. We estimate that in 1992, discrete opto will still have an estimated 63 percent share of the total market.

While linear ICs presently are the largest of the three GaAs IC product families, digital device sales are expected to experience the highest growth rate—more than 70 percent through 1992. Combined with the nonrecurring (NRE) costs, the digital segment growth rate is forecast at 52 percent. Analog/linear ICs will grow rapidly at expected CAGRs of 42.4 percent (devices) and 31.0 percent (overall, including NRE) rates. Together, the three GaAs IC segments are expected to exceed shipments of $1 billion in the early 1990s.

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Table 1

Worldwide GaAs Semiconductor Market Consumption*
(Millions of Dollars)

	1986	1987	1988	1989	1990	1991	1992	CAGR 1987-1992
Total GaAs Devices	1,947	2,228	2,605	2,742	3,168	3,806	4,622	15.7%
Analog/linear ICs	107	138	177	228	294	413	532	31.0%
Devices	56	85	127	178	254	378	497	42.4%
NRE	51	53	50	50	40	35	35	
DigICs	51	71	96	140	208	345	577	52.0%
Devices	16	35	61	110	178	315	547	73.3%
NRE	35	36	35	30	30	30	30	
Optoelectronics	1,586	1,797	2,088	2,111	2,378	2,730	3,168	12.0%
Discrete Opto	1,558	1,754	2,021	2,007	2,216	2,528	2,915	10.7%
OEICs	28	43	67	104	162	202	253	42.5%
u/mmwave Discretes	203	222	244	263	288	318	345	9.2%

*Excludes full captives. Includes intercompany for merchant suppliers.

Source: Dataquest
April 1988

The optoelectronic devices market and microwave discrete markets temper the overall GaAs market dramatically. Discrete opto devices are growing less rapidly than the IC segments, at 10.7 percent CAGR through 1992. Growth in discrete microwave devices is expected to be less than 10 percent per year and may decrease faster than shown, as MMICs replace many hybrid module designs.

The anticipated 1991–1992 growth of more than $270 million in the IC segments will depend on continued market development and pervasiveness, similar to that experienced since 1986 in the supercomputer, graphics processor, and optical communication hardware segments. For example, a shift in cache memory consumption from ECL to higher-performance GaAs SRAM could account for more than a $60 million per-year increase in sales in the early 1990s.

Adoption of collision avoidance hardware, especially if federally legislated, could create a demand for more than $100 million in MMICs annually. Evidence of potentially explosive growth in the analog/linear IC and digIC segments has been demonstrated in recent announcements such as the MMIC Phase 1 awards, the extension of the Cray contract with Gigabit Logic, and the $15 million ASIC agreement between GAIN Electronics and Interface Technology, Inc.

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DSP EVOLUTION EVIDENT AT 35TH ISSCC

SUMMARY

The International Solid State Circuits Conference (ISSCC), held February 17 through 19, 1988, in San Francisco, celebrated its 35th year of reporting continuing progress in semiconductor technology. One hundred papers by more than 600 industry and academic participants emphasized the rapid rate of evolution of IC functions. Significantly, a record 30 percent of these were specifically oriented to digital signal processing (DSP) chips, and another 50 percent described general-purpose functions that are directly usable in DSP applications.

Dataquest broadly categorizes DSP IC functions as signal processing, graphics generation, image processing, and scientific computing products. This newsletter examines major ISSCC presentations in each of these areas, then discusses their impact on trends in products, technology, and applications.

ANALYSIS AND DISCUSSION

Since the first 4-bit microprocessor of 1970, microprocessor chips have evolved to 32-bit word length, CMOS and GaAs processing, <1-micron design rules, clock rates beyond 30 MHz, and throughputs measured in tens to hundreds of mops. Where appropriate, on-board EPROM or EEPROM is used for microcontrol storage. The DSP functions presented at this conference represent a continuation of this progress.

Some of the major developments discussed at the conference are summarized in Table 1. All of the devices shown use CMOS processing, with transistor counts as high as 368,000. All incorporate two-layer metal and/or double-poly interconnections for efficient use of chip area. Minimum geometries are on the order of 0.8 to 2.0 microns. Power dissipation for each of the two largest functions is 4 watts.

Table 1

1988 ISSCC—Major Silicon DSP Chips

Characteristic	Company: Hitachi	Matsushita	National	NTT	Toshiba	VITI
Function	Video signal processing	3-D hidden surface processing	Video signal processing	Geometric mapping processing	Graphics processing	Parallel image processing
Gate Count	9,000	N/A	N/A	105,000	N/A	50,000
Transistor Count	36,000	330,000	40,000	N/A	368,000	200,000
Process	CMOS	Twin-tub CMOS	CMOS, 2L poly	CMOS	Twin-tub CMOS	CMOS
Minimum Feature Size (u)	1.0	1.2	2.0	1.2	0.8	2.0
Metal	2L Al	2L	N/A	2L	2L	2L
Die Size (cm^2)	6.8 x 5.5	11.1 x 11.5	7.0 x 5.5	14.5 x 14.5	10.9 x 12.2	11.7 x 10.7
Clock Rate	N/A	20 MHz	27 MHz	50 MHz	40 MHz	N/A
Performance	50 mips	N/A	N/A	N/A	40M pixels/s	114 mops
Pinouts (S + P)	80	57 + 7	37 + 3	280	144	119 + 30
Package	N/A	N/A	DIP	PIP	Ceramic FP	PGA
Voltage(s)	+5V	+5V	+5V, -5V	+5V	+5V	V_{DD}, V_{SS}
Power Consumption	N/A	4W	500mW	4W	800mW	N/A
Remarks		256-pixel processing	Maximum rate--30 MHz			12 transistors per register bit

N/A = Not Available

Source: Aztek Associates

Signal Processing Products

Companies and other organizations presenting information on developments in signal processing products include AT&T Bell Laboratories, Fujitsu, General Electric, Hitachi, Matsushita, National Semiconductor, NEC, Philips, Siemens, and Stanford University. Notable are the AT&T communications signal processing chips, the 4Gb/s optical repeater by Fujitsu, and Sony's CMOS thermal printer head LSI logic/driver chip containing 11,448 transistors and parallel heating elements.

Numerous improvements in A/D and D/A conversion were evident. Philips and others continue to advance the state of the art of audio signal processing using digital techniques. Several telecommunications functions were presented, including an echo canceller and switching functions including cross-point switches. These are included in Table 2.

Table 2

1988 ISSCC Developments in Signal Processing Chips

Company	Chip Developments
AT&T Bell Labs	45-MHz P/FLL (phase/frequency-locked loop) timing recovery circuit, 146Mb/s time/space switch, 64 x 17 nonblocking cross-point switch, 2-GHz CMOS dual-modulus prescaler
Catholic University (Leuven, Belgium)	Micropower monolithic data acquisition
Fujitsu Opto Systems Lab	4Gb/s repeater chip set
General Electric	A mixed A/D chip for phased array single processing
Hitachi	Voice-band DSP chip with A/D and D/A, 10Mb/s link-level CMOS processor
Matsushita ERL	GaAs programmable timer with 125ps resolution
National Semiconductor	33Mb/s data-synchronizing phase-locked loop (PLL)
NEC, BSR (Newton, Massachusetts)	18-bit oversampling A/D converter for digital audio
Philips	Stereo 16-bit CMOS D/A for digital audio, algorithmic 15-bit CMOS D/A converter

(Continued)

Table 2 (Continued)

1988 ISSCC Developments in Signal Processing Chips

Company	Chip Developments
Siemens	2u CMOS equalizer for quadriture amplitude modulation (QAM) digital radio, self-calibrating 16-bit CMOS A/D converter
Sony	Thermal printer head with CMOS logic and drivers
Stanford University	Asynchronous multiplexer for biotelemetry
University of California at Berkeley ERL	250 Mbit/s CMOS cross-point switch

Source: Dataquest
April 1988

Graphics-Generation Products

Charge-coupled device (CCD) chips topped the list of graphics-generation functions discussed at the 1988 ISSCC. The largest of these, a 2 million-pixel chip by Toshiba, is organized in high-definition television (HDTV) format, 1,920 horizontal by 1,036 vertical pixels, allowing a 9:16 aspect ratio. The unit cell measures 7.3 x 7.6 microns, with a charge-handling capacity of 200,000 electrons per picture element. At F11 illumination, a signal current of 300nA has been obtained.

Texas Instruments' 128Kx8 video RAM allows storage and manipulation of 256 individual colors or shades of gray at standard HDTV resolution and frequency. Philips engineers have developed a 835Kb video serial memory and a 400K-pixel CCD imager, both aimed at HDTV. Table 3 summarizes the graphics-generation product developments.

Table 3

1988 ISSCC Developments in Graphics-Generation Functions

Company	Chip Developments
Philips	835-Kbit video serial memory (VSM), 400K-pixel CCD imager
Sony	Comb filter
Texas Instruments	128Kx8, 70-MHz video RAM
Toshiba	2M-pixel CCD imager

Source: Dataquest
April 1988

Image Processing Products

Video signal processing (VSP) functions have evolved to include 3-D manipulation and elimination of hidden areas from processed images. Matsushita presented an approach to this problem that incorporates a skewed systolic architecture fabricated on a 11.1 x 11.5mm^2 die containing 330,000 transistors. This chip is detailed in Table 1.

Significant developments were described by the France's National Telecommunications Center, General Electric, Hitachi Central Research Laboratories, Matsushita Central Research Laboratories, Nippon Telegraph and Telephone, Toshiba, and Visual Information Technology, Inc. (VITI). The parallel image processor (PIP) chip by VITI is a graphics computer incorporating the properties of two-dimensional DSP of pixel data, pixel enhancement, and interactive processing rates. Performance of 50 mips is achieved in CMOS with relatively conservative design rules of 2 microns. VITI's chip is detailed in Table 1. Table 4 is a summary of image processing product developments presented at the conference.

Table 4

1988 ISSCC Developments in Image Processing

Company	Chip Developments
French Government	27-MHz D/A VSP
General Electric	10-MHz ICs for graphics processing designed on a silicon compiler
Hitachi CRL	20ns CMOS DSP core for VSP
Matsushita CRL	Hidden surface processor
NTT	50-MHz CMOS geometrical mapping processor
Toshiba	32-bit 3-D graphics processor with 10M-pixels/s Gouraud shading, 40M-pixels/s graphics processor
VITI	PIP chip

Source: Dataquest
April 1988

Scientific Computing Products

Table 5 identifies the major developments in scientific computing products described by LSI Logic's Stanford Research Laboratory, Rockwell, a Stanford team, and Texas Instruments.

Table 5

1988 ISSCC Developments in Scientific Computing Chips

Company	Chip Developments
LSI Logic SRL	30-mflops, 32-bit CMOS floating point processor
Rockwell	150-mops GaAs 8-bit slice
Stanford University	Pipeline 64x64 array multiplexer
Texas Instruments	200-mips GaAs 32-bit microprocessor

Source: Dataquest
April 1988

Technology Trends

While CMOS processing at 0.8- to 2.0-micron geometries represents the present "workhorse" technology, advances in silicon emitter-coupled logic (ECL) and GaAs processing were visible in the presentations. The yield data for GaAs devices at LSI density levels indicate significant improvements during the last 12 to 18 months. Dataquest believes that more applications will shift toward GaAs as speed becomes a larger factor in new applications. Table 6 compares two approaches to DSP using GaAs hardware developed by Rockwell and Texas Instruments.

Table 6

GaAs Microprocessor IC Comparison

Characteristic	Company: Rockwell Design	Company: Texas Instruments/CDC Design
Function	150 mops 8-bit ALU (1,750 type)	32-bit RISC microprocessor
Architecture	3-bus bit slice (expandable to 16 bits)	6-stage pipeline
Performance	150 mops	200 mips
Operations	Add, subtract, modified Booth multiply, divide, bit operations	4 address modes, 16 ALU and 5 control instructions, 10 memory instructions
Power (Watts)	Low--4.2, high--9.2	Estimated 20 maximum
Die Size--mm	4.9 x 3.9	7.6 x 7.6
Chip Complexity	9,400 transistors, 3,000 diodes	12,872 gates (typical gate is 1 transistor and 5 resistors)
I/Os: Signal + Power/Gnd	64 + 29	256 + 70
Process	1.0u GaAs D-MESFET	1.5u GaAs HBT
Logic Form	Buffered FET logic (BFL)	I^2L (modified RTL)
Cell Speed/Power	120ps/1.6mW (register)	160ps/2mW (gate)
Yield Data	18 percent	Experienced 2 percent, projected 8 percent

Source: Aztek Associates

Product Trends

The development of several VSP devices by ISSCC participants is an indication of an emerging product area for chips oriented toward solving the unique problems incurred in high-definition video system designs. A similar evolution is occurring in voice-processing hardware. An estimated 50 other papers described DRAMs and SRAMs, microprocessors, and other DSP-related functions. These gave evidence of trends toward continuing increase in SRAM, DRAM, and DSP function densities and speeds with accompanying decreases in power per bit.

Application Trends

Enhancing human interface with systems is a major new thrust in semiconductor applications. The main focus of this year's ISSCC developments in chip architectures is toward improving the human-system interface. This was portrayed by the focus of many papers on voice and graphics communication and processing. HDTV is a major application addressed by many chip suppliers, followed by optical communications and massive main memories. Dataquest expects many product announcements in these applications areas in the near future.

DATAQUEST CONCLUSIONS

The IC world is rapidly evolving toward submicron processing of chips ranging above 1 million transistors in complexity (silicon CMOS), with GaAs now within a factor of 16 in complexity and 4 to 5 times faster in speed. The competing technologies are causing a proliferation of application-specific DSP designs. Dataquest expects DSP functions to play an increasingly important role in IC suppliers' product portfolios for at least the next two to three years. Realignments among IC competitors are expected as these developments accelerate the obsolescence of many existing products.

Gene Miles

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Research *Newsletter*

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32-BIT GaAs RISC uP DEBUTS AT 35th ISSCC

INTRODUCTION

The International Solid State Circuits Conference (ISSCC), held February 17 through 19, 1988, in San Francisco, celebrated its 35th year of reporting continuing progress in semiconductor technology. One hundred papers, coauthored by more than 600 engineers and scientists, and 10 informal discussion sessions enlightened a record audience. This newsletter summarizes the reported progress in GaAs technology and provides additional information on progress in silicon technology for comparison purposes.

PROGRESS IN GaAs TECHNOLOGY

The most significant GaAs development discussed at ISSCC was Texas Instruments' 32-bit GaAs RISC (reduced instruction set architecture) microprocessor. This session was attended by more than 1,000 persons. Other developments in compound semiconductor technology included Rockwell's 150-mops (millions of operations per second) GaAs ALU (arithmetic logic unit), Hughes' 25-GHz frequency dividers using 0.2u design rules and InP wafers, Fujitsu's HEMT data register, Matsushita's 125ps-resolution programmable delay timer, and a 26dB wideband D-MESFET amplifier. One of the evening sessions was devoted to the never-ending discussion of GaAs versus silicon for high-speed analog ICs.

TI Builds 32-Bit RISC Chip

A GaAs RISC-architecture 32-bit microprocessor chip, described by Texas Instruments (TI), represents the most complex logic IC reported to date by the compound IC industry. The chip contains 12,872 bipolar gates implemented in HI^2L (heterojunction integrated injection logic) circuitry, which is a form of RTL (resistor-transistor logic). The initial design, based on 2u-gate and 8u-metal-pitch rules, resulted in a chip size of 445 x 415 mils. TI has demonstrated the device at a 1-GHz clock rate and up to SDI radiation levels. The chip is functional at power supply levels from 1.5 to 4.0 volts; nominal operation is expected at 2.5 volts.

TI used SPICE and other CAD tools to develop the chip family. Some of the models were developed at the company's Bedford, England, design facility. Many of the CAD tools, such as the autorouter, were adapted directly from VHSIC CAD software.

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A redesigned version is to be complete in June 1988; it will use 1.5u gates and 2.5u-wide, 2.5u-spaced two-layer metal to achieve 160ns gate speeds on a 300 x 300 mil^2 die. Performance of 200 mips is expected, limited primarily because the critical CPU path consists of 30 gate levels. TI has achieved 250ps gate delays at 2mW/gate with the 2u process. Yield of 2 percent per lot of 100 chips was experienced. Projected yield for the 1.5u version is 8 percent, based on test array runs made to date.

The chip is intended to function as part of a microcomputer containing two cache memories, two MMUs, and a processor board interface. The system can be expanded with as many as six floating-point coprocessors. TI performed the work jointly with Control Data Corporation (CDC) under a DARPA contract, partially supported by TI and CDC funding. McDonnell Douglas is a competitor on the program.

Rockwell ALU Performs at 150 mops

Rockwell International Corporation presented results of its development of an 8-bit-slice ALU architecture. The IC contains 9,400 transistors and 3,010 diodes comprising BFL (buffered FET logic) gates. The chips are fabricated with 1u D-MESFET, non-self-aligned, ion-implanted technology. Die size is 4.9 x 3.9 mm^2 with 4u-pitch first-layer metal and 6u-pitch second-layer metal. At 9.2 watts P_D, the ALU performs add instructions in 6.6ns.

The chip includes a 31-word, 8-bit register file. A three-bus architecture was used to enhance logic efficiency. Hardwired algorithms include modified Booth multiplier, nonresidual divider, and variable bit-length operations. Single-step shifters (left and right 1, 2, 4, 8) were used instead of a barrel-shifter, for reduced complexity.

The present chip design is sensitive to V_{DD} supply variations; this parameter is presently set at -2.5 -0.1, +0.5 volts. Within this limit, yields have been very good at 18 percent for 150-mops devices and 22 percent for the low-power version. Table 1 summarizes the major characteristics of the Rockwell design and provides important data for comparative analysis of the Rockwell and TI/CDC chips.

Table 1

GaAs Microprocessor IC Comparison

Characteristic	Rockwell Design	TI/CDC Design
Function	8-bit ALU (1750A type)	32-bit RISC uP
Architecture	3-bus bit slice (expandable to 16 bits)	6-stage pipeline
Performance	150 mops	200 mips

(Continued)

Table 1 (Continued)

GaAs Microprocessor IC Comparison

Characteristic	Rockwell Design	TI/CDC Design
Operations	Add, subtr., mod. Booth multiply, divide, bit operations	4 address modes, 16 ALU and 5 control instructions, 10 memory instructions
Power (Watts)	4.2 (low), 9.2 (high)	Estimated 20 max.
Voltage(s)	V_{DD}=+2.5, V_{SS}=-2.0, V_{ref}=-0.1 volts	V_{CC}=+2.5±1.0 volts
Die size	193 x 154 mils 4.9 x 3.9 mm	300 x 300 mils 7.6 x 7.6 mm
Chip complexity	9,400 transistors, 3,000 diodes	12,872 gates (typical gate is 1 transistor and 5 resistors)
I/Os	64 (signal) 29 (power/ground)	256 (signal) 70 (power/ground)
Process	GaAs D-MESFET	GaAs HBT
Min. feature size	1.0u	1.5u
Metal width/spacing	2u/2u (1st layer) 3u/3u (2nd layer)	2.5u/2.5u (1st layer) 2.5u/2.5u (2nd layer)
Logic form	BFL	I^2L (modified RTL)
Cell speed (type)	120ps (register)	160ps (gate)
Cell power	1.6mW	2mW
Yield data	18 percent	Experienced 2 percent, projected 8 percent
Minimum system	Must add controller, RAM	Must add MMU, 1K cache ICs
Other	5-xstr/3-diode cells	Critical path--30 gates; Ti/Pt/Au Schottky metal

Source: Aztek Associates

Hughes Develops 0.2u HEMT, 25-GHz Dividers

Hughes Research Laboratories has developed a 0.2u modulation-doped AlInAs/GaInAs process, which enables it to demonstrate BFL and CEL frequency dividers at 25 GHz. Table 2 compares the two approaches.

Table 2

Hughes InP HEMT Frequency Dividers

Logic Type	Speed	Power
BFL (buffered FET logic)	25.2 GHz	450mW
CEL (capacitor enhanced logic)	25.4 GHz	63.8mW

Source: Dataquest
March 1988

The epitaxial process developed by Hughes includes the following layers, starting with the substrate and building to the top:

- InP substrate
- AlInAs buffer layer
- 80nm GaInAs channel layer
- 2nm undoped AlInAs spacer
- n^+ 1nm doped AlInAs donor layer
- 20nm undoped AlInAs Schottky layer
- n^+ GaAlAs contact layer

Fujitsu HEMT Register Uses 0.5u Geometries

Fujitsu Laboratories Ltd. has developed a 36-bit (4x9) register IC using high electron mobility transistor (HEMT) structures and 0.5u minimum geometries. The metal pitch is 4u, with 2u width and 2u spacing. The HEMT layers are grown by MBE, and e-beam lithography is used. Transistor cutoff frequency is 31 GHz. Unloaded gate delay is 19ps at room temperature; average gate delay is 43ps (ring oscillator) and 86ps for a fan-in = 3, fan-out = 3, 1mm interconnection load. The 6.1 x 6.2 mm^2, 1137-gate chip is ECL compatible. Power dissipation is more than 4 watts. This development is part of the Japan National Research and Development Program on Scientific Computing Systems.

Matsushita's Programmable Timer Has 125ps Resolution

Using non-self-aligned 1u GaAs MESFET processing, Matsushita Electronics Research Laboratory has demonstrated an ECL-compatible programmable timer with 125ps resolution and ±125ps linearity. The die includes a 7-bit digital-to-analog converter (DAC), comparators, flip-flop, and current switches. Power dissipation of the 3.3 x 3.65 mm^2 chip is 0.9 watts.

Wideband Amplifier Features 26dB Gain at 2.5 GHz

The University of California, Los Angeles, reported developing a high-performance amplifier, supported by TriQuint Semiconductor Corporation. This amplifier has 26dB gain, 6.5dB noise figure, 3.2-GHz bandwidth and 10-dBm saturation power. The 1mm^2 die dissipates 850mW.

PROGRESS IN SILICON TECHNOLOGY

Ninety-five percent of the papers at this conference were devoted to silicon technology. The major topics included:

- High-speed circuits, data recovery, microprocessors
- Analog devices and techniques, including A/D conversion
- Video signal processors
- CCD and sensors
- Telecom circuits
- ASICs, including gate arrays
- DRAMs, SRAMs, and nonvolatile memories

Although GaAs and InP devices dominated the high-speed results presented at ISSCC, significant progress was reported by Fujitsu, General Electric (GE), LSI Logic, and others. Fujitsu described a 4-GHz optical repeater chip set. LSI Logic presented a 30-mflops, 32-bit CMOS floating-point processor design. GE described its 40MHz, 32-bit CPU chip with instruction cache.

Hitachi, National Semiconductor, and TI each described BICMOS 256Kbit ECL SRAMs. The Hitachi and TI parts feature 8ns address access times; the National design has 12ns access time. Three of the papers featured 16Mb DRAMs. These three papers were presented by employees of Japanese companies—Hitachi, Mitsubishi, and Toshiba. Some of the RAM designs are oriented toward video and graphics signal processing applications.

A paper authored by Lattice Semiconductor engineers described a 9ns CMOS EEPLD (electrically eraseable programmable logic device). The architecture includes an industry-standard eight-input programmable AND array and a fixed OR array of eight product terms. The eight I/Os are also individually programmable.

Video signal sensor presentations included a paper by Toshiba devoted to a CCD image sensor for HDTV applications. The imager contains two million pixels in a 1,920 (horizontal) x 1,036 (vertical) configuration, on a 14 x 7.8mm die (adaptable to one-inch optical format). The charge readout frequency is 74.25 MHz, in the proposed HDTV format. Demonstrated sensitivity is 210nA/lux, several times that of conventional TV CCDs.

A novel solution to the difficult problem of integrating CMOS transistors onto a thermal printer head was described by Sony Corporation. The solution involves a line-type chip measuring 27 x 4mm. It contains 11,448 CMOS transistors and 216 heating-element dots (density 8 dots/mm), and it uses doped polysilicon as the heating element material.

Regarding IC device feature sizes, the environment will soon become a submicron world. While GaAs has set the pace, silicon suppliers are quick to take advantage of emerging production technology. This is, of course, essential for the production of leading-edge, high-density chips; this fact was underscored by many companies' presentations.

SUMMARY AND CONCLUSIONS

The 1988 ISSCC emphasized the continuation of intense competition in the IC industry, with advances reported across the entire range of chip functions. The mainstream is shifting rapidly to submicron geometries. A new variable to competition is evident with the arrival of practical GaAs LSI chips. The designers of the next round of personal computers and workstations have an unprecedented array of devices from which to choose, as does the entire range of electronics equipment houses.

GaAs LSI is here; the reproducibility of 8-bit ALUs and 32-bit microprocessors has been demonstrated. Suppliers of leading-edge-performance systems would do well to rethink their hardware and marketing strategies, based on what their competitors are now capable of offering to the world's markets.

Gene Miles

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Research *Bulletin*

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GaAs ICs GROW BY 45 PERCENT IN 1987

The worldwide market for GaAs semiconductors grew by 8.6 percent in 1987, up from 1986 shipments of an estimated $2.04 billion to more than $2.20 billion. The predominant devices were discrete optoelectronics; integrated circuits constitute less than 10 percent of these figures, excluding nonrecurring engineering (NRE) costs. The only segment showing a decline is microwave/millimeter wave discretes, which are increasingly impacted by MMICs and, to a lesser extent, by digital ICs (digICs).

During 1987, GaAs IC shipments grew substantially (see Table 1), at a combined rate estimated at 45 percent. The largest segment—analog/linear—grew from $107 million to approximately $138 million, a 29 percent increase. NRE costs are a decreasing percentage of the total, now accounting for approximately 40 percent of analog/linear GaAs IC shipments.

ANADIGICs, Avantek, MSC, and TriQuint were among those companies bringing additional capabilities, including fab capacity, on-line during 1987, in preparation for continuing rapid market growth. M/A-COM experienced significant downsizing and is believed to be now operating at less than 20 percent of its previous full capacity.

The GaAs digIC segment experienced the highest growth rate in device shipments, as the effects of near defect-free (NDF) wafers were reflected in significant yield improvements for LSI chips. DigIC device shipments grew by more than 66 percent, from $21 million in 1986 to an estimated $35 million in 1987. NRE costs for this segment are almost equal to IC shipments. Total shipments for this segment grew by $20 million, to approximately $71 million in 1987.

The star performer in 1987 in the digIC arena was Gigabit Logic, which became profitable in the fourth quarter. Gigabit increased its yields on MSI-density ASICs to more than 50 percent and became the sole source for CRAY-3 GaAs computer chips.

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The acceptance of GaAs ICs in the general marketplace is accelerating. Dataquest expects continued strong growth of this technology, particularly in the digIC segment in 1988, as minisupercomputers (e.g., the system currently under development at Gould, Inc.) and other equipment applications increasingly adopt GaAs ICs into their designs.

Gene Miles

Table 1

Worldwide GaAs Semiconductor Shipments*
(Millions of Dollars)

Category	1984	1985	1986	1987	Percent Change 1986-1987
Total GaAs Semiconductors	$1,471	$1,580	$2,043	$2,218	8.6%
Optoelectronics**	$1,290	$1,296	$1,657	$1,787	7.8%
Discrete Opto	1,262	1,276	1,629	1,754	7.7%
OEICs	8	20	28	33	17.9%
Analog/Linear ICs	$ 39	$ 80	$ 107	$ 138	29.0%
Devices	19	40	56	85	51.8%
NRE Costs	20	40	51	53	4.0%
DigICs	$ 11	$ 26	$ 51	$ 71	39.2%
Devices	2	6	21	35	66.3%
NRE Costs	10	20	30	36	20.2%
uw/mmw Discretes	$ 131	$ 178	$ 228	$ 222	(2.6%)
Small-Signal	73	111	141	136	(4.3%)
Power	48	61	73	72	(1.4%)
Other	10	10	14	15	7.1%

Note: Columns may not add to subtotals and totals shown because of rounding.

OEIC = Optoelectronic integrated circuit
uw = Microwave
mmw = Millimeter wave

*Dataquest's merchant shipment figures include intracompany transfers for merchant suppliers at estimated market value. No full-captive supplier data are included.
**Optoelectronics data for 1984, 1985, and 1986 do not include silicon devices. Data for 1987 include silicon emitters and detectors.

Source: Dataquest
March 1988

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Research *Bulletin*

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GaAs ICs ENTER THE MAINSTREAM OF SUPERCOMPUTER PRODUCTION

Cray Research Inc., the world's leading supercomputer manufacturer, has ordered an additional $6.8 million of GaAs logic and memory ICs from Gigabit Logic (GBL) of Newbury Park, California, to be used in the final phase of CRAY-3 development. Dataquest believes that this order, coupled with other business from a base of more than 200 customers, will allow GBL to maintain its position throughout 1988 as the world's largest merchant supplier of commercial GaAs computer ICs.

The GaAs components to be delivered to Cray in 1988 represent a 30 percent increase in the value over the 1987 order, and a much greater increment in run rate, due to yield improvements that resulted in lower average selling prices. The contract requires shipment of more than 200 unique standard cell IC types, double the number already delivered on the CRAY-3 program. As previously reported by Dataquest, each CRAY-3 supercomputer uses approximately 48,000 GaAs gate-array chips and 4,000 GaAs memory chips in its CPU, providing 64-bit floating-point add cycle time of 2ns.

GBL's manufacturing organization has accomplished continual yield improvements over the last two years. Average yields for the GaAs ICs now exceed 50 percent, making the available cost-performance ratio very effective for high-speed logic designs. This progress, coupled with a rapidly developing market, has allowed GBL to increase its overall business by approximately 100 percent per year since 1985. Dataquest expects that other computer houses will announce GaAs-based hardware as 1988 progresses and that at least three additional U.S. suppliers of GaAs chips will offer sub-200ps standard cell logic ICs to the merchant marketplace before the fourth quarter.

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RESEARCH NEWSLETTER

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1987-1

SIGNIFICANT PRODUCT ANNOUNCEMENTS--GaAs ICs

Product development activity is accelerating in the GaAs industry. Important announcements have been made by several GaAs houses in recent months; this newsletter examines the most significant recent product introductions.

BIT SLICES--THE RACE IS ON

Vitesse introduced the first commercially available LSI GaAs digital IC set, an ECL 100K compatible 4-bit slice family, on September 10, 1986, at Midcon. The product family consists of the VE29G01 4-Bit Microprocessor Slice, the VE29G02 Look-Ahead Carry Generator, and the VE29G10 Microcontroller. Engineering samples of the VE29G02 are available now, and engineering samples of the VE29G01 and VE29G10 are expected by February 1987. Earlier, McDonnell-Douglas released details on a 2901-type GaAs bit slice; however, McDonnell-Douglas is not a merchant market supplier of the device. Vitesse's product family is supported by a 3.5ns cycle 1024x4 registered static RAM, the VE12G474.

The VE29GXX family is expected to permit customers to achieve a factor of 3x speed improvement over a CPU implementation using the AMD2901C, a bipolar device. Interestingly, Vitesse has employed LCC packaging to preserve the device speed advantage at the system level as much as practical. Very aggressive forward pricing is available from Vitesse, allowing the user to project systems costs through 1990. So far, more than 1,000 customers have expressed interest in this product set. Dataquest expects a wide range of applications to make use of this technology, including minisupercomputers, "smart" high-speed instrumentation, DSPs and other military functions, arithmetic/logic accelerators, and high-speed graphics equipment.

STATIC RAMs

For several months, 1K SRAMs have been offered for beta site evaluation by GigaBit, Ford Microelectronics, and others. GigaBit just received a $500 thousand, two-year U.S.A.F. contract to perform Class 8 screening, reliability evaluation, and radiation hardness evaluation on its 1K SRAM.

Vitesse's VE12G474 is the first commercially available 4K GaAs SRAM. Other announcements are expected this month, including devices from Honeywell, Rockwell, and GAIN. Several Japanese companies have been working on SRAMs for at least three years; these products appear targeted first for internal needs before being taken to merchant market. GaAs SRAMs feature cycle times in the 0.6 to 3.5ns range at 1K and 4K densities, compared to the 5 to 7ns range for the fastest commercially available silicon ECL RAMs (see Table 1).

CUSTOM DESIGN

GAIN Electronics Corporation has announced a custom design service based initially on E/D MESFET technology and followed by SDHT (selectively doped heterostructure transistor), otherwise known as HEMT (high electron mobility transistor), technology. SDHT, invented by Dr. Raymond Dingle (GAIN's president), offers the highest-performance commercially available GaAs circuitry. Typical transistor cutoff frequency is 80 GHz, versus 50 and 15 GHz, respectively, for GaAs FETs and Si bipolar transistors. GAIN will also offer a full line of device and design capabilities, and an epitaxial GaAs/ALGaAs wafer.

GigaBit Logic (GBL) has announced a standard cell library of D-MESFET logic blocks featuring 1 geometries and 100 to 200ps gate delays at 1 to 2mW per gate. The initial family includes 13 macrocells, with 17 additional macros including a 4-bit adder planned for 1987. GigaBit charges $10,000 for its cell library diskette and user manual, refundable against the cost of the first development program.

MMICs

Dataquest believes that the most significant announcement in GaAs MMIC (microwave monolithic IC) technology in recent months is the introduction of a GaAs linear/analog macrocell library by Pacific Monolithics. The library consists of more than 25 macrocells fabricated and tested prior to July 1986, with another 20 macros in development. The cells cover the 0.5 to 18 GHz frequency range and include amplifiers, switches, combiners, splitters, attenuators, and VCOs (see Table 2).

Pacific Monolithics' macrocell library offers its users two major advantages. First, the design lead time, which ranges from 1 to 2-1/2 years for a custom MMIC, can be reduced by a factor of 2 to 5 using standard cells. Second, development cost is dramatically reduced, by a factor of 3 to 8 for a typical MMIC design. Dataquest believes that Pacific Monolithic's library availability at this device performance level may radically alter the approach to electronic warfare systems design. Furthermore, the approach may have a major impact on the entire present microwave industry structure, which includes hybrid houses, silicon device suppliers, third-party designers and other relatively expensive, time-consuming factors.

GATE ARRAYS

Honeywell, TriQuint, Texas Instruments, and others are developing gate arrays using GaAs technology. Honeywell recently withdrew its 2K gate array and is reportedly developing a standard cell alternative. Suppliers are polarizing into two camps regarding GaAs ASICs. One group is pursuing gate arrays of 400 to more than 5,000 gate density. The second group is proceeding on the basis that a standard cell solution will offer the best performance/cost trade-off to the user. Dataquest believes that sufficient applications exist to support both approaches, and expects additional announcements in this area in the coming months.

DATAQUEST CONCLUSIONS

The pace of GaAs product activity is quickening, spurred by major capital investments in 1984 and 1985 and by a soft electronics market in 1985 and 1986. Users have a growing variety of GaAs design options available, supported by an expanding infrastructure of suppliers. Dataquest believes that performance-oriented applications will gravitate at an accelerating rate toward the use of GaAs in critical hardware paths. Significant commercial systems house announcements based on the use of GaAs components are expected, starting in 1987.

Gene Miles

Table 1

GaAs RAM PRODUCTS

Part Number (Company)	Organization	Taa Maximum (ns)	Pd Maximum (mW)	100-Piece Price	Intro. Date	Package	Comments
40G01 (Ford)	256 x 4	3.0	1,400*	TBA	TBA	28-pin LCC	E/D MESFET, I/O latches
12G014 (GBL)	256 x 4	3.0	2,000	N/A	1Q87	40-pin LCC	D MESFET, I/O latches
12G474 (Vitesse)	1K x 4	3.5	N/A	$595	9/86	LCC, FP	E/D MESFET, I/O latches
Rockwell	1K	0.6	N/A	N/A	TBA	N/A	E/D HEMT
Honeywell	256 x 4	3.0	150	N/A	TBA	N/A	E/D MESFET, 110 x 110 sq. mil die
Texas Instruments	1K	6.0	500	N/A	N/A	N/A	GaAs on silicon substrate

*Typical Value
TBA = To Be Announced
N/A = Not Available

Source: AZTEK Associates

Table 2

PACIFIC MONOLITHICS CELL LIBRARY

Existing

Function	Frequency (GHz)
Amplifier Gain Blocks:	
10dB	2 to 6
15dB	0.1 to 2
15dB	1 to 3
AGC amp, 10dB	2 to 6
Oscillators (VCOs, DROs):	
Neg. resistance	1 to 3
Neg. resistance	3 to 6
Double-Balanced Mixers:	
Diode Mixer	1 to 3
Diode Mixer	3 to 6
Diode Mixer	6 to 8
Attenuator	DC-12
FET SPDT switch	DC-12
Low-Noise Amplifiers	
FET LNA, 16dB	3.7 to 4.2
FET LNA, 13bB	4.4 to 5.0
FET LNA, 16dB	1.2 to 1.6
Power Amplifier, 12dB	3 to 7
Biphase Modulator	5 to 10
QPSK Modulator	5 to 10
Power Splitter/Combiner	5 to 10
90° Hybrid	3.5 to 4.5
Active Isolator	0.1 to 10
Balun	1 to 3
Balun	2 to 6
Balun	5 to 8

In Development

Function	Frequency (GHz)
Amplifiers:	
SS amp, 10dB	6 to 18
SS amp, 10dB	6 to 12
LNA, 12dB	11 to 14
Power amp, 10dB	6 to 18
Power amp, 10dB	6 to 12
AGC amp, 10dB	6 to 18
Mixers:	
Balanced-Diode	6 to 10
Balanced-Diode	10 to 18
Dual-Gate	2 to 6
High-Dynamic Range	6 to 10
Oscillators:	
Neg. resistance	6 to 12
Neg. resistance	12-18
Subsystems:	
Freq. Downconv.	10 to 14
Freq. Downconv.	6 to 17
Freq. Synthesizers	DC-5
Digital ICs:	
Dividers	6
Flip-Flops/Latches	1.5
Other Building Blocks:	
Balun	6 to 12
Balun	6 to 18
Attenuator	6 to 18
Limiting Amplifiers	2 to 6
Vector modulator	5 to 10
Subsystems:	
Freq. Downconv.	1 to 3
Freq. Downconv.	3 to 6
Freq. Downconv.	5 to 8
Image-Rej. Dnconv.	3.7 to 4.2

Source: Pacific Monolithics

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RESEARCH NEWSLETTER

GATA Code: Newsletters
1987-1

SIGNIFICANT PRODUCT ANNOUNCEMENTS--GaAs ICs

Product development activity is accelerating in the GaAs industry. Important announcements have been made by several GaAs houses in recent months; this newsletter examines the most significant recent product introductions.

BIT SLICES--THE RACE IS ON

Vitesse introduced the first commercially available LSI GaAs digital IC set, an ECL 100K compatible 4-bit slice family, on September 10, 1986, at Midcon. The product family consists of the VE29G01 4-Bit Microprocessor Slice, the VE29G02 Look-Ahead Carry Generator, and the VE29G10 Microcontroller. Engineering samples of the VE29G02 are available now, and engineering samples of the VE29G01 and VE29G10 are expected by February 1987. Earlier, McDonnell-Douglas released details on a 2901-type GaAs bit slice; however, McDonnell-Douglas is not a merchant market supplier of the device. Vitesse's product family is supported by a 3.5ns cycle 1024x4 registered static RAM, the VE12G474.

The VE29GXX family is expected to permit customers to achieve a factor of 3x speed improvement over a CPU implementation using the AMD2901C, a bipolar device. Interestingly, Vitesse has employed LCC packaging to preserve the device speed advantage at the system level as much as practical. Very aggressive forward pricing is available from Vitesse, allowing the user to project systems costs through 1990. So far, more than 1,000 customers have expressed interest in this product set. Dataquest expects a wide range of applications to make use of this technology, including minisupercomputers, "smart" high-speed instrumentation, DSPs and other military functions, arithmetic/logic accelerators, and high-speed graphics equipment.

STATIC RAMs

For several months, 1K SRAMs have been offered for beta site evaluation by GigaBit, Ford Microelectronics, and others. GigaBit just received a $500 thousand, two-year U.S.A.F. contract to perform Class 8 screening, reliability evaluation, and radiation hardness evaluation on its 1K SRAM.

Vitesse's VE12G474 is the first commercially available 4K GaAs SRAM. Other announcements are expected this month, including devices from Honeywell, Rockwell, and GAIN. Several Japanese companies have been working on SRAMs for at least three years; these products appear targeted first for internal needs before being taken to merchant market. GaAs SRAMs feature cycle times in the 0.6 to 3.5ns range at 1K and 4K densities, compared to the 5 to 7ns range for the fastest commercially available silicon ECL RAMs (see Table 1).

CUSTOM DESIGN

GAIN Electronics Corporation has announced a custom design service based initially on E/D MESFET technology and followed by SDHT (selectively doped heterostructure transistor), otherwise known as HEMT (high electron mobility transistor), technology. SDHT, invented by Dr. Raymond Dingle (GAIN's president), offers the highest-performance commercially available GaAs circuitry. Typical transistor cutoff frequency is 80 GHz, versus 50 and 15 GHz, respectively, for GaAs FETs and Si bipolar transistors. GAIN will also offer a full line of device and design capabilities, and an epitaxial GaAs/ALGaAs wafer.

GigaBit Logic (GBL) has announced a standard cell library of D-MESFET logic blocks featuring 1 geometries and 100 to 200ps gate delays at 1 to 2mW per gate. The initial family includes 13 macrocells, with 17 additional macros including a 4-bit adder planned for 1987. GigaBit charges $10,000 for its cell library diskette and user manual, refundable against the cost of the first development program.

MMICs

Dataquest believes that the most significant announcement in GaAs MMIC (microwave monolithic IC) technology in recent months is the introduction of a GaAs linear/analog macrocell library by Pacific Monolithics. The library consists of more than 25 macrocells fabricated and tested prior to July 1986, with another 20 macros in development. The cells cover the 0.5 to 18 GHz frequency range and include amplifiers, switches, combiners, splitters, attenuators, and VCOs (see Table 2).

Pacific Monolithics' macrocell library offers its users two major advantages. First, the design lead time, which ranges from 1 to 2-1/2 years for a custom MMIC, can be reduced by a factor of 2 to 5 using standard cells. Second, development cost is dramatically reduced, by a factor of 3 to 8 for a typical MMIC design. Dataquest believes that Pacific Monolithic's library availability at this device performance level may radically alter the approach to electronic warfare systems design. Furthermore, the approach may have a major impact on the entire present microwave industry structure, which includes hybrid houses, silicon device suppliers, third-party designers and other relatively expensive, time-consuming factors.

GATE ARRAYS

Honeywell, TriQuint, Texas Instruments, and others are developing gate arrays using GaAs technology. Honeywell recently withdrew its 2K gate array and is reportedly developing a standard cell alternative. Suppliers are polarizing into two camps regarding GaAs ASICs. One group is pursuing gate arrays of 400 to more than 5,000 gate density. The second group is proceeding on the basis that a standard cell solution will offer the best performance/cost trade-off to the user. Dataquest believes that sufficient applications exist to support both approaches, and expects additional announcements in this area in the coming months.

DATAQUEST CONCLUSIONS

The pace of GaAs product activity is quickening, spurred by major capital investments in 1984 and 1985 and by a soft electronics market in 1985 and 1986. Users have a growing variety of GaAs design options available, supported by an expanding infrastructure of suppliers. Dataquest believes that performance-oriented applications will gravitate at an accelerating rate toward the use of GaAs in critical hardware paths. Significant commercial systems house announcements based on the use of GaAs components are expected, starting in 1987.

Gene Miles

Table 1

GaAs RAM PRODUCTS

Part Number (Company)	Organi- zation	Taa Maximum (ns)	Pd Maximum (mW)	100- Piece Price	Intro. Date	Package	Comments
40G01 (Ford)	256 x 4	3.0	1,400*	TBA	TBA	28-pin LCC	E/D MESFET, I/O latches
12G014 (GBL)	256 x 4	3.0	2,000	N/A	1Q87	40-pin LCC	D MESFET, I/O latches
12G474 (Vitesse)	1K x 4	3.5	N/A	$595	9/86	LCC, FP	E/D MESFET, I/O latches
Rockwell	1K	0.6	N/A	N/A	TBA	N/A	E/D HEMT
Honeywell	256 x 4	3.0	150	N/A	TBA	N/A	E/D MESFET, 110 x 110 sq. mil die
Texas Instruments	1K	6.0	500	N/A	N/A	N/A	GaAs on silicon substrate

*Typical Value
TBA = To Be Announced
N/A = Not Available

Source: AZTEK Associates

Table 2

PACIFIC MONOLITHICS CELL LIBRARY

Existing Function	Frequency (GHz)	In Development Function	Frequency (GHz)
Amplifier Gain Blocks:		Amplifiers:	
10dB	2 to 6	SS amp, 10dB	6 to 18
15dB	0.1 to 2	SS amp, 10dB	6 to 12
15dB	1 to 3	LNA, 12dB	11 to 14
AGC amp, 10dB	2 to 6	Power amp, 10dB	6 to 18
		Power amp, 10dB	6 to 12
Oscillators (VCOs, DROs):		AGC amp, 10dB	6 to 18
Neg. resistance	1 to 3		
Neg. resistance	3 to 6	Mixers:	
		Balanced-Diode	6 to 10
Double-Balanced Mixers:		Balanced-Diode	10 to 18
Diode Mixer	1 to 3	Dual-Gate	2 to 6
Diode Mixer	3 to 6	High-Dynamic Range	6 to 10
Diode Mixer	6 to 8		
		Oscillators:	
Attenuator	DC-12	Neg. resistance	6 to 12
		Neg. resistance	12-18
FET SPDT switch	DC-12		
		Subsystems:	
Low-Noise Amplifiers		Freq. Downconv.	10 to 14
FET LNA, 16dB	3.7 to 4.2	Freq. Downconv.	6 to 17
FET LNA, 13bB	4.4 to 5.0	Freq. Synthesizers	DC-5
FET LNA, 16dB	1.2 to 1.6		
		Digital ICs:	
Power Amplifier, 12dB	3 to 7	Dividers	6
		Flip-Flops/Latches	1.5
Biphase Modulator	5 to 10		
		Other Building Blocks:	
QPSK Modulator	5 to 10	Balun	6 to 12
		Balun	6 to 18
Power Splitter/Combiner	5 to 10	Attenuator	6 to 18
90^{o} Hybrid	3.5 to 4.5	Limiting Amplifiers	2 to 6
Active Isolator	0.1 to 10	Vector modulator	5 to 10
Balun	1 to 3	Subsystems:	
		Freq. Downconv.	1 to 3
Balun	2 to 6	Freq. Downconv.	3 to 6
		Freq. Downconv.	5 to 8
Balun	5 to 8	Image-Rej. Dnconv.	3.7 to 4.2

Source: Pacific Monolithics

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RESEARCH NEWSLETTER

GATA Code: Newsletters
1987-2

JAPAN'S EXPANDING SPACE PROGRAMS DEMAND HI-REL ICs

SUMMARY

Dataquest expects Japan to increase emphasis on high-reliability (hi-rel) GaAs and Si ICs in support of its expanding space programs. While Japan claims to have a zero military budget, it has massed tremendous capabilities in aerospace hardware in recent years, and has aggressive plans for the next decade. This bulletin details some of Japan's capabilities and plans in this area.

Japan's space activities include the following programs, which require mil range and, in many cases, radiation-hardened (rad-hard) ICs and discrete semiconductors:

- Three new expandable boosters: H-I, M-38-2, and H-II
- More than ten advanced satellites
- Space platforms
- A space shuttle
- Participation in a U.S. shuttle mission
- Participation in the U.S./international space station
- Moon and Venus probes

Japan's space activities represent an increasing threat to Western leadership in satellites, platforms, and shuttles. Dataquest believes that there will be increased international interest in Japan's satellite launch capability as a result of 1986's shuttle, Ariane, and other launch failures.

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DISCUSSION AND ANALYSIS

Japan has two space agencies: NASDA (National Space Development Agency) and ISAS (Institute of Space and Astronautical Science). These agencies have been responsible for launching about one satellite per year since 1970. MITI (Ministry of International Trade and Industry) serves to create competitive pressures by funding specific payloads.

Japan's space agencies are developing more than 10 satellites and space probes, many designed for geosynchronous orbit (approximately 22,000 miles altitude). These satellites require state-of-the-art GaAs and Si ICs to accomplish the intended functions within launch payload constraints. In addition, rad-hard requirements are expected to impact the IC designs.

Thirteen Japanese companies are studying the MITI/ISAS platform concept for launch by the U.S. shuttle and Japan's H-II booster (developed by Mitsubishi). The H-II booster will support manned launches by 1995. A summary of Japan's spacecraft including launch dates, type of payload and other pertinent data is given in Table 1. These include four communications satellites and two meteorological satellites designed for geosynchronous orbit.

DATAQUEST CONCLUSIONS

Japan is developing a demand for low volumes of domestically produced hi-rel, rad-hard ICs. To achieve better economies of scale, the next logical step is to take these ICs to the international marketplace. Western suppliers of mil-range ICs may experience increased market pressure as a result of Japan's space efforts.

Japan's investment in its space efforts is resulting in far greater capacities in hi-rel semiconductors, satellite systems, and launch hardware than required to support the programs listed in Table 1. In view of recent Western launch failures, we believe that Japan will likely experience increasing difficulty in attempting to keep a low profile regarding its space programs.

Gene Miles

Table 1

JAPANESE SPACECRAFT

Launch Date	Type	Name	Company	Payload (Lbs.)	Orbit Height	Comments
8/1/86	EGP	Experimental Geodetic Payload	Kawasaki	1,500	900 miles	Laser target, first H-I payload
Mid-1987	ETS-5	Engineering Test Satellite #5	Mitsubishi	N/A	Geosync.	Mobile Satcom with ships, planes
1/87	MOS-1	Marine Observation Satellite	NEC	1,650	545 miles	Carrying CCDs and other multispectral detectors
Early 1988	CS-3A	Communications Satellite #3A	Mitsubishi	N/A	Geosync.	Third-generation, 6,000 voice channels plus K- and C-band transponders
Mid-1988	CS-3B	Communications Satellite #3B	Mitsubishi	N/A	Geosync.	Sister to CS-3A
Mid-1989	GMS-4	Geosync. Meteorological Sat.	NEC	N/A	Geosync.	Weather spacecraft; H-I launch vehicle
Mid-1989	GMS-5	Geosync. Meteorological Sat.	NEC	N/A	Geosync.	$185 million development cost; 3-axis stabilized; H-I launch vehicle
Mid-1990	BS-3A	Broadcast Satellite	NEC	N/A	Geosync.	Color TV--3 channels
Mid-1991	BS-3B	Broadcast Satellite	NEC	N/A	Geosync.	Sister to BS-3A
N/A	ERS-1	Earth Resources Satellite #1	NEC/Mitsubishi	3,000	N/A	Will carry synthetic aperture radar, visible and IR sensors
1/92	ETS-6	Engineering Test Satellite #6	Mitsubishi	N/A	N/A	First H-II payload
1994	N/A	Moon Probe	N/A	N/A	Inapplic.	H-II payload; seismic detection
Mid-1990s		Venus Probe	N/A	N/A	Inapplic.	H-II payload; magnetosphere probe

Geosync. = Geosynchronous orbit (approximately 22,700 miles above Earth's surface)
N/A = Not available at press time
Inapplic. = Inapplicable

Source: AZTEK Associates

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Research Newsletter

GATA Code: Newsletters
1987-03

GaAs TECHNOLOGY UPDATE

SUMMARY

The development activity in GaAs ICs in 1986 resulted in significant breakthroughs in materials, design techniques, and new products. There were more start-ups to aid the overall market growth, which exceeded 50 percent. The largest commercial contract for digital ICs (digICs) announced to date was awarded to GigaBit Logic by Cray Research, Inc. The year was not all rosy, however, as two participants were involved in staff reductions and a third withdrew from commercial activity.

Major product announcements expected in SRAMs and other areas are still to come. Some industry observers, Dataquest included, factored their forecasts to account for the cautious approach of "wait and see" taken by some of the major users and potential users, particularly in the digIC arena.

Papers to be presented at the International Solid States Circuits Conference (ISSCC) reflect a major emphasis on moving GaAs technology from the laboratory to the marketplace. For example, a paper by Mitsubishi describes a 16K SRAM with an access time of 15ns; this comes 2-1/2 years after an NTT paper that described a 4ns 16K GaAs SRAM.

START-UPS

Notable start-up activity occurred in 1986, including new companies in III-IV materials. In the United States, Kopin Corporation performed significant R&D in GaAs-on-Si technology. In France, a new firm called PicoGiga, founded by two individuals from Thomson-CSF, moved into the GaAs wafer arena.

Ford Microelectronics demonstrated several GaAs products at the GaAs IC Symposium in October and at GOMAC in November. These included amplifiers, coders, decoders, and a multiplier implemented on a gate array chip. Gain Electronics, TriQuint, and other GaAs start-ups also had hospitality suites and booths at one or both conferences.

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In addition to the companies previously reported by Dataquest, there are at least five start-up groups in GaAs technology, involved in initial planning that had not formally announced their intentions as of January 8, 1987.

CONTRACTS

A major contract, in excess of $3 million, was placed with GigaBit Logic (Newbury Park, California) by Cray Research, Inc., for logic and memory devices procured over a one-year period. This contract positions GigaBit to continue as Cray's principal outside GaAs IC supplier for the Cray-III Project. GigaBit claims to have achieved yields approaching 40 percent on GaAs VLSI ICs with 30,000 components per device in support of this project.

