Dataquest
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February 1996

Dear Dataquest Client,

By now, you should have received the 1996 Dataquest research program binders for filing the newsletters and reports that will be sent to you throughout the year.

To let you know what documents you can expect to receive as part of your subscription, enclosed please find the 1996 datasheet for the research program to which you subscribe. The back side of the datasheet lists the Dataquest Perspectives, Market Trends reports, Market Statistics books, reports, and electronic newsletters that are included in this year's research portfolio.

If you have any questions about the research schedule, please contact your Dataquest research analyst or client services representative.

Sincerely,

Jeffrey A. Byrne
Vice President
Worldwide Marketing

SEMICONDUCTOR DIRECTIONS IN PCs AND PC MULTIMEDIA

As PC product life cycles grow shorter than ever, semiconductor vendors must work harder to get and keep the big design wins. Don't miss out on your share of this rapidly growing market! Dataquest's Semiconductor Directions in PCs and PC Multimedia program keeps your finger on the pulse of the semiconductor industry as it relates to PCs. Dataquest's hard-hitting analysis and industry statistics ensure that you know what is selling today as well as what features and products you'll need to gain market share tomorrow. Grounded in primary research and system teardown analysis, this program provides its client with forward-looking analysis for all major semiconductor devices in PCs.

What's Driving Next-Generation PC Designs?

Consider if you have ever asked any of the following questions:

- What features should I integrate into my graphics products to stay competitive?
- What type of DRAM will PCs use in 2 years?
- When will audio chips be designed into the motherboard?
- Who sells more core logic chips than anybody else? And who is catching up?
- What technologies impact power management in notebook PCs?
- How much does it cost to add wavetable sound to a PC?
- How many Pentiums is Intel selling?
- How does Company X's new product impact the graphics controller market?

Geared for Product Managers

Semiconductor Directions in PCs and PC Multimedia is geared for product managers and strategic planners. This program offers timely, insightful analysis of the technologies, companies, products, and issues that drive the semiconductors in PCs.

In fact, anyone who needs to understand the semiconductor market as it relates to PCs can benefit from this service. Clients of the program span the semiconductor food chain from test equipment companies to semiconductor companies to OEMs for PCs and other consumer equipment.

The MPU Is the Key

The key to the PC is the microprocessor. Faster PCs, bus designs, new caching schemes, and memory management all hinge on evolving MPU architectures.

Focused Research

With this in mind, Dataquest has developed a program to focus specifically on the MPU and surrounding technologies in next-generation PC designs. Topical coverage and market statistics in this program include:

- Microprocessor trends: x86 and PowerPC
- PC memory content
- Advanced graphics processor design trends
- Trends in standard versus custom IC designs
- PC multimedia trends
- I/O trends
- PC core logic chipsets
- PC semiconductor content analysis based on system teardown analysis and industry trends
- Quarterly forecasts of x86 microprocessors
- Manufacturing issues
- x86 competitive analysis
- MPU price forecasts

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WHAT YOU WILL RECEIVE AS A CLIENT

SEMICONDUCTOR DIRECTIONS IN PCs AND PC MULTIMEDIA

Perspectives

Dataquest Perspectives present analysis and commentary on key technologies, companies, market opportunities, trends, and issues in the market. Ten Perspectives will be published throughout the year. Scheduled Perspectives for 1996 include:

- Teardown Analysis: Specific information about implementation trends in today's PCs, including drawings of current designs
- Industry Standards: Including native signal processing (NSP), universal serial bus (USB), and new motherboard form factors (ATX)
- Feature trends for functional subsystems and key semiconductor devices, including multimedia and graphics core logic, communications, media engines, and others.

Market Trends

Market Trends Reports: Worldwide trends in microcomponent demand, PC unit production, industry competition, system architecture trends, and semiconductor device opportunities are addressed in these detailed reports. Also includes five-year revenue forecasts of the semiconductor-value composition of PCs by processor generation (e.g., 486, Pentium, P6) and type (e.g., RISC PC), derived by reconciling device forecasts for memory, graphics, and core logic with PC unit forecasts. Separate reports will be published for graphics, MPU, core logic, and other devices.

Available in the Second Quarter 1996

Market Statistics

Market Statistics Documents: Detailed market share statistics, unit shipments, and ASPs of MPUs, graphics and core logic, I/O, and PC audio semiconductors.

Available in the First and Second Quarters 1996

Worldwide Semiconductor Consumption Forecast: Five-year revenue forecasts for the global semiconductor market by region: Asia/Pacific, North America, Japan, and Europe.

Available in the Second and Fourth Quarters 1996

Reports

Two in-depth reports on growing semiconductor opportunities. PC audio will be the subject of one report. The other will focus on another hot topic. These reports will detail all major aspects of these markets including information on leading-edge products, the companies driving the markets, feature trends, and a five-year forecast of semiconductor content.

Available in August and September 1996

Electronic News

Alerts: These are timely, industry-driven updates focused on current events and issues that significantly affect the semiconductor market. Alerts are delivered via fax or electronic mail to get concise analysis in your hands fast. Alert topics in 1995 ranged from trend-setting product announcements to industry impact of power outages in Taiwan.

Event-driven Faxes

The DQ Monday Report: These newsletter provides a weekly update of news, events, and analysis for the entire semiconductor industry. You also get regular updates of stock prices for Silicon Valley companies, as well as the Dataquest 100 stock index of leading semiconductor companies.

Available Weekly via Electronic Mail

Conferences

Dataquest hosts the industry's preeminent semiconductor conferences in the United States, Europe, Japan, Taiwan, and Korea. Clients receive a discount on conference fees.

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Program Code: PSAM-WW MKTG 1/96 (JCG)

December 1995

Dear Dataquest Client:

In 1996, Dataquest will celebrate its 25th year as the leading global supplier of market intelligence to the IT vendor and financial communities. I would like to thank you, on behalf of all Dataquest associates worldwide, for your support. We are proud to be your information partner by providing the IT market insight and analysis you need to make crucial business and planning decisions.

The enclosed binder is for filing and storing the printed market research newsletters and reports that you will receive on an ongoing basis throughout 1996 as part of your subscription to Dataquest. You may notice that we've streamlined the binder tab and document filing structure this year. We hope that this 5-tab scheme increases your efficiency in filing and locating documents.

You probably know that in addition to paper-based delivery, Dataquest is also committed to delivering our market statistics and analysis electronically. We expect that our electronic products, known collectively as *Dataquest on the Desktop*, will play an increasing role in our ability to deliver information to you in a timely, efficient way. For your information, our electronic tools include:

- ***Dataquest on Demand***—Our monthly CD-ROM containing a rolling 13 months of Dataquest's printed documents
- ***MarketView***—A data analysis tool containing many of Dataquest's market statistics databases
- ***Electronic NewsTakes and Dataquest Alerts***—Weekly/event-driven summary and analysis of top IT news, published via e-mail or fax by most Dataquest research groups
- ***Dataquest Interactive***—Our Internet-based electronic delivery system that you are invited to preview at this URL: http://www.dataquest.com

One last note: an optional binder called *Electronic News* is available on request for clients who wish to file their electronic newsletters and Dataquest Alerts. To order your copy, please fill out the FaxBack form found in the binder pocket and fax it back to us.

We look forward to working with you in our continuing process to improve the content, quality, and timeliness of our products and services. I encourage you to share with us your comments about our publications and electronic delivery tools.

Sincerely,

Jeffrey A. Byrne
Vice President, Worldwide Marketing

1996 RESEARCH PROGRAMS

From semiconductors to systems, software to services, telecommunications to document management, Dataquest's scope of expertise provides clients with a clear view of the relationships among information technology segments – relationships that can have a profound impact on making strategic business decisions.

Computer Systems and Peripherals

Computer Systems
- Client/Server Computing *Worldwide*
- Computer and Client/Server Systems *Europe*
- Servers *Europe*
- UNIX and Open Systems *Europe*

Workstations
- Advanced Desktop and Workstation Computing *Worldwide*
- Workstations *Europe*

Computer Storage
- Removable Storage *Worldwide*
- Optical Disk Drives *Worldwide*
- Optical Disk Drives *Europe*
- Rigid Disk Drives *Worldwide*
  - RAID Storage Systems *Worldwide*
- Rigid Disk Drives *Europe*
- Tape Drives *Worldwide*
- Tape Drives *Europe*

Graphics
- Graphics and Displays *Worldwide*

Personal Computing
- Personal Computers *Worldwide*
- Personal Computers Strategic Service *Europe*
- Personal Computers *Asia/Pacific*
- Mobile Computing *Worldwide*
- PC Distribution Channels *Worldwide*
- PC Distribution Channels *Europe*
- Desktop PC Technology Directions *Worldwide*
- Mobile PC Technology Directions *Worldwide*
- Personal Computers *Central and Eastern Europe*

Quarterly Statistics
- Advanced Desktop and Workstation Quarterly Statistics *Worldwide*
- Workstation Quarterly Statistics *Europe*
- Server Quarterly Statistics *North America*
- Server Quarterly Statistics *Europe*
- PC Quarterly Statistics *United States*
- PC Quarterly Statistics *Europe*
- PC Quarterly Statistics *Japan*
- PC Quarterly Statistics *Asia/Pacific*
- PC Quarterly Statistics *Worldwide by Region*

Online, Multimedia, and Software

Emerging Technologies
- Multimedia *Worldwide*
- Multimedia *Europe* (Module)
- Online Strategies *Worldwide*
- Online Strategies *Europe* (Module)

Productivity/Development Tools
- Client/Server Software *Worldwide*
- Workgroup Computing *Worldwide*
- Workgroup Computing *Europe* (Module)
- Personal Computing Software *Worldwide*
- Personal Computing Software *Europe* (Module)

Technical Applications
- AEC and GIS Applications *Worldwide*
- Electronic Design Automation (EDA) *Worldwide*
- Mechanical CAD/CAM/CAE *Worldwide*
- CAD/CAM/CAE/GIS *Europe* (Module)
- CAD/CAM/CAE *Asia/Pacific* (Module)

Services

Customer Services
- Customer ServiceTrends *North America*
- Customer Services and Management Trends *Europe*

Professional Services
- Professional Service Trends *North America*
  - Systems Integration and Applications Development
  - Consulting and Education
  - Systems Management
- Vertical Market Opportunities *North America*
- Professional Services *Europe*
  - Systems Integration
  - Consulting and Education
  - Systems Management
- Professional Services Vertical Market Opportunities *Europe*
- Professional Service Trends *Asia/Pacific*

Sector Programs
- System Services *North America*
  - Desktop Services
  - Notebook Services
  - Server Services
- User Computing Services *Europe*
- Network Integration and Support Services *North America*
- Network Integration and Support Services *Europe*
- Software Services *North America*
- Strategic Service Partnering *North America*

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1996 RESEARCH PROGRAMS

Document Management

Copiers
- Copiers *North America*
- Copiers *Europe*

Facsimile
- Facsimile *North America*

Printers
- Printers *North America*
- Printers *Europe*
- Colour Products *Europe* (Module)
- Printer Quarterly Statistics *Europe*
- Printer Distribution Channels *Europe*
- Printers *Asia/Pacific*
- Printer Quarterly Statistics *Asia/Pacific*

Semiconductors

Regional Markets
- Semiconductors *Worldwide*
- Semiconductors *Europe*
- Semiconductors *Japan*
- Semiconductors *Asia/Pacific*
  - China/Hong Kong
  - Taiwan
  - Korea
  - Singapore

Devices
- ASICs *Worldwide*
- ASIC Applications *Europe*
- Memories *Worldwide*
- Memory Applications *Europe*
- Memory IC Quarterly Statistics *Worldwide*
- Embedded Microcomponents *Worldwide*
- Microcomponent Applications *Europe*
- DRAM Quarterly Supply/Demand Report

User Issues
- Semiconductor Supply and Pricing Worldwide

Application Markets
- Semiconductor Application Markets *Worldwide*
- Semiconductor Application Markets *Europe*
- Semiconductor Application Markets *Asia/Pacific*
- Communications Semiconductors & Applications *WW*
- Consumer Multimedia Semiconductors & Applications *Worldwide*
- Semiconductor Directions in PCs & PC Multimedia *WW*
- PC Teardown Analysis
- PC Watch *Europe*
- Electronic Equipment Production Monitor *Europe*
- Electronic Application Markets *Europe* —Automotive
- Electronic Application Markets *Europe* —Communications
- Electronic Application Markets *Europe* —Consumer
- Electronic Application Markets *Europe* —EDP

Manufacturing
- Semiconductor Equipment, Manufacturing, & Materials *Worldwide*
- LCD Industry *Worldwide*
- Semiconductor Contract Manufacturing *Worldwide*

Telecommunications

Networking
- Networking *North America*
  - Local Area Networks *North America*
  - Wide Area Networks *North America*
  - Modems *North America*
- Networking *Europe*
  - Asynchronous Transfer Mode *Europe*
  - ISDN *Europe*
  - Modems *Europe*
  - Local Area Networks *Europe*
  - WANs *Europe*
- Quarterly Market Watch *North America*
  - Intelligent Hubs & Switches
  - Network Interface Cards
- Network Distribution Channels *Europe*

Voice
- Voice Communications *North America*
  - Voice Processing *North America*
  - Computer-Integrated Telephony & Automatic Call Distributors *North America*
  - Premise Switching Systems *North America*
- Voice Communications *Europe*
  - Voice Processing *Europe*
  - Call Centres *Europe*
  - Telephones *Europe*
  - PBX/KTS Systems *Europe*

Public
- Public Network Equipment & Services *North America*
  - Public Network Equipment *North America*
  - Public Network Services *North America*
- Public Network Equipment & Services *Europe*
  - Public Network Equipment *Europe*
  - Public Network Services *Europe*

Personal
- Cellular Telephony *Worldwide*
- Personal Communications *North America*
- Personal Communications *Europe*
  - Infrastructure and Services *Europe*
  - Terminals *Europe*
- Personal Communications Distribution Europe

Cross-Technology Programs

Technology Insights for:
- Financial Services
- Government Agencies
- Publishing, Media, and Consulting Firms
- IT Business Development for Financial Organizations
- IS and Purchasing Organizations
- IT Supporting Industries

Emerging IT Markets

Central and Eastern Europe
- Personal Computers
- Telecommunications

Latin America
- Personal Computers
- Printers

Asia/Pacific
- IT Market Insight *Asia/Pacific*
- Personal Computers *Asia/Pacific* & Quarterly Statistics
- Printers *Asia/Pacific* & Quarterly Statistics
- Professional Service Trends *Asia/Pacific*
  - Country-level reports on Asia/Pacific IT markets

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DATAQUEST 1996 CONFERENCES

Dataquest sponsors an on-going series of conferences and invitational events focusing on trends and issues in information technology and IT services. These conferences are the preeminent source of insight and analysis of global IT market dynamics.

North America	January 24	Capitalizing on the Wireless Phenomenon	San Jose, California
	January 30	Dataquest Predicts	Boston, Massachusetts
	February 20	Dataquest Predicts	San Jose, California
	March 7	Channel Trends Conference	San Jose, California
	April 1-2	ServiceTrends Conference	Orlando, Florida
	April 1 *	Mining the Internet	Boston, Massachusetts
	May 6-7	Personal Computer Conference	San Jose, California
	May 13-14	Copier Conference	Boston, Massachusetts
	June 26-27	Storage Track Conference	Monterey, California
	July 1 *	SEMICON/West	San Francisco, California
	September 25-26 *	Multimedia	San Jose, California
	October 24-25	Semiconductors '96	Palm Desert, California
	December 1 *	Mining the Internet	San Jose, California
Europe	January 24	Computer Storage	Munich, Germany
	May 22-23	Semiconductors '96	Frankfurt, Germany
	September 10	Computer Storage	London, England
Japan	May 13-14	Semiconductors '96	Tokyo, Japan
	September 10-12	Computers and Peripherals	Tokyo, Japan
	December 6	Telecommunications	Tokyo, Japan
Dataquest Invitational Computer Conferences	December 1 *	Asia/Pacific Series	Tokyo, Japan
	December 1 *	Asia/Pacific Series	Seoul, Korea
	December 1 *	Asia/Pacific Series	Beijing, PRC
	December 1 *	Asia/Pacific Series	Shanghai, PRC
	December 1 *	Asia/Pacific Series	Xi'an, PRC
	December 1 *	Asia/Pacific Series	Guangzhou, PRC
	March 5	Dataquest Storage Solutions Series - USA	San Jose, California
	April 10	Dataquest Storage Solutions Series - USA	Irvine, California
	April 24	Dataquest Storage Solutions Series - USA	Nashua, New Hampshire
	September 24	Dataquest Storage Solutions Series - USA	Newton, Massachusetts
	April 1	Mediterranean Series	Dubai, UAE
	May 21	Mediterranean Series	Athens, Greece
	October 30	Mediterranean Series	Tel Aviv, Israel
	November 6	Mediterranean Series	Istanbul, Turkey

** Date tentative/may change*

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Dataquest Invitational Computer Conferences *(continued)*

January 17	Dataquest Storage Solutions Series-Europe	Paris, France
January 23	Dataquest Storage Solutions Series-Europe	Munich, Germany
January 30	Dataquest Storage Solutions Series-Europe	Milan, Italy
February 1	Dataquest Storage Solutions Series-Europe	Rome, Italy
June 10	Dataquest Storage Solutions Series-Europe	Budapest, Hungary
June 12	Dataquest Storage Solutions Series-Europe	Prague, Czech Republic
June 21	Dataquest Storage Solutions Series-Europe	St. Petersburg, Russia
June 25	Dataquest Storage Solutions Series-Europe	Moscow, Russia
July 1	Dataquest Storage Solutions Series-Europe	Warsaw, Poland
September 1	Dataquest Storage Solutions Series-Europe	Amsterdam, Holland
September 5	Dataquest Storage Solutions Series-Europe	Stockholm, Sweden
September 11	Dataquest Storage Solutions Series-Europe	London, England
September 19	Dataquest Storage Solutions Series-Europe	Frankfurt, Germany
October 1 *	Latin America Series	Caracas, Venezuela
October 1 *	Latin America Series	Mexico City, Mexico
October 1 *	Latin America Series	São Paulo, Brazil
October 1 *	Latin America Series	Buenos Aires, Argentina
October 1 *	Latin America Series	Santiago, Chile
October 1 *	Latin America Series	Bogotà, Columbia
October 1 *	Latin America Series	Lima, Peru
February 19	South Africa Series	Capetown, South Africa
February 22	South Africa Series	Johannesburg, South Africa
April 11	LINK Series - North America	Orlando, Florida
April 30	LINK Series - North America	Austin, Texas
May 1	LINK Series - North America	Philadelphia, Pennsylvania
May 9	LINK Series - North America	Charlotte, North Carolina
May 14	LINK Series - North America	Denver, Colorado
May 21	LINK Series - North America	Portland, Oregon
November 1 *	LINK Series - North America	Montréal, Québec
November 1 *	LINK Series - North America	Ottawa, Ontario
November 1 *	LINK Series - North America	Calgary, Alberta
November 1 *	LINK Series - North America	Vancouver, BC
November 1 *	LINK Series - North America	Toronto, Ontario

Want more information about Dataquest?

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Here's How to Order Your *Electronic News* Binder

Dataquest provides a separate binder called *Electronic News* to help you organize your printouts of the electronic newsletters and Dataquest Alerts that will be sent to you by your Dataquest North America research programs throughout the year.

Although not all clients will print out electronic news bulletins or file faxes, the *Electronic News* binder is available by request for those who do.

To order your *Electronic News* binder, just fill out the form below and fax it back to us. We will mail your binder to you immediately.

Note: If you subscribe to more than one Dataquest North America research program, then indicate how many binders you need in the space provided below (plan on one binder per research program), and we'll send them to you in one shipment.

Thank you for helping us serve you better.

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**SEMICONDUCTOR DIRECTIONS IN PCs
AND PC MULTIMEDIA WORLDWIDE 1996**

TABLE OF CONTENTS

PERSPECTIVES

MARKET TRENDS

9601	5/27/96	PC Semiconductor Application Markets: Graphics Controllers
9602	6/17/96	PC Semiconductor Application Markets: Core Logic
9603	7/29/96	Trends in the Semiconductor Content of PCs and Workstations
9604	9/2/96	Compute Microprocessor Market Trends and Forecast

GUIDES

9601	12/3/0/96	Microcomponent Market Definitions

REPORTS

9601	5/13/96	3-D Graphics Adds Sizzle and Semiconductor Content to Multimedia PCs (Focus Report)
9602	9/9/96	Audio Chips Let PCs Be Heard and Not Just Seen (Focus Report)

Dataquest ALERT

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Memo to Professor Murakami, re MPU Project

Murakami-san:

I read with interest the notice of the consortium that you have formed to create a new microprocessor to challenge Intel's hold on the microprocessor market. I wish you and your associates at Toshiba, Matsushita, NEC, Hitachi, Sony, Fuji Xerox, TI Japan, and SGS-Thomson much success in your undertaking. I'd like to assist your efforts by suggesting a few metrics you can use to target your program and measure your success.

First and foremost, make sure that whatever you develop can run Windows 95 and Windows NT, along with all the 16-bit and 32-bit applications available on these platforms (including those old DOS and Windows 3.1 programs for which nobody can find the source code anymore). By the way, if your chip can't run *all* these programs, and run them *much* faster than whatever Intel is selling at the time, buyers will not even take a second look. The RISC guys tried the "twice the performance at half the cost" approach, but ignored the x86 compatibility issues, and look where they ended up.

Next, be prepared to match the price per bit that commodity DRAM vendors will be charging when you get to market. Since your design combines CPU and memory on one chip, you will need a more complex manufacturing process than is needed to make either DRAM or logic devices alone, but I'm sure you can find other places to trim costs. Some users may need more memory than others, and the design you are proposing includes a CPU on each memory device. To remain competitive with commodity DRAMs, you might not be able to charge for these additional CPUs. Analysts like me have been talking about the ever-decreasing cost of computing cycles. Your approach could hasten this trend.

Third, be careful that any cost savings you introduce by integrating the memory and processor on one chip do not get eaten up by other logic you need to make the system operational. Take a look at any contemporary Pentium or Pentium Pro motherboard. Aside from the CPU, a few core logic chips, and the memory SIMMs or DIMMs, there isn't a lot on it. And be prepared to design the motherboard for your key OEMs; the last engineer at a PC company who knew how to design a motherboard took early retirement a few years ago.

Finally, take a good look at Intel's financial statements. It's easy to be dazzled by the $20 billion or so in revenue, but look too at the capital investment needed to keep buying new state-of-the-art fabs the way most of us buy bottles of good wine. Given its margins, Intel obviously has a bit of room to adjust its prices in response to any serious threat, but maybe you will catch the company napping. It's not as if it were paranoid or anything like that.

I wish you much luck in your endeavors. I suspect you will need it.

Dataquest ALERT

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Now There Are Two

Not too long ago, analysts everywhere went on record with forecasts that showed how the architecturally neutral Windows NT spelled the end for Intel's domination of mainstream computer markets. NT would usher in a new era in which software developers could support multiple hardware platforms (possessing differing underlying architectures) with almost no incremental effort, and users could source systems with little or no regard for the underlying hardware, as long as it supported Windows NT. Had I been analyzing and forecasting at the time, I would have joined in these forecasts. Last week, IBM quietly announced its intent to drop Windows NT-based PowerPC platforms from its workstation lineup. (The announcement was whispered from rooftops in the dead of night and received little attention.) The current release (version 4.0) of Windows NT on PowerPC will be the final release. The few customers who signed up for this package can file this new information, along with other declarations of architecture neutrality, between "Santa Claus" and "tooth fairy." At this point, Windows NT spans just two architectures—x86 and Alpha. To date, Microsoft has only hinted at ending support for the PowerPC version of NT, unlike IBM, which has bludgeoned it to death.

The promise of Windows NT on PowerPC appealed primarily to those who accepted the "Win" part of "Wintel" but who wanted an alternative to the "tel." Those who do not mind the "tel," but seek "Win" alternatives, still have OS/2, SCO UNIX, Solaris, and NetWare. Of the three AIM (Apple, IBM, and Motorola) partners, only Motorola placed a priority on Windows NT. Apple always cared more for the Mac OS environment, and IBM's interests fell into the AIX and AS/400 camps. Like Shelley's Ozymandias, these vendors focused on preserving, rather than expanding, their spheres of influence, at best a difficult proposition.

The collapse of the Windows NT/PowerPC platform raises interesting questions about the future of the PowerPC Platform (PPCP) formerly known as the Common Hardware Reference Platform (CHRP). PPCP aimed at making all major PowerPC software systems work with all standard PowerPC configurations, in much the same way that all major PC operating environments can be used across all "IBM-compatible" PCs. Because IBM's AIX plays but a small role in all this, the PPCP's real goal was to allow users to buy Macintosh systems today that can be converted (via future software upgrades) to Windows NT systems. This could have provided a "graceful migration path" for users unsure of Apple's long-term product direction. The ability to move to alternate software platforms at a later date has little value if one does not expect alternate software platforms to exist at a later date. Dataquest anticipates that while PPCP momentum has built slowly (no vendor has introduced a PPCP-based system yet), vendors are well past the point of no return, and we expect to see such systems emerge in the latter part of 1997.

The PowerPC camp now must depend entirely on the Macintosh market to fuel its growth. Unfortunately, the Macintosh market is poorly positioned to support any major vendor's growth objectives. Large customers, still nervous from Apple's recent near-death experiences, anxiously await the unveiling of a new strategy that will provide the Macintosh community with a new, contemporary operating system environment in the wake of the Copland collapse. Macintosh clones have finally emerged, but are they too late to spark renewed interest in the platform?

For the swelling ranks of Windows NT users, there now remain but two architectural choices — x86 and Alpha. Digital Equipment Corporation must now demonstrate that it can capitalize on its undisputed No. 2 position in the NT marketplace. If it can keep up with the blistering rate of growth for NT overall, it will strengthen its position. As usual, Digital brings impressive technology to the table but fails to present it in ways understandable to the nondigerati. Compute-intensive programs ported directly to Alpha outrun the x86 versions on the speediest Pentium Pros. So could programs running on 240-MHz 604es, although the advantage was not as great. The principal difference between Digital's approach to the NT market and PowerPC's approach lies in their approaches to the installed base of x86 software that any would-be Intel competitor must address. Fx32! emulation capability (available only recently) lets customers run a mixture of x86 and Alpha-based software simultaneously on the same hardware system, without seriously compromising performance. This frees users from the choice of a very fast machine with limited software versus a slower machine that runs virtually all software titles. The PowerPC camp never addressed the migration issue in as coherent a manner as Digital has. Now the PowerPC camp will not need to solve this problem at all.

By Nathan Brookwood

Ozymandias

I met a traveller from an antique land
Who said: Two vast and trunkless legs of stone
Stand in the desert. Near them, on the sand,
Half sunk, a shattered visage lies, whose frown,
And wrinkled lip, and sneer of cold command,
Tell that its sculptor well those passions read
Which yet survive, stamped on these lifeless things,
The hand that mocked them, and the heart that fed;
And on the pedestal these words appear:
"My name is Ozymandias, king of kings:
Look on my works, ye Mighty, and despair!"
Nothing beside remains. Round the decay
Of that colossal wreck, boundless and bare
The lone and level sands stretch far away.

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Intel Smashes Earnings Expectations and Bashes Proposition 211

If it seems like just yesterday that almost everyone was worried about the health of the PC industry following three flat revenue quarters at Intel (and the prospect for a fourth), it is because it *was* just yesterday. In July, Intel suggested that third quarter revenues would be essentially flat with the $4.62 billion reported for the second quarter. About a month ago, the company officially hinted that things looked a bit rosier and sales might actually increase five percent from the prior quarter. That action kept analysts busy for several days as they revised their sales and earnings projections, and investors bid up the Intel share price.

Yesterday, when the company posted sales of $5.14 billion, up 11 percent on a sequential basis, and 23 percent on a year-to-year basis, the results exceeded most everyone's expectations. These increased revenues were accompanied by a dramatic increase in gross margins to 57.2 percent, up from 53.5 percent in the second quarter. At this level of sales, each incremental point of gross margin adds approximately $50 million to Intel's gross profit for the quarter.

Intel blamed its inability to forecast its revenues more precisely on its customers' newly acquired habit of waiting until the very last minute to place their orders for microprocessors. In the good old days, customers would place orders three or four months in advance of shipment, and this allowed the company to use its backlog as a fairly accurate predictor of quarterly revenue. This year, these same customers have learned to delay placing their purchase orders until just days before they needed the parts. This behavior lets them tune their purchases to near-term market conditions, so they do not end up holding a bag of microprocessors that nobody wants. With the thin gross profit margins system vendors earn today, they cannot afford very many costly mistakes in this regard.

While system vendors may be forced to find new techniques to make large profits on thin margins by turning inventories ever faster, Intel still makes its money the old fashioned way—it sells products for a lot more than it costs to make them. This is especially true now that it has reined in its low-margin motherboard operations. Intel still controls enough of this market to keep other board vendors on their toes, but does not need, nor should it want to dilute its margins any more than necessary in this cause. Consumer preference for higher clock rate processors (with higher gross margins) also helped the quarter's results. Intel charges $100 for a 100-MHz CPU, $200 for a 133-MHz CPU, $400 for a 166-MHz CPU, and $500 for the top-of-the-line 200-MHz variety. All these speed grades have about the same manufacturing cost. The extra dollars customers pay for higher-performance models swell both the top and bottom lines on Intel's financial statements.

It is hard to take issue with financial results like these, but Intel's report raises two forward-looking concerns regarding future market conditions. Dataquest's biggest worry is that Intel's strong performance might reflect vendor purchases in excess of actual end-user demand for the coming quarter. Two major players, Sony and Toshiba, have entered the home market in a major way, and nobody knows how successful they will be in the near term. The sum of all the market shares projected in all the business plans of all the major vendors quite likely exceeds 100 percent. If it exceeds this figure by too much, we will face the same kind of inventory glut and correction in 1997 that we had to deal with at the start of this year. Our second concern involves Intel's statement that "flash memory, embedded processors, and microcontrollers were slightly down in unit volumes ... and strong downward pricing pressure continued throughout the quarter." This statement, although consistent with Dataquest's view of the market, demonstrates that even Intel finds the competition tough, once it strays beyond the boundaries of its well-protected x86 turf.

Of course, in the topsy-turvy, litigious world of late twentieth-century American jurisprudence, Intel appears concerned that some California shareholder, led by greedy securities lawyers, might sue the company for understating last month's projections for this quarter's results. Recent federal legislation makes such suits much more difficult, but the Proposition 211 initiative on next month's California ballot, should it pass, would make them easier, at least in California. The prospect that voters might approve this initiative (as polls suggest they might) caused Intel to shut up like a clam and refrain from issuing any "forward-looking statements."

By Nathan Brookwood

This Alert was published by Dataquest's Semiconductor Directions in PCs and PC Multimedia Worldwide service. We are sending it to you because we thought the subject matter would be of interest to other semiconductor clients.

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S3 Enters the PC Audio Market

S3 Inc. officially entered the PC audio market today. In a press release today, the company formally announced the SonicVibes chip, which is a complete audio subsystem on a single chip. This announcement is a major step for S3 because it follows through on the company's stated goals of expanding beyond its core competencies of graphics and video processing.

The new product has an impressive list of features, including wave table synthesis, FM synthesis, SRS stereo enhancement, a speed-compensating joystick interface, and a PCI bus interface. Yes ... that is correct ... a PCI bus interface. The SonicVibes chip may also be implemented on the ISA bus but then requires an external memory device for wave table synthesis. The new chip takes advantage of the higher bandwidth over PCI to use the PC's main memory for the wave table samples. S3 has reduced the total subsystem cost by eliminating the external ROM (typically 512KB or 1MB) that many other solutions require. A typical implementation requires only the SonicVibes chip. This reduces cost as well as board space for a wave table solution.

SonicVibes is sampling now and is scheduled for volume production in the first quarter of 1997. List price for quantities of 10,000 is $30 per chip in a PQFP-160 package.

Dataquest Perspective

This is a bold step for S3. The company's rapid growth has been fueled by its graphics and video accelerator business as S3 has grown to be the largest supplier of PC graphics accelerators. S3's success in the graphics arena has been a trend of capturing a growing share of a growing market. Now that S3 has such a large share of that business, additional market share is more difficult to get. S3 needs to address new product segments within the PC semiconductor market to continue its trend of growing so much faster than the overall market. S3 has been working on expanding its available market, and SonicVibes is part of that effort.

The SonicVibes product is a step ahead of the mainstream PC audio chips today. This is necessary for S3 to break into this market because a "me too" solution would not compel very many OEMs to switch from the established audio chip suppliers. S3 is early to the market for PCI-based audio chips. The SonicVibes chip is compatible with the ISA bus, but is much more compelling with the PCI bus because of memory issues. This makes the risk of switching to an unproven audio chip vendor more palatable for an OEM because there are rewards (lower cost given the feature set) associated with that risk. One open issue is Sound Blaster compatibility. S3 has arranged for compatibility testing by a third party and has already received results from testing using an ISA-based implementation. Those results show solid compatibility with the Sound Blaster standard, but Dataquest is very interested in the results from the PCI-based implementation. The distinction is important because of the challenges associated with Sound Blaster compatibility over the PCI bus.

S3's foray into the PC audio market should be very exciting to watch. The company has executed very well in the graphics market, bringing compelling products to market on time and at an attractive price. S3 also has strong relationships with key OEMs at the PC and the add-in board level. These strengths will help to open doors for SonicVibes, but the company must build credibility in the audio market as well. It appears that S3 has hired the talent and experience to enter the audio market with a bang, so a measure of credibility has been established through the reputations and relationships of those employees. The task of winning new designs is next on the list.

By Geoff Ballew

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Intel Adjusts P55C, Klamath Schedules: "All the Nonnews That's Fit to Print"

Last week, several publications broke the story that Intel had moved the introduction date for its best-known unannounced product, the P55C, out one quarter, to January 1997. Intel blamed the delay on its inability to ramp P55C production fast enough to meet an anticipated increase in market demand on the original schedule. The fact that Intel had pulled the introduction date of its second-best-known unannounced product, Klamath (the redesigned Pentium Pro), into the first quarter of 1997 (from the second quarter) received far less attention but is far more significant.

The media coverage this minor event received boggles the mind. Dataquest hates to think what would have happened had Bob Dole named Andy Grove as his running mate, given the manner in which the press pursued this story. Intel last used the "we can't make enough of them, so we are delaying the introduction" story when it rescheduled the original Pentium launch (from September 1992 to March 1993), and nobody believed it then, either.

This delay in the P55C launch a good thing, regardless of the reasons behind it. Dataquest has heard a variety of conspiracy theories, along with doubts about the whole MMX program. Quite frankly, we don't care. MMX availability in 1996 could only have added sizzle but little steak to the Pentium story. Most applications will use MMX indirectly, via support that Microsoft plans to incorporate in its DirectX libraries. DirectX is gaining momentum, but the final version of Direct3D is only now hitting software developers' labs and will have at best a minor effect on programs to be released this calendar year. Independent of the MMX and production issues (if any), the P55C introduction in the fourth quarter posed many potential problems. System vendors do not want to worry about introducing new models during their busiest selling season. End users, confused over the positioning and relative merits of the 200-MHz Pentium, the 200-MHz Pentium Pro, and the 200-MHz P55C, might have decided to postpone their purchases until things settled down, much as they did the last time they got confused in 1994. Nobody wants a repeat of that awful market stall.

The Klamath pull-in is far more significant than the P55C push-out. Like the P55C, Klamath adds MMX capability, along with higher speeds and a new packaging scheme (no more L2 cache inside the package). The Klamath launch had moved into the second quarter to accommodate a new generation of core logic that supports AGP, the new, fast Accelerated Graphics Port that Intel launched at last spring's WinHec conference. Now, Intel apparently has opted to launch Klamath using an old, non-AGP chipset instead. (By then, the 440FX chipset introduced this June will be nine months old. Ordinarily, it would be destined for the old chips' home at that point, but now it will get a second chance in the market.)

The Klamath launch will mark the beginning of Intel's campaign to shift the market from Pentium to Pentium Pro. Pentium and Pentium Pro competitors like the Cyrix 6x86 and M2 and the AMD K6 need to be in the market close on the heels of the Klamath product, or they will lose even more ground. AMD and Cyrix liked the idea of a second quarter Klamath introduction, which gave them a little bit of time to fix whatever problems may show up in their own next-generation designs, but Intel just pulled that slack out of their schedules. There is no rest for the weary.

by Nathan Brookwood

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Macworld Ushers in New Power Macs; Is PowerPC Catching Up?

This week's Macworld show in Boston differs from all that preceded it. Although Apple Computer introduced new versions of the 604-based Power Macintosh and the 603-based Performa, the big news came from the newly emerging Macintosh clone camp. For the first time, the fastest machine on the floor comes not from Apple but from Power Computing. And the least-expensive machine to be announced comes not from Apple but from UMAX Computer Corporation. These new alternatives provide real-world demonstrations of the advantages and disadvantages that result from the opening of the Mac architecture. Some users, who might otherwise have defected to the Wintel camp for reasons of price, performance, or availability, now have alternatives to keep them in the Macintosh family, even if the hardware they purchase doesn't come from Apple. This is a real plus for Apple; those who defect to Wintel are lost forever, but those who stray into PowerPC platforms from other vendors may eventually return. Of course, some users who might otherwise purchase Apple's systems may opt instead for those of a cloner. Welcome to the competitive world, Gil.

Apple Uses the Processor as a Way to Differentiate Product Lines

Apple introduced updates to its two Macintosh product lines: the Power Macintosh, sold primarily to businesses, and the Macintosh Performa, sold mostly into the home. Aside from the entry-level 7200/120, which uses a 120-MHz PowerPC 601 processor, the Power Macintosh line was upgraded to 150-MHz, 180-MHz, and 200-MHz PowerPC 604e processors. Prices start at $2,299 and go up to $4,899 for the 9500/200. For the first time, Apple also added multiprocessor-capable Macs on the high-end 8500 and 9500 Power Macintosh lines. Based on the posted prices, Apple appears more interested in boosting profitability than market share with these offerings.

The new Performa 6400 line uses the PowerPC 603e processor, an enhanced version of the earlier 603 model, and drives it at speeds of 180 MHz and 200 MHz. Several nonprocessor enhancements have been made to the line, including faster CD-ROMs, larger drives, PC-compatible cards, and some very interesting multimedia capabilities, such as Avid Cinema, a digital video editing system, and 3-D sound that uses the computer case as a subwoofer.

Power Computing Forges Ahead of Apple

In late July, Power Computing announced a new Macintosh with a 225-MHz PowerPC 604e. The system is based on Apple's Power Mac 9500 six-slot PCI design. By introducing the 225-MHz configuration before Apple, Power Computing gains a performance advantage. Apple has hesitated to introduce its 225-MHz system, because it cannot get enough of the very fastest chips it needs to feed its huge worldwide distribution channels. Power needs far fewer chips and systems to kick off its launch and is able to meet its needs using PowerPC chips manufactured by IBM, which announced its 225-MHz version of the chip last week. (Motorola's fastest chips top out at 200 MHz.) End users, Power Computing, and Apple all come out of this as winners. End users get a taste of the high-performance systems they need, but which Apple cannot deliver in volume. Power Computing gets to claim it brings both price and performance advantages to the party. And Apple gets to hang onto Macintosh users who otherwise might now be test-driving Windows NT/Pentium Pro systems.

In all, Power Computing announced three members of its PowerTower Pro line. They use 180-MHz, 200-MHz, and 225-MHz PowerPC 604e processors and start at $4,200, $4,500 and $5,000, respectively.

UMAX Stakes Out the Low End

UMAX announced the Typhoon SuperMac line, which uses 140-MHz and 200-MHz 603e chips priced at $1,500 and $2,500, respectively. A 160-MHz or 180-MHz processor may be added shortly to fill the $2,000 price point. These products are significantly lower in price than Apple's and should allow the company to grow its new Macintosh revenue quickly, once again demonstrating the advantages (to Apple) of the cloning strategy Apple is finally executing. Mac users looking for low-cost solutions will no longer be forced into the Wintel "white box" camp. UMAX also updated its high-end line, the SuperMac line, by announcing the S900/200, which uses a 200-MHz 604e processor.

Power Mac versus Wintel: Who's Faster Now?

Performance comparisons between high-end Macintosh and Wintel systems have become so complicated that both sides can now claim victory. There exists no accepted set of benchmarks that runs in both environments and produces unambiguous results. UNIX is the only software environment that encompasses both architectures, but UNIX accounts for a very small part of actual x86 and PowerPC usage. The UNIX-based SPEC95 benchmarks give the PowerPC at 225 MHz a slight performance edge over the 200-MHz Pentium Pro: 8.3 to 9.0 versus 8.1 in integer (general-purpose) calculations and 6.5 to 7.5 versus 6.8 for floating-point calculations. After adjusting these results for the relative efficiencies and inefficiencies of the UNIX, Macintosh, Windows, and Windows NT environments, everyone emerges a winner. This stalemate in high-end performance actually works to Apple's detriment. Existing Wintel customers have little price or performance motivation to migrate to Macintosh, while some Macintosh customers will surely be tempted to cross over for reasons of price and software availability. In a war of attrition, the side with the biggest starting position wins.

Power Mac versus Wintel: Who's Faster Later?

The performance battle must be fought not only today but also tomorrow. End users require periodic assurance that their strategic computing platforms will not run out of steam in the foreseeable future. Road maps are the weapons of choice in the battle for future performance advantage. Until recently, Intel's road maps, covering a wide range of rivers in the Western United States, provided a far more exciting future than the maps drawn up by the PowerPC partners. This week, IBM and Motorola gave their first indications of two new Somerset-based PowerPC design efforts, cleverly labeled "G3" and "G4." (Hey, don't they have rivers in Texas?) These new products still are far off (1997 for G3 and 1999 for G4), but they represent the first major additions to the PowerPC family since the kick-off of the architecture in 1992. If both the Intel and PowerPC camps achieve their goals, the performance battle will continue to be too close to call.

PowerPC Chips from IBM and Motorola: Who's Cheaper Now?

One of the major arguments for a multivendor partnership model like the PowerPC consortium is that competition between individual members will drive prices to the optimum economic point. Until now, there has been little overlap between the IBM and Motorola versions of the chips, and both vendors had trouble meeting demand as the Macintosh base converted from the 68000 to PowerPC. This year, supply and demand are better matched, and we are beginning to see signs of the promised price competition. The official prices announced by IBM and Motorola (for essentially the same components) differ dramatically (see Table 1).

Table 1

PowerPC Prices

Model/Speed	IBM Price ($)	Motorola Price ($)
604e/166 MHz	375	243
604e/180 MHz	424	365
604e/200 MHz	523	520
604e/225 MHz	594	NA

NA = Not applicable
Source: Dataquest (August 1996)

From a market dynamics viewpoint, there are relatively few customers to whom IBM or Motorola can sell PowerPCs in interesting quantities, and this gives the buyers of these chips a negotiating advantage about which Intel's customers can only dream. (Intel rarely needs to cut prices for competitive reasons, although it has chosen of late to lower prices aggressively in order to maintain a high rate of growth for unit shipments to fuel its own growth.)

Dataquest Perspective

Apple's efforts to spawn clone vendors are finally bearing fruit. In the first quarter of 1996, Power Computing accounted for just over 5 percent of Macintosh unit sales worldwide. However, the major long-term problem that confronts Apple is how to keep the entry-level buyer from bypassing the Macintosh and going directly to Wintel. After all, this is why the cloning effort was implemented in the first place. Many buyers have moved from the Macintosh to Wintel for a variety of reasons (for example, lack of high-integrity, high-security system software, trailing performance, poor offerings in portables), but we see little movement from Wintel to the Macintosh.

The cloners have, in general, attacked the low end of the market, but they are more focused on the high end where margins are better. They tend to compete with Apple based on better price and performance, not just better price. Power Computing's announcement of the 225-MHz 604e-based Mac demonstrates that they are now attacking with higher-performance products than Apple can bring to market.

The Macintosh market still lacks systems priced below the name-brand vendors. White box Wintel PC vendors offer PCs at far lower prices than are available from name-brand makers. These are products offered from mail order businesses or storefronts without a recognized name or that are built from parts by customers. They account for over one-third of the PC market. There is no equivalent in the Macintosh world. IBM's chip division (IBM Microelectronics) is trying to jump-start such a market, and if Apple can deliver a shrink-wrap version of the Mac OS that runs on PowerPC platform-compliant systems, then we may see white box Macs next year. Apple needs this to happen so that cost-conscious customers can enter the Macintosh market and so that maybe eventually that customer will upgrade to
one of its Macs.

by Nathan Brookwood and Kimball Brown

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The Intel Internet Media Symposium Tells Us Why Everyone Needs a Fast Pentium PC to Surf the Web

What do you get when you cross big, multimedia data files with analog modems operating at speeds measured in kilobits per second?

Anyone who answered "a big mess" probably did not attend the Intel Internet Media Symposium on July 24. This one-day event was sponsored by Intel to demonstrate some new Internet applications and the underlying technologies necessary for those applications. Intel also used this event to reiterate the need for fast PCs (and therefore Intel microprocessors) in every consumer's home. Those who've been thinking about using a Network Computer (NC) rather than a PC for surfing the World Wide Web may find that it's time to think again.

A new breed of Internet applications is forming, and fast, multimedia PCs will be more important than ever before. Intel calls these new applications hybrid applications because they combine the local resources of a multimedia PC with the benefits of connectivity over the Internet. Hybrid applications promise to maintain an acceptable level of online performance as multimedia content grows on the Web. This acceptable level of performance is necessary despite the trend that users' demand for bandwidth will increase faster than their actual bandwidth.

Intel and a host of other companies, such as Microsoft, Macromedia, 3DO, CNET, Adobe Systems, and NBC, demonstrated new technologies that are enabling these applications as well as the applications themselves.

In each case, the local resources of the PC are used to maximize the PC user's online experience by making the most of the available bandwidth to the Internet. This is achieved through several techniques, including delivering bulk content on static media such as CD-ROM discs and supplementing it with online content, downloading information and caching it on the hard disk before the user requests it, and segmenting information so the user receives the requested information quickly, without having to wait for related (but unrequested) information to be downloaded. Examples of hybrid applications are online gaming, TV programming with Intercast data delivery, and information services that deliver content during off hours rather than on demand.

One example is Meridian 59, an online role-playing game from 3DO. This game uses a CD-ROM disc to deliver bulk information such as the castle layout, 3-D models, and documentation. During game play, only information like the positions and actions of characters as they move around in the 3-D scene needs to be exchanged over the Internet. The user needs a full-featured PC to play this game because a CD-ROM drive, space on a hard disk, and 3-D graphics features (either dedicated graphics hardware or a fast MPU) are all necessary for smooth game play.

NBC demonstrated its Intercast capability with a short segment of the broadcaster's 1996 Olympics programming. Intercast uses the available bandwidth between the lines in analog television broadcast signals to transmit data. The result is a display that includes the TV picture in the corner of the PC display, with additional information formatted much like a Web page. This allows the viewer to watch TV while getting related information on the same screen. The Olympics example included biographical information about athletes and other information, such as the judges' scores before the TV camera panned to show them. A PC used for receiving Intercast programming must be able to parse the television signal from the data stream and display both on a real-time basis.

A third example of a hybrid application is downloading information before the user requests it and caching it on the hard disk. CNET offers this service in conjunction with its television programming. The service allows large data files to be transferred and stored, so users gain immediate access to the multimedia files once they start browsing CNET's Web page for the day. This of course requires megabytes of available hard disk space and merely serves to minimize the user's perception of waiting time rather than the actual time required for downloading.

Another application demonstrated was Intel's Internet Phone. This is not a hybrid application, but it does warrant discussion. Intel must be applauded for the very reasonable positioning of this product during the symposium. The Internet phone was portrayed not as a replacement for the phone company but as an integrated enhancement to the online experience. The example was shopping online. A Web surfer was perusing the site of a videocassette store and wanted to make a purchase but had a few questions. Instead of walking over to the phone and calling the store, the user clicked a button and was connected with a salesperson. The salesperson answered a few questions and completed the order. In this case, the phone call was not the central activity, as it would have been if the user had been telephoning a friend. Voice quality was fine for a quick business transaction, and the seamless integration of the call with the Web site made this demonstration impressive.

Each of these examples is important because the actual bandwidth is less of an issue than the user's perception of performance. Typical users do not care about the bandwidth of their Internet connection as long as they do not spend a lot of time waiting for a Web page to come up or for a requested file to download. This does not mean that higher bandwidth is not necessary, it simply means that a user's perception of performance is based on waiting time as well as data rate. Leveraging the dedicated resources of a PC to store, cache, and accelerate multimedia content over the Web gives the user the impression of higher performance.

Dataquest Perspective

Hybrid applications are good news for semiconductor manufacturers and PC OEMs. With all the talk about the NC and lower-cost PCs, these applications are real examples of why consumers can justify purchasing more powerful PCs than they have today and why the $2,000 PC will remain compelling compared with lower-cost variations. Performance standards for multimedia applications have been established in consumers' minds by the applications they run from their CD-ROM drives. They will apply these standards to Web-based multimedia in the same way that consumers compare digital video on PCs to analog television.

Higher-speed communications and powerful PCs are both necessary to meet these expectations, but only one of the two, powerful PCs, is widely available today. Dedicated resources in PCs will be the difference between compelling multimedia over the Web and the wake-me-up-when-it-finishes-downloading multimedia that many consumers will not tolerate. Local storage will be a requirement, and fast microprocessors (or other multimedia semiconductors) will be necessary to decompress audio and video data. High-bandwidth communications could reduce these requirements but cannot replace them in the near term. As the World Wide Web continues to drive sales of consumer PCs, consumers who want to access the latest sites will continue to buy feature-rich PCs. Even as consumer bandwidth increases with technologies such as cable modems and digital subscriber loop (DSL), there is plenty of headroom to continue leveraging the PC's dedicated resources to deliver a better user experience than a terminal or a NC will be able to match.
By Geoff Ballew

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Samsung Licenses Digital's Alpha Technology: Third Time's a Charm?

Earlier this week, Digital Equipment Corporation and Samsung Electronics Co. Ltd. announced that Samsung has licensed Digital's Alpha microprocessor technology and has worldwide rights to market, sell, and distribute Alpha microprocessors. The companies suggested that Samsung will produce its first Alpha chips in 1997.

Samsung has already entered into a licensing agreement with Advanced RISC Machines for its ARM microprocessor and last month announced that it intends to license Sun Microsystems' PicoJava processor as well. The ARM and PicoJava efforts both focus on the embedded microprocessor (MPU) applications market, one where Samsung's size and capacity greatly increase the likelihood of success. These factors play a much smaller role in determining the likely success of processors aimed at the computational market.

This agreement represents Samsung's third attempt to enter the computational microprocessor market via licensing arrangements. Its earlier attempts, with Intergraph's CLIPPER in 1989 and Hewlett-Packard's PA-RISC in 1992, both ended in failure. In this Alert, Dataquest reviews what Digital and Samsung have to gain from this alliance, and what they are doing to avoid a repeat of the earlier missteps.

In its prior efforts with Intergraph and Hewlett-Packard, Samsung licensed "also-ran" architectures that had failed to gain acceptance beyond a narrow user community and that therefore attracted relatively small bases of applications software. The availability of applications software has proven to be *the* barrier to mass-market acceptance for all architectures except x86, 68000, and PowerPC. The CLIPPER and PA-RISC products depended on UNIX-based software environments; in 25 years of trying, UNIX has never been able to capture more than a small fraction of the overall computer market. The earlier ill-fated ventures also gave Samsung valuable lessons in the difference between selling "commodity" semiconductors like DRAMs and proprietary chips like microprocessors; the latter require a far more sophisticated sales and support structure.

This time around, Samsung is licensing the second most popular architecture in the small but rapidly growing Windows NT market that already exceeds the UNIX market as measured by unit shipments. Further, Digital (alone among non-x86 MPU vendors) has recognized the need to run the installed base of x86 software and provides a new translation facility (FX!32) that lets customers run all x86/Windows NT applications at acceptable levels of performance. FX!32 will be distributed as a standard part of this summer's Windows NT 4.0 release but runs only on Alpha-based systems. The net of all this is that this time Samsung needs to focus on delivering a competitive chip but should not have to put too much effort into creating demand for the environment surrounding that chip. Instead, it can leave the demand creation to Bill Gates, who has demonstrated some ability in this regard in prior ventures. This is a *big* advantage.

Samsung indicates that its initial efforts will focus on high-end Windows NT/Alpha products. Digital's sales of Alpha-based servers have been aided immeasurably by the high performance levels 64-bit database applications achieve when executing on multigigabyte configurations. Given the 32MB memory granularity possible with current 64Mb DRAM technology, such servers must look very tempting to a company like Samsung. The company also indicates that it sees a market for Alpha chips in its consumer and communications product lines. This seems like more of a stretch—cell phones need to transmit at 800 MHz, but it is hard to imagine why they need to compute at 400 MHz.

This agreement also gives Samsung access to Digital's semiconductor manufacturing technology. Although it is certainly no slouch in this area (Samsung is shipping production versions of its 64Mb DRAM and sampling versions of a 256Mb device), DRAM manufacturing processes differ from those used for logic devices in many key regards. DRAMs require only two interconnect layers, while advanced MPUs need four or five; adding these extra layers has proven difficult for many producers, and the technology to do this cannot be purchased off the shelf. Digital developed a respectable salicide process, along with the chemical mechanical polishing (CMP) skills needed to implement three-layer and four-layer metal interconnect schemes. Samsung can use Digital's experience in this area to jump-start its own programs.

Digital certainly gains as well from this alliance. Although its Alpha architecture usually holds one of the top two positions with regard to computational performance, it lags with regard to market share and lags even more with regard to strategic partnerships. Few vendors can succeed on their own in today's rapidly evolving markets and technology. Until now, Digital has had to provide virtually all the muscle with regard to Alpha's architecture, production, and systems marketing. Once Samsung gets up to speed, we would expect it to share many of these burdens with Digital. Looking even further down the road, one can foresee a manufacturing partnership that allows Samsung and Digital to share the huge costs of moving to 0.28-micron process technology.

By Nathan Brookwood

Dataquest ALERT

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If It's the First Day of the Second Month of the Quarter, It Must Be Time for Intel to Lower Processor Prices

Intel has established a practice of reducing its microprocessor prices once each quarter, usually on the first day of the second month. Today's the day. It is no longer a question of if or when, but of how much. Table 1 shows the latest prices for quantities of 1,000.

Table 1
Intel Microprocessor Prices (U.S. Dollars)

Processor	Clock Speed (MHz)	May 1, 1996, Price
Pentium Pro	200	707
Pentium Pro	180	632
Pentium Pro	150	534
Pentium	166	498
Pentium	150	364
Pentium	133	257
Pentium	90/100	134
Pentium	75	106

Source: Dataquest (May 1996)

It is easy to lose sight of what is happening here. In May 1994, Intel had just begun shipping the 90-MHz Pentium, its fastest ever, at a price of $750. In just two years, that model has gone from being too expensive to think about to being the lowest-performing chip worth thinking about. One year ago, Intel's fastest chip was a 133-MHz Pentium that sold for $750. It has come down 66 percent in the past year. Today, a 200-MHz Pentium Pro, with about twice the performance of the 133-MHz Pentium (at least on 32-bit applications under Windows NT), occupies the $700 price point, and an entry-level Pentium Pro sells for little more than a midrange Pentium did a year ago. Combined with the well-publicized decrease in DRAM pricing over the past two quarters, this means that Windows NT/Pentium Pro systems are definitely entering the affordability zone ($2,500 to $3,000), at least within corporate America. We expect to see Intel place great emphasis on this combination throughout the remainder of the year. This can only increase the already torrid pace at which corporate accounts, having tried Windows 95, plan their migration to Windows NT. If Microsoft meets the August release date for NT version 4.0, IS departments will be very busy during the second half of the year.

Intel has been aggressively lowering prices to keep demand high. Based on recent reports from Compaq and Gateway, the strategy seems to be working. Intel needs to keep demand high if it is to recoup the massive capital investment it has made over the past three years in anticipation of continued high demand. These latest pricing actions appear completely unrelated to the recent commencement of shipments of Pentium-class products by Cyrix and Advanced Micro Devices. These two vendors can ship a combined total of 10 million chips this year, less than 20 percent of the 50 million units Dataquest anticipates that Intel will ship in 1996.

Intel's recent pricing actions bring prices to a far lower level than the company itself projected just six months ago; in some cases, up to 30 percent lower than projections. This in turn suggests that Intel has either decided to accept lower gross margins to spur demand or is experiencing better than anticipated yields on its new 0.35-micron lines. Given the company's recent guidance to Wall Street that margins will rise in the second quarter, we suspect that the latter is the more likely explanation.

Price reductions like this usually raise concerns within the financial community that customers will purchase less expensive systems and thus destroy Intel's margins. There is now lots of data that suggests that this view is incorrect. Corporate accounts tend to buy to a price point, rather than a fixed amount of capacity. They buy "all the computer they can get for $2,500" rather than buying a model as powerful as last year's $2,500 system for only $2,000 this year. They have learned that the initial hardware purchase is one of the smallest costs of owning a computer, so it rarely pays to be penny-wise and pound-foolish. Even the man on the street has figured this out; last Christmas, purchasers opted for systems with faster CPUs rather than bigger memories. It's relatively expensive to upgrade a 75-MHz CPU to a 133-MHz model after the fact, but it's easy and not too expensive to buy another 8MB or 16MB of memory, should you later discover you need it. Since most of Intel's cost structure is tied up in fixed investment in development and manufacturing, it hardly matters what chips customers buy as long as they buy chips. We would expect that this extraordinary level of performance will keep them buying. It should be noted that this is the third year in a row that Intel plans to play "double the performance at the price point across the product line." No wonder Intel's competitors are getting tired.

Of course, everybody knows that eventually systems will become "fast enough for all practical purposes." Everybody wants an early warning signal, since at that point, users will no longer be motivated to buy new systems, and the entire pyramid scheme based on ever-increasing performance will come to a crashing halt. We would argue that, to the contrary, as long as process and processor designers can figure out ways to make systems go faster, software designers will be able to come up with new approaches and applications that make them go slower. It is this "virtuous circle" of more hardware performance enabling more ambitious software applications at affordable prices that has driven the computer industry for the past twenty years, and there is little reason to expect a change in the foreseeable future. Unlike fixed-function machines (cars, airplanes, factories, stereos, and millions of others), the personal computer's complexion and utility evolves and absorbs all the processing power we can throw at it. In the course of history, humans have invented only one other commodity with insatiable demand—money. If you need an early warning sign regarding the impending satiation of demand for computational power, here it is: watch for Bill Gates and Warren Buffett both to declare they have enough money and they plan to take it easy for a while. When this occurs, all bets are off.
By Nathan Brookwood

Dataquest ***ALERT***

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If It Seems Like Things Are Moving at an Ever-Faster Pace, It's Only Because They Are.

A week ago, Cyrix introduced its 6x86 P200+ and seized control of the high ground for fifth-generation x86 microprocessors. This marked the first time that any of Intel's competitors actually had a product that outperformed Intel's. Cyrix's advantage was short-lived. Today Intel launches its 200-MHz Pentium processor, and the two vendors are in a virtual tie for mainstream desktop performance. This still represents an unusual state of affairs; Intel's x86 competitors typically have run far behind Intel and often have struggled just to stay in the race. Dataquest anticipates the rapid availability of systems containing these devices.

Motorola announced that it has begun deliveries of the 200-MHz PowerPC 603e that it announced a few weeks ago. Apple indicates that it will incorporate this device into its Power Macintosh systems before the end of the year.

It is no illusion that the rate at which performance is improving is itself accelerating. The first microprocessor, Intel's 4004, ran at 0.11 MHz when it appeared in 1971. Microprocessors did not reach 10 MHz until the middle of the 286 era in 1985. Speeds for 486DX2 and Pentium processors got to 100 MHz just two years ago, in mid-1994. This month, Cyrix, Intel, and Motorola all begin shipping 200-MHz parts. Last year's high-end personal computer contained a 133-MHz Pentium; by the end of this year, that system is likely to be the entry-level configuration. This is pretty awesome stuff and shows no sign of slowing down. Table 1 and Figure 1 summarize this incredible journey to 200 MHz.

The Cyrix 6x86 P200+ actually runs at an internal speed of 150 MHz, but outperforms Intel's 200-MHz part (91.6 on Winstone 96, versus 89.0 for the Pentium.) To accommodate this CPU, Cyrix needed core logic and motherboards capable of operation at 75 MHz; most boards designed for Pentium processors cannot run faster than 66 MHz. Cyrix persuaded several chipset vendors, including VLSI Technology, VIA Technologies, and Silicon Integrated Systems to create 75-MHz versions of their core logic. Thus far, only VLSI has introduced such a product, based on its Lynx chipset. The faster bus speed of this design gives Cyrix's systems a slight (1 percent to 2 percent) performance edge.

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Source: Dataquest (June 1996)

Figure 1
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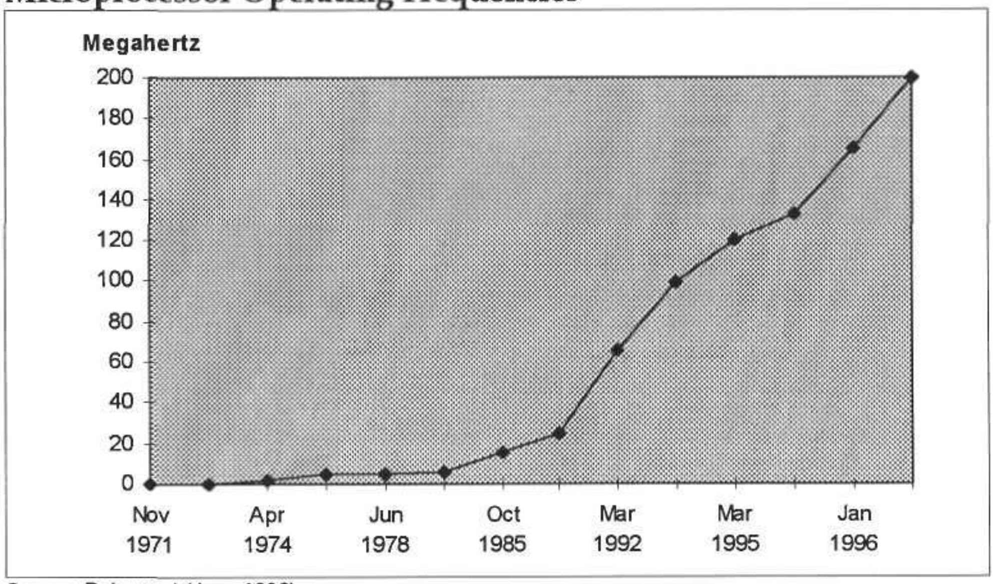

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The 200-MHz Pentium runs at an internal speed of 200 MHz and uses a 66-MHz external bus. The 3x multiplier between the core and external bus makes this version slightly less efficient in converting its clock frequency into delivered performance. At 5.47 on the SPECint95 scale (a measure of general performance), this processor delivers 0.027 SPECint95 per MHz, the lowest of any Pentium to date and far below the 0.033 figure for the 100-MHz model. This comes as no surprise; as the ratio between internal and external speed increases, overall efficiency drops. The larger caches planned for future Pentium and 6x86 processors should offset some of this loss in efficiency. Table 2 and Figure 2 show operating efficiencies.