The U.S. Department of Defense reportedly has awarded at least 12 design contracts of up to $1 million each to prime contractors for the study phase of the MIMIC initiative. The teams include:

- Under Navy direction (prime contractor underlined):
  - Bendix, Pacific Monolithics, TriQuint
  - Ford, Singer, Pacific Monolithics, M/A-COM, TriQuint
  - Raytheon/TI (joint venture), General Dynamics, Magnavox, Norden, Teledyne, others
  - Sanders, others
- Under Air Force direction:
  - Harris, General Electric, TriQuint, others
  - Hughes, AT&T, M/A-COM
  - Unisys, Alpha Industries, M/A-COM, TriQuint, Varian
  - Westinghouse, Avantek, Cominco, Essof, Rockwell, TriQuint
- Under Army direction:
  - Eaton, M/A-COM
  - ITT, Pacific Monolithics, Watkins-Johnson
  - Martin-Marietta, Alpha Industries, Harris, TI, others
  - TRW, General Dynamics, Honeywell

Also, Hittite, Ball Aerospace, E-Systems, and Loral may receive contracts ranging to $500,000. A smaller number of contractors will be chosen for awards expected in fiscal year 1988, following the study phase. Dataquest believes that the MIMIC initiative may exceed $500 million over the next five years.

PRODUCT ANNOUNCEMENTS

Tables 1 and 2 summarize some of the significant products recently introduced in GaAs digital (digIC) and analog, including microwave ICs. The digital circuits of Table 1, together with gate arrays offered by several GaAs houses and SRAMs now in development, comprise a viable product set for use in the general-purpose logic design of very high-speed digital hardware. These circuits will lead to significant performance improvements in end equipment, such as minisupercomputers, high-speed VLSI testers, radar data processors and communications buffers.

Table 2 reflects impressive gains in cost reduction of amplifiers and associated analog circuitry. For example, Anadigics is now offering an operational amplifier with 350 MHz gain bandwidth at a 1,000-piece price of less than $85. TriQuint, Pacific Monolithics, and others also have made significant contributions to this technology, as shown in Table 2.

HONEYWELL DE-EMPHASIZES GaAs

Honeywell is dropping commercial GaAs ICs and consolidating its GaAs research and government work at the Physical Sciences Center (Bloomington, Minnesota). The Richardson, Texas, production facility will be converted to support silicon solid state centers after existing GaAs gate array and custom IC contracts are completed. Dataquest believes that these actions are a direct result of Honeywell's sale of 57.5 percent of its computer business and the associated de-emphasis of data processing, and expects additional cost-cutting measures in Honeywell's merchant silicon IC activities.

APPLICATIONS

The acceptance of GaAs by designers is rapidly increasing. Applications such as optical disk drives produced by Laser Magnetic Storage International (joint effort by CDC and Philips) and ITT's terabit optoelectronic program are creating new demands for GaAs ICs and discretes, including integrated optoelectronic devices. The popular "laser gun" toys introduced for the 1986 gift-giving season each contain an IR LED in the transmitter (gun) and a photodetector in the target. Sales of this type of toy may exceed 2 percent of the $12 billion toy market by late 1987.

FORECAST

Table 3 gives Dataquest's current forecast of the GaAs semiconductor worldwide consumption. The 1986 results were slightly lower than previously forecast, primarily due to difficulties experienced by several digital IC suppliers. Dataquest believes that the materials breakthroughs realized over the last several months will offset the softness of 1986, and that the long term outlook of the previous forecast is still valid. The MIMIC initiative will have a positive impact on analog/microwave consumption starting in 1988 or 1989 and may significantly impact the 1990 and 1991 forecast shown here.

NEW TECHNOLOGY

Table 4 summarizes the presently planned presentations at the ISSCC, to be held in New York City in February 1987. Four of the papers will cover digital device developments by Hitachi, Toshiba and Mitsubishi of Japan, and LEP of France. The highest density device is the 16K SRAM by Mitsubishi; however, the 4K SRAM presented by Hitachi has significantly higher performance with t_{aa} of 1ns, ECL interface and 1.6W power dissipation. LEP has demonstrated reduction of variations in SRAM access time through the use of word line clamping and other circuit techniques. Toshiba's 6K gate array uses SCFL to achieve 284ps tpd per gate at pd of 1mW per gate and attains noise margins of 400mV.

Four papers describe advances in analog and microwave ICs. Both Anadigics and Hewlett-Packard present results of breakthroughs in sample and hold design. Hughes and LEP (France) report advances in video signal processing at frequencies to 300 and 800 MHz respectively.

CONCLUSIONS

GaAs technology remains one of the bright spots in the semiconductor industry, with anticipated growth rates for digital and analog ICs far above the growth rates of most silicon IC product lines. This is characteristic of the relative youth of this emerging industry. The GaAs and other III-V compound IC business areas will offer substantial opportunities to astute participants for at least the decade to come.

Gene Miles

Table 1

GaAs DigIC PRODUCTS

Company	Part. No.	Description	100-Piece Price ($)	Comments
Anadigics	ADV3040	Divide-by-4 prescaler	435.00	3 GHz max data rate
GigaBit	10G022	Octal register	79.50	1.5 GHz max clock rate
	10G061	4-bit synchronous binary counter	99.50	1.5 GHz max clock rate
	10G045	9-bit parity generator	46.00	800ps t_{pd}
Harris Microwave	HMD11188-2	Clock fanout buffer	TBA	
	TDMX1500	8:1 multiplexer; 1.5 Gbit/s max data rate	400.00	
	TDDX1500	1:8 demultiplexer; 1.5 Gbit/s max data rate	400.00	
Vitesse	VE29G01	4-bit microprocessor slice; 72 MHz max clock frequency	435.00	29xx family architecture
	VE29G02	Lookahead carry generator; 200 MHz max clock frequency	225.00	29xx family architecture
	VE29G10A	Microcontroller; 100 MHz max clock frequency	475.00	29xx family architecture

Source: Dataquest
January 1987

Table 2

GaAs ANALOG PRODUCTS*

Company	Part. No.	Description	100-Piece Price ($)	Comments
Anadigics	AOP3510	Op amp; 350 MHz gain	32.75**	
Harris Microwave	HMR10502	Monolithic rf amp; 10dB gain from 500 MHz to 5 GHz	29.00**	Needs external bypass capacitors
	MHR 10503	Same as 10502 but has on-chip source-bypass capacitors	39.00**	
	HMM-11810-0	Amplifier; 5dB gain from 6 to 18 GHz	175.00	
Microwave Semiconductor	LDCM1500	Diode-current modulator	100.00**	3 GHz max data rate
	TIA1500	Transimpedance amp	150.00	2 GHz max input rate
	TIRC1500	Transimpedance receiver	250.00	2 GHz max input rate
Pacific Monolithics	PM-AM0607	Amplifier; 10dB gain from 2 to 6 GHz	205.00	
TriQuint	TQ9111	Amplifier; 7dB gain from 1 to 18 GHz	144.00	
	TQ9141	Two-way power splitter 1 to 10 GHz frequency	155.00	
	TQ9151	SPDT switch; 1 to 10 GHz	143.00	
	TQ9161	Variable attenuator; 1 to 10 GHz	155.00	

*Analog includes a subset of high-frequency ICs called "MIMICs."
**1,000-piece pricing

Source: Dataquest
January 1987

Table 3

WORLDWIDE GaAs MERCHANT CONSUMPTION FORECAST BY TECHNOLOGY
(Millions of Dollars)

Category	1984	1985	1986	1987	1988	1989	1990	1991	CAGR 1984-1991
Analog ICs	46	80	117	173	237	331	448	551	42.6%
Digital ICs	11	26	51	99	187	337	506	657	79.4%
Discrete Opto	1,152	1,089	1,361	1,602	1,811	1,866	2,136	2,367	10.8%
Integrated Opto	8	20	28	43	67	104	162	267	65.1%
Microwave Discrete	122	156	210	273	341	410	450	529	23.3%
Total	1,339	1,371	1,767	2,190	2,643	3,048	3,702	4,371	18.4%

Columns may not add to totals shown because of rounding.

Assumptions:

Sustained materials, quality improvements and open-market availability of DF wafers.

No predatory pricing by major suppliers.

Successful MIMIC program funded in excess of $300 million over five years.

Source: Dataquest
January 1987

Table 4

1987 GaAs PRODUCT DEVELOPMENTS--ISSCC

Company	Description	Comments
Digital		
Hitachi	4K SRAM	0.7u gates, 1ns access, 1.6W, ECL interface, 3.7 x 4.7mm die
LEP	1K SRAM	2ns cycle, 210mW p_d, ECL compatible
Mitsubishi	16K SRAM	1.5ns t_{aa}, 1V supply, 1W, 5.8 x 4.7mm die
Toshiba	6K gate array	284ps t_{pd} 1mW gates
Analog		
Anadigics	GaAs sample and hold amp	170 MHz bandwidth; die size $1mm^2$
Hewlett-Packard	1 GHz 6-bit A/D converter	1 sample and hold chip, 4 A/D chips
Hughes	GaAs VSP circuit	Video signal processor with filters
LEP	Video front end	II-chip set; AGC, mixers, VCO, divider, amps, total chip area $2.15mm^2$

Source: AZTEK Associates

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a company of The Dun & Bradstreet Corporation

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ASIAN GaAs ACTIVITIES IN 1986

SUMMARY

This research report examines many of the major Asian company activities in GaAs and other III-V compound semiconductors in 1986. The report focuses on R&D, product announcements, specifications, pricing, production volumes, shipment data, and related business actions.

Thirty-seven Asian companies are referenced in this newsletter. Their activities in III-V compound semiconductors range from research through product sales of materials, devices, subsystems, and end equipment. Applications of III-V devices discussed herein are diverse, from chips costing 69 cents for use in consumer products to laser chips selling for more than $3,000 each for use in telecommunications and satellite applications. Brief summaries of Japan's activities in space and China's major thrusts in optoelectronic telecommunications are included. The 37 Asian companies in this report are listed below. Those companies making product announcements are indicated by an asterisk (*).

Anam Industrial Co. Ltd.
Fujitsu Ltd.*
Gakei Electric Works Co. Ltd.
Hamamatsu Photonics K.K.
Hitachi Cable Ltd.*
Hitachi Ltd.*
Kawasaki
Kadenshi Corp.*
Kwang Han Electronic Co. Ltd.
Kyokuto Bomki Kaisha, Ltd.
Matsushita Electric Ind. Co. Ltd.*
Matsushita Electronics Corp.*
Mitsubishi Corp.
Mitsubishi Electric Corp.*
Mitsubishi Monsanto Chemical Ind. Ltd.*
NEC Corp.*
Nippon Gakki Co. Ltd.*
Nippon Kogaku K.K.
Nippon Telegraph & Telephone (NTT)
Nisshin Steel Co. Ltd.
Oki Electric Industry Co. Ltd.
RHD Inc.
Roha
Samsung Electronic Parts Co. Ltd.
Sanken Electric Co. Ltd.*
Sanyo Electric Co. Ltd.
Sharp Corp.*
Showa Arco Solar Inc.
Showa Arco Solar Far East
Showa Shell Sekiyu K.K.
Sony Corp.*
Stanley Electric Co. Ltd.*
Sumitomo Electric Industries Ltd.
Teksel Co. Ltd.
Tokyo Electron Ltd.
Toshiba Corp.*
Toyo Ink Manufacturing Co. Ltd.

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1986 CHRONOLOGY AND DISCUSSION

The major activities in GaAs and other III-V semiconductors by Asian companies in 1986, listed by month, are as follows:

January

- Fujitsu has developed an InGaAsP APD for 1.55μ optical communications applications, to be commercialized later this year. The device has a current multiply ratio 15 to 20 times greater than other APDs.
- Mitsubishi Electric Corporation's LSI Research Laboratory announced a 1-GHz GaAs prescaler IC comprised of 440 transistors on a 1.0 x 1.1mm^2 die. Production of the IC started later in 1986.
- The Chemical Compound Semiconductor Division of Hitachi Cable, Ltd., announced 1989 target sales of $59 million, catching up with Sumitoac Electric Industries. Hitachi began quantity production of MOCVD GaAs wafers in the spring of 1986. The company expects to increase its epi wafer sales from one-third to one-half of total sales by late 1987.
- Mitsubishi Monsanto Chemical Industries, Ltd., developed the first 100mm DF GaAs wafers using full-encapsulated Czochralski vertical magnetic-field methodology developed by NTT. The company was in production of 75mm DF GaAs wafers in 1986 and planned quantity production of 100mm wafers starting in 1987.
- Sharp Corporation exceeded a production volume of 800,000 semiconductor lasers/month; Mitsubishi planned to increase its laser production by 50 percent to 600,000 per month by mid-1986. Sony and Matsushita also planned large increases. These four companies supply lasers to the CD player market. NEC and Hitachi planned increased production to support the telecom equipment market.

February

- Matsushita Electric Industrial Co. Ltd.'s Semiconductor Research Center has developed a set of three GaAs optoelectronic ICs. The E-FET structure provides IC operation of 1.6 Gbps at P_d less than 500mW. Shipments started in mid-1986. The ICs are:

Function	FETs	Die Size	Sample Lot Prices
Multiplexer	378	1.3 x 1.9mm	$1,478.00 (¥300,000) each
Demultiplexer	495	1.5 x 1.9mm	$2,463.00 (¥500,000) each
Recognition Logic	96	0.9 x 1.15mm	$ 493.00 (¥100,000) each

- Mitsubishi Electric Corporation began marketing three GaAs MMIC products in January 1986, with the production target set at 20,000 per month. The products are:

Product	Frequency Range	Noise Index	Gain	Sample Price
MBF7002	0.90 to 1.6 GHz	2.5dB	17dB	$4.09 (¥830)
MBF7003	0.21 to 1.8 GHz	2.5dB	9dB	$3.45 (¥700)
MBF7004	0.20 to 1.8 GHz	3.0dB	9dB	$2.46 (¥500)

- Dataquest forecasted the following GaAs SRAM research papers by NTT: 64K density by early 1987 and 256K density by mid-1988. The mid-1984 paper on 16K GaAs SRAMs was six months ahead of Dataquest's forecast.

- Matsushita Electronics Corporation announced a GaAs wideband, low-loss, double-balanced mixer IC for operation from 50 MHz to 2 GHz. The product is priced at $1.58 (¥300) each; planned run rate (by April 1986) was 50,000 per month.

- NEC entered the GaAs digIC (digital IC) market and began shipments of three ECL-compatible SSI chips. The μPG700 master-slave D-type flip-flop, the μPG701 T-type FF, and the μPG702 3-input OR/NOR gate are priced at $252.63 (¥48,000) each. Planned run rate (by late 1986) was 5,000 per month.

- Hitachi has developed an InP optoelectronic amplifier IC containing an optical switch, four DFB Lasers, and a waveguide on a 1.6 x 1.0mm die. Hitachi expects this to lead to the development of optical exchange equipment and optical computers.

- Under MITI sponsorship, Mitsubishi's LSI Development Laboratory has attained 9.6 percent conversion efficiency on a 100-cm^2 amorphous solar cell.

<u>March</u>

- Sharp began marketing the LT300 small-signal FED for 69 cents (¥125) per unit in miniature molded package, with production slated initially for 110,000 per month. The dual-gate MESFET has a typical gain of 20dB and a noise figure of 1.4dB at 1GHz. Die size is 0.52 x 0.54mm; package size is 2.9 x 1.5 x 1.1mm.

- NEC has developed a 3,000-gate GaAs gate array using 1.4μ structures. The 7.5 x 7.4mm die contains about 36K transistors and diodes and dissipates 4.6mW per gate. Unloaded gate t_{td} is 56ps; loaded with 2mm interconnect, the delay increases to 186ps.

- Mitsubishi started a fab line for telecommunications lasers at its Kitaitami Works, doubling the plant capacity for laser production. Plant production rate for lasers for CDs is 600,000 per month. Telecommunications lasers account for one-third of the company's semiconductor sales.

- Showa Shell Sekiyu K.K. planned to establish two joint ventures with Arco Solar Inc. to develop and sell amorphous solar cells. Capitalization is 75 percent by Showa Shell and 25 percent by Arco Solar. The companies are as follows:

  - Showa Arco Solar Inc., capitalized at $856,000 (¥154,000,000) and headquartered in Tokyo, will build a pilot plant for amorphous solar cells in Atsugi, Kanagawa Prefecture, in 1987.

  - Showa Arco Far East, to be established in Singapore, will take charge of all Far East sales except in Japan; the first year sales target is $5.6 million to $8.3 million (¥1 billion to ¥1.5 billion).

- Fujitsu has prototyped a 1,520-gate HEMT array and used it to test an 8-bit multiplier at 3.1ns t_{pd} when operated below 77 degrees Kelvin. The chip has an array of 76 x 20 cells and 72 I/Os.

April

- The Optoelectronic Industry and Technology Development Association of Japan has released production figures indicating huge growth in optoelectronics since 1980, as shown in Table 1.

- Matsushita introduced a GaAs laser nose canceller IC, the MEL5005, priced at $2.81 (¥500) each. Volume production was scheduled to start in June 1986 at 10,000 per month.

- Mitsubishi announced that it will begin marketing a 1.55μ-wavelength semiconductor laser in June 1986, priced at several hundred thousand yen per unit. The device functions to 115 degrees C and has a threshold current of approximately 10mA.

- Hitachi Cable Ltd. began sampling a high-powered linear LED array (LLA). The device was developed for optical printer applications and allows higher-speed operation than that of conventional serial scan beam printers.

- NEC announced an InP optoelectronic IC transceiver capable of 1.2 Gbps transfer speed with 1.2μ bandwidth. NEC plans to develop a production process and begin manufacturing the device within three years.

- Optoelectronics Joint Research Laboratory of Japan has developed a technology for InP single-crystal wafer production that reduces impurities by a factor of 10 and cuts production costs to less than one-tenth that of conventional methods.

Table 1

JAPANESE OPTOELECTRONIC PRODUCTION
(Millions of Dollars)

Products	1980	1983	1984	1985	CAGR 1980-1985
Optical Components	$345	$1,341	$1,549	$1,714	38%
Machines and Equipment	100	871	1,574	2,516	91%
Optical Fiber Systems	62	380	445	572	56%
Total	$507	$2,592	$3,568	$4,802	57%

Source: Optoelectronic Industry and Technology Development Association of Japan

May

- At the Applied Physics Society meeting, the Electrotechnical Laboratory of Japan's Agency of Industrial Science and Technology presented a paper on its GaAs IBT (inverted base bipolar transistor). The IBT is claimed to be faster than HEMT structures.

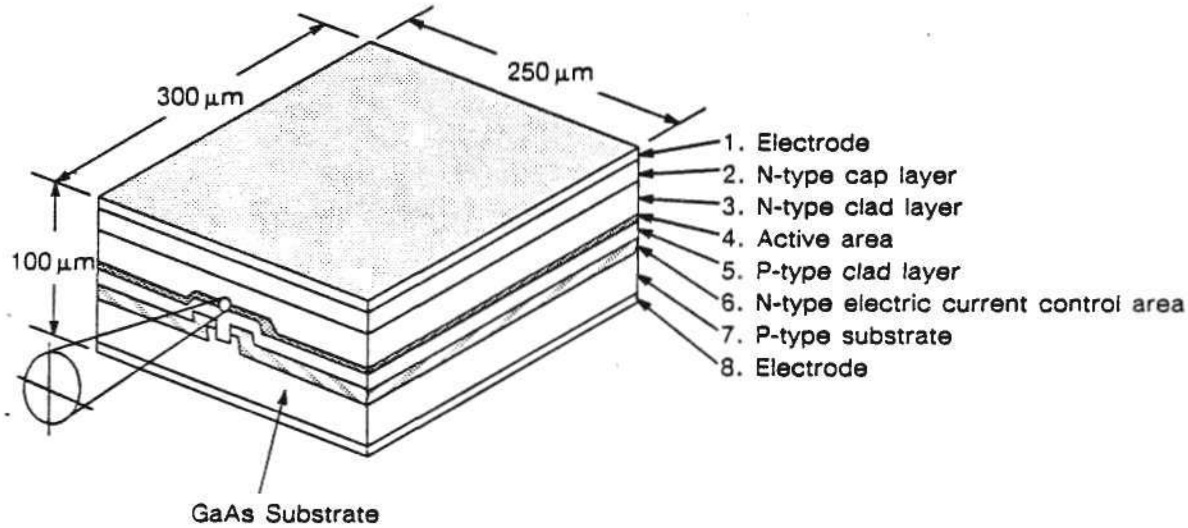
- Sony and Sharp announced an agreement on standardization of specifications for consumer equipment lasers. Under the agreement, both fires have developed miniaturized semiconductor lasers, one-fifth the volume and less than one-third the weight of existing lasers. Sharp is shipping its LT022MS at $13.89 (¥2,500) each, and Sony began sampling its SLD101U at the same price. Both companies planned volume production by October 1986 at rates of 200,000 per month.

- Matsushita achieved 280mW output in a GaAlAs laser by improving its BTRS (buried twin ridge substrate) structure. The company will produce the chip in volume as a 50mW device. A BTRS structure is shown in Figure 1.

- Tokyo Electron Ltd. and Mitsubishi's Development Laboratory have jointly developed an opto/plasma assist laser CVD machine using a high-output excimer laser together with an ultraviolet lamp and plasma. The machine can handle wafers up to 6 inches in diameter.

Figure 1

BTRS SEMICONDUCTOR LASER STRUCTURE



Source: Dataquest
February 1987

- RHD Inc. and Gakei Electric Works Co. have jointly developed an InP/GaAs crystal-pulling machine and will soon begin producing test wafers. The equipment will be marketed within two years. RHD is an R&D concern owned jointly by Nisshin Steel Co. Ltd., Toyo Ink Manufacturing Co. Ltd., and Mitsubishi Corporation. The three parent companies and RHD may establish a new company for the pulling equipment and wafers in the future.

- Japanese production of CD and VD players and video cameras grew substantially from 1984 through 1986. These items represent 11.3 percent of Japan's total consumer electronics production. Details are given in Table 2.

- Japanese production of visible-range (0.78µ wavelength) semiconductor lasers has grown rapidly to support the CD and VD player markets. Company plans to increase production still further are as follows:

  - Sharp--800,000 per month; increase to 1,200,000 per month

  - Mitsubishi--500,000 per month; increase to 600,000 per month

  - Matsushita--160,000 per month; increase to 500,000 per month

  - Sony--200,000 per month; increase to 400,000 per month

- Toshiba--100,000 per month; increase to 400,000 per month

- Rohm--Will begin volume production at 100,000 per month

- Oki Electric Industry Co. Ltd. completed installation of a production line in its Hachioji Factory for GaAs device production to support the car telephone market. Oki plans sample shipments of GaAs digICs (digital ICs) for telecommunications and instrumentation equipment markets by late 1986.

Table 2

JAPANESE CD PLAYER, VD PLAYER, VIDEO CAMERA PRODUCTION
(Millions of Yen, Thousands of Units)

	CD Player	VD Player	Video Camera	Total
1984				
Units	769	403	1,571	2,743
Value	¥ 45,586	¥47,697	¥154,891	¥248,174
Ratio to Total CE Equipment (%)	1.0%	1.0%	3.3%	5.3%
1985				
Units	4,133	503	2,574	7,210
Percent Change 1984 to 1985	437.8%	24.9%	63.9%	162.9%
Amount	¥150,872	¥54,166	¥352,430	¥557,468
Percent Change 1984 to 1985	231.0%	13.6%	127.5%	124.6%
Ratio to Total CE Equipment (%)	3.1%	1.1%	7.1%	11.3%
1986				
Units	18,000	900	3,300	22,200
Percent Change 1985 to 1986	93.6%	78.9%	28.2%	207.9%
Amount	¥220,000	¥85,500	¥430,000	¥735,500
Percent Change 1985 to 1986	45.8%	57.8%	22.0%	31.9%
Ratio to Total CE Equipment (%)	4.5%	1.7%	8.8%	15.0%

Source: Dempa Shimbun
Dataquest
May 1986

June

- Fujitsu, Sony, and Toshiba are marketing HEMTs for the satellite communications market. Other major suppliers are expected to create heavy sales competition. Sample pricing ranges from $294 to $882 (¥50,000 to ¥150,000) each.

- Stanley Electric Co. Ltd. has started shipment of an outdoor electric lamp incorporating LEDs. Power consumption is 0.3W to 0.6W, about one-thirtieth that of conventional lamps. Pricing is $2.88 (¥1,000) to $5.76 (¥2,000) each; production volume is targeted at 15,000 to 20,000 per month.

- Toshiba's new Super MLEC method of pulling GaAs crystals is claimed to increase productivity by 5 to 6 times that of existing processes.

- NEC's Otsuki Factory in Yamanashi Prefecture began producing optical communications devices such as optical data links, LEDs, receiver modules, and optoconnectors. First-year production by the five-story, 16,000-square-meter factory is targeted at $174 million (¥30 billion).

July

- Hitachi announced production of its HL1341A (1.3μ wavelength) and HL1541A (1.55μ wavelength) DFB laser diodes. Device pricing is $2,410 (¥400,000) and $3,012 (¥500,000), with production to start at 500 units per month in July and September, respectively. Volumes are slated to increase to 3,000 per month for the HL1341A and 1,000 per month for the HL1541A by March 1987.

- Matsushita Electronics Corporation introduced a GaAs op amp IC, claimed to be 100 times faster than Si op amps, for high-frequency applications including video amplifiers. Die size is 0,93 x 1.18mm; operating frequency ranges to 200 MHz. Sampling is scheduled for late 1986.

- Matsushita Electric Company's Semiconductor Research Center announced development of an SHG (second harmonic generation) device for 0.4μ wavelength operation. The niobic acid lithium crystal device will be combined with YA6 lasers and semiconductor lasers to implement practical hardware. Matsushita expects to start sampling within six months.

- Anam Industrial Co. Ltd. of the Republic of Korea exported $249.7 million between January and May 1986, up 46 percent from the same period in 1985, according to Korea's Electronic Times. Exports included $1.87 million in LEDs.

- Hamamatsu Photonics K.K. planned volume production of optical semiconductors for January 1987. Its new $12 million (¥2 billion), 7,900-square-meter plant was built exclusively for optosemiconductor production. Planned start day for operation was October 1986.

- Sharp shipped its 10,000,000th semiconductor laser in July 1986. The company has produced these devices since 1981 for CD and VD players, laser beam printers, and other applications.

- Hitachi announced two low-noise GaAs FETs, the 2SK779 and the 2SK780. Sampling started in August 1986.

Product	Noise Specification	Sample Price	10,000 PC. Price
2SK779	1.3dB	$124.24 (¥20,000)	$62.11 (¥10,000)
2SK780	1.6dB	$ 31.11 (¥ 5,000)	$15.53 (¥ 2,500)

- Matsushita Electronics Corporation and Matsushita Electric Industrial Co. Ltd.'s Wireless Research Laboratory jointly developed a GaAs RF amplifier for UHF frequency operation, the GN1030/1031. Volume pricing is $1.00 (¥150); production was planned to start later in 1986 at 50,000 per month.

- Sharp Corporation announced the development of a low-noise semiconductor laser and a laser driver IC, both of which operate from a single +5V power supply.

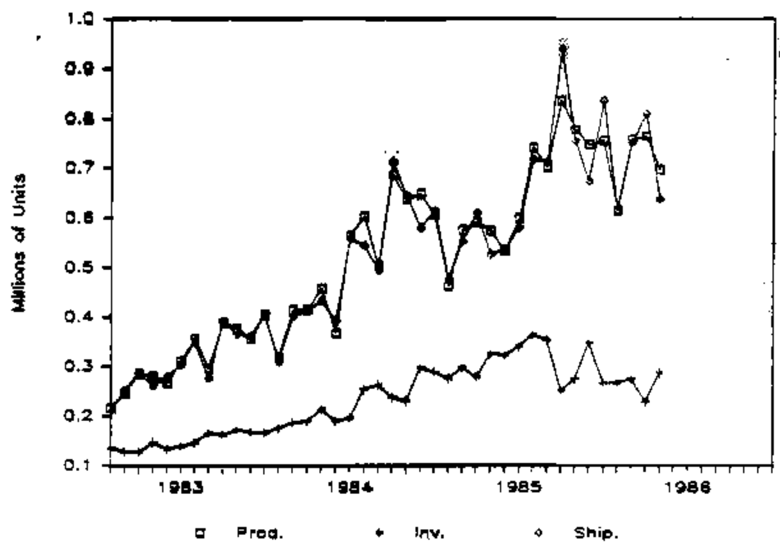
- Sanken Electric Co., Ltd., is now marketing a new series of contact-mounting LEDs. The devices are identified as the SEL3000 series. The company has also introduced an ultrahigh-brightness LED, the SEL1615. This LED product reportedly has achieved 1,000 millicandelas by employing GaAlAs.

- Japanese makers became increasingly concerned about excessive exports of compact disk players to the United States. Although the U.S. CD player market has been increasing, exports from Japan have exceeded the increase in demand. As a result, underselling the competition due to oversupply has started. Under the circumstances, Japanese makers might start controlling shipments to the United States. Because 40 percent of the CD players made in Japan are exported to the United States, oversupply in the U.S. market can greatly influence CD player production in Japan.

- The graph in Figure 2 shows Japanese production, inventory, and shipments of microwave ovens from January 1983 through April 1986.

Figure 2

JAPANESE PRODUCTION, INVENTORY, AND SHIPMENTS
OF MICROWAVE OVENS
(January 1983 through April 1986)



Source: Dataquest
February 1987

August

- Toshiba Corporation has developed an ultrasmall semiconductor laser that is compatible with standardized models built by Sharp Corporation and Sony Corporation. The laser features low noise through use of Toshiba's structure called the New ISSS (inner stripe square-channel substrate). Sample shipments will begin in September 1986 at a price of $15.82 (¥2,500) per unit. Other makers such as Hitachi Ltd., Matsushita Electronics Corporation, Mitsubishi Electric Corporation, and NEC Corporation also plan to manufacture standardized ultrasmall semiconductor lasers.

September

- Demand for compact disk player ICs continued to slow down. Among major makers, there is currently a move toward production control. Distributors expected orders received for September 1986 shipment to be 10 to 15 percent less than the record numbers reached in June and July 1986. CD player production had rapidly increased since the last half of 1985. Total production between January and May 1986 reached nearly 3.3 million units, about 80 percent of total production for the year 1985. The decline in demand for CD player ICs may indicate that CD player production has peaked.

- The Republic of Korea's Ministry of Trade and Industry has reported a national production plan for 116 items of electronic components. Eighty-four companies are participating in the project. Upon completion of the plan, we expect that national products will replace $472 million worth of imports and that the increase in exports will reach $309 million. Research and development costs for the project total W 137, which will be invested jointly by the government and the private companies. Major products included in the project are shown in Table 3.

- NEC Corporation announced that it started volume production of single-axis-mode, DFB (distributed feedback) lasers in September 1986. NEC is the second Japanese maker to start volume production of DFB lasers, following Hitachi Ltd. The lasers are the NDL5600 for the 1.3μ range, priced at $2,922 (¥450,000), and the NDL5650 for the 1.55μ range, priced at $3,571 (¥550,000). Initial run rate is 500 to 1,000 units per month, which are to be increased to 2,000 units in the first half of 1987.

- Teksel Co., Ltd., signed a sales agency contract with Anadigics Inc. of the United States and started selling GaAs ICs. Under the contract, Teksel markets the ADA25001, a superwideband amplifier, and the AOP1510, a superwideband operational amplifier. Prices are $246.10 (¥37,900) per unit (in 100-unit lots) for the ADA25001 and $80.52 (¥12,400) per unit for the AOP1510.

- Matsushita Electronics Corporation developed a new semiconductor laser called a monolithic 2-beam GaAlAs laser array, for read-write optical disk applications. The laser is capable of generating two kinds of laser optical output--one for writing and the other for reading--on a single chip. The new product makes it possible to produce compact optical pickups for disk systems.

- Matsushita Electronics Corporation prototyped an OEIC (optoelectronic integrated circuit). The device is a combination of an AlGaAs semiconductor laser with 30mW output and a high-frequency oscillator for laser noise reduction. Forty-four elements that include one semiconductor laser, 25 MESFETs, and 18 diodes are integrated onto a chip measuring 0.35 x 1.2mm. Laser noise has been reduced to negative 135dB. The new device will pave the way toward making small, high-performance optical disks. Matsushita expects to put the device to practical use within two years.

- Toshiba Corporation recently succeeded in exposing electronic circuits of 0.35μ line width on a silicon wafer by use of an excimer laser. The technology, which will enable the development of 64MB-class memories, will be put to practical use during 1987.

- NEC Corporation had developed a prototype InP FET for microwave/millimeter waveband width, succeeding in making a layer on InP substrate with ion implantation and, on that layer surface, forming a GaAlAs insulating gate using MBE. The new device, with 1μ gate features, has high-power gain of more than 83dB at 12 GHz. The company plans to commercialize a high-power, 30 GHz to 40 GHz device for satellites in 1987.

- Fujitsu Ltd. accomplished 20km nonrelay transmission at 600Mb per second, using an edge-emitting LED developed by the company. Fujitsu claims that this is a world's record in transmitting capacity in terms of distance and data volume. Using edge-emitting LEDs as light sources for optical communications can cut costs to one-tenth that of the existing method. The technical breakthrough is expected to accelerate the spread of optical communication to households.

Table 3

MAJOR DEVELOPMENTS OF CONSUMER PRODUCTS BY KOREAN COMPANIES

Product	Company	Application	R&D Period	R&D Expense	Capital Expense
IR LEDs	Kwang Han	Televisions	6/86 to 12/86	$250,000	$375,000
Display LEDs	Kwang Han	Copiers, calculators	6/86 to 12/86	N/A	N/A
Solar Cells	Samsung	Computers, watches	7/85 to 10/87	$140,000	$2 million

Source: Electronic Times (Korea)

October

- Hitachi Ltd. recently disclosed that it shipped a large quantity of semiconductor lasers, which will be used for transpacific and transatlantic optical submarine cables, to AT&T Corp. of the United States. Shipment volume is estimated to total 4,000 to 5,000 units at a value of several billion yen. AT&T will equip submerged repeaters with the lasers.

- Hitachi Ltd. has entered the photodiode merchant market by introducing 15 models of InGaAs PIN diodes. The new series, which is adaptable to long-distance optical communication systems, has detector sensitivity for 1.3μ and 1.55μ wavelengths. The 50-, 80-, 100-, and 300- models were placed on the market in September 1986. The price for 10-unit lots is $180.65 (¥28,000) per unit. The 3mm versions were shipped as samples beginning in September. Sample price is $1,290.32 (¥200,000) per unit.

- Kodenshi Corp. has developed a series of photo interrupters and has started sample shipment. The devices, dubbed the Photo Interrupter LC Series, have been developed by using a GaAs LED and adding a photo IC for the light-emitting diode. Model numbers are LG-0101, 0201, 0401, and 0501.

- NEC Corporation has developed a 1.55μ bandwidth, single-mode semiconductor laser. By using a new laser, transmission distance by quartz fiber without relay can be extended from the current 30 kilometers to 50 kilometers or longer. The company is continuing research on the laser so that it can be used commercially as soon as possible.

- Nippon Gakki Co., Ltd., has developed an 18-bit signal processing LSI for compact disk players. The new LSI DSP chip is capable of processing CD signals at 16 times higher resolution than the attainable with the conventional digital processing method. By using the LSI in a CD player, noise can be substantially reduced. The device will be adapted to high-grade CD players to be marketed in October 1986.

- China is expected to experience major transitions in its communications technology and facilities over the next two to three decades. These include:

  - Conversion of electromechanical exchanges to solid state

  - Conversion of analog audio and video links to digital, incorporating ISDM

  - Replacement of copper networks with fiber optics

  Each of these changes will generate tremendous demand for silicon and III-V semiconductor technologies. China expects to organize these conversions into separate programs governed by sequential five-year plans.

  The fiber-optic intercity links will use InGaAsP laser sources and InGaAs PIN diode/GaAs FED preamp detectors. Conversion of intracity (local office) nets will occur later. In China, fiber-optic LANs are now used for highway traffic surveys, factory monitors, and OA. Shallow-sea fiber-optic cable links are planned along China's coasts, across bays, and among islands. Deep-sea cable will not convert to fiber optics before the late 1990s.

  China's first use of fiber optics for interoffice trunks was in Shanghai in 1979. All equipment and cables were made in Shanghai for a 1.8km link operated at 8Mb using GaAs LED sources and PIN detectors. A field trial of a 50km, 140Mb digital link is now planned in Shanghai. The Railway Ministry and the Electric Power Ministry of China have already installed fiber-optic systems.

November

- Fujitsu Ltd. is marketing four models of GaAs prescaler ICs. Two of the new devices, dubbed the MB50104/50106, are fixed-ratio prescaler ICs for microwave telecommunications; the other two, the MB50201/50202, are variable types for portable mobile radio communications systems. Sample prices are:

  - MB50104--$96.77 (¥15,000) per unit
  - MB50106--$193.55 (¥30,000) per unit
  - MB50201--$32.26 (¥5,000) per unit
  - MB50202--$58.06 (¥9,000) per unit

  Volume production will begin in spring of 1987 at a rate of 50,000 to 60,000 units per month.

- Sanyo Electric Co., Ltd., had developed a high-efficiency GaAlAs semiconductor laser, using the MBE method. In the new laser, external differential quantum efficiency has been increased to 80 percent. Internal quantum efficiency is 95 percent. The company plans to commercialize the semiconductor laser by March 1987 for use in short-distance optical communications applications.

- Sharp Corporation developed a new VSIS-structure (V-channeled substrate inner strip) semiconductor laser. Threshold current of the new laser has been reduced to 25mA at the 780nm visible range, half that of the conventional model. Volume production is planned for 1987. The VSIS-structure semiconductor laser is Sharp's original product. Since its development in October 1981, the company has sold more than 10 million units.

- Matsushita Electric Corporation developed a new semiconductor laser process by using MOCVD. With the new process, which applies the self-alignment method to crystal growth, submicron light-emitting stripes can be formed easily. The company has already manufactured on an experimental basis a 1μ stripe GaAlAs laser, which has 15mA threshold current and 1.05 ellipticity. It plans to commercialize the 1μ laser for short-distance optical communication within two years.

December

- According to a report from the Korean Ministry of Science and Technology (MOST), Korea will develop new semiconductor materials such as polycrystalline materials, ceramics, fiber optics, and high-quality single-crystal silicon. The specific areas of focus are:

  - Silicon semiconductors

    - Large integration and high purification of single crystals

    - Improvement of silicon wafer process

  - Polycrystalline materials

    - Mass production technology for solar cells (i.e., amorphous silicon)

    - New material development

  - Semiconductors

    - GaAs single-crystal technology

    - Now semiconductor components

  - Fiber optics

    - Laser diodes

    - Fiber-optic components

  - Semiconductor sensors

- While Japan claims to have a zero military budget, it has amassed tremendous capabilities in aerospace hardware in recent years and has aggressive plans for the next decade. The aerospace program is expected to cause Japanese companies to focus on rad-hardened circuits because many of the spacecraft must pass through the Van Allen Belt. Table 4 details some of Japan's capabilities and plans in this area.

- The Ministry of International Trade and Industry (MITI) in cooperation with the Optoelectronics Industry and Technology Development Association framed a rough plan to standardize 33 items of opto telecommunication products. It will gradually designate the products as JIS (Japanese Industrial Standard) items from March so that compatibility of optical fibers, which connect components and perform other functions, will be increased.

Table 4

PLANNED JAPANESE SPACECRAFT
AND SATELLITE LAUNCHINGS

Launch Date	Type	Company	Payload (Pounds)	Orbit (Height)	Comments
8/1/86	EGP	Kawasaki	1,500	900 miles	Laser target; first H-I payload
Mid-1987	ETS-5	Mitsubishi	N/A	Geosync.	Mobile satcom with ships and planes
1/87	MOS-1	NEC	1,650	545 miles	Carrying CCDs and other multispectral detectors
Early 1988	CS-30	Mitsubishi	N/A	Geosync.	Third-generation; 6,000 voice channels plus K- and C-band transponders
Mid-1988	CS-3B	Mitsubishi	N/A	Geosync.	Sister to CS-3A
Mid-1989	GMS-4	NEC	N/A	Geosync.	Weather spacecraft; H-I launch vehicle
Mid-1989	GMS-5	NEC	N/A	Geosync.	$185 million development cost; 3-axis stabilized; H-I launch vehicle
Mid-1990	BS-3A	NEC	N/A	Geosync.	Color television--three channels
Mid-1991	BS-3B	NEC	N/A	Geosync.	Sister to BS-3A
N/A	ERS-1	NEC/Mitsubishi	3,000	N/A	To carry synthetic aperture radar, IR and visible sensors; electrically sequenced trans-mitters used for careful study of ground

(Continued)

Table 4 (Continued)

PLANNED JAPANESE SPACECRAFT AND SATELLITE LAUNCHINGS

Launch Date	Type	Company	Payload (Pounds)	Orbit (Height)	Comments
81/92	ETS-6	Mitsubishi	N/A	N/A	First H-II payload
1994*	N/A	N/A	N/A	N/M	H-II payload; seismic detection
Mid-1990s	Venus Probe	N/A	N/A	N/M	H-II payload; magnetosphere probe

Geosync. = Geosynchronous orbit (approximately 22,000 miles above Earth's surface
N/M = Not Meaningful
N/A = Not Available

*Moon Probe

Source: AZTEK Associates

- Prices of semiconductor lasers to be used for CD players and video disks have declined sharply. In the case of 0.78μ lasers, the wholesale prices for large users in Tokyo are \$5.25 to \$5.86 (¥850 to ¥950) per unit, a 5.3 percent decline in two months. Some new makers' models are sold at \$4.94 (¥800) per unit, with underselling competition expected to continue toward the end of the year as makers plan for production increases. Sharp Corporation's production capacity has increased six times since the beginning of this year.

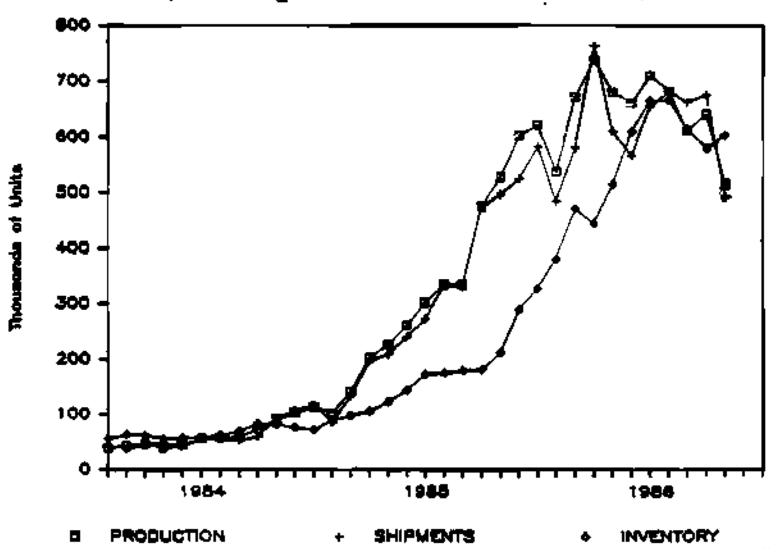
- Stanley Electric Co., Ltd., will supply Nissan Motor Co., Ltd., with LED high-mounted brake lights for the 1987 Fairlady 2, Nissan's sports car, marking the first time that LEDs will be used as automobile illuminators. Monthly shipments to Nissan are expected to be 6,000 units. Because of interest by automobile makers at home and abroad, including the big three U.S. companies, Stanley plans to expand its LED lamp market throughout the world.

- Stanley Electric Co., Ltd., and Kyokuto Bomki Kaisha, Ltd., have jointly established I.I. Stanley Inc. in Battle Creek, Michigan. The new company, capitalized at $1 million (60 percent by Stanley, 30 percent by Kyokuto, and 10 percent by Stanley Electric U.S.) will start production of LEDs and lighting apparatus in May 1987. Capital investment in the company is expected to total $10 million.

Dataquest estimated that semicondutor consumption for digital audio disk (DAD) players was around ¥3 billion ($18.52 million) per month in 1986. Since the production cost per unit was going down, semiconductor consumption tended to decrease also (see Figure 3).

Figure 3

JAPANESE DIGITAL AUDIO DISK PLAYERS
PRODUCTION, SHIPMENTS, AND INVENTORY
(January 1984 to October 1986)



Source: Dataquest
February 1987

DATAQUEST CONCLUSIONS

The field of GaAs and other III-V compound semiconductors is advancing rapidly every year, and 1986 was no exception. Asian companies are very active in the application of GaAs technology to consumer products, fiber-optic communications, and satellite hardware, and they continue to refine the traditional LED display devices. There is increasing competition in the IC field, particularly in MMICs and digICs, with new players entering the marketplace. Dataquest expects this pace of activity to continue into the 1990s as IC suppliers, pressured by declining profits in Si, seek out niches in III-V markets.

Gene Miles

Dataquest
a company of The Dun & Bradstreet Corporation

Research Newsletter

GATA Code: Newsletters
1987-5

III-V MATERIALS--WHO'S ON FIRST?

Since our August 1986 newsletter on GaAs materials, the compound semiconductor materials situation has evolved into a new game. In most high-technology business areas, innovation never ceases, leading to gyrations in the competitive lineup. The III-V materials industry is no exception.

Recent developments that we consider worth watching include:

- GaAs on Si substrates
- Progress in NDF wafer manufacture
- New entrants and start-ups
- Increases in the price of gallium in Japan
- Innovations in InP manufacture

DATAQUEST ANALYSIS

Although Sumitomo Electric in Japan is the acknowledged leader in GaAs wafers with an estimated world market share of 50 percent, the competition is heating up with major expansions under way. For this newsletter, Dataquest identified 39 companies in the Free World marketplace that are involved in compound semiconductor materials manufacturing operations. These include 18 in the United States, 2 in Canada, 11 in Japan, 3 in West Germany, 2 in the United Kingdom, 2 in France, and 1 in Sweden. As we predicted earlier, materials companies are becoming increasingly aggressive in their attempts to establish a significant presence in this market.

A key factor in the growth of the compound semiconductor industry is the ability to move into LSI and VLSI levels of integration. This movement is presently limited by the quality of substrate material. Although NTT announced development of a 16K SRAM in 1984, none of the device suppliers has been able to mass-produce the chip for the commercial market, at any price. Dataquest believes that recent laboratory work by Westinghouse and others on GaAs crystal growth has resolved the technical problems associated with VLSI from the standpoint of materials. Which company or companies will be first to benefit from this in the merchant market is not yet clear.

A promising alternative to GaAs substrates is the possible move to GaAs on silicon substrates, with pioneering work under way at start-up Kopin Corporation and other companies. Vertically integrated companies believed to be working in the field of GaAs on Si include AT&T Bell Laboratories, Ford, Fujitsu, GTE, HP, NEC, NTT, Oki, Texas Instruments, and Xerox. TI demonstrated a 1K SRAM implemented on a GaAs on Si substrate, in 1986. IBM's position in this area is not known, although it is believed to be heavily engaged in GaAs device and chip development, and has publicized its work on GaAs ballistic transistors. GaAs on Si, when perfected, will also significantly reduce wafer and, therefore, chip costs, bringing GaAs cost/performance at the system level much closer to that of Si ECL.

Table 1 summarizes the activities of merchant suppliers of GaAs and other compound semiconductor materials companies. It is arranged alphabetically and identifies the companies' corporate nationalities, major compound semiconductor products, methods of manufacture, wafer sizes, expansion plans, and other information that Dataquest believes is of value to its clients.

In addition to Kopin Corporation, the table shows other compound semiconductor materials start-up companies including Picogiga (France) and Preussag AG (West Germany). Dataquest expects 1987 to bring more new players to this field, as if it weren't crowded already.

Gene Miles
Peggy Wood

Table 1

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Airtron	U.S.	GaAs undoped and Si-doped wafers	Growth method: LPLEC Firm is a division of Litton Industries 2", 2.5", and 3" wafers available
Bertram Labs	U.S.	GaAs wafers	Growth method: HB 2" GaAs wafers available
Boliden Finemet AB	Sweden	GaAs wafers	Growth method: HPLEC 2" and 3" GaAs wafers available
Cominco Electronic Materials	Canada	GaAs GaSb, InSb, InAs, CdTe, HgTe, and CdHgTe wafers	Growth methods: HPLEC, HB Completed expansion of LEC GaAs wafer plant in Trail, BC, Canada in 1985. Capacity 250K sq. in./year; 2", 3", and 4" wafers available
Commercial Crystal	U.S.	GaAs, GaP, InP wafers	Growth methods: LEC, HB 2" wafers available
Cryscon Technologies	U.S.	GaAs wafers	Growth method: LEC Subsidiary of Alcan Aluminum of Canada. Started shipping GaAs Q4/85. Cryscon supplies 2" and 3" GaAs wafers produced by LEC and electrodynamic gradient freeze (EFG) technique. Annual capacity approx. 2 million sq. in./year. Cryscon was for sale as of 10/22/86
Crystacomm Inc.	U.S.	InP crystals and wafers	Growth method: LEC 2.5" wafers available
Crystal Specialties	U.S.	GaAs wafers, MOULD epi reactors	CSI became subsidiary of Kollmorgen Co. in summer 1984. Wafer facility moved to Colorado Springs, CO, from Ephraim, UT, in Q3/86; reactor facility in Portland, OR
Dowa Mining	Japan	GaAs, InP wafers, poly InP, high purity In	Growth method: HB Research lab located in Akita
EMCORE	U.S.	GaAs epitaxial wafers (MOCVD epi reactors)	Start-up in New Jersey Founded in late 1984 2" and 3" wafers
Epitaxy	U.S.	Epi wafers, photodetectors	Start-up in Puncton, NJ, founded in 1984. Adding InGaAs layer onto InP wafers for photonics and other applications
Epitronics	U.S.	GaAs expitaxial wafers	MOCVD and LPE epi methods Subsidiary of Alcan Aluminum of Canada

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Furukawa Electric	Japan	GaAs, InP wafers, GaAs epi wafers	Growth method: LEC Wafers produced at Tokyo lab
GAIN Corporation	U.S.	GaAs epi wafers	Production expected in 1987
Galarix Corporation	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Growth method: HB Started in 1983 as research organization Marketing of GaAs materials primarily focused toward R&D facilities
Gallium Arsenide Substrates	U.S.	GaAs wafers, poly and single-crystal GaAs ingots	Using gradient freeze process with less than 1,000 dislocation defects/square cm Capitalized with $1 million in private funding
Hitachi Cable	Japan	GaAs, InP epi wafers, single-crystal GaAs ingots	Growth method: LEC Production of III-V materials at Takasago plant in Ibaraki. Investing ¥2 billion to expand two plants including epi plant at Kidaka
Hitachi Metals	Japan	Single-crystal GaAs ingots	Growth method: LEC Developing single-crystal undoped GaAs
ICI Wafer Technology	U.K.	GaAs, InP wafers, poly and single-crystal GaAs and InP ingots	Growth method: LEC ICI bought Cambridge Instruments' III-V operations in 1/85. 2" and 3" GaAs and 2" InP wafers available
Iwaki Handotai	Japan	GaAs wafers	Growth method: LEC 50-50 joint venture of Furukawa Mining/Shin-Etsu Handotai (SEH), founded 1982. Plant in Fukushima prefecture began 2" and 3" wafer production in June 1983. SEH began shipping 2" GaAs wafers to subsidiary, SEH America, from Iwaki Handotai June 1985. 3" wafers available in R&D quantities
Kopin Corporation	U.S.	GaAs-on-Si wafers	Start-up in Taunton, MA 3" and 4" wafers. Developing MOCVD epi process
M/A-COM Semiconductor Products	U.S.	GaAs and GaAs epi wafers	Growth method: LEC Merchant sales as well as captive consumption of GaAs wafers. Microwave Assoc. Ltd. is M/A-COM distributor in the United Kingdom
MCP Limited	U.K.	GaAs wafers	Located in Wembley, Middlesex, England

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Metal-Specialties Inc.	U.S.	GaAs, GaP, GaSb InAs, InP, InSb wafers	Growth methods: LEC, HB
Meteaux Speciaux	France	InP ingots wafers	Growth method: LEC Plant located in Moutiers, France Production expected mid-1987
Mitsubishi Metal Corporation	Japan	GaAs wafers	Growth methods: LEC, HB Wafer plant located in Omiya, Saitama prefecture. Nissho Iwai Corp. is the U.K. distributor
Mitsubishi Monsanto Kasei (MMK)	Japan	GaAs, GaP wafers	Growth methods: LEC, HB Production system for 3" NDF GaAs wafers developed at Tsukuba plant. MMK spending ¥3 billion for expansion; plans to double sales by 1989. Planned capacity is 500 wafers/month. MMK using NTT's vertical magnetic CZ method to produce 3" wafers with 10 defects/ square cm. max. MEMC to sell MMK wafers in U.S. market
Morgan Semiconductor (division of Ethyl Corp.)	U.S.	GaAs wafers; GaAs epitaxial wafers	Growth methods: LEC, HB Started sampling LP LEC 3" GaAs wafers in 1984; med. pressure LEC 3" GaAs in September 1986. Shipment of 2" and 3" GaAs epi wafers began 4Q/1986
Nippon Mining	Japan	InP wafers, poly and single-crystal InP, single-crystal GaAs and CdTe ingots	Growth method: LEC First Japanese company to grow NDF 3" InP crystal material. Nimio (Cupertino, CA) is a Nippon Mining subsidiary; purpose is to promote sales of GaAs, InP, CdTe, other III-V and II-VI materials in the U.S. market
OMVPE Technologies	Canada	GaAs epitaxial wafers	Start-up located in St. Laurent, Quebec, Canada
Picogiga	France	GaAs epi wafers	Start-up with $4 million in private funding, located in Les Ulis (Orsay). Began operation in August 1986. 2" GaAs MBE wafers
Preussag AG	West Germany	GaAs wafers	New division of Preussag, located in Gossiar, West Germany. Spending $30 million+ to develop wafer capability. Preussag is a major mining interest and supplier of Ga material.