Table 2
Operating Efficiency (SPECint95/ Megahertz)

	Clock Spee	SPECint9	SPECint95/MH
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P-90	9	2.7	0.03
P-100	10	3.3	0.03
P-120	12	3.7	0.03
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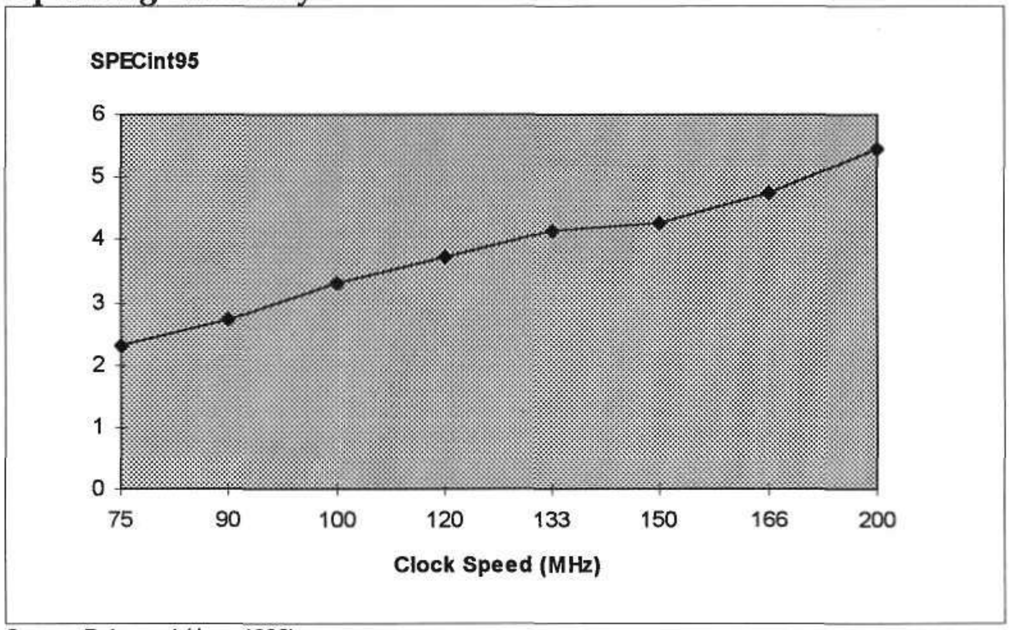

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The 200-MHz Pentium is also notable for its new plastic pin-grid array (PPGA) package. Until now, Pentiums have always used ceramic PGA packages (or the more exotic thermal conductivity package, or TCP, for mobile applications). The new plastic package uses a copper/nickel metallic slug to draw heat out of the die and is more efficient at removing heat from this chip than the earlier ceramic package. Dataquest anticipates that Intel will move the rest of the Pentium line to a similar package over the next 18 months.

The 200-MHz PowerPC 603e from Motorola measures 5.1 on the SPECint95 scale, which puts it about halfway between the 166-MHz and 200-MHz versions of the Pentium; this is about where Dataquest expected it to fall. Of course, these SPECint95 measurements are performed in special environments, and these speeds are unlikely to be achieved in practice on either the Intel or Motorola devices. (Cyrix argues that SPECint is so misleading it doesn't even bother to post these results.)

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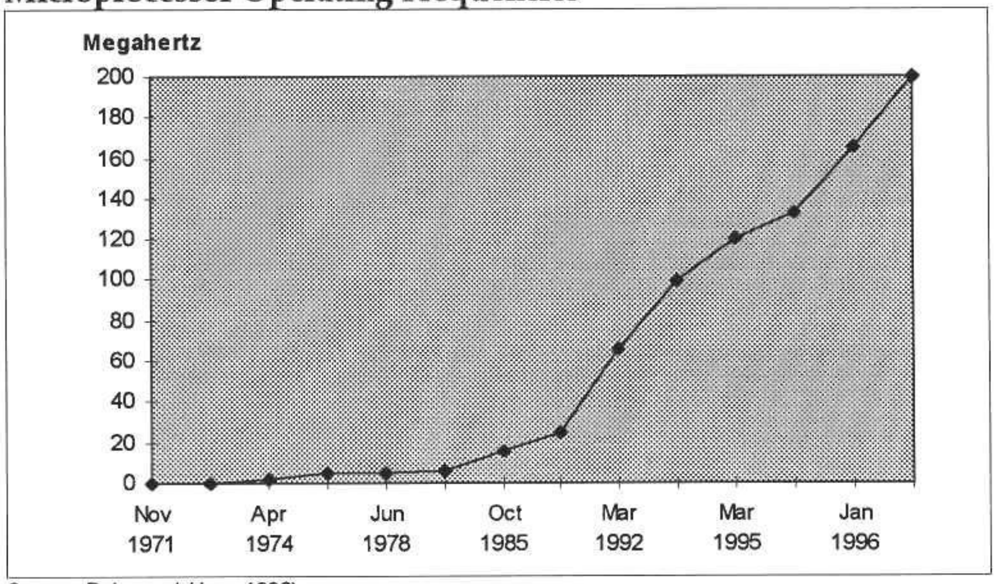

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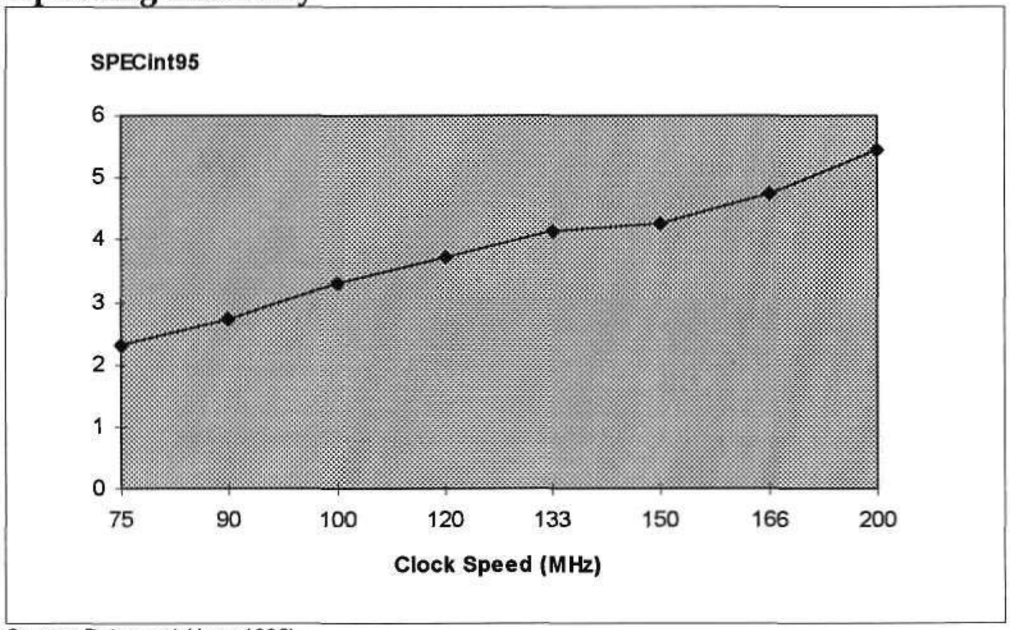

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Intel's First Quarter Results: Is the Glass Half Full or Half Empty?

Yesterday, Intel reported first quarter sales and earnings in line with what the company had said it expected back in January (up a little from the fourth quarter of 1995) and in line with Wall Street expectations; the results beat the consensus estimate by a few cents, just as they had missed by a few cents in December. This event provides a few more tea leaves for professional tea leaf readers to examine. The key question to be answered: Is the spate of earnings disappointments we have witnessed over the past few months a sign of weakening PC demand or just the result of a variety of company-specific issues?

We view Intel's results as a positive indicator for the industry's performance during the remainder of the year. Revenue and profits increased on a quarter-to-quarter basis as well as on a year-to-year basis; a relatively rare event as first quarters go. There were no announcements of massive layoffs, restructuring, or curtailments of capital investment programs. Cash is up, even after the company spent $234 million buying back its own stock. Inventories and accounts receivable are down, in spite of the larger revenue base. Andy Grove even got to take a long-deferred sabbatical. Intel's competitors must wish he would take vacations more often.

A few tea leaves stand out in this report. The company indicated that its transition from 0.6-micron to 0.35-micron manufacturing technology was going better than expected. This reduces the size of its high-volume Pentium processor by 40 percent, from 150 square millimeters to 90 square millimeters, and dramatically increases the number of useful parts that result from each 8-inch wafer that goes through the line. These new parts run faster, so they command a higher price in the market. Given the company's desire to spur market demand, Intel has shown a willingness of late to share the results of its technical virtuosity and capital investment program with its customers. Consequently, the 133-MHz Pentium it introduced less than a year ago at a price of $750 will sell for less than $200 by the end of this year. Do not shed too many tears over these eroding Pentium prices; Intel seems always ready to introduce a new $750 processor for those users who need more power than today's fastest machines can deliver. Just when you think your system is finally fast enough, some software developer figures out how to do something new and exciting with all this horsepower, and the cycle begins anew. This game can continue as long as Intel (or other x86 vendors) can find techniques to make systems go faster and greedy software types can find new applications that make them go slower.

Another positive tea leaf comes in the form of Intel's guidance that it expects its gross margin to rise above 50 percent in the current quarter. It attributes this increase to a shift in its revenue mix away from low-margin motherboards, especially those populated with DRAM. We never understood why Intel wanted to dilute its high-margin semiconductor sales with these low-margin commodity sales, and we are glad to see that it seems to be kicking this habit.

Dataquest sees only one potential problem on Intel's near-term horizon. The company reported that its book-to-bill ratio fell below 1.0 in the quarter just ended. We have been somewhat skeptical of the Wall Street reaction to the SIA's book-to-bill reports because the SIA bases its calculations on sales in North America, where markets have cooled over the past year, and entirely misses the strong growth in the Japanese and Asia/Pacific markets. We assume Intel calculates its ratio on a worldwide basis, since 58 percent of its revenue came from non-U.S. markets in the first quarter. Nevertheless, we choose to interpret Intel's declining book-to-bill ratio more as a change in its customers' behavior (they do not feel compelled to order far in advance, given the adequate supply of components), rather than as a sign of weakness in end-user markets.
By Nathan Brookwood

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Intel Moves to Close Workstation/PC 3-D Performance Gap

At this year's just-completed Windows Hardware Engineering Conference (WinHEC), Intel unveiled a new aspect of PC system architecture that has the potential to drive a wave of system upgrades and, quite by accident, do major damage to vendors focused on the classic workstation market. Intel calls its new technology the "Accelerated Graphics Port" or AGP. The good news, if you are a workstation vendor, is that this technology will not enter the market until mid-1997 and will be introduced then only on P6-based products.

The driving force behind AGP is the need to increase the available bandwidth between the system's main memory elements and its graphics controller, in order to accelerate the task of creating realistic on-screen 3-D images. Personal computers already have all the performance they need for today's 2-D graphic user interfaces (GUIs). When most 2-D images are dragged around on the screen, they move as fast as the eye can follow. They do not need to move any faster—the eye cannot sense it. But when systems try to create 3-D images, the computational task becomes far more daunting. For every pixel on the screen (there are over 300,000 of them in a 640 x 480 screen, small by today's 2-D standards), the system must figure out which of several objects will be visible, what color it will be, and how that color will be affected by available lighting sources within the image. Then the system must determine where everything will be in the next frame, and repeat all these shading and lighting calculations. It must accomplish all this at a rate of thirty frames per second, or the eye can tell the difference. Developers refer to the process of translating the abstract definition of 3-D objects in the computer's memory into a series of shaded pixels on the computer's screen as rendering, and it is key to 3-D imaging.

Until just a few years ago, computers had no way to accomplish all the calculations needed to render realistic 3-D simulation in real time, so developers cheated. They did all the calculations offline and stored the final result (that is, the completed frames) on the disk for later playback in real time. Even this is not easy, because the system must move lots of data very quickly to the display buffer, but it at least eliminates all the real-time calculations. Of course, it also eliminates any opportunity for interaction; the system is merely replaying a digitally created movie, so this approach is of limited value for games. In order to create the movie *Toy Story*, Pixar needed to render a few billion polygons each second. Arcade-quality games must be capable of rendering one half million polygons per second in order to achieve a more impressive visual effect than "Donkey Kong" provided a few years ago. Today's fastest PCs can render about 100,000 polygons per second, and midrange technical workstations (from Sun, Hewlett-Packard, Silicon Graphics, and others) achieve rates of 500,000 to 750,000 polygons per second. Table 1 provides a rough estimate of the graphics performance needed to render scenes of varying complexity in real time. Some really neat games can be played on a $20,000 workstation! Of course, it does not take a sophisticated market research analyst at Dataquest to figure out that the consumer market for $20,000 game consoles is quite small, and thus few game developers have put any effort into this segment.

Table 1
Graphics Performance Requirements for Image Rendering

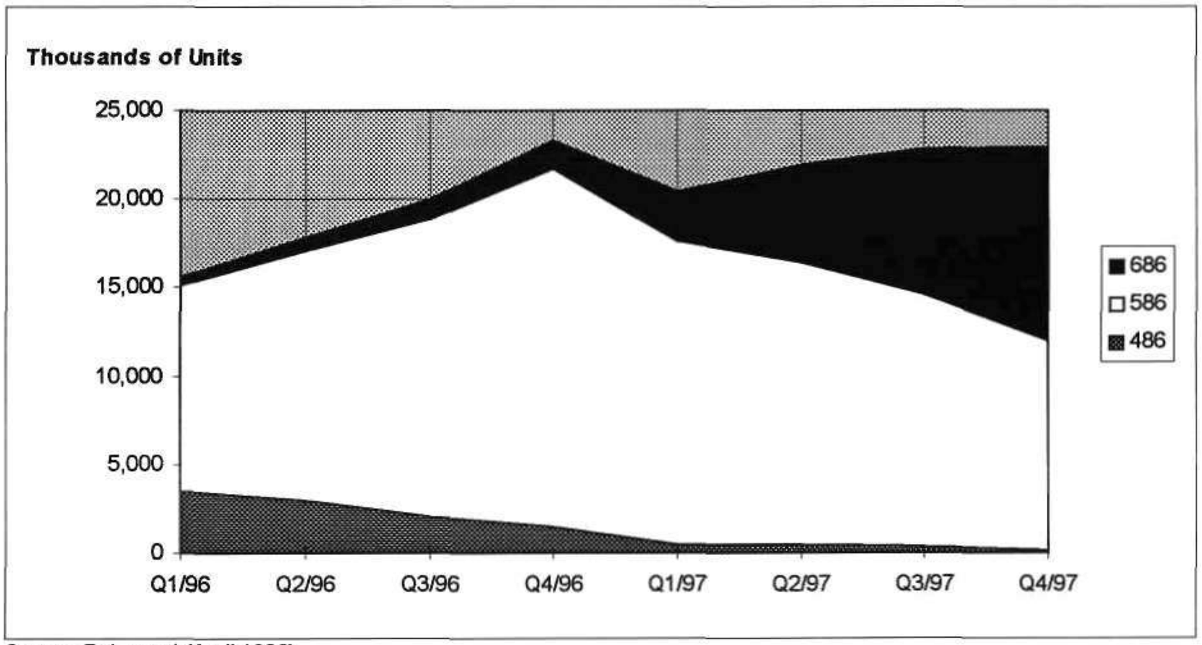
Hardware Environment	Today's personal computer	Today's workstation	Today's super-computer	No real-time solution	No real-time solution	No real-time solution
3-D Graphics Capabilities	Low-resolution games	Complex interiors	Realistic interiors	Realistic faces	*Toy Story*	Photo-realism
Bandwidth (Polygons per Second)	100,000	1 million	10 million	100 million	1 billion	10 billion

Source: Rendition Inc.

With its new AGP technology, Intel set out to solve the price/performance problem for 3-D graphics rendering in personal computers. Intel hopes to bring the system cost of rendering 500,000 pixels per second from $20,000 to $2,000, a more workable figure for high-end consumer devices. In order to accomplish this, the system must provide 250 MB/sec to 300 MB/sec of bandwidth between the display controller and the system's main memory. Today, a well-implemented PCI interface between these two points delivers a peak rate of 100 MB/sec, not nearly enough capacity. In order to break this bottleneck, the PCI specification would need to be increased from 32 bits and 33 MHz to 64 bits and 66 MHz. This would take years to implement and would add extra cost to other PCI devices (disk controllers, LAN controllers, and so forth) that really do not need increased performance. Instead, Intel chose a more expedient path, one that enhances a single PCI-like port on the system to 133-MHz operation, and provides over 500 MB/sec of memory bandwidth. Intel ended up calling this port the Accelerated Graphics Port, or AGP. Before this announcement, Intel had referred to it as the Graphics Attachment Point, or GAP.

All this memory bandwidth would be useless without a graphics controller that knows how to use it, and Intel is not (yet) in the graphics controller business. So, Intel took its concept to ATI, S3, and Cirrus Logic, and together they worked out the details of the interface between the graphics controller and main memory. This interface will be incorporated into chipsets Intel plans to deliver early next year. Dataquest anticipates that the graphics vendors will target a similar introduction date for their wares. Intel plans to add this feature only to its P6 chipsets; there may be an opportunity for astute Pentium-class chipset vendors to incorporate this technology. Figure 1 shows Dataquest's latest estimate of 586-class and 686-class unit shipments by quarter through the end of 1997. The majority of units will still comprise 586-class components and 686-type devices with Pentium pinouts, including the Cyrix 6x86 and the AMD 6K86, at the end of 1997.

Figure 1
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications



Source: Dataquest (April 1996)

Historically, the lack of 3-D software standards meant that hardware vendors designing a new 3-D controller had to undertake a major selling effort with software developers to get them to support his device. This took time and limited the market for such devices. This situation is about to change dramatically. For the past year, Microsoft has been getting ready to release Direct3D, a new software component for Windows 95 and Windows NT. Direct3D enters its beta test phase this month. With Direct3D, application software developers design their programs to work with an abstract 3-D device, and then the operating system maps these commands into the specific instructions needed by each individual hardware controller. Microsoft claims that this can be done without adding lots of overhead, which historically has limited customer acceptance of approaches like this. The proof of this pudding will be in the testing, which starts soon. If it delivers acceptable levels of performance, it will unleash a wave of 3-D software applications late this year and early in 1997. Users will be clamoring for increased 3-D performance at the precise moment that AGP hits the market, and its arrival will trigger the onset of a major upgrade cycle to lower-cost ($2,500 to $3,000) Pentium Pro systems equipped with AGP graphics.

Dataquest Perspective

Dataquest sees the AGP technology as a major enhancement to PC architecture that should benefit everyone, with the exception of traditional workstation vendors (Sun, HP, IBM, Digital Equipment, and Silicon Graphics), and dedicated game console vendors (Sega, Sony, and Nintendo). We are particularly encouraged that the DirectX APIs in Windows 95 can permit such radical architectural changes with so little impact on application-level software. If the AGP scenario plays out as smoothly as it was presented at WinHEC, it will signal the start of a new boom in PC hardware innovation, which historically has been held back by the need to be compatible with older hardware interfaces in order to gain software support. Rapid hardware innovation drives industry growth and provides increased value to end customers.

Workstation vendors should pay special attention to this announcement. Three years ago, it was easy to differentiate workstations selling for $10,000 to $50,000 from personal computers selling for $1,500 to $5,000. Workstations had sophisticated multitasking operating systems based on UNIX that were far more capable than the DOS/Windows environment on PCs. A variety of designer RISC CPUs allowed workstations to compute much faster than PCs with mass-market 486 processors or clunky early Pentiums. Workstations could display their results faster, and in more colors, using high-performance 3-D graphics subsystems with lots of dedicated processing power. The introduction of Windows NT in 1993 began the erosion of the workstation's software advantage, a process that continues today. The introduction of the Pentium Pro began to diminish the workstation's computational advantage, which continues to erode today. The introduction of AGP accelerators in 1997 will eradicate the last major competitive advantage that expensive workstations have over mass-market personal computers. It will become increasingly difficult for workstation vendors to justify the premium prices they need to charge to support their relatively low-volume (compared with PC markets) products. It is ironic that Intel does not appear to have targeted workstations with its AGP initiative; workstations are merely innocent bystanders impacted by Intel's desire to expand the PC market through improved 3-D gaming facilities.

PC chipset vendors need to move quickly on this opportunity or they run the risk of being at a substantial performance disadvantage. Intel has proclaimed that the AGP specification, to be released this quarter, will be an open specification, available royalty-free. It has avoided the confusing gobbledygook that surrounded last fall's unveiling of MMX technology.

CPU vendors (both x86 and RISC) must find a way to tap the AGP performance potential and must respond to Intel's MMX extensions, or they will find themselves at a serious competitive disadvantage by the end of 1997.

Graphics controller chip developers have a wide-open field with lots of running room. They will have four times the memory bandwidth they've had up to now, and DirectX puts them squarely in charge of their own software destinies.

Developers of gaming hardware and software also need to take note. Intel has put them on notice that it intends to make the personal computer the ultimate 3-D virtual reality gaming platform. Intel's moves here mesh nicely with Microsoft's gaming initiatives and its DirectX programs.

Content developers for the World Wide Web and for intranets should also study the opportunities created by Intel's 3-D initiative. The combination of Intel's MMX and AGP initiatives means that 3-D capabilities will become a standard feature in personal computers in the 1997 to 1998 period. As the installed base of such systems grows, there will be opportunities for program content to rise above the network clutter via compelling 3-D user interfaces. It hardly matters whether content is authored in VRML, Java, or C++ over DirectX; the hardware will move into place to support a major shift in user interface styles.

By Nathan Brookwood

Dataquest ALERT

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Multimedia Extensions Spark Pentium Performance

Intel today introduced an expanded instruction set for future x86 microprocessors. The new instructions, collectively referred to as multimedia extensions (MMX), will allow future Pentium, Pentium Pro, and P7 processors to manipulate digital data for audio, video, and graphics applications far more efficiently than has been possible until now. This will allow personal computers to tackle tasks previously reserved for high-end workstation-class systems. Those RISC and CISC vendors competing with Intel-based systems had best take notice of the enhanced performance wrought by this new technology.

Dataquest anticipates that these new MMX features will appear first in Intel's next half-generation Pentium processor, popularly known as the P55C, in the second half of 1996. Pentium Pro processors launched in 1997 will also include these features, as will Merced, the next-generation 64-bit version of the x86 family due "before the end of the century." Application software must be modified to exploit these new instructions, and this will limit the initial impact of this new capability on the market. We anticipate a few "showcase" applications this year, with many more to follow in 1997 and 1998. Independent software vendors (ISVs) with the applications that will benefit the most from MMX (including image processing, videoconferencing, and voice recognition) will gain competitive advantage by moving to support MMX ahead of their competitors.

MMX gains its performance advantage by better use of the internal 64-bit data paths found in most contemporary systems. These paths speed 64-bit floating-point performance, a key aspect of traditional workstation computing that primarily benefits engineers and scientists doing heavy-duty number crunching. MMX allows these same paths to be used simultaneously to process two 32-bit streams, four 16-bit streams, or eight 8-bit streams. This means that a 150-MHz Pentium processor that previously had a maximum of approximately 250 million operations per second now has a theoretical maximum of 2 billion operations per second. This is not bad performance for a chip that Intel can manufacture for less than $50 and that OEMs can purchase for less than $500. It wasn't too long ago that the price for this level of performance was measured in millions of dollars.

Intel claims that MMX will enhance performance by up to 400 percent in selected applications, although improvement of 50 percent to 100 percent will be more typical. The performance benefit will depend on the way that a hardware vendor builds the system and that software vendors adapt their codes to use MMX.

Dataquest Perspective

Intel's performance claims for MMX closely match those that Sun Microsystems has demonstrated can be achieved with its Visual Instruction Set (VIS), an MMX-like extension that Sun introduced in its UltraSparc processor last year. MMX clearly has the potential to increase system performance at virtually no increase in cost, and this formula usually works to propel market demand.

Unlike the clock-rate scaling, which drives much of the increased system performance that users have come to expect and which is transparent to most software programs, MMX, in computer lingo, is "software-visible." That is, MMX can deliver improved performance only if software developers modify their codes to use it. This explains why Intel chose to unveil MMX at InterMedia World, a conference for multimedia software developers. Whether and how these developers incorporate of support for MMX will have an effect not only on the performance of their programs but also on the manner in which the industry evolves over the next few years.

Many MMX hardware instructions perform the work now performed by library subroutines. Intel argues that, in order to extract the maximum performance benefit from MMX, developers should embed MMX instructions directly in their codes, rather than merely replace the old non-MMX libraries with newer ones that incorporate these features. This represents the path of maximum effort for the ISV, and the tools needed to incorporate MMX into these applications make this an even more difficult task. If ISVs follow this path, the industry will become locked into Intel's very specific definition of MMX, and vendors offering functionally similar but technically incompatible solutions, as planned by some x86 cloners, will have trouble gaining support. On the other hand, ISVs may conclude they can gain enough performance benefit with less effort if they segregate MMX support into standard libraries, such as the DirectX calls recently introduced by Microsoft. Proceeding down this path would give both hardware and software developers more flexibility and would allow multiple incompatible versions of MMX to coexist in the market without undue technical complexity. This approach opens the door for alternative approaches to improved performance, such as those advocated by Chromatic Research and Philips. It is too early in the game to determine which path is likely to prevail.

By Nathan Brookwood

Dataquest ALERT

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$100 Million Memory Writedown Mars Intel's Otherwise Awesome 1995 Finish

Intel yesterday posted earnings of $3.566 billion ($4.03 per share) on revenue of $16.2 billion for 1995. Had the (memory) chips fallen in a slightly different fashion, the company would have been able to report higher earnings—Intel said the effect of a memory inventory writedown cost it $0.06 to $0.08 per share.

But, in spite of the company's overly ambitious forecast for the fourth quarter and its memory inventory hangover, 1995 really was a bang-up year for Intel. The company drove its Pentium processor into the mainstream PC market and left its x86 competitors in the dust. Its recently launched Pentium Pro processor provided performance that embarrassed those who have for a long time predicted the imminent demise of CISC. Intel's aggressive capital investment program positioned it to deliver an awesome number of advanced CPUs and put even more distance between Intel and other CPU vendors from a manufacturing capacity standpoint.

It's a shame that too many people will remember 1995 as the year Intel overbought DRAMs in anticipation of a spectacular holiday selling season that turned out to be really good but fell short of spectacular. What went wrong?

Dataquest suspects that Intel feared that a fourth quarter DRAM shortage might constrain system sales. To forestall this possibility, the always-vigilant Intel stockpiled DRAMs for use in the motherboards that have become a key part of its one-stop shopping mall for system vendor customers. The anticipated DRAM crunch never arrived, both because of the slower-than-forecast adoption of Windows 95 and a consumer buying preference for higher-speed (and higher-margin) CPUs instead of larger DRAM configurations. It also appears likely that some of the top five PC vendors missed their goal of capturing 30 percent of the market. The DRAM supplies intended to facilitate CPU and board sales instead became a dead weight. The recent spot market erosion in DRAM pricing forced an inventory writedown, making Intel's mistake all too visible on the bottom line.

In a conference call, Intel indicated that it was not changing its capital investment or its 1996 spending plans in any significant manner as a result of the fourth quarter DRAM misfire. We agree with that decision. Intel also indicated that it sees its motherboard business as a key element in its program to move PC users to ever-increasing performance levels and that the problems it experienced in the fourth quarter will not deter it from continuing in the board business. This is bad news for those motherboard suppliers hoping that Intel would turn away from this arena in the face of razor-thin board margins.
By Nathan Brookwood

Dataquest

November 4, 1996
Semiconductor Directions in PCs and PC Multimedia Worldwide
MARKET ANALYSIS
Geoff Ballew

NICs Get Nixed as Ethernet Controllers Migrate onto the PC Motherboard

Many PC OEMs are changing the face of PC networking by integrating Ethernet chips onto their motherboard designs. This bucks the long-term trend of adding networking capability with network interface cards (NICs) and opens a new opportunity for PC OEMs to add value to their products. This trend toward integrated networking is fueled by the availability of low-cost, single-chip Ethernet controllers and the popularity of 10-Mbps Ethernet as a standard. This report provides an overview of the market dynamics for Ethernet controllers in PCs, including implementation trends and insight into the strategies of key chip suppliers for PC networking and a forecast for unit shipments and revenue. For the purposes of this report, the term " controller" refers to a chip rather than a NIC.

More PCs Are Getting Integrated Networking

PC peripherals often migrate to the motherboard when technology is relatively stable and chip count is minimal. Ethernet controllers satisfy both of those requirements and are getting designed onto PC motherboards with greater frequency. Ethernet is the most popular standard for PC networking, and chip suppliers are delivering single-chip controllers for well under $10. Dual-speed controllers that provide a complete 10-Mbps solution as well as a low-cost upgrade path to 100 Mbps are attractive for motherboards as well and sell for a decreasing premium over the 10-Mbps-only chips. Figure 1 shows how a 10/100-Mbps Ethernet controller might be implemented on a PC motherboard. Improvements in software are also helping this trend toward integrated networking as corporations move away from Windows 3.x running on top of DOS in favor of Windows 95 and Windows NT. These newer operating systems simplify network configuration and maintenance by including network driver support for the more popular networking controllers.

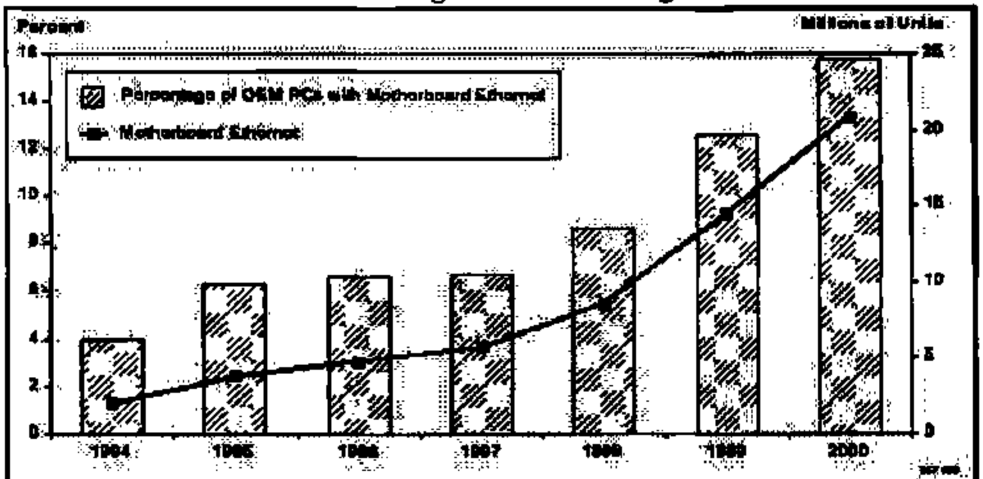
Figure 1
Possible Motherboard Implementation for a 10/100-Mbps Ethernet Controller

Source: Dataquest (November 1996)

Many PC OEMs are integrating Ethernet controllers onto their motherboard designs for their business desktop lines. Some of those designs use a custom daughtercard or module approach rather than soldering the controller onto the motherboard itself. For the purposes of this report, daughtercard implementations will be considered motherboard implementations because the PC OEMs are sourcing the chips directly instead of buying network interface cards (NICs). Table 1 lists a few PCs that have integrated Ethernet controllers.

Figure 2 shows Dataquest's forecast for integrated networking in PCs through the year 2000. (The data for this figure is located in Table 3.)

Figure 2
Forecast for Integrated Networking in PCs



Source: Dataquest (November 1996)

Table 1
Several PC Product Lines Featuring Integrated Network Controllers

Brand	Product Line
Compaq	Deskpro 4000
	Deskpro 6000
Dell	Optiplex (some models)
Hewlett-Packard	Vectra XM2, XM3, XU
IBM	PC Power Series 830, 850
Apple	Quadra (some models)
	Power Macintosh (some models)
AST Research	Premmia GX
ICL	ErgoPRO
Siemens-Nixdorf	RM4000
Source: Dataquest (November 1996)	

Integrated Networking Allows PC OEMs to Add Value and Differentiate Their Products

PC OEMs benefit in two ways from integrating networking ICs onto their motherboards. First, a PC with networking capabilities sells for a higher price, so the OEM gets a higher dollar margin on the sale of that PC. Motherboard implementations are less expensive than using ISA or PCI add-in cards, so OEMs get maximum economic benefit from integrating the network controller onto the motherboard.