(Continued)

Table 1 (Continued)

WORLDWIDE III-V COMPOUND SEMICONDUCTOR MATERIALS SUPPLIERS

Company	Country	Products	Comments
Raytheon	U.S.	GaAs epitaxial wafers	Growth methods: LEC, HB
Showa Denko	Japan	GaAs, GaP, InP wafers	Growth method: LEC First company in Japan to produce InP wafers by MLEC. Sampled reduced-defect GaAs wafers in summer 1985
Siemens Company, Inc. Opto Div. (Litronix)	U.S.	GaAs wafers	Growth method: HB Facility located in Cupertino, CA 1.6" to 3" wafers available
Spectrum Technology	U.S.	GaAs wafers	Growth method: HP and LP LEC Spectrum founded in 1982, acquired in Q2/1985 by NERCO Advanced Materials, Inc. (Portland, OR), a large mining interest
Spire Corporation	U.S.	GaAs epitaxial wafers and equipment	Located in Bedford, MA. MOCVD growth of III-V and II-VI compounds, including GaAs, AlGaAs, GaAsP, InP, ZnS, ZnSe on 2" and 3" substrates
Sumitomo Electric	Japan	GaAs, GaP, InP, InSb, InAs, GaSb wafers	Growth method: LEC, HB Largest III-V substrate supplier in the world; 50 percent share of GaAs market. Has capacity for 3,000 3" GaAs wafers/month. GaAs material produced in Itami City (north of Osaka), Hyogo prefecture
Sumitomo Metal Mining	Japan	GaAs, GaP and CdTe wafers	Growth method: LEC
United Epitaxial Technologies	U.S.	GaAs and AlGaAs epitaxial wafers	Start-up in Oregon; received approx. $5 million in first-round venture funding. Founded mid-1984. Working with Crystal Specialties to develop MOCVD equipment. 2" and 3" epi wafers
Wacker	West Germany	GaAs, GaP InP wafers	Growth methods: LEC, HB Shipping 2" and 3" epi wafers

Note: LPLEC = Low Pressure Liquid-Encapsulated Czochralski, HB = Horizontal Bridgeman,
HPLEC = High Pressure Liquid-Encapsulated Czochralski, LEC = Liquid Encapsulated Czochralski,
MOCUD = Metal Organic Chemical Vapor Desposition, LPE = Liquid Phase Epitaxy,
MBE = Molecular Beam Epitaxy, MLEC = Magnetic Liquid-Encapsulated Czochralski

Source: Dataquest
March 1987

GATA Code: Newsletters
1987-6

FORD OFFERS E/D GaAs FOUNDRY SERVICES

Ford Microelectronics, Inc., has established a 12,000-square foot GaAs foundry at Colorado Springs, Colorado, the United States. This facility has a 3-inch capacity of 500 wafers per week. The clean room exceeds Class 10 criteria and reduces LSI/MSI density devices on a self-aligned E/D process. The circuits feature loaded gate delays of 150ps at 0.7mW per gate pd and a worst case noise margin of 300mV.

Ford offers proprietary SPICE-based circuit simulation software called GASSIM. Hermetic IC packaging capability includes a variety of standard packages. The fab site has both environmental screening and 100 percent burn-in capabilities. Electrical testing is performed on Sentry 21 and MegaTest's MegaOne VLSI testers. Table 1 delineates foundry charges at the new Ford Microelectronics facility.

Table 1

Ford Microelectronics, Inc.
FOUNDRY CHARGES

E/D Gate Array--1,000 Equivalent Gates	
NRE and 10 Prototypes	$75,000
Custom Foundry--E/D SAGFET	
Foundry Kit	$24,000
Engineering Consultation	$3,000
5-wafer minimum:	
First 25 wafers	$7,000 each
Next 25 wafers	$6,000 each
Next 50 wafers	$5,000 each
More than 100 wafers	Negotiable

Source: Dataquest
March 1987

Ford Microelectronics is a full-service supplier of GaAs digital and analog standard, semicustom, and full-custom products. The company reportedly is establishing an E/D GaAs IC alternate source agreement and capability in conjunction with Vitesse Electronics Corporation of Camarillo, California.

Dataquest believes that adequate E/D foundry capacity is critical to the successful long-term application of GaAs technology to commercial digital hardware, and that Ford's capabilities will enhance the development and growth of this industry.

Gene Miles
Tom Wang

Dataquest
a company of The Dun & Bradstreet Corporation

Research Newsletter

GATA Code: Newsletters
1987-7

ADVANCED PRODUCTION-WORTHY GaAs ICs PRESENTED AT CICC

SUMMARY

The 1987 IEEE Custom Integrated Circuits Conference, held in Portland, Oregon, earlier this month, featured a special session on GaAs ICs. Late papers added emphasis to the rapid changes that are taking place in this technology. This newsletter highlights the significant products and related technology featured in several of the presentations.

The papers showed that the GaAs industry is experiencing difficulty as it moves to the VLSI level of integration, not unlike the Si industry of the mid-1970s. E/D MESFET technology is believed to be the vehicle for the next advancement in chip density. Several of the papers indicated that yields of up to 70 percent are now being realized in producing MSI level functions such as error detection chips and encoder/decoder-enhanced optical transceivers. Experience was reported showing yields to 35 percent for LSI circuits containing more than 40,000 transistors and other components.

PROGRESS IN GaAs FOR COMMUNICATIONS APPLICATIONS

Encoder/decoder functions for serial data streams readily lend themselves to GaAs implementation. For example, in fiber-optic transmission systems, a line code is often used to achieve an equal distribution of 1s and 0s to optimize performance over long distances. Because this line code adds redundancy to the signal, it can be used to monitor the link for bit errors. The low I/O count and high bit rates involved, coupled with the real-time nature of these functions, dictate the use of a highly exotic version of silicon technology or a straightforward, loose-tolerance approach with GaAs technology. Companies presenting results of efforts in this field included ITT and GE, in addition to work by the Center for Digital Systems Research (Research Triangle Park, North Carolina).

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398, (408) 971-9000, Telex 171973

The ITT device features a 144-gate error detection circuit that has been tested at 2.5 GHz and has experienced less than 12 percent speed degradation when operated at 125 degrees C. The chip was designed, fabricated, and tested by a team of engineers from ITT Standard Telefon O.G. Kabelfabrik A/S (Oslo, Norway) and ITT GaAs Technology Center (Roanoke, Virginia).

The GE chip incorporates an encoder, laser driver, optical detector, and decode logic; die size is 45 mils x 90 mils. TriQuint fabricated the GE circuit using a 1u E/D process, as part of a multichip project. A lot of four wafers was tested, with combined transceiver yields of 65, 70, and 82 percent for the three best wafers.

Triple modular redundancy (TMR) is a fault-tolerant technique used extensively in hardware for high reliability. Because TMR can lengthen system cycle time, GaAs is a more attractive medium than Si for implementation. A TMR chip developed by Research Triangle Institute has been built and demonstrated. The design was based on TriQuint's 1u D-MESFET process; TriQuint fabricated the prototypes. Initial tests indicate that the circuit adds less than 3ns overhead to a TMR processor configuration.

MSC DEVELOPS 1.5-GHz, DIVIDE-BY-N PRESCALER

Microwave Semiconductor Corporation discussed a 1.5-GHz, divide-by-N prescaler with the highest operating frequency reported to date. The circuit is capable of dividing an input frequency of DC to 1.5 GHz by any integer from 3 to 64. The MSC design is based on 3-diode BFL internal logic, and features ECL-compatible output buffers.

GBL AND SEATTLE SILICON PRODUCE AND APPLY GaAs COMPILER

GigaBit Logic, Inc., (GBL) presented a GaAs standard cell family developed for LSI applications. The family was created to support the wide variety of applications for ultrahigh-speed, low-power GaAs LSI. GBL stated that it chose D-MESFET technology for this family because it has obtained yields of more than 35 percent on 14,000-transistor, 28,000-component circuits at its Newbury Park facility. The microcell family offers gate delays of less than 100ps and flip-flop toggle rates above 2 GHz. The family is commercially available for design of chips of up to 4,000 gates.

A joint paper by Seattle Silicon Corporation and GigaBit Logic described a 4-bit ALU that was designed using a compiler. The ALU is functionally equivalent to the 100181, 100K ECL chip. The GaAs ALU chip contains 96 CDFL gates, features ECL compatible I/Os, and measures 64 x 96 mils. Initial tests demonstrated power dissipation of less than 4mW per gate and gate propagation delays of 155ps for a speed-power product of 565 femtojoules under system loading conditions. This performance contrasts very favorably with that of a commercially available silicon 100181; the GaAs 100181 offers one-half of the power consumption and 5.7 times faster throughput than its silicon counterpart.

HEMT GATE ARRAY EXCEEDS 4,000 GATES

A late paper by Fujitsu described a 4.1K gate array using HEMT devices. The company has fabricated a 16 x 16 parallel multiplier that was operated at 4.9ns at 300°K and 3.1ns at 77°K. The chip was developed as a part of Japan's Research and Development Program on the Scientific Computing System, a MITI-sponsored project.

GaAs DSPs NOW INCLUDE FIR FILTERS

A GaAs MESFET implementation of a FIR (finite-duration impulse response) filter design was presented by a team from the Computer Systems Laboratory of Tampere University of Technology (Finland) and the Department of Electrical and Computer Engineering of the University of California at Santa Barbara. The circuit consists of approximately 260 BFL gates, dissipates 1.6W, and has ECL-compatible I/Os. Process is depletion mode, 1u, n-type MESFET.

NEW SPICE MODEL OF GaAs MESFET

GaAs MESFET modeling, featured in several of the papers, was the subject of a presentation by a team from the University of California at Berkeley. This group's model has been implemented in SPICE 2G.6. This work was supported by Digital Equipment Corporation, McDonnell Douglas Astronautics Company, and the California MICRO Program.

DATAQUEST CONCLUSIONS

Practical GaAs functions, usable in upgrades of existing electronic hardware and in next-generation designs, have become increasingly available. The major investments of the last few years are producing workable, Si-compatible GaAs at MSI/LSI density levels. Systems designers can no longer ignore GaAs technology in today's competitive environment, where a delta of 200ps per clock cycle can make or break a new design. Foundry services of companies like TriQuint stand ready to support new users of this exciting, rapidly growing, technology.

Gene Miles

Dataquest
a company of
The Dun & Bradstreet Corporation

Research Newsletter

GATA Code: Newsletters
1987-8

GaAs IC FOUNDRIES EXPAND THEIR SERVICES

SUMMARY

GaAs foundry activity is intensifying. The lineup of players is changing, and new services are being offered the market. Since our 1986 newsletter on this topic, Ford, GAIN, ANADIGICS, Tachonics, and Texas Instruments have joined the quest for market share; Honeywell has consolidated its effort, closing its Richardson, Texas, facility in favor of the Minneapolis operation. This newsletter is an update on available merchant market GaAs foundry services. A revised list of GaAs foundries, contact names, and telephone numbers is included for your convenience in Table 1.

THE COMPANIES

Adams-Russell

Adams-Russell offers custom-fabricated GaAs MMICs, 1u MESFET foundry service, and a design seminar for GaAs IC users. The company's 54,000-square-foot semiconductor center was established in Burlington, Massachusetts, in 1982. Foundry charges are approximately $40,000 per four-wafer prototype lot for customer-owned mask set and tooling. Multiproject design participation is priced at $10,000 per group (up to four persons per group). The available library of MMIC components includes transistors, diodes, capacitors, resistors, and spiral inductors for MMIC design. The company accepts Calma GDSII or CIF data base tapes and offers 10- to 12-week throughput for tested chips.

Table 1

GaAs MERCHANT MARKET FOUNDRY CONTACTS

Company/Location	Phone	Foundry Contact
Adams-Russell Burlington, Massachusetts	(617) 273-5830	Bryan Reardon Marketing Director
ANADIGICS Warren, New Jersey	(201) 668-5000	Michael Gagnon Marketing Director
Avantek Santa Clara, California	(408) 970-3084	Peter Manno Marketing
Ford Microelectronics Colorado Springs, Colorado	(303) 528-7660	Charlotte Diener Marketing Manager
GAIN Somerville, New Jersey	(201) 526-7111	Michael D. Logan Marketing Director
GigaBit Logic Newbury Park, California	(805) 499-0610	Michael Pawlik Foundry Manager
Harris Microwave Milpitas, California	(408) 433-2222	Jim Klug Program Director
Honeywell Minneapolis, Minnesota	(612) 887-4047	Dr. Richard Cirillo Program Manager
ITT GTC Roanoke, Virginia	(703) 563-8600	Ed Donoho Senior Manager, Technical Services
M/A-COM Lowell, Massachusetts	(617) 937-2800	Larry Ward Marketing Director
Plessey Towcester, United Kingdom	(0327) 51871	Ray Evans Foundry Marketing
Rockwell Anaheim, California	(714) 762-4074	Phil Dee Marketing Manager
Tachonics Plainsboro, New Jersey	(609) 275-2525	Leonard Lea Marketing Director
Texas Instruments Dallas, Texas	(214) 995-0899	Ray Toole Operations Manager

(Continued)

Table 1 (Continued)

GaAs MERCHANT MARKET FOUNDRY CONTACTS

Company/Location	Phone	Foundry Contact
TriQuint Beaverton, Oregon	(503) 629-3100	Dr. Ajit Rode Foundry Manager
Vitesse Semiconductor Camarillo, California	(805) 388-3700	Jim Brye Marketing Vice President

Source: AZTEK Associates

ANADIGICS

ANADIGICS offers GaAsIC (a trademark of ANADIGICS) foundry services. The process is 0.5u gate length D-MESFET with 24-GHz foot standard transistors. ANADIGICS' design tools include the following trademarked services and support: AISPICE design software, AIGRAPH layout, and AICHECK verification programs. Examples of microwave circuits that can be designed using the company's tools and processing are: wideband, power, and low-noise amplifiers; limiters, buffers, and mixers; and switches, VCOs, and phase shifters. Linear and digital circuit examples include: transimpedance amplifiers, mux/demux circuits, laser drivers, A/Ds and D/As, dividers, and ECL-compatible logic.

Capacity of ANADIGICS' 6,400-square-foot, Class 100 clean room is claimed to be 300 3-inch wafers per week. Wafer probe equipment is rated to 40 GHz; final testing is rated at DC to 26.5 GHz (rf) and 4 Gb/s (digital). High-speed linear testing includes automatic on-wafer laser trimming. In addition to wafer fab, dicing, packaging, and screening, ANADIGICS offers backside processing including thinning metallization and via holes. Packaging includes DIPs, LCCs, flatpacks, and proprietary metal-ceramic packages to 20 GHz.

Avantek

Avantek has recently expanded its facilities to include a 3-inch wafer fab. Process is state-of-the-art 0.5u GaAs MESFET. Foundry charges are $40,000 for the first wafer, which includes design rule package and engineering services, $10,000 each for additional wafers (minimum lot size is five wafers).

Ford Microelectronics

Ford Microelectronics, Inc., has established a 12,000-square-foot GaAs foundry at Colorado Springs, Colorado, with a 3-inch capacity of 500 wafers per week. The clean room exceeds Class 10 criteria and is producing LSI/MSI density devices on a self-aligned E/D process. The circuits feature loaded gate delays of 150ps at 0.7mW per gate pd and a worst-case noise margin of 300mV.

Ford offers proprietary SPICE-based circuit simulation software called GASSIM (a trademark of Ford Microelectronics). Hermetic IC packaging capability includes a variety of standard packages. The fab site has both environmental screening and 100 percent burn-in capabilities. Electrical testing is performed on Sentry 21 and MegaTest MegaOne VLSI testers. Table 2 delineates Ford's foundry charges.

Ford Microelectronics is a full-service supplier of GaAs digital and analog standard, semicustom, and full-custom products. The company reportedly is establishing an E/D GaAs IC alternate source agreement and capability in conjunction with Vitesse Semiconductor of Camarillo, California.

Table 2

Ford Microelectronics, Inc.
FOUNDRY CHARGES

E/D Gate Array, 1,000 equivalent gates	
NRE and 10 prototypes	$75,000
Custom Foundry, E/D SAGFET	
Foundry Kit	$24,000
Engineering Consultation	$ 3,000
5 Wafer Minimum	
First 25 wafers	$ 7,000 each
Next 25 wafers	$ 6,000 each
Next 50 wafers	$ 5,000 each
Over 100 wafers	Negotiable

Source: Ford Microelectronics

GAIN Electronics Corporation

GAIN has placed in operation a 55,000-square-foot facility including a foundry at Branchburg (near Somerville), New Jersey. Initially, the foundry services are based on GAIN's E/D process; migration to SDHT structures is planned. The company recently introduced a 3,456 E/D gate array based on its proprietary GFL device architecture. Design tools are Mentor/Apollo based.

The GFL35000 features E/D processing, 100ps gate delays, 250uW/gate p_d and 140 I/Os that may be ECL or TTL/CMOS compatible. NRE costs are competitive. GAIN states that the production cost of its array is less than twice that of equivalent-density ECL arrays.

GigaBit Logic

GBL has developed a standard cell library for custom digital designs to support chips of up to 4,000-gate density. GBL states it chose D-MESFET technology for this family because it has obtained yields of over 35 percent on 14,000-transistor, 28,000-component circuits at its Newbury Park, California, facility. The macrocell family offers gate delays of less than 100ps and flip-flop toggle rates above 2 GHz. Foundry charges are $50,000 for two prototype runs and $35,000 per production run at eight wafers per run.

Harris Microwave Semiconductor, Inc.

In April 1987, Harris Microwave Semiconductor, Inc., announced the availability of a library of GaAs standard cells for semicustom digital designs. The process is Harris' proprietary DIGI-2, 1u MESFET using two-layer metal; t_{pd} is typically 280ps/cell at 10 to 40mW/cell ps. I/Os consume 11 to 88mW each and may be ECL, TTL, CMOS, and GaAs compatible. The cells range in complexity from two-input NAND gates to a two-bit full adder.

Harris' CAD/CAE tools are a modification of tools developed by Silicon Design Automation for the ASIC business. Other tools include a logic simulator, developed by SIMUCAD, and place-and-route software. The system is UNIX-based and runs on the Harris MCX-3, Sun 3/160, Apollo, Masscomp, and other workstations.

Harris states that a typical prototype digital chip design effort costs approximately $60,000, which includes a CAE user's manual, cell library manual and 25 packaged, tested prototypes. The company plans to expand the existing library of 38 standard cells during 1987. Harris' Milpitas, California, facilities include a 0.5u foundry that also supports custom MMIC production. Cost for a prototype two-wafer run for MMICs is similar to that for a prototype digital run.

Honeywell

During a recent major reorganization of Honeywell operations, the company consolidated its GaAs activities into the corporate R&D center at Minneapolis, Minnesota, under the direction of Dr. Richard Cirillo, GaAs Department Program Manager. New opportunities are being addressed on a case-by-case basis. A spokesperson stated that the Richardson GaAs facility has been transferred to the control of the Opto Division of Honeywell.

ITT

ITT's Roanoke, Virginia, GaAs Technology Center (GTC) offers MMIC and high-speed digIC foundry support on a limited basis for military and commercial applications. Foundry charges are negotiable.

M/A-COM

M/A-COM has one of the largest GaAs foundry production facilities available, exceeding 90,000 square feet. The company primarily supports MMIC designs, and offers processing to 0.8u, 0.5u, and 0.25u design rules. Wafer runs processed to 0.8u fab cost $25,000; processing to 0.5u rules costs $30,000 per run. Mask charges usually involve 9 to 14 levels at $1,200 per level. Special testing and other services are negotiable.

Plessey

Plessey's Three-Five Group offers its F1 foundry process based on D-MESFETs with 0.9u nominal gate length. Available circuit elements include FETs, diodes, resistors, capacitors, and inductors. Cost is approximately $40,000 for a design manual that includes a description of standard components and $14,000 per wafer run. Plessey prefers projects that require at least two to five runs per year.

Rockwell

Rockwell's Microelectronics Research and Development Center (MRDC) pioneered the development of GaAs materials and ICs. Its 41,000-square-foot Newbury Park facility near Thousand Oaks, California, is equipped to produce 250 3-inch wafers per week per shift. Foundry operations started in August 1985, initially supporting D-MESFET designs including LSI density chips. HEMT and HBT processes are in development. Calma and Daisy Chipmaster systems are in place; additional design tools are added as needed. Foundry charges are negotiable.

Tachonics

A subsidiary of Grumman, Tachonics has established a GaAs IC standard product and foundry facility in Plainsboro, New Jersey, with initial capacity of 300 3-inch wafer starts per week. The company is developing a fully self-aligned gate E/D digital process and a 0.5-micron microwave process. The digital capability includes a cell library based on typical gate speed-power characteristics of 100ps/500uW. Tachonics will provide workstation capability and support for Mentor workstations on the Apollo network.

Texas Instruments

In April 1987, Texas Instruments announced availability of MMIC foundry services at its Microwave Military Components Division (MMCD). The division has an 8,000-square-foot fab that runs three process profiles on 3-inch wafers. The 0.5-micron processes are each optimized with special characteristics, such as low noise high gain or high power intermediate gain. Texas Instruments offers a training course to familiarize designers with design runs, process parameters, and circuit examples. Pricing of Texas Instruments' foundry services is available from the factory.

TriQuint

TriQuint offers its foundry customers Q-chip, multiproject chip, full custom, and ASIC services. Full-custom charges for customer-designed chips range from $42,000 for a 1-micron D-MESFET design to $60,000 for a 1-micron E/D design. These charges include design manual, mask making, and first prototype wafer run. ASIC charges for TriQuint designs to customer specifications are negotiable.

The company charges $55,000 for first 5 to 10 Q-chip samples, including design manual, standard cells on Daisy equipment, and evaluation board. Multiproject wafer cost is $9,900 for MSI-density design samples.

TriQuint periodically offers multiproject chip design courses, such as the two during March 16-20, 1987, in Portland, Oregon. The courses were led by 14 of their expert staff who had a combined engineering experience of more than 190 years. The microwave design course typically consists of lectures on design logistics, GaAs processing, circuit models and SPICE modeling, chip design, packaging, testing, and reliability. The digital design course is similar, focusing on E/D processing, digital IC design, and standard cells. Informal design consulting is included in each course. TriQuint offers each of the attendees the opportunity to successfully specify, design, and evaluate samples of a custom state-of-the-art GaAs IC.

Vitesse Semiconductor Corporation

Vitesse's facilities in Camarillo, California, include an E/D foundry. The company has demonstrated production capability in such standard products as the VE29G01, a GaAs equivalent of the popular silicon 2901 4-bit microprocessor slice. Vitesse's foundry has implemented a proprietary process called VEGA (Vitesse E-D GaAs), a 1.25-micron, enhancement/depletion mode self-aligned, nine-mask process featuring three levels of interconnects and subloop gate delays. Figure 1 illustrates a typical Vitesse and customer relationship and flow chart for a typical foundry project.

Vitesse has a one-time setup charge of $33,000 per design for a typical nine-layer chip. V-SPICE software, rule-check software, and a design guide cost $5,000. Engineering consultation costs $100 per hour. Processing cost for the first five wafers is approximately $6,000 per wafer; charges for more than five wafers are negotiable.

Figure 1

FOUNDRY-CUSTOMER INTERFACE AND PROJECT FLOW

Source: Vitesse Semiconductors

DATAQUEST CONCLUSIONS

The GaAs industry clearly has an abundance of capacity to support MSI/LSI density digital and microwave analog custom and semicustom IC production. Substantial advancement in yields and level of service have been noted over the last year. Commercially viable products are increasingly evident in the many multiproject wafer and semicustom activities now under way throughout this industry. The infrastructure is rapidly evolving to provide CAD tools and other necessary support. GaAs foundries represent a valuable resource that can be used by electronic systems houses to maintain or regain leadership positions in their respective markets.

Gene Miles

Dataquest

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Research Newsletter

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1987-9

GaAs TEAMS, AGREEMENTS, PARTNERSHIPS, AND ACQUISITIONS

SUMMARY

A natural consequence of GaAs technology development in the United States is the increasing number of partnerships, agreements, mergers/acquisitions, joint ventures, and team efforts. This newsletter summarizes some of the major such actions in this industry.

MIMIC PROGRAM

The DOD MIMIC (millimeter-microwave IC) initiative represents a major effort to incorporate the advantages of compound semiconductors into a variety of military applications. These applications include:

- Ultrareliable radar for the U.S. Air Force ATF
- Shared-aperture radar for the U.S. Navy ATA
- MILSTAR network communications terminals
- Smart munitions
- Wideband jammers
- Antiradiation missiles
- Other "brilliant" weapons

The MIMIC program entered Phase 0 early in 1987 with the award of 12 major and 4 smaller contracts to prime contractors. Table 1 is a compilation of the responsible services, prime contractors, approximate amounts of awards, and team members involved in the major Phase 0 contracts. Additional awards went to Hittite Microwave ($500,000), Ball Aerospace ($497,000), E-Systems ($100,000), and Lorål ($100,000). Funding for the remainder of the seven-year program recently was estimated at more than $530 million. Dataquest believes that Phase I of MIMIC will see some realignment of the participants, as the program becomes more competitive and the number of teams decreases.

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Table 1

MIMIC PHASE 0

Service	Army			
Prime Contractor	Eaton	ITT	Martin Marietta	TRW
Award ($K)	886	995	986	1,000
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T				
Avantek				
Cascade			X	
Cominco				
Compact Software				
Consilium				
Cornell University				
EEsof			X	
General Dynamics				X
General Electric				
Harris			X	
Honeywell				X
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics		X		
Rockwell				
Singer				
Spectrum			X	
Teledyne Ryan				
Texas Instruments			X	
TriQuint				
Varian				
Watkins-Johnson		X		

(Continued)

Table 1 (Continued)

MIMIC PHASE 0

Service	Navy			
Prime Contractor	Bendix	Ford	Raytheon/TI	Sandecs
Award ($K)	751	1,000	999	981
Team Members:				
Adams Russell				X
Aerojet			X	
Airtron (Litton)			X	
Alpha Industries				
AT&T				
Avantek				
Cascade				
Cominco				
Compact Software			X	
Consilium			X	
Cornell University				
EEsof				
General Dynamics			X	
General Electric				
Harris				
Honeywell				
Lockheed				X
M/A-COM		X		
Magnavox			X	
Motorola				X
Norden (United Technologies)			X	
Pacific Monolithics	X	X		
Rockwell				
Singer		X		
Spectrum				
Teledyne Ryan			X	
Texas Instruments				
TriQuint	X	X		
Varian				X
Watkins-Johnson				

(Continued)

Table 1 (Continued)

MIMIC PHASE 0

Service	Air Force			
Prime Contractor	Harris	Hughes	UNISYS	Westinghouse
Award ($K)	748	998	953	989
Team Members:				
Adams Russell				
Aerojet				
Airtron (Litton)				
Alpha Industries			X	
AT&T		X		
Avantek				X
Cascade				
Cominco				X
Compact Software				
Consilium				
Cornell University	X			
EEsof	X			X
General Dynamics				
General Electric	X	X		
Harris		X		
Honeywell				
Lockheed				
M/A-COM				
Magnavox				
Motorola				
Norden (United Technologies)				
Pacific Monolithics				
Rockwell				X
Singer				
Spectrum				
Teledyne Ryan				
Texas Instruments				
TriQuint	X		X	X
Varian			X	
Watkins-Johnson				

Source: Dataquest
August 1987

Pacific Monolithics/TriQuint

TriQuint has performed well as Pacific Monolithics' primary foundry, supplying processed wafers to mutually acceptable specifications. Dataquest believes that this relationship led to some of the specific teaming on the DOD MIMIC program (see Table 1).

Pacific Monolithics/COMSAT LABS

In July 1987, Pacific Monolithics announced it had signed an exclusive agreement with COMSAT Laboratories of Clarksburg, Maryland, to develop and pursue products and markets for power and millimeter-wave MMICs, and to seek Phase I through III contracts under the DOD MIMIC program. Pacific will provide design and marketing skills; COMSAT will contribute 30-GHz MESFET foundry capability. The agreement is also intended as a vehicle for exploring additional business opportunities in monolithic and millimeter-wave devices.

Rockwell/IBM

Early in 1987, Rockwell International and IBM entered into an agreement for the cooperative development of high-speed digital and optoelectronic GaAs devices for future computers and telecommunications equipment. The program involves Rockwell's GaAs pilot line at Newbury Park, California; Rockwell development teams at Newbury Park and Thousand Oaks, California; and IBM development teams at East Fishkill, New York; and Yorktown Heights, New York. Dataquest believes that this agreement positions IBM to take a leadership role in GaAs digIC (digital integrated circuit) applications.

Cray/GigaBit

For about three years, Cray Research, Inc., has been working with GigaBit Logic, Inc., to develop a reliable source of GaAs devices for use in a Cray-3 computer. Early in 1987, Cray increased the amount of its order for GigaBit GaAs IC chips to be delivered in 1987 to $5.2 million. Dataquest believes that this agreement allows Cray to redirect its internal GaAs capability toward development of HEMT, E/D MESFET, or other high-speed technology. Cray Research participated in GigaBit Logic's round 3 financing in May 1987, along with Analog Devices, Inc., Digital Equipment Corporation, and others.

AMD/Vitesse

In 1986, AMD and Vitesse agreed to a technology exchange involving AMD's 2900 bit-slice family and Vitesse's E/D MESFET GaAs technology. The effort resulted in Vitesse's announcement of its 29G01, 29G10 and other GaAs bit-slice products late in 1986.

GigaBit/Seattle Silicon

GigaBit and Seattle Silicon Corporation have developed a 4-bit ALU that is functionally equivalent to the 100181, a 100K ECL chip. Design engineering support was provided by the Washington Technology Center (WTC). The chip is 5.7 times faster than its silicon counterpart and consumes half the power.

GigaBit/Prisma Corporation

In July 1987, GigaBit and Prisma Corporation announced an agreement to produce a complete family of custom GaAs logic and memory digICs for use in Prisma's new family of real-time supercomputers. The machine architecture is based on a 32-bit RISC structure. Under the agreement, Prisma will design the ICs to GigaBit's newly released HME/D (high-margin enhancement/depletion) process, which is characterized by sub-100ps gate delays at power levels significantly lower than those of silicon ECL gates.

Ford/Vitesse

Ford Microelectronics, Colorado Springs, Colorado, and Vitesse Semiconductor Corporation, Camarillo, California, are establishing an E/D self-aligned gate GaAs IC alternate-source agreement and capability. Initially, the agreement includes custom and semicustom circuits, but it may be extended to standard products. Dataquest believes that Ford has successfully processed wafers containing gate array chips to mutually agreed-upon design rules.

Microwave Technology, Inc./Monolithic Microsystems, Inc.

In June 1987, Microwave Technology, Inc., Fremont, California, completed its acquisition of Monolithic Microsystems, Inc., of Santa Cruz, California. Under the agreement, Monolithic Microsystems will become a wholly owned subsidiary of Microwave Technology and will continue manufacturing at its present 8,200-square-foot facilities.

TRW/TriQuint

TRW Components International (a subsidiary of TRW, Inc.) and TriQuint have agreed to jointly supply GaAs devices for space applications. The companies are working together on procedures for producing Class S-level GaAs components. TriQuint will provide foundry support.

Ciba-Geigy/Spectra-Physics

In June 1987, it was reported that Ciba-Geigy had signed a definitive agreement to acquire Spectra-Physics for $266 million. A prior lawsuit seeking to enjoin Ciba-Geigy's initial (reportedly hostile) takeover offer was reported as being dismissed without prejudice by the Delaware Federal Court. Dataquest believes that this acquisition will strengthen Ciba-Geigy's ability to participate in the GaAs industry infrastructure.

California Micro Devices/Tachonics

A June 1987 announcement stated that California Micro Devices, Milpitas, California, has formed an alliance with Tachonics, Plainsboro, New Jersey, to produce a family of GaAs ASICs for military applications. Tachonics is a subsidiary of Grumman Aerospace Corporation of Bethpage, New York.

Amoco/Spectra Diode/Kodak/Litton Airtron

Amoco Laser Company, a wholly owned subsidiary of Amoco Corporation, has formed a strategic alliance with Eastman Kodak, the Airtron Division of Litton Industries, and Spectra Diode Labs to support Amoco's laser systems product line. Kodak provides production support, Litton Airtron supplies wafers, and Spectra Diode makes the semiconductor lasers. Amoco intends to use this alliance to pursue communications, projection TV, reprography, and other commercial and military applications.

Thorne-EMI/Varian

TEV is a United Kingdom-based joint venture of Thorne-EMI Electronics (United Kingdom) and Varian Associates (United States). The company supplies tubes for broadband EW and expendables for military applications. TEV also is developing 70 to 80mW 90-GHz oscillators for missile-seeking mortars (smart munitions). The company is focusing on applications in earth resources satellites and SARs (synthetic aperture radars).

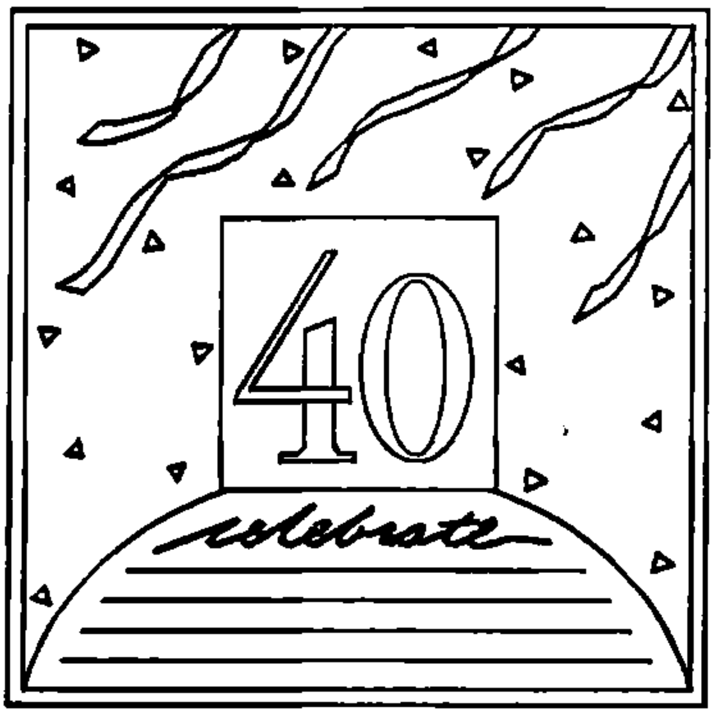
DATAQUEST CONCLUSIONS

The interaction of GaAs industry participants is intensifying as this industry moves ahead, with national objectives as much a part of the scenario as they were in the silicon world 15 years ago. Interestingly, the majority of large computer houses have remained silent about their GaAs technology plans. The commercial marketplace now has IBM to consider, and one has to wonder how long IBM's competitors have left to refine their strategies and to take viable positions, either with GaAs merchant suppliers or by acquisition, or both.

Gene Miles

Mark your calendars now!

Semiconductors' Midlife Crisis



1987 Semiconductor Industry Conference

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GATA Code: Newsletters
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ANOTHER APPLICATION FOR GALLIUM ARSENIDE: LOW-COST COLLISION-AVOIDANCE RADAR

SUMMARY

Low-cost collision-avoidance radar, a new application for gallium arsenide semiconductors, can significantly improve motor vehicle safety. One company, Vehicle Radar Safety Systems, Inc., is already producing a $900 unit, and development activity among other companies and major auto makers is intense.

We expect widespread use of this equipment on passenger automobiles by the mid- to late 1990s. We believe that this will create a high-frequency GaAs circuits market that will exceed today's military market.

This is another example of a new application for gallium arsenide that is emerging as designers become familiar with the unique properties of the material. Gallium arsenide devices originally were developed for high-speed supercomputing applications, but now designers are realizing that these devices can also be used for high-temperature, radiation hard, and ultrahigh frequency applications.

BACKGROUND

More than two years ago, companies such as Pacific Monolithics developed low-cost (less than $10) GaAs ICs for satellite downconverters in TVRO applications. This and similar efforts in discrete GaAs have resulted in production-worthy GaAs chips, which in turn have made possible low-cost Doppler radar units. By adding a nominal amount of DSP hardware, such units can provide collision-danger warning signals to the driver of an automobile or other vehicle. Functions such as a Gunn diode oscillator, power amplifier, mixer, receiver low-noise amplifier (LNA), filters and, if required, an A/D converter, are easily implemented with GaAs. Other functions in the unit, including DSP, can be built with silicon devices as can the filters and A/D converter (depending on operating frequency).

DEVELOPMENT PROJECTS

The following paragraphs discuss the current collision-avoidance projects.

Battelle

Battelle has recently developed a millimeter-wave radar concept for vehicle collision-avoidance systems. The proposed system operates at a frequency between 35 and 95 GHz, has a beam-steerable antenna, uses FM/CW (frequency modulated, continuous wave) Doppler radar circuitry, and requires a 10Mb/second computer for DSP. Battelle estimates the prototype funding requirement at approximately $750,000.

Daimler-Benz

The European Prometheus project, launched in 1986 by Daimler-Benz, includes development of a collision-avoidance system. A spokesman for Daimler-Benz estimates that the Prometheus system could reduce European traffic casualties by a factor of two within 15 years. The project involves more than 15 European auto producers and at least 50 research organizations throughout Europe.

Nissan

Nissan Motor Corp. is developing a system using two pulse-Doppler transceivers and an on-board computer to detect danger conditions ahead. Progressive audible alarms will alert the driver as conditions change.

Ford

In the United States, the Ford Motor Company and GM/Hughes are working on collision-avoidance systems for vehicles. These companies had not announced availability dates for any such products as of press time.

DATAQUEST CONCLUSIONS

GaAs semiconductors have unique properties that lend themselves to heretofore unrealized applications. Automotive collision-avoidance radar is a prime illustration of innovation made possible by GaAs technology. Other examples are:

- Fiber-optic transceivers
- High-speed, high-resolution color-graphics mux/demux functions
- The Cray-3 supercomputer

- Multi-GHz satellite communications links
- Hall-effect sensors for automotive brakes and other high-temperature environments
- Low-cost TVRO chips

Dataquest believes that the semiconductor industry has an exciting opportunity for growth in the emerging market for vehicular collision-avoidance radar. A major contribution to highway and street safety can be made by those manufacturers that excel in this marketplace.

Gene Miles

GaAs ICs MOVE INTO PRODUCTION

The young GaAs IC industry, no longer an infant, is walking well and learning to run. Recent presentations, announcements, and product displays at the GaAs IC Symposium (Portland, Oregon) and Government Microcircuits Applications Conference (GOMAC) (Orlando, Florida) emphasized the movement of production-run GaAs ICs into prototype and preproduction systems. Of particular interest to present and prospective GaAs IC buyers is the usage of more than 50,000 GigaBit Logic (GBL) GaAs ICs per Cray-3 computer CPU, with delivery and installation running ahead of schedule. This newsletter examines the recent progress in GaAs IC development for current and near-future production systems applications.

THE RACE IS ON

Cray Research Company's Cray-3 supercomputer uses 48,000 GaAs gate array chips, of approximately 200- to 300-gate density, and 4,000 GaAs register file chips, each containing a 64x4 SRAM. Address access time for the file register is 1.5ns, and on-chip gate delay of the gate array chips is 150ps. Cray chose this level of density for the IC devices to maintain a very conservative design philosophy; one result of this approach is the prototyping of the system two months ahead of an aggressive schedule.

Earlier this year, Cray discontinued captive production of GaAs chips and awarded a sole-source contract—which exceeds $5 million for 1987—to GBL. Thus, Cray is ahead in the race to take advantage of GaAs in production of supercomputers, and GBL is the leading supplier of GaAs ICs to this market.

Another supercomputer house, startup Prisma Inc., is building a GaAs-based real-time scalar supercomputer. Prisma is using a 32-bit RISC architecture and expects 150- to 250-mips performance. Such throughput is expected to command system pricing from $500,000 for a single-processor machine to approximately $5,000,000 for a four-processor, 64-Mbyte version. GBL is supplying GaAs ICs to Prisma.

Dataquest notes that the 1987 GaAs IC conference was attended by a large number of persons from Amdahl, CDC, Digital Equipment, Fujitsu, IBM, Unisys, and several other computer houses. This may indicate a further acceleration of GaAs IC usage in high-performance commercial EDP systems.

MORE RISCs ARE ON THE WAY

Reduced instruction set computer (RISC) architectures have heretofore been dominated by silicon chip sets, and this trend will continue where computational speed is less important than system cost. However, GaAs (or GaAs-on-Si) technology offers higher performance at lower power and other attributes that are appropriate to many RISC applications, especially DSP.

CDC, McDonnell Douglas, and RCA are developing RISC architectures designed to take advantage of one or more properties of GaAs. CDC's GaAs RISC architecture is believed to incorporate a set of 66 instructions; the others have less than 64 instructions each. CDC's GaAs chip complexity is 10,000 gates each, and three chips comprise the CPU. McDonnell Douglas is using E-JFET processing and device complexity on the order of 20,000 transistors. The RCA microprocessor uses E/D MESFET technology. All three companies' GaAs RISC computers are designed for DSP applications.

PROGRESS IN GaAs MEMORIES

Several companies have recently demonstrated manufacturable 4K and 16K GaAs SRAMs. The performance and other salient characteristics of the devices indicate the nature of the end equipment usage. The Japanese chips are speed-oriented at the expense of power, radiation hardness, and other parameters. These devices are expected to be used by Amdahl in the United States and by Fujitsu, Hitachi, NEC, and other Japanese large-scale mainframe houses in Japan.

One company, NTT, has built and tested GaAs ROMs. Details of many of the GaAs SRAMs and the NTT ROM are highlighted in the following paragraphs and in Table 1.

Table 1

GaAs IC Memories

Company	Type	Part Number	t_{aa}	P_d	Comments
Ford	256x4 SRAM	41G01	3ns		Latched address inputs and data I/Os
Ford	Dual port 64b SRAM	41G06	3ns	1W	ECL 100K-compatible 28-pin LCC
Fujitsu Labs	1Kx4 SRAM		0.5ns	5.7W	E/D DCFL HEMT; 0.5u gate Die size 2.8 x 3.6mm^2
GigaBit	16x4 SRAM	10G030	1ns		0.5ns write cycle; 3-port reg. file
GigaBit	256x4 SRAM (registered)	12G014	2.5ns		ECL-compatible
Hitachi CRL	4K SRAM		1ns		60-80fC critical charge 0.7u gate length
McDonnell Douglas	1Kx4 SRAM		10ns	200mW	Complementary E-JFET; 18mW standby power
Mitsubishi LSI R&D Lab	4Kx4 SRAM		11ns	1.0W	1.0u E/D DCFL SAG MESFET dual-layer metal; die size 5.79 x 4.73mm^2
NTT Labs	512x8 ROM		1.2ns	3.75W	0.5u-gate E/D DCFL; ECL-compatible
Rockwell	16K SRAM		25ns	200mW	D-MESFET, 40 x 40u^2 cell Works at -60 to +90°C
Vitesse	1K SRAM	VS12G422T	4ns	1W	Pin-compatible with TTL 93422 SRAM; 22-pin ceramic.
Vitesse	1K SRAM	VS12G422E	3ns		Pin-compatible with ECL 100422
Vitesse	4K SRAM		3ns		ECL-compatible; available 4Q1987

*Blank spaces indicate information did not exist or was not available at press time.

Source: Aztek Associates

Japan's MITI Continues Sub-ns and Low-Voltage SRAM Development Support

Fujitsu Laboratories, Ltd., (owned by Fujitsu, Ltd.) Atsugi, Japan, has implemented a 500ps address-access-time 1K x 4 SRAM using GaAs E/D DCFL HEMT processing with 0.5u gates. Chip power dissipation is 5.7 watts; die size is 2.8 x 3.6mm^2.

Hitachi Central Research Lab, Tokyo, Japan, has fabricated a GaAs 4K SRAM with 1ns access time. The Hitachi MESFET process uses 0.7u gate lengths, resulting in cells with 60 to 80fC critical charge.

A low-voltage 4Kx4 GaAs SRAM is in development at Mitsubishi's LSI R&D Laboratory, Itami, Hyogo, Japan. Test devices, using 1.0u E/D DCFL SAG MESFET process and dual-layer metal, operate at 1.0V power supply voltage, t_{aa} of 11ns maximum and P_d of 1.0W. The 5.79 x 4.73mm^2 die incorporates four blocks, each containing 128x32 memory cells. Cell size is 31.5 x 24um^2.

Both of the sub-ns GaAs SRAM design efforts and the low-voltage SRAM effort are supported by MITI's National R&D Program on Scientific Computing Systems.

GigaBit, Rockwell, and Vitesse SRAMs

GigaBit and Vitesse are producing ECL-compatible GaAs SRAMs, and Vitesse now offers a TTL version of its 256x4 SRAM that is a 4ns-cycle plug-in replacement for the 93422. Rockwell's presentation at the GaAs IC Symposium described a production 16K RAM designed for rad-hard applications.

The Rockwell 16Kx1 SRAM chip is the highest-density production GaAs SRAM reported to date. The device design constraints include manufacturability, low standby power, and large DC margins at the expense of speed. The chip contains more than 250,000 circuit elements. The process involves D-MESFET technology, ion-implanted channels, proton-implanted isolation, DSW lithography, RIE vias, and ion-implanted cermet resistors.

Also at the GaAs IC Symposium, Vitesse demonstrated its TTL-interface VS12G422T SRAM with 4ns t_{aa}, approximately twice as fast as its silicon counterpart. The chip is pin-compatible with the silicon standard TTL 93422 SRAM and is priced at $70.00 each in 1,000-piece quantities.

NTT Is First to Report a GaAs ROM

NTT is the first company to report a GaAs read-only memory (ROM). The company's Electrical Communications Labs (Kanagawa, Japan) has developed an ECL-compatible GaAs 512x8 ROM. The chip has t_{aa} of 1.2ns; p_d is 3.75W. The ROM uses 0.5u-gate E/D DCFL technology.

GaAs LSI GATE ARRAYS ADVANCE INTO PRODUCTION

GAIN Electronics Corporation offers a family of gate arrays including its GFL6000. This product is a 5,776-gate array with 204 I/O buffers, 3 watts of maximum power dissipation, and unloaded gate delays of 100ps. The I/Os may be CMOS-, TTL-, or ECL-compatible. Package options include LCC and PGA. The company is processing production orders for its gate arrays products.

A 6,000-gate GaAs gate array was developed by Toshiba VLSI Research Center at Saiwai-ku, Kawasaki, Japan, as part of the MITI Scientific Computing Systems Program. The array uses a conventional SCFL structure to implement 232 rows by 26 columns of cells. A test structure with serial-parallel-serial registers occupying 80 percent of the die consumed 952mW when operated at a 850-MHz data rate. Die size is 8 x $8mm^2$.

In late September, TriQuint announced the availability of a 3,000-equivalent-gate GaAs gate array, the TQ3000, that is based on the company's Q-ED foundry process. The product uses 50 percent less power than the fastest ECL and operates at clock rates two to three times faster. TriQuint now offers throughput time of 13 to 15 weeks from customer design input to delivery of tested parts, assuming no design reiteration.

GaAs APPLIED TO HIGH-PERFORMANCE DSP

High-performance digital signal processing (DSP) applications such as transform-based algorithms are taking advantage of the superior system speed offered by GaAs ICs. General Electric and McDonnell Douglas reported GaAs DSP evaluation results at GOMAC.

Ford Microelectronics is developing a family of GaAs DSP circuits based on its E/D MESFET process. The family includes two types of SRAMs (see Table 1), a 10ns full-precision 8x8 multiplier, a 500-MHz mux/demux, serial-to-parallel converter, clock generator, comparator, and gate array chips (for customization).

GaAs RELIABILITY IMPROVES WITH PRODUCTION EXPERIENCE

GigaBit Logic, TriQuint, and others have accomplished comprehensive reliability testing of GaAs ICs. GigaBit has published an extensive booklet on reliability test results and projections for its products. At the GaAs IC Symposium, TriQuint reported results obtained from accelerated life tests of digICs and MMICs. Other reliability test results were described at the GOMAC conference.

TriQuint described accelerated life tests and gave results for more than 100,000 non-rerated device hours of operation for MSI-density GaAs ripple counters, and additional data for GaAs ASICs. The TriQuint data show that reliability improved rapidly during 1986 and 1987, with recent data indicating circuits to be 10 times more reliable than those produced six months earlier. Preliminary data for MMICs indicated results similar to the digIC test data. TriQuint concluded that:

- MESFET tests are valid indicators for GaAs IC reliability.

- Digital and microwave D-MESFET GaAs ICs exhibit median lives exceeding 200 years at 150°C channel temperature.

- Process maturity significantly enhances GaAs reliability.

- GaAs reliability is not necessarily inversely proportional to IC integration level or complexity.

RADIATION HARDNESS

A good indicator of production-worthiness of ICs for military applications is the extent to which rad-hard testing has been performed and the range of products under test. Recent papers on this subject describe a number of advances made in the hardness of GaAs ICs.

Transient radiation effects on GaAs BFL ICs have been studied by TriQuint and others. Measurements were made on NOR gates, ring oscillators, ripple counters, and gate arrays. Upset levels for transient radiation pulses of 3ns, 50ns, and 1.5us (1,500 ns) duration were investigated in terms of dosage and dose rate. Test results showed that the dose per pulse had more impact on upset level than did dose rate. The results also showed that the apparent hardness level increases with increasing dose rate.

A design constraint of the Rockwell 16K GaAs SRAM chip design was a requirement for radiation hardness. Test results indicate that an additional benefit of the hardness of the design is assurance that alpha-particle errors will be nonexistent.

Radiation hardness tests have been performed by Honeywell on GaAs ring oscillators. Degradation in transconductance was shown to be less than 4 percent at 250 Mrads (GaAs) total dose. Shift in FET threshold was less than 15 percent, several orders of magnitude better than for silicon chips. Flash X-ray exposure tests showed hardness to 2×10^{10} rads(GaAs)/s dose rate for frequency divider and digital multiplier circuits, at least one order of magnitude harder than for silicon circuits. The particular circuits under test were not designed specifically for tolerance of radiation.

GaAs ON SILICON

The first paper on GaAs-on-Si was presented by MIT researchers in 1981 in the IEEE Electron Device Letters. Since then, the potential for large-diameter wafers for GaAs manufacture and for monolithic integration of photonic and electronic functions at low cost has attracted R&D talent and investment capital.

Kopin Corporation disclosed at the GaAs IC conference that it has sampled 2-inch, 3-inch, and 4-inch GaAs-on-Si wafers to more than ten beta sites and will start shipping 4-inch production wafers by December 1987. The growth of GaAs on silicon wafers on a production basis is described by John C. C. Fan, founder of Kopin, as "the enabling technology for future GaAs market growth."

Beta sites for Kopin wafers include TriQuint, which reported satisfaction with the mechanical properties of 3-inch material. From the standpoint of interface defects due to lattice mismatch, GaAs-on-Si is believed to be equivalent to GaAs wafers for FETs and other majority-carrier devices, but inferior for minority-carrier devices such as lasers and solar cells.

Kopin's proprietary approach minimizes the propagation of lattice mismatches at the Si-GaAs interface, into the GaAs layer. Kopin starts with a variation of 1-0-0 Si wafers for processing through a series of steps including a proprietary cleaning procedure, CVD-growth of approximately 5u of GaAs, then thermal cycling to remove stress and lattice mismatches.

Other companies and groups involved in GaAs-on-Si technology include AT&T Bell Labs, Ford, GTE, Hewlett-Packard, MIT, NTT, Oki, Spire Corporation, TI Materials Science Laboratory, and the University of Illinois. Some examples are:

- TI fabricated 1K SRAMs using GaAs-on-Si in 1986.
- Ford Microelectronics is planning products that combine III-V and II-VI materials on Si substrates of up to 200mm (8 inches) diameter.
- University of Illinois researchers recently fabricated the first reported GaAs-on-Si continuous-wave (cw) lasers that operate at room temperature.

Much research is under way to determine whether GaAs-on-Si cw lasers can be reduced to practice. Should long life and reproducibility be established, GaAs cw lasers would be obsoleted rapidly by GaAs-on-Si, which would foster significant high volumes of innovative products.

ALLIANCES CONTINUE TO FORM

Another sign of the potential acceleration in growth of an industry is the teaming of companies to gain an early competitive advantage. GaAs IC suppliers are no exception, and the pace of alliance formation has quickened. Dataquest believes that these alliances will eliminate or reduce the reluctance to use GaAs at those electronics houses requiring multiple sourcing of critical technology.

The Ford ASMMIC Team

Ford Aerospace and Communications Corporation recently described a team effort to enable insertion of microwave/millimeter wave ICs into widespread system applications. The team consists of Ford Aero; Ford Microelectronics, Inc.; Singer Dalmo Victor Division; IBM Federal Systems Division; Comsat; Pacific Monolithics; and TriQuint. The approach is called ASMMIC, for "application-specific MMIC."

GaAs IC designs based on this approach have been produced and tested to 28 GHz, and new designs to 100 GHz are in process. A reduction in system integration time by a factor of three is claimed for the approach. Typical applications include communications receivers, antennas, radar, and electronic support systems.

GigaBit and Tachonics

On October 21, 1987, GigaBit Logic Inc. and Tachonics Corporation announced their agreement to second-source GaAs digital ICs developed by both companies. The two companies reported that their agreement includes:

- Transfer of logic design data bases, schematics, and test specifications
- Full support by both companies of Daisy, Mentor, and VLSI Technology workstations
- Co-development of cell libraries for future processes

Ford and Vitesse

On October 14, 1987, Ford Microelectronics, Inc., and Vitesse Semiconductor Corporation announced what both companies consider the first agreement among commercial GaAs manufacturers to provide alternate sourcing for foundry production of custom LSI GaAs E/D MESFET ICs. Ford Microelectronics' president, John R. Wallace, stated that "The agreement between Ford and Vitesse allows customers a choice of vendors and the opportunity for backup supplies." Both companies project that their GaAs technology will be used to achieve lower power, higher speed, and increased functionality in less space and at lower cost.

JAPANESE COMPETITION

In addition to the memory developments already discussed in this newsletter, Japanese companies continue to progress in many areas of GaAs chip technology. Some of their recent developments in optoelectronic ICs (OEICs), device structures, and chip functions are reviewed in the following paragraphs.

Hitachi Is Pushing OEICs to 10 GHz

Hitachi Central Research Lab (CRL), Tokyo, Japan, has fabricated a family of three OEICs. The circuits include a 4-GHz laser driver, a 2.4-GHz preamp, and a 2.4-GHz gain-controllable amplifier implemented with 0.7u-gate GaAs SAG MESFET processing. Hitachi plans to refine GaAs ICs to achieve at least 10-GHz optical transmit/receive rates.

Matsushita Builds MMICs with 0.3u Gates; GaAs Op Amp Has 63dB CMRR

Matsushita Semiconductor Research Center, Osaka, Japan, has demonstrated 0.3u-gate GaAs transistors with gain equal to 9.5dB at 12 GHz, developed for use in MMICs. The process implements self-aligned dummy-gate MESFETs.

Matsushita Electronic Research Laboratory (ERL), also located in Osaka, has demonstrated a high-CMRR (common mode rejection ratio) GaAs operational amplifier with CMRR equal to 63dB at unity-gain frequency of 150 MHz. ERL has also built a GaAs four-stage wideband MMIC amplifier. The chip operates at more than 2 GHz. Gate lengths are 1u; 2u gate-source and 4u gate-drain spacings are used. Gain is relatively flat at 23 ± 0.5dB over the operating frequency range of 0.2 to 2.0 GHz.

Mitsubishi Builds 42-GHz f_T Transistor; Prescaler Operates on Battery

Mitsubishi LSI R&D Laboratory has built a 0.5u-gate GaAs SAG-MESFET with cut-off frequency (f_T) of 42 GHz. The process has silicon-tungsten/titanium/gold gate electrodes and gold-germanium/nickel/gold ohmic electrodes at source and drain. The company developed the process to extend the performance of MMICs. Mitsubishi has also developed an LDD (lightly-doped drain) SAGFET GaAs 128/129 prescaler that operates at 1 GHz, consuming 2mA at 5V. The circuit has been packaged in plastic with no observed degradation in reliability.

NEC Develops Matrix Switch for HDTV, 50-GHz HBTs, 5-Gb/s GaAs FF

NEC Corporation, Kanagawa, Japan has developed a GaAs LSI 8 x 8 matrix switch for high-speed digital communications applications such as high-definition television (HDTV). The 3.1 x 4.1mm^2 die is packaged in 40-pin flatpack. The chip has 390 internal BFL gates and SCFL I/O buffers.

NEC Microelectronics Research Labs, Kawasaki, Japan, has developed a current-mode-logic (CML) SSI chip family using AlGaAs/GaAs HBTs formed by MBE. The structures consist of 0.15u emitters, 0.10u bases, and 0.50u collectors formed by a self-aligned fabrication process; f_T of 50 GHz has been achieved. A 17-stage ring oscillator was operated at t_{pd} of 12.3ps per stage.

NEC Compound Semiconductor Devices Division, also located in Kawasaki, has produced a 5-GHz ECL-compatible master-slave flip-flop (FF) based on an 0.8u SAG-MESFET process. The chip is intended for use in high-speed communications and instrumentation applications.

Oki Explores Side-Gating Solutions

Oki Electric Industry Company Research Lab, Tokyo, Japan, is exploring solutions to the problem of "side-gating" in an effort to increase the density level achievable in GaAs LSI circuits. Oki has proposed the use of a negatively biased p-region between devices as an effective solution.

Sony Demonstrates MOCVD-Grown HBTs and HEMTs

Sony Corporation Research Center, Yokohama, Japan, has applied MOCVD technology (previously used for laser fabrication) to the construction of GaAs HEMTs with 0.5u gates. GaAs HBTs were also grown by MOCVD.

Toshiba Builds GaAs Mux/Demux

Toshiba's VLSI Research Center, Kawasaki, Japan, has fabricated a 16:1/1:16 mux/demux chip set based on 1.2u-gate GaAs DCFL MESFET processing. The chips have ECL- and TTL-compatible I/Os, and operate at 1.4 and 1.0 GHz, respectively.

SUMMARY AND CONCLUSIONS

Dataquest has observed an acceleration in the development, manufacture, and application of GaAs technology in recent months. Production LSI-density gate arrays and SRAMs are now available. In the United States, at least two supercomputers and three RISC computers are based on GaAs CPU chips. Japan's Scientific Computer project is moving ahead with GaAs chip designs featuring performance that is unattainable in silicon at present or in the near future.

Systems houses have a broadening range of high-performance multisourced GaAs products from which to choose. GaAs is now a practical alternative to silicon ECL where superior speed is required, both for systems going into production in the near future and for retrofitting enhancements into existing systems.

GaAs technology is here to stay. Some forward-looking silicon IC suppliers have prepared for the future by adding internal capacity (through expansion or acquisition) or by aligning themselves with GaAs houses. Companies using the former approach include Mitsubishi, NEC, Raytheon, Siemens (through its acquisition of MSC), and Texas Instruments. A prime example of the latter is the AMD-Vitesse alliance, which includes high-performance bit-slice architecture. Ford Microelectronics has used both approaches, adding GaAs to its existing CMOS capabilities and establishing its second-source agreement with Vitesse.

Dataquest believes that this is just the tip of the iceberg. We expect the following industry actions in the near future:

- Major user announcements of systems and products using GaAs ICs
- Proliferation of innovative GaAs digital and linear IC (digIC and MMIC) chips moving to production status
- Possible acquisition activity
- More silicon/GaAs IC supplier strategic alliances

The time for IC suppliers to take positions in this technology is fleeting. It is apparent that those who hesitate are allowing others to decide the future for them.

Gene Miles

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GOMAC-87: "CHALLENGES FACING GOVERNMENT ELECTRONICS IN THE 1990s"

The 1987 Government Microcircuits Applications (GOMAC) conference was held in Orlando, Florida, on October 27 through 29, 1987. Approximately 1,000 attendees participated in 21 sessions on subjects ranging from IC design concepts to discontinued parts. Due to time constraints, parallel sessions were held, up to four at a time, making it necessary for those involved in defense programs to split up their delegations in order to attend as many sessions as possible. Exhibits of products, services, and capabilities of more than 30 companies were on display in an area adjoining the lecture halls. This newsletter discusses some highlights of this important conference.

VHSIC INSERTION

Progress in VHSIC insertion was reported by most of the participating companies. Many of the exhibits featured examples of VHSIC chips and their application to defense electronics systems. The presentations indicate that VHSIC technology has been applied to a wide range of hardware including ruggedized computers, imaging systems, digital signal processing (DSP) functions, and radar electronics.

SIGNAL PROCESSING

Applications of silicon or Si/GaAs IC technology to signal processing problems have been accomplished by numerous defense electronics suppliers. For example, TRW described its superchip family and presented data on its high-performance 6-bit analog-to-digital converter (ADC). The TRW ADC uses a GaAs front end to drive a silicon bipolar flash quantizer.

Bipolar Integrated Technology, Inc. (Beaverton, Oregon), presented a family of integer and floating-point DSP circuits based on its 2.0 silicon bipolar process. The company claims that the process offers the higher speeds of ECL at the VLSI functional density of CMOS.

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VTC (Bloomington, Minnesota) has developed a bipolar cell library of analog/digital cells for signal processing applications. The bipolar structures use complementary transistors with f_T of 6 GHz (NPNs) and 1 GHz (PNPs). The cell library is augmented with components for use in customization.

MIL-STD-1750A

Performance Semiconductor presented and displayed information on its 40-MHz VHSIC-class PACE 1750A system. The system is a CMOS three-chip set consisting of a central processor unit, a processor interface chip, and a memory management unit/combination support chip. The set provides system performance greater than 2 mips. Performance Semiconductor supports its PACE 1750A with a product line consisting of the world's fastest CMOS SRAMs, with chip densities ranging through 256Kx1.

Other companies presenting information on 1750A architectures and products included Allied Signal, General Electric, IBM, Loral, Texas Instruments, TRW, and UTMC.

GaAs SEMICONDUCTORS

GaAs has been applied to high-performance military electronics for several reasons, among which are frequency response and speed superior to silicon, and inherent radiation hardness. General Electric described innovations in using GaAs to implement radar transmit/receive modules.

Several companies, including AT&T, GAIN Electronics, Raytheon, TriQuint, and TRW, made presentations or displayed information about their progress in developing and producing GaAs ICs. AT&T is offering a 1-GHz divide-by-128/129 prescaler, the DG1096AX. The circuit is fabricated using GaAs E/D MESFET process and comes in 8-lead flatpack or DIP. The chip consumes less than 40mW and has TTL/MOS-compatible I/Os.

GAIN Electronics Corporation is marketing a family of gate arrays including its GFL6000. This product is a 5,776-gate array with 204 I/O buffers, 3W maximum power dissipation, and unloaded gate delays of 100ps. I/Os may be CMOS-, TTL-, or ECL-compatible. Package options include chip carriers and pin-grid arrays. The company is processing production orders for its gate arrays.

Raytheon offers GaAs IMPATT diodes for selected applications. The devices are specified to 60-GHz frequency and 10W output power, and to 44-GHz and 25W output. The devices are produced at the research division in Lexington, Massachusetts.

TriQuint is producing a 3,000-gate ASIC array called the TQ3000, which has 1,020 core cells and 64 I/Os. NRE charges are $80,000 including design manual and workstation software. The ASIC is supported by Daisy, Mentor, and Tek/CAE workstations.

TRW is developing microwave and millimeter wave ICs for communications and other defense applications. TRW, Honeywell, and General Dynamics compose one of the DOD teams developing this technology; TRW is the prime contractor for this team.

RELIABILITY AND FAULT TOLERANCE

The United States Air Force has launched a program called R&M 2000. In implementing this program, the Air Force Systems Command is challenging the electronics industry with specific goals, such as "double-R, half-M" (double the reliability and half the maintenance) and 2,000-hour MTBF for line-replaceable units (LRUs), to be met by defense contractors.

TRW summarized the historical development of fault diagnosis and presented fault-tolerant methodologies that lend themselves to present-day design activities. The discussion emphasized the need for increased focus on fault-tolerance in future designs.

Fault-tolerant software was the subject of a joint paper by Westinghouse, SRI International, and NASA. The authors described a distributed general-purpose, fault-tolerant operating system for use on VHSIC 1750A processors.

Intel reported close work between its Military Operation (Chandler, Arizona) and one of its major accounts to significantly reduce incoming VLSI reject rates. The company said it plans to extend the approach to other customers.

Lockheed described a design methodology for extending traditional fault-tolerant design techniques to analog functions. Included are techniques for self-test, self-diagnosis, and self-correction, previously used only in digital circuit design.

TESTABILITY

Honeywell made two presentations on VHSIC testability and maintainability. The first described a control function block to be included on-chip. The second described a standard design methodology for producing inherently testable systems on a consistent basis.

Teradyne has developed a tester calibration architecture for VHSIC modules. The company says the system calibration allows maintaining a maximum of ±1.5ns skew at 40-MHz frequency across more than 400 pins.

Silicon Compiler Systems described the growing importance of integrating test development into the design process. The company's exhibit included a demonstration of its automatic test generation (ATG) system.

A joint presentation was made by VTC, Inc., and Control Data Corporation describing a rad-hard standard cell testability structure. Other companies presenting information on testability included Mitre, Unisys, and UTMC.

RADIATION HARDNESS

Two of the GOMAC sessions and more than a dozen papers were devoted to radiation hardness. LockHeed, M/A-COM, Motorola, VTC, and others made presentations on this subject.

The UTMC exhibit included information on its UTB-R and UTD-R rad-hard gate array families and other rad-hard products. The UTMC products are designed to withstand these levels of radiation:

- Data sheet specification operation to $2x10^5$ rads (Si) total dose
- Functional to 10^6 rads (Si) total dose
- No upset of less than 10^9 rads (Si)/s dose rate
- Dose rate latch-up $>10^{10}$ rads (Si)/s
- Neutron fluency 10^{14} N/cm

DISCONTINUED PARTS

The life cycles of many commercial IC devices and families are shorter than those of most military electronics equipment. As the rate of technological change increases, discontinued parts generate a growing set of problems to defense contractors. Four organizations made presentations of methods useful in resolving some of these problems.

Honeywell, for example, has developed a replacement for many of the (DTL) functions that are no longer procurable. The replacement device is a 16-pin bipolar generic array. Another company, SAIC, has worked with DESC on an R&D program to develop TTL, LSTTL, ECL, linear, and other emulation devices for fabrication on a bipolar baseline process at a silicon foundry.

PACKAGING AND INTERCONNECTION

Kyocera Corporation, Kyoto, Japan, displayed state-of-the-art packages at its exhibit. The company claims world leadership in technical ceramics. One of the more exotic of Kyocera's products was a 1,700-pin grid array (PGA) of approximately 15-square inches.

Kyocera has steadily increased its account penetration in the United States and is a leading supplier to VHSIC chip houses. This raises an interesting issue regarding DOD's dependence on foreign suppliers.

Dow Corning Corporation has developed materials for implementing a novel hermetic package concept for improved chip reliability. The approach is called surface protected electronic circuits (SPEC) and involves applying multiple layers of polymeric materials directly to the circuits.

Honeywell discussed a package design that may in many instances solve the problem of having to tool separate packages to accommodate various chip designs and multiple chip suppliers. A joint paper by Interamics and Texas Instruments described a package development to support multiple VHSIC chips in a single ceramic module.

DATAQUEST CONCLUSIONS

Although much progress has been made in semiconductors for military applications, major challenges remain. The R&M 2000 initiative, requiring doubling of MTBFs and halving maintenance, is but one example.

Although great strides are being taken in domestic chip technology, it appears that the U.S. defense industry still relies heavily on a sole foreign source for large-volume production of IC packages. This is not new; the situation has existed for several years. Two questions remain:

- Is reliance on non-United States-based sources of electronic parts really a high-priority matter?
- If so, who in the industry or in Washington is responsible for working on the packaging issue, and what is the timetable for resolution?

Gene Miles
Greg Sheppard

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ASIAN GaAs ACTIVITIES IN 1987

SUMMARY

This research study, the second annual report of its type, examines many Asian organizations' activities in GaAs and other III-V compound semiconductors in 1987. The report focuses on R&D, product developments, applications, pricing, production volumes, shipment data, and related business actions.

More than 50 Asian companies and other organizations and several U.S. and European companies are referenced in this newsletter. Their activities in III-V and other compound semiconductors range from research through product sales of materials, devices, subsystems, and end-use equipment. Applications of compound semiconductors described herein are diverse, from chips costing $0.69 that are used in consumer products to laser chips selling for more than $200.00 each that are used in fiber-optic and satellite applications. Brief discussions of some of China's and Japan's activities in space are included.

1987 CHRONOLOGY AND DISCUSSION

The major compound semiconductor activities by Asian companies in 1987 are listed by month in the sections below.

January

- NTT has developed a 4-GHz wideband GaAs limiting amplifier IC with phase-shift deviation less than five degrees for use in radar receivers and in optical and space communications systems.
- NTT licensed GAIN Electronics of Branchburg, New Jersey, to build GaAs chips with NTT's SAINT (self-aligned implanted n+ transistor) process. The first product application was a 2ns 4K SRAM.

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- MITI and the Optoelectronic Industry and Technology Development Association of Japan outlined a plan to standardize 33 items of opto telecom products. Standardized items will carry the designation "JIS" (Japanese Industrial Standard). The objective is enhanced compatibility of components for fiber-optic systems.

- Prices of consumer-product-grade (CD and video disk player) LED lasers declined sharply in recent months. In Tokyo, wholesale prices for large users ranged from ¥850 to ¥950 ($5.25 to $5.86) per unit for 780nm lasers, a 5.3 percent decline in two months. Leading-edge pricing was at ¥800 ($4.94). Severe competition and resultant price erosion was anticipated throughout the year as production volumes increased. Sharp Corporation increased laser production six times since April 1986.

- Fuji Electric (Japan) and Siemens A.G. (West Germany) strengthened their relationship with an agreement to exchange hardware and technology in the areas of factory automation, semiconductors, sensors, and telecommunications.

- Stanley Electric began to supply Nissan Motor Co. with LED high-mounted brake lights for the 1987 Z-model sports cars. This is the first use of LEDs for exterior illuminators on automobiles. The initial shipment rate was 6,000 units per month. Stanley intends to pursue other auto makers worldwide, including the big three U.S. companies.

- Fujitsu marketed the FMM100FG, a SSI GaAs frequency divider for applications to 4.2 GHz. The intended applications are prescaling and frequency synthesis.

- Japan launched its MOS-1 Marine Observation Satellite. Instrumentation on board includes a radiometer using a 2,048-element CCD integrated circuit.

- NEC offered a family of discrete power GaAs FETs called the NEZ series, featuring linear output power of 37.5 dBm over the range of C through Ku band frequencies. NEC claims the devices are space-qualified.

- A line of low-noise AlGaAs/GaAs microwave discrete high-electron-mobility transistors (HEMTs) became available from Sony and features a maximum noise figure of 1.0dB at 12 GHz. The HEMTs are fabricated by metal oxide chemical vapor deposition (MOCVD) and are intended for C band through Ka band satellite and other communications applications. Designated 2SK878-1, -2, and -3, sample prices were ¥10,000, ¥8,000, and ¥6,000 ($65.79, $52.63, and $39.47) respectively.

- Japan's National Space Development Agency (NASDA) forecast expenditures of $3.6 billion by the newly formed Space Station Integrated Project Center (SSIPC). The work force is estimated at 300 engineers and is expected to exceed 500 engineers by 1992.

- Space activities in Japan included development of the 4,400-lb. ETS-6 (sixth engineering test satellite). Toshiba, NEC, and Mitsubishi are responsible for overall system design/assembly, command/communications, and solar arrays/power, respectively. Approximate awards to the three companies were: Toshiba ($100 million), NEC ($75 million), and Mitsubishi ($75 million). NASDA apportioned the awards to maintain the technical staff at each of the Japanese satellite hardware suppliers.

- February 5 was set by Japan Institute of Astronautical Sciences for launch of the 925-lb. Astro-C spacecraft into a 320-mile orbit aboard a Nissan Motor Co. MU-3S-2 launch vehicle. Sensors on board included X-ray detection circuitry.

- Japan Technical Research Development Institute began to plan a portable antiaircraft missile using a visible image infrared homing mechanism. The missile is intended for use by its ground and air forces starting in 1990. Dataquest believes the device will require state-of-the-art military-range semiconductors.

February

- Toshiba planned to present a paper describing its development of a GaAs 6K gate array, at the ISSCC in New York, NY, USA, Feb. 25-27, 1987. Toshiba's chip features 284 ps gate delay at 1 mW per gate. Other ISSCC papers included a GaAs 1 ns 4K SRAM by Mitsubishi that dissipates 1.6 W, and a GaAs 16K SRAM by Hitachi.

- Mitsui strengthened its position in semiconductors with the formation of VM Technology Corporation, a joint venture with ASCII Corporation. VM Technology is to develop a virtual MPU for use in automobiles, word processors, copiers, and other products. Annual sales for 1989 are targeted at ¥5 billion ($31 million). (Note that Mitsui is a major backer of GAIN Electronics, a GaAs startup in Somerville, New Jersey.)

- Niigata Engineering Co. and Machine Technology Inc. (MTI) of the United States agreed to establish a joint venture to produce and market semiconductor manufacturing equipment. Initial capitalization was at ¥100 million to ¥200 million ($617,000 to $1,230,000). Operation started in Tokyo in March 1987. The 1990 sales target is ¥5 billion ($31 million).

- Hitachi announced the development of a high-speed logic circuit for telecom and imaging applications using sidewall contact structure (SICOS) technology. Propagation delay is 63ps per gate. The company also announced a low-power complementary version.

- Matsushita Electric Industrial Co., Ltd., reported its development of a 415nm-wavelength (blue-light) laser by coupling an 830nm laser with a second-harmonic generator (SHG) device. The device allows compression of optical storage area by a factor of four. Matsushita integrated the two components on a single chip for use in higher-density optical disk equipment; shipments started in second quarter 1987.

- Matsushita began marketing a standard cell library of analog cells early in 1987. The library includes A/D and D/A converters, op amps, comparators, and switches.

- NEC Corporation Microelectronics Laboratory announced completion of a lithography machine capable of drawing 0.25u patterns over a 20mm-square area.

- Hitachi Electronics Engineering Company, Ltd., began booking orders for its LS-5000 wafer surface tester, capable of inspecting haze and slipline defects at 0.16u accuracy. Pricing was ¥28 million to ¥30 million ($173,000 to $185,000). The first-year sales target was 70 to 80 units.

- Nippon Kogaku K.K. began marketing an X-ray lithography machine with 0.5u resolution over the exposure range of 29mm x 29mm. The equipment is adaptable to 3- to 6-inch wafers. Nippon Kogaku's sales target for the first year was five units, each of which is priced at ¥250 million ($1.54 million).

- Osaka University's laser nuclear fusion research center reported developing an X-ray exposure system capable of drawing 0.1u features. The research group plans to miniaturize the equipment for practical use.

- Hitachi and the Optoelectronics Joint Research Laboratory announced the development of a high-speed FET using lanthanum hexafluoride (LaF_6). The breakthrough is aimed toward development of GaAs VLSIs; LaF_6 could make dramatic increases in the level of integration possible. Hitachi plans to manufacture a compound semiconductor 256K SRAM based on LaF_6 FET technology.

- ERTI, the Korean Electronics & Telecommunications Institute, planned to proceed with 38 R&D projects with a budget of W45 billion ($52 million). These include several fiber-optic projects.

March

- Samsung Semiconductor and Telecom (Korea) announced a plan to develop GaAs chips for use in next-generation systems. Raw materials are to be developed by Goldstar Cable and Samsung in Korea.

- Matsushita announced production of GaAs gate arrays slated for mid-1987. The 200- to 1,000-gate devices feature 280ps gate delays and 1.5mW-per-gate power consumption. Initial pricing was ¥50 ($0.32) per gate.

- Toshiba began manufacturing a GaAs multiplexer that operates at a 2-GHz throughput rate. The logic IC contains approximately 700 elements. The company will make the device commercially available at a later date.

- Japan's opto industry production as reported by OEITDA grew 22 percent during the preceeding year. Data for fiscal years 1985 and 1986 (ending March 1987) are shown in Table 1.

Table 1

Japan Opto Industry Production
(Billions of Yen)

	FY 1985	FY 1986
Components	¥302.1	¥ 369.5
LEDs	134.7	159.3
Photodetectors	23.9	29.3
Photocouplers	32.5	39.2
Solar Cells	10.5	12.0
Fiber-Optic Cable	54.1	67.2
Other	46.4	62.4
Optical Equipment	446.7	543.2
Optical Applied Systems	99.1	126.9
Total	¥847.9	¥1,039.6

Source: OEITDA

- NEC introduced two photointerrupter products in molded resin packages. The PS4601 and PS4602 were initially priced at ¥40 and ¥45 ($0.26 and $0.29), respectively, in quantities of 50,000. Production started at 400,000 units per month and was increased to 800,000 units per month in October 1987.

- NEC reported operating a 678nm (visible) AlGaInP laser continuously for 3,000 hours at room temperature, claiming a record for this type of device.

April

- The Electrotechnical Laboratory of the Industrial Science and Technology Agency of Japan reported development of a superlattice Hall-effect device with sensitivity equivalent to that of InSb devices. The structure consists of AlGaAs and GaAs on GaAs substrate, and features 12V output at a magnetic field strength of 10,000 gauss. Nippondenso Co. is performing application studies.

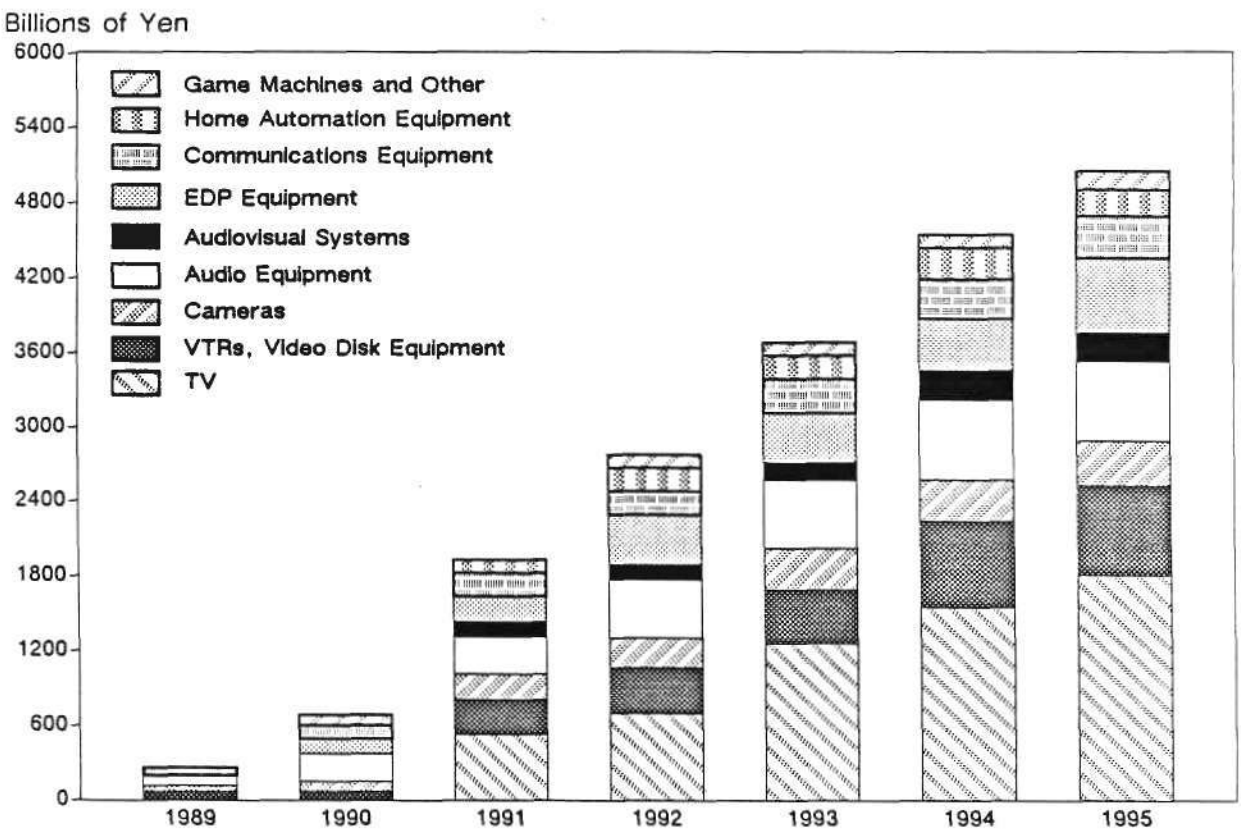
- Korea's Goldstar Cable Co. and KAIST jointly developed a process for growing GaAs crystals. The companies plan shipments of GaAs wafers to semiconductor suppliers in 1988.

- Matsushita reported a materials breakthrough for making blue LEDs four times brighter than those currently available. This was accomplished by mixing selenium, zinc, and chlorine to achieve resistance of 0.003 ohms per centimeter, one-tenth of that previously attainable.

- Electronic Industries Association of Japan (EIAJ) compiled a forecast of domestic consumer electronics through 1995. During the next 10 years, 129 new products are expected, including automatic translation machines. Figure 1 gives the details.

Figure 1

Japanese Consumer Electronics Production Forecast (Billions of Yen)



Source: EIAJ

May

- NEC began sampling five types of GaAs digital ICs (digICs) in Japan. The devices are ECL-compatible and guaranteed for operation to 2 GHz. Table 2 shows sample pricing.

Table 2

NEC GaAs DigICs

Part Number	Function	Price (Yen)	Price ($)
UPG703B	4-stage counter	¥40,000	$287.77
UPG704B	4:1 mux	¥54,000	$388.49
UPG705B	1:4 demux	¥54,000	$388.49
UPG706B	Decision circuit	¥38,000	$273.38
UPG707B	Laser driver	¥38,000	$273.38

Source: Dataquest
December 1987

- Toyota bought 8.1 percent (2 million shares) of Hamamatşu Photonics K.K., an optoelectronics company, for ¥3.8 billion ($26.6 million), assuring Toyota of a strong position in optoelectronics technology.

- Sharp Corporation reported success in forming AlGaAs superlattice lasers by MBE. The company has fabricated MQW lasers with threshold current density of 145 amps per square centimeter, stripe width of 817nm, quantum well width of 45 angstroms (15-molecule layers) and 490u resonance length.

- Toshiba exported 10 CVD units to Siemens and 1 to Korea. The company planned to export epitaxial equipment and EB writing equipment in the near future.

- IBM's new System 2 has featured as an option an optical disk memory based on a Matsushita drive and media subassembly. The write-once unit incorporates a GaAs 20mW laser diode.

- Sanyo has developed a read-write-erase laser for application in erasable optical disk hardware such as read-mostly memories for EDP systems. The chip uses three monitor diodes to control the read, write, and erase beams.

- NEC began marketing its new NE202 low-noise GaAs HEMTs in the United States via California Eastern Labs. The devices are available in chip and package form, and feature 1.0dB noise figure at 12 GHz with 12dB associated gain.

- NEC announced development of GaAs-on-InP heterostructures and successful testing of long-wavelength (1300nm to 1550nm) OEICs.

- The Japanese Defense Agency reported its fiscal 1986 (ending March 1987) procurement figures. The data is shown in Table 3.

Table 3

Japanese Defense Agency Procurement in Fiscal Year 1986

Ranking FY '86	Ranking FY '85	Company	Amount (Billions of Yen)	Percent Change from FY 1985
1	1	Mitsubishi Heavy Industries Ltd.	¥291.4	16.2%
2	2	Kawasaki Heavy Ind. Co., Ltd.	¥144.8	17.5%
3	3	Mitsubishi Electric Corp.	¥ 81.3	(23.2%)
4	5	IHI	¥ 78.2	13.3%
5	4	Toshiba Corp.	¥ 67.4	(8.0%)
6	6	NEC Corp.	¥ 48.5	19.9%
7	7	Japan Steel Works	¥ 22.2	(22.3%)
8	10	Fuji Heavy Ind. Co., Ltd.	¥ 18.2	2.9%
9	9	Hitachi Shipbuilding and Engineering	¥ 18.2	(15.8%)
10	-	Mitsubishi Corp.	¥ 17.0	-

Source: The Japan Economic Journal

- Sony's SLD300 series AlGaAs/GaAs lasers are now marketed in the U.S. The diodes feature a selection of CW power from 100mW to 1W. Packaging options are 9mm or TO-3 headers; wavelength options range from 770nm to 840nm.

June

- Fujitsu Laboratories, Ltd., has built and operated a GaAs HEMT 16-bit multiplier, achieving 4.1ns multiplication time at room temperature. The multiplier was constructed on a 4,000-gate array chip.

- Semiconductor laser prices experienced increasing pressure due to sluggish demand from CD-player makers. Volume pricing for 870nm lasers dropped to ¥500 ($3.57), a 30 percent decrease in six months. Mitsubishi reduced production by 33 percent to 400,000 lasers per month.

- At a press interview, NEC Corporation officials announced that the company would establish a compound semiconductor wafer fabrication facility within NEC Kansai, Ltd. The plant started production within 90 days of the announcement. Its first year production target is ¥10 billion to ¥15 billion ($69 million to $104 million).

- Three important high-tech exhibitions are held each May in Japan: BIOTEX, High-Tech Materials Exhibition, and Business Show. Each of these attracted approximately 100,000 attendees. Current Japanese government-sponsored projects featured at the shows are summarized in Table 4.

Table 4

Current Japanese Government-Sponsored New Materials R&D Projects

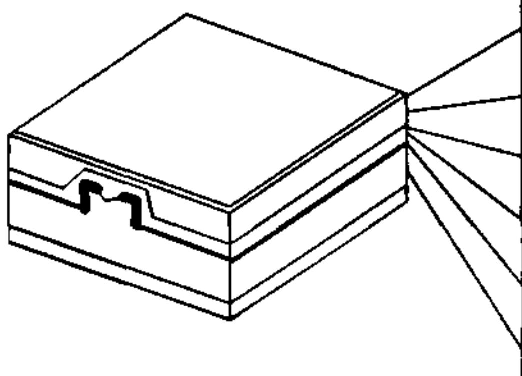
Theme	Private Organization	National Institute
Fine Ceramic	Engineering Research Association for High-Performance Ceramics (15 companies)	Government Industry Research Institute, Nagoya Government Industry Research Institute, Osaka National Institute on Research Organic Materials Machinery Engineering Lab
High Molecular Membrane for New Separation Technology	Research Association for Basic Polymer Technology (15 companies)	National Chemical Lab for Industry Research Institute for Polymers and Technology Industrial Products Research Institute
Molecular Materials	Research Association for Basic Polymer Technology (5 companies)	Electric Technology Lab Research Institute For Polymers and Technology
High-Performance Plastics	Research Association for Basic Polymer Technology (5 companies)	Research Institute for Polymers and Technology
Advanced Array with Controlled Crystalline Structure	Research and Development Institute of Materials and Composites for Future Industries (7 companies)	National Research Institute for Materials National Research Institute for Machines Government Industry Research Institute, Nagoya
Advance Composite Materials	Research and Development Institute of Materials and Composites for Future Industries	Government Industry Research, Osaka National Research Institute for Machines Research Institute for Polymers and Technology

Source: Dataquest
December 1987

- Matsushita described its GaAlAs laser designed for optical disk storage applications. It has 50mW output at 780nm wavelength, which allows increasing information storage density by a factor of 1.5 to 2.0, compared with 830nm-laser capability. The company plans to market the laser by early 1988. The structure of the laser is shown in Figure 2.

Figure 2

Matsushita's 780nm GaAlAs Laser



	High-Output Shortwave Laser	
n-GaAs	3 μm	Contact layer
n-GaAlAs	7 μm	Cladding layer
p-GaAlAs	0.04 μm	Active layer
p-GaAlAs	0.2 μm	Cladding layer
n-GaAs	2.5 μm	Block layer
p-GaAs	80 μm	Substrate

Source: Matsushita Electric Industrial Co. Ltd.

July

- According to the Japan Manufacturers' Society of Compound Semiconductor Materials (JAMS-CS), Japanese production of compound substrates totaled ¥17B ($116 million), flat for the third consecutive year. GaAs accounted for 49 percent, GaP for 42 percent, and all others, 9 percent.

- The Electrotechnical Laboratory of MITI's Agency of Industrial Science and Technology and Sumitomo Electric Industries announced that they would jointly construct a small synchrotron using superconductor technology. The machine is expected to be the world's smallest, at a diameter of 4 meters and weight of 20 tons. The laboratory plans to produce synchrotrons in volume for semiconductor makers.

- Sortec Corporation announced that it would develop synchrotron orbital radiation (SOR) equipment for use in high-resolution processing of ICs for Hitachi, Mitsubishi, Sumitomo, and Toshiba at a plant in Tsukuba. The project will cost ¥14.3B ($98 million).

- Sumitomo started building SOR equipment that will be set up in the company's opto technology research building in Tanashi, Tokyo, by April 1988. Production cost of the equipment will range from ¥1B to ¥2B ($6.8 million to 13.7 million).

- Sharp Corporation outlined a plan to increase opto device production, which includes photocouplers and interruptors, from the current rate of 40 million per month to 60 million per month. Opto devices accounted for 80 percent of Sharp's semiconductor usage, or $106 million in 1986 and $117 million in 1987.

- NTT is converting Japan's microwave long-haul telephone and television circuits to digital microwave, to be completed by the year 2000. Japan's systems today are 80 percent analog, particularly 4-, 5-, and 6-GHz bands using FDM/FM. The links between Japan and Okinawa were digitized in 1984. Table 5 provides some data on Japan's primary digital microwave systems.

Table 5

Japan's Primary Digital Microwave Systems

Frequency GHz	Capacity Per Channel Mb/s	Channel Spacing MHz	Repeater Spacing km	Modulation Method	Transmitter Power dBm
2.1-2.3	3	1.25	25	PSK	21
2.1-2.3	32	7	50	QAM	23
3.6-4.2	200	40	50	QAM	26
4.4-5.0	200	40	50	QAM	26
10.7-11.7	100	40	25	PSK	30
10.7-11.7	12.5	1.25	15	QAM	26
10.7-11.7	12.5	5	15	PSK	26
14.4-15.2	100	40	8	PSK	23
17.7-21.2	400	160	6	PSK	26

Source: Dataquest
December 1987

- Korean Semiconductor Research Association (KSRA) announced plans for six joint projects in addition to its 4Mb DRAM effort. These include GaAs ICs, standard cell ICs, compound materials, epoxy molding, and others, with a total budget of W8.6 billion ($10 million).

August

- Japan has been accelerating the process of "hollowing out" by relocating many semiconductor production facilities overseas. Compound semiconductor manufacturers in countries other than Japan should be aware of the potential competitive threat posed by these moves. Table 6 identifies Japanese overseas semiconductor plants.

Table 6

Japanese Semiconductor Makers' Overseas Plants

Company	Plant Name	Location	Year Established	Fab	Assy	Test
NEC	NEC Electronics USA	Mountain View, California	1979	-	X	X
		Roseville, California	1984	X	X	X
	NEC Ireland	Ireland	1976	-	X	X
	NEC Semiconductor U.K.	Livingston, U.K.	1982	X	X	X
	NEC Malaysia	Malaysia	1974	-	X	X
	NEC Singapore	Singapore	1976	-	X	X
Hitachi	Hitachi Semiconductor	Irving, Texas	1987	X	X	X
	Hitachi Semiconductor	West Germany	1980	-	X	X
	Hitachi Semiconductor	Malaysia	1972	-	X	X
Toshiba	Toshiba Semiconductor	Sunnyvale, California	1980	-	X	X
	Toshiba Semiconductor GmbH	West Germany	1983	-	X	X
	Toshiba Electronics Malaysia	Malaysia	1974	-	X	X
	Industrial Mexican Toshiba	Mexico	1966	-	X	X
Fujitsu	Fujitsu Microelectronics	San Diego, California	1980	-	X	X
	Fujitsu Microelectronics Ireland	Ireland	1981	-	X	X
	Fujitsu Microelectronics Asia	Malaysia	1986	-	X	X
Matsushita Electric	Matsushita Electric Singapore Plant	Singapore	1988	-	X	X
Mitsubishi	Mitsubishi Semiconductor USA	Durham, North Carolina	1985	-	X	X
Sanyo	Korea Tokyo Silicon	Korea		-	X	X
	Taiwan Tokyo Semiconductor	Taiwan		-	X	X
	Shenzhen Sanyo Semiconductor	China		-	X	X
Oki	Oki Semiconductor	Sunnyvale, California	1984	-	X	X

Source: Dataquest
December 1987

- Sharp Corporation announced the development of a 780nm wavelength semiconductor laser with 5mW maximum output. The device features an operating temperature range of -30 to +85 degrees Celsius. The company has serialized the device into four types—the LT022HC/WC (standard size) and the LT022HS/WS (small size)—and put them on the domestic market. Sample prices are ¥1,500 ($10.00) to ¥1,700 ($11.33) each. Production is targeted at 200,000 units per month.

- Matsushita Electric Industrial's Semiconductor Research Center reported the development of new superlattice manufacturing technology based on MOCVD. Early in 1988, the company plans to commercialize a II-VI compound semiconductor optical wave guide implemented in the new technology.

- A Chinese spacecraft was launched August 5 to obtain data on processing semiconductor materials in space. Tests during the five-day mission included smelting and recrystallization of alloys and semiconductor materials.

September

- NEC began marketing in the United States—via California Eastern Laboratories—eight GaAs digICs designed for DSP applications at or above 2 GHz (see Table 7). All are packaged in hermetic ceramic DIP.

Table 7

NEC GaAs DigICs

Part Number	Function	Clock Rate	Comments
UPG501B	Divide by 4	5 GHz	For 100 pieces, price each $105
UPG502B	Divide by 2	5 GHz	For 100 pieces, price each $95
UPG504B	Divide by 2	10 GHz	
UPG703B	4-stage counter	2 GHz	ECL-compatible
UPG704B	4:1 mux	2 GHz	ECL-compatible
UPG705B	1:4 demux	2 GHz	ECL-compatible
UPG706B	Decision circuit	4 GHz	Rise/fall times 100ps
UPG707B	Laser driver	2 GHz	Rise/fall times 150ps

Source: Dataquest
December 1987

- Listed as new participants in the Korean GaAs semiconductor industry were Goldstar Cable, Hanil Textile, and Samsung Corning; considered as possible newcomers were Asia Cement and Hanryo Development (photomasks), Korea Pilot (hybrids), Pochul (wafers and leadframes), and Koryo Systems.

- Fujitsu outlined plans for a new IC factory in Gresham, Oregon, that will initially specialize in ASIC fab, assembly, and test.

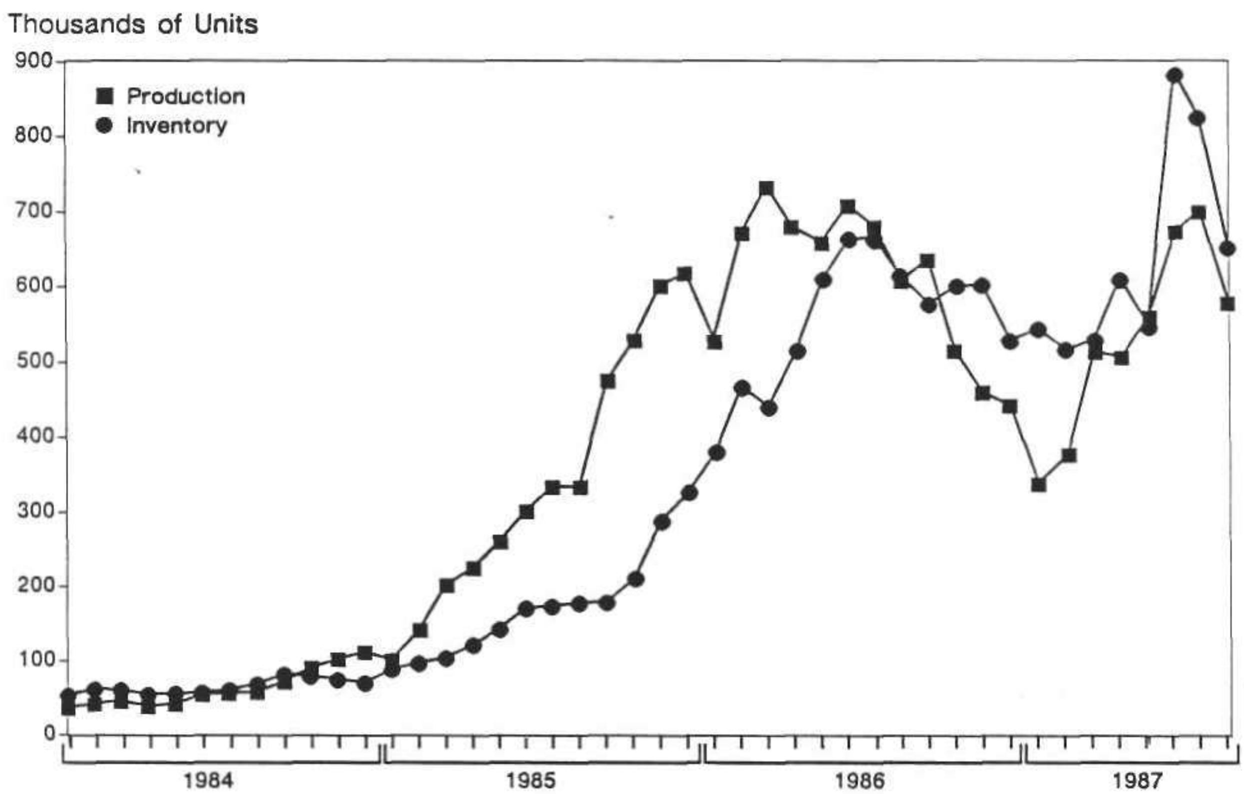
- NTT reported operating a GaAs/InGaAs heterojunction bipolar transistor (HBT) at 5.5ps delay time at room temperature, claiming a world speed record for such a device.

- Japan's ETS-5 Engineering Test Satellite was launched August 27 and achieved geosynchronous orbit on August 30. The satellite accomplished a large-scale test of the influence of space radiation on 64K CMOS SRAMs and GaAs devices. Its large semiconductor solar arrays were opened a half-day earlier than planned due to a high-temperature problem. The ETS-5 was also intended to demonstrate mobile satellite communications with ships and aircraft.

- Japan's production of CD players recovered gradually in mid-1987. Production was expected to exceed 10 million units in 1987, up 25 percent from 1985. Figure 3 plots Japanese CD player production and inventory.

Figure 3

**Japanese Digital Audio Disk Player
Production and Inventory**



Source: Dataquest
December 1987

October

- NTT developed an X-ray stepper capable of 0.2u feature-size IC production. Processing speed is 20 six-inch wafers per hour.

- NEC succeeded in forming 0.2u features using SOR, and claims it can achieve 0.1u geometries with this technology. NEC plans to use SOR in production of ICs by 1990.

- A low-voltage 4Kx4 GaAs SRAM is being developed by Mitsubishi's LSI R&D Laboratory in Itami, Hyogo, under the MITI Scientific Computing Systems Program. Test devices, using 1.0u E/D DCFL self-aligned-gate MESFET process and dual-layer metal, were operated at 1.0V power supply voltage, t_{aa} of 11ns max and P_D of 1.0W. The 5.79 x 4.73 mm^2 die incorporates four blocks of 128x32 memory cells, each 31.5 x 24 um^2.

- A 6,000-gate GaAs gate array was built by Toshiba VLSI Research Center at Saiwai-ku, Kawasaki, as part of MITI's Scientific Computing Systems Program. The array used a conventional SCFL structure to implement 232 rows by 26 columns of cells. A test structure with serial-parallel-serial registers occupying 80 percent of the die consumed 952mW when operated at an 850-MHz data rate. Die size is 8 x 8 mm^2.

- Under the MITI Scientific Computing Systems Program, Hitachi's Central Research Lab, Kokubunji, Tokyo, fabricated and tested ECL-compatible GaAs 1K and 4K E/D DCFL SRAMs. The chips have an access time spread of less than 1ns and max t_{aa} of 3ns, and use conventional SCFL interface structures for improved noise margin.

- Mitsubishi LSI R&D Laboratory, Hyogo, built a 0.5u-gate GaAs SAG-MESFET with cut-off frequency (f_T) of 42 GHz. The process has silicon-tungsten/titanium/gold gate electrodes and gold-germanium/nickel/gold ohmic electrodes at source and drain. The company developed the process to extend microwave monolithic (MMIC) performance.

- Hitachi Central Research Lab (CRL), Tokyo, has fabricated a family of three optoelectronic ICs (OEICs). The circuits include a 4-GHz laser driver, a 2.4-GHz preamp, and a 2.4-GHz gain-controllable amplifier implemented with 0.7u-gate GaAs SAG MESFET processing. Hitachi plans to refine GaAs ICs to achieve at least 10GHz optical transmit/receive rates.

- NEC Microelectronics Research Labs, Kawasaki, has developed a CML SSI logic family using AlGaAs/GaAs HBTs formed by MBE. The structures consist of 0.15u emitters, 0.1u bases, and 0.5u collectors formed by a self-aligned fabrication process; f_T of 50 GHz has been achieved. A 17-stage ring oscillator was operated at t_{pd} of 12.3ps per stage.

- Matsushita Semiconductor Research Center, Osaka, has performed testing of 0.3u-gate GaAs FETs with gain of 9.5dB at 12 GHz. The process implements self-aligned dummy-gate MESFETs. The devices were developed for use in MMICs.

- Matsushita Electronic Research Laboratory (ERL), Osaka, has demonstrated a high-CMRR (common mode rejection ratio) GaAs op amp with CMRR (common mode rejection ratio) of 63dB at unity-gain frequency of 150 MHz.

- Matsushita ERL has also built a GaAs four-stage wideband MMIC amplifier. The chip operates at more than 2 GHz. Gate lengths are 1u; 2u gate-source and 4u gate-drain spacings are used. Gain is relatively flat at 23 $\pm$ 0.5 dB over the operating frequency range of 0.2 GHz to 2.0 GHz.

- Oki Electric Industry Company Research Lab, Tokyo, is exploring the problem of "side-gating" in an effort to increase the density level achievable in GaAs LSI chips. Oki proposed using negatively biased p-regions between devices as an effective solution.

- Hitachi Central Research Lab, Tokyo, has built a GaAs 4K SRAM with 1ns access time. The process uses 0.7u gates, resulting in cells with 60 to 80 femto-Coulombs (fC) critical charge. The effort is supported by MITI's National R&D Program on Scientific Computing Systems.

- Fujitsu Laboratories (owned by Fujitsu, Ltd.) Atsugi, has implemented a 500ps address-access-time 1Kx4 SRAM using GaAs E/D DCFL HEMT processing with 0.5u gates. Chip power dissipation is 5.7W; die size is 2.8 x 3.6 mm^2. This effort is also being supported by MITI's National R&D Program on Scientific Computing Systems.

- NTT was the first company to report the demonstration of a GaAs ROM. The company's Electrical Communications Lab (Kanagawa) has developed an ECL-compatible GaAs 512x8 ROM. The chip has t_{aa} of 1.2ns; p_d is 3.75W. The ROM uses 0.5u-gate E/D DCFL technology.

- NEC Compound Semiconductor Devices Division, Kawasaki, produced a 5-GHz ECL-compatible master-slave flip-flop (FF) based on 0.8u SAG-MESFET process. The chip is intended for use in high-speed communications and instrumentation applications.

- NEC Corporation, Kanagawa, has developed a GaAs LSI 8 x 8 matrix switch for high-speed digital communications applications such as high-definition television (HDTV). The 3.1 x 4.1mm^2 die is packaged in 40-pin flatpack. The chip has 390 internal BFL gates and SCFL I/O buffers.

- Mitsubishi LSI R&D Lab, Hyogo, developed a lightly doped drain (LDD) SAGFET GaAs 128/129 prescaler that operates at 1 GHz, consuming 2mA at 5V (and therefore capable of battery operation). The circuit has been packaged in plastic with no observed degradation in reliability.

- Sony Research Center, Yokohama, has applied MOCVD technology (previously used for laser fabrication) to the construction of GaAs HEMTs with 0.5u gates. GaAs HBTs were also grown by MOCVD.

- Toshiba's VLSI Research Center (Kawasaki, Japan) has fabricated a 16:1/1:16 mux/demux chip set based on a 1.2u-gate GaAs DCFL MESFET process. The chips have ECL- and TTL-compatible I/Os, and operate at 1.4 GHz and 1.0 GHz, respectively.

- Shimazu Seisakusho began marketing 1300nm LED lasers priced at ¥30,000 ($209.79). The fiscal 1988 sales target is 10,000 units.

- Since NHK, the Japan Broadcasting Corporation, began 24-hour direct broadcast satellite (DBS) service in July, the demand for HEMTs for consumer products increased sharply. Fujitsu planned a large production boost by year end. NEC expanded HEMT production by 500 percent, and Sony increased its run rate from 10,000 per month to 100,000 per month. Mitsubishi, already producing 50,000 per month, was taking a cautious attitude.

November

- Fujitsu Laboratories, Atsugi, Japan, has been studying resonant tunneling transistors as a means of extending circuit-switching speeds beyond that of HEMT. Fujitsu researchers believe that future HEMTs will peak at 1ps transit time, and that 0.2u is the lowest practical gate length (limited by punch-through). The company has been examining both resonant hot-electron transistor (RHET) and resonant bipolar transistor (RBT) structures for possible use in future high-speed digital hardware.

- A high-speed computer in development at Fujitsu began to employ HEMT technology to implement extremely fast CPU operation. Completion is scheduled for 1990.

- Fujitsu has signed agreements in the United States and Australia to export HEMTs for use in radio telescopes. The Nobeyama Radio Observatory in Japan has used such chips since 1986 to study previously unobserved radio waves from space.

- Oki Electric Industry Co. Research Laboratory, Tokyo, has grown high-quality 4u-thick GaAs layers on (1-0-0) 50mm, 280u-thick silicon wafers, and has fabricated MESFETs, ring oscillators, power FETs and AlGaAs LEDs on the GaAs-on-Si substrates. Test results were similar to those for devices built on GaAs wafers. A company spokesperson expects Oki to manufacture monolithic ICs containing silicon ICs and optical devices for future products.

- Tokki Corporation, a factory automation house, began marketing its electron cyclotron resonance (ECR) plasma CVD machine. The technology was introduced from NTT. The machine is priced at priced at ¥40M to ¥100M ($280,000 to $690,000). Tokki plans to sell 5 to 10 units in the initial year.

- NTT has built and tested polymethylmenthacrylate (PMMA) fibers, demonstrating an attenuation loss limit near 35dB/km at 568nm wavelength. Using deuterium to replace hydrogen in the polymer, the attenuation loss was reduced to 9dB/km at 680nm wavelength, indicating a potential usage for plastic fibers in optical communications.

- Toyota Central R&D Laboratory, Aichi, has developed a negative differential resistance (NDR) device based on a 10-layer superlattice structure.

- Mitsubishi's LSI Research Center has developed a low-impedance gate GaAs FET with 42-GHz cutoff frequency for use in manufacturing MMICs, starting in 1988.