Strategic benefits arise as well. Several PC OEMs use integrated networking to position themselves as solution providers rather than just equipment providers. The difference is that solution providers address cost-of-ownership issues. The message is "value" rather than "lowest price."

Some New Features Require Motherboard Implementation

Some new features available in network controllers are easier to implement on motherboards than on NICs. The Magic Packet technology, 3.3V operation, and user-visible status LEDs are some specific examples. (Magic Packet is a trademark of Advanced Micro Devices Inc.)

Magic Packet technology was developed by AMD and Hewlett-Packard as a way to turn on a PC remotely by sending a special message or "magic packet" over the network. This enables corporate IS staffs to remotely manage a number of functions, such as software or BIOS update, system backups, and other tasks, even if the PC is turned off. PC users can turn off their PCs at night to save electricity, and the IS staff can do its job without having to run around a building turning PCs on and off.

This technology requires that the network controller be powered up, although in a low-power sleep mode, when the PC is turned "off." The network controller must also be able to turn the PC "on" so that the PC boots up and is ready for operation. The PCI specification does not include these capabilities, so PC OEMs must enable these features through their motherboard designs. Special motherboard features require the network controller to be integrated into the motherboard design, even though the network controller may be soldered to a custom module or daughtercard. Hewlett-Packard and IBM are two PC OEMs that offer Magic Packet or similar features in their PC products.

Another benefit OEMs can realize by implementing network controllers on the motherboard is 3.3V operation. Some PCI motherboards do not include 3.3V power signals to the PCI connectors, so designers of PCI-based NICs must add a 3.3V voltage regulator if they want 3.3V signals on their card. The advantage of operating at 3.3V instead of 5V is lower power requirements.

Another opportunity for PC OEMs to differentiate their products is adding a simple network-activity LED, similar to the hard disk-activity LED and visible to the PC user. Many NICs have status LEDs today that are visible from the back of the PC, but few users can see the back of their PCs. Standard NICs do not provide an opportunity to route the LED signal to the front of the PC, so a motherboard implementation (and appropriate redesign of the PC case) would be necessary. This feature must be enabled through the controller itself for a true indication of network activity.

Feature Comparison of Several Ethernet Controllers

Suppliers of Ethernet controllers compete on features and price just like other chip vendors. Table 2 shows some of the basic features of several Ethernet controllers that are available today.

Table 2
Feature Comparison of Several Ethernet Controllers

	Product Family	Part Number	Speed (Mbps)	Integrated Transceiver?	Full-Duplex Operation?	Voltage	Bus Interface	Po M
AMD	PCnet-PCI	-	10	Yes	No	3.3, 5	PCI	Ye
AMD	PCnet-PCI II	-	10	Yes	Yes	3.3, 5	PCI	Ye
AMD	PCnet-Fast	79C971	10/100	10 Mbps Only	Yes	3.3, 5	PCI	Ye
Digital	None	21041	10	Yes	Yes	3.3, 5	PCI	Ye
Digital	None	21142	10/100	10 Mbps Only	Yes	3.3, 5	PCI CardBus	Ye
Digital	None	21143	10/100	10 Mbps Only	Yes	3.3, 5	PCI CardBus	Ye
Fujitsu	None	MB86965	10	Yes	No	5	ISA	Ye
Fujitsu	None	MB86965B	10	Yes	Yes	5	ISA	Ye
National Semiconductor	SONIC-T	DP83936	10	Yes	Yes	5	Direct to MPU	N
Standard Microsystems	None	SMC91C94	10	Yes	No	5	ISA	N
Standard Microsystems	None	SMC91C100	10/100	10 Mbps Only	No	5	ISA PCMCIA	N
Texas Instruments	ThunderLAN	TNETE100	10/100	10 Mbps Only	No	3.3, 5	PCI	Ye
Texas Instruments	ThunderLAN	TNETE110	10	Yes	Yes	3.3, 5	PCI	Ye

Source: Dataquest (November 1996)

10/100-Mbps Controllers Provide an Upgrade Path

PC OEMs must balance the cost benefits of integrating peripherals versus configuration flexibility. Suppliers of Ethernet controllers have addressed this dilemma by offering 10/100-Mbps Ethernet controllers. These controllers offer 10-Mbps operation with a single chip, but are easily upgradable to 100-Mbps capability by adding a 100-Mbps transceiver chip.

Full-Duplex Operation Gives 10 Mbps a Boost

Full-duplex operation is a new feature for 10-Mbps Ethernet controllers that doubles the peak bandwidth to 20 Mbps (10 Mbps into the controller and 10 Mbps out). The performance increase is moderate (2x compared to the 10x increase offered by 100-Mbps Ethernet) but is compelling because of the low cost and single-chip configuration.

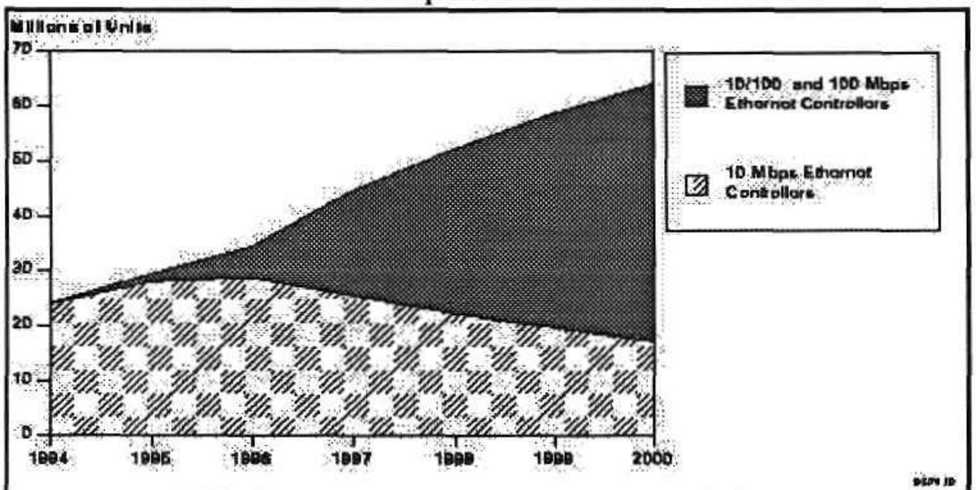
Power-Saving Modes Are a Requirement for Network Controllers in Mobile PCs

Most of the network controllers shown in Table 1 have some ability to go into a low power mode or sleep mode. This is a critical feature as semiconductor suppliers target the mobile PC market. Mobile PCs are frequently connected to networks when users are in their offices, so integrated networking makes sense, but battery life must be considered. Some mobile PCs from Hitachi have integrated network controllers today, and models from other vendors are sure to follow.

Forecast for Ethernet Controllers

Networking continues to be a critical function of the corporate PC. Dataquest's forecast for Ethernet controllers reflects this with almost a 17 percent compound annual growth rate (CAGR) from 1995 to 2000. Figure 3 and Table 3 show the actual forecast. This forecast shows a dramatic shift toward controllers capable of Fast Ethernet speeds (100 Mbps) as demand for network bandwidth continues to climb and the price premium for 10/100 Mbps gets smaller.

Figure 3
Forecast for Unit Shipments of Ethernet Controllers



Source: Dataquest (November 1996)

PCI will play a greater role for networking in the future, as system vendors want the performance and configuration benefits that that interface provides. True plug-and-play capability as well as lower CPU utilization are two tremendous advantages that PCI has over ISA.

Another major trend is the rising tide of application-specific standard products (ASSPs) in the Fast Ethernet category. Dataquest believes that ASSPs will increase from 30 percent of Fast Ethernet unit shipments to 70 percent over the next four years. ASIC vendors will enjoy higher unit growth from 1996 to 1997 if the total Ethernet controller market is considered, but subsequent years will bring slower growth for ASICs as ASSPs begin to dominate the Fast Ethernet category in addition to the 10-Mbps Ethernet category.

One ASIC vendor, 3Com, is selling chips directly to at least one PC OEM. In the past, 3Com has used its ASICs to sell board-level networking products and capture the added value of board-level integration. Dataquest believes that 3Com's willingness to sell chip-level products validates the trend toward integrated networking.

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Abstract DQi

CD-ROM Controllers Enable New Classes of CD Drives

PREVIEW

PURCHASE

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Abstract

Suppliers of CD-ROM controllers are adding new features to their chips that will change the dynamics of the CD-ROM drive market. CD-ROM drives are typically judged by data transfer rate and price, and CD-ROM controllers are a key component. The speed race from 2x- to 4x-speed and now 12x-speed drives is pushing several technology limits. Differentiation among CD-ROM controllers from the leading suppliers will continue to be performance-oriented, but the integration of new features is essential for the higher speeds to be usable. Support for other types of compact disc drives such as CD-Recordable (CD-R) and CD-ReWritable (CD-RW, also called CD-Erasable or CD-E) is necessary for CD drives to compete with other mass storage options. For the purposes of this document, the term "CD-ROM controller" will be used to describe controllers for CD drives that are CD-ROM-compatible but may have CD-R or CD-RW capabilities as well.

Table of Contents

List of Figures

List of Tables

Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Dataquest Predicts

Quarterly x86 Compute Microprocessor Forecast

Abstract: *Dataquest has lowered its forecast of average selling prices (ASPs) to better reflect both our final 1995 estimates and Intel's ongoing, relentless price reductions intended to spur continued market growth (and succeeding). We have increased our first quarter 1997 estimate for Pentium Pro shipments to reflect Intel's recent decision to launch its Klamath design in the first quarter instead of the second quarter. We do not believe that Intel's decision to delay the P55C launch until early 1997 will have a material effect on Pentium unit shipments this year or next.*
By Nathan Brookwood

"Steady as She Goes"; Only Minor Tweaks to Our Prior Forecast

Dataquest has tuned its x86 computational processor forecast to reflect recent changes in market conditions and strategies of key vendors. The Computer Systems program stands by its earlier forecast for x86-based systems, and we have held steady our x86 unit shipment forecast (largely driven by PC unit shipment demand), as well. Based on our final roll-up of 1995 data, we have adjusted average selling prices (ASPs) downward for 1995 through 1999. These changes result in minor adjustments to factory revenue generated by x86 processor sales during the period.

Two recent Intel decisions cause minor perturbations to the forecast. First, Intel announced that it intends to forgo its customary November price adjustments for the Pentium (but not the Pentium Pro) line in the interest of maintaining market stability during the busiest season of the year for most system OEMs. Some of the price reductions we anticipated for November were incorporated in the August adjustments, and some will be deferred until February. Second, Intel announced a plan to delay the launch of its Pentium-class processor with MMX capabilities (the P55C) by a quarter, until

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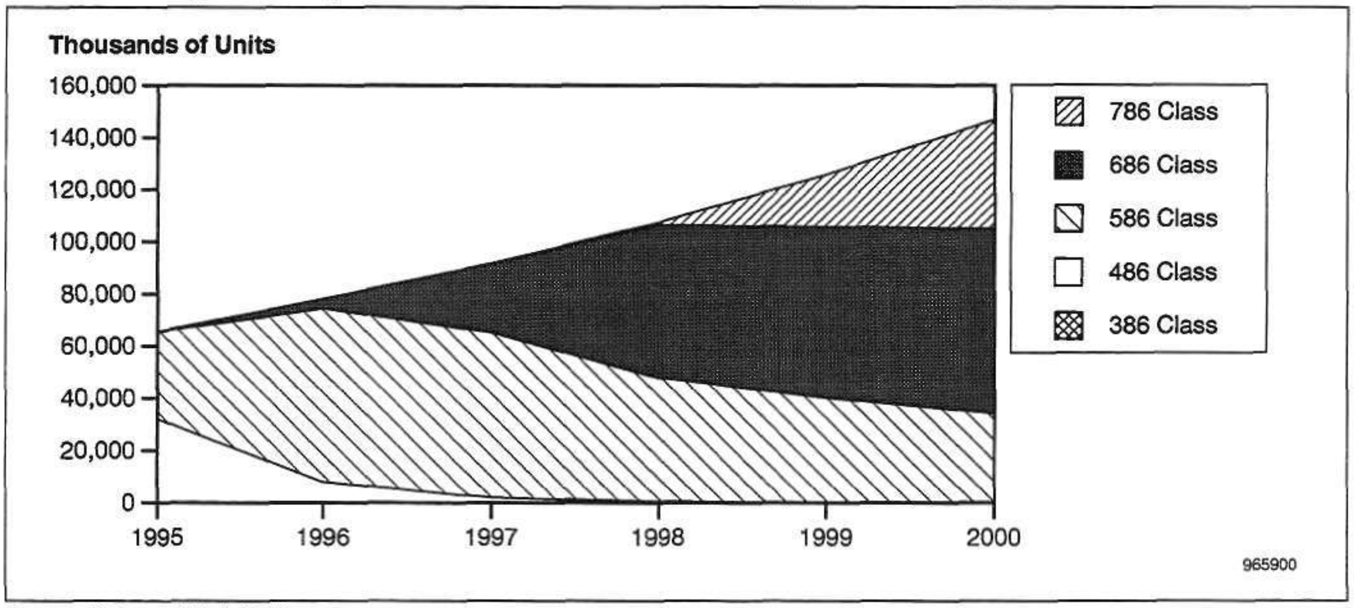
early 1997, again in the interest of market stability. It also announced its intent to pull in the release of its Pentium Pro-class product with MMX (Klamath) to early 1997, even though initial platforms may not be able to use all of the chip's performance potential. We see this pull-in increasing slightly the number of Pentium Pros sold in the first half of the year.

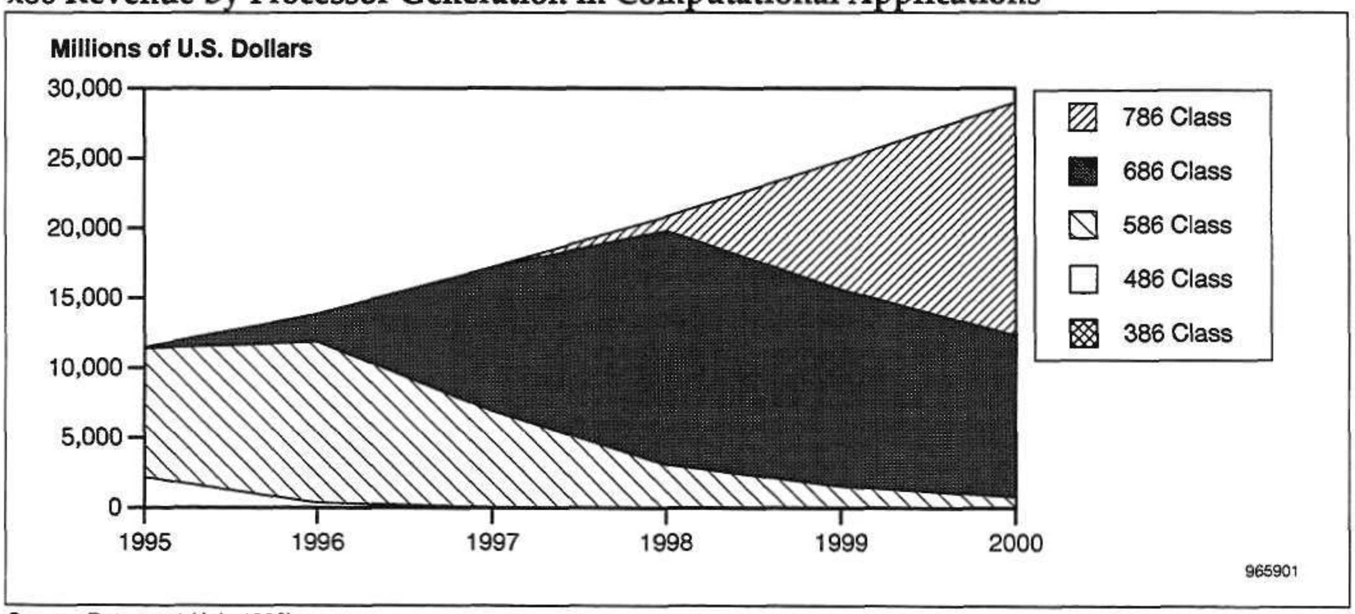
Figures 1, 2, and 3 and Table 1 illustrate Dataquest's projections for unit shipments, revenue, and ASPs over 1995 to 2000.

Figure 1
x86 Unit Shipments by Processor Generation in Computational Applications



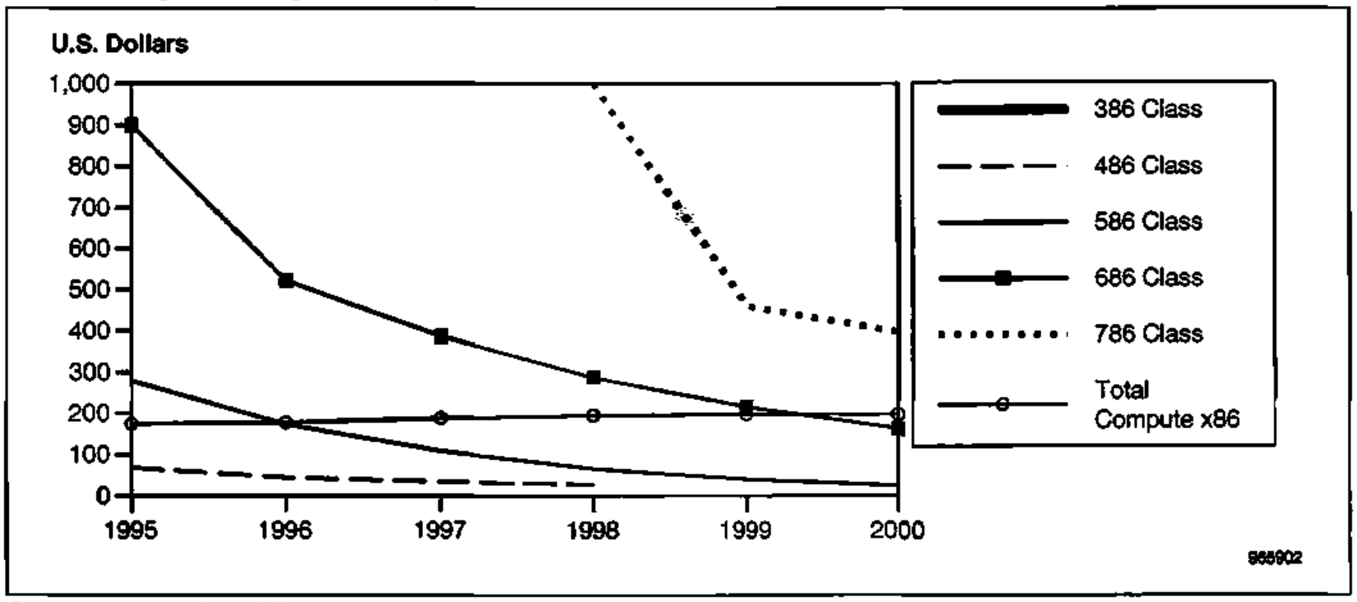
Source: Dataquest (July 1996)

Figure 2
x86 Revenue by Processor Generation in Computational Applications



Source: Dataquest (July 1996)

Figure 3
x86 Average Selling Prices by Processor Generation in Computational Applications



Source: Dataquest (July 1996)

Quarterly Projections: Strong PC Unit Growth to Continue

Dataquest projects that worldwide PC unit sales will continue to grow at an annual rate of about 19 percent over the next two years. Intel's reduced processor prices, combined with continued erosion in DRAM and hard disk prices, make this year's personal computers an incredible bargain by any standard, especially any standard more than two years old. The most successful vendors in the current market have learned how best to cope with the ever-decreasing product life cycles for systems and the need to manage assets and turn inventories as never before. This environment has produced incredible values for the consumer—and incredible headaches for PC system vendors. Dataquest regrets to report that it sees no letup in sight for these vendors, who have been dragged by Intel onto an ever-accelerating treadmill.

Table 2 and Figure 4 provide a quantitative view of Dataquest's forecast for x86 compute microprocessors over the next eight quarters.

Table 1
x86 Units, Revenue, and ASPs by Processor Generation in Computational Applications

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 Class							
Units (K)	290						-100
ASP ($)	20						-100
Revenue ($K)	5,771						-100
486 Class							
Units (K)	31,904	7,976	1,994	499			-100
ASP ($)	68	44	33	27			-100
Revenue ($K)	2,169,472	352,539	66,101	13,220			-100
586 Class							
Units (K)	33,214	66,428	63,107	47,330	40,231	34,196	1
ASP ($)	278	173	108	65	39	24	-39
Revenue ($K)	9,216,904	11,521,130	6,840,671	3,078,302	1,569,934	827,355	-38
686 Class							
Units (K)	95	3,800	26,600	58,520	65,542	70,786	275
ASP ($)	900	522	386	286	214	163	-29
Revenue ($K)	85,500	1,983,600	10,275,048	16,727,778	14,051,334	11,533,335	167
786 Class							
Units (K)				1,000	20,000	42,000	NM
ASP ($)				1,000	460	396	NM
Revenue ($K)				1,000,000	9,200,000	16,615,200	NM
Total Compute x86							
Units (K)	65,503	78,204	91,701	107,349	125,773	146,982	18
ASP ($)	175	177	187	194	197	197	2
Revenue ($K)	11,477,646	13,857,269	17,181,820	20,819,300	24,821,268	28,975,890	20

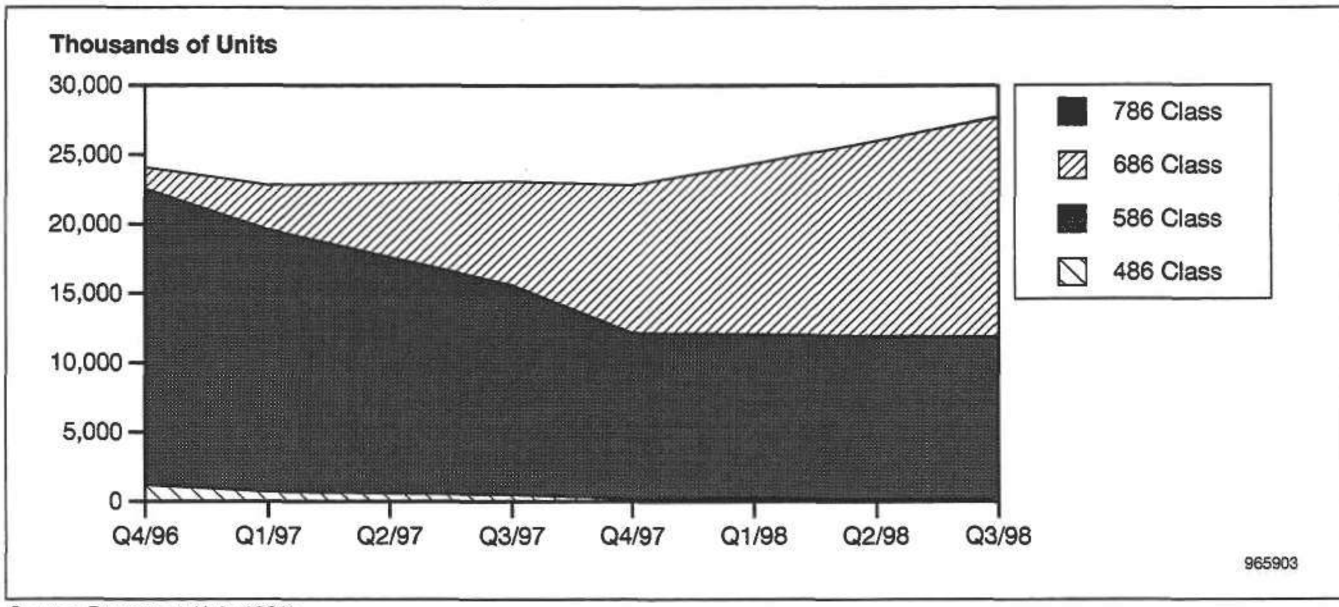
NM = Not meaningful
Source: Dataquest (July 1996)

Table 2
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications (Thousands of Units)

	Q4/96	Q1/97	Q2/97	Q3/97	Q4/97	Q1/98	Q2/98	Q3/98
486 Class	1,196	698	598	499	199	249	125	75
586 Class	21,384	18,932	17,039	15,146	11,990	11,833	11,833	11,833
686 Class	1,520	3,192	5,320	7,448	10,640	12,289	14,045	15,800
786 Class	0	0	0	0	0	0	0	50

Source: Dataquest (July 1996)

Figure 4
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications



Source: Dataquest (July 1996)

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Market Analysis

PCs Will Consume $88 Billion of Semiconductor Content in the Year 2000

Abstract: *PCs are the largest application for semiconductors and represent over one-quarter of total semiconductor market revenue. This document provides an update to the PC semiconductor content forecast published earlier this year. The new forecast is based on Dataquest's latest PC forecast, which is also presented in this document. The semiconductor content of a typical PC peaked in 1995, and total revenue for the PC semiconductor market is forecast to decline significantly for 1996 in spite of nearly 20 percent growth in PC unit shipments. Dramatic (and well-publicized) changes in memory prices are the primary cause of the decline for 1996. Growth for the PC semiconductor market is forecast to resume in 1997 and continue through the year 2000.*

By Geoff Ballew

1996 PC Semiconductor Revenue Is Leaner than 1995, But Growth Will Return for 1997

PCs are the largest single application for semiconductors and continue to be the major driver of semiconductor growth. That growth does not always proceed unchecked, and 1996 clearly stands out as a year of decline. The PC semiconductor revenue forecast for 1996 is down primarily because of the dramatic declines in memory prices over the past year. PC OEMs have responded by stuffing more megabytes into each PC, but the increased bit consumption does not offset the declines in price per bit. Figure 1 shows Dataquest's latest forecast for the PC semiconductor market.

Overall, the PC market is forecast to consume $88 billion worth of semiconductor devices in the year 2000, up from $48 billion in 1995. This reflects a 12.9 percent compound annual growth rate (CAGR) despite the 14

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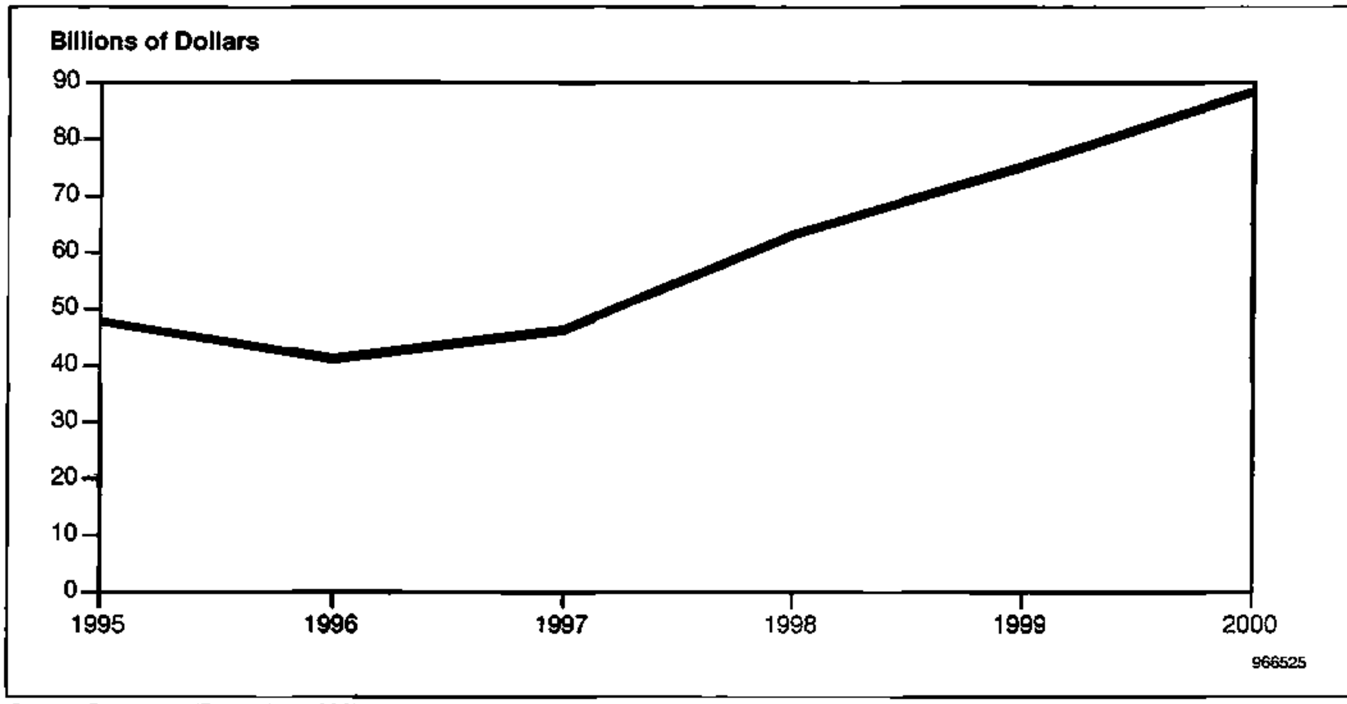
percent decline from 1995 to 1996. Table 1 includes the data from Figure 1. In 1997, revenue will show growth over 1996, but it is expected to be lower than 1995 revenue.

Figure 1
PC Semiconductor Revenue Forecast



Source: Dataquest (December 1996)

Table 1
PC Semiconductor Revenue Forecast

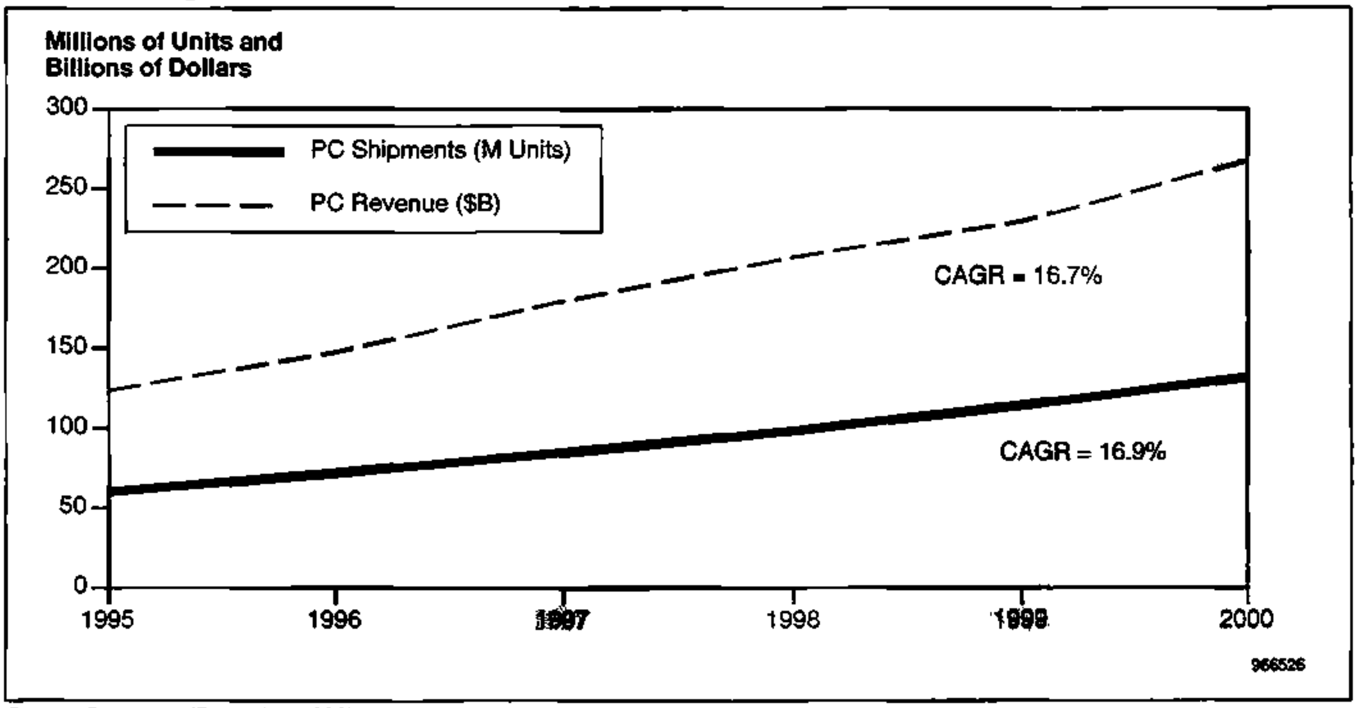
	1995	1996	1997	1998	1999	2000
PC Semiconductor Revenue ($B)	47.8	41.2	46.4	63.2	75.2	88.3
Growth over Previous Year (%)	-	-13.9	12.6	36.2	19.0	17.5

Source: Dataquest (December 1996)

The decline in PC semiconductor revenue is softened by the continued strong demand for PCs. PC shipments are on track to meet Dataquest's latest forecast of almost 20 percent unit growth for 1996. Figure 2 and Table 2 show Dataquest's most recent PC forecast. Note that unit shipments are expected to grow slightly faster than revenue over the forecast period.

The worldwide growth of the PC market is getting a boost from the markets in Japan and the Asia/Pacific region. Dataquest forecasts 40 percent unit growth for Japan and 35 percent for Asia/Pacific. These two markets are getting significant growth from home PC sales, just as the U.S. market was buoyed by sales of consumer PCs through most of the 1990s. The U.S. market is forecast to be a bit slower, at 15.5 percent unit growth. This is due in part to a level of saturation in the U.S. home PC market. Most consumers who want PCs (and can afford them) have purchased one, so the U.S. market is increasingly characterized by a replace-and-upgrade cycle rather than the dynamic of increasing market penetration. Economic issues in western Europe are limiting the unit growth there, and Dataquest expects only a 10.9 percent increase for that region.

Figure 2
PC Unit Shipment and Revenue Forecast



Source: Dataquest (December 1996)

Table 2
PC Unit Shipment and Revenue Forecast

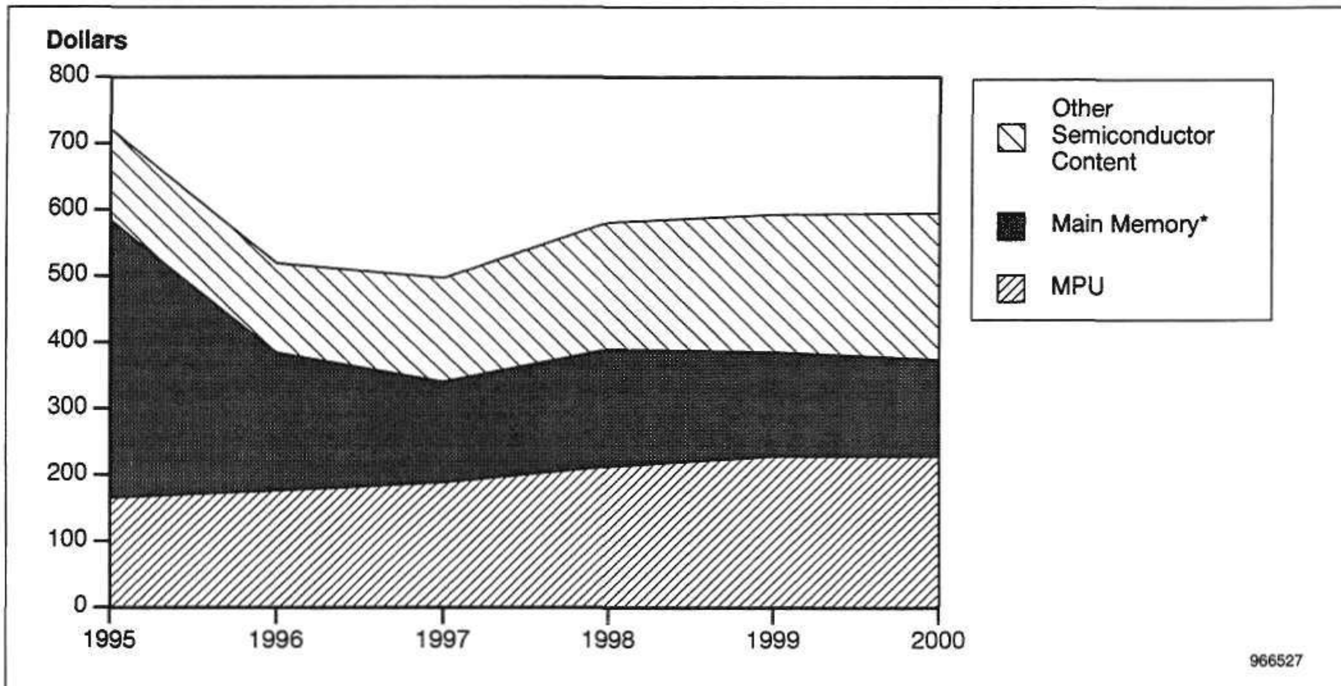
	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
PC Shipments (M Units)	60.2	72.0	84.8	98.5	114.1	131.5	16.9
PC Revenue ($B)	123.6	147.3	179.5	207.1	229.2	267.1	16.7
PC ASP ($K)	2.05	2.05	2.12	2.10	2.01	2.03	-0.2
Other Equipment Included in Semiconductor Consumption Forecast							
Additional PC Motherboards (M Units)	5.5	6.6	7.7	9.0	10.3	11.9	16.5
Handheld PCs (M Units)	0.5	0.6	0.8	1.3	2.4	5.1	60.0
Total Shipments (M Units)	66.2	79.2	93.4	108.8	126.8	148.5	17.5
PC Semiconductor Revenue ($B)	47.8	41.2	46.4	63.2	75.2	88.3	13.1
Semiconductor Revenue per Unit ($)	722	520	497	581	593	595	-3.8

Source: Dataquest (December 1996)

Semiconductor Content per PC Will Decline through 1997

Declining memory prices have driven the average semiconductor content of a PC from $722 in 1995 to $520 in 1996. This trend will continue into 1997 as semiconductor content falls to $497 before rebounding in 1998. Figure 3 shows the forecast for semiconductor content per PC through the year 2000. There is good news in these numbers for companies selling nonmemory devices rather than memory devices. The semiconductor content excluding main memory is forecast to grow each year through the year 2000. Table 3 provides the data from Figure 3.

Figure 3
Semiconductor Content of a Typical PC



*Main memory includes factory-installed as well as aftermarket memory upgrades.
Source: Dataquest (December 1996)

Table 3
Semiconductor Content per PC (Dollars per PC)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
MPU	165.6	176.3	188.3	212.6	228.6	228.4	6.6
Main Memory*	419.2	208.4	152.6	177.0	157.1	146.3	-19.0
Main Memory* (MB per System)	15.8	23.0	31.8	44.1	46.8	52.1	26.9
Cost per MB Assumption ($)	26.5	9.1	4.8	4.0	3.4	2.8	-36.1
Other Semiconductor Content	137.3	135.0	155.9	191.3	207.4	220.3	9.9
Total	722.2	519.8	496.8	581.0	593.1	595.1	-3.8

*Main memory includes factory-installed as well as aftermarket memory upgrades.
Source: Dataquest (December 1996)

Multimedia features and performance are the key drivers for PC semiconductor growth in the future. This trend is driven by peripheral chipsets but also includes microprocessors.

PC OEMs will spend significantly more dollars per PC on peripheral chipsets over the next few years as business PCs gain many of the multimedia features that characterize consumer PCs today. Audio and digital video features are penetrating the business PC market, particularly on mobile PCs. Networking is another driver as PC OEMs integrate Ethernet controllers onto many of their motherboard designs and make this a standard feature for many of their corporate PC product lines. The 9.9 percent growth of the Other Semiconductor Content line in Table 3 is due primarily to the growth of multimedia functions. 3-D graphics, higher-quality video and audio processing, and LAN/WAN peripheral chipsets are all part of this trend.

Consumer PCs will also get more new features that require additional semiconductor content. Examples are MPEG-2 and AC-3 decoding, new plug-and-play interfaces, 3-D graphics, and 3-D audio. These features will be added with a combination of fixed-logic and programmable devices. The programmable devices include media processors, as well as others that are not openly programmable but can be updated with software. One example is the U.S. Robotics 28.8-Kbps modem chipset that can be upgraded to 56-Kbps via software.

Microprocessor average selling prices (ASPs) continue to climb slowly. The higher prices are justified by advances in architecture (such as transition from Pentium-class to Pentium Pro-class MPUs) as well as new functionality, such as the multimedia instruction sets (for example, Intel's MMX) that all major MPU manufacturers are adding to their products. Demand for faster microprocessors is increasingly driven by requirements for processing multimedia types of data.

Dataquest Perspective

Demand for semiconductors in PCs is forecast to decline this year before resuming a pattern of growth. The revenue decline for 1996 is expected to be 14 percent, even though PC unit shipments are forecast to increase almost 20 percent. Higher unit shipments of PCs are necessary to offset in part the decline in dollars of semiconductor content per PC. PC OEMs are putting more megabytes of memory in PCs than ever before, but the larger memory sizes do not compensate entirely for the memory price erosion. PC semiconductor revenue growth is dependent on strong PC unit shipments.

Demand for PC semiconductors, excluding main memory, is much stronger and is forecast to grow at an 8.2 percent CAGR in terms of revenue per PC or 26.5 percent in actual revenue. The two growth rates are multiplied because the dollars per PC are growing at the same time that unit shipments are growing (that is, $1.082 \times 1.169 = 1.265$). The 8.2 percent growth rate is derived by adding the MPU revenue line and the Other Semiconductor Content revenue line from Table 3 and calculating the CAGR on the sum.

This is good news for microprocessor and peripheral chipset vendors because their products are the growth opportunities in the PC market. Memory suppliers will have a tougher time as the dollars per PC spent on main memory will decline at almost a 20 percent CAGR from 1995 to 2000.

PC semiconductor revenue will resume double-digit growth in 1997 and mirror the growth of PC revenue over the long term as supply and demand for semiconductor devices come back into balance.

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Dataquest Predicts

Quarterly x86 Forecast: A River Runs through It

Abstract: *We have adjusted our chip forecast up slightly, to reflect the strong market conditions in the fourth quarter, and a slightly more optimistic forecast on the part of Dataquest's Computer Systems and Peripherals group. We have also reclassified the forthcoming "M2" from Cyrix and "K6" from AMD as sixth-generation devices, albeit sixth-generation devices with fifth-generation external buses.*

By Nathan Brookwood

Sixth-Generation Microprocessors Go Mainstream

Dataquest anticipates that shipments of fifth-generation ("586") x86 microprocessors—including the Intel Pentium, the Cyrix 6x86, and the AMD 5K86—will reach a peak of about 21.3 million units per quarter in the fourth quarter of 1996, and will then begin their slow descent into history, at least within computational (or general purpose) markets. New sixth-generation ("686") parts from Intel, AMD, and Cyrix will begin to ship in meaningful quantities in the first half of 1997, and the generational transition will be in full force by the end of the year; quarterly shipments of sixth-generation processors will surpass fifth-generation MPUs by the fourth quarter, a bit earlier than previously forecast.

Our reclassification of the planned AMD and Cyrix processors as sixth-generation devices contributes to the acceleration of this transition. In earlier forecasts, the Dataquest Semiconductor group classified these devices as "fifth-generation," primarily because they use the same external bus interface as Intel's Pentium processor, instead of the newer (and more complex) external interface used in Intel's Pentium Pro line. It now appears certain that AMD and Cyrix will avoid the Pentium Pro bus entirely, primarily because of intellectual property concerns. These vendors also argue that the

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newer bus fails to provide any performance benefit in uniprocessor configurations. Intel markets its Pentium Pro line into both uniprocessor (desktop) and multiprocessor (server) environments, and the latter do benefit from the more complex bus. In any event, given that Dataquest's Semiconductor group counts chips, while the Computer Systems and Peripherals group more properly looks at sockets, we are parting ways with regard to this generational taxonomy. The Computer Systems and Peripherals group will continue to use bus architecture (and its associated processor socket) as the key determinants for generational definitions, and will thus categorize systems containing the K6 and M2 as "fifth-generation" personal computer architectures. Alert readers may observe slight differences in the forecast transition between generations as published by each group; the inclusion of K6- and M2-based systems in the fifth generation (586-class) tends to slow the Computer Systems and Peripherals group's transition from 586 to 686 systems, relative to the Semiconductor group's chip forecast.

Intel faced no sixth-generation competition during 1996, but this was a year of market development, and Dataquest estimates that fewer than three million Pentium Pro devices will have been sold by year end. Neither AMD nor Cyrix has shipped a sixth-generation device to date, although AMD claims to be shipping samples of its K6 device this quarter. This represents a remarkable turnaround for AMD, which could not ship any fifth-generation processors until March of this year. If AMD continues to execute well on this program, and if its sales and marketing departments can match the success of its engineering and manufacturing staff, then the company will be well positioned as 1997 unfolds. Although Cyrix has yet to see first silicon for its "M2" processor, this effort is primarily an enhancement to the existing M1 design, as contrasted to the radical new designs incorporated in the Pentium Pro and K6 programs. Consequently, it carries a lower level of technology risk than those other two programs.

Table 1, along with Figures 1 and 2, provides Dataquest's estimate of the size of the computational x86 market, and the shift in the generational mix within that market.

MMX and AGP Enhancements Facilitate Multimedia Performance

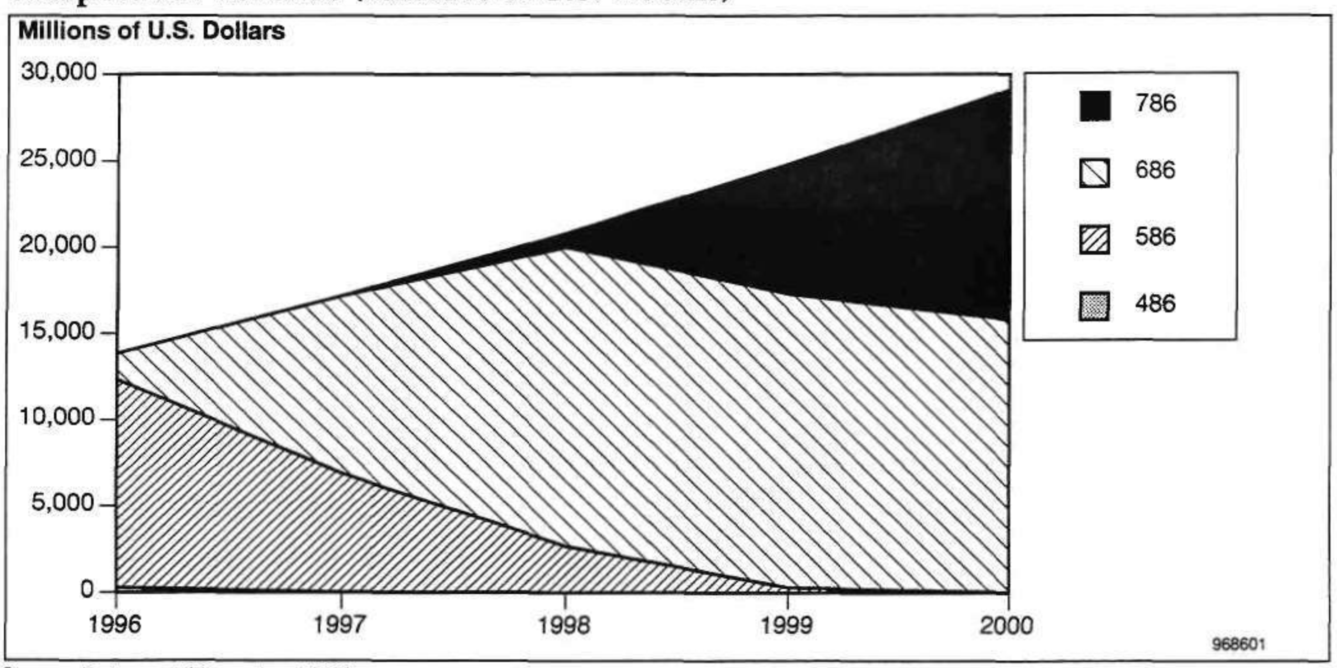
All three new processors incorporate the MMX extensions Intel originally defined for its (as yet unannounced) P55 microprocessor. The new MMX instructions allow an x86 processor to operate simultaneously on multiple data items (2 by 32 bits, 4 by 16 bits, or 8 by 8 bits), and facilitate video and audio decoding, DSP-like compression and decompression algorithms, and image processing. Both Cyrix and AMD are striving to provide binary compatibility with Intel in their MMX designs, which means software developers can exploit MMX extensions with the knowledge that such MMX-aware coding will operate on most x86 processors shipped in 1997 and beyond.

Table 1
Compute x86 Shipments, Average Selling Prices, and Revenue

	1996	1997	1998	1999	2000
Shipments (Thousands of Units)					
486	6,700	335	17	-	-
586	66,200	59,200	29,301	5,226	395
686	2,834	29,916	73,625	99,533	105,302
786	-	-	800	16,000	33,600
Total	75,733	89,451	103,743	120,759	139,296
Average Selling Price (U.S. Dollars)					
486	40	30	24		
586	182	116	91	54	20
686	530	344	235	171	150
786			1,000	470	395
Total	183	192	201	205	209
Revenue (Millions of U.S. Dollars)					
486	268	10	0	-	-
586	12,070	6,896	2,678	282	8
686	1,502	10,279	17,322	17,005	15,813
786	-	-	800	7,520	13,272
Total	13,840	17,185	20,801	24,807	29,093

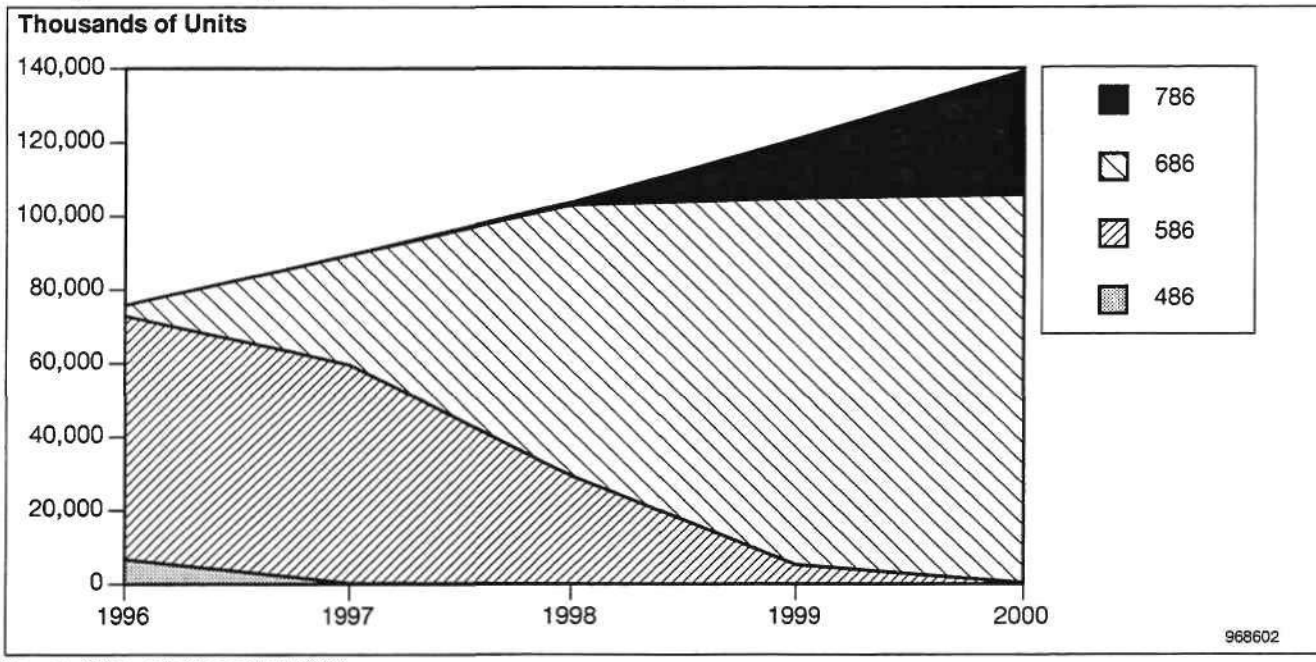
Source: Dataquest (December 1996)

Figure 1
Compute x86 Revenue (Millions of U.S. Dollars)



Source: Dataquest (December 1996)

Figure 2
Compute x86 Shipments (Thousands of Units)



Source: Dataquest (December 1996)

Along with its MMX extensions, Intel also defined a new high-speed interconnection between a system's main memory and its graphics controller. This architecture, known as the Accelerated Graphics Port (AGP) is (in theory) processor independent, and can be incorporated into other system architectures, merely by redesigning the core logic that supports those architectures. Intel has indicated its intent to offer AGP features only in conjunction with its Pentium Pro core logic. Intel's decision not to provide these features in its popular line of Pentium core logic products could impact AMD and Cyrix. These x86 clone chips contain a Pentium-style bus, and thus require Pentium-style core logic. Dataquest anticipates that several suppliers of Pentium core logic will incorporate the AGP features into their products, and thus provide a functionally equivalent platform for vendors choosing to pursue high-end, non-Pentium Pro desktop alternatives in 1997.

Bus Structures Diverge

Fourth- and fifth-generation x86 processors experienced an unusual convergence of external bus architectures. From the first 486 design in 1989 to the last in 1995, the nature of the protocol between an x86 microprocessor and its host environment barely changed. All Pentium processors, along with 6x86s and K5s, have shared a common bus architecture that simplified compatibility and design efforts for system vendors. Historically, this is an exception, rather than a rule. First-generation processors (the 8086 and 8088) used different interfaces (16- and 8-bits wide, respectively), while the third-generation 386 came with both 32-bit (DX) and 16-bit (SX) bus architectures. Sixth-generation systems will once again experience a multitude of incompatible busing arrangements.

Intel introduced a new bus architecture (the P6 bus) in 1995 with its initial Pentium Pro products. Although Dataquest expects the shape of the Pentium Pro package to change with the Klamath introduction early in 1997, the electrical properties of the Pentium Pro bus should remain unchanged. The new bus architecture was driven largely by Intel's desire to make Pentium Pro performance scale more closely in multiprocessor systems, and over a higher range of operating frequencies. The original Pentium design forces high-speed cache operations to a bus aimed primarily at input-output tasks, and this makes the cache less and less efficient as the core processor speed increases. The Pentium Pro design includes a bus for I/O, and a separate "backdoor bus" to access the cache.

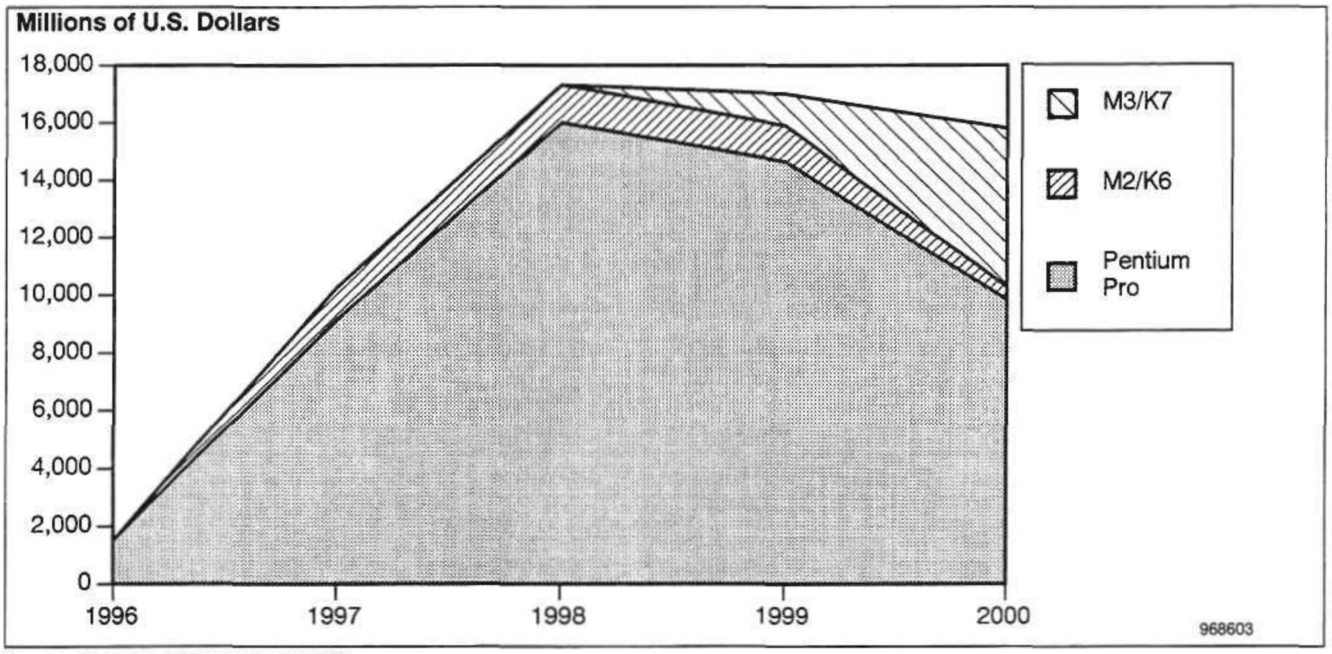
Dataquest speculates that as Cyrix and AMD finalize their M3 and K7 designs, they will be forced to add backdoor buses for performance (NexGen already had such a bus, and removed it in the final K6 design). But the wall of IP protection Intel erected around the P6 bus may keep the clones away from that design. Consequently, they will be driven to adopt some variation of the current Pentium scheme, augmented by a separate backdoor bus. Thus, the sixth-generation x86 architecture will encompass three different bus designs, which we will name simply as "6A," "6B," and "6C." 6A products include the original Pentium Pro, along with the planned Klamath and Deschutes processors. 6B includes the soon-to-be-released M2 and K6 products. 6C will include the K7 and M3 designs. It is not yet clear whether AMD and Cyrix will converge on a single "6C" architecture, or if they will further bifurcate the market; an eventuality that will aid neither vendor. Table 2 and Figures 3 and 4 illustrate the interplay between products based on these three distinct sixth-generation bus designs.

Table 2
Sixth-Generation Bus Architectures

	1996	1997	1998	1999	2000
Shipments (Thousands of Units)					
6A—Pentium Pro	2,834	25,460	65,360	81,858	82,037
6B—M2/K6	-	4,456	8,264	15,679	7,496
6C—M3/K7	-	-	-	1,997	15,769
Average Selling Price (U.S. Dollars)					
6A—Pentium Pro	530	360	245	179	120
6B—M2/K6		250	160	80	60
6C—M3/K7				550	350
Revenue (Millions of U.S. Dollars)					
6A—Pentium Pro	1,502	9,165	16,000	14,653	9,844
6B—M2/K6	-	1,114	1,322	1,254	450
6C—M3/K7	-	-	-	1,098	5,519

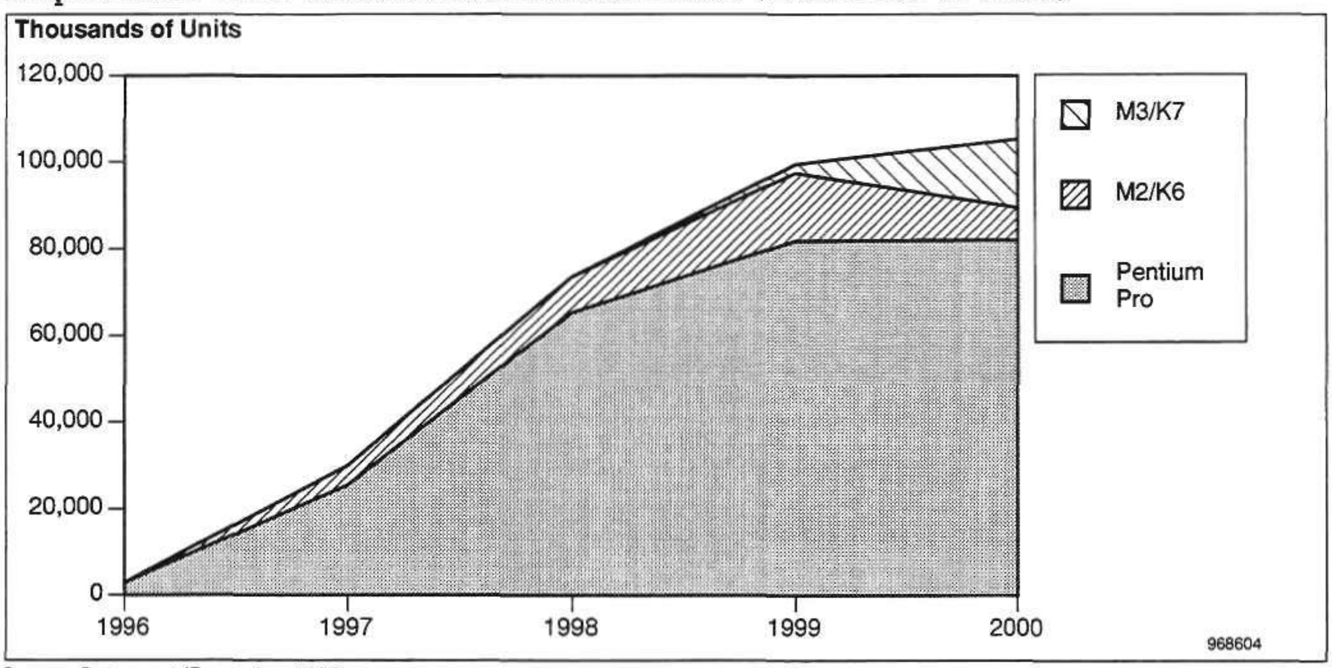
Source: Dataquest (December 1996)

Figure 3
Revenue from Sixth-Generation Bus Architectures (Millions of U.S. Dollars)



Source: Dataquest (December 1996)

Figure 4
Shipments of Sixth-Generation Bus Architectures (Thousands of Units)



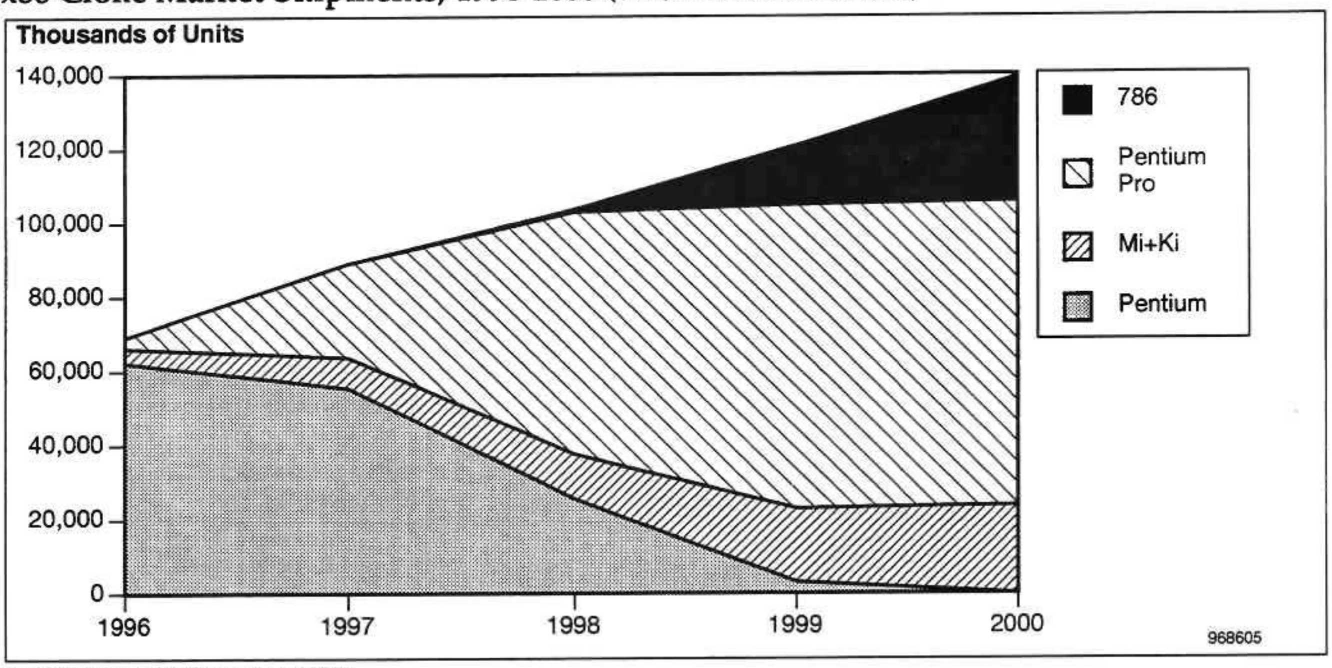
Source: Dataquest (December 1996)

x86 Clone Market to Grow Dramatically

Historically, products offered by x86 clone vendors have lagged the performance of those offered by Intel by one to three years, and this has precluded these vendors from participating in mainstream markets. By the time AMD and Cyrix have gotten to market, Intel has moved on and the cloners must deal with constantly eroding price structures. Events may play out differently during this cycle.