- Sumitomo claims it is the world leader in III–V semiconductor materials, offering doped and undoped polycrystal and single-crystal GaAs, GaP, InP, InSb, InAs, and GaSb ingots, substrates, and epitaxial wafers. Sumitomo has more than 200 customers, in more than 20 countries including Bulgaria, Poland, and the U.S.S.R.

- Matsushita's Wireless Research Laboratory has investigated a multiple self-aligned process for AlGaAs/GaAs HBTs. The process uses one mask for emitters, emitter contacts, emitter contact leads, buried collectors, base contacts, and base contact leads. HBTs with 1 x $20um^2$ emitters, base islands of 4 x $20um^2$, base contacts of 1.5 x $20um^2$ and oxygen ion-implanted buried collectors demonstrated f_T of 54 GHz and f_{max} of 42 GHz. Base contact to emitter spacing was 0.25u. Process refinements are expected to increase the maximum gain available cutoff frequency to a value greater than 100 GHz.

- Sony and Philips have jointly developed data formats and other standards for CD–ROMs, including preliminary mixed-mode formats. These have been issued to licensees. The specifications contribute to lowering the cost of CD–ROM mastering, which will boost the market for players and hence for III–V lasers and sensors.

- Panasonic is offering a line of CD–ROM drives and optical disk players ranging in price from $895 to $3,995, and plans to announce a 5.25-inch WORM drive in the near future. All of the units use laser diodes in the read circuitry. Recording capacity of the 8-inch (200mm) TQ–FH224 unit is 24,000 frames of standard video resolution data (approximately 540 megabytes).

- Japan expects to launch its next H–1 booster on February 1, 1988. The mission is scheduled to carry the Mitsubishi CS–3A communications satellite into geosynchronous orbit.

DATAQUEST CONCLUSIONS

The field of GaAs and other III–V compound semiconductors is advancing rapidly every year; 1987 was no exception. Asian companies are very active in the application of GaAs technology to EDP, consumer, fiber-optic communications, and satellite hardware, and continue to refine the traditional LED display devices. There is increasing competition in the worldwide IC marketplace, particularly in MMICs and digICs, with new players entering the performance race. Dataquest expects this pace of activity to continue into the 1990s as Asian IC suppliers, pressured by declining profits in silicon devices, seek out niches in III–V markets.

Gene Miles
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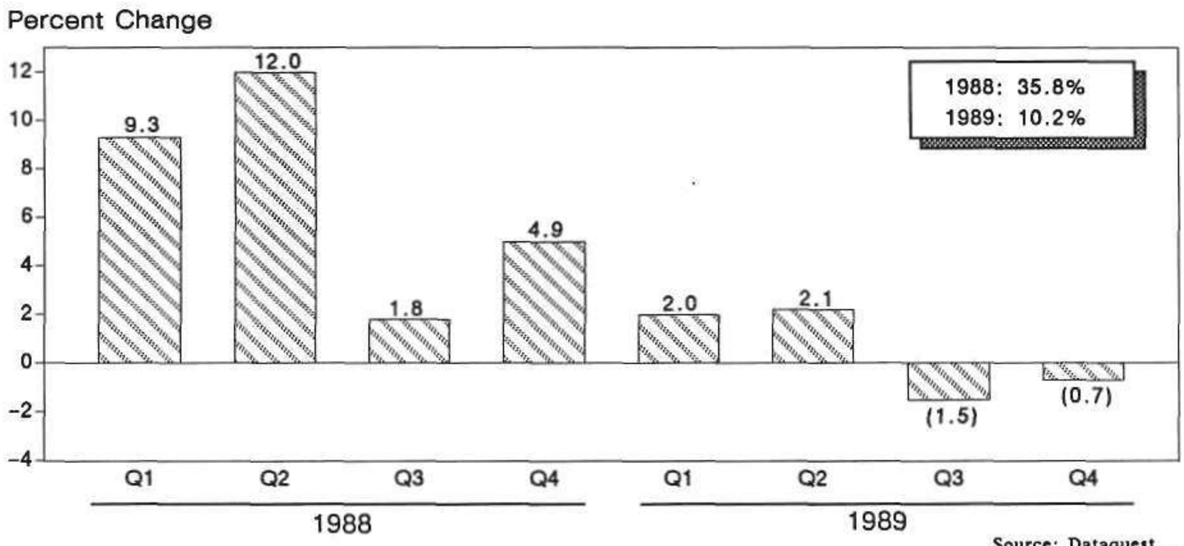
WORLDWIDE SEMICONDUCTOR INDUSTRY UPDATE: WHEN WILL THE DOWNTURN HIT?

SUMMARY

The year 1988 has been a booming one for the worldwide semiconductor industry, with estimated total growth of 35.8 percent, continuing the good times of 1987 (a year of 22.8 percent growth). During the third quarter of 1988, bookings began to soften, and many semiconductor manufacturers experienced poorer than usual August bookings. However, the existing backlog, combined with shortages in key product areas--most notably, DRAMs and SRAMs--should keep shipments strong through the end of the year. Dataquest forecasts much slower growth in the first two quarters of 1989. This slow growth will be followed by negative growth in the second half of 1989, as supply catches up with and then exceeds demand and both unit shipments and ASPs fall. The short-term forecast is summarized in Figure 1.

Figure 1

Worldwide Semiconductor Shipment Forecast



Source: Dataquest
October 1988

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WORLDWIDE FORECAST

A summary of the worldwide forecast by region is shown in Tables 1 and 2.

Table 1

Estimated Worldwide Semiconductor Market
(Billions of U.S. Dollars)

	1988	1989	1990	1991	1992	1993	CAGR 1988-1993
North America	15.7	17.2	17.5	20.4	24.8	26.7	11.2%
Japan	19.5	21.3	21.5	25.2	30.5	33.3	11.3%
Europe	8.2	8.8	8.8	9.8	11.3	12.5	8.8%
Rest of World	6.1	7.3	7.9	9.9	12.7	14.3	18.4%
Total World	49.5	54.6	55.7	65.3	79.3	86.8	11.9%

Source: Dataquest
October 1988

Table 2

Estimated Worldwide Semiconductor Market
(Percent Change, U.S. Dollars)

	1988	1989	1990	1991	1992	1993
North America	32%	10%	1%	17%	22%	8%
Japan	36%	9%	1%	17%	21%	9%
Europe	29%	7%	0	12%	15%	11%
Rest of World	57%	19%	9%	25%	28%	13%
Total World	36%	10%	2%	17%	22%	10%

Source: Dataquest
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North America

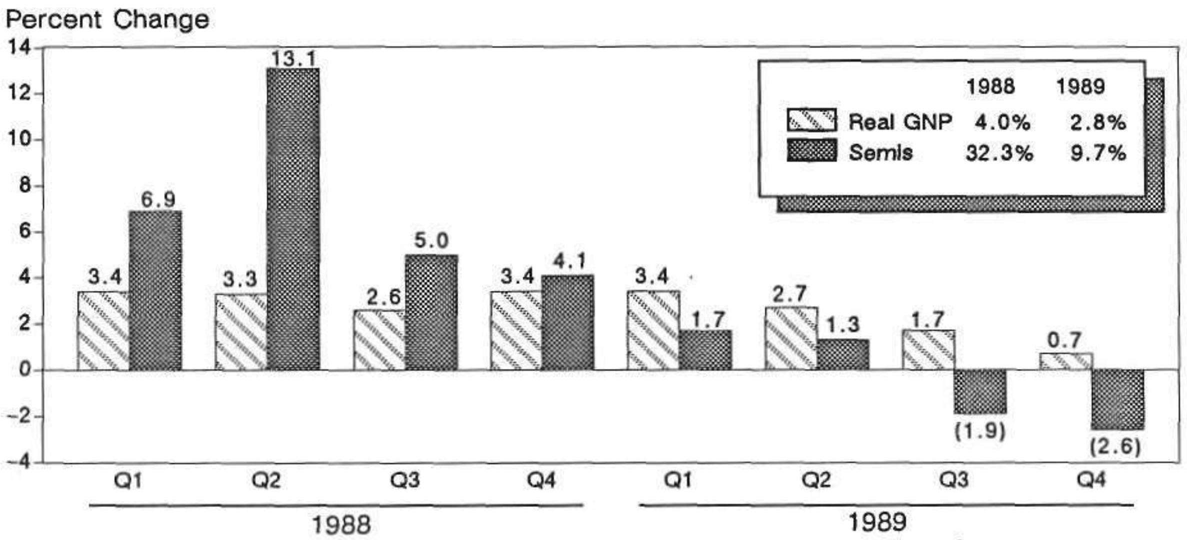
Both in the 1988 to 1989 time frame and over the long term, we believe that North America will be the second slowest growing market after Europe; through 1993, however, it will remain second largest in overall size after Japan. In 1988, North America will account for 31.7 percent of worldwide semiconductor consumption. Although capital spending in North America will increase by some 40.0 percent in 1988, this growth is modest compared with the capacity buildup in 1983 and 1984, which led to the 1985 market glut.

Historical patterns of billings and bookings show that bookings may begin to fall on a 12/12 basis any time now, but billings will not start to decline until 9 to 10 months later (i.e., mid-1989). Semiconductor inventory levels are rising, but they are being held in better check by OEMs than in 1984, due to careful tracking of target and actual inventory levels.

Dun & Bradstreet forecasts show that the U.S. economy will slow in 1989, with real GNP growth of 2.8 percent, versus 4.0 percent growth in 1988. This reduced GNP growth, combined with slower electronic equipment production growth and lowered capital expansion plans, will slow the semiconductor industry as well. We believe that the sluggishness in semiconductors will last through the first half of 1990. Figure 2 compares U.S. GNP growth with North American semiconductor consumption growth.

Figure 2

U.S. Economy versus Semiconductors



Source: Dun & Bradstreet
Dataquest
October 1988

Japan

The GNP outlook for Japan is very strong, with growth rates forecast at 4.6 percent for fiscal 1988 and 3.5 percent for fiscal 1989. We expect Japan to be the second fastest growing market after the ROW market, in both the short and long term. We expect prices to remain firm through the second half of this year, with shortages of DRAMs and SRAMs continuing at least until the first quarter of 1989 (one quarter sooner than in the United States). Although Japanese capital spending will grow 56.0 percent in dollar terms in 1988, the yen growth will be significantly lower, at 40.0 percent.

Europe

PCs are the driving factor in European semiconductor growth this year, particularly in MOS microdevices, memory, and bipolar digital logic. The PC build rate has slowed substantially, and bookings are collapsing, except for 1Mb DRAMs. We expect Europe to be the slowest growing market in the long term, and we believe that ROW will surpass Europe in dollar size in 1991.

ROW

The 1988 Seoul Olympics drove 1988 consumer demand worldwide, stimulating the ROW semiconductor market. Currently, PC shipments are slowing because of memory shortages. The telecommunications industry is growing extremely quickly in ROW, but telecommunications is still a small market. We expect the ROW market to be the fastest growing in both the short and long term. ROW will surpass Europe in total dollar consumption in 1991 to become the world's third largest market.

Shipments by Product

Tables 3 and 4 give Dataquest's short- and long-term forecasts, respectively, for the worldwide semiconductor industry. By 1993, we forecast a total market of $86.7 billion. In the long term, the fastest growing products will continue to be MOS ICs. Bipolar memory is forecast to decline steadily through 1993, as BICMOS memory edges it out. Optoelectronics growth will continue to be strong over the long term, as its use in consumer and telecommunications products continues to grow; at the same time, new applications such as medical, dental, machine vision, and submarine communications are proliferating.

Table 3

Estimated Worldwide Semiconductor Shipments (Millions of U.S. Dollars)

	1987	Q1/88	Q2/88	Q3/88	Q4/88	1988	% Chg. 1988
Total Semiconductor	$36,449	$11,112	$12,442	$12,669	$13,286	$49,509	35.8%
Total IC	$28,619	$ 8,718	$ 9,885	$10,128	$10,672	$39,403	37.7%
Bipolar Digital	$ 4,672	$ 1,297	$ 1,359	$ 1,419	$ 1,495	$ 5,570	19.2%
Memory	565	154	163	166	169	652	15.4%
Logic	4,107	1,143	1,196	1,253	1,326	4,918	19.7%
MOS Digital	$16,739	$ 5,385	$ 6,380	$ 6,561	$ 6,924	$25,250	50.8%
Memory	6,019	2,182	2,762	2,785	2,904	10,633	76.7%
Micro	4,770	1,521	1,765	1,813	1,906	7,005	46.9%
Logic	5,950	1,682	1,853	1,963	2,114	7,612	27.9%
Linear	$ 7,208	$ 2,036	$ 2,146	$ 2,148	$ 2,253	$ 8,583	19.1%
Discrete	$ 6,112	$ 1,805	$ 1,918	$ 1,887	$ 1,939	$ 7,549	23.5%
Optoelectronic	$ 1,718	$ 589	$ 639	$ 654	$ 675	$ 2,557	48.8%
Exchange Rate Yen/$	144	128	125	134	134	130	(9.7%)
European Basket/$	1.25	1.17	1.17	1.20	1.20	1.18	(5.6%)

	1988	Q1/89	Q2/89	Q3/89	Q4/89	1989	% Chg. 1989
Total Semiconductor	$49,509	$13,556	$13,843	$13,636	$13,536	$54,571	10.2%
Total IC	$39,403	$10,882	$11,104	$10,917	$10,833	$43,736	11.0%
Bipolar Digital	$ 5,570	$ 1,518	$ 1,519	$ 1,451	$ 1,400	$ 5,888	5.7%
Memory	652	169	161	151	146	627	(3.8%)
Logic	4,918	1,349	1,358	1,300	1,254	5,261	7.0%
MOS Digital	$25,250	$ 7,058	$ 7,209	$ 7,101	$ 7,057	$28,425	12.6%
Memory	10,633	2,950	3,022	2,972	2,953	11,897	11.9%
Micro	7,005	1,944	1,990	1,969	1,959	7,862	12.2%
Logic	7,612	2,164	2,197	2,160	2,145	8,666	13.8%
Linear	$ 8,583	$ 2,306	$ 2,376	$ 2,365	$ 2,376	$ 9,423	9.8%
Discrete	$ 7,549	$ 1,976	$ 2,010	$ 1,996	$ 1,988	$ 7,970	5.6%
Optoelectronic	$ 2,557	$ 698	$ 729	$ 723	$ 715	$ 2,865	12.0%
Exchange Rate Yen/$	130	134	134	134	134	134	3.1%
European Basket/$	1.18	1.20	1.20	1.20	1.20	1.20	1.2%

Source: Dataquest
October 1988

Table 4

Estimated Worldwide Semiconductor Shipments
(Millions of U.S. Dollars)

	1988	1989	1990	1991	1992	1993	CAGR 1988-1993
Total Semiconductor	$49,509	$54,571	$55,600	$65,230	$79,233	$86,730	11.9%
Total IC	$39,403	$43,736	$44,767	$53,295	$65,734	$73,213	13.2%
Bipolar Digital	$ 5,570	$ 5,888	$ 5,878	$ 6,737	$ 7,813	$ 8,509	8.8%
Memory	652	627	606	595	546	530	(4.1%)
Logic	4,918	5,261	5,272	6,142	7,267	7,979	10.2%
MOS Digital	$25,250	$28,425	$29,333	$35,487	$44,610	$49,663	14.5%
Memory	10,633	11,897	12,141	14,762	18,562	20,262	13.8%
Micro	7,005	7,862	7,993	9,800	12,482	13,867	14.6%
Logic	7,612	8,666	9,199	10,925	13,566	15,534	15.3%
Linear	$ 8,583	$ 9,423	$ 9,556	$11,071	$13,311	$15,041	11.9%
Discrete	$ 7,549	$ 7,970	$ 7,917	$ 8,668	$ 9,712	$ 9,254	4.2%
Optoelectronic	$ 2,557	$ 2,865	$ 2,916	$ 3,267	$ 3,787	$ 4,263	10.8%
Exchange Rate Yen/$	130	134	134	134	134	134	
European Basket/$	1.18	1.20	1.20	1.20	1.20	1.20	

Source: Dataquest
October 1988

DATAQUEST CONCLUSIONS

We believe that worldwide semiconductor shipments will slow down through the first half of 1989 and begin to decline slightly in the second half of 1989, continuing into the first half of 1990. However, due to careful OEM management of semiconductor inventory, careful semiconductor manufacturer management of capacity (capacity utilization is at 86 percent in 1988, and we expect it to be a still-healthy 80 percent in 1989 and 78 percent in 1990), and a generally healthy world economy, we forecast the downturn to be modest, particularly in comparison with the 1985 industry depression.

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THE OMNIBUS TRADE BILL:
WHAT IT MEANS TO THE SEMICONDUCTOR INDUSTRY

SUMMARY

The fortunes of U.S. high-technology industries have played no small part in the formulation of U.S. trade policy of late. In the semiconductor industry alone, a number of trade-related issues have combined to elevate chip making concerns to a level of political visibility far beyond what the industry's significance as a generator of revenue and jobs would suggest.

It is therefore not surprising to find a number of measures within the more than 1,000 pages of the Omnibus Trade and Competitiveness Act of 1988 that seem very much directed at high-technology systems and the components that enable them. Potentially, the most significant portions of the bill, with regard to producers and users of semiconductors, deal with the following areas:

- Amendments to Section 301 of the Trade Act of 1974
- The tightening of antidumping regulations
- The strengthening of intellectual property laws
- Restrictions on foreign takeovers of U.S. companies
- The relaxation of high-technology exports

This newsletter reviews the likely industry impact of each of the above aspects of the trade bill, with attention as well to the implications of the Toshiba sanctions to electronics original equipment manufacturers (OEMs).

TRADE: A HIGHER PLACE ON THE NATIONAL AGENDA

The Omnibus Trade and Competitiveness Act of 1988 represents a significant effort by the U.S. government to advance the competitive interests of American industry without resorting to self-defeating, protectionist measures. Clyde Prestowitz, former counselor for Japanese affairs to the secretary of commerce, has pointed out that government has typically viewed trade as an activity of the private sector, rather than as a strategic issue. For this reason, past issues of unfair practices by trade partners have at times been subordinated to other political agendas, such as national security concerns.

The trade bill signed by President Reagan breaks with the past by moving authority to respond to unfair trade practices from the president to the U.S. trade representative (USTR). Nevertheless, the bill still allows the president override power if any such response violates the General Agreement on Tariffs and Trade (GATT) or is judged by the president to jeopardize national security or economic interests. As a result, while avoiding the complete tying of the president's hands, the trade bill forces the chief executive to take a position in instances of unfair trade practices, and, to that extent, furthers the decoupling of trade and national security issues.

SECTION 301

The amendments to Section 301 of the Trade Act of 1974 may strengthen the efforts of the Semiconductor Industry Association (SIA) to increase U.S. semiconductor manufacturers' share of the Japanese market. The amendments require that the USTR submit an annual report to Congress on foreign trade practices that adversely affect U.S. commerce. This report must include a list of "priority" foreign countries that maintain unfair trade barriers, which from the SIA's point of view would certainly include Japan.

These amendments, however, do not necessarily mandate retaliatory action in instances where a foreign government tolerates anticompetitive activities by private firms--unless it can be demonstrated that the purchasing practices of these firms are "inconsistent with commercial considerations." This will be the acid test of this portion of the trade bill: proving that trade barriers against U.S. rice are "inconsistent with commercial considerations" is one thing; proving that point with regard to vertically integrated Japanese electronics companies' purchases of foreign semiconductors is another matter altogether. The SIA will therefore have to continue pressing its case that Japan's reluctance to increase its consumption of U.S. chips flies in the face of its own commercial self-interest. It will, however, most certainly have the attention of a more powerful USTR in the process.

DUMPING LAWS

The trade bill allows domestic industries to petition the USTR to request that foreign governments initiate their own antidumping investigations, and to use "constructed values" (similar to the scheme followed for DRAM and EPROM pricing) as the basis for foreign market values (FMVs). As a result, the trade bill is an assurance to the U.S. semiconductor industry that government will address dumping issues <u>before</u> their impact causes the forced withdrawal of U.S. suppliers from a key market.

To guard against "diversionary input dumping," the trade bill broadens the scope of the dumping regulations to cover "downstream products." In the case of semiconductors, this would apply to subsystems or board-level products containing components that have been subject to a dumping or subsidy finding of 15 percent or more in the past five years. To put even more of a bite in the dumping regulations, the trade bill authorizes the Department of Commerce (DOC) to disregard intracompany transfer prices for components and materials used in products subject to any dumping investigation. In addition, measures in the trade bill establish a method for determining whether or not domestic subsidies by foreign governments constitute a dumping violation.

In the case of countries that have been found to be repeated dumping violators, the trade bill requires the DOC to conduct expedited antidumping investigations in the case of "short life cycle" products: products that the International Trade Commission (ITC) "determines (are) likely to become outmoded within four years . . ." One can certainly appreciate the relevance of this measure to new generations of memory products, if not to the chip industry as a whole. The intent of this measure is to ensure that, by the time a dumping investigation concerning an existing generation of a product is concluded, the aggrieved industry has not hopelessly lost market share opportunities to a next-generation device.

Finally, the dumping regulations in the trade bill include a section that requires the ITC to look at the issue of material damage to a domestic industry from a number of factors distinctive to the affected industry, and not solely from the standpoint of business cycles and general competitive conditions. The trade bill even includes a section that requires the ITC to evaluate factors that create the "threat" of material injury, such as the ability of domestic producers to develop subsequent generations of a product, and whether third-country dumping suggests a threat.

In these measures, one sees evidence of lessons learned from the U.S.-Japan Semiconductor Trade Arrangement. The Section 301 violations, the resulting FMVs, and the market gyrations that followed have made government and industry a bit more savvy about the complexities of dumping issues. Elements such as intracompany sales, incorporation of dumped goods into higher-integration products, the effects of government subsidies on cost, and the relationship between distributors and third-country markets must all be taken into account as a part of the FMV equation.

Although the trade bill clearly strengthens antidumping laws to provide deterrents to multiple foreign offenders, the version of the bill signed into law falls short of the measures the SIA would like to have seen included. The SIA had sought to modify trade legislation dating back to 1916 that allows victims of dumping to sue for treble damages if they can prove that a competitor had clearly intended to drive them from a market. The SIA had hoped to modify this law in a way that would have shifted the burden of proof to the defendant in a dumping suit. Under these regulations, third-time dumping offenders would have had to prove that they had not intended to damage a competitor as a result of their pricing strategy or face being barred from participating in that market.

INTELLECTUAL PROPERTY

If you think the industry currently has a growing love affair with litigation, the intellectual property regulations in the trade bill look like the honeymoon hotel. Since the Tariff Act of 1930, victims of unfair acts of competition have been able to obtain exclusion orders from the president, provided they could prove injury or the threat of injury to the ITC along with evidence of intellectual property violation.

The trade bill amends Section 337 of the Tariff Act of 1930 by removing the proof-of-injury requirement. In fact, the amendments minimize the requirements that a petitioner show investments in R&D, plants and equipment, or employment as constituting an industry. Also removed is the requirement that the aggrieved company be efficiently and economically operated. Had these amendments been in force last year, it is conceivable that Intel could have taken its DRAM patent infringement case against Samsung to the ITC in order to block the import of DRAMs from that company. As it was, Intel was able to press only its EPROM case against Samsung, since it was still a manufacturer of those devices.

The trade bill amends patents so that holders of patents on processes by which products are made can sue importers of products from countries where the patents are not protected. Furthermore, if a plaintiff shows that there is a substantial likelihood that such products use the patented process, the burden falls to the defendant to prove that the patented process was not used.

EXPORT CONTROLS

Although the changes to export controls in the trade bill do not appear to have a significant impact on chip producers, the fact that they are aimed at the removal of unnecessary controls should prove a further stimulus to electronics exports. Essentially, the provisions of the trade bill abolish controls on the export of many widely available electronics products to Japan and 14 North Atlantic Treaty Organization Allies—subscribers to COCOM regulations. The Pentagon's role in reviewing export licenses for goods still on the export control list is confined to "national security" concerns, an effort to eliminate the possibility that such approval would be used as a tool of foreign policy.

THE TOSHIBA SANCTIONS

For their role in the supply of specialized milling machines to the Soviet Navy, the trade bill places a three-year moratorium on any U.S. procurement of products and services from Toshiba Machine Company and Kongsberg Trading Company. These measures have no significant impact on the ability of Toshiba's semiconductor operations to supply components to the U.S. market, except in the case of sales to U.S. government agencies. As a whole, Toshiba Corporation is prohibited from providing goods and services to government agencies for a three-year period.

OEMs using Toshiba components in their products are less apt to be sanguine about the ban on Toshiba government sales. What is the effect of the trade bill, for example, on the government sales of a U.S. memory board supplier if the boards use memories from Toshiba, the world's number one producer of 1Mb DRAMs? Fortunately, the trade bill makes exceptions to the ban both in cases of the procurement of defense articles or services and, in the case of "component parts," which it defines as " . . . any article which is not usable for its intended functions without being imbedded in or integrated into any other product and which, if used in production of a finished product, would be substantially transformed in that process."

One question concerning the Toshiba sanctions incorporated in the trade bill is whether or not they will supersede the sterner measures spelled out in the defense appropriations bill for fiscal 1988. These sanctions prohibit the purchase, using Department of Defense (DOD) funds, of any systems in which Toshiba components make up 50 percent or more of the systems' value.

FOREIGN TAKEOVERS

In the past, the president could prevent the acquisition of a U.S. company by a foreign-based firm only if U.S. antitrust laws were violated or if a state of national emergency was declared. The trade bill (as a result of the Exon-Florio Amendment) amends Title VII of the Defense Production Act of 1950, allowing the president to block a foreign takeover if it is determined, upon investigation, that U.S. national security is compromised.

Had the trade bill been in force last year, it is interesting to speculate on whether or not President Reagan would have invoked this power to block Fujitsu's acquisition of Fairchild. It is probably no coincidence that, with the trade bill headed for presidential signature, Gould, Inc., divested itself of its semiconductor operations <u>before</u> completing the arrangements of its acquisition by Nippon Mining Company. In this sense, the effects of this portion of the bill may already have been felt by industry.

TECHNICAL COMPETITIVENESS

A number of trade bill sections deal with the role of government agencies in enhancing the technological prowess and worldwide competitiveness of U.S. high-technology industries. These measures include the creation of a Competitiveness Policy Council (comprising government, business, labor, and academic leaders), and an annual assessment of the impact of the federal budget on the U.S. trade balance.

In addition, the bill renames the National Bureau of Standards, calling it the National Institute of Standards and Technology, and expands its charter to aid in the development of leading-edge technologies such as superconductivity, advanced materials, and biotechnology.

A number of sections pertaining to technological competitiveness deal specifically with the semiconductor industry. These include:

- The creation of the National Advisory Committee on Semiconductors (NACOS), which will monitor the semiconductor industry and recommend a national strategy to promote greater U.S. competitiveness in semiconductors. Members are currently being solicited for this advisory body.

- The creation of the National Critical Materials Council. This council will initially develop a plan for advanced materials research and development.

- The requirement of an annual report to Congress by the Council on Federal Participation in Sematech, updating the progress of the consortium toward its objectives. This report will also identify prospects for the recoupment of federal investments from royalties or fees generated from Sematech technology.

DATAQUEST CONCLUSIONS: THE ROLE OF GOVERNMENT

Several years ago, the semiconductor industry took its case to the federal government in the form of Section 301 dumping allegations against Japanese semiconductor manufacturers. Prior to this, and during the creation of the U.S.-Japan Trade Arrangement, semiconductor business leaders argued before often skeptical legislators that the current trade climate threatened to destroy a key U.S. industry. However one feels about the effectiveness of the arrangement, its eventual creation came too late for a number of U.S. companies.

For the most part, the aspects of the trade bill described in this newsletter remain in keeping with the federal government's traditional trade posture: that of the defender of free trade among U.S. industry and its trading partners. In defining how best to fulfill this role in an increasingly global environment, U.S. trade policy is obviously intent on fostering improved trade conditions for domestic industry without intervening aggressively on behalf of any particular business sector. Nonetheless, in regard to the U.S. high-technology industries, certain aspects of the trade bill define a government role closer to that of coach than referee in the game of international trade and competitiveness.

Most significantly for chipmakers, the trade bill signed by President Reagan marks a departure from the attitude that the woes of the industry were brought upon it solely by some lack of competitive fire. By defining its role in fostering a trade climate more conducive to the success of the U.S. semiconductor industry, government can do much to encourage investments in capacity that systems companies would dearly love to see in the memories area. A proactive role in trade may also ensure that future government measures look less like closing the barn door after the horses have escaped.

Michael J. Boss

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Research Newsletter

AT&T TARGETS HIGH-GROWTH MERCHANT OPPORTUNITIES

INTRODUCTION

During the week of November 5, 1990, AT&T Microelectronics made two announcements that hopefully will lead the company to greater fortune in the merchant semiconductor market. On November 6, the company announced the availability of its first field-programmable gate arrays (FPGAs) based on designs licensed from Xilinx Corporation of San Jose, California. AT&T announced availability of its 2,000-gate FPGA with performance speeds of 125, 100, and 75 MHz; in addition, the company is sampling 4,200-gate and 9,000-gate devices.

On November 7, AT&T announced its entry into the SRAM market with the availability of a 10ns very fast SRAM, manufactured under a product-rights agreement with Logic Devices. Targeted applications for the high-performance SRAMs include cache memory, high-performance RISC and CISC computers, digital signal processing (DSP), and data communications.

These two announcements are the latest in a series of steps taken in the last two years by AT&T to enhance its position in the merchant semiconductor market. This newsletter examines AT&T's merchant strategy and discusses some of the company's actions designed to address its merchant market opportunities.

CORPORATE STRATEGY

As early as 1988 it was apparent that, as part of its strategy to survive in nonregulated business areas, AT&T began encouraging its equipment manufacturing groups to obtain components from the best available source. By doing so, the company hoped to make its equipment more competitive in the marketplace. For the captive semiconductor operation at AT&T, this policy represented a business challenge. No longer would there be a guaranteed market inside the company for its semiconductors. As the semiconductor operation strove to make its products more competitive, it seemed only logical that AT&T would try to pursue more business in the merchant semiconductor market.

In July 1989, AT&T announced its intention to balance the percentage of semiconductor production that was used for captive consumption and merchant sales. The company also indicated that it would be targeting fast SRAMs and microcontrollers in future strategic agreements and product development. AT&T achieved great success in the merchant marketing of its cell-based IC (CBIC) products; in fact, the company was the leading worldwide supplier of CBICs in 1989. AT&T's strategic agreements in the past two years have helped it expand its product portfolio into other markets, where its production expertise may be best utilized.

ALLIANCES

Table 1 lists the major alliances that AT&T entered in 1989 and 1990. The company has gained access to several new markets—including FPGAs, gate arrays, microcontrollers, and fast SRAMs—through these alliances. Concomitant with the corporate goals stated in July 1989, many of AT&T's recent agreements pertain to fast SRAMs. In January 1989, AT&T entered a foundry relationship with Logic Devices. Under terms of the agreement, AT&T provides finished wafers to Logic Devices. Since the signing of the initial agreement, AT&T and Logic Devices have entered a licensing agreement whereby AT&T is licensed to manufacture and market SRAMs designed by Logic Devices. In turn, Logic Devices receives foundry services from AT&T. AT&T's most recent SRAM product announcement is a result of the pact with Logic Devices.

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TABLE 1
AT&T Semiconductor Alliances—1989-1990

Company	Date	Product(s)
Logic Devices	January 1989	Wafer foundry
Paradigm	August 1989	SRAMs
Xilinx	December 1989	FPGAs
Mitsubishi	February 1990	SRAMs
NEC	March 1990	ASICs, MCUs
M/A-COM	May 1990	GaAs MMICs
Logic Devices	August 1990	SRAMs
Mitsubishi	September 1990	Bipolar IC assembly

Source: Dataquest (December 1990)

AT&T also has licensed fast SRAM capability from Paradigm Technology. In August 1989, the two companies signed a five-year agreement to codevelop fast SRAMs, under which AT&T provides Paradigm with equity and codevelopment funding and Paradigm gains access to AT&T's worldwide foundry capabilities. To date, AT&T has not announced products based on this licensed technology.

In another agreement to gain fast SRAM technology, AT&T and Mitsubishi signed a five-year agreement in February 1990 that provides AT&T access to Mitsubishi's SRAM design and process technology, beginning with the 256K SRAM. In addition, AT&T gains worldwide manufacturing and marketing rights to all Mitsubishi SRAM products. In return, AT&T will manufacture current and future SRAM products for Mitsubishi.

In December 1989, AT&T signed an agreement with Xilinx to manufacture and market Xilinx's 3000 and 4000 families of FPGAs. Xilinx gains access to AT&T's worldwide fab capability, including European capacity, through AT&T's fab in Madrid, Spain. On November 6, 1990, AT&T introduced the first products that resulted from this agreement.

In addition to fast SRAMs and FPGAs, AT&T also gained access to microcontroller and gate array technology through its March agreement with NEC. Under the terms of the five-year relationship, AT&T will be licensed to design, manufacture, and market NEC's gate array products, starting with NEC's most advanced CMOS gate array family. In return, NEC will receive AT&T's sophisticated CAD tools for ASICs. The relationship also calls for AT&T to provide manufacturing support for NEC's 4-bit microcontrollers.

DATAQUEST ANALYSIS

AT&T's pursuit of strategic partnerships appears to be driven by three goals, the first of which is filling its fab capacity. At one time, AT&T had more excess leading-edge fab capacity than any company in the world. In the last two years, the company has signed numerous foundry agreements in an attempt to better utilize its capacity. Second, these alliances are serving as a cornerstone of a more extensive product portfolio. As mentioned earlier, AT&T has gained licensing or manufacturing rights to products in the gate array, PLD, microcontroller, memory, and GaAs MMIC markets. Finally, by strengthening its position in these new product markets, AT&T is attempting to improve its position in the merchant semiconductor market in general.

In the past year, a number of companies—including AMD, National Semiconductor, Philips, Saratoga Semiconductor, and VLSI Technology—have exited the SRAM business. As the market experiences consolidation, it seems an odd time for AT&T to be entering this market. However, AT&T is positioning itself in the very fast segment of the SRAM market. Dataquest considers devices with access times of less than 25ns to be very fast SRAMs. AT&T's new products, with access times of 10, 12, and 15ns, will be competing with products by the likes of Cypress, IDT, Motorola, NEC, and Sony in the very fast SRAM market. Dataquest predicts a compound annual growth rate of 88.6 percent in the very fast SRAM market between 1990 and 1994. By 1994, we expect the market to be nearly $1.8 billion.

In choosing new markets for the company's merchant entry, AT&T has done a fine job. The very fast SRAM market has excellent growth expectations, and Dataquest believes that the FPGA segment of the PLD market also is ripe for significant growth and can support numerous suppliers. With extensive leading-edge fab capacity in North America and Europe, AT&T also is well positioned for an extensive merchant operation from a manufacturing technology standpoint. While some companies choose to hire additional engineering expertise to penetrate new markets, AT&T has chosen a strategy of well-planned strategic partnerships. As the decade unfolds, Dataquest expects to see AT&T further strengthen its position in the merchant semiconductor market. The company appears to be off to a fine start.

Phil Mosakowski

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Research Newsletter

DATAQUEST CONFERENCE LOOKS TO DECADE OF OPPORTUNITIES

INTRODUCTION

October is one of the loveliest months of the year along the Northern California coast, with warm clear days and crisp cool nights. This was the environment for Dataquest's 16th annual Semiconductor Industry Conference in Monterey, October 8 and 9, 1990. A near-capacity crowd enjoyed the Monterey weather, good food, and challenging discussions as participants and speakers looked ahead through the decade.

Dataquest president Manny Fernandez set the conference theme—"The Next Decade. . .Where Do the Opportunities Lie?"—with a look at future products and the technologies necessary to support them. He envisioned a decade of growing wireless communications, smart home products, higher automation in the office, multiple-use smart cards, real-life imaging, multimedia, and electric cars. To make these products work, Mr. Fernandez said, we need microprocessors that run at 250 mips, ASICs with logic that use more than 100,000 gates, analog devices that operate in the gigahertz ranges, and memories beyond the 64Mb size.

But the industry must deal with some major issues such as the education crisis, which is a major limiting factor for industry, he said. The industry will need to change, because the cost of capital is forcing new intercompany agreements. Common R&D and production facilities may become necessary. Cooperation, a theme repeated by nearly every speaker, emphasized an urgency for closer relationships between suppliers and customers.

Figures 1, 2, and 3 show conference attendees working hard exploring future opportunities and later enjoying a private tour and buffet dinner at the Monterey Bay Aquarium.

FIGURE 1
All Work and No Play. . .

Source: Dataquest (November 1990)

SIS Newsletters Components Group

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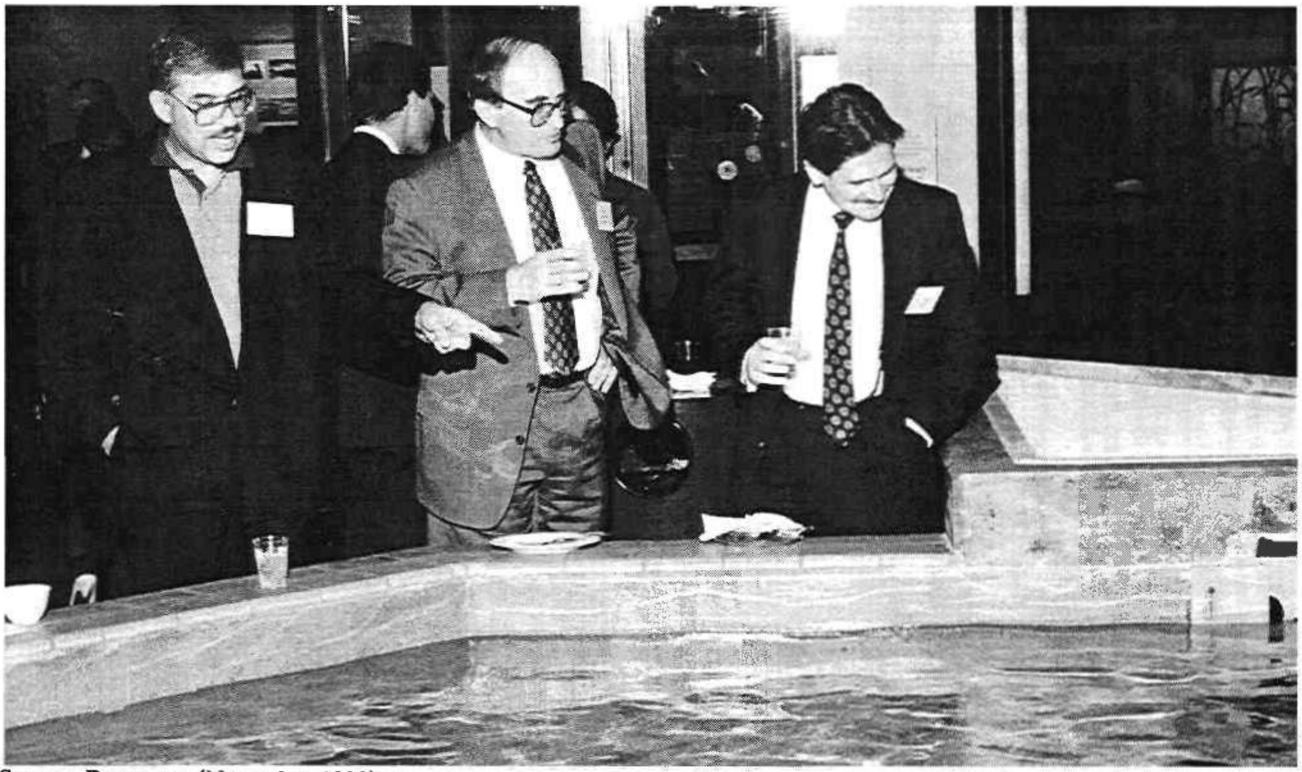
FIGURE 2
Attendees at Buffet Dinner

Source: Dataquest (November 1990)

FIGURE 3
Visiting the Aquarium



Source: Dataquest (November 1990)

THE ISSUES

The Evolving PC

Roger Johnson, chairman, president, and CEO of Western Digital Corporation, examined the changing PC as a driving force in semiconductor development. The PC will be a companion to the way we think, replacing pencil and paper, operating without a keyboard, and offering new ways to communicate, he said. PCs will be smaller, be lighter, and have more functions, and they will be fully portable like a notebook or vest pocket date book, not just carryable.

These PCs will be able to draw on vast networks and databases because of their high connectivity. Their low cost and ease of use will place them in the hands of average people who today have little direct contact with computers. Mr. Johnson believes that mass storage will change from the disk to solid state. "The days of PCs being technology driven are over," he said. "In the future they will be application driven, based on the user's needs." He sees the small and portable computers as the drivers for expanding the existing market areas.

The New Face of Personal Electronics

Hiroyuki Mizuno, executive vice president and member of the board of Matsushita Electric Industrial Co., Ltd., said the boundaries between science, industry, and home products are fading as personal electronics gain more information-handling and communications abilities. Systems are becoming more user friendly, often being preprogrammed for human needs, Mr. Mizuno said. For instance, there are washing machines that use fuzzy logic to determine the amount of detergent needed and how long to wash, based on the amount of dirt in the clothing. Or air conditioners that self-adjust, depending on the outside temperature, the humidity, and the number of people in the room.

Mr. Mizuno sees an increasing trend toward personalization of electronics in the growth of individually used products. This trend is leading to more interactive multimedia technology for information, education, and business and will grow in home use.

Straining for a National Budget

Congressman Tom Campbell, a representative from the Silicon Valley area, brought the governmental point of view to the conference attendees, but not according to plan. Scheduled to speak at Monday's luncheon, he was kept in Washington, D.C., by the budget conflict. However, Congressman Campbell spoke from his office via an audio link.

He reported on the difficulties of arriving at a budget compromise because of economic assumptions that, at the time, he believed to be flawed. The assumptions included an oil price at $24 per barrel or less, an inflation rate of 5.2 percent in 1990 dropping to 3.0 percent in 1994, and a 90-day T-bill interest rate falling from 7.7 percent in 1990 to 4.2 percent in 1995.

Congressman Campbell sees the Administration position on high technology as one of macroeconomics, preferring to provide the right environment through lower interest rates, lower capital gains tax, a lower budget deficit, R&D tax credits, and a better intellectual property regime rather than direct support. He believes that the White House will oppose direct governmental contributions to commercial technology, similar to that for military technology through DARPA.

Corporate Strategies for Success

The industry has seen three basically different types of semiconductor companies develop and grow in the 1980s—fabless, pure-play semiconductor, and building-block supplier. The issue of which type will be the most successful in the 1990s was examined by a panel of three top executives from three successful companies: Dr. T.J. Rodgers, CEO of Cypress Semiconductor (pure-play); Frank Gill, Intel Corporation senior vice president and president of Intel Systems Group (building-block); and Gordon Campbell, president and CEO of Chips & Technologies (fabless). David Angel, vice president of Dataquest's Semiconductor Components Group, moderated the discussion. Mr. Gill, Dr. Rodgers, and Mr. Campbell are shown in Figure 4.

Representing the pure-play position, Dr. Rodgers led the session by attacking the concept that Japan was an unbeatable juggernaut in the

FIGURE 4
Corporate Strategists

Source: Dataquest (November 1990)

electronics industry. He noted that the United States, not Japan, has the highest productivity level and the world's largest economy, and Germany has the most favorable trade balance. Dr. Rodgers did the following:

- He disputed the estimates of capital needed to design and build a fab. (Cypress has invested only $80 million in two fab locations.)
- He disputed the estimates of $200 million to design a microprocessor. (Cypress invested $7 million in Ross Technologies to produce a RISC microprocessor.)
- He said that a major competitive hindrance for many US semiconductor producers is low production yields, but Cypress is closing this gap with Japan.

Mr. Gill said that the building-block supplier looks at the different functions of a PC and then logically combines those functions, often onto a single chip. This building-block approach has resulted in the number of chips in a PC being reduced from 170 to less than a dozen plus memory.

He said that it is necessary to market at a product level the customer wants. Intel, for example, sells chips, modules, subsystems, or even complete systems but does not consider itself a vertically integrated company. However, it can result in a company relationship as customer, vendor, and competitor simultaneously.

Mr. Campbell said the advantages of the fabless supplier for the producers include higher profitability, more consistent costs, lower financial risks, faster product ramp-ups, and the ability to migrate technologies quickly.

The customer's advantage of using a fabless supplier is as follows:

- The value added by design
- Time to market
- Stable product costs, because equipment utilization does not impact costs as it does in companies with fabs
- The ability to move quickly into new technologies, because a fabless company uses multiple foundries and can offer a variety of technologies

Mr. Campbell believes that chips of the future will be more complex, containing more software and performing more functions. He also foresees more use of outside foundries, even by companies that have fabrication facilities.

The panelists said that the increasing cost of capital is a key issue and could slow the rate of technology development. They all said that the business climate for semiconductor producers in the United States is becoming more difficult, so company executives should be better educated about the marketplace and should change their companies to fit market shifts.

The Semiconductor Wake-Up Call

Conference attendees heard Professor Carver Mead of the California Institute of Technology comment on the perpetuation of change in the semiconductor industry. Dr. Mead shared his "Mead's Laws of the Economics of Innovation," which include Return on Innovation, the Headroom Principle, and the Repeated Major Innovation Law. Figure 5 shows Dr. Mead meeting with Dataquest's David Angel before speaking to a capacity audience.

Dr. Mead foresees no slowdown in innovations during the 1990s. He defines a "major" innovation as ". . .you weren't looking for it there. Most of these innovations I was standing right there looking, and I was looking the wrong way. Major innovations are always the ones in a different direction than everybody is going and therefore cannot be planned."

FIGURE 5
Decade of Innovation Discussed

Source: Dataquest (November 1990)

FIGURE 6
Trying to Get Smaller

Source: Dataquest (November 1990)

Getting to Smaller Geometries

Lithography represents a critical enabling technology for producing semiconductors of submicron geometries, a principal requirement for developing the high-performance products of the 1990s. Lithography equipment constitutes the largest segment within the worldwide wafer fabrication equipment market, essentially 25 cents of every dollar spent on front-end equipment. But very little of the equipment purchased in the 1980s will be usable for making the masks needed in semiconductor production.

Dataquest gathered a panel of four experts from the equipment and user communities to discuss these issues. The panelists were Dr. Gene Fuller, manager, Stepper Programs, SEMATECH (optical lithography); Robert Hill, functional manager, Advanced Lithography Systems, IBM (X-ray lithography); Dr. Neil Berglund, assistant to the president and executive director of marketing, ETEC Systems (e-beam lithography); and Dr. John Skinner, director of advanced photomask technology at DuPont Photomask (maskmaking). Dr. Fuller, Dr. Berglund, and Mr. Hill are shown in Figure 6. Dr. Peggy Wood, senior industry analyst of the Dataquest Semiconductor Equipment, Manufacturing, and Materials Service (SEMMS), moderated the panel discussion.

The panelists concluded that optical lithography will continue to be the dominant technology for several years because of the significant installed equipment base and know-how. Also, a considerable time lag is associated with developing new technologies. If optical lithography is going to be replaced in the next ten years by another lithography technology, a full development effort must be started today. Lithography equipment costs will go up in every equipment category as mask specifications get tighter and the design rules continue to shrink.

The Memory Impact

Most of Tuesday morning was devoted to memories, specifically DRAMs. Dr. Tsugio Makimoto, general manager, Semiconductor Design and Development Center, Hitachi Ltd., said that the current $14 billion DRAM market will grow to $100 billion by the year 2000. The gigabit era will replace the megabit era. Memory consumption today at 160Kb for every man, woman, and child in the world will become 8Mb by the end of the decade.

The most crucial issues affecting the ability to meet user needs are lithography, packaging, and costs, said Dr. Makimoto. Product diversification will increase, and many memory products will include ASIC-type logic functions. But progress will have a price, he said. The cost to produce a million parts a month will go up, yield will become more critical, and the investment costs will become much heavier.

A panel discussion, led by Mr. Angel, focused on operating conditions, costs, and constraints of the 1990s. The panelists included David Sear, vice president of Fujitsu America; Robert Brown, vice president and group executive of Toshiba America Electronic Components; William Gsand, vice president and general manager of Hitachi America Ltd.; Joseph Parkinson, chairman and CEO of Micron Technology; and Frank Jelenko, vice president of NEC Corporation. Figure 7 shows Mr. Brown, Mr. Sear, Mr. Gsand, and Mr. Jelenko enjoying the balmy weather during the morning break.

The panel believed that the price-per-bit would be influenced by the following:

- Die size—Die size is becoming increasingly difficult to shrink.
- Wafer size—Increasing wafer size increases the number of die processed at the same time, reducing unit die cost.
- Wafer fab cost—Increasing equipment cost will drive up cost per bit.
- Cost of capital—Higher capital costs reduce return on investment.
- Process cost—Complex architectures may need up to 30 mask steps. Mr. Parkinson disagreed that so many mask steps are needed.
- Diversification—As the number of formats and packages increases, smaller process lots are run, thus increasing costs. The number of distinctive parts estimated by Mr. Brown and Mr. Gsand reach into the hundreds for the four standard DRAM sizes.

All agreed that multichip modules (MCMs), particularly with embedded logic functions, were in the future. Mr. Brown thought DRAMs would be shifting to 3.3V by 1994, and Mr. Sear said he thought epitaxial wafers would be needed for the 64Mb parts.

Packaging for High Performance

As chip performance increases, packaging issues become more critical. Dataquest's industry analyst for packaging, Mary Olsson, forecast some dramatic changes that could alter the semiconductor and printed circuit board industries. The demand for high-density interconnect capabilities will drive the industry toward MCM (see Table 1).

Ms. Olsson said that although the dual in-line package (DIP) still is the leader, it is experiencing

FIGURE 7
Enjoying a Break

Source: Dataquest (November 1990)

TABLE 1
Multichip Module Drivers

	Current	Near Term 1993-1995	Long Term 1997-2000
MPU Speed	20 MHz	100 MHz	300 MHz
ECL			Photonic logic
Logic/ASIC	150-400ps	50-150ps	1.5-2.0ps
Memory	CMOS	BiCMOS	BiCMOS/FERRAM
PC	1MB	16MB	128MB
Workstation	8MB	128MB	512MB
Speed	20-80ns	9-60ns	<25ns
GaAs			
Logic/ASIC	50-80ps	20-60ps	<5-10ps
Memory	16K/3ns	>60K/3ns	>100K/3ns

Source: Dataquest (November 1990)

the end-of-life decline, from 79 percent of all packages in 1989 to 68 percent in 1990. Surface-mount technology will dominate by the year 2000, with the quad flat pack showing the greatest growth rate because of the increasing number of leads.

The Change in User/Supplier Relations

Irv Abzug, General Technology Division vice president and director of corporate procurement at IBM, used the IBM example to tell the audience how semiconductor supplier/customer relationships must change. IBM buys 1.5 billion devices a year and has gone from an "arm's length" relationship to one of shared information using electronic data interchange and a partnership in technology.

The challenges of the 1990s are to provide solutions, not just products, said Mr. Abzug. "Clearly, we are entering a period when companies will either satisfy their customers or simply pass into history." Mr. Abzug noted that quality is a key element in the 1990s because if 99.9 percent of the products shipped were defect-free, then with 1.5 billion devices shipped to IBM each year, 1.5 million would be defective. Mr. Abzug said that suppliers need to be included in product cycles earlier than ever before and that system makers need to share more information with key suppliers.

Redrawing Borders

Europe's semiconductor market is being rejuvenated as Europe goes to a single market in 1992, reported Dr. Jonathan Drazin, Senior Industry Analyst at Dataquest's Denham, England, office. The most difficult challenge for the European Community (EC) is to break down the provincial barriers on technical issues, such as telecommunications standards.

Pan-European markets are beginning to form through R&D projects and the EC's standards committees. Dr. Drazin said he already sees an impact through the restructuring of companies, such as GEC and Siemens buying the telecommunications and defense company Plessey, to take advantage of a more unified market.

Dr. Drazin said the initial opportunities for business with Eastern Europe are in telecommunications. Eastern Europe and the USSR cannot wait to build a telecom infrastructure from the inside. "Without a telecom infrastructure that works, no industry in Eastern Europe can compete effectively. Without an industry, there will be no private income for individuals to sustain the consumer electronics market," he concluded.

Conference attendee Tom Egan (AT&T) chats with Dataquest president Manny Fernandez in Figure 8.

FIGURE 8
A Moment to Socialize

Source: Dataquest (November 1990)

The Price of the Future

Accomplishments do not come free, and the cost to compete is growing faster than the semiconductor market, Dataquest's Fred Zieber, vice president, told conference participants. The magnitude of current and future costs points to a change in the structure and nature of the semiconductor industry, and he envisions a significant attrition in the future.

Mr. Zieber concluded:

- The next five years will be difficult for semiconductor companies, and the survivors will be the ones pursuing long-term strategic roles.
- In some product areas, success will have as much to do with finance as with technology.
- The cost and complexity of building a fab, requiring outside project management, will have a leveling effect on technology.
- The expected decline in the number of chips per wafer will increase wafer capital and processing costs and slow the rate of price/performance improvement.
- Midsize semiconductor companies will feel extreme pressure, being too small to be major and too large to be niche players. So small players will have to take a quantum step to become major players.
- Many companies will need to make a choice between competing with dollars and competing with creativity. Some companies will forego fabs, design, or marketing.
- The full-service company is disappearing, and companies must seek new ways to cut costs outside the corporate walls, such as cooperative efforts with suppliers, customers, or other industry members.
- The real price of the future is meeting the need for a quantum increase in efforts outside the corporate walls.

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Research Newsletter

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THE SEMICONDUCTOR CHIP PROTECTION ACT IS FINALIZED

This newsletter is the first in a series of several dealing with current intellectual property issues affecting the semiconductor industry. This series is the result of joint research efforts of Dataquest's Semiconductor Industry Service (SIS) and Dr. Judith K. Larsen, senior industry analyst for Dataquest's Research Operations Group.