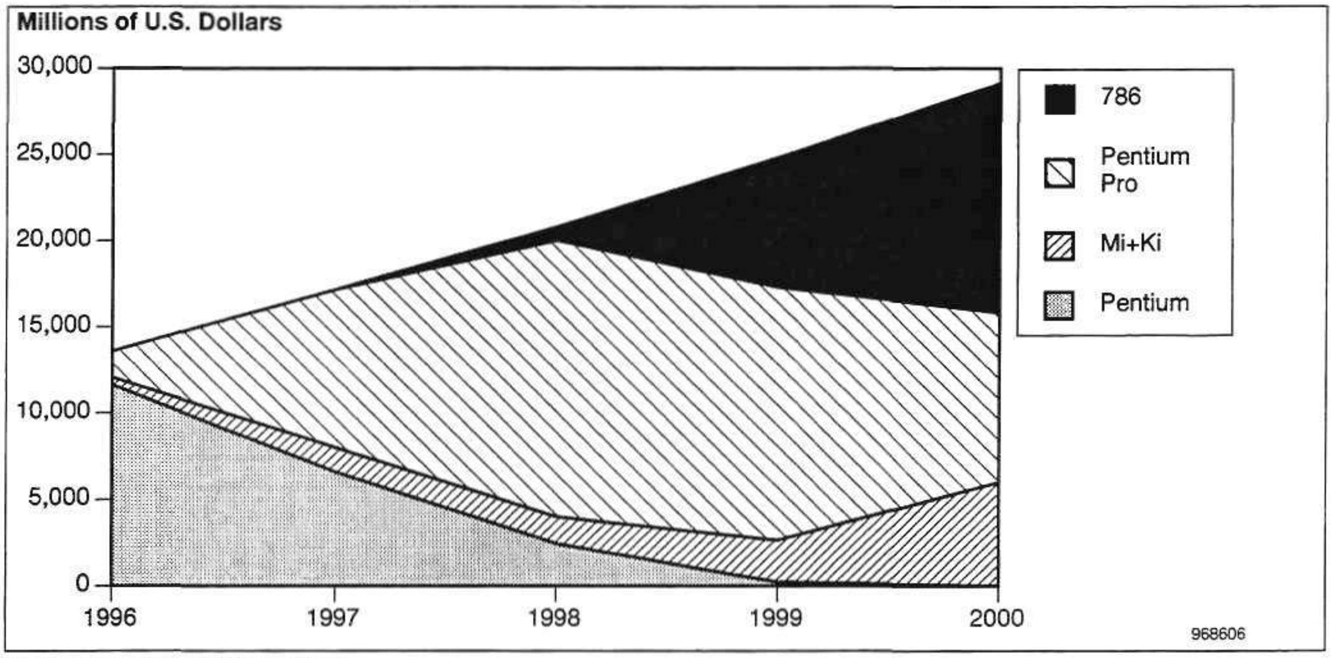
Dataquest anticipates that both AMD and Cyrix will introduce processors that can compete across the board with Intel's products in desktop environments. This has never happened before. Although Intel is highly regarded for its marketing prowess, and feared because of its market presence, it has always had a technological lead over other x86 vendors. Given Intel's margin structure, AMD and Cyrix may well be able to offer competitive products at substantial discounts to Intel's prices. Intel may be reluctant to respond with across-the-board price reductions, which would reduce its revenue stream far more than any competitive inroads AMD or Cyrix might achieve. Should such a competitive environment develop, Dataquest believes the x86 clone market could grow to over 23 million units, worth over $6 billion by the year 2000. Table 3 and Figures 5 and 6 illustrate how the small trickle of x86 clones may turn into a raging flood over the next few years. This river of clones will carve an ever-larger canyon between Intel's Pentium and Pentium Pro (and later Merced) product lines.

Figure 5
x86 Clone Market Shipments, 1996-2000 (Thousands of Units)



Source: Dataquest (December 1996)

Figure 6
x86 Clone Market Revenue, 1996-2000 (Millions of U.S. Dollars)



Source: Dataquest (December 1996)

Table 3
Clone Penetration of x86 Market, 1996-2000

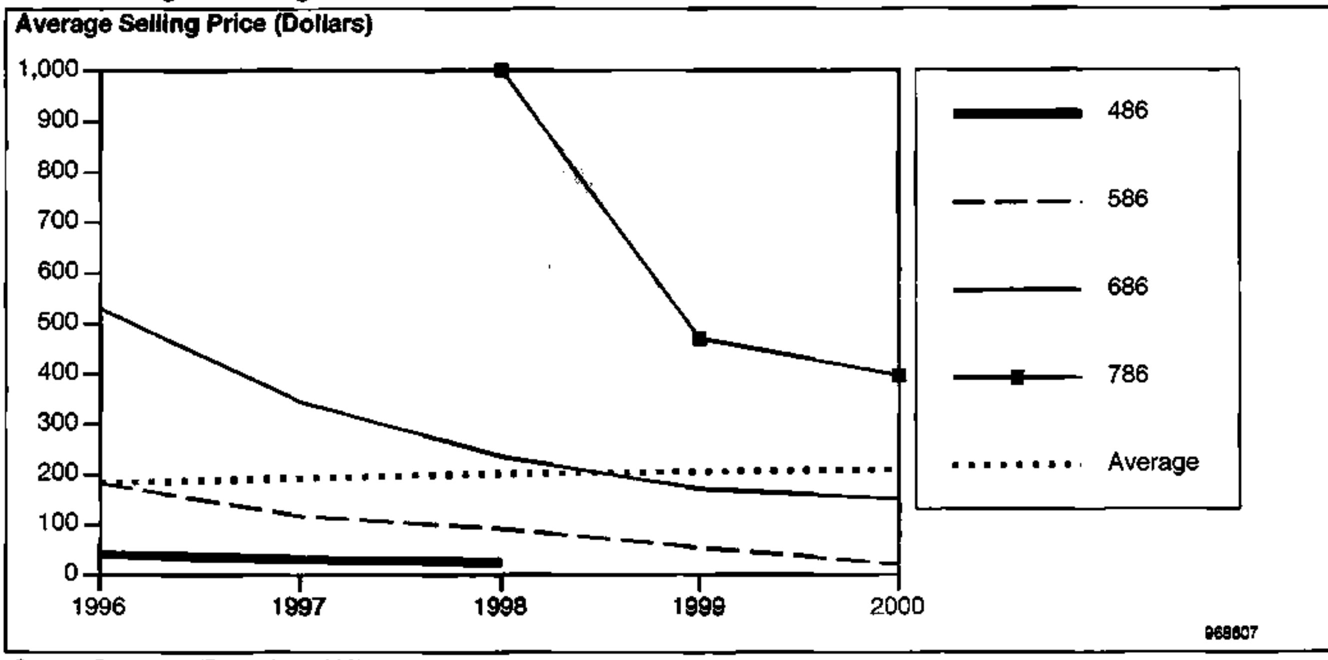
	1996	1997	1998	1999	2000
Shipments (Thousands of Units)					
486	6,700	335	17	-	-
Pentium	62,228	55,381	25,545	3,136	-
M1, 2, 3+K5, 6, 7	3,972	8,275	12,021	19,766	23,659
Pentium Pro	2,834	25,460	65,360	81,858	82,037
786			800	16,000	33,600
Total	75,733	89,451	103,743	120,759	139,296
Average Selling Price (U.S. Dollars)					
486	40	30	24		
Pentium	187	119	96	70	
M1, 2, 3+K5, 6, 7	109	172	129	122	253
Pentium Pro	530	360	245	179	120
786			1,000	470	395
Average	183	192	201	205	209
Revenue (Millions of U.S. Dollars)					
486	268	10	0	-	-
Pentium	11,637	6,590	2,452	219	-
M1, 2, 3+K5, 6, 7	433	1,420	1,548	2,415	5,977
Pentium Pro	1,502	9,165	16,000	14,653	9,844
786	-	-	800	7,520	13,272
Total	13,840	17,185	20,801	24,807	29,093

Source: Dataquest (December 1996)

Declining Chip Prices Lead to Higher Average Selling Prices

Dataquest projects that the x86 market will continue to display its paradoxical behavior in which rapidly falling prices for each product family accompany an overall increase in the average selling price of an x86 microprocessor. A product mix that continually shifts toward the high end accounts for this unusual phenomenon, which is illustrated in Table 4 and Figure 7.

Figure 7
x86 Average Selling Prices



Source: Dataquest (December 1996)

Table 4
x86 Average Selling Prices (Dollars)

	1996	1997	1998	1999	2000
486	40	30	24	-	-
586	182	116	91	54	20
686	530	344	235	171	150
786	-	-	1,000	470	395
Average	183	192	201	205	209

Source: Dataquest (December 1996)

Shipments of Fifth-Generation Microprocessors Begin to Decline

Table 5 and Figure 8 illustrate the manner in which sixth-generation designs will seize the mainstream market over the next four quarters, while fifth-generation designs move increasingly toward the low end. Quarterly sales of 686 processors will increase tenfold, from just over a million units in the fourth quarter of 1996, to just under 12 million in fourth quarter 1997.

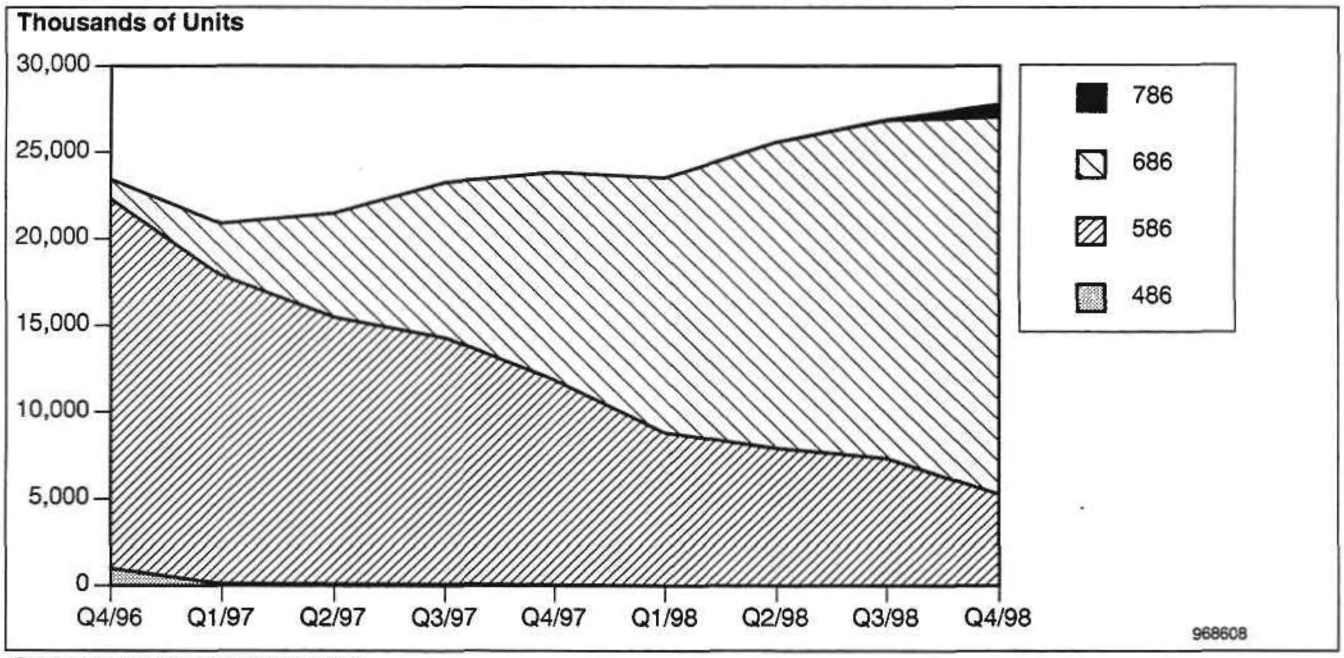
During this same period, shipments of 586-class products will decrease 45 percent, from over 21 million to just under 12 million in fourth quarter 1997. Dataquest anticipates that Merced, the first of Intel's seventh-generation products, and the first 64-bit x86, will stage an appearance in the latter part of 1998, but will not achieve mainstream status until the next century.

Table 5
Quarterly Shipments of Compute x86 Microprocessors (Thousands of Units)

	Q4/96	Q1/97	Q2/97	Q3/97	Q4/97	Q1/98	Q2/98	Q3/98	Q4/98
486	1,005	117	100	84	33	8	4	3	2
586	21,310	17,760	15,392	14,208	11,840	8,790	7,911	7,325	5,274
686	1,134	2,992	5,983	8,975	11,966	14,725	17,670	19,510	21,719
786	0	0	0	0	0	0	0	40	760

Source: Dataquest (December 1996)

Figure 8
Compute x86 Microprocessors Shipments (Thousands of Units)



Source: Dataquest (December 1996)

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Dataquest Predicts

Quarterly x86 Forecast: A River Runs through It

Abstract: *We have adjusted our chip forecast up slightly, to reflect the strong market conditions in the fourth quarter, and a slightly more optimistic forecast on the part of Dataquest's Computer Systems and Peripherals group. We have also reclassified the forthcoming "M2" from Cyrix and "K6" from AMD as sixth-generation devices, albeit sixth-generation devices with fifth-generation external buses.*

By Nathan Brookwood

Sixth-Generation Microprocessors Go Mainstream

Dataquest anticipates that shipments of fifth-generation ("586") x86 microprocessors—including the Intel Pentium, the Cyrix 6x86, and the AMD 5K86—will reach a peak of about 21.3 million units per quarter in the fourth quarter of 1996, and will then begin their slow descent into history, at least within computational (or general purpose) markets. New sixth-generation ("686") parts from Intel, AMD, and Cyrix will begin to ship in meaningful quantities in the first half of 1997, and the generational transition will be in full force by the end of the year; quarterly shipments of sixth-generation processors will surpass fifth-generation MPUs by the fourth quarter, a bit earlier than previously forecast.

Our reclassification of the planned AMD and Cyrix processors as sixth-generation devices contributes to the acceleration of this transition. In earlier forecasts, the Dataquest Semiconductor group classified these devices as "fifth-generation," primarily because they use the same external bus interface as Intel's Pentium processor, instead of the newer (and more complex) external interface used in Intel's Pentium Pro line. It now appears certain that AMD and Cyrix will avoid the Pentium Pro bus entirely, primarily because of intellectual property concerns. These vendors also argue that the

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newer bus fails to provide any performance benefit in uniprocessor configurations. Intel markets its Pentium Pro line into both uniprocessor (desktop) and multiprocessor (server) environments, and the latter do benefit from the more complex bus. In any event, given that Dataquest's Semiconductor group counts chips, while the Computer Systems and Peripherals group more properly looks at sockets, we are parting ways with regard to this generational taxonomy. The Computer Systems and Peripherals group will continue to use bus architecture (and its associated processor socket) as the key determinants for generational definitions, and will thus categorize systems containing the K6 and M2 as "fifth-generation" personal computer architectures. Alert readers may observe slight differences in the forecast transition between generations as published by each group; the inclusion of K6- and M2-based systems in the fifth generation (586-class) tends to slow the Computer Systems and Peripherals group's transition from 586 to 686 systems, relative to the Semiconductor group's chip forecast.

Intel faced no sixth-generation competition during 1996, but this was a year of market development, and Dataquest estimates that fewer than three million Pentium Pro devices will have been sold by year end. Neither AMD nor Cyrix has shipped a sixth-generation device to date, although AMD claims to be shipping samples of its K6 device this quarter. This represents a remarkable turnaround for AMD, which could not ship any fifth-generation processors until March of this year. If AMD continues to execute well on this program, and if its sales and marketing departments can match the success of its engineering and manufacturing staff, then the company will be well positioned as 1997 unfolds. Although Cyrix has yet to see first silicon for its "M2" processor, this effort is primarily an enhancement to the existing M1 design, as contrasted to the radical new designs incorporated in the Pentium Pro and K6 programs. Consequently, it carries a lower level of technology risk than those other two programs.

Table 1, along with Figures 1 and 2, provides Dataquest's estimate of the size of the computational x86 market, and the shift in the generational mix within that market.

MMX and AGP Enhancements Facilitate Multimedia Performance

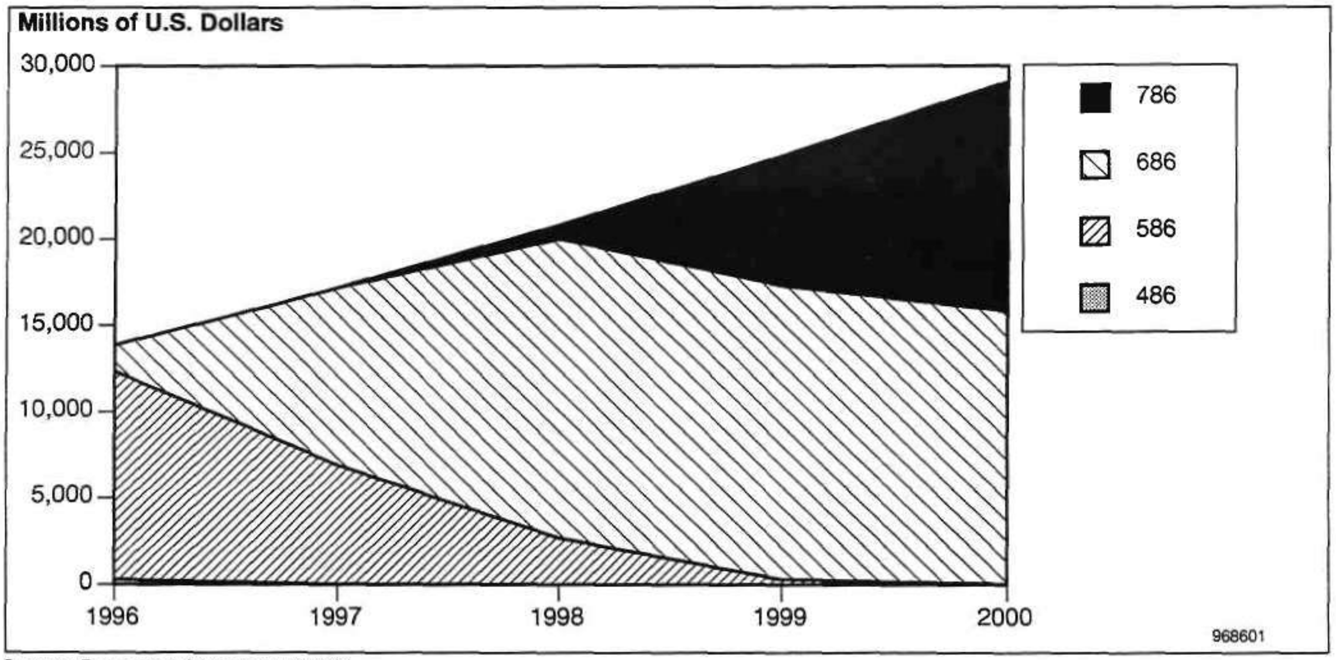
All three new processors incorporate the MMX extensions Intel originally defined for its (as yet unannounced) P55 microprocessor. The new MMX instructions allow an x86 processor to operate simultaneously on multiple data items (2 by 32 bits, 4 by 16 bits, or 8 by 8 bits), and facilitate video and audio decoding, DSP-like compression and decompression algorithms, and image processing. Both Cyrix and AMD are striving to provide binary compatibility with Intel in their MMX designs, which means software developers can exploit MMX extensions with the knowledge that such MMX-aware coding will operate on most x86 processors shipped in 1997 and beyond.

Table 1
Compute x86 Shipments, Average Selling Prices, and Revenue

	1996	1997	1998	1999	2000
Shipments (Thousands of Units)					
486	6,700	335	17	-	-
586	66,200	59,200	29,301	5,226	395
686	2,834	29,916	73,625	99,533	105,302
786	-	-	800	16,000	33,600
Total	75,733	89,451	103,743	120,759	139,296
Average Selling Price (U.S. Dollars)					
486	40	30	24		
586	182	116	91	54	20
686	530	344	235	171	150
786			1,000	470	395
Total	183	192	201	205	209
Revenue (Millions of U.S. Dollars)					
486	268	10	0	-	-
586	12,070	6,896	2,678	282	8
686	1,502	10,279	17,322	17,005	15,813
786	-	-	800	7,520	13,272
Total	13,840	17,185	20,801	24,807	29,093

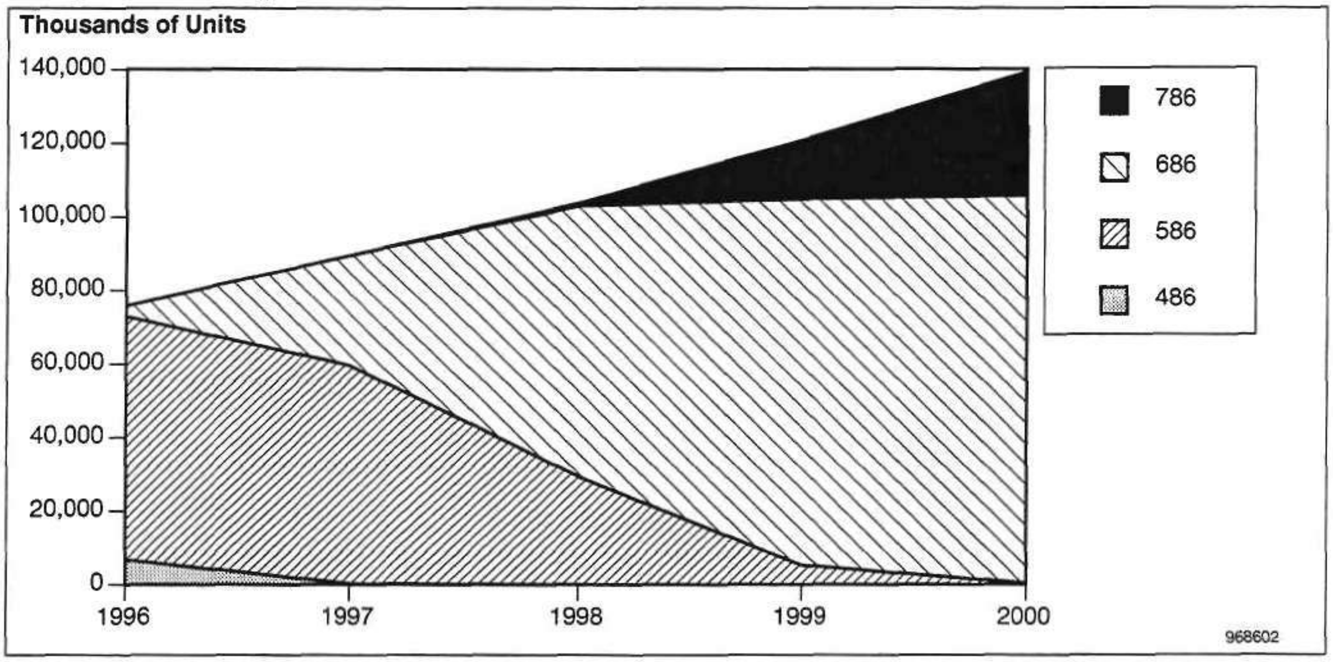
Source: Dataquest (December 1996)

Figure 1
Compute x86 Revenue (Millions of U.S. Dollars)



Source: Dataquest (December 1996)

Figure 2
Compute x86 Shipments (Thousands of Units)



Source: Dataquest (December 1996)

Along with its MMX extensions, Intel also defined a new high-speed interconnection between a system's main memory and its graphics controller. This architecture, known as the Accelerated Graphics Port (AGP) is (in theory) processor independent, and can be incorporated into other system architectures, merely by redesigning the core logic that supports those architectures. Intel has indicated its intent to offer AGP features only in conjunction with its Pentium Pro core logic. Intel's decision not to provide these features in its popular line of Pentium core logic products could impact AMD and Cyrix. These x86 clone chips contain a Pentium-style bus, and thus require Pentium-style core logic. Dataquest anticipates that several suppliers of Pentium core logic will incorporate the AGP features into their products, and thus provide a functionally equivalent platform for vendors choosing to pursue high-end, non-Pentium Pro desktop alternatives in 1997.

Bus Structures Diverge

Fourth- and fifth-generation x86 processors experienced an unusual convergence of external bus architectures. From the first 486 design in 1989 to the last in 1995, the nature of the protocol between an x86 microprocessor and its host environment barely changed. All Pentium processors, along with 6x86s and K5s, have shared a common bus architecture that simplified compatibility and design efforts for system vendors. Historically, this is an exception, rather than a rule. First-generation processors (the 8086 and 8088) used different interfaces (16- and 8-bits wide, respectively), while the third-generation 386 came with both 32-bit (DX) and 16-bit (SX) bus architectures. Sixth-generation systems will once again experience a multitude of incompatible busing arrangements.

Intel introduced a new bus architecture (the P6 bus) in 1995 with its initial Pentium Pro products. Although Dataquest expects the shape of the Pentium Pro package to change with the Klamath introduction early in 1997, the electrical properties of the Pentium Pro bus should remain unchanged. The new bus architecture was driven largely by Intel's desire to make Pentium Pro performance scale more closely in multiprocessor systems, and over a higher range of operating frequencies. The original Pentium design forces high-speed cache operations to a bus aimed primarily at input-output tasks, and this makes the cache less and less efficient as the core processor speed increases. The Pentium Pro design includes a bus for I/O, and a separate "backdoor bus" to access the cache.

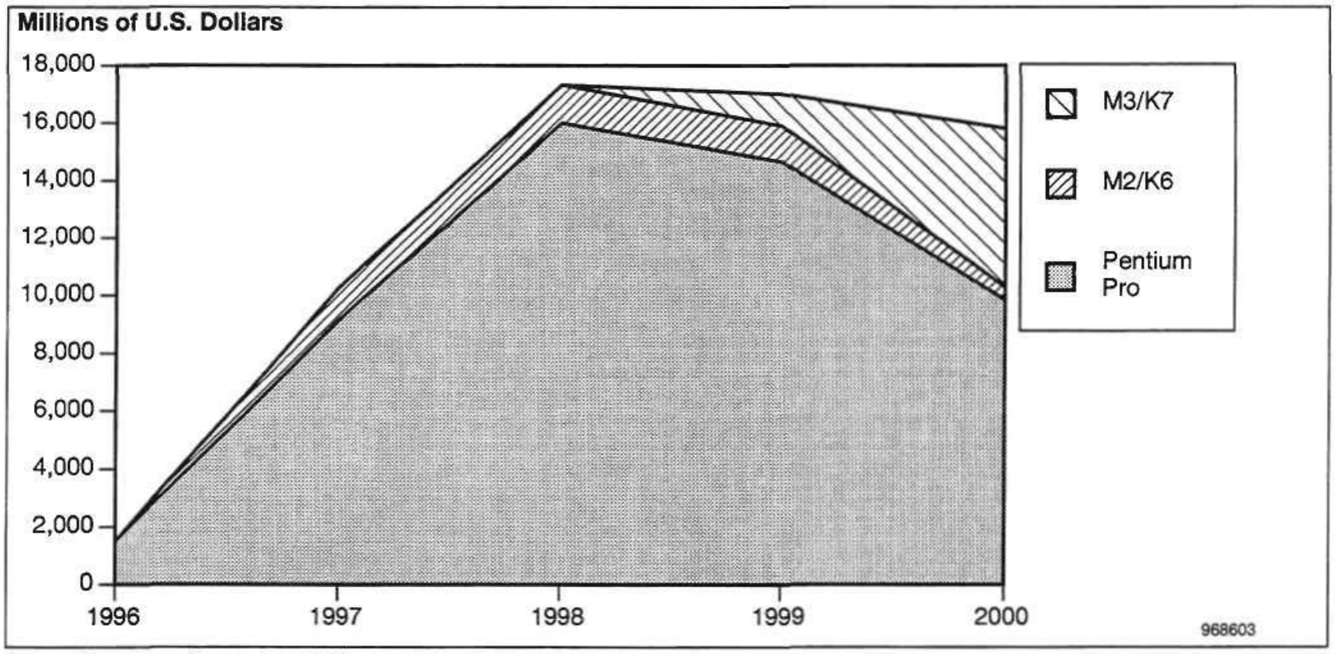
Dataquest speculates that as Cyrix and AMD finalize their M3 and K7 designs, they will be forced to add backdoor buses for performance (NexGen already had such a bus, and removed it in the final K6 design). But the wall of IP protection Intel erected around the P6 bus may keep the clones away from that design. Consequently, they will be driven to adopt some variation of the current Pentium scheme, augmented by a separate backdoor bus. Thus, the sixth-generation x86 architecture will encompass three different bus designs, which we will name simply as "6A," "6B," and "6C." 6A products include the original Pentium Pro, along with the planned Klamath and Deschutes processors. 6B includes the soon-to-be-released M2 and K6 products. 6C will include the K7 and M3 designs. It is not yet clear whether AMD and Cyrix will converge on a single "6C" architecture, or if they will further bifurcate the market; an eventuality that will aid neither vendor. Table 2 and Figures 3 and 4 illustrate the interplay between products based on these three distinct sixth-generation bus designs.

Table 2
Sixth-Generation Bus Architectures

	1996	1997	1998	1999	2000
Shipments (Thousands of Units)					
6A—Pentium Pro	2,834	25,460	65,360	81,858	82,037
6B—M2/K6	-	4,456	8,264	15,679	7,496
6C—M3/K7	-	-	-	1,997	15,769
Average Selling Price (U.S. Dollars)					
6A—Pentium Pro	530	360	245	179	120
6B—M2/K6		250	160	80	60
6C—M3/K7				550	350
Revenue (Millions of U.S. Dollars)					
6A—Pentium Pro	1,502	9,165	16,000	14,653	9,844
6B—M2/K6	-	1,114	1,322	1,254	450
6C—M3/K7	-	-	-	1,098	5,519

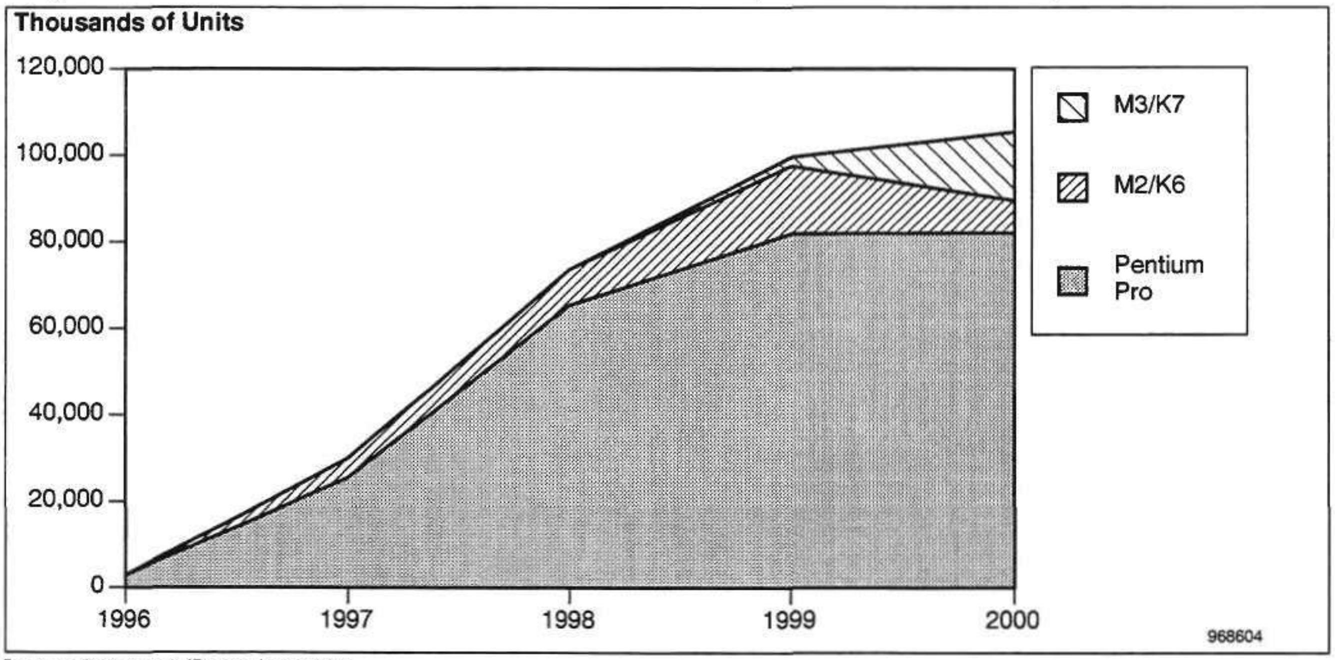
Source: Dataquest (December 1996)

Figure 3
Revenue from Sixth-Generation Bus Architectures (Millions of U.S. Dollars)



Source: Dataquest (December 1996)

Figure 4
Shipments of Sixth-Generation Bus Architectures (Thousands of Units)



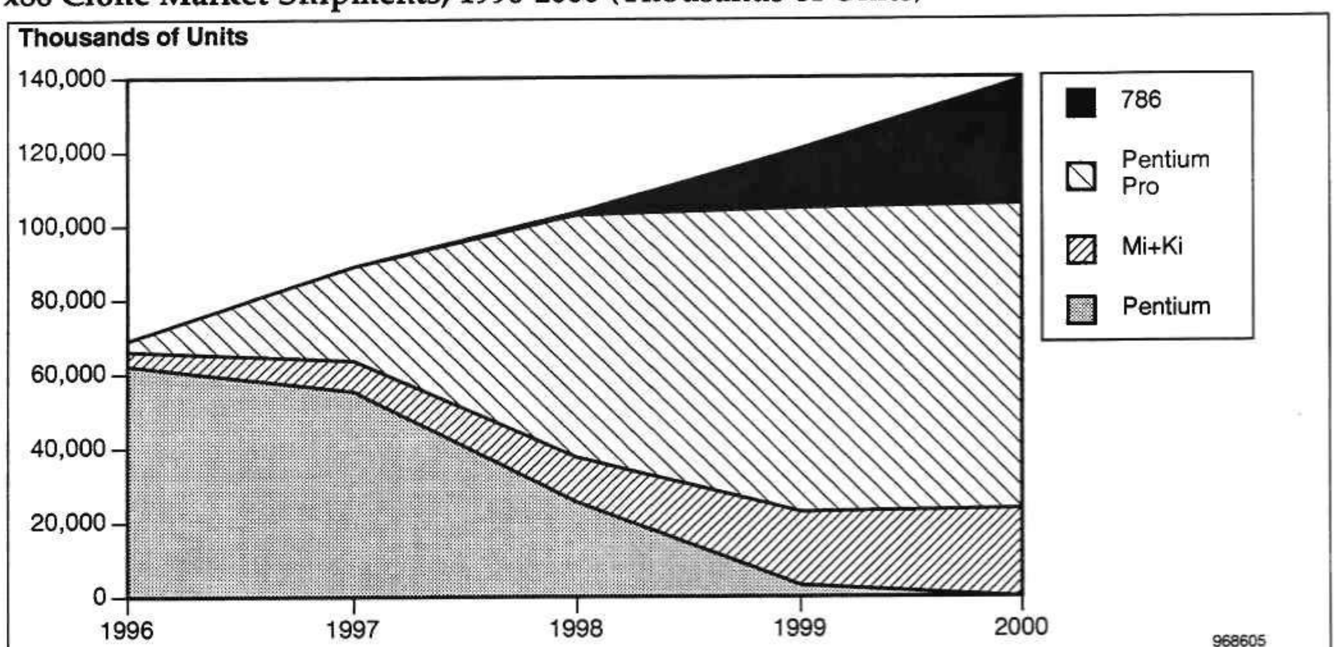
Source: Dataquest (December 1996)

x86 Clone Market to Grow Dramatically

Historically, products offered by x86 clone vendors have lagged the performance of those offered by Intel by one to three years, and this has precluded these vendors from participating in mainstream markets. By the time AMD and Cyrix have gotten to market, Intel has moved on and the cloners must deal with constantly eroding price structures. Events may play out differently during this cycle.

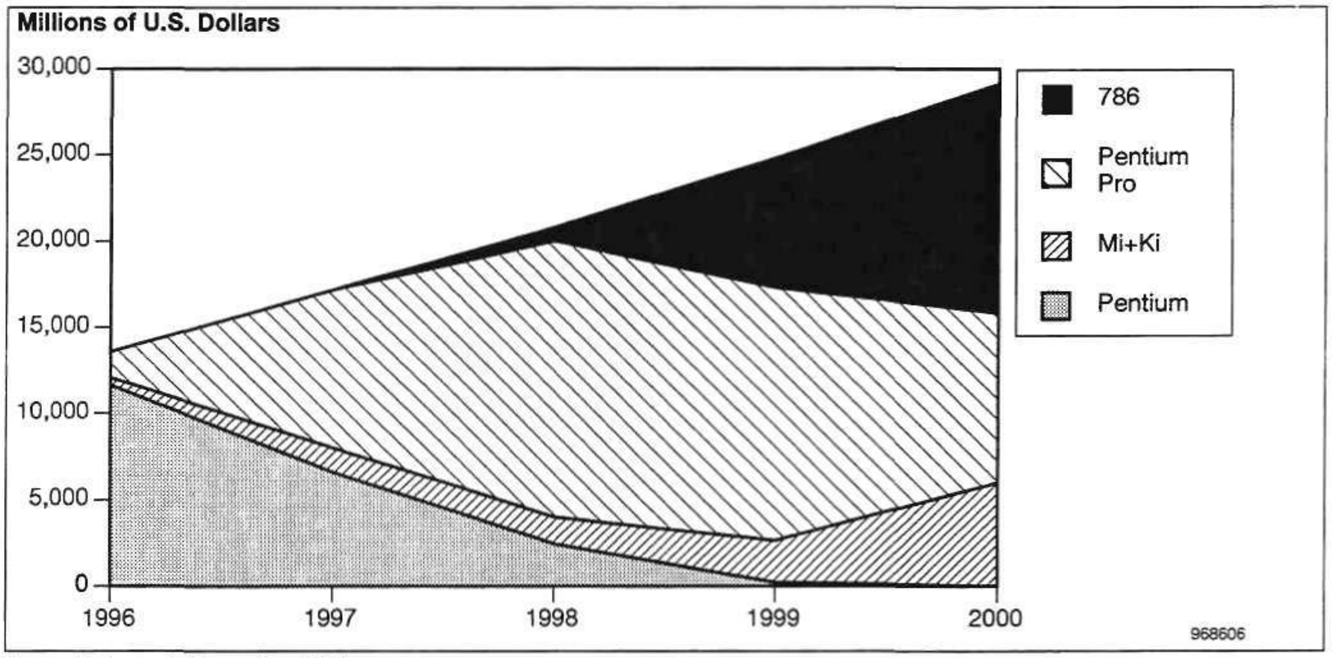
Dataquest anticipates that both AMD and Cyrix will introduce processors that can compete across the board with Intel's products in desktop environments. This has never happened before. Although Intel is highly regarded for its marketing prowess, and feared because of its market presence, it has always had a technological lead over other x86 vendors. Given Intel's margin structure, AMD and Cyrix may well be able to offer competitive products at substantial discounts to Intel's prices. Intel may be reluctant to respond with across-the-board price reductions, which would reduce its revenue stream far more than any competitive inroads AMD or Cyrix might achieve. Should such a competitive environment develop, Dataquest believes the x86 clone market could grow to over 23 million units, worth over $6 billion by the year 2000. Table 3 and Figures 5 and 6 illustrate how the small trickle of x86 clones may turn into a raging flood over the next few years. This river of clones will carve an ever-larger canyon between Intel's Pentium and Pentium Pro (and later Merced) product lines.

Figure 5
x86 Clone Market Shipments, 1996-2000 (Thousands of Units)



Source: Dataquest (December 1996)

Figure 6
x86 Clone Market Revenue, 1996-2000 (Millions of U.S. Dollars)



Source: Dataquest (December 1996)

Table 3
Clone Penetration of x86 Market, 1996-2000

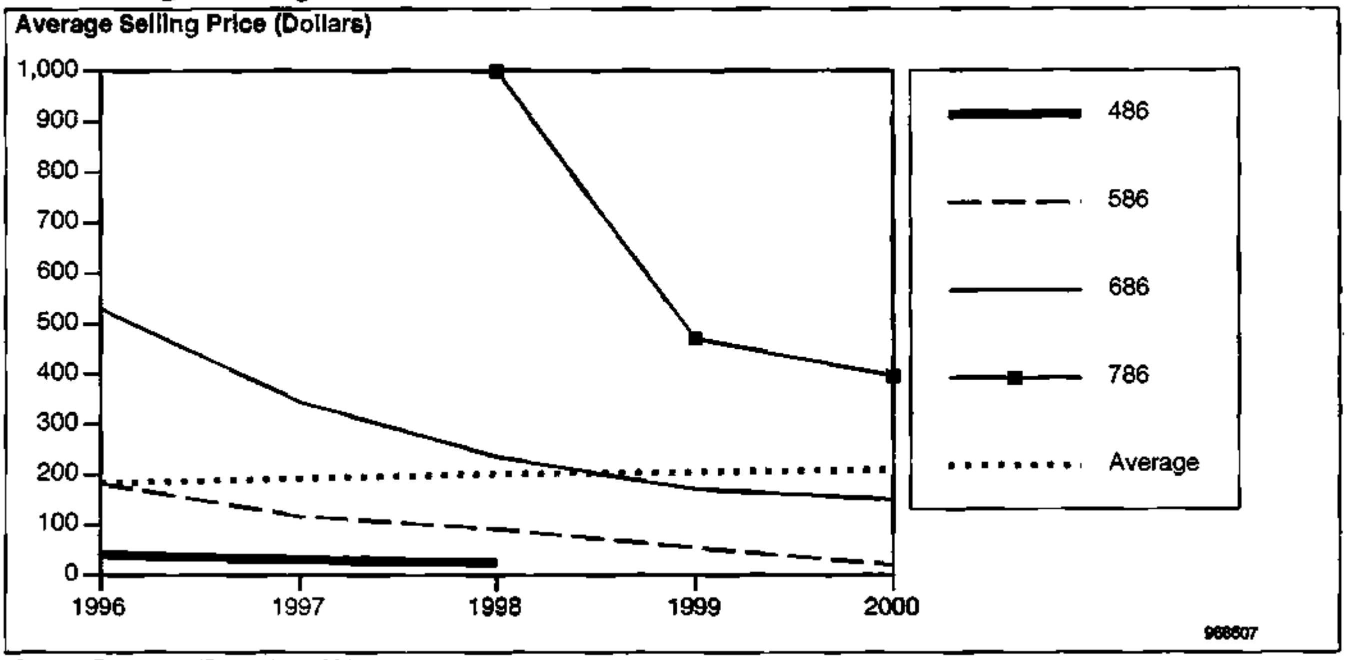
	1996	1997	1998	1999	2000
Shipments (Thousands of Units)					
486	6,700	335	17	-	-
Pentium	62,228	55,381	25,545	3,136	-
M1, 2, 3+K5, 6, 7	3,972	8,275	12,021	19,766	23,659
Pentium Pro	2,834	25,460	65,360	81,858	82,037
786			800	16,000	33,600
Total	75,733	89,451	103,743	120,759	139,296
Average Selling Price (U.S. Dollars)					
486	40	30	24		
Pentium	187	119	96	70	
M1, 2, 3+K5, 6, 7	109	172	129	122	253
Pentium Pro	530	360	245	179	120
786			1,000	470	395
Average	183	192	201	205	209
Revenue (Millions of U.S. Dollars)					
486	268	10	0	-	-
Pentium	11,637	6,590	2,452	219	-
M1, 2, 3+K5, 6, 7	433	1,420	1,548	2,415	5,977
Pentium Pro	1,502	9,165	16,000	14,653	9,844
786	-	-	800	7,520	13,272
Total	13,840	17,185	20,801	24,807	29,093

Source: Dataquest (December 1996)

Declining Chip Prices Lead to Higher Average Selling Prices

Dataquest projects that the x86 market will continue to display its paradoxical behavior in which rapidly falling prices for each product family accompany an overall increase in the average selling price of an x86 microprocessor. A product mix that continually shifts toward the high end accounts for this unusual phenomenon, which is illustrated in Table 4 and Figure 7.

Figure 7
x86 Average Selling Prices



Source: Dataquest (December 1996)

Table 4
x86 Average Selling Prices (Dollars)

	1996	1997	1998	1999	2000
486	40	30	24	-	-
586	182	116	91	54	20
686	530	344	235	171	150
786	-	-	1,000	470	395
Average	183	192	201	205	209

Source: Dataquest (December 1996)

Shipments of Fifth-Generation Microprocessors Begin to Decline

Table 5 and Figure 8 illustrate the manner in which sixth-generation designs will seize the mainstream market over the next four quarters, while fifth-generation designs move increasingly toward the low end. Quarterly sales of 686 processors will increase tenfold, from just over a million units in the fourth quarter of 1996, to just under 12 million in fourth quarter 1997.

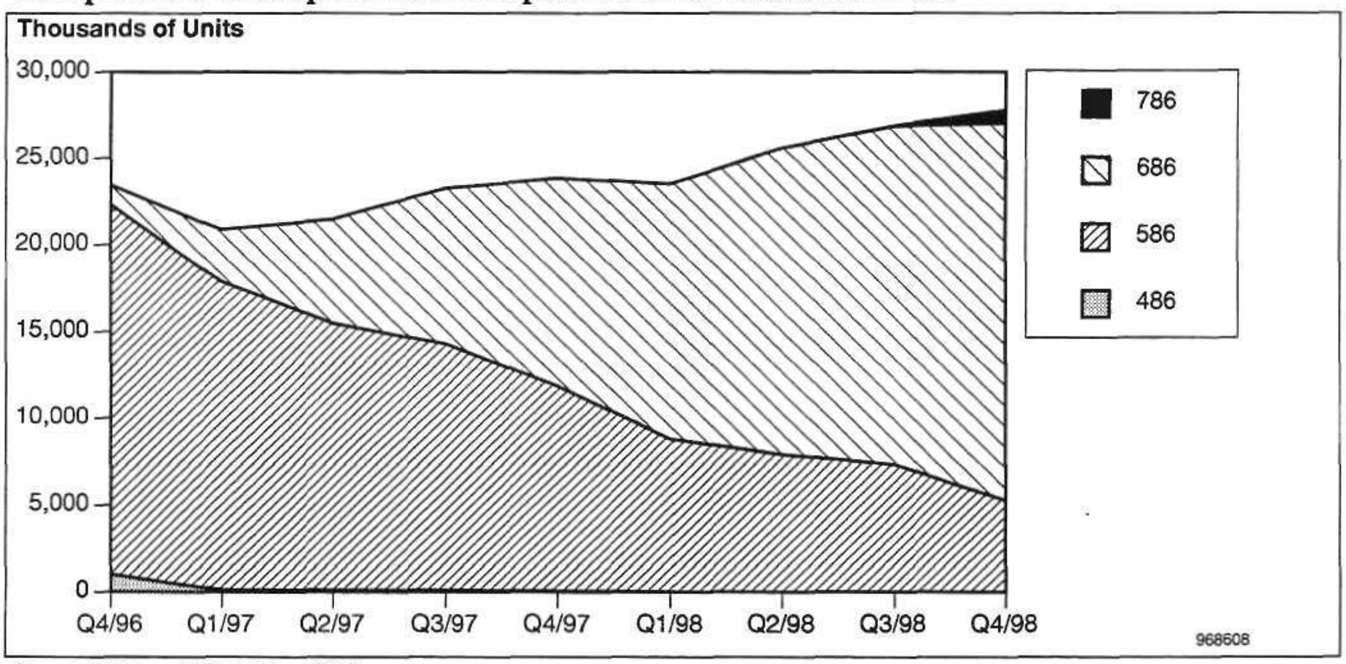
During this same period, shipments of 586-class products will decrease 45 percent, from over 21 million to just under 12 million in fourth quarter 1997. Dataquest anticipates that Merced, the first of Intel's seventh-generation products, and the first 64-bit x86, will stage an appearance in the latter part of 1998, but will not achieve mainstream status until the next century.

Table 5
Quarterly Shipments of Compute x86 Microprocessors (Thousands of Units)

	Q4/96	Q1/97	Q2/97	Q3/97	Q4/97	Q1/98	Q2/98	Q3/98	Q4/98
486	1,005	117	100	84	33	8	4	3	2
586	21,310	17,760	15,392	14,208	11,840	8,790	7,911	7,325	5,274
686	1,134	2,992	5,983	8,975	11,966	14,725	17,670	19,510	21,719
786	0	0	0	0	0	0	0	40	760

Source: Dataquest (December 1996)

Figure 8
Compute x86 Microprocessors Shipments (Thousands of Units)



Source: Dataquest (December 1996)

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Event Summary

COMDEX Demonstrations Herald Exciting Year to Come

Abstract: *This document is a collection of short news items with analysis about some of the major semiconductor announcements at this year's COMDEX show in Las Vegas. Contributions were made by several analysts, so the topics range from microprocessors to multimedia ICs, with a smattering of other software and semiconductor issues.*
By Geoff Ballew, Nathan Brookwood, Xavier Pucel, and George Iwanyc

1997 Brings New Technologies with Mass Appeal

If the displays on and off the floor at this year's COMDEX show in Las Vegas are any indication, 1997 will see the introduction of much new personal computer technology, which will have the potential to drive strong unit growth. The 19 percent market growth Dataquest expects to see for 1996 was achieved the old-fashioned way—vendors offered incredible values and kept prices low while they increased feeds and speeds across the board. At this time last year, the fastest machines included 133-MHz CPUs and 16MB DRAM and were priced at $2,500 to $3,000. Do not kick yourself too hard if you bought one then, just because the same configurations are going for $1,400 today. But aside from the improved speed and lower cost, there is nothing you can do on this year's systems that you cannot do with last year's machines.

MMX and MPUs

The year 1997 appears likely to be one in which the shape of new PCs may change more than usual. New x86 microprocessors from Intel, Advanced Micro Devices, and Cyrix, all with MMX technology, should hit the street during the first four months of the year. Several notebook vendors offered "technology demonstrations" of new, faster notebooks based on Intel's as-

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yet-unannounced P55C Pentium processors. AMD demonstrated (behind semiclosed doors) a side-by-side comparison of its forthcoming K6 processor and a 200-MHz Intel Pentium Pro; the two performed similarly on 32-bit applications, which are the Pentium Pro's strongest suit. Cyrix indicated that it is waiting for the first silicon on its next-generation M2 processor, which should also hit the market in this time frame. All three vendors have experienced strong demand over the past few months, with Intel and Cyrix (and its partners, IBM and SGS-Thomson) needing to allocate processor deliveries to customers that want to buy more units than they can supply. These system vendors clearly expect a strong selling season. If they do not get it, there could be some finished goods inventory hangover in January. The risk of an inventory hang for semiconductor devices is buffered by the relatively low inventories at most PC OEMs. At this time last year, PC OEMs had large inventories that they spent the first half of 1996 working through. This year presents a different scenario, but, nevertheless, Christmas sell-through of PCs will impact chip orders in the first quarter.

Core Logic

The coming year should see an interesting struggle at the PC infrastructure level. Intel will push hard to ramp Klamath, its next-generation Pentium Pro, which requires motherboards and core logic that differ significantly from the boards used for Pentium-based products. AMD and Cyrix will argue that boards originally designed for Pentium sockets can provide adequate performance for their new products, which will offer Pentium-Pro levels of performance. Pentium core logic vendors, which have been squeezed badly by Intel this past year, are poised to return next year with low-cost core logic for AMD, Cyrix, and Pentium systems that support features Intel plans only for its Pentium Pro products. Intel will thus leave its Pentium flank exposed; if the market votes for the lower-priced AMD and Cyrix approach, then these core logic vendors stand to benefit as well.

Media Processors

Chromatic Research and its partners demonstrated the Mpact media processor, now shipping, on and off the floor, and announced that the partnership had been broadened to include SGS-Thomson as well as Toshiba and LG Semicon. Philips demonstrated production prototypes of its forthcoming TM-1 media processor on and off the floor, as well. The open demonstrations included AC-3 audio decoding that produced sound that could be heard and felt. (This COMDEX set new decibel records and probably caused untold damage to participants' auditory systems. Doses of aspirin were a popular giveaway.) Off the floor, Philips showed early versions of MPEG-2 decoding and H.324 videoconferencing over plain old telephone service (POTS). Apple Computer acknowledged publicly, for the first time, its intent to incorporate the TM-1 into future Macintosh products.

3-D Graphics

The market for 3-D graphics chips is heating up! Several suppliers are shipping parts now, and virtually all of the others have 3-D products in their 1997 road map. These new chip offerings will raise the level of competition in the 3-D segment of the PC graphics market, and unit volumes should explode as a result. The year 1996 was a battle between S3 and ATI because only those two companies brought single-chip graphics subsystems (2-D, 3-D, video, and RAMDAC all in one chip) to market in time for motherboard design-wins. Both those companies have already "refreshed" their lines with faster versions of their 3-D chips. Cirrus Logic is shipping its Laguna3D chip, and Trident Microsystems was showing its new 3DImage, which was just out of the fab. Those four companies are the largest suppliers of PC graphics chips. Smaller graphics vendors are also into this game, including a number of start-up companies and even some big companies newly targeting this market. 3Dfx's Voodoo Graphics chips were running demonstrations in a number of booths. Voodoo Graphics does not include 2-D functions, so a traditional graphics chip is also required for PC applications. The company is teaming with Alliance Semiconductor and Trident Microsystems. Alliance Semiconductor was showing a reference design using its 3-D graphics chip with connectors for upgrading to 3Dfx's 3-D chipset. These pairings offer PC OEMs considerable scalability while maintaining software compatibility. NEC and VideoLogic were showing off the PowerVR chip called PCX1. Like 3Dfx's current product, PCX1 needs an additional graphics chip for 2-D functions. 3Dlabs is now shipping Permedia, which has a much lower price point than its popular GLint products. Permedia is being manufactured by both IBM and Texas Instruments. TI will serve as a foundry for 3Dlabs, as well marketing and selling Permedia itself. Both companies will develop and sell products based on 3Dlabs' 3-D graphics technology.

Software MPEG

It seemed like everywhere the COMDEX enthusiast might go on the show floor, there was a TV or a monitor showing MPEG demos. Most of the attention was on MPEG-2, but MPEG-1 still has a bit of life left in it. Sony's own software MPEG-1 codec, running on its VAIO PC line, looked great. With software decompression that looks this good, it is really hard to justify paying for MPEG-1 hardware. On the MPEG-2 side, demonstrations of software codecs were quite promising for the future. Some of the differences between MPEG-1 and MPEG-2 revolve around the variable-rate bitstream and higher data rate for MPEG-2, as well as the issue that MPEG-2 was designed for playback on interlaced displays such as TVs rather than progressive-scan monitors. These differences require more processing power for MPEG-2 decompression compared with MPEG-1, as well as additional processing to compensate for image defects caused by displaying interlaced video on a progressive display. The bottom line is that software MPEG-2 will be a reality for high-end PCs in the Christmas 1997 time frame and will migrate into the mainstream PC market as high-speed (200 MHz and higher) versions of Intel's Klamath MPU proliferate. This trend will be boosted by graphics controllers that have motion compensation engines, effectively offloading some (not all) of the video processing from the CPU.

Quicktime on Wintel

Macintosh-related announcements tend to be few and far between at COMDEX, but this year, Apple was pushing its new "platform agnostic" stance. Apple's Ellen Hancock gave a stirring speech in which she indicated her intent to sweep all vestiges of Apple's legendary NIH ("not invented here") syndrome out of the company. Apple is also taking a more aggressive attitude toward the licensing of its technology on non-Macintosh platforms and plans to emphasize the presence of its Quicktime Media Library (QTML) on Wintel platforms. This may help these standards achieve critical mass in the market but will also deny Apple the use of these features to differentiate itself from Wintel platforms. Neither alternative is ideal for Apple, but we would agree that it has chosen the better alternative.

Flat-Panel Displays

Flat panel vendors emphasized bigger and cheaper, but not necessarily both together. Crowds gathered at the Fujitsu booth to view a new 42-inch-diagonal (about 1.1-meter) plasma display. NEC showed the largest TFT (20 inches, or 0.5m) that this analyst has ever seen. Both these displays are showpieces, and neither is manufacturable in high volume today. Nor are they priced for volume markets—yet. The good news is that TFTs priced for volume markets are getting bigger all the time. Fourteen-inch displays are the next step beyond 12 inches, and many vendors were showing off displays of that size. Although 14-inch-and-larger flat panels are tough to shoehorn into a notebook PC, these displays will help to bring TFTs into other applications where a thin screen is preferred to a bulky CRT, including deskbound PCs. Dataquest expects CRTs will continue to dominate the desktop for several years, but these larger panels will make TFTs more attractive for desktop applications.

Windows CE

A myriad of Windows CE handheld computers debuted at this show. Typically the size of a classic handheld organizer, these devices possess a user interface close enough to Windows 95 to allow most users to use the handhelds with little or no retraining, and they address the "data synchronization" problem (between desktop and mobile devices) in a fairly clean manner. Just as standardization of the desktop environment with DOS, Windows, and Windows 95 has driven growth in that segment, the extension of these standards to handhelds may spur further growth here, too. These new handhelds use RISC microprocessors from Hitachi (SH-3) and MIPS (via NEC). Thus, growth in this area could give the RISC vendors a fighting chance in computational microprocessor markets, where they have been struggling of late.

Memory Devices

Memory producers have a lot to look forward to in the next decade. Everywhere Dataquest looked, another digital camera or 3-D graphics card screamed a need for more memory. It looks as though 32MB of EDO DRAM will soon become the standard configuration for desktop PCs, and 1997 will be the year that synchronous DRAM starts to gain market share. Looking further into the future, Andy Grove shared Intel's prediction that PCs will be configured with 512MB of memory in 2011. Samsung, NEC, Hitachi, and the rest of the DRAM producers are definitely up to the task. Samsung displayed several 8-inch wafers with 1Gb DRAMs. Even at 0.18-micron geometries, Samsung can fit only 28 of the huge chips—easily 1 inch by 1/2 inch—on an 8-inch wafer! It's a certainty that the company will be one of the first to go to 300mm wafers. Samsung estimates that a single 1Gb chip can store 8,000 pages of text, 400 photos, or 14 hours of audio.

Memory Modules

Third-party memory module manufacturers were well represented at COMDEX. Kingston Technology remains the largest and most visible module manufacturer, but an abundance of competitors offered slight twists to the quick and flexible manufacturing business model Kingston champions. If there is a common ground for this camp, it is its dedication to educating the distribution channels and end users about the benefits of more megabytes and the undiluted interest in growing OEM relationships with PC manufacturers and DRAM producers. The memory module manufacturers have followed up on Samsung's announcement two months ago about the benefits of increased memory sizes on system performance. The module manufacturers realize they have a lot to gain if end users pick up on the megabyte message, so they have grabbed the megaphone. As for the common goal of increasing third-party presence in the PC OEM channel, Kingston again was the most visible with its announcement last week about its teaming with Toshiba. Kingston announced that it has been selected by Toshiba America Information Systems as the company's official supplier of memory upgrades for Toshiba's entire line of notebook and desktop personal computers. All the manufacturers Dataquest met with expressed a strong desire to expand their presence in this channel. Dataquest expects that more than a few will be successful in growing this channel in 1997. There is a clear need for PC OEMs to have quick and flexible manufacturing, and the module manufacturers are very well positioned to fill this need.

Convergence and the Modular PC

With the rapid convergence of computers, telecommunications, and consumer electronics, connectivity and data transfer speed are top priorities and are offering tremendous opportunities. Dataquest can envision a scenario in which modular PCs give consumers the flexibility and affordability they currently enjoy with modular stereos. Such a scenario could significantly impact the business models of every personal computer vendor in business today and open new directions as well as challenges for the semiconductor manufacturers. COMDEX revealed the status of several emerging data exchange technologies that represent a critical step toward the modular PC. Universal Serial Bus (USB) exhibited an impressive presence and assertively positioned itself as a raging new wave to watch in 1997. IrDA is also very promising for the mobile worker because it has wide industry support and is already on the mainstream hardware and software, but it needs a marketing boost in order to really take off next year. Fibre Channel/Arbitrated Loop is a viable solution for decreasing connectivity cost and increasing performance for server clusters, mass storage, and LANs, possibly including home networking applications. For FC/AL, 1997 should provide opportunity. IEEE 1394 will see growing acceptance as the bus of the future for audio/video systems and PCs, but it has still a few challenges to be ironed out before it can be widely implemented.

IrDA

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USB

Like 3-D and DVD, USB was one of more popular buzzwords of the show, and most COMDEX buses stopped at the Universal Serial Bus booth. The PC industry has divided into two USB camps: those that have already introduced USB-compatible products and those that will make their introductions next year. USB is gaining industry acceptance for many peripheral connectivity applications enabling low-cost, outside-the-box plug-and-play to the computer user. USB allows for a data transfer rate of 12 Mbps and therefore is aimed at I/O devices such as monitors, keyboards, joysticks, mice, printers, scanners, digital cameras, modems, phones, and speakers, among others. USB monitors still plug into a VGA port for the video signal, but monitor control parameters can be handled over USB. Several core logic chipsets from Intel are USB compliant, and major PC OEMs (IBM, Compaq, Digital, and Toshiba) have already introduced USB-capable units. On October 29, Microsoft started shipping core OHCI-based USB drivers to OEMs as an update to the current operating system and will include class drivers in its next OS to be released in June or July 1997. In the meantime, products in the long line of peripherals introduced at the show come with their own drivers. Various microcontrollers, chipsets, and developer kits are available from many companies. Intel's Jim Pappas claims that more than 200 designers have USB peripherals and systems in development; at a similar stage of development, the PCI community included about 20 companies. Pappas should know; he was one of the PCI progenitors, as well.

IEEE 1394 (Also Known as FireWire)

IEEE 1394 complements USB by providing outside-the-box plug-and-play for devices requiring much higher speed. IEEE 1394 is being targeted at the multimedia/entertainment segment and enables the consumer to plug or unplug, without rebooting, devices such as digital VCRs, digital camcorders, audio systems, and digital set-top boxes, among others. After a quick survey of companies exhibiting at COMDEX but not present among the 14 companies in the 1394 association booth, it became apparent that IEEE 1394 has attracted industrywide attention but that wide adoption and implementation are still a couple of years away. Although the chipsets (physical and link layers) are coming down in price rapidly, the technology is still viewed as too expensive and as "requiring too many gates to be integrated on the motherboard in the near term," said Jim Pappas of Intel. However, Microsoft reported that it is planning on having 1394 software drivers in the June or July 1997 OS, and PC host adapter and audio/video add-in cards are currently available. Some speculated that IEEE 1394 could replace IDE and PCI by end of the decade. Xyratex, now providing development tools for USB, SCSI, and Fibre Channel, reported that it is ready to roll out IEEE 1394 emulators and analyzers as soon as demand appears on the horizon. Besides concerns about cost issues, several exhibitors expressed their concern about the controversy surrounding the next generation of the current IEEE 1394-1995. Current versions of the standard achieve speeds of 100 Mbps and 200 Mbps. The technology road map calls for 800 Mbps by 1998 and 2 Gbps by 2001. Two proposed extensions are being discussed at the IEEE working level, 1394a and 1394-2 (also known also as Serial Express). Both proposals have advantages and disadvantages, but only 1394a is backwardly compatible. "Until there is a clear indication of the path the technology will take, my company is postponing an implementation plan," said one exhibitor.