SUMMARY

The U.S. Patent and Trademark Office recently announced the finalization of regulations concerning the Semiconductor Chip Protection Act (SCPA), a distinct form of intellectual property law that protects mask works fixed in semiconductor chips. Although originally created in 1984, the SCPA has up until now granted protection to mask works from foreign countries only on an interim basis.

The newly enacted regulations describe the procedures the U.S. government will follow in granting permanent protection to chips from foreign countries. As a result, while the finalized version of the SCPA will have only an indirect impact on U.S. chipmakers, foreign semiconductor manufacturers will be affected directly by the ruling.

This newsletter provides a basic description of the Semiconductor Chip Protection Act, discusses the background of the new regulations, outlines the steps that Dataquest's international clients must take if they believe that this unique piece of intellectual property law applies to their business operations in the United States, and, lastly, considers the SCPA's implications for non-U.S. manufacturers.

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WHAT IS THE SCPA?

The Semiconductor Chip Protection Act of 1984 extends copyright protection to semiconductor mask works, making it illegal for companies to reproduce and distribute mask works based on protected chip architectures without the permission of the copyright holder. However, in the strictest sense, the SCPA is neither a traditional patent law nor a traditional copyright law; rather, it is termed a sui generis law—a one-of-a-kind law that is created for a specific purpose. It came about because the traditional intellectual property protection awarded through patents and copyrights did not adequately cover semiconductors.

Because chip architectures are not always original, meeting the criteria for novelty required by the U.S. Patent and Trademark Office has often made patents difficult to obtain. From a more pragmatic consideration, the time required to obtain a patent often exceeds the product life of a semiconductor device, limiting the amount of useful protection that patents can offer. Traditional copyright law has not applied to semiconductors at the mask level because these were considered to be "utilitarian" in nature and, therefore, outside the bounds of copyright protection. Although copyright law prohibits unauthorized persons from copying actual drawings of chip designs, it does not prevent someone from copying the mask-level design itself. As a result, an important intellectual property asset fell through the cracks of a legal system created long before the invention of semiconductors.

Although the SCPA is neither patent nor copyright, it is most similar to copyright law, with the following significant differences:

- It provides protection for only 10 years, compared with 75 years for corporate copyright.
- It requires mandatory registration in which applicants must submit a simple form describing their chip architectures. Protection follows as soon as the form has been filed.
- It permits reverse engineering as a method for getting at the ideas expressed in a mask design, although outright copying of the design itself is prohibited.
- It does not apply to chips that are "commonplace or familiar."

EXTENSION TO NON-U.S. SUPPLIERS

At the time the U.S. Semiconductor Chip Protection Act was passed, few other countries had comparable protection for mask works. Before granting long-lasting protection to mask works from foreign suppliers, the U.S. government wanted to ensure that foreign countries would protect U.S. chips. Non-U.S. semiconductor manufacturers could apply for interim protection under Section 914 of the SCPA, provided they entered into a chip protection treaty with the United States or enacted legislation of their own that would protect U.S. semiconductor devices.

In the years since the passing of the SCPA, all major U.S. trading partners have enacted chip protection legislation. Japan actually passed its own chip protection act in 1984, followed by the 12 member states of the European Economic Community (EEC) plus Sweden, Australia, Canada, Switzerland, and Finland. Naturally, once other nations passed legislation protecting mask works, they thought that they should receive permanent protection in the United States under Section 902 of the SCPA, which grants protection to foreign mask works under any of three conditions:

- The mask work owner's nation is party to a chip protection treaty with the United States.

- The foreign mask work is first commercially exploited in the United States.

- The foreign mask work comes within the scope of a presidential proclamation (which could be made if the mask owner's nation protects U.S. intellectual property owners on substantially the same basis as the SCPA).

The United States was slow in responding to the requests of trading partners to grant chip protection under Section 902, partly because the language of that section was unclear. It referred to rules establishing more binding protection, but the rules proved impossible to implement until clarified.

Earlier this year, the U.S. Patent and Trademark Office began to work on the problem of clarifying Section 902. Comments from the public were invited, and two groups—the Commission of the European Communities and the Semiconductor Industry Association (SIA)—responded. On June 29, 1988, the Patent and Trademark Office announced the final rules, thus clearing the way for Section 902 protection to be granted to mask works from foreign countries.

Protection Procedures

The procedures for applying for mask work protection for non-U.S. companies are covered in Subchapter C, Section 150, of the Code of Federal Regulations. The rules describe how to begin the process of obtaining protection, what information is required, how the review process is to proceed, and how the decision is to be announced. These steps may be summarized as follows:

- The protection process can be initiated by request from a foreign government, from the U.S. Secretary of Commerce (through the Commissioner of Patents and Trademarks), or from an international intergovernmental organization (such as the EEC). It is important to note that individual companies cannot make request for protection.

- Extensive documentation regarding the country's mask protection must accompany the request, including copies of laws, legal rulings, regulations, and administrative orders. If a country has already received interim protection through Section 914, the information gathered in that examination will be considered again in the review for Section 902 protection.

- Once a country has requested protection under Section 902, or once the Commissioner of Patents and Trademarks begins an assessment, a notice will be published in the Federal Register. At that time, the public will have the opportunity to submit written comments, and a hearing may be scheduled if issues are raised that cannot be settled informally.

- The commissioner then reviews all the information and prepares a draft recommendation, which is sent to the Secretary of Commerce. The Secretary of Commerce submits a recommendation to the president, who makes a Section 902 proclamation.

There are certain limitations included in the new regulations. The rules state that the proclamation may contain conditions regarding its duration. In addition, procedures are described for considering suspension or revocation of the Section 902 protection. This essentially states that even when Section 902 protection is obtained, intellectual property rights must continue to be respected.

Who is Affected?

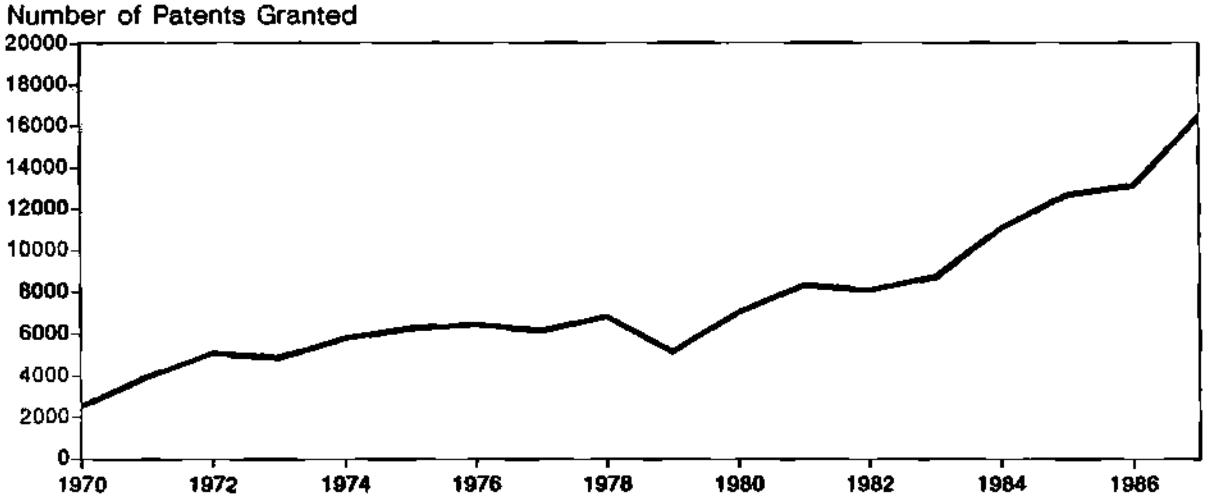
The countries most immediately affected by the new regulations are those that already have effective chip protection acts in place and that currently have interim protection under Section 914. These countries are eligible to apply for Section 902 protection immediately. Countries that do not have chip protection legislation but are moving in that direction would be affected by these rules only when they apply for protection in the United States.

For Japan, the importance of extending permanent protection to the mask works of its semiconductor manufacturers is that it acknowledges Japan's transition from price-cutting copycat to technology innovator. With the Japanese becoming leaders in many technologies (such as ICs, optoelectronics, robotics), protection of intellectual property will be as much an issue in the 1990s as avoiding lawsuits has been in recent times. The pace of Japan's U.S. patent filings alone underscores this trend, as is illustrated in Figure 1. As Japan looks over its shoulder at the newly industrialized countries (NICs) of the Pacific Rim, securing intellectual property assets marks a transition from a defensive to a more aggressive legal posture.

For the Asian NICs, the finalized SCPA may seem more like an obstacle than an opportunity. Although the SCPA has never been tested in court, it is one more legal reef that Pacific Rim competitors will have to avoid as they navigate an increasingly litigious U.S. market. Just as intellectual property law protects the interests of U.S. and Japanese chipmakers, Asian manufacturers eventually will find it working to their advantage as well. In the meantime, a certain amount of education on the intricacies of intellectual property law unfortunately will be attained through lawsuits.

Figure 1

U.S. Patents Granted to Residents of Japan
1970–1987



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Source: Dataquest
November 1988

DATAQUEST CONCLUSIONS

The main impact of the new Semiconductor Chip Protection Act regulations may be to underscore international awareness that intellectual property is a valuable resource. All major trading nations have enacted legislation protecting mask works in the last few years. The fact that Section 902 regulations were finally defined indicates that the United States recognizes the actions of other countries. The regulations also illustrate the continuing efforts of the U.S. government to protect intellectual property and to firm up agreements with countries sharing that concern.

Michael J. Boss
Judith K. Larsen

Dataquest
a company of The Dun & Bradstreet Corporation

Research *Bulletin*

CD Code: 1988 Newsletter: December
0002092

FOURTH QUARTER 1988 SEMICONDUCTOR OUTLOOK GLOOMY

SUMMARY

With end-equipment markets sending mixed signals and some semiconductor manufacturers experiencing declining sales, Dataquest believes that fourth quarter 1988 semiconductor billings, particularly in the North American market, will be lower than third quarter billings as a result of semiconductor inventory adjustments, price erosion of certain devices, and rising equipment inventory levels. Panic has begun to set in as the ghost of bust cycles past appears. However, we continue to forecast single-digit growth in the North American market for 1989; we do not foresee a replay of 1985. We will publish our revised quarterly forecast and outlook for 1989 and 1990 in early February 1989. (It will be available on-line also.)

MARKET STATUS

A survey of the largest U.S. semiconductor manufacturers shows that many will have decreased fourth quarter 1988 billings in the North American market. Our October 1988 forecast for the fourth quarter (predicting a positive 4 percent growth) now appears to be too high, although several U.S. companies—among them LSI Logic and VLSI Technology—continue to do well. Several Japanese companies also continue to see strong growth in the North American market, particularly in DRAMs and SRAMs. Nevertheless, we believe that fourth quarter North American market billings will be down from the third quarter. Products that have been hit hard in this softening of demand are 16-bit and slower 32-bit microprocessors and also programmable array logic (PAL) devices and PAL-replacement devices. (PAL is a registered trademark of Advanced Micro Devices.)

We believe that semiconductor buyers have slowed purchases in order to make up for overbuying earlier in the year brought on by shortages in key products such as the 80386 microprocessor and 1Mb DRAMs. Demand is still high for 25-MHz 80386 and 16-MHz 80386SX devices; however, slower and older versions are in excess supply. Shortages still exist for most SRAMs and 256K DRAMs.

Areas of strength still exist in the end-equipment market. The laptop computer market is poised to explode in 1989; this product consumes large volumes of 80286 microprocessors. IBM, Apple, and Compaq, the big three U.S. personal computer makers, continue to report strong sales and expect a good year in 1989. In the automotive market, Ford Motor Company anticipates another strong year in 1989 and plans to increase semiconductor procurement. The market for facsimile equipment is expected to continue strong growth next year, with semiconductor consumption levels growing almost 30 percent. (Almost all facsimile equipment is produced in Japan.)

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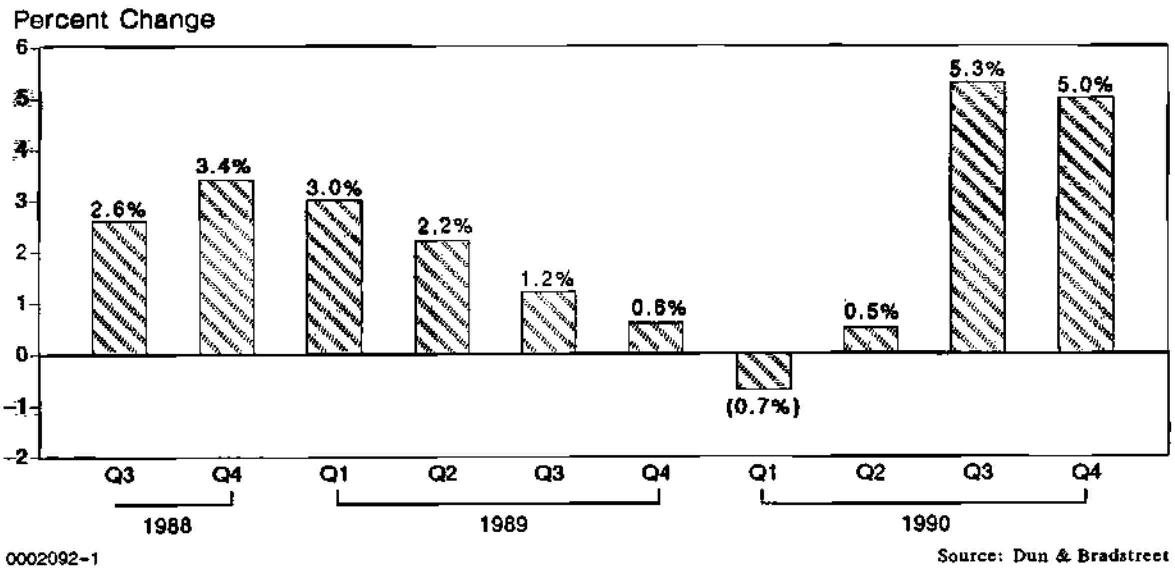
U.S. Department of Commerce statistics show inventory levels of the total computer category growing, with October 1988 inventory levels at 8.8 weeks of sales, compared with the October 1987 figure of 8.5 weeks of sales. No trend is yet visible on bookings and billings for this category. Growth has been flat for several months.

On the plus side of the equation, the U.S. economy looks surprisingly strong. Dun & Bradstreet (D&B) continues to forecast total 1988 GNP growth at 3.9 percent, in spite of the drought, which knocked at least $23 billion out of the economy. GNP growth for 1989 and 1990 is forecast to be 2.5 percent and 1.3 percent, respectively. D&B no longer forecasts a recession (two quarters of negative growth) between now and 1991. The current D&B GNP forecast is shown in Figure 1. Other positive economic signs include an October increase in leading economic indicators of 0.1 percent and personal income up a healthy 1.8 percent in October.

Figure 1

Forecast of U.S. GNP Growth



At this time, it appears that our 1988 yearly forecasts for the European, Japanese, and ROW markets are still on track, based on preliminary estimates of company revenue in each region. We will issue any revisions with our quarterly industry forecast in early February 1989.

DATAQUEST CONCLUSIONS

The basic trends underlying our current industry forecast are playing out as we had predicted, with an inventory adjustment occurring earlier than forecast. This is resulting in a much poorer than expected fourth quarter 1988 for the North American market, always the first market to turn. The North American market is undergoing inventory adjustment and price erosion in PALs, standard logic, 16-bit microprocessors, and EPROMs. Products maintaining price firmness include high-speed 32-bit microprocessors, DRAMs, and SRAMs. Fourth quarter 1988 billings in the North American market will probably be lower than third quarter billings, and we continue to foresee slow growth in the first two quarters of 1989, followed by two quarters of slightly negative growth in the last half of 1989.

Patricia S. Cox

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To: Dataquest Clients

The SIS preliminary 1987 worldwide semiconductor market share newsletter is attached. This year the content of this newsletter has been enhanced to include rankings in product areas such as MOS memory, micro, and ASIC. Total semiconductor and IC rankings for the North American market are also included. Detailed analysis of regional market data is available from our JSIS, ESIS, ASETS, and SIS groups.

We are making a schedule change in the collection of final company semiconductor revenue data. We would like to review the estimates in February and March and publish the market share service section in April in its final form. This will be a two-month improvement in our historical schedule and will allow publication of the market share data service section to coincide with that of the market consumption data service section, which is scheduled for updating in April.

Thank you for your support. Happy New Year!

Gene Norrett
Corporate Vice President & Division General Manager
Components Division

Dataquest

a company of The Dun & Bradstreet Corporation

February 5, 1988

Dear Client,

Enclosed is our new brochure, "Introduction to Dataquest's Semiconductor Industry Service (SIS)." We realize that many of you are longtime clients and friends of Dataquest and need no introduction. We still want to share this with you because like you, we have grown and improved our service and want you to know about all of the resources that are available to you.

Some of you, of course, may be new to Dataquest. You may be a new client or you may have recently taken on the Dataquest interface within your company. If so, you may not have had a chance to learn about all of the facets of the Semiconductor Industry Service. This brochure will help acquaint you with the resources that we offer.

As new semiconductor services have evolved, we want you to understand the distinction between them. The Semiconductor Industry Service is positioned as a product-oriented, executive-level perspective on the worldwide semiconductor industry. The enclosed brochure helps clarify that position and briefly outlines our forecast methodology.

We publish our information in two formats: notebooks and newsletters. The notebooks contain topics that we agree to follow on an ongoing basis, while newsletters may summarize major service section updates or deal with one-time-only topics that are of transient importance.

As a client, you have access to our inquiry center as well as the inquiry privilege with our senior research staff. The inquiry center provides quick-turnaround answers of a quantitative nature and help in finding information in the binders. Inquiry with the research staff will assist you with more strategic issues that require dicussion and opinion from our market experts. The inquiry privilege is limited to you and two alternates that you designate. You may call as often as you need, and we will be happy to help you. The inquiry privilege is intended to access information that is in our files or data bases, not to provide special research.

In addition, you can access the SIS information via an on-line computer system. You will need an ASCII terminal or PC, a modem, and a phone line that can accommodate data transfer. Our on-line service manager will establish a password for you and give you initial instructions. Please call Karen Foley at (408) 437-8576 for more information.

February 5, 1988

Another important element of our service is the annual Semiconductor Industry Conference held each year during the third week in October. This year's conference will be held in San Diego, from October 17 through 19. This is one of the highlights of the service, so please mark your calendar now.

I have enclosed a list of our staff members and their areas of responsibility. You may call any of them depending upon the nature of your questions. If you are not sure who to call, direct your questions to the inquiry center for assistance.

You're always welcome to visit us; whenever you are in San Jose, please let us know and we will be happy to show you around. We are pleased that you have chosen Dataquest's Semiconductor Industry Service, and we appreciate the opportunity to serve your strategic information needs.

Sincerely;

Mel Thomsen
Director
Semiconductor Industry Service

Enclosures (2)

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Research Newsletter

THE TIGERS PREPARE FOR GRADUATION

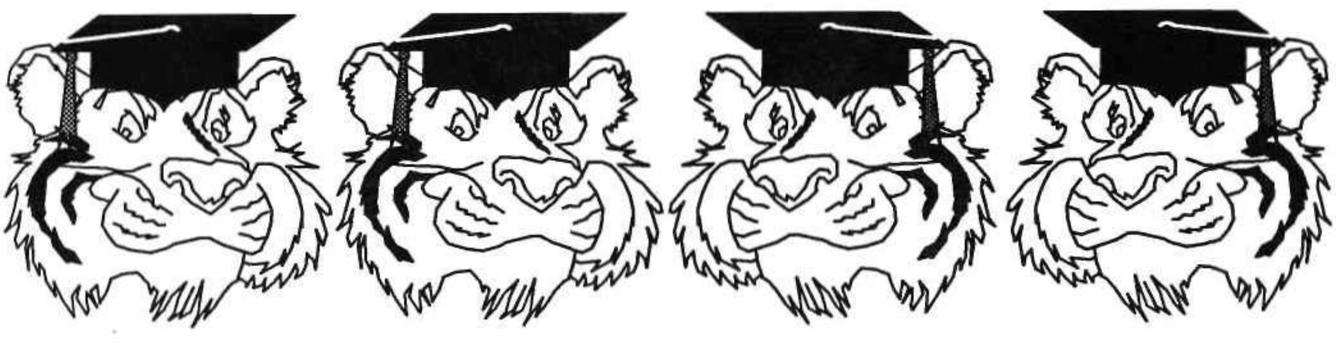
SUMMARY

The decision of the Reagan administration to remove Asia's "Four Tigers" from the Generalized System of Preferences (GSP) will add more than $75 million in tariffs to imports of electrical and electronics products from those countries when the action goes into effect in 1989, a Dataquest analysis shows. While the financial impact is not large, ad valorem duties on some products are high enough to cause importers to consider alternative sources.

Dataquest views the action as an election-year signal that Asia's export-oriented countries are under severe pressure to revalue their currencies, open their markets to U.S. imports, and take other steps to reduce trade imbalances. The situation presents companies doing business in those countries with both opportunities and challenges. It may also impede industry efforts to wring concessions on intellectual property and other issues from the affected countries and others in the region.

BACKGROUND

The 12-year-old GSP program exempts from U.S. tariffs imports of about 3,000 products from 140 developing countries. About $15 billion, out of total U.S. imports of $424 billion in 1987, arrived under the GSP program. The so-called Tigers—Hong Kong, Singapore, South Korea, and Taiwan—accounted for almost $10 billion of the GSP imports last year.



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The program was designed to help infant industries gain a foothold in the U.S. market. Typically, products or countries are removed from the GSP list on a case-by-case basis as part of an annual review process. Countries can be "graduated" from the program if their exports of a product to the United States exceed about $75 million or if they account for at least 50 percent of total U.S. imports of the product. The limits are lower for countries deemed to be "sufficiently competitive" in making a product. For example, South Korea has already lost its GSP status for high-volume exports such as microwave ovens and tape recorders.

Congress amended the GSP law in 1984 to allow U.S. trade negotiators to use the program as a tool to open up foreign markets and to protect intellectual property. In fact, a package of GSP benefits helped convince the government of Singapore to enact new copyright protections in January 1987. The new GSP benefits for Singapore went into effect just last July.

Secretary of the Treasury James Baker first proposed removing the four Asian countries from the GSP program last fall. Observers said reasons for the move included cutting the U.S. trade deficit and retaliating against trade policies and currency practices of the Tigers. Trade sources indicate that political considerations, including a desire to sidetrack protectionist elements of the massive trade bill now nearing completion in Congress, also entered into the decision. In any case, the President announced on January 29 that the Tigers will be ineligible for any GSP treatment, effective January 1, 1989.

ANALYSIS OF IMPORT DATA

On the basis of projections from detailed import figures for the first 10 months of 1987, Dataquest estimates that the GSP program saved exporters in the four countries a total of $600 million in tariff payments on $10 billion worth of products for the full year. The benefit was probably $75 million for exporters of electrical and electronics products valued at $1.5 billion (see Table 1). For the 10 months through October, Taiwan alone accounted for GSP imports totaling $3.6 billion. It has been and remains the primary beneficiary of the program. South Korea shipped products valued at $2.1 billion under the program; Hong Kong, $1.4 billion; and Singapore, $1.0 billion.

The order of ranking is reversed when electrical and electronic products are examined. Dataquest estimates that these products accounted for GSP imports of $1.272 billion from the Four Tigers in the 10-month period. For Singapore, which has attracted manufacturing operations of such U.S. multinationals as Apple Computer, AT&T, Digital Equipment, and Hewlett-Packard electronics accounted for $449 million, more than 40 percent of its GSP exports. In contrast, only $177 million, or 5 percent, of Taiwan's booming GSP exports fall into the electrical/electronics sector.

Table 1

Electrical/Electronics Products As a Share of GSP Imports
(Millions of Dollars)

Country	All GSP Imports Jan.-Oct. 1987	Tariffs Saved	Electrical/ Electronic GSP Imports	Tariffs Saved
Taiwan	$3,622	$217	$ 176.8	$ 7.5
South Korea	2,106	126	303.9	14.9
Singapore	1,033	62	448.6	23.9
Hong Kong	1,422	85	342.5	16.4
Total	$8,183	$490	$1,271.8	$62.7
Full-Year Projection	$9,800	$600	$1,500.0	$75.0

Source: Dataquest
March 1988

Table 2 is a selected list of 1987 imports, through October, for the principal electrical and electronics imports affected by removal of Taiwan, Singapore, Hong Kong, and South Korea from the GSP. Products are grouped according to their Tariff System of the United States (TSUS) classification.

A closer look at electrical and electronics import figures for the 10-month period shows that telephone equipment, including handsets, answering machines, and cordless telephones, was the largest product category affected, with a combined total of $284 million. Accounting and computing equipment, primarily from Singapore and South Korea, accounted for $230 million in GSP imports. Electrical accessories, a catchall category that includes switches, relays, connectors, and printed circuit boards totaled $188 million. Radio equipment, magnetic recording media, signaling apparatus, calculators, and office machines were other significant product areas.

Dataquest's analysis is based on statistics covering the top 50 duty-free products from each country, as compiled by the Office of the U.S. Trade Representative. Totals may not be complete because products representing small import values are not included.

Table 2

Electrical/Electronics Imports That Will Lose GSP Status (Millions of Dollars)

Product	Taiwan	Singapore	Hong Kong	South Korea	Total
Magnetic Recording Media (TSUS 724.45)	$ 24.3	$ 2.9	$ 96.3	0	$ 123.5
Electrical Accessories (TSUS 685.90)	0	57.5	72.5	$ 58.6	$ 188.6
Accounting, Computing Machines (TSUS 676.15)	0	127.5	18.0	84.1	$ 229.6
Calculators (TSUS 676.20, 676.25)	39.6	5.4	24.2	16.1	$ 85.3
Telephone Sets, Terminal Equipment, Switching Apparatus (TSUS 684.58, 684.57)	0	90.4	27.7	29.2	$ 147.3
Telephone Answering Machines (TSUS 685.39)	0	33.1	24.6	33.9	$ 91.6
Cordless Telephones (TSUS 685.25)	0	29.7	15.4	0	$ 45.1
Transceivers, Radio Navigation Aids, Receivers (TSUS 685.24, 685.60, 685.14, 685.20)	57.2	43.5	18.9	59.2	$ 178.8
Signaling Apparatus (TSUS 685.70)	55.7	0	27.2	22.8	$ 105.7
Office Machines (TSUS 676.30)	0	58.6	17.7	0	$ 76.3
Totals	$176.8	$448.6	$342.5	$303.9	$1,271.8

Source: Office of the U.S. Trade Representative

ANALYSIS OF FINANCIAL IMPACT

Duties payable on imports of the electronic and electrical products identified in this analysis range from 2.7 percent for signaling apparatus to 8.5 percent for telephone sets, terminal equipment, and switching equipment (see Table 3). The average duty that would have been paid by the Tigers on their GSP exports of these products was 4.9 percent, or $62.6 million, for the 10 months. The saving probably reached $75 million for the full year and would be substantially larger in 1989, when GSP status ends, assuming continued increases in trade.

Table 3

Electrical/Electronics GSP Imports—Financial Impact (Millions of Dollars)

Product	Duty-Free Imports from Four Tigers Jan.-Oct. 1987	Ad Valorem Duty	Tariffs Saved
Magnetic Recording Media	$ 123.5	4.4%	$ 5.4
Electrical Accessories	188.6	5.3%	10.0
Accounting, Computing Machines	229.6	3.9%	8.9
Calculators	85.3	3.7%	3.2
Telephone Sets, Terminal Equipment, Switching Apparatus	147.3	8.5%	12.5
Telephone Answering Machines	91.6	3.9%	3.6
Cordless Telephones	45.1	6.0%	2.6
Transceivers, Radio Navigation Aids, Receivers	178.8	6.0%	10.7
Signaling Apparatus	105.7	2.7%	2.9
Office Machines	76.3	3.7%	2.8
Total	$1,271.8	4.9%*	$62.6

*Average

Source: U.S. Customs Service
Dataquest
March 1988

Dataquest believes that, in most cases, the duties are too small to force radical changes in trading patterns. One exception is telephone equipment, a highly competitive product area where a prospective cost increase of 8.5 percent is already causing some importers to consider alternative sources of supply. "It could affect our sourcing and our price to end users," said one telecommunications equipment executive.

In other product areas, the new duties can probably be absorbed or offset by manufacturing efficiencies. Still, the Far Eastern Economic Review reported in its February 11 issue that Hong Kong officials fear that the GSP action could affect future investment decisions.

Far more significant to the Tigers and to companies relying on them as sources of low-cost products are the longer-term implications of the Reagan administration's action. If the United States succeeds in forcing these countries to revalue their currencies significantly (against the dollar) or to curtail exports artificially, the cost impact could be much greater than the duties at issue in the GSP debate. With bilateral U.S. trade surpluses that totaled $37 billion last year, the Tigers are clearly approaching an import limit set by political realities in the United States.

ANALYSIS OF POLITICAL IMPLICATIONS

The Reagan administration is under increasing pressure to look "tough on trade" during this election year. The growing Democratic primary strength of Congressman Richard A. Gephardt, known for his support of aggressive action on the trade deficit, is one factor. Another is the omnibus trade legislation that has been working its way through Congress for more than a year. The bill contains several tough provisions that stem from congressional impatience with the administration on trade matters. As a result, according to the International Trade Reporter, 1987 was "the most active year in trade since President Reagan took office." The GSP action continues that tradition.

Dataquest expects to see continuing political heat focused on Taiwan and South Korea, because their contribution to the U.S. trade deficit is large and their markets are still relatively restricted. Taiwan recently took major steps to reduce tariffs and open its markets in areas such as banking, insurance, and shipping. Still, U.S. negotiators apparently are not satisfied with progress in either Taiwan or South Korea. Even lobbyists for the GSP see no chance that the administration's decision can be reversed in the case of the two largest Tigers.

Both Hong Kong and Singapore can make a good case that they have met most U.S. demands for open markets and protection of intellectual property rights, but both seem adamantly opposed to tinkering with their currencies. The 10 percent increase in the Singapore dollar since 1985 is "far enough," stated an official of the Singapore Economic Development Board. Thus, while Congress theoretically could overturn the administration's action—at least for Singapore and Hong Kong—that seems unlikely in the present political climate.

DATAQUEST CONCLUSIONS

The Four Tigers are being pushed quickly down the road that Japan has already followed—away from reliance on exports to the United States as an engine of growth and toward expansion of domestic markets and imports. The action to remove their GSP status, abrupt and unfair though it appears, is a reminder that the future of these countries does not lie in the labor-intensive export industries that launched their economic revolution. Companies that can help the Tigers build higher value-added industries and expand their internal markets should prosper. U.S. exporters are already finding a warmer welcome in Taiwan, and South Korea can be expected to start opening its trade doors, once the government of President Roh Tae Woo settles in. Companies depending on these countries for low-margin products should expect more trade and currency shocks and should be exploring alternative sources.

Dataquest believes, however, that the GSP action may send the wrong signals to governments where trade barriers are under negotiation. By graduating four countries with very different records on such issues as market access and intellectual property protection, the United States appears to have thrown away the negotiating "carrot" of continued GSP status. Hopefully, this will not slow progress toward the goal of open markets and fair treatment of patents and copyrights around the world.

John W. Wilson

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Research Newsletter

CAPITAL SPENDING PLANS LOOK STRONG FOR 1988

SUMMARY

The stock market plunge of October 19, 1987, caused most economists to lower their projections for economic growth in 1988. But a survey conducted after the crash by The Dun & Bradstreet Corporation, Dataquest's corporate parent, indicates that most U.S. companies are not cutting back their spending plans for new capital equipment and facilities. Instead, three quarters of the companies surveyed expect to maintain or increase capital spending in 1988. Together with Dataquest surveys of client companies and a recent U.S. Commerce Department forecast of capital spending intentions, the Dun & Bradstreet survey buttresses the view that 1988 will be a strong growth year for those high-technology markets that are closely linked to the capital investments of Corporate America.

SURVEY RESULTS

Dun & Bradstreet's Dun's 5000 survey is based on a sample of companies that is statistically representative of the distribution of companies by size in the U.S. economy. Of the companies surveyed, only 22 percent indicated they plan to decrease their capital spending in 1988 from 1987 levels, a solid 36.7 percent expect no change, and 41.3 percent are planning capital spending increases (Figure 1). These gains reflect the continuation of a trend that began last year, according to Joseph W. Duncan, Dun & Bradstreet's corporate economist. Mr. Duncan pointed out that almost 25.0 percent of the companies surveyed spent more than they had planned in 1987, while only 17.2 percent saw their spending come in lower than expected (Figure 2).

Only 8.4 percent of the Dun's 5000 respondents said the decline in stock prices would have a negative impact on their capital spending. But nearly 16 percent of small companies—those with fewer than 20 workers—said the crash would crimp their plans (Figure 3). And, looking at spending intentions by size of firm shows a far more bullish mood among large companies than is reflected in the small-business sector (Figure 4). Because of their need to carefully manage financial resources, explained Mr. Duncan, "small companies are more likely to reduce spending during periods of uncertainty."

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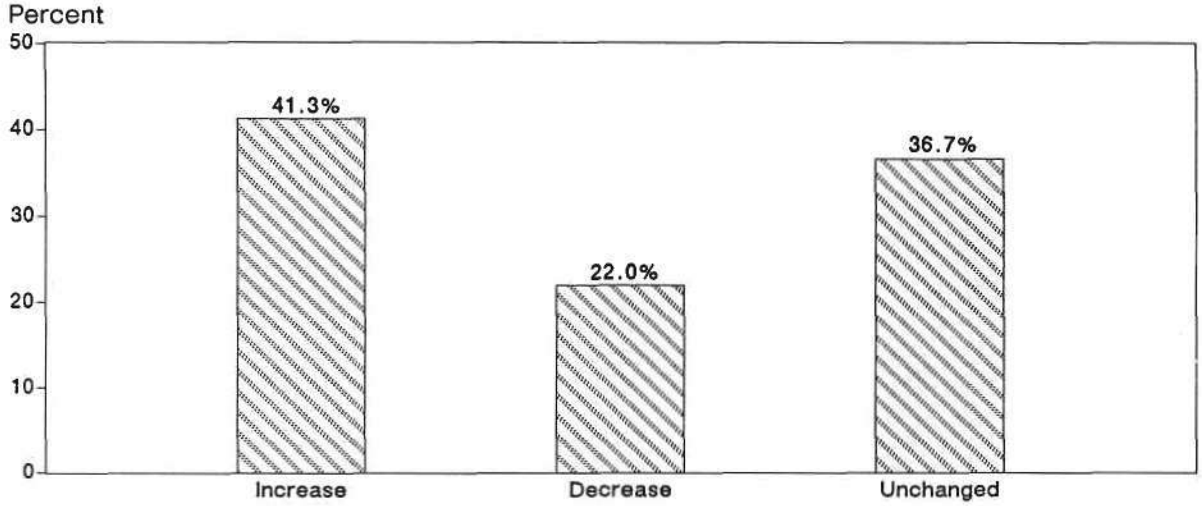
Figure 1

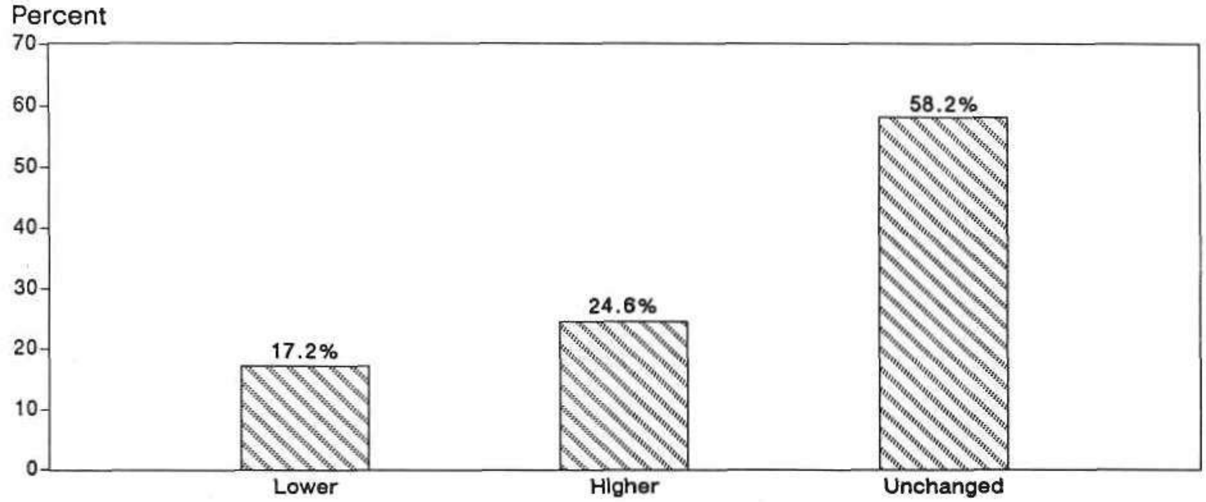
**Capital Spending Plans
1988 versus 1987**



Source: Dun & Bradstreet

Figure 2

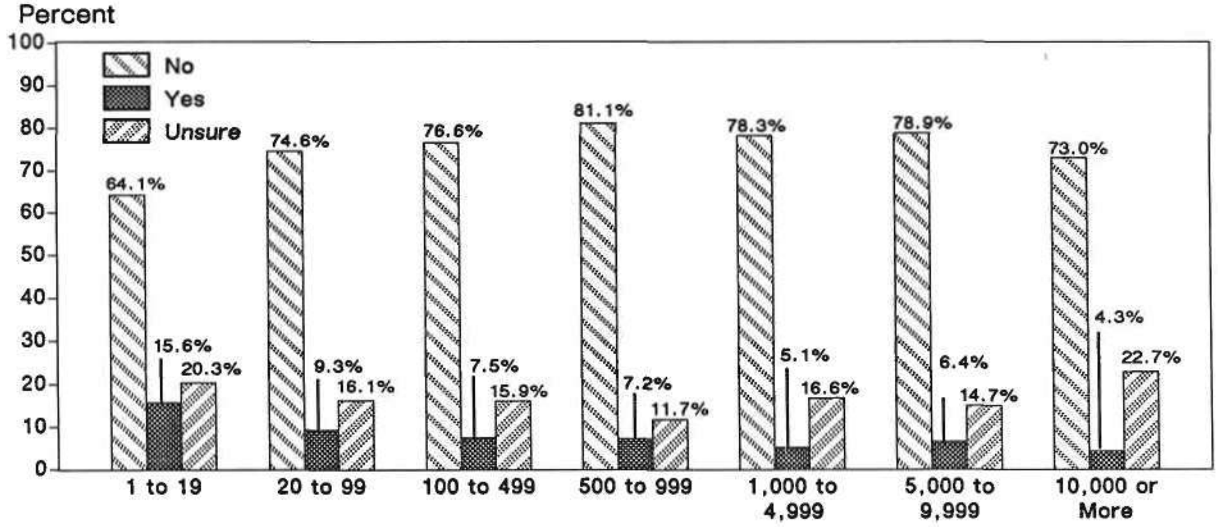
**1987 Capital Spending
Actual versus Planned**



Source: Dun & Bradstreet

Figure 3

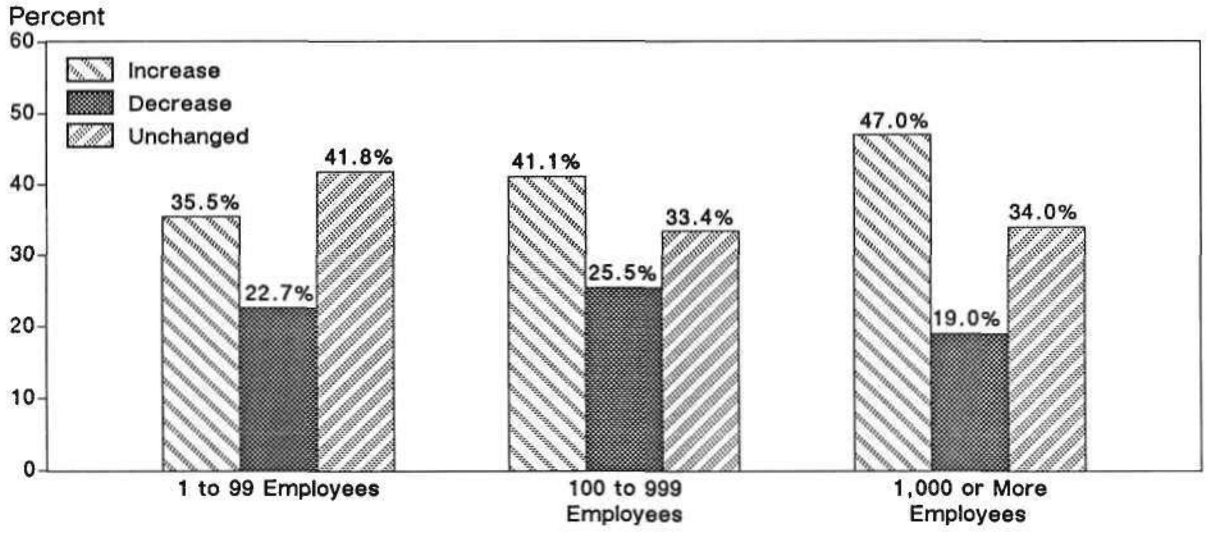
**Will Stock Market Crash Have Negative Impact on Spending?
(By Company Size)**



Source: Dun & Bradstreet

Figure 4

**Capital Spending Plans
1988 versus 1987
by Company Size**

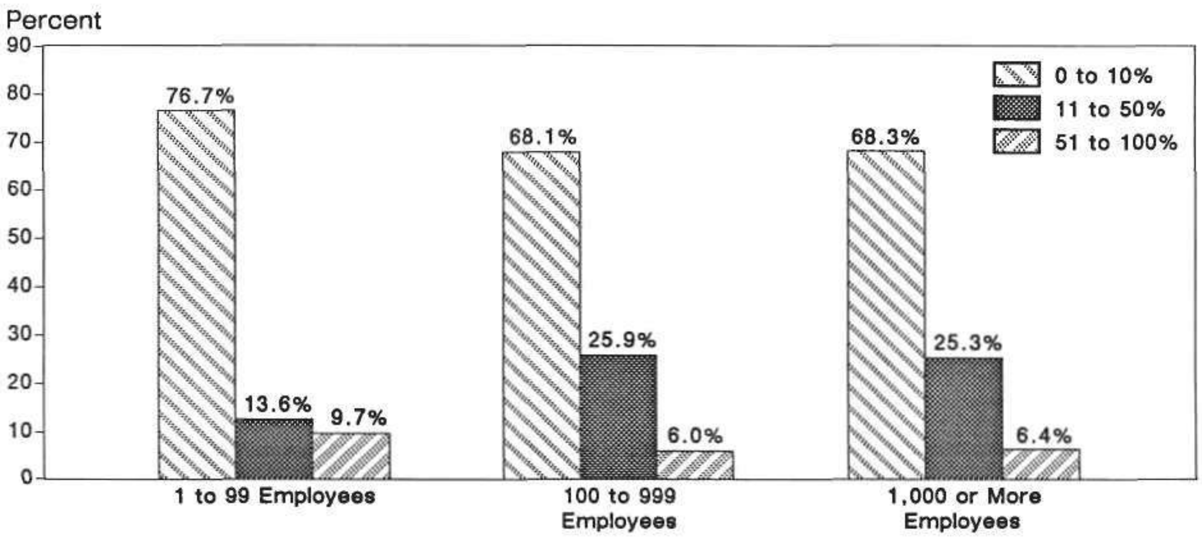


Source: Dun & Bradstreet
Dataquest
January 1988

Small companies are a hard sell for another reason: According to the survey, they allocate less of their capital budgets to computers and telecommunications equipment than larger firms (Figure 5).

Figure 5

Budget Allocation for Computers and Telecommunications Equipment by Company Size

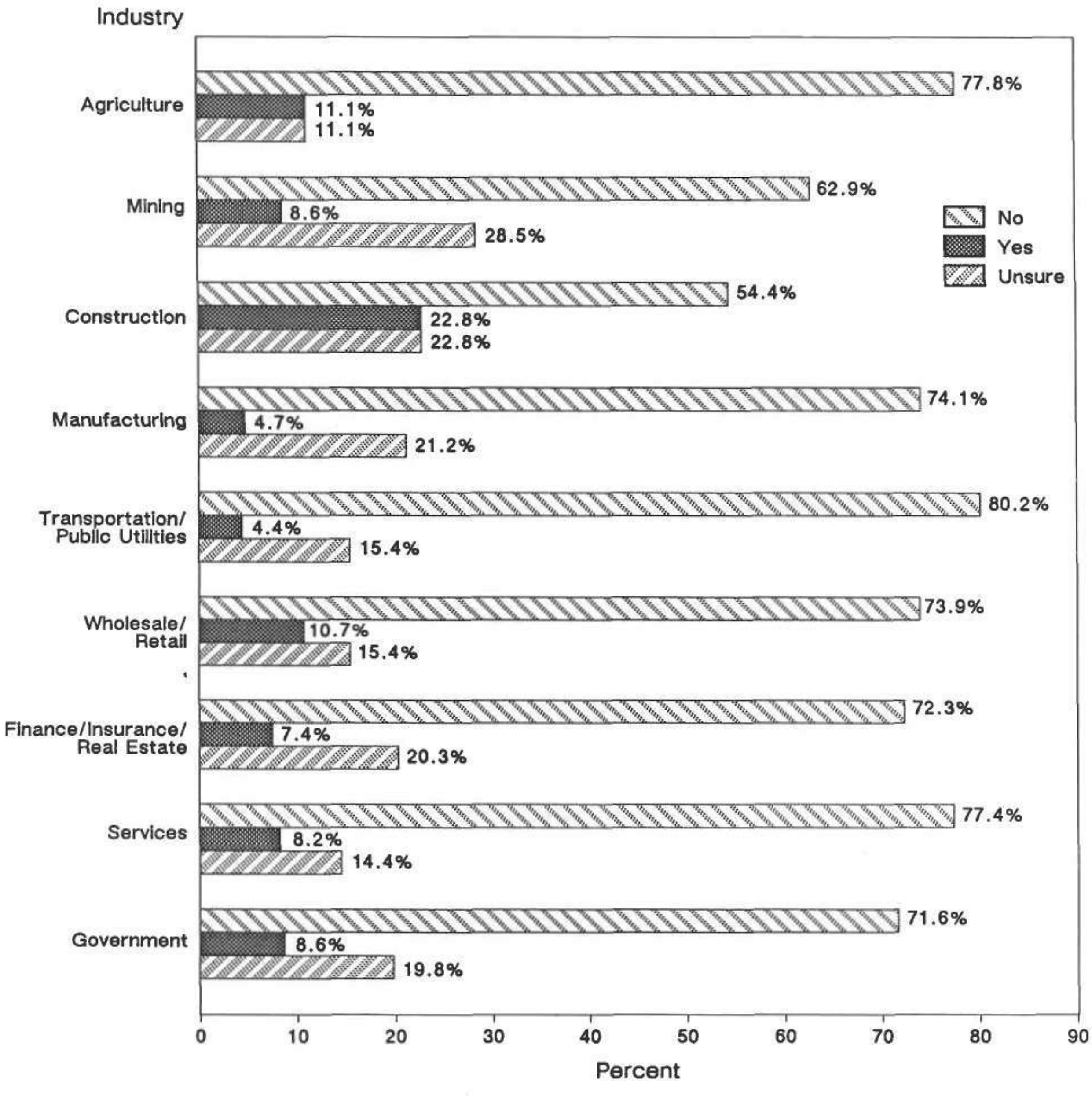


Source: Dun & Bradstreet
Dataquest
January 1988

The survey turned up few disparities in spending intentions among industry sectors. Construction companies, which were more likely than other companies to cut capital budgets in 1987, felt the largest impact from the stock crash (Figure 6). On the other hand, plans for increased spending in 1988 were fairly uniform across industries (Figure 7). While 41.3 percent of the manufacturers surveyed plan to increase spending, even more service companies, transportation companies, and utilities also expect higher capital outlays. But there are marked sectoral differences in the share of capital spending budgets devoted to information systems. Computers loom largest in the plans of financial, real estate, and insurance companies. Almost all the construction, mining and agricultural firms devote 10 percent or less of their capital budgets to computers and telecommunications equipment (Figure 8).

Figure 6

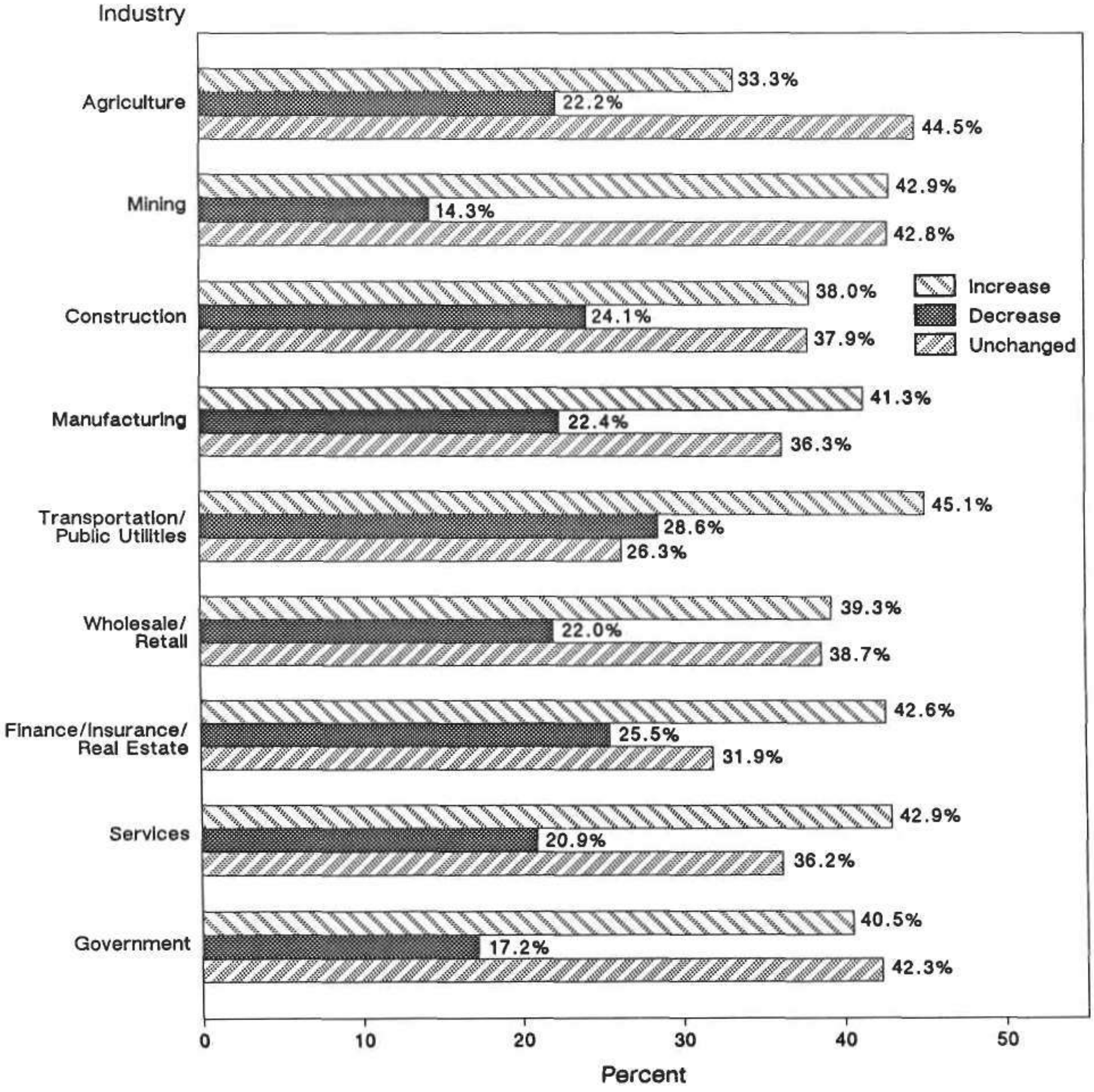
Will Stock Market Crash Have Negative Impact on Spending by Industry?



Source: Dun & Bradstreet

Figure 7

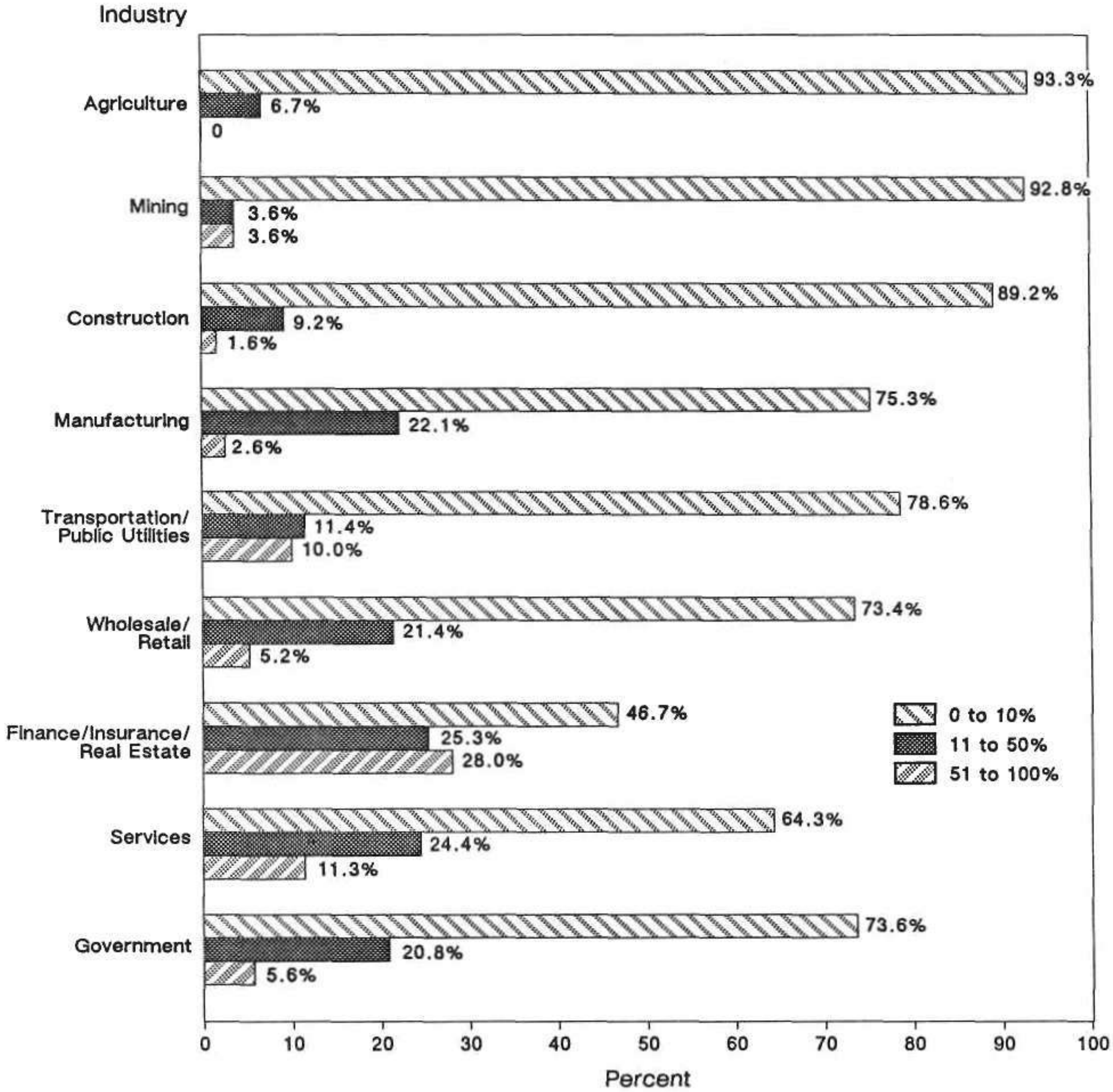
Capital Spending Plans
1988 versus 1987
by Industry



Source: Dun & Bradstreet
Dataquest
January 1988

Figure 8

Budget Allocation for Computers and Telecommunications Equipment by Industry



Source: Dun & Bradstreet
Dataquest
January 1988

OTHER INDICATORS

The Dun's 5000 survey is only the latest in a series of indicators pointing toward strong U.S. demand for capital equipment this year. The Commerce Department reported in mid-December that U.S. companies are planning to increase capital spending by 7.3 percent in 1988. That is more than three times the estimated 2.3 percent rise in 1987. According to the Commerce Department survey, manufacturers will lead the way with an 8.6 percent increase in capital spending.

Dataquest's survey of chief financial officers, reported to clients in late November, also predicted that buyers of electronics equipment would ignore the market crash. Another important indicator of strength came in December, when Dataquest's Personal Computer Industry Service surveyed four major personal computer retailers, representing more than 1,500 U.S. outlets. The chains reported that December sales were up 20 to 25 percent over December of 1986, and their growth expectations for the first quarter of 1988 ranged from 12 to 28 percent.

DATAQUEST CONCLUSIONS

It is clear that manufacturing industries in the United States are booming and that the market crash has had little or no immediate impact on their prospects. Although domestic spending has slowed from the strong growth pace of the last few years, the sharp decline of the dollar has vastly improved export prospects for many industries. Capacity utilization, at 82 percent in November, is tighter than it has been in almost a decade. Manufacturers' profits are strong—up 19 percent from the second quarter to the third quarter of 1987—and are expected to keep improving. As a result, companies across a wide range of industry sectors are committing to long-postponed expansion and modernization projects. The Dun's 5000 survey shows that service companies are also gearing up for capital projects.

Dataquest believes that vendors positioned to take advantage of an upsurge in capital spending will prosper in 1988. The cloud of uncertainty that was created by the market crash has been all but dispelled. Dangers still lurk in the potential for higher interest rates if the dollar resumes its free-fall or if inflation heats up. And, a delayed consumer reaction to the woes of Wall Street is still possible. But the combination of a healthy capital spending climate and a presidential election means that for most Dataquest clients, 1988 should be a year to remember.

John W. Wilson
Bernadette Joseph
Dataquest Corporate Research

Dataquest
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EUROPE 1992: GOING DUTCH—A STRATEGIC ADVANTAGE

SUMMARY

The deregulation of Europe in 1992 will mark the most important shift in the high-tech market—or any market—that the world has seen in recent history. U.S. and Japanese firms will rush to set up shop in Europe in order to grab a piece of the action. Key contributors in this process will be national development agencies (some of which are listed below in this newsletter). These organizations will form the link between incoming companies and the new, integrated European market.

European development agencies have been actively recruiting high-tech industry for years. Substantial clusters of activity have emerged throughout Europe in places such as Austria, England, Ireland, Italy, Scotland, Wales, and West Germany. Dataquest now views the Netherlands as an important player in this field.

This newsletter gives an overview analysis of European deregulation. Then, using the Netherlands as an example, an aggressive national high-tech development strategy is examined. Finally, opportunities for non-EEC companies are identified. Dataquest's assessment is that the gradual deregulation of European markets over the next decade will represent a rising challenge to the remainder of the industrialized world and alter the structure of global competition. Most importantly, Europe 1992 will provide a significant opportunity for those firms wise enough to get in early.

THE UNITED STATES OF EUROPE

In a sweeping move to invigorate European markets, the European Economic Community (EEC) has targeted 1992 as the date to have legislation in place that would eliminate all trade barriers between member nations. The EEC is also working toward technical, environmental, and financial standardization. Unified standards will increase profitability within the Common Market. Companies that, in the past, have had to meet the unique specifications of each country will now be able to sell standard products into a mass European market.

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With 320 million people, the 12 EEC nations contain a population approaching that of Japan (130 million) and the United States (230 million) combined. To avoid being left out, non-EEC European countries such as Austria, Norway, Sweden, and Switzerland have stepped up efforts to join the Economic Community, or at least to conform to its standards. Europe expects deregulation to result in more open procurement practices with countries such as Japan and the United States. The stated position from Brussels is that the EEC will continue to react to protectionist legislation with reciprocal measures. However, companies that have an established presence in Europe by 1992 will be able to participate as insiders. To take full advantage of this new arena, many companies are realizing that they must position themselves now.

PAN-EUROPEAN COOPERATION IN HIGH TECHNOLOGY

In concert with moves toward deregulation, cross-border cooperative research programs have been set up aimed at creating sufficient economies of scale in the development and marketing of high-technology products. The main thrust is to overcome the national market orientation and scattered R&D efforts that have hampered Europe's competitiveness in the global marketplace.

The European Strategic Program for Research and Development in Information Technology (ESPRIT) has created a 10-year program among EEC nations (1984-1994). This effort is intended to develop internationally accepted standards and create a pool of basic research and development to allow Europe to compete more effectively in the world market. The cost of ESPRIT is shared by the EEC and participating companies. Cross-border strategic alliances will ideally result in long-term industrial cooperation. With the first phase of the program completed, 277 ESPRIT projects are now in progress.

Eureka, a complementary Pan-European R&D program, was initiated by France in early 1985. Eureka's focus is to exploit advanced technologies through the development and marketing of specific products and processes with a profitable global sales potential. Eureka has a broad base, involving large and small firms, research institutes and universities, and government research centers that are represented in the 165 Eureka projects currently under way.

The RACE (Research and Development in Advanced Communications Technologies for Europe) project was initiated in 1985 by the EEC to develop a wideband digital communications network for all of Europe. This system will be capable of high-speed transmission of voice, images, data, and text. The 45 RACE projects now actively involve international consortia of universities, telecommunications equipment manufacturers, and network operators.

A DEEPENING POOL OF VENTURE CAPITAL

Deregulation of European financial markets, a process already solidly under way, will open up the entire EEC venture capital pool to European companies. According to the European Venture Capitalist Association, the European venture capital industry raised ECU 3.9 billion ($5.1 billion) in 1987, increasing its growth rate by 42.9 percent and raising the total pool to ECU 13 billion ($17 billion). During this time, U.S. venture capitalists raised only ECU 3.8 billion ($4.9 billion) and the growth rate of the industry decreased by 20 percent, bringing the total pool to ECU 22 billion ($29 billion. Nineteen eighty-seven was the first year that European venture capitalists raised more funds than their U.S. counterparts.

The rapid growth in European venture capital can be attributed, in part, to the anticipated increase of start-up opportunities in Europe under deregulation and to the cumulative contributions of EEC, government, and private venture capital funds. With the opening of inter-European markets, more venture opportunities will be created, especially in distribution, marketing, financial services, design, and contract assembly. For details on the U.S. venture capital industry, see the August 1988 Dataquest Strategic Issues newsletter entitled "The New Face of Venture Capital."

The Dutch have been particularly active in promoting their venture-capital industry. In 1982, their government began guaranteeing half of the losses of officially recognized venture capital firms. Additionally, the Amsterdam Stock Exchange set up the Parallel Market to list younger, less established companies. Government-sponsored venture capital organizations were created to spur the growth of the venture capital industry. A substantial portion of the ECU 1 billion of venture capital available in the Netherlands is from the MIP Equity Fund. However, government sponsorship has been on the wane recently as the private sector has grown. These policies have been effective: In 1987, the Netherlands was the second-largest contributor to the European venture capital fund following the United Kingdom.

THE NETHERLANDS—A SUCCESSFUL STRATEGY

Many national and local jurisdictions now recognize that stimulating the emergence of a vibrant high-technology industry cluster within their borders is essential to economic growth in general. This newsletter focuses on the development strategy of the Netherlands for two reasons: First, it is Dataquest's view that the Dutch serve as a good example because they have enacted an aggressive, broad-based, and successful high-tech development strategy; second, the opportunities in the Netherlands are not widely perceived by many high-tech companies.

The Netherlands, building on its established role as Europe's distribution center, is actively laying the groundwork for 1992. A host of government programs and agencies, spearheaded by the Netherlands Foreign Investment Agency (NFIA), are in place to attract high-technology companies that are seeking manufacturing, design, assembly, and distribution facilities in Europe. Government research grants of up to $650,000 are available on the condition that the resulting products are manufactured, at least in part, in the Netherlands. Investment incentives can cover 25 percent of fixed capital costs for incoming companies.

According to the NFIA, more than $12 billion have been invested in the Netherlands by more than 1,200 U.S. companies to date, creating 120,000 jobs. Recent additions to the Netherlands high-tech corporate community, according to the NFIA, are listed below:

Company	Product	Activity
Adobe Systems	Software	European headquarters
Align-Rite Int.	Semiconductors	Manufacturing
Intergraph	CAD systems	Manufacturing and distribution
Memorex Telex	Computer equipment	Distribution, assembly, and repair
Mentor Graphics	CAE systems	Manufacturing and accounting
Prime Computer	Computer equipment	Distribution
Oracle	Software	European headquarters and R&D
Sierra Semiconductor	Semiconductors	European headquarters and design
Tandem Computer	Computers	European headquarters
WordPerfect	Software	European headquarters

PUBLIC/PRIVATE PARTNERSHIP-BUILDING A HIGH-TECH KNOWLEDGE INFRASTRUCTURE

To implement a policy of inward investment, the government developed a Technology Policy Action Program for 1987 and 1988 to fund research at three Technical Universities located in Delft (outside The Hague), Eindhoven (within the Silicon Triangle), and Enschede (in Twente). The research programs at Dutch universities have produced innovations that have resulted in the spin-off of Dutch-based high-tech firms such as EDA Systems.

Key to the Dutch development strategy is a focus on bringing research efforts to market. Technical development loans at 5 percent interest are available to companies with fewer than 20,000 employees to fund 40 to 60 percent of product development costs. To develop regional information networks, 18 proposed innovation centers will act as brokers between universities, consultants, and research institutions on one hand, and small and medium-size companies on the other. The function of these centers will be to disseminate technological knowledge as an information and education center. They will also act as a referral service, offering integrated analysis and advice.

University research is an important element of a comprehensive strategy for any firm considering a European expansion. Close relationships between university research labs and industry foster product development specifically aimed at European markets, and ensures the ability to rework imported hardware and design systems adapted to those markets. Most importantly, it produces a talented labor pool of Dutch nationals.

Greasing the Skids—A High-Tech Physical Infrastructure

For more than three centuries, the Dutch have had a strong export orientation that has allowed them to become major global traders. Today, with only 4.5 percent of the EEC population, the Netherlands accounts for 13.5 percent of the EEC's foreign trade. Exports represent 64 percent of the Dutch GNP. In addition, 40 percent of all Japanese imports to Europe pass through the Netherlands.

Because they are so dependent on trade, the Dutch have developed flexible, highly automated distribution networks to speed port-to-warehouse movement of goods. Shippers and customs officials make use of a computerized clearance system (SAGITTA) and merchant-controlled bonded warehouses (FEMAC). In anticipation of increased traffic due to deregulation within Europe, Amsterdam's Schiphol International Airport is expanding its automated cargo docks to create a Federal Express-style distribution hub. Because air cargo spends less than 10 percent of its time in the air, a computerized air cargo communications system (CARGONAUT) was developed to cut the time taken to get goods in and out of the airport.

Once in the Netherlands, well developed trucking, rail, and water routes move goods rapidly throughout continental Europe on the carrier of the customers choice. Forty percent of the continent's trucking is handled by Dutch companies. Many globally based companies, such as Seagate and Wyse, have located distribution facilities in the Netherlands because of the rapid turnaround times achieved. A typical scenario for Netherlands-based companies, like Canon, is to fly goods into Schiphol airport for manufacture and assembly, and ship them out again by road to the rest of Europe and by sea to the United Kingdom through Rotterdam. According to the Rotterdam Port Authority, nearly half of the outbound container cargo is destined for the U.K. market.

Existing High-Tech Clusters

The development efforts of the Netherlands have begun to bear fruit. Several regions within the country are emerging as high-technology industry clusters, particularly The Hague Corridor, the Amsterdam/Utrecht region, and the Silicon Triangle (see Figure 1).

The Hague Corridor

The swath that comprises The Hague Corridor contains a concentration of distribution activity because of its convenient access to the port facilities in Rotterdam, the largest in the world. Family-run distribution houses, some in existence for nearly a century, have extensive networks in this region that enhance their ability to move goods on schedule and make close supervision by foreign management unnecessary.

Amsterdam/Utrecht

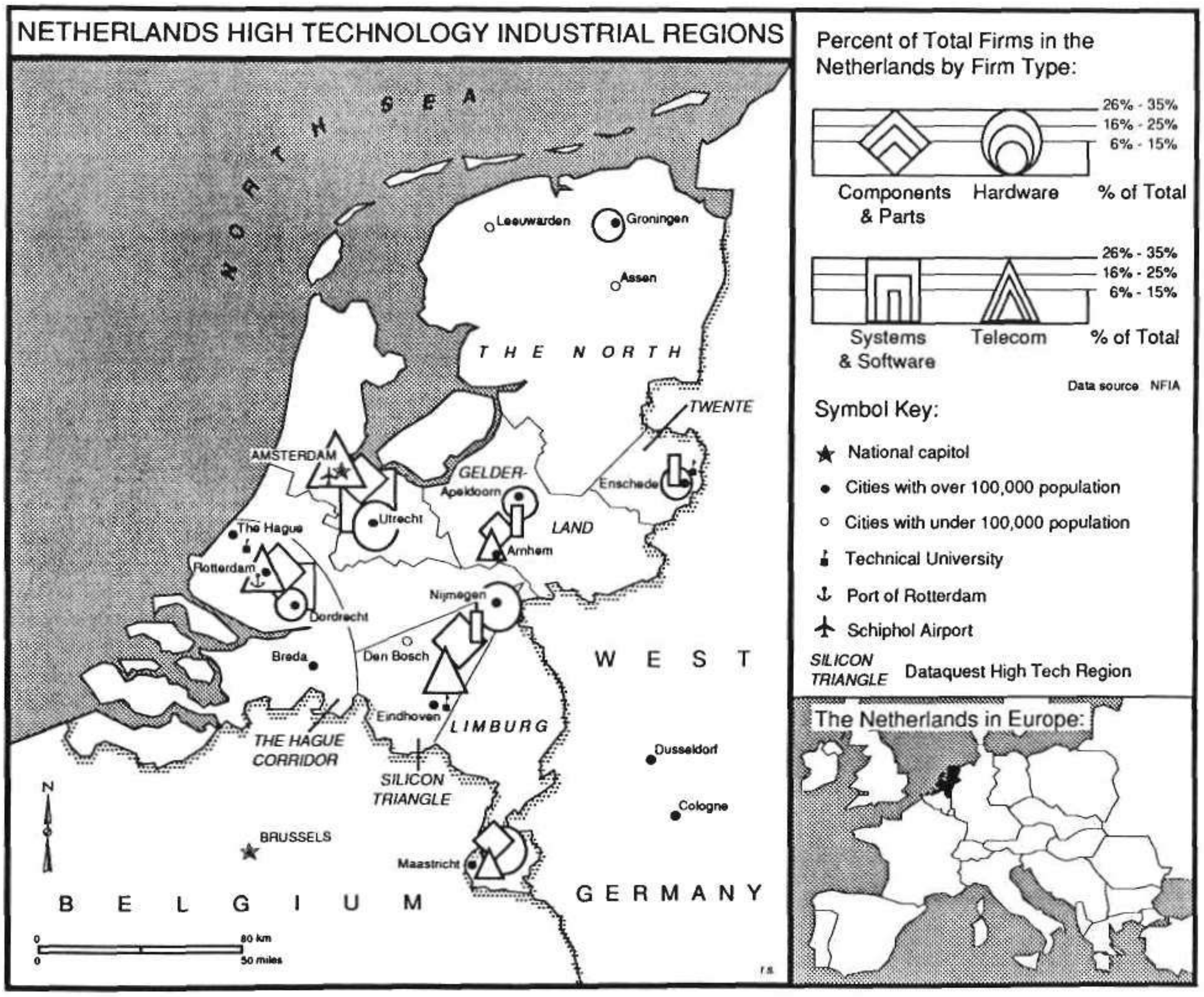
The Amsterdam/Utrecht region is home to 31.8 percent of all high-tech firms and 45 percent of the software firms in the country. Utrecht is one of the fastest-growing provinces in the Netherlands for a number of reasons. It is very accessible from the Schiphol airport, without having the traffic and parking problems of Amsterdam. In addition, Utrecht, unlike Amsterdam, has available land and a much lower building tax on industrial construction.

The Silicon Triangle

The cities of Den Bosch, Eindhoven, and Nijmegen encompass the region that is known locally as the Silicon Triangle. This region is strategically placed between Rotterdam and Amsterdam on the west, and the industrial powerhouse of West Germany's Rhine-Ruhr on the east. Philips is headquartered in Eindhoven, while Nijmegen is home to the company's SRAM memory chip plant, the largest in Europe. With sales exceeding $30 billion, Philips was the only European semiconductor company to appear in the world's top 10 in 1987. Nijmegen has developed a critical mass of electronics companies. To attract chip makers, the city built an industrial park intended solely for chip-related activity. The park has attracted semicustom chip firms such Align-Rite and Eurasem. Nijmegen is also home to a new joint venture—the "Fab '87 megabit project"—between Philips and Siemens. As a whole, the Silicon Triangle contains 23 percent of the electronic components firms in the Netherlands.

Figure 1

Netherlands High-Technology Industrial Regions



Source: Dataquest
October 1988

The Netherlands as a High-Tech Development Model?

In shaping their high-tech development policy, the Dutch have taken the following steps:

- Building on their strengths: physical infrastructure for distribution
- Forming a strong public/private partnership: in R&D and venture capital
- Maintaining an international focus: R&D and market orientation
- Creating a dual development strategy:
  - Attracting investment and technology transfer from abroad
  - Developing domestic high-tech expertise by investing in R&D and technical education

Although Dataquest believes that this development strategy is a good one, the Netherlands had some obvious drawbacks as a possible high-tech location. The existing industrial base and internal market are both small in comparison with EEC nations such as France, the United Kingdom, and West Germany. Lacking a significant internal market, the Dutch have tapped larger ones by acting as a conduit for goods entering Europe. Because of this tradition, economic activity in the Netherlands has developed a distinctly international flavor that will serve it well come 1992. With English mandatory in Dutch schools, the Netherlands has the highest ratio of multilingual nationals in Europe. The lack of concentrated heavy industry in the country adds to the quality of life, allowing the recruitment and retention of engineering talent essential for high-technology-based industries.

OPPORTUNITIES FOR NON-EEC COMPANIES

Dataquest believes that significant growth opportunities will be created by the deregulation of European markets (see Table 1 for forecast growth from 1988 to 1992 in Europe as compared with Japan and the United States). Many high-tech products have not penetrated European markets nearly to the extent they have in the United States. For instance, personal computers reside on only 12 percent of all European desktops compared with 18 percent in the United States. Although the European market will increasingly take on mass market characteristics, many national market elements will remain. The finely differentiated language and cultural differences that exist will heighten the importance of niche markets for high-tech products.

Table 1

Selected European Growth Market Revenue Forecast CAGR 1988–1992

Industry	Europe	Japan	United States
CAD/CAM Workstations	9.2%	4.6%	7.7%
Semiconductor Fabrication Equipment	13.5%	32.3%	11.3%
Manufacturing Software	17.3%	20.3%	12.0%
Personal Computers	9.5%	10.2%	6.8%
5.25-inch Rigid Disk Drive	9.0%	1.2%	(0.4%)
3 to 4-inch Rigid Disk Drives	51.9%	58.6%	41.8%

Source: Dataquest
October 1988

Application-specific semiconductor (ASIC) companies are well positioned in this market. System firms and value added resellers (VARs) will be able to target niche European market segments by integrating, reworking, and writing software packages for existing hardware products. Software houses will be busy adapting existing software as well as writing new programs for European consumers. Joint ventures between U.S. firms that may have a technologic or financial edge and European firms that know specific market segments will be popular. Although manufacturing in Europe will be the key to bypassing trade barriers, a strong distribution presence will be required by all companies that hope to participate.

European Development Agencies

The following is a partial listing of European development agencies that have established offices in the United States to encourage high-technology companies to invest in their country:

Country	Agency	U.S. Location
Austria	ICD Austria	Menlo Park, CA
Britain	Invest In Britain	San Francisco, CA
Belgium	Belgian Consulate General	New York, NY
France	DATAR	Los Angeles, CA
Ireland	IDA	Menlo Park, CA
Netherlands	Netherlands Foreign Investment Agency	San Francisco, CA
Scotland	Scottish Development Agency	San Mateo, CA
Wales	WinVest	Sunnyvale, CA

Note that all of the agencies listed above have additional regional offices in the United States and multiple locations in Pacific Rim countries. Clients may contact Dataquest for additional information.

DATAQUEST CONCLUSIONS

Dataquest believes that the deregulation of European markets represents a unique opportunity for firms inside and outside the EEC. Non-EEC firms should now consider a strategic location within Europe to take advantage of fresh opportunities. European development agencies, like the NFIA, are key contacts for companies considering this type of move. As Malcolm Penn, the vice president and director of Dataquest's European Operations, said recently in an address to the European semiconductor manufacturers: "Ladies and gentlemen, 1992 is a reality." It is not just European governments that need to heed this reality, but individual firms as well if they plan to survive in a restructured global economy.

Mary Dean
Tim Sturgeon

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U.S.-SOVIET JOINT VENTURES: AN OVERVIEW

Will the openness (Glasnost) and restructuring (Perestroika) within the Soviet Union offer opportunities to Western high-technology firms? Two factors have stimulated us to address this issue. First, a business trip to Moscow in December 1987 and, secondly, the flood of press articles about changes in Russia and the possibilities for joint ventures. For those readers wishing to investigate the pros and cons of a joint venture, Dataquest has received permission from the American Bar Association to reprint the article attached at the end of this newsletter.

In our opinion, negotiating a joint venture with a Soviet partner is not easy. But for those companies with patience, time, and capital, an agreement structured with profitability in mind could provide an adequate return on investment. We met executives who participated in some of the early joint ventures on the Western side and are willing to advise the newcomers so that the wheel does not have to be completely reinvented.

The following are several basic factors to be considered in this situation:

- Does the Western company have products that the Russians cannot build in their own country?
- Are components in the Western product embargoed under COCOM?
    - If so, will these embargoes be eased soon?
- On January 1, 1988, many major ministries were allowed to deal directly with Western partners on joint ventures, without the use of a trading company, as noted on page 82 of the attachment.
- The IBM PS/2 (except models using the 386 chip) is being sold by IBM in Moscow.
- The Perestroika committee has published a stated goal of going through the steps to make the ruble exchangeable hard currency in five years or less. Will it succeed?

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- Will Gorbachev's policies stay in effect?
- Can Russia compete in the world economy without restructuring its economy?
- If all the good "ifs" happen, will the pioneer joint ventures reap greater rewards than the latecomers?

One area with potential for joint venture activity is telecommunications. For example, the deputy minister of postal and telecommunications informed us that the Soviet Union presently has 38 million telephones installed. He claims that by the year 2000, the Russians plan to have 100 million phones installed. Considering the physical size of the Soviet Union, that involves a lot of switching and transmission equipment, let alone the telephone key sets.

On another front, we heard recently that several protocols (prerequisite to signing a joint venture contract) have been signed since December by Western firms hoping to form joint ventures to export software from Russia.

Experts with whom we have consulted believe that everyone should exercise caution; however, they say that this may be an opportunity not to be ignored. If the trade doors do stay open and the ruble becomes convertible, then the potential business could be enormous.

Clifford M. Lindsey

U.S.-Soviet Joint Ventures: A New Opening in the East

*By Russell H. Carpenter, Jr. and Bradford L. Smith**

U.S.-Soviet Joint Ventures: A New Opening in the East

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Early this year, the Soviet Union's Council of Ministers[1] and the Presidium of the Supreme Soviet[2] enacted new laws authorizing joint ventures between Soviet enterprises and Western foreign partners in the Soviet Union.[3] These

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Editor's note: Edward S. Davis of the New York bar served as reviewer for this article.

1. The Council of Ministers is "the highest executive and administrative body" in the Soviet Union. Konst. SSSR (USSR Constitution) art. 128. During the last two decades, the Council has been responsible for enactment of the largest share of major Soviet legislation. J. Hough & M. Fainsod, How the Soviet Union Is Governed 380–81 (1979).

The Council consists of over 100 members, but most Western observers believe that important decisions are made by either its Presidium or specially-created commissions. *Id.* at 381–83. In October 1986, in conjunction with foreign economic reforms including the proposed creation of joint ventures, the Council established a new State Foreign Economic Commission. *Foreign Economic Relations of the USSR*, ECOTASS No. 42 at 3 (Oct. 20, 1986). The Council delegated to this Commission responsibility for overseeing the activities of the Ministry of Foreign Trade, the USSR State Committee for Foreign Economic Relations, the Bank for Foreign Trade, and other departments participating in foreign economic operations. *Id.*

2. The Supreme Soviet is the highest body of state authority. Konst. SSSR art. 108. The Supreme Soviet never meets more than twice a year, however, and most action is taken by the Presidium, which functions in place of the entire body between sessions. J. Hough & M. Fainsod, *supra* note 1, at 370.

3. On January 13, 1987, the Council of Ministers enacted a decree on the "Procedure of Setting Up on the Territory of the USSR of Joint Enterprises with the Participation of Soviet Organizations and Firms of Capitalist and Developing Countries . . . . " *Soviet Council of Ministers Decision on Joint Ventures with Western Firms*, 4 Int'l Trade Rep. (BNA) No. 4, at 358–61 (Mar. 11, 1987) (*"Council of Ministers' Joint Venture Law"*). On the same day, the Supreme Soviet passed an edict "On Questions Connected with the Creation on the Territory of the USSR and the Activity of Joint Enterprises, International Associations, and Organizations with the Participation of Soviet and Foreign Organizations, Firms and Agencies of Administration." Union of Soviet Socialist Republics: Edict Concerning Taxation of Joint Enterprises in the Soviet Union and Dispute Settlement, 26 Int'l Legal Materials 759 (1987) (*"Supreme Soviet Joint Venture Edict"*). Both laws were retroactive in effect to January 1, 1987.

The first published English summary of these enactments appeared in ECOTASS on January 19, 1987. *Reform of Soviet Economic Relations*, ECOTASS No. 04, at 22–25 (Jan. 19, 1987). In the United States, the most readily available English translation of the Council's decree is published by Bureau of National Affairs (BNA), *Council of Ministers' Joint Venture Law*, *supra*. The most new enactments, capping a major Soviet initiative, followed the publication of preliminary guidelines in September 1986[4] and subsequent discussions with Western business representatives.

Americans and Soviets have been doing business with each other for years, but their commercial relationships have typically not gone much beyond trade. Now, for the first time, the Soviets have indicated a serious interest in permitting "capitalist" foreign investment and business operations within their borders. In the new laws, the Soviets have proved willing to make substantial commitments to attract Western enterprises and to accommodate the concerns Western businessmen are likely to have about operating in a centralized, state-run economy.

Like the earlier invitation to joint venturing extended to Western business by the Peoples Republic of China,[5] Soviet joint ventures hold out the allure of a vast untapped market. Indeed, the Soviet joint venture initiative was probably inspired in part by the enthusiasm that greeted China's opening to the West,[6] as well as by the development of Western joint ventures in Eastern European countries in recent years.[7]

But Soviet joint ventures are unlikely to benefit from the same aura of romance that attaches, at least for Americans, to doing business in China. Moreover, the Soviet initiative comes at a time when the bloom may be fading from Chinese joint ventures, as Western partners have struggled with the Chinese bureaucracy and its ingrained ideology, the shortage of foreign exchange, and recent uncertainties about the durability of China's commitment to economic reform.[8] In these circumstances, most American companies are likely to be cautious about plunging into this new opening in the East.

readily available English translation of the *Supreme Soviet Joint Venture Edict* is published by the American Society of International Law in volume 26 of its Int'l Legal Materials (1987).

4. The Council of Ministers published preliminary guidelines on joint ventures in ECOTASS on October 20, 1986. *Foreign Economic Relations of the USSR, supra* note 1. These preliminary guidelines operated as a trial balloon, enabling the Soviets to solicit reactions from, among others, interested Western business leaders and government officials.

5. China opened the door to joint ventures with foreign enterprises in 1979, when the Fifth National People's Congress adopted the Law of the People's Republic of China on Joint Ventures and Foreign Investment. *See* 18 Int'l Legal Materials 1163 (1979).

6. Despite criticism that the provisions of the Chinese law were vague, Western business leaders quickly moved to take advantage of the 1979 joint venture law, establishing 89 joint ventures between July 1979 and September 1983. Brehm, *Flex Trade,* China Bus. Rev. 16, 25 (Sept.–Oct. 1983).

7. Western joint ventures have been allowed in Yugoslavia since the late 1960s and have since been approved in Bulgaria, Hungary, Poland, Romania, and most recently, Czechoslovakia. *See* Czechoslovak Chamber of Commerce and Industry, Joint Ventures in Czechoslovakia (1986); Buzescu, *Joint Ventures in Eastern Europe,* 32 Am. J. Comp. L. 407 (1984); Scriven, *Co-operation in East-West Trade: The Equity Joint Venture,* 10 Int'l Bus. L. 105 (1982); Lorinczi & Dorian, *U.S.-Hungarian Joint Ventures: Prospects and Problems,* 10 Law & Pol'y Int'l Bus. 1205 (1978).

8. Gargan, *Foreign Investors in China Skeptical,* N.Y. Times, Nov. 17, 1986, at D10, col. 4. Foreign currency restrictions, in particular, have led to increasing pessimism about the prospects for Chinese joint ventures. *Id.*

THE NEW SOVIET LAWS

The new joint venture laws, like the preliminary guidelines they replace, are plainly designed to address central Western business concerns. For example, the decree enacted by the Council of Ministers[9] promises that a Western-Soviet "joint enterprise" will be free to decide upon its own economic activities and will not be subject to State planning targets.[10] The prices a joint venture receives for sales in the Soviet Union are to be linked to world market prices.[11] The decree includes a "guarantee" that foreign partners will have the right to take out profits and to repatriate their share of the net assets in the event the joint venture is liquidated.[12] It also promises protection against expropriation by administrative order[13] and provides for recognition of foreign patents and other "industrial property rights" contributed to a joint venture. There is even an assortment of possible tax breaks for deserving joint ventures.[14]

These provisions have the unmistakable ring of accommodation to free enterprise. They seem to be evidence of a deliberate effort to come to grips with the substantial difficulties confronting joint ventures that bridge fundamentally different economic systems.

While addressing fundamental concerns in a serious way, however, the new laws also contain some express restrictions and limitations on Western joint ventures. Many of these seem unimportant, but several are potentially significant.

First, the laws make clear that, whatever a joint venture's success in selling to the Soviet domestic market, it will have to produce for export from the Soviet Union.[15] A joint venture's access to foreign exchange is expressly tied to foreign exchange generated through its exports. If the joint venture does not earn

9. The decree enacted by the Council of Ministers is more detailed and comprehensive than the edict enacted by the Supreme Soviet. The latter contains only five substantive provisions, three of which pertain to taxation. *Supreme Soviet Joint Venture Edict, supra* note 3.

10. *Council of Ministers' Joint Venture Law, supra* note 3, at 360.

11. The Council of Ministers' decree provides that all of a joint venture's domestic purchases and sales shall be in roubles "at contractual prices with account of world market prices." *Id.*

12. Under the new laws, liquidation can result either from a decision by the parties to end the joint venture or from a decision of the Soviet Council of Ministers. While the laws ensure that a joint venture's "property cannot be requisitioned or confiscated in the administrative order," it gives the Council of Ministers authority to terminate the venture "if its activities are not consistent with the objectives and tasks envisaged" in its founding documents. *Id.* at 359, 361.

In the event of liquidation resulting from either cause, the foreign partner is entitled to receive its share of the venture's assets "in cash or commodity form" after satisfying its obligations to the Soviet participant and any third parties. *Id.* at 361. Soviet officials have recently stated that the foreign partner can take its assets in the form of foreign currency to the extent that the venture has earned such currency through exports. To the extent that such currency is not available, the foreign partner will be compensated in roubles, which can be used to purchase local products for countertrade purposes.

13. *See supra* note 12.

14. *See infra* notes 48–52 and accompanying text.

15. *See infra* notes 23–27 and accompanying text.

foreign exchange, it will be unable to import supplies or repatriate profits to the foreign partner.

Second, a joint venture's transactions in the Soviet economy, whether in the form of purchases of inputs or sales of its output, are to be passed through the medium of a Soviet foreign trade organization.[16] The joint venture apparently will not be free to deal directly with Soviet customers.

Third, the foreign partner is limited to a maximum forty-nine-percent share of the equity in a Soviet joint enterprise,[17] and both the chairman of the board of directors and the director general, or chief operating officer, must be Soviet citizens.[18]

In addition, Soviet law is to govern all aspects of the terms of employment of the labor force, except for the wages, vacations, and pensions of foreign specialist employees.[19]

Finally, the Council of Ministers reserves the power to liquidate a joint venture if it determines that the joint venture does not conform to the objectives for which it was established.[20]

As discussed *infra*, some of these restrictions may significantly restrict the appeal of Soviet joint ventures or their prospects for success. But it is nonetheless noteworthy that there are no more serious limitations than these few. The critical question is whether prospective joint venture partners will be free to negotiate terms that address their particular needs so long as they do not run afoul of the express restrictions in the laws, or whether the Soviet bureaucracy will in practice impose a web of further limitations and restraints not expressed in the laws.

On this question, the Council of Ministers' decree offers some ground for optimism. It expressly stipulates that joint venture agreements may include "other provisions, not contradicting Soviet legislation and relating to the specific activities of a joint enterprise."[21] If this apparent endorsement of freedom of contract for joint venture participants is a signal that everything not specifically prohibited is permitted, or is at least negotiable, then there is reason to believe that many of the lurking concerns about doing business in the Soviet Union can be overcome.

16. Foreign trade organizations (FTOs) in the Soviet Union are state-owned and typically subject to administrative direction from some office of the government. Although the structure and powers of FTOs may change as part of the government's ongoing economic reform efforts, each FTO has traditionally had a monopoly over the export and import of a particular range of goods. The FTO does not produce or consume these goods itself, but rather sells and purchases items on behalf of other institutions within the Soviet economy. *See* T. Hoya, East-West Trade: Comecon Law, American-Soviet Trade 11–12 (1984). For a more detailed discussion of the involvement of FTOs in the activities of joint ventures, *see infra* notes 28–36 and accompanying text.

17. *Council of Ministers' Joint Venture Law*, *supra* note 3, at 359.

18. *Id.* at 360.

19. *See infra* notes 41–43 and accompanying text.

20. *See supra* note 12.

21. *Council of Ministers' Joint Venture Law*, *supra* note 3, at 359.

Even the express restrictions in the Soviet laws could themselves be amenable to modification through flexible interpretation by Soviet authorities and creative negotiation between joint venture partners. Here, the early signs are mixed. The limitations were included in the preliminary guidelines published last fall and were the focus of critical commentary by Western business observers.[22] In the final legislation, the Soviets responded to some of these comments, most notably by recognizing intellectual property rights and promising joint venture partners the right to receive their share of the assets if the venture is terminated. But in important respects, such as the requirement that a joint venture generate the foreign exchange it uses or repatriates and the broad imposition of Soviet labor law, the Soviets adhered to and even hardened the restrictions originally proposed. Negotiation may not readily resolve concerns in areas such as these.

THE NEED TO EXPORT

The new joint venture laws leave no doubt that joint ventures will be expected to pay their own way in foreign exchange. They provide that all foreign exchange payments by a joint venture, including payments of profits and distributions of assets to foreign partners, "must be ensured by the joint enterprise on account of receipts from the sales of its products on the external market."[23] Foreign exchange credits and bank loans may be available for some needed imports or to pay foreign workers,[24] but exchange obtained by these means must be paid back,[25] and exchange credits are unlikely to be useful for repatriating profits or distributing joint venture assets after liquidation.

Such a rigid foreign exchange requirement is understandable in an economy where foreign exchange is scarce. By stating it explicitly, the Soviets may avoid disappointments such as those experienced by Chinese joint venture partners who found their enterprises starved in practice by the lack of needed foreign exchange.[26] But the effect of the requirement is at cross purposes with the primary interests of most potential western joint venture partners for whom the pot of gold worth pursuing in an intimidating economic system is likely to be the prospect of selling in the Soviet market.

To be sure, there may be some Western enterprises who would be interested in establishing primarily export-oriented joint ventures in the Soviet Union. Production for export could be attractive if the Soviets enjoy some competitive advantage in the manufacture or sale of the product, or where the joint venture partner lacks a substantial foreign marketing operation and could benefit from

22. Although most discussion took place within meetings between business leaders and Soviet governmental representatives, some also appeared in the press. *See, e.g., Does Moscow Mean It This Time?*, N.Y. Times, Jan. 18, 1987, § 3, at 4, col. 3; *see also* D'Anastasio, *Capitalists Wary of Moscow's Hard Sell to Invest in Joint-Venture Enterprises*, Wall St. J., Apr. 6, 1987, at 25, col. 4.

23. *Council of Ministers' Joint Venture Law*, *supra* note 3, at 360.

24. *See infra* notes 53–54 and accompanying text.

25. Such credits would also subject a joint venture to increased supervision by Soviet banking authorities. *See infra* note 53.

26. *See supra* note 8.

association with a Soviet foreign trade organization. Most companies that already sell widely in foreign markets, however, will not see much to be gained by exporting from the Soviet Union in competition with their existing foreign sales operations.

For the typical joint venture partner looking for access to the Soviet domestic market, the export requirement will be at best a deterrent and often a bar to participation in Soviet joint ventures. It is not clear that many businesses oriented toward the Soviet market will also be able to export from the Soviet Union. Even those that can do so will be concerned that they may confront an overriding Soviet interest in exports that will in practice inhibit their Soviet domestic sales efforts.

Companies that cannot or do not wish to export might still find a place for themselves in the Soviet joint venture scheme if they succeed in obtaining Soviet commitments to purchase the products they make outside the Soviet Union. Some Western companies have found that participation in Yugoslav joint ventures, for example, has enabled them to establish a market presence and thereby increase their exports of other products to Yugoslavia.[27] This approach could prove profitable for joint venture partners even if the ventures themselves are unable to repatriate profits. Alternatively, a joint venture candidate that is unwilling to export might seek to negotiate arrangements allowing it to repatriate profits in the form of countertrade.

Other solutions could be found if the Soviets were willing to bend their foreign exchange rule for the sake of attracting particular foreign investments. But the early indications are that foreign exchange is for now a predominant concern. In substance, the new laws' express "guarantee" of the "right to take out profits in foreign exchange" and to recover net capital after the joint venture is terminated will apparently apply only when the necessary foreign exchange has been earned.

RELATIONSHIP TO THE SOVIET ECONOMY

A second critical question is how a joint venture will be able to function in relation to the Soviet economy. An autonomous capitalist joint venture is an anomaly in a state-directed economy, and the basic economic relationships will have to be worked out without obvious analogies in the experience of Soviet enterprises.

The new laws do not purport to set joint ventures free to make their own way in these uncharted waters. For all the effort to accommodate the Soviet economic regime to Western needs, joint ventures are effectively treated as "offshore" entities. While they are permitted to trade directly with foreigners,[28] their

27. A recent survey of 42 North American and Western European joint ventures in Yugoslavia found that 71% of the foreign partners had enjoyed increased exports to Yugoslavia following the establishment of a venture there. Artisien & Buckley, *Joint Ventures in Yugoslavia: Comment*, 18 J. World Trade L. 163, 166 (1984).

28. A joint enterprise is given the right to independently conduct export and import operations indispensable for its economic activities, including operations on the markets of the CMEA

purchases and sales in the Soviet economy are to be conducted through a Soviet foreign trade organization, just as if the joint venture were trading with the Soviet Union from abroad.[29] This restriction was the subject of some critical commentary when it was proposed in the preliminary guidelines,[30] and its inclusion in the final legislation appears to represent a firm Soviet commitment to controlling joint ventures' access to the domestic Soviet market.

Intermediation by foreign trade organizations could be helpful to an American joint venture partner, for example in assisting it to predict Soviet demand for the joint venture's products or in formulating its marketing strategy for an unfamiliar market. But unlike Soviet enterprises subject to state planning, a foreign joint venture will not be guaranteed a market for its products,[31] and an entity that controls both a joint venture's supplies and sales is obviously in a position to control its prospects for success in the Soviet market.[32] If the responsible Soviet foreign trade organization is motivated to promote exports over domestic sales or to protect Soviet industries whose products may be in competition with the joint venture's products, a joint venture oriented toward sales in the Soviet Union will not succeed.

> member-countries. The above-said export and import operations can also be performed through Soviet foreign trade organizations or the marketing network of foreign participants on the basis of corresponding treaties.

Council of Ministers' Joint Venture Law, supra note 3, at 360.

29. The Council of Ministers' enactment provides that:

> The sale of the products of a joint enterprise on the Soviet market and the supplies to the joint enterprise from this market of equipment, raw materials, supplies, furnishing articles, fuel, energy and other products are carried out with payment in roubles through the corresponding Soviet foreign trade organizations at contractual prices with account of world market prices.

Id. The role of the FTO appears to be similar to the role these organizations play in Soviet foreign trade transactions. Whenever a foreign enterprise enters into an import or export contract with a Soviet party, a Soviet FTO represents the Soviet entity and signs the contract on its behalf. In this manner, FTOs act essentially as middlemen. T. Hoya, *supra* note 16, at 285–86.

30. At a meeting of the U.S.-U.S.S.R. Trade and Economic Council in New York on December 8, 1986, Soviet trade and economic officials listened to American criticism of this provision, and at least one official expressed the view that this restriction might not be included in the final joint venture laws.

31. "The state bodies of the U.S.S.R. do not fix mandatory plan assignments to a joint enterprise and the sale of its products is not guaranteed." *Council of Ministers' Joint Venture Law, supra* note 3, at 360.

32. In the past, Soviet foreign trade organizations have exercised substantial influence over a foreign company's ability to sell its products to a Soviet end-user. For example, because the foreigner can negotiate directly only with the FTO, it must rely on the FTO to make its sales presentation to the ultimate Soviet purchaser. This problem may be compounded when the intermediary FTO knows the end user's purchasing needs in only a general way and is thus unable to tailor the sales presentation—or to advise the foreign seller how to tailor it—to the buyer's requirements. T. Hoya, *supra* note 16, at 286. Moreover, even if foreign sellers can overcome these communication problems, the FTOs have developed reputations for hard bargaining with foreign traders. An FTO may purchase large quantities, sometimes as a virtual monopoly representative of the entire USSR. In such instances, it can afford to maintain a hard line in negotiations with foreign companies. *Id.*

It is difficult to predict how the Soviet foreign trade organizations will view and perform their roles as domestic agents for Western joint ventures. These organizations, whose function has been to serve as middlemen for Soviet foreign trade, are themselves undergoing changes as part of a broad reorganization of the Soviet foreign trade apparatus.[33] But, as the name foreign trade organization implies, they are still expected to play a major role in promoting Soviet export efforts and other Soviet trade policies. As prospective joint venture partners enter into negotiations, they will need to gain a clearer understanding about the particular Soviet trade organization responsible for their product area—how it is staffed and operated, what policy direction it receives from the Soviet Government or the state planning system, and what assurances the foreign partner can obtain that the Soviet organization will be responsive to the joint venture's interest in domestic sales.

Apart from the role of the foreign trade organizations, American companies new to a state-directed economy will need some assurance that a joint enterprise will be able to function successfully within the Soviet system as a quasi-autonomous economic entity. For example, while joint ventures will not be subject to production requirements imposed by the Soviet State Plan,[34] they will need to make substantial purchases in the Soviet economy to obtain raw materials, energy, labor, or other resources. The new joint venture laws do not guarantee access to these resources, and Soviet leaders have been reluctant to commit themselves on the extent to which they will be made available. Accordingly, when negotiating the establishment of joint ventures, foreign investors will want concrete assurances that the necessary inputs can be obtained.

In practice, the prospects for integrating joint ventures into the Soviet economy may well depend on the success of other Soviet economic reforms. The Soviet government has developed its joint venture initiative together with a larger package of reforms affecting not only foreign commercial relations[35] but also state economic planning and the organization of production. In July, the Communist Party's Central Committee approved reform guidelines giving

33. The Soviet Council of Ministers announced in October a "radical reorganization of the management of the foreign economic relations system . . . ." *Foreign Economic Relations of the USSR, supra* note 1, at 3. This reorganization included permission for 70 enterprises and amalgamations to set up foreign trade organizations within their existing structures. *Id.* In addition, the Council granted permission to 21 government ministries and departments to trade directly with foreigners through foreign trade organizations attached to each of these units. *Id.* In discussions with Western business leaders, some Soviet officials have strongly emphasized the improvements that may result from this reorganization through closer identification of the new FTOs with the ultimate Soviet parties in foreign trade transactions. Other Soviet officials, particularly those in the Ministry of Foreign Trade, which exercises control over existing FTOs, have minimized the reorganization as representing a relatively modest change.

34. *Council of Ministers' Joint Venture Law, supra* note 3, at 360.

35. In January 1987, the Soviets adopted a wide-ranging array of economic reforms in addition to the joint venture laws. These included the adoption of new cost-accounting principles, a reorganization of the Ministry of Foreign Trade, approval for joint ventures with Eastern European partners, and other forms of cooperation between the Soviet Union and Eastern Europe. *Reform of Soviet Foreign Economic Relations*, ECOTASS No. 04 (Jan. 19, 1987).

individual enterprises unprecedented autonomy to determine their own production goals and enter into their own contracts. Over time, these guidelines are intended to allow market forces, rather than state agencies, to set prices in the Soviet domestic market.[36] The course of such systemic reforms may well affect the relationship of joint ventures to the Soviet economy more profoundly than any specific measures that joint venture partners might negotiate. If Soviet enterprises in fact become substantially autonomous economic actors, Western joint ventures will have a better chance to do the same.

MANAGEMENT OF THE JOINT VENTURE

Another area of potential concern is the foreign partner's role in the management of the joint venture. Most American participants will want really to participate in managing and running the enterprise. Several Eastern European countries that have permitted joint ventures have required, like the Soviet laws, that a majority of the equity must be held by citizens of the host country.[37] But they have also been willing to allow the foreign partner an equal number of directors and a veto power over policy decisions through a requirement of unanimity for all board of directors' decisions.[38]

The Soviets have not yet made clear whether they will be flexible in such matters. While the preliminary guidelines promised foreign partners a "right to a meaningful participation in running the enterprise and in monitoring the quality of its output,"[39] the final legislation omits this promise. In its place is a vapid recital in the official summary of the laws, not even included in the laws themselves, that "foreign citizens can be members of management."[40] If this is not a repudiation of the earlier commitment to Western managers, it is something less than a ringing reaffirmation.

Moreover, both the question of quality control and the overall prospects for success of a joint venture will be affected by the degree of freedom that the joint venture enjoys to select and manage its labor force. In China, joint ventures with Western companies have often had to accept employees chosen by party officials or bureaucrats without regard to their qualifications for the work to be done or their motivation and responsiveness to direction. Although American business leaders have stressed their concern about flexibility in hiring and firing to Soviet officials, the new legislation specifically requires the application of Soviet labor

36. The Central Committee called for these reform guidelines to be implemented on a step-by-step basis over the next five years. Bohlen, *Soviet Party Leadership Endorses Sweeping Economic Restructuring*, Washington Post, June 27, 1987, at A24, col. 1. This implementation will gradually reduce the scope of centralized economic planning and enable Soviet enterprises to determine their own production targets. Soviet leaders estimate that at the conclusion of the five-year implementation period, an average of only 25% of a typical Soviet company's production will remain under the purview of centralized economic planning. Keller, *New World For Russians*, N.Y. Times, June 27, 1987, at A1, col. 2.

37. Scriven, *supra* note 7, at 108.

38. *See generally* Buzescu, *supra* note 7, at 428.

39. *Foreign Economic Relations of the USSR*, *supra* note 1, at 6.

40. *Reform of Soviet Economic Relations*, *supra* note 35, at 24.

rules[41] and stipulates that the management of each joint venture must conclude collective agreements with trade union organizations.[42] Further, the official summary of the new laws states that "only a very limited number of highly skilled specialists" may be recruited from outside the Soviet Union, although no such restrictive language appears in the laws themselves.[43] Thus, the prospects for flexibility in the labor area may have to depend on possible reforms of Soviet labor policies rather than on much chance of negotiating desirable labor provisions in joint venture agreements.

ABILITY TO MAKE A PROFIT

Some American companies may establish Soviet joint ventures without any expectation of near-term profit. Like early joint ventures in China, they will be hoping to get a foot in the door at modest expense, or to prevent competitors from getting there first. But most American entrepreneurs will enter into joint ventures for the ultimate purpose of making a profit. In addition to the matters already discussed, foreign participants must be concerned with such elements of profitability as pricing freedom, the valuation of capital contributions, taxes, and the availability of foreign exchange. For the most part, these questions seem amenable to negotiated solutions.

PRICES

The question of how prices are set may be the most difficult element of profitability to deal with effectively. Under the new legislation, both the prices an enterprise pays for its inputs and the prices it can charge for its output will be subject in some degree to the control of the Soviet foreign trade organization that is responsible for the joint venture's transactions in the Soviet economy.

The new legislation purports to link the prices of Soviet transactions to world market prices by providing that a joint venture's purchases and sales within the Soviet Union will be paid for in roubles "at contractual prices with account of world market prices."[44] These prices will be negotiated by the responsible foreign trade organization.[45] The question is how freely the trade organization will act to impose prices different from those that could be agreed to by joint ventures and their Soviet customers or suppliers. On the one hand, world prices could be invoked to require less favorable price terms than would be appropriate in the Soviet market. On the other hand, for reasons having nothing to do with world price levels, an officially determined relationship to world prices

41. The Council of Ministers' joint venture decree requires that "[t]he conditions for the remuneration of labor and a routine of work and leisure for Soviet citizens employed at joint enterprises, the social security and social insurance are regulated by the norms of Soviet legislation." *Council of Ministers' Joint Venture Law, supra* note 3, at 361.

42. *Id.*

43. *Reform of Soviet Foreign Economic Relations, supra* note 35, at 25.

44. *Council of Ministers' Joint Venture Law, supra* note 3, at 360.

45. *See supra* note 29.

may not be an effective constraint on the trade organization's discretion to veto a joint venture's price proposals.

CAPITAL CONTRIBUTIONS

The question of pricing also bears on the valuation of capital contributions, which has been a recurring bone of contention in joint venture negotiations in China. These contributions are the basis for allocation of profits between joint venture partners, and the valuation placed upon them effectively determines the rate of return on investment at any given profit level.

The new legislation links the value of capital contributions to world prices.[46] But world prices will not be of much help in determining the value of technology or know-how contributed by an American partner, or in valuing such likely Soviet contributions as local real estate, buildings and facilities, utilities, or services. Valuation problems of this sort can best be resolved by case-by-case negotiations between the participants in particular proposed joint ventures. The new laws appear to defer to such negotiated valuations in cases where world prices are unavailable,[47] but joint venture negotiators could still find themselves under pressure to accept officially prescribed artificial values.

TAXES

The tax regime has an obvious importance for the profitability of a Western investment in a Soviet joint venture. After an initial two-year exemption, joint ventures will be subject to two-tier taxation. First, the venture itself will pay a thirty percent tax on its profits.[48] Second, the foreign partner will be subject to an extra twenty percent tax on the profits it repatriates to the West.[49]

There are several indications that these taxes are partly or even totally negotiable. For one thing, the laws seem to allow joint ventures to set up their own depreciation schedules under principles different from those applicable to Soviet enterprises.[50] For another, joint ventures may take deductions for a reserve fund of ten percent of each year's profits, up to a cumulative maximum

46. The legislation passed by the Council of Ministers provides:

> The installment [contribution] made by a Soviet participant into the authorized fund of a joint enterprise is assessed in roubles in contractual prices with account of world market prices. The installment of foreign participation is assessed in the same order, with the cost of the installment evaluated in roubles under the official exchange rate of the State Bank of the U.S.S.R. on the day of signing the treaty on the creation of a joint enterprise or any other date agreed upon by its participants.

Council of Ministers' Joint Venture Law, *supra* note 3, at 359.

47. The Council of Ministers' joint venture decree specifies that, in the absence of applicable world prices, "the cost of the invested property is established by agreement between participants." *Council of Ministers' Joint Venture Law*, *supra* note 3, at 359.

48. *Id.* at 361.

49. *Id.*

50. The Council of Ministers' joint venture decree provides that "[j]oint enterprises make depreciation deductions in accordance with the directions which are in effect for Soviet state

of twenty-five percent of the total equity of the enterprise, and for unspecified other funds related to the joint venture's work.[51] Beyond that, joint ventures may seek tax relief from the Ministry of Finance, which is authorized to reduce the amount of the tax or to wholly exempt individual payors from the tax.[52]

This Soviet-style tax reform seems to promise loopholes wider than any of those closed by the recent American tax reform. A favored joint venture may hope for a light tax burden or even for none at all. Whether those hopes will be realized can be answered only by the experience of actual negotiations.

FOREIGN EXCHANGE

Finally, many joint ventures will need to import some raw materials, and they will probably need to do so before they have been able to generate foreign exchange. As some parties to early Chinese joint ventures have found, an inability to obtain exchange for necessary imports can cripple a joint venture from the start.

The new Soviet legislation permits joint enterprises to take advantage of foreign currency credits from the U.S.S.R. State Bank and the Bank for Foreign Trade of the U.S.S.R.[53] It also allows joint enterprises, with the consent of the Bank for Foreign Trade, to borrow from foreign banks or firms.[54] However, joint venture parties for whom access to foreign exchange will be critical to successful operation will undoubtedly want to negotiate for more concrete guarantees.

CONCLUSION

Notwithstanding the Soviets' clear interest in promoting joint ventures with the West, the new joint venture laws do not go as far toward satisfying Western concerns as potential joint venture partners would have liked. In insisting on joint venture exports to pay for any foreign currency used and in imposing the broad range of Soviet labor policy on joint ventures, the laws clearly reflect the influence of Soviet lobbies other than those primarily interested in attracting

organizations, unless envisaged otherwise in the constituent instruments." *Council of Ministers' Joint Venture Law, supra* note 3, at 360.

51. *Council of Ministers' Joint Venture Law, supra* note 3, at 360–61.

52. *Id.*

53. The Council of Ministers' joint venture decree provides that joint ventures may obtain credits for foreign currency from the Bank for Foreign Trade of the USSR or, with that Bank's permission, from foreign banks or firms (*Council of Ministers' Joint Venture Law, supra* note 3, at 360), but stipulates that the Bank for Foreign Trade is "entitled to exercise control over the proper utilization, material provision and timely repayment of the [foreign] credits issued to a joint enterprise." *Id.* at 360.

54. Although the Soviets have throughout this decade taken a cautious attitude toward borrowing from Western banks—with their total hard currency foreign debt actually declining from 1981 to 1984—the new efforts to revitalize economic growth may require a more liberal policy. Many bankers now estimate that the Soviets will increase their foreign debt by $6 to $8 billion a year for each of the next three years. *Inside the Soviet Debt Machine,* Euromoney 46, 51–54 (Jan. 1987).

Western investment. And in preserving a large role for Soviet foreign trade organizations, the Soviets have made clear that they are not yet ready simply to turn Western joint ventures loose in the Soviet economy without a mentor. The Soviet commitment to joint ventures appears to be genuine and earnest, but it is not overriding.

At the same time, the Soviets have moved a substantial way, at least on paper, in the direction of adapting their centralized economic regime to Western participation. The joint venture laws do not raise insuperable barriers to successful joint ventures, at least for Western investors who can live with a requirement that joint ventures must earn their own foreign exchange. With few exceptions, the laws are relatively unconstraining, and because they are general in nature they potentially leave wide room for innovative negotiated solutions. Much will depend on how hospitable the Soviets are willing to be to variant arrangements tailored to the needs of particular joint ventures.

One broad determinant of the prospects for successful joint ventures will be the fate of the Soviets' contemporaneous efforts at domestic economic reform. If the Soviet leadership is able to develop a decentralized and more market-oriented economy, as it has set out to do, the distance between economic systems may be reduced and it should be easier for new Western joint ventures to adapt and prosper. Conversely, if the Soviets are unable to sustain the broader reforms, it is likely to be much more difficult for such joint ventures to succeed.

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OREGON CHALLENGES SILICON VALLEY: NEW TECHNOLOGY CENTERS EMERGE

EXECUTIVE SUMMARY

For decades, California's Silicon Valley has been the premier center of high-technology research, giving rise to a plethora of new technologies and industries. But this postwar era of unchallenged domination is over. In recent years, other U.S. states and other regions around the world have aggressively recruited brainpower and developed their own industrial strategies. This is the first of a series of newsletters highlighting the advanced technology in the emerging high-technology regions.

OREGON'S HIGH-TECHNOLOGY INDUSTRIES

Unlike the Silicon Valley, which evolved spontaneously and is primarily driven by local industry, Oregon's thrust is based on the following factors:

- Clean water and low-cost, dependable electric power supporting manufacturing plants that produce a substantial portion of all silicon substrates manufactured in the United States
- Designation of the area as a center for Japanese high-technology manufacturing in the United States
- A major emphasis on public and private research and development underscored by a $100 million investment in the construction and expansion of local research facilities in the Willamette Valley (In 1986-1987, Oregon public institutions received about $170 million from research sponsors.)

Tektronix's Influence

Planting the Seeds

Oregon's high-technology industry took root with the founding of Tektronix, Inc., in the early 1940s by physicist Howard Vollum, and his partner, Jack Murdock, of the U.S. Army Signal Corps. In 1946, Tektronix sold its first synchronized oscilloscope.

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After Mr. Murdock's death in 1971, the company established a charitable trust that has become a major impetus for high-technology research and development in private colleges in the region. This R&D effort has enhanced Oregon's success in the high-technology arena.

Today, Tektronix has approximately 17,000 employees worldwide, of whom 12,500 work at four sites in Oregon. Its 1987 revenue was $1,395.8 million.

New Start-Up Companies

Tektronix has been the seed bed for numerous start-up companies, many of which are clustered around Tektronix in the Hillsboro and Beaverton "Sunset Corridor" area west of Portland.

- Floating Point Systems was founded by C. Norman Winningstad, a Tektronix sales executive.
- CableBus Systems was founded by a former Tektronix engineer and partly funded by Howard Vollum.
- Mentor Graphics, Metheus Corporation, and Planar Systems evolved from Tektronix's information display division.

In November 1983, Tektronix established a venture capital operation, Tektronix Development Company (TDC). TDC invests in technological projects involving companies at their start-up or early stages of growth that are of strategic interest to Tektronix. See Table 1 for TDC investments.

Table 1

Start-Up Companies Funded by Tektronix Development Company

Year Founded	Company
1983	Planar Systems
1984	Ateq Corporation Anthro Corporation
1985	TriQuint Semiconductor, Inc. Sequent Computer Systems Mikros Systems*

*Mikros recently merged with another company and is now called Tel Systems Corporation.

Source: Tektronix, Inc.

The California Emigrants

Since the mid-1970s, Spectra-Physics, Siltec, Hewlett-Packard, and Intel, all of Silicon Valley, have opened plants in Oregon to take advantage of lower production costs and improved working conditions.

In 1976, Intel opened a plant in Hillsboro. Currently, Intel occupies in excess of 1.2 million square feet of space and has spent $37 million to renovate its Aloha wafer fabrication plant. Intel recently established its world headquarters for its Systems Group in Hillsboro and has contributed to local start-up companies. In 1983, former Intel engineers became officers of three start-up companies: Bipolar Integrated Technology, Lattice Semiconductor, and Sequent Computer Systems.

In 1979, Hewlett-Packard moved its impact and ink-jet printer plant to Vancouver, located in the Portland metropolitan area, where HP now employs 560 people.

National Semiconductor has two research centers in the Sunset Corridor. National's Beaverton laboratory has developed a 32-bit computer board, the Integrated Computer Module, based on the company's 32332 microprocessor, while the Cornell Oaks Corporate Center is developing board-level products.

RECESSIONS AND GLOBAL COMPETITION

Like other regions, Oregon was hit hard by the 1979 oil shock and 1982 industry recession, which threw the state into an economic tailspin that lasted from 1980 until 1983. The electronics recession in 1985 worsened the situation.

Oregon emerged from the 1985 recession recognizing that the fierce competition and rapid globalization of high-technology industries required new approaches and ideas. To this end, Oregon state policies are designed to leverage the following four key factors driving the state's current economic recovery:

- Promote the region's clean water and low-cost dependable electrical power resources
- Establish public tax policies to encourage foreign investment from Japan and West Germany
- Emphasize the region's ability to attract and retain key managers and engineers in marketing efforts to attract new plant equipment investment into the state
- Adopt sweeping changes in corporate law and taxation that will encourage and support local business

Japanese and West German Investments

Foreign investment has become a major growth factor in recent years. Since the late 1970s, Oregon has attracted a growing number of foreign companies, especially from Japan and West Germany. Three major silicon wafer producers are located within a 75-mile radius of Portland:

- Wacker Siltronic, the U.S. subsidiary of Bavaria-based Wacker-Chemie, a European silicon plant, operates a silicon wafer facility in Portland.
- SEH America, a subsidiary of Shin-Etsu Handotai of Japan, the largest silicon wafer producer in the world, built a $30 million silicon wafer plant and a $15 million epitaxial silicon wafer plant for advanced MOS chips in Vancouver, Washington.
- Mitsubishi/Siltec Corporation, formed after Mitsubishi Metal acquired Siltec, operates a silicon wafer plant in Salem and is expanding its investment by $30 million.

The region has a number of plants involved in semiconductor device fabrication, recently underscored by the announcement of a $130 million investment by Fujitsu Microelectronics, following that company's unsuccessful bid to acquire Fairchild.

Since 1984, a handful of other Japanese companies have opened shop in Oregon to lower their production costs (due to the strong yen), gain greater access to the U.S. market, and avoid protectionist barriers. Their arrival coincided with a hugely popular television program, "From Oregon, with Love," aired by Japan Broadcasting Company (NHK) in Tokyo last year. The show has attracted a steady flow of Japanese businessmen and tourists to Oregon. Some of the better-known companies include:.

- Kyocera Northwest—Since 1984, Kyocera has produced ceramic chip capacitors.
- Fujitsu America—The Fujitsu plant, which opened in 1985 in Hillsboro, produces disk drives and recently expanded into optical communications equipment.
- NEC America—This company is adding 200,000 square feet to its existing plant for a new hardware engineering design center.
- Epson Portland—This U.S. subsidiary of Seiko Epson is adding 81,000 square feet to its printer assembly plant in Hillsboro.
- America Kotobuki—This U.S. subsidiary is producing consumer electronics.
- Mitsubishi Metals—This company, which was acquired for $33 million, includes a silicon plant in Salem, Oregon.
- Fujitsu Microelectronics—This company is investing $80 million in a wafer fabrication plant in Gresham, Oregon.

Nomura Securities of Tokyo reported in 1985 that Oregon is the leading center for Japanese high-technology investments in the United States.

Dataquest expects more Pacific Rim companies to open manufacturing and design facilities in Oregon due to the weakening dollar, growing U.S. trade protectionism, strategic funding of university research programs, proximity to Asia, and the state's vigorous industry recruitment campaign. The availability of low-cost hydroelectric power is also a key factor.

OREGON'S EMERGING ADVANCED TECHNOLOGY INDUSTRY

Today, 22 percent of Oregon's manufacturing employment is in high-technology companies, most of which are clustered along major transportation corridors supported by the state's freeway system. The largest concentration of advanced technology companies is in the Beaverton and Hillsboro area, located west of downtown Portland. Table 2 shows the evolution of this "critical mass" of high-technology companies.

Table 2

Major Electronics Companies in Oregon's Willamette Valley

Company	Founded	Number of Employees: Oregon	Number of Employees: Total	Major Products
COE Manufacturing	1852	260	750	Computerized lumber machines
Leupold & Stevens	1907	370	405	Rifle scopes, hydro equipment
Tektronix	1946	11,270	16,800	Electronic measurement
Electro Scientific	1953	600	820	Precision measuring equipment, laser system
Rodgers Organization	1958	153	160	Electronics and pipe organs
Deco	1961	612	612	Power supplies, light dimmers
Drake Willock Division	1964	205	220	Kidney dialysis equipment
Kentrox Industries	1967	160	175	Voice and data communications
Floating Point Systems	1970	900	1,246	Array processors, minisuper-computers, supercomputers
Intel	1976	3,100	20,000	MPUs, modules, and systems
Sentrol	1977	200	200	Security system electronics
Union Carbide	1977	192	50,000	Semiconductor materials
Wacker Siltronic	1978	825	845	Silicon wafers
SEH America	1979	750	750	Silicon wafers
Hewlett-Packard	1979	562	82,000	Impact and ink-jet printers
SpaceLabs	1981	200	1,000	Clinical data and patient-monitoring systems
Mentor Graphics	1981	475	875	CAD/CAE, electronic publishing

(Continued)

Table 2 (Continued)

Major Electronics Companies in Oregon's Willamette Valley

Company	Founded	Number of Employees: Oregon	Number of Employees: Total	Major Products
N-Cube	1983	N/A	N/A	Parallel processing computers
Sequent Computer	1983	160	190	Parallel processing computers
Electronic Specialty	1983	137	137	Relays, solenoids
Kyocera Northwest	1984	220	255	Ceramic chip capacitors
Logic Automation	1984	N/A	N/A	EDA software models
NEC America	1985	260	2,500	Fiber optic, modems, cellular phones, digital microradius
Fujitsu America	1985	150	1,315	Disk drives
Epson Portland	1986	187	187	Personal computer printers
America Kotobuki	1986	150	150	Color TVs and VCRs

Sources: Portland Business Journal
THK Associates, Inc.

Corporate and Research Parks

New corporate and research parks are also being developed throughout the state to attract new corporate investment and to promote university research. These include:

- Dawson Creek Corporate Park—This new 319-acre park is located in Hillsboro, Oregon. It was designed to meet stringent requirements of new expanding industries in the areas of communications, sub-micron manufacturing, and environmental protection.

- Oregon Graduate Center Science Park—This 175-acre research park is located at the Oregon Graduate Center.

- Riverfront Research Park—The City of Eugene and the University of Oregon are developing a 71-acre park near the university campus.

- Sunset Research Park—This 79-acre research technology center is located near Oregon State University in Corvallis.

- Timber Hill and West Hills research centers—These two research parks are under development near Oregon State University in Corvallis.

University Research Programs

In the increasingly competitive global arena, a critical success factor is the strength of academic institutions and their relationship to business and government.

Oregon's Governor Neil Goldschmidt recently approved Senate Bill 1014, a $100 million college and university construction program to expand local research facilities. Table 3 shows several new university research programs in progress.

Oregon universities are also building closer ties with local industries through a variety of educational and training programs.

Table 3

New University Research Programs in Oregon

University	Financing ($M)	Open	Activities
University of Oregon Science Facilities	$45.0	March 1989	Physics, geology, biology, computer sciences
Oregon State University	$ 7.0	January 1988	Solid-state materials
Portland State University Professional Schools Bldg.	$ 7.0	September 1987	International trade, business school
Oregon Institute of Technology Laboratory Building	$ 6.0	September 1987	Computer systems, electronics, laser optics
Western Interstate Commission for Higher Education	$ 1.8	1987	Supercomputer network linking R&D centers to NSF Supercomputer Centers

Source: THK Associates, Inc.

DATAQUEST CONCLUSIONS

Dataquest believes that Oregon has an excellent opportunity to become a leading high-technology region. Key developments to watch are the emergence of more start-up companies, the entry of Pacific Rim companies, and the increasing university research and venture capital activity in the Willamette Valley. Key industries and technologies to monitor include:

- Parallel processing—A critical mass of industry participants are located in Oregon (NCUBE, Sequent, Intel, Floating Point).
- Silicon producers—A regional strength, Oregon is already a major world participant in this market.
- New materials—This is an emerging area (Mitsubishi, Fujitsu, Wacker Siltronic, Union Carbide, SEH, Oregon State University).

The current mood of protectionism and erosion of the dollar are encouraging non-U.S. companies to establish operations in the United States, especially Pacific Rim companies. Oregon, not unlike other state and international development agencies, has observed the success of the Silicon Valley and is learning from its mistakes. Although the state is still a minor participant worldwide, Dataquest believes that Oregon could challenge Silicon Valley in several fields within a very short time.

Mary Dean
Sheridan Tatsuno

Dataquest
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SES *Exchange*

December 1988, No. 5
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INTRODUCTION

The SES Exchange is a publication of the Dataquest Strategic Executive Service (SES), with additional distribution to the Dataquest senior staff and research group leaders. The SES Exchange provides company backgrounds and significant news about member companies, and it acts as a clearinghouse to communicate market needs of member companies to the entire SES client base.

From the Editor

A special Holiday Greeting to you from all of us in the Strategic Executive Service at Dataquest!

In the fifth issue of the SES Exchange, you will find not only profiles of new SES members, but a special briefing by Cliff Lindsey, Director of the Strategic Executive Service, about SES activities to enhance our market research ability in new, emerging markets. As an update to Cliff's newsletter, "U.S.–Soviet Joint Ventures," (1988–02), Cliff will discuss our November 21 private meeting with Dr. Abel Aganbegyan, who is Mikhail Gorbachev's chief economic advisor.

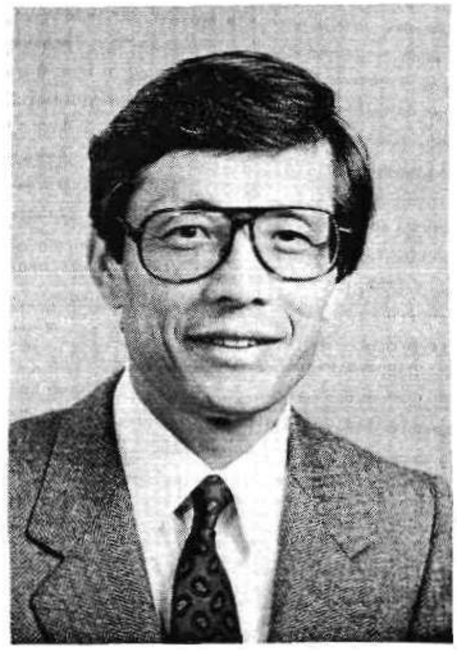
The Strategic Executive Service is pleased to announce that one of our team, Elizabeth Levy, has been chosen by the President of Dataquest to head a very special year–long software applications project. Starting in 1990, the results of this project will greatly enhance the quality of service Dataquest can deliver to you, our clients. Not only will we be able to to deliver the information by which you make critical decisions faster, but the information will be even more thorough and accurate. We wish Liz great success in this special assignment.

Gary Bruder, Editor

SEIKO INSTRUMENTS USA, INC.

Background

Seiko Instruments USA, Inc., is a marketing and development arm of Seiko Instruments, Inc. The U.S. subsidiary was founded in 1981 and is located in Torrance, California. Current yearly sales exceed $130 million.



Hiroshi Fukino, President

Operations

Seiko Instruments USA, Inc., is organized into seven semiautonomous divisions.

Components

Seiko Instruments offers a wide variety of liquid crystal displays that are being engineered into everything from pocket pagers to typewriters to computers.

Seiko Instruments' broad line of thermal printer mechanisms are designed into calculators, point-of-sale terminals, telephone devices, and scientific and medical instruments. Also, the company manufactures a line of standalone printers specialized for bar coding, labeling, and other types of documentation.

Emerging product technologies include active matrix and color liquid crystal display modules for use in computers; thin, flat rechargeable lithium batteries; additional application-specific integrated circuits; surface-mount quartz crystals and oscillators; and faster, more compact thermal printer mechanisms.

Consumer Products

Seiko Instruments has produced a variety of pocket electronic products such as: phone cards; linguistics products, including foreign language translators, spell checkers, dictionaries, and thesauruses; a golf scorecard; and a unique line of calculators designed specially for use in the kitchen.

Graphics Products

Today, the company holds a 70 percent share of the graphics market in Japan. Current products include color graphics display terminals, color hard copiers, digitizing units, monitors, and accessories.

PC Products

PC products are marketed by this group, the company's newest division. The first products to be marketed include high-resolution color monitors, graphic tablets, and digitizing tablets. Within the next year, the company will offer a full line of monitors, including several new 14-inch and 19-inch models, a color printer, and several LCD-based products.

Robotics/Automation Products

The company offers a family of high-speed, precision assembly robots for use in the telecommunications, computer/computer peripherals, and automotive electronics marketplaces. It also provides Class 1 through Class 100 clean room robots for use in semiconductor wafer-handling applications.

Scientific Instruments

Scientific instruments include fluorescent X-ray coating thickness measurement systems and thermal analysis systems.

Semiconductor Equipment

Seiko Instruments has the world's largest installed base of advanced, production-proven, focused ion-beam (FIB) technology products. One product is the world's first production-worthy photomask repair system. A second product, an IC development system, embraces the previously unaddressed need for the cutting and rewiring of integrated circuits. It eliminates the need for experimental device reiterations and increases turnaround time on new device development.

Future Direction

The company anticipates significant growth over the next several years, with a sales projection of $500 million by 1992. In part, this will be driven by rapid expansion of consumer, computer graphics, and electronic component products.

Additional growth will come from the company's plan to establish research and development, design, and manufacturing operations in the United States for both consumer and industrial technology products. This will be accomplished both directly and through strategic alliances.

Needs

Seiko Instruments plans to grow the PC Products Division to $100 million in two to three years. The company is also looking for consumer electronic products to sell in Japan. Seiko wants to form alliances to expand offshore wafer capacity, secure a U.S. source of SRAMs, and enhance its VLSI design capabilities. Additionally, Seiko has established a market for its focused ion beam IC development system in Japan and would like to expand its U.S. customer base for this product.

Hiroshi Fukino, President

Mr. Fukino joined Seiko Instruments, Inc., in Japan in 1974 as international marketing manager. He helped formulate the company's diversification strategy and was instrumental in establishing manufacturing relationships and distribution networks throughout Europe and the Asia/Pacific regions. In 1986, he was appointed president of Seiko Instruments USA, Inc. Previously, Mr. Fukino was with JEOL in Tokyo. JEOL is a leading manufacturer of electron microscopes. Mr. Fukino graduated from Hitotsubashi University in 1965 with a bachelor's degree in economics. In 1985, he completed the Advanced Management Program at Harvard Business School.

ACER INCORPORATED

Overview

Acer Incorporated is the parent company of a group of nine major companies. The company's principal business is in the research and development, manufacturing, and global marketing of computer products.

In addition to its major product line of IBM-compatible personal computers, Acer supplies five other product lines including UNIX-based, multiprocessor multiuser minicomputers; bilingual systems, peripherals, communications products; and application-specific integrated circuits (ASIC). Other group businesses include worldwide trading of information products, venture investments, and publishing and education in computer-related fields.

Stan Shih, Chairman and CEO

Acer was ranked the tenth-largest personal computer supplier in the world and the first-largest 80386 system supplier in the United States in 1987. Acer systems are recognized worldwide for their price/ performance.

As a corporation, Acer, is characterized by its unique strengths in integrating group technologies, operating a large-scale flexible manufacturing system, and managing a comprehensive global distribution network covering 75 countries.

Since its founding in 1976 with a meager $25,000 in registered capital and 11 employees, Acer has grown to become a multimillion dollar business with targeted annual consolidated sales exceeding $550 million. Acer expects to have 4,900 employees by the end of 1988 and subsidiaries in the United States, Canada, Japan, West Germany, the United Kingdom, the Netherlands, and Hong Kong.

Acer endeavors to be a full-range computer company supplying quality, price performance products to worldwide markets. The company has an ongoing strategy to maintain a balance in both OEM and brand name distribution sales. Long-term relations with its strategic business partners such as vendors, technology development partners, and distributors are regarded as the key to Acer's future development.

The coming decade will witness Acer's continued rapid growth through increased integration of global resources. Current expansion plans include the establishment of manufacturing and research and development facilities in the United States and Europe in the near future.

Stan Shih is chairman and CEO of Acer Incorporated. Prior to founding Acer Incorporated (formerly Multitech) in 1976, Mr. Shih served as vice president of Qualitron Industrial Corp. from 1972 to 1976 and as deputy director of Unitron Industrial Corp. In 1983, Mr. Shih received one of "Ten Most Outstanding Young Persons in the World" awards from the International Jaycees for his contribution to computer technology in the Republic of China (ROC).

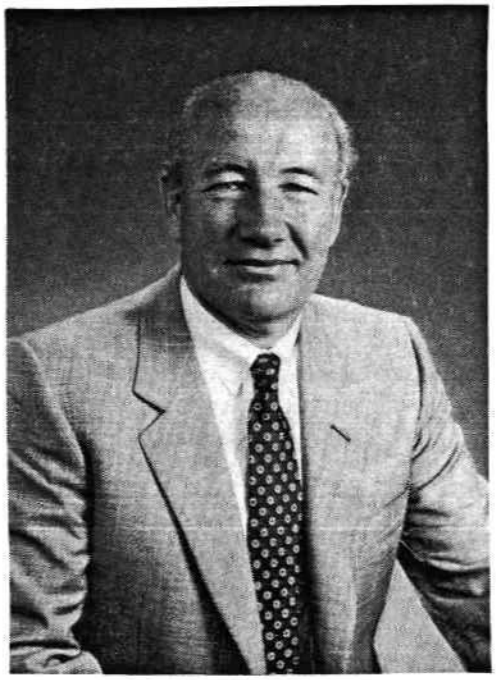
In 1987, he received the CIE/USA Distinguished Achievements Award from the Chinese Institute of Engineers, USA, for his significant contributions toward technological development in the ROC.

Mr. Shih is the author of more than 100 articles in the areas of research and development (R&D), management, and corporate culture in ROC newspapers and magazines. He is also a guest lecturer at various ROC industrial and commercial associations, media, television, and many overseas associations. Mr. Shih has B.S.E.E. and M.S.E.E. degrees from Chiao Tong University.

LSI LOGIC CORPORATION

Background

LSI Logic Corporation, founded in January 1981, is the number one CMOS gate array ASIC company in the world. It is a U.S.-based corporation with affiliated companies in Japan, Europe, and Canada, employing more than 3,000 people worldwide. The company headquarters is located in Milpitas, California. LSI Logic is the ninth-largest U.S. integrated circuit company and is ranked fifth in the world for ASIC suppliers. The company had revenue of $262 million in 1987; this was the sixth consecutive year in which revenue rose 30 percent per year.



Wilfred J. Corrigan, Chairman and CEO

LSI Logic is the leading designer, developer, and manufacturer of gate arrays and cell-based ASIC products. In addition to manufacturing customer-specific ASIC devices, the company produces customer-specific ASIC systems that can range from a computer on a chip to a board comprising primarily or entirely ASIC devices. This system-level capability is particularly well suited to standard products within the personal computer industry and is being marketed by G-2 Incorporated, an LSI Logic-affiliated company.

Founded in 1987, G-2 Inc. designs and markets standard product chips and chip sets to makers of IBM-compatible personal computers and other electronic products. These chip sets dramatically reduce component count on printed circuit boards. G-2 Inc. has the rights to manufacture and sell PS/2 chip sets incorporating IBM's Micro Channel Architecture.

In 1987, LSI Logic entered the RISC (reduced instruction set computer) microprocessor marketplace when it received rights to manufacture and sell MIPS Computer Systems' R2000 and R3000 family of 32-bit RISC-based microprocessors. LSI Logic is also licensed to use Sun Microsystems SPARC architecture in developing future products. In 1988, the company acquired a 70 percent interest in Video Seven Incorporated, a leading developer, manufacturer, and marketer of advanced graphics technology for the business and professional computer user.

Products and Technologies

LSI Logic has developed a host of products in the area of gate arrays and cell-based custom technologies. As the technology leader, LSI Logic offers gate arrays with 100,000 usable gates (400,000 transistors) processed in 0.7-micron channel length technology with three layers of metalization. The company specializes in high-performance HCMOS technology and has introduced a BICMOS process that combines analog and digital functions on a single chip. The company offers more than 250 different package types with up to 299 pins and fully tests all products.

Software Services

The Modular Design Environment (MDE) is LSI Logic's suite of advanced CAE/CAD software tools and services for ASIC design and development. These advanced tools are responsible for more than 5,000 designs and work on the industry's most popular workstations including Apollo, Digital Equipment, IBM, Silicon Graphics, and Sun Microsystems. The Company's CAD Connection Program allows users of Daisy Systems, Mentor Graphics, and Valid Logic platforms, as well as IBM PC users, access to LSI Logic's software programs and extensive libraries.

Manufacturing and Facilities

In 1987, LSI Logic manufactured 35 billion gates of logic representing the equivalent of one billion TTL chips. This was accomplished via manufacturing facilities located in Asia, Europe, and the United States.

All LSI Logic facilities are geared to meet the special ASIC needs of worldwide geographic markets—large, high-density chips; a wide variety of packages; short manufacturing runs; and complex test patterns. Tested and working array prototypes can be delivered in as little as seven days. Tested and working cell-based prototypes are delivered in less than six weeks. The company's advanced wafer fabrication, assembly, testing, and packaging technologies make LSI Logic a leader in ASIC manufacturing.

Marketing and Sales

With an active customer base of more than 2,000 customers, LSI Logic addresses EDP, military, telecommunications, and other end-user markets. The company has 22 domestic sales and Design Resource Center locations, as well as 17 sales and Design Resource Center locations in Canada, Europe, Japan, and Korea. Distributors are Hamilton/Avnet, Wyle Laboratories, and Hall-Mark.

Wilfred J. Corrigan

Wilfred J. Corrigan is chairman of the board and CEO of LSI Logic Corporation. Prior to joining LSI Logic, Mr. Corrigan was president, chairman, and chief executive officer of Fairchild Camera and Instrument Corporation in Mountain View, California. Mr. Corrigan joined Fairchild in August 1968 and held a series of management positions before becoming president and CEO in July 1974. He became chairman of Fairchild in May 1977.

Before joining Fairchild, Mr. Corrigan was director of Transistor Operations at Motorola Inc.'s Semiconductor Products Division in Phoenix, Arizona. He graduated from Imperial College of Science, London, England, with a B.Sc. degree in chemical engineering.

Key Management

George Wells is president and CEO of LSI Logic. Dr. Gerry Thomas is president and chief executive officer of LSI Logic Europe plc; Mick Bohn is president and chief executive officer of LSI Logic Corporation of Canada, Inc.; Keiske Yawata is president and chief executive officer of LSI Logic K.K.; and William O'Meara is president and chief executive officer of G-2 Incorporated.

SOVIET UNION UPDATE

On November 21, 1988, Cliff Lindsey and his staff had a 45-minute private meeting in San Jose, California, with Abel Aganbegyan, Mikhail Gorbachev's chief economic advisor and architect of perestroika. The main reason for this meeting was to work out arrangements for Academician Aganbegyan to speak at the 1989 SES Presidents' Summit Conference in San Diego and to get an update of Soviet markets for our SES clients.

Cliff Lindsey and Abel Aganbegyan

Dataquest has proposed that Dr. Aganbegyan hold a mutual dialog in front of our conference audience with James T. Barton, president of Prudential-Bache Securities (Dataquest's largest customer). Dr. Aganbegyan expressed great interest, but has some difficulty with the proposed August date. He will be returning to California in February, and we hope to have the date resolved at that time. If Dr. Aganbegyan cannot attend the conference, we will have a special briefing in San Jose, either during his February visit or in June, when he returns to spend a week at Esalen in Big Sur, California.

In our discussions of joint ventures, Dr. Aganbegyan wanted to know if Dataquest could help him locate a medium-size software company to enter a joint venture with a group of software people at the Soviet Academy of Sciences. He mentioned that this joint venture could be accomplished in a matter of weeks. Cliff said that in his experience, these joint venture negotiations have taken more than a year for other American companies. Dr. Aganbegyan replied that it was because those were being done with ministries, which are large and monopolistic. His software team would be assembled outside the Academy of Sciences into an independent organization that would be able to consummate the joint venture in a matter of weeks because of the lack of bureaucratic process.

Dr. Aganbegyan listed four areas of interest in software and mentioned that his team would like to include distribution into the United States and other western countries. One area of interest is a product called Master, which is somewhat of a desktop manager software package that Cliff saw demonstrated in Moscow last December. This seemed to be "state of the art," but would not by unique in the West, as far as Cliff could tell at that time. A second area is game software, at which the Soviets are very good. The games are more mathematical or intellectual, as opposed to war games. The third area is medical software. The last area of interest may run into some problems with the U.S. Department of Commerce; however, Dr. Aganbegyan said that the Soviets want to do this joint venture effort legally and obtain whatever licenses are required. The area of interest: they think future personal computer developments will move into the area of RISC processing and transputers and would like a partner to work in this software area for future generations of hardware.

With respect to Cliff's question as to whether the ruble will be convertible currency within five to ten years, Dr. Aganbegyan provided a detailed answer. He said if one takes the standard route, it will take seven to ten years for the ruble to evolve as convertible currency. First of the major preconditions is for the Soviet Union to develop its own domestic markets and make sure that its currency is convertible within its own country first. The Soviets have to create financial markets via commercial banks and legislation on shares and bonds and initiate their own stock market. They also need to create industrial markets internally. By the end of the 1990s, Dr. Aganbegyan anticipates that there will be hard currency markets within the country for its own needs.

Second, he intends to change the pricing system by moving to wholesale pricing using a scheme that approximates the level of prices in European markets. He also anticipates assigning normal tariffs that are compatible with the General Agreement on Trade and Tariffs (GATT).

Third, he wants to ensure that foreign economic relationships are maintained, that the Soviet Union's products are compatible with existing western products, and that they are efficiently produced. He also wants to improve the Soviet Union's trade balance. The government recently announced publicly that it has a deficit.

Fourth, the Soviet Union needs to have the assistance, support, and cooperation of several international financial organizations; specifically, the GATT, the International Monetary Fund (IMF), and the World Bank. Dr. Aganbegyan says it will be depending on these organizations, and others, within the various countries.

In view of the seven to ten years necessary for convertibility, Dr. Aganbegyan suggested that a way around this problem would be to create a second currency other than the ruble by establishing economic zones within the Soviet Union with partially convertible currencies. A project to do this is under way right now. These trade zones will be located internally inside the U.S.S.R. rather than just on the borders. He said that less stringent U.S.S.R. labor laws will apply in these zones.

In cooperation with Dr. Aganbegyan, the Furth Foundation and the Esalen Institute Soviet-American Exchange Program are establishing a prize of $25,000 for the best research paper written by Soviets or Americans or both that would propose a practical solution to the problem of the convertibility of the ruble. This announcement is to be made public soon. In addition, Esalen is currently working to assemble a delegation of Soviet bankers to come to San Francisco and New York in the spring of 1989 to discuss banking reform with their American counterparts.

The day after Cliff's visit, Dr. Aganbegyan spoke before 500 people at the Fairmont Hotel in San Jose for the World Forum. During his talk, he made several statements of great interest. His initial sentence was "Perestroika is life or death, and we have no alternative." He continued by criticizing current conditions in the Soviet Union. Among his points: living conditions are poor, far below what you would expect for a country of the Soviet Union's standing; housing is in decline; while mortality is rising. Salaries in education and medicine are far too low. Agriculture investment policy has been wrong. The country has far too many bureaucratic and dictatorial managers. He stated that there is resistance to this new economic plan (perestroika) and he thought that the next three years would be very painful as the old management will have to work in parallel with the new management. In response to a question from the floor, "Is the independence movement in Afghanistan perestroika?", he replied, "The withdrawal from Afghanistan is perestroika, and if we had had perestroika eight years ago, no troops would have gone in in the first place."

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SES *Exchange*

August 2, 1988, No. 4
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INTRODUCTION

The SES Exchange is a publication for members of the Dataquest Strategic Executive Service, with additional distribution to the Dataquest senior staff and research group leaders. The SES Exchange provides company backgrounds and significant news about member companies, and it acts as a clearinghouse to communicate market needs of member companies to the entire SES client base. (Please contact your account manager when you wish to provide information for this publication.)

Verity Inc.

Background

Verity Inc., founded in 1988, is a spin-off of Advanced Decision Systems (ADS), a government contract research and development firm founded in 1979. ADS provides consulting services such as technology studies and custom software to DARPA (Defense Advance Research Products Agency), the military services, and the intelligence community. In 1987, the company's seventh consecutive year of growing profits, ADS posted $15 million in sales and had 170 employees.

During the 1980s, ADS developed a number of customized artificial-intelligence-based systems to meet the intelligence community's information management requirements. The genesis of Verity and its dominant product, Topic, can be traced to this work, which was initially called RUBRIC, a rule-based text retrieval system. By 1986, ADS had developed a LISP-based version of RUBRIC that contained many of the features later to be included with Topic, such as topics and weightings. Unfortunately, RUBRIC ran in limited environments, was difficult to use, and was slow.

Michael S. Pliner, Chairman, President, and CEO

Dataquest Incorporated, 1290 Ridder Park Drive, San Jose, CA 95131-2398, (408) 437-8000, Telex 171973, Fax (408) 437-0292

In 1986, the intelligence community, recognizing the potential of RUBRIC to solve the community's massive text retrieval demands, invested $3 million in a two-year project to make RUBRIC operational. The result of this project is Topic, developed in C and available on the IBM PC. Topic was completed in May 1987 and was licensed to the first intelligence client.

Verity has received $3.25 million in venture financing from three venture capital companies: U.S. Ventures, Palo Alto, California; Olympic Ventures, Seattle, Washington; and Grotech, Washington, D.C.

Key Management

Dr. Michael S. Pliner, 42, is chairman, president, and chief executive officer of Verity Inc. Before co-founding Verity in 1988, Mr. Pliner founded Sytek Inc., a California-based manufacturer of broadband local-area networks, where he served as chairman, president, and chief executive officer until May 1986. Mr. Pliner oversaw the growth of Sytek from its inception in 1979 to its established position in 1986 as a $91 million manufacturer of LAN equipment.

Before founding Sytek, Mr. Pliner spent four years (1975 through 1979) with Ford Aerospace and Communications Corporation. Initially, he served Ford as a principal engineer, developing data base management systems and data communications networks. He was later promoted to manager of the company's software technology department. Before his career in private industry, Mr. Pliner spent eight years (1967 through 1975) with the National Security Agency in several technical and management positions.

Mr. Pliner has a Ph.D. and an M.S. degree in computer and information science from Case Western Reserve University in Cleveland, Ohio, and holds a B.S. degree in electrical engineering from the Case Institute of Technology. Since 1986, he has served on the board of directors of ADS and the Corporation for Open Systems, an organization dedicated to monitoring compliance with the International Standards Organization networking specifications.

Needs

Verity's strategic relationships include joint marketing and product development with OEMs, VARs, or system houses, both domestically and internationally. Its target markets include legal, information publishing, documentation, military intelligence, and market research.

Western Microtechnology, Inc.

Background

Western Microtechnology, Inc., founded in 1977 by Marshall G. Cox, chairman and chief executive officer, and Bernard T. Marren, president, is a leading full-service electronic distributor specializing in complex integrated circuits and systems. The company became publicly owned in 1983 (it trades over-the-counter on the NASDAQ National Market System with the symbol WSTM) and is one of the fastest-growing publicly owned electronic distributors in the United States. Electronic News, in its annual ranking of all electronic distributors in the United States, placed Western Microtechnology 45th in sales in 1982, 19th in 1985, 18th in 1986, and 16th in 1987.

The company serves the top three U.S. geographical locations in terms of the total available electronic distribution market—Southern California, Northern California, and New England. Nationwide, it serves approximately 50 percent of the total U.S. market for distribution. The future addition of the Metropolitan New York/New Jersey, the Southeast, and Texas geographical locations will bring the total available market served to approximately 70 percent.

Marshall G. Cox, Chairman and CEO

Western Microtechnology was founded on the premise of the developing needs of engineering departments of small and medium-size companies for technical support from a trained distribution sales and service staff. The company pioneered the concept of technical value-added services in the distribution industry.

Operations

New commercial electronic systems are often developed by small and medium-size companies that manufacture these products with advanced complex electronic components such as microprocessors, memories, and peripheral devices. Many of these companies do not require large enough quantities of electronic products or advanced subsystems to deal directly with manufacturers of such devices. Western Microtechnology fills this need. Through franchise agreements with the manufacturers, Western Microtechnology purchases and markets the products to its customers, to which it also serves as a source of technical and design information and as a warehousing location. The electronic distribution industry has demonstrated its importance by supplying approximately 27 percent of the U.S. sales of electronic components in 1987, an increase from about 18 percent in 1982.

The Western Microtechnology Distribution Group's line consists of advanced products from leading suppliers in the United States, Europe, and Japan. The company is the only distributor in the United States to have franchise agreements with all of the major Japanese semiconductor suppliers. Five of the suppliers—Fujitsu, Hitachi, Mitsubishi, NEC, and Toshiba—are among the world's top 10 semiconductor suppliers.

The Western Micro Labs Division, which provides value-added services, is recognized as one of the nation's leading test labs, providing fully automatic memory testing to semiconductor manufacturers and OEM customers. Its capabilities extend to static and dynamic RAMs of up to 1 million bits in complexity. Additionally, the test labs provide programming services for a wide variety of PROMs, EPROMs, EEPROMs, and PLDs.

New Suppliers

Among the new suppliers Western Microtechnology has added during the most recent 12 months are IBM, Link Technology, Micropolis, Optotech, SMOS, TEAC, Telex Computer Products, Xilinx, and ZyMOS.

New Products

Among the new products the company has added during the most recent 12 months are mass-data storage optical disk drives for use with personal computers; hard-disk drives with high performance, high reliability, and shock/vibration resistant characteristics; personal computer board-on-a-chip products; multiuser computer systems; and high-performance, high-density, digital integrated circuits.

Western Microtechnology, with approximately 260 employees, has its headquarters in Saratoga, California, with stocking locations in Mountain View, San Diego, Orange, and Agoura Hills, California; Beaverton, Oregon; Redmond, Washington; and Burlington, Massachusetts. Western Micro Labs' testing operations are located in Santa Clara, California, and Durham, North Carolina. The latter location serves the entire East Coast.

The address of Western Microtechnology's corporate headquarters is 12900 Saratoga Avenue, Saratoga, California 95070; Phone (408) 725-1660.

Precision Monolithics Inc.

Background

Precision Monolithics Inc. (PMI), a Bourns company, designs, manufactures, and sells precision analog integrated circuits. Founded in 1969, PMI developed a range of products for instrumentation, process control, communication, and military/aerospace applications. These products include operational amplifiers, instrumentation amplifiers, analog-to-digital and digital-to-analog converters, communications devices, and related data acquisition and signal processing devices.

PMI became a leader in its field as early as 1970 when it introduced the first monolithic digital-to-analog converter—PMI's DAC-01. PMI "firsts" such as the OP-05, OP-07, OP-27, DAC-100, and DAC-08 have become industry standards, contributing to sustained growth over the last 10 years. Today, PMI is carrying on its innovative tradition, introducing 10 to 20 new products a year.

Alan V. King, President

Through 1987, PMI had grown to approximately $80 million in sales, 900 employees, and more than 12,000 customers in 37 countries throughout the world. Substantial investments in R&D and manufacturing capacity are the result of the company's goal to achieve more than 15 percent annual growth over the next five years. CMOS and high-speed bipolar technologies have positioned the company in the high-speed and microprocessor-compatible data acquisition markets.

Product Applications

Commercial and military aircraft use specially processed PMI products in engine control and navigational systems. PMI participates in the JAN 38510 program with fully qualified devices.

Superior performance in hostile radiation environments make PMI devices ideal in space applications. PMI products are widely used in industrial/commercial applications such as instruments, process controls, hybrids, medical equipment, and telecommunications.

What Makes PMI Unique?

PMI's sales have grown steadily in both good years and bad. The analog market has not been subject to the dramatic economic and technical variations of the digital market over the past several years. The analog market is not "tied" to the cyclical computer market nor is it subject to Japanese or European competition. PMI's ownership of the precision analog niche has also made the company less susceptible to competition and economic swings. A significant penetration into the military segment has lent a stabilizing influence to PMI's growth.

Historically, precision linear products are characterized by relatively small chip size, mature technology, heavy dependency on design and applications, and moderate dependency on high-volume manufacturing techniques. By focusing on design, fab technology, precision testing, and special military back-end processing, PMI achieves a revenue five times the industry standard per 4-inch wafer.

Additionally, the evolutionary aspect of analog products evolves from close interaction between design, technology, and market knowledge. This type of interaction or synergy optimizes product performance. The ability to integrate its marketing, design, and technology strengths synergistically allows PMI to compete effectively against companies with greater resources. This is PMI's particularly unique advantage.

PMI's Future

The integrated circuit industry is one with enormous potential growth, high risk, extreme dynamics, and ferocious competition. Within this environment, PMI plans a doubling of sales with substantial profits over the next five years.

There will continue to be many opportunities to capture and dominate selected small market segments. A great deal of these opportunities can only be supplied by design and technology creativity coupled with expert analog market knowledge. PMI is geared to take advantage of such opportunities while maintaining a leadership position in the analog marketplace.

The intent is to expand upon existing strengths and momentum in the analog market, while positioning in defensible market niches. PMI's strategy is to protect the existing business base and expand business attainable through current products; create new products for existing and emerging market segments; and, position the company for long-term growth in defensible markets.

The cornerstone of this strategy is the maintenance of a stable organization of extremely talented people.

Vitelic Corporation

Background

Vitelic Corporation was founded by Alex Au in 1983. Prior to forming Vitelic, Dr. Au was manager of VLSI Research at Fairchild Semiconductor for four years. In that position, he developed, organized, and oversaw a lab with 100 employees and a $7 million budget.

Before that, he was with Intersil for four years as director of Research and Development.

Dr. Au received his master's and doctorate degrees in Electrical Engineering from Stanford University, and a BSEE from UCLA in 1969. He holds four patents for MOS memory circuits.

Alex Au, President and CEO

Vitelic designs, produces, and markets high-performance dynamic and static specialty random access memories using state-of-the-art CMOS technology. Vitelic's market focus is on the fast-growing 32-bit PC and workstation segment, and on graphics and multiprocessor systems. To this end, Vitelic specializes in feature-intensive and customer-specific memory devices. The engineering staff is composed of the best memory design and process/product engineering talent in the country. All manufacturing is currently performed through foundry alliances with leading semiconductor companies around the world. The company does, however, plan to build its own fabrication facility in the near future.

Corporate Financing

Vitelic is a privately held company with equity financing exceeding $16 million. Financing is provided through venture capital funding as well as corporate investments.

- Investors:
  - Bessemer Venture Partners
  - J.H. Whitney & Company
  - Kyocera International, Inc.
  - Oak Investment Partners

- Sony Corporation
- Oxford Partners
- Waverley Vencap, Ltd./Crest Holdings
- Inco Venture Capital/North American Partners
- Pathfinder/Montgomery Securities

The Markets

High-performance 16-bit and 32-bit microprocessor-based systems, high-resolution graphics display terminals, and high-end image processing systems are the main target areas for Vitelic's specialty memory products. High-speed, feature-intensive, CMOS static RAM (SRAM) and dynamic RAM (DRAM) memories, as well as specialty devices including FIFOs, dual port memories, cache data memories, and video RAMs, will all be required by these systems. Vitelic's focus, consistent with its marketing strategy, is in these well-defined, fast-growing markets.

Vitelic also offers a custom memory service for customers who need unique memory devices. The customer-specific memory (CSM) capability gives Vitelic's customers an edge over their competitors and enables Vitelic to satisfy the ever-changing needs of its client base.

The Product Families

Vitelic offers a wide range of CMOS DRAM and SRAM products. Its specialty memories offer many unique features and advantages; the DRAM product line offers feature-intensive functions such as Fast Page and Static Column mode access. These products provide the high-performance, high data rate capability needed for graphics display and signal processing applications. The 256K DRAM offers access times as fast as 70ns and the 1-Mbit device can reach speeds of 80ns. These devices are among the fastest in the industry.

Vitelic's CMOS dual port video RAM interfaces with both the video processor and the display controller to satisfy the demands of a growing graphics market, while the dual port SRAMs and FIFOs allow processors operating at different speeds to communicate with each other. Cache memory applications are another area of major focus for Vitelic. The 25ns 8Kx8 fast SRAM addresses this market need. In addition, Vitelic is developing unique cache data memory chips to solve specific microprocessor interface issues.

The Technology

Vitelic has used CMOS technology to its fullest extent to produce a series of highly complex circuits that operate at advanced speeds but at low power. Examples of these circuits are Vitelic's 1-Mbit DRAM and 256K dual port video RAM, which operate at 80ns. These products are manufactured with Vitelic's proprietary DRAM process that combines advanced CMOS process architecture using double-polysilicon/silicide layers with 1.1-micron feature sizes and 0.8-micron device channel lengths. Another example is Vitelic's 25ns 64K SRAM, which uses two metal layers and 0.8-micron device lengths.

The Manufacturing Strategy

Vitelic has formed alliances with leading semiconductor manufacturing companies around the world. In most cases, these are manufacturing, licensing, and joint-development relationships.

Vitelic is able to exploit its advanced-design and high-performance process capabilities to manufacture cost-effective products through its partnerships. These foundry partnerships offer highly automated and ultraclean manufacturing facilities. Vitelic has the proven capability of transporting its advanced process architectures into manufacturing facilities by using the individual process units that already exist in the host facility. Thus, Vitelic can integrate the host's manufacturing capabilities and specific process expertise into Vitelic's advanced process architectures. As the manufacturing partners develop advanced unit processes, Vitelic is able to integrate them quickly and effectively into its process architectures and future products.

Vitelic also has the benefit of high yields and stable processes that are the results of the partners' highly automated and large-capacity factories.

Vitelic's headquarters and corporate offices address is 3910 North First Street, San Jose, California 95134-1501; Phone (408) 433-6000.

Synthesis Software Solutions, Inc.

Background

Synthesis Software Solutions, Inc., was formed in March 1988 as an independent company that acquires, ports, distributes, and supports third-party software for computer systems using MIPS Computer Systems' RISC components. The company was funded with $10 million from investors including MIPS, its customers, its three semiconductor partners, and MIPS' private investment group.

Owen Brown, President and CEO

Synthesis is a direct result of the success of MIPS Computer Systems. Since introducing the industry's first commercially available RISC processor in 1986, MIPS has achieved over 75 design wins, including ones for Ardent Computer, Prime Computer, Loral/ROLM MIL-spec, RC Computer, Silicon Graphics, Sumitomo, and Tandem Computer. In November 1987, MIPS formed a technology sharing alliance with its semiconductor partners: Integrated

Device Technology, LSI Logic Corporation, and Performance Semiconductor. While MIPS concentrated its efforts on its RISC systems business, the partners began to manufacture MIPS RISC components and market them worldwide. This explosive proliferation of MIPS systems and components laid the groundwork for the formation of Synthesis in March 1988.

Synthesis was created as an independent company of private investors and a consortium of MIPS customers. By combining their resources, Synthesis enables MIPS customers to gain immediate and affordable access to the best software available.

Unique Approach to Software Acquisition

Synthesis differs in several ways from other independent software companies in the industry. In contrast to a company like Apple's Claris, Synthesis is not owned and run by a single manufacturer nor is it designed primarily to perform original development. Instead, the company is owned by numerous corporate manufacturers and resellers, each of which has a direct voice in determining the priority of software packages to be provided, as well as the directions and policies of the company. Company direction and decisions are made by the CEO and Board of Directors and an Executive Committee whose representatives are selected from among the charter members.

Also, unlike other ventures in the industry, Synthesis is not merely dedicated to product development and engineering. It has a full marketing organization to help promote products and expand sales, and a dedicated support team to ensure ongoing customer satisfaction with Synthesis-supplied products.

Synthesis also differs from other software companies in truly understanding its market and the underlying technology. With close ties to MIPS and its customers, Synthesis is in a unique position to provide software more rapidly and at a lower cost than its individual customers could obtain on their own.

Owen Brown Named President

When the company was founded in March 1988, Owen Brown was named president and CEO. Previously, Mr. Brown held a number of senior management positions during his 19-year career in the computer industry, which included positions with Digital Equipment Corporation, Sun Microsystems, and Xerox Corporation. During his 11 years at Digital, Mr. Brown performed several senior management roles in sales and marketing, including primary responsibility for the company's highly lauded U.S.-wide reorganization in the early 1980s. Following his term at Digital, Brown served as president and COO of Sun Microsystems, where he worked with the founders to successfully launch the company and establish its directions in the marketplace. After Sun, he served as CEO at Parallel Computers in Santa Cruz, California.

Rapid Progress

Founded just four months ago, Synthesis is already shipping a dozen software packages and is negotiating with more than 40 software suppliers. Synthesis is always looking for new products in a variety of application areas and expects to be shipping 40 to 50 packages by the end of the year.

The company's address is 292 Commercial Street, Sunnyvale, California 94086; Phone (408) 720-1557.

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