FC/AL

Fibre (pronounced fiber) Channel Arbitrated Loop (FC/AL) is a technology derived from the Fibre Channel connectivity standard for high-speed storage access and server clustering. FC/AL was developed with peripheral connectivity in mind. FC/AL can support 126 nodes and either 30m (copper) or 10km (optical) cable lengths between nodes. Also, it can deliver 800 Mbps per port, does not require jumpers to configure the drive, and has a sophisticated error detection code (EDC) that provides high data integrity. FC/AL is expected to appear first in redundant arrays of independent disks (RAID) and mass storage subsystems, in clustered servers, and video and graphics networks. Fiber Channel technology is intended to complement wide area networks (WANs) and offer a valid option for LANs and campus applications. With support for 16 million switched port connections, FC's switched topology is as much of a network as Asynchronous Transfer Mode (ATM) is. Current silicon cost ranges between $80 and $250. Although FC/AL will most likely prevail in high-end servers (supercomputers, mainframes, and top midrange computers), storage access, and clustering, it will compete strongly with Ultra SCSI in the workstation segment. The merging of IBM's Serial Storage Architecture (SSA) with FC/AL, recently announced informally, will bring the aggressive, two-year-old competition to an end.

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Market Analysis

PC Graphics: Does Third Quarter Momentum Bode Well for Fourth Quarter Results?

Abstract: *This document provides a quick overview of the third quarter financial results for the leading PC graphics chip suppliers, as well as a qualitative outlook for the fourth quarter. Third quarter results indicate that the inventory correction that has characterized 1996 is over, and Dataquest continues to forecast double-digit growth for PCs as well as some other categories of electronic equipment. New orders for PC semiconductor components should be in sync with PC production over the quarter because of the low inventories held by major PC OEMs. These trends together provide a positive outlook for fourth quarter results.*
By Geoff Ballew

Third Quarter Earnings Were Good but Weren't the Upside Surprise That Some Expected

The largest suppliers of PC graphics controllers posted good results for the third calendar quarter but not as good as Intel had posted just a few days earlier. Stock prices for the leading graphics vendors fell about 10 percent even though the earnings per share (EPS) figures exceeded official estimates made by many stock market analysts. The results simply did not have the upside surprise that Intel's earnings showed, and the investment community was disappointed. Table 1 shows some third calendar quarter financial data for the three largest graphics vendors, S3 Inc., Cirrus Logic Inc., and Trident Microsystems Inc.

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Table 1
Financial Highlights from the Top Three Graphics Chip Suppliers (Millions of Dollars)

Company	Fiscal Year Ends	Q3/96 Revenue	Q3/96 EPS ($)	Q3/95 Revenue	Q3/95 EPS ($)	Year-to-Year Revenue Growth, Q3 (%)
S3	December	119.4	0.23	84.8	0.20	41
Cirrus Logic	March	236.0	0.05	317.8	0.47	-25.7
Trident	June	44.8	0.26	36.6	0.34	22.6

Source: Dataquest (December 1996)

Outlook for Fourth Quarter

Despite the perception that results should have been better, the trends that produced the third quarter results also provide optimism for the current quarter, the fourth quarter. This optimism hinges on several factors—the transition to 3-D graphics, relatively low inventories at key OEMs, and expectations of a strong Christmas buying season.

Shift to 3-D Increases ASPs

The shift to 3-D graphics chips allows graphics vendors to command higher average selling prices (ASPs), reversing the previous trend of declining ASPs. Severe competition for 2-D graphics chips (including video acceleration features, too) drove the trend of price erosion over the past 12 months. The falling prices were driven by a sudden shift from 32-bit graphics chips to 64-bit graphics chips in the fall of 1995, coupled with a general surplus of 64-bit graphics chips this year. Suppliers were dependent on greater unit shipments for revenue growth during this period because of the lower ASPs. The transition to 3-D graphics does offer graphics vendors a chance to push ASPs back up to the $15 mark. Dataquest believes that the low-end 3-D graphics chips are selling in the low $20s, compared with $11 to $13 for a typical 2-D graphics chip.

Two of the top five graphics chip companies, S3 Inc. and ATI Technologies Inc., brought their 3-D chips to market early enough to win motherboard designs for PC OEMs' fall updates to their product lines. Cirrus Logic was too late for motherboard design-wins, but its Laguna3D chip will sell through to end users on add-in cards such as Creative Labs' Graphics Blaster. S3's family of 3-D accelerators is called ViRGE, while ATI's line is called RAGE. Both companies crossed the million-unit shipment mark for 3-D graphics chips earlier this year, with the lead held by S3, which shipped 1 million 3-D chips by the end of the June and as many as 2 million more last quarter. Trident Microsystems announced its 3DImage graphics chip and is sampling now, preparing for volume shipments in 1997. Chips & Technologies will be the last of the top five graphics suppliers to bring a 3-D chip to market, as the company's cooperative efforts with Lockheed Martin are expected to bear fruit in the first half of 1997. The timing of Chips' 3-D graphics chip is less critical than the timing for other major graphics vendors because of Chips' focus on the mobile PC graphics market. 3-D features will migrate into mobile PCs, but desktop PCs are leading the way.

OEM Inventories Are Relatively Low

Low inventories at some of the largest PC OEMs are good news for the PC graphics suppliers as well as other semiconductor companies. New orders for chips will be required to replenish inventories as OEMs continue their production ramp for the holiday PC buying season. This has not been the case for most of 1996. The large inventories that many OEMs carried into 1996 allowed them to produce PCs and other electronic equipment without placing new orders for all of the semiconductors their production required. Table 2 shows the reported inventories and sales revenue for both Compaq and Dell Computer. Note that revenue is up, while inventory value is down.

Table 2
Revenue and Inventory Data for Compaq and Dell Computer (Millions of Dollars)

	Revenue 1H/96	Revenue 1H/95	Change (%)	Inventory 1H/96	Inventory 1H/95	Change (%)
Compaq	8,206	6,460	27	1,535	2,036	-25
Dell	3,328	2,342	42	204	382	-47

Notes: Inventory includes parts, raw materials, work in process, and finished goods.
All periods for Dell are shifted one month forward. For example, Dell's numbers for the first half of 1996 are actually for the six-month period from February through July rather than January through June.
Source: Dataquest (December 1996)

The third quarter of 1996 was the turning point, as many semiconductor companies reported a strong increase in September orders. OEMs are likely to maintain conservative inventory strategies as long as lead times for new orders stay relatively short. PC OEMs face ongoing price competition and are keeping tighter controls on inventory to increase the number of "turns" they have each year. Inventory turns are defined as the average dollar amount of inventory on hand divided by the total value of goods moved through inventory in a year. For example, a company that has $100,000 of inventory on hand and will move $1 million worth of goods through its inventory over the year has 10 turns ($1 million divided by $100,000 equals 10).

19.7 Percent Growth Expected for PC Unit Shipments in 1996

One more reason for optimism about the fourth quarter outlook for the PC graphics chip market is robust demand for PCs. The PC market consumes a lot of semiconductor content (about $41 billion expected in 1996, climbing to $88 billion in the year 2000), so continued demand for PCs is good news for the semiconductor market. PC OEMs will not be able to build all of those new PCs with their existing inventories, so it is likely that the recent upswing in new orders for PC semiconductors will keep pace with PC production.

The worldwide PC market is on track to match Dataquest's forecast of 19.7 percent unit growth, year over year. Continued strength in the PC market will predictably create growing demand for PC semiconductors such as graphics chips, microprocessors, and DRAM.

Dataquest Perspective

The third quarter results of the leading graphics chip companies do bode well for fourth quarter. New orders during the quarter should be in sync with PC production for the Christmas selling season. If PC inventories at retailers sell through to end customers, then the first quarter of 1997 will bring new orders to restock those depleted shelves. There is also a buffer against a repeat of last year's inventory hangover caused by the overoptimistic forecasts that many OEMs had for December PC sales. The conservative inventory policies of many PC OEMs today do provide a measure of protection against such a severe inventory correction, even if PCs do not sell through as well as expected.

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Event Summary

COMDEX Demonstrations Herald Exciting Year to Come

Abstract: *This document is a collection of short news items with analysis about some of the major semiconductor announcements at this year's COMDEX show in Las Vegas. Contributions were made by several analysts, so the topics range from microprocessors to multimedia ICs, with a smattering of other software and semiconductor issues.*
By Nathan Brookwood, Geoff Ballew, Xavier Pucel, and George Iwanyc

1997 Brings New Technologies with Mass Appeal

If the displays on and off the floor at this year's COMDEX show in Las Vegas are any indication, 1997 will see the introduction of much new personal computer technology, which will have the potential to drive strong unit growth. The 19 percent market growth Dataquest expects to see for 1996 was achieved the old-fashioned way—vendors offered incredible values and kept prices low while they increased feeds and speeds across the board. At this time last year, the fastest machines included 133-MHz CPUs and 16MB DRAM and were priced at $2,500 to $3,000. Do not kick yourself too hard if you bought one then, just because the same configurations are going for $1,400 today. But aside from the improved speed and lower cost, there is nothing you can do on this year's systems that you cannot do with last year's machines.

MMX and MPUs

The year 1997 appears likely to be one in which the shape of new PCs may change more than usual. New x86 microprocessors from Intel, Advanced Micro Devices, and Cyrix, all with MMX technology, should hit the street during the first four months of the year. Several notebook vendors offered "technology demonstrations" of new, faster notebooks based on Intel's as-yet-unannounced P55C Pentium processors. AMD demonstrated (behind

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semiclosed doors) a side-by-side comparison of its forthcoming K6 processor and a 200-MHz Intel Pentium Pro; the two performed similarly on 32-bit applications, which are the Pentium Pro's strongest suit. Cyrix indicated that it is waiting for the first silicon on its next-generation M2 processor, which should also hit the market in this time frame. All three vendors have experienced strong demand over the past few months, with Intel and Cyrix (and its partners, IBM and SGS-Thomson) needing to allocate processor deliveries to customers that want to buy more units than they can supply. These system vendors clearly expect a strong selling season. If they do not get it, there could be some finished goods inventory hangover in January. The risk of an inventory hang for semiconductor devices is buffered by the relatively low inventories at most PC OEMs. At this time last year, PC OEMs had large inventories that they spent the first half of 1996 working through. This year presents a different scenario, but, nevertheless, Christmas sell-through of PCs will impact chip orders in the first quarter.

Core Logic

The coming year should see an interesting struggle at the PC infrastructure level. Intel will push hard to ramp Klamath, its next-generation Pentium Pro, which requires motherboards and core logic that differ significantly from the boards used for Pentium-based products. AMD and Cyrix will argue that boards originally designed for Pentium sockets can provide adequate performance for their new products, which will offer Pentium-Pro levels of performance. Pentium core logic vendors, which have been squeezed badly by Intel this past year, are poised to return next year with low-cost core logic for AMD, Cyrix, and Pentium systems that support features Intel plans only for its Pentium Pro products. Intel will thus leave its Pentium flank exposed; if the market votes for the lower-priced AMD and Cyrix approach, then these core logic vendors stand to benefit as well.

Media Processors

Chromatic Research and its partners demonstrated the Mpact media processor, now shipping, on and off the floor, and announced that the partnership had been broadened to include SGS-Thomson as well as Toshiba and LG Semicon. Philips demonstrated production prototypes of its forthcoming TM-1 media processor on and off the floor, as well. The open demonstrations included AC-3 audio decoding that produced sound that could be heard and felt. (This COMDEX set new decibel records and probably caused untold damage to participants' auditory systems. Doses of aspirin were a popular giveaway.) Off the floor, Philips showed early versions of MPEG-2 decoding and H.324 videoconferencing over plain old telephone service (POTS). Apple Computer acknowledged publicly, for the first time, its intent to incorporate the TM-1 into future Macintosh products.

3-D Graphics

The market for 3-D graphics chips is heating up! Several suppliers are shipping parts now, and virtually all of the others have 3-D products in their 1997 road map. These new chip offerings will raise the level of competition in the 3-D segment of the PC graphics market, and unit volumes should explode as a result. The year 1996 was a battle between S3 and ATI because only those two companies brought single-chip graphics subsystems (2-D, 3-D, video, and RAMDAC all in one chip) to market in time for motherboard design-wins. Both those companies have already "refreshed" their lines with faster versions of their 3-D chips. Cirrus Logic is shipping its Laguna3D chip, and Trident Microsystems was showing its new 3DImage, which was just out of the fab. Those four companies are the largest suppliers of PC graphics chips. Smaller graphics vendors are also into this game, including a number of start-up companies and even some big companies newly targeting this market. 3Dfx's Voodoo Graphics chips were running demonstrations in a number of booths. Voodoo Graphics does not include 2-D functions, so a traditional graphics chip is also required for PC applications. The company is teaming with Alliance Semiconductor and Trident Microsystems. Alliance Semiconductor was showing a reference design using its 3-D graphics chip with connectors for upgrading to 3Dfx's 3-D chipset. These pairings offer PC OEMs considerable scalability while maintaining software compatibility. NEC and VideoLogic were showing off the PowerVR chip called PCX1. Like 3Dfx's current product, PCX1 needs an additional graphics chip for 2-D functions. 3Dlabs is now shipping Permedia, which has a much lower price point than its popular GLint products. Permedia is being manufactured by both IBM and Texas Instruments. TI will serve as a foundry for 3Dlabs, as well marketing and selling Permedia itself. Both companies will develop and sell products based on 3Dlabs' 3-D graphics technology.

Software MPEG

It seemed like everywhere the COMDEX enthusiast might go on the show floor, there was a TV or a monitor showing MPEG demos. Most of the attention was on MPEG-2, but MPEG-1 still has a bit of life left in it. Sony's own software MPEG-1 codec, running on its VAIO PC line, looked great. With software decompression that looks this good, it will be really hard to justify paying for MPEG-1 hardware. On the MPEG-2 side, demonstrations of software codecs were quite promising for the future. Some of the differences between MPEG-1 and MPEG-2 revolve around the variable-rate bitstream and higher data rate for MPEG-2, as well as the issue that MPEG-2 was designed for playback on interlaced displays such as TVs rather than progressive-scan monitors. These differences require more processing power for MPEG-2 decompression compared with MPEG-1, as well as additional processing to compensate for image defects caused by displaying interlaced video on a progressive display. The bottom line is that software MPEG-2 will be a reality for high-end PCs in the Christmas 1997 time frame and will migrate into the mainstream PC market as high-speed (200 MHz and higher) versions of Intel's Klamath MPU proliferate. This trend will be boosted by graphics controllers that have motion compensation engines, effectively offloading some (not all) of the video processing from the CPU.

Quicktime on Wintel

Macintosh-related announcements tend to be few and far between at COMDEX, but this year, Apple was pushing its new "platform agnostic" stance. Apple's Ellen Hancock gave a stirring speech in which she indicated her intent to sweep all vestiges of Apple's legendary NIH ("not invented here") syndrome out of the company. Apple is also taking a more aggressive attitude toward the licensing of its technology on non-Macintosh platforms and plans to emphasize the presence of its Quicktime Media Library (QTML) on Wintel platforms. This may help these standards achieve critical mass in the market but will also deny Apple the use of these features to differentiate itself from Wintel platforms. Neither alternative is ideal for Apple, but we would agree that it has chosen the better alternative.

Flat-Panel Displays

Flat panel vendors emphasized bigger and cheaper, but not necessarily both together. Crowds gathered at the Fujitsu booth to view a new 42-inch-diagonal (about 1.1-meter) plasma display. NEC showed the largest TFT (20 inches, or 0.5m) that this analyst has ever seen. Both these displays are showpieces, and neither is manufacturable in high volume today. Nor are they priced for volume markets—yet. The good news is that TFTs priced for volume markets are getting bigger all the time. Fourteen-inch displays are the next step beyond 12 inches, and many vendors were showing off displays of that size. Although 14-inch-and-larger flat panels are tough to shoehorn into a notebook PC, these displays will help to bring TFTs into other applications where a thin screen is preferred to a bulky CRT, including deskbound PCs. Dataquest expects CRTs will continue to dominate the desktop for several years, but these larger panels will make TFTs more attractive for desktop applications.

Windows CE

A myriad of Windows CE handheld computers debuted at this show. Typically the size of a classic handheld organizer, these devices possess a user interface close enough to Windows 95 to allow most users to use the handhelds with little or no retraining, and they address the "data synchronization" problem (between desktop and mobile devices) in a fairly clean manner. Just as standardization of the desktop environment with DOS, Windows, and Windows 95 has driven growth in that segment, the extension of these standards to handhelds may spur further growth here, too. These new handhelds use RISC microprocessors from Hitachi (SH-3) and MIPS (via NEC). Thus, growth in this area could give the RISC vendors a fighting chance in computational microprocessor markets, where they have been struggling of late.

Memory Devices

Memory producers have a lot to look forward to in the next decade. Everywhere Dataquest looked, another digital camera or 3-D graphics card screamed a need for more memory. It looks as though 32MB of EDO DRAM will soon become the standard configuration for desktop PCs, and 1997 will be the year that synchronous DRAM starts to gain market share. Looking further into the future, Andy Grove shared Intel's prediction that PCs will be configured with 512MB of memory in 2011. Samsung, NEC, Hitachi, and the rest of the DRAM producers are definitely up to the task. Samsung displayed several 8-inch wafers with 1Gb DRAMs. Even at 0.18-micron geometries, Samsung can fit only 28 of the huge chips—easily 1 inch by 1/2 inch—on an 8-inch wafer! It's a certainty that the company will be one of the first to go to

300mm wafers. Samsung estimates that a single 1Gb chip can store 8,000 pages of text, 400 photos, or 14 hours of audio.

Memory Modules

Third-party memory module manufacturers were well represented at COMDEX. Kingston Technology remains the largest and most visible module manufacturer, but an abundance of competitors offered slight twists to the quick and flexible manufacturing business model Kingston champions. If there is a common ground for this camp, it is its dedication to educating the distribution channels and end users about the benefits of more megabytes and the undiluted interest in growing OEM relationships with PC manufacturers and DRAM producers. The memory module manufacturers have followed up on Samsung's announcement two months ago about the benefits of increased memory sizes on system performance. The module manufacturers realize they have a lot to gain if end users pick up on the megabyte message, so they have grabbed the megaphone. As for the common goal of increasing third-party presence in the PC OEM channel, Kingston again was the most visible with its announcement last week about its teaming with Toshiba. Kingston announced that it has been selected by Toshiba America Information Systems as the company's official supplier of memory upgrades for Toshiba's entire line of notebook and desktop personal computers. All the manufacturers Dataquest met with expressed a strong desire to expand their presence in this channel. Dataquest expects that more than a few will be successful in growing this channel in 1997. There is a clear need for PC OEMs to have quick and flexible manufacturing, and the module manufacturers are very well positioned to fill this need.

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Like 3-D and DVD, USB was one of more popular buzzwords of the show, and most COMDEX buses stopped at the Universal Serial Bus booth. The PC industry has divided into two USB camps: those that have already introduced USB-compatible products and those that will make their introductions next year. USB is gaining industry acceptance for many peripheral connectivity applications enabling low-cost, outside-the-box plug-and-play to the computer user. USB allows for a data transfer rate of 12 Mbps and therefore is aimed at I/O devices such as monitors, keyboards, joysticks, mice, printers, scanners, digital cameras, modems, phones, and speakers, among others. USB monitors still plug into a VGA port for the video signal, but monitor control parameters can be handled over USB. Since mid-1996, USB has been on Intel's motherboards, and major PC OEMs (IBM, Compaq, Digital, and Toshiba) have already introduced USB-capable units. On October 29, Microsoft started shipping core OHCI-based USB drivers to OEMs as an update to the current operating system and will include class drivers in its next OS to be released in June or July 1997. In the meantime, products in the long line of peripherals introduced at the show come with their own drivers, and PCI host adapter cards are also available to upgrade the installed base of PCs. Various microcontrollers, chipsets, and developer kits are available from many companies. Intel's Jim Pappas claims that more than 200 designers have USB peripherals and systems in development; at a similar stage of development, the PCI community included about 20 companies. Pappas should know; he was one of the PCI progenitors, as well.

IEEE 1394 (Also Known as FireWire)

IEEE 1394 complements USB by providing outside-the box plug-and-play for devices requiring much higher speed. IEEE 1394 is being targeted at the multimedia/entertainment segment and enables the consumer to plug or unplug, without rebooting, devices such as digital VCRs, digital camcorders, audio systems, and digital set-top boxes, among others After a quick survey of companies exhibiting at COMDEX but not present among the 14 companies in the 1394 association booth, it became apparent that IEEE 1394 has attracted industrywide attention but that wide adoption and implementation are still a couple of years away. Although the chipsets (physical and link layers) are coming down in price rapidly, the technology is still viewed as too expensive and as "requiring too many gates to be integrated on the motherboard in the near term," said Jim Pappas of Intel. However, Microsoft reported that it is planning on having 1394 software drivers in the June or July 1997 OS, and PC host adapter and audio/video add-in cards are currently available. Some speculated that IEEE 1394 could replace IDE and PCI by end of the decade. Xyratex, now providing development tools for USB, SCSI, and Fiber Channel, reported that it is ready to roll out IEEE 1394 emulators and analyzers as soon as demand appears on the horizon. Besides concerns about cost issues, several exhibitors expressed their concern about the controversy surrounding the next generation of the current IEEE 1394-1995. Current versions of the standard achieve speeds of 100 Mbps and 200 Mbps. The technology road map calls for 800 Mbps by 1998 and 2 Gbps by 2001. Two proposed extensions are being discussed at the IEEE working level, 1394a and 1394-2 (also known also as Serial Express). Both proposals have advantages and disadvantages, but only 1394a is backwardly compatible. "Until there is a clear indication of the path the technology will take, my company is postponing an implementation plan." said one exhibitor.

FC/AL

Fibre (pronounced fiber) Channel Arbitrated Loop (FC/AL) is a technology derived from the Fibre Channel connectivity standard for high-speed storage access and server clustering. FC/AL was developed with peripheral connectivity in mind. FC/AL can support 126 nodes and either 30m (copper) or 10km (optical) cable lengths between nodes. Also, it can deliver 800 Mbps per port, does not require jumpers to configure the drive, and has a sophisticated error detection code (EDC) that provides high data integrity. FC/AL is expected to appear first in redundant arrays of independent disks (RAID) and mass storage subsystems, in clustered servers, and video and graphics networks. Fiber Channel technology is intended to compliment wide area networks (WANs) and offer a valid option for LANs and campus applications. With support for 16 million switched port connections, FC's switched topology is as much of a network as Asynchronous Transfer Mode (ATM) is. Current silicon cost ranges between $80 and $250. Although FC/AL will most likely prevail in high-end servers (supercomputers, mainframes, and top midrange computers), storage access, and clustering, it will compete strongly with Ultra SCSI in the workstation segment. The merging of IBM's Serial Storage Architecture (SSA) with FC/AL, recently announced informally, will bring the aggressive, two-year-old competition to an end.

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Dataquest Interactive DQi

November 8, 1996
Semiconductor Directions in PCs and PC Multimedia Worldwide
DATAQUEST ALERT
Geoff Ballew

S3 Enters the PC Audio Market

S3 Inc. officially entered the PC audio market today. In a press release today, the company formally announced the SonicVibes chip, which is a complete audio subsystem on a single chip. This announcement is a major step for S3 because it follows through on the company's stated goals of expanding beyond its core competencies of graphics and video processing.

The new product has an impressive list of features, including wave table synthesis, FM synthesis, SRS stereo enhancement, a speed-compensating joystick interface, and a PCI bus interface. Yes ... that is correct ... a PCI bus interface. The SonicVibes chip may also be implemented on the ISA bus but then requires an external memory device for wave table synthesis. The new chip takes advantage of the higher bandwidth over PCI to use the PC's main memory for the wave table samples. S3 has reduced the total subsystem cost by eliminating the external ROM (typically 512KB or 1MB) that many other solutions require. A typical implementation requires only the SonicVibes chip. This reduces cost as well as board space for a wave table solution.

SonicVibes is sampling now and is scheduled for volume production in the first quarter of 1997. List price for quantities of 10,000 is $30 per chip in a PQFP-160 package.

Dataquest Perspective

This is a bold step for S3. The company's rapid growth has been fueled by its graphics and video accelerator business as S3 has grown to be the largest supplier of PC graphics accelerators. S3's success in the graphics arena has been a trend of capturing a growing share of a growing market. Now that S3 has such a large share of that business, additional market share is more difficult to get. S3 needs to address new product segments within the PC semiconductor market to continue its trend of growing so much faster than the overall market. S3 has been working on expanding its available market, and SonicVibes is part of that effort.

The SonicVibes product is a step ahead of the mainstream PC audio chips today. This is necessary for S3 to break into this market because a "me too" solution would not compel very many OEMs to switch from the established audio chip suppliers. S3 is early to the market for PCI-based audio chips. The SonicVibes chip is compatible with the ISA bus, but is much more compelling with the PCI bus because of memory issues. This makes the risk of switching to an unproven audio chip vendor more palatable for an OEM because there are rewards (lower cost given the feature set) associated with that risk. One open issue is Sound Blaster compatibility. S3 has arranged for compatibility testing by a third party and has already received results from testing using an ISA-based implementation. Those results show solid compatibility with the Sound Blaster standard, but Dataquest is very interested in the results from the PCI-based implementation. The distinction is important because of the challenges associated with Sound Blaster compatibility over the PCI bus.

S3's foray into the PC audio market should be very exciting to watch. The company has executed very well in the graphics market, bringing compelling products to market on time and at an attractive price. S3 also has strong relationships with key OEMs at the PC and the add-in board level. These strengths will help to open doors for SonicVibes, but the company must build credibility in the audio market as well. It appears that S3 has hired the talent and experience to enter the audio market with a bang, so a measure of credibility has been established through the reputations and relationships of those employees. The task of winning new designs is next on the list.

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Perspective

Semiconductor Directions in PCs and PC Multimedia

Market Analysis

NICs Get Nixed as Ethernet Controllers Migrate onto the PC Motherboard

Abstract: *Many PC OEMs are changing the face of PC networking by integrating Ethernet chips onto their motherboard designs. This bucks the long-term trend of adding networking capability with network interface cards (NICs) and opens a new opportunity for PC OEMs to add value to their products. This trend toward integrated networking is fueled by the availability of low-cost, single-chip Ethernet controllers and the popularity of 10-Mbps Ethernet as a standard.*

This report provides an overview of the market dynamics for Ethernet controllers in PCs, including implementation trends and insight into the strategies of key chip suppliers for PC networking and a forecast for unit shipments and revenue. For the purposes of this report, the term "controller" refers to a chip rather than a NIC.

By Geoff Ballew

More PCs Are Getting Integrated Networking

PC peripherals often migrate to the motherboard when technology is relatively stable and chip count is minimal. Ethernet controllers satisfy both of those requirements and are getting designed onto PC motherboards with greater frequency. Ethernet is the most popular standard for PC networking, and chip suppliers are delivering single-chip controllers for well under $10. Dual-speed controllers that provide a complete 10-Mbps solution as well as a low-cost upgrade path to 100 Mbps are attractive for motherboards as well and sell for a decreasing premium over the 10-Mbps-only chips. Figure 1 shows how a 10/100-Mbps Ethernet controller might be implemented on a PC motherboard. Improvements in software are also helping this trend toward integrated networking as corporations move away from Windows 3.x running on top of DOS in favor of Windows 95 and Windows NT. These newer operating systems simplify network configuration and maintenance

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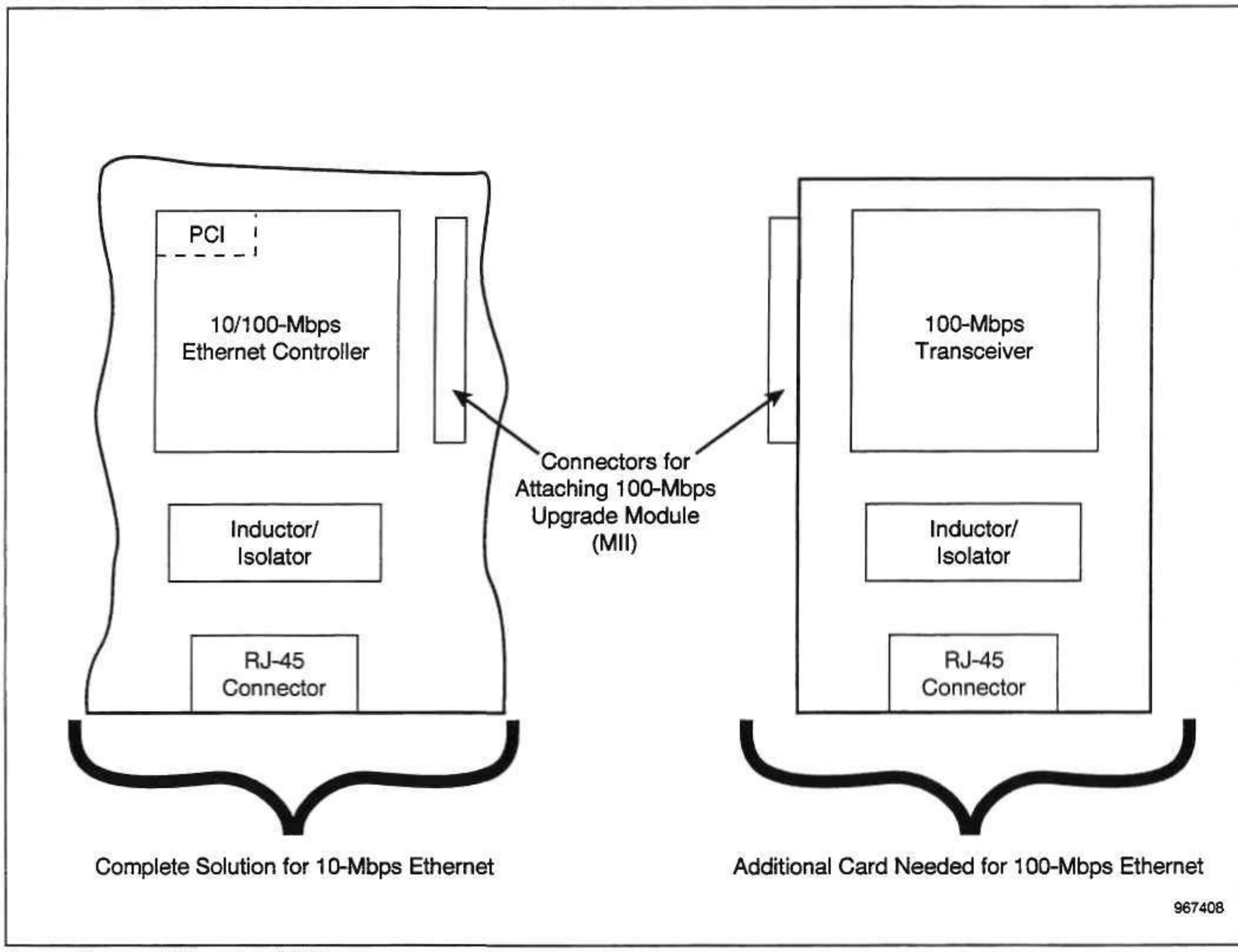
by including network driver support for the more popular networking controllers.

Figure 1
Possible Motherboard Implementation for a 10/100-Mbps Ethernet Controller



Source: Dataquest (November 1996)

Many PC OEMs are integrating Ethernet controllers onto their motherboard designs for their business desktop lines. Some of those designs use a custom daughtercard or module approach rather than soldering the controller onto the motherboard itself. For the purposes of this report, daughtercard implementations will be considered motherboard implementations because the PC OEMs are sourcing the chips directly instead of buying network interface cards (NICs). Table 1 lists a few PCs that have integrated Ethernet controllers.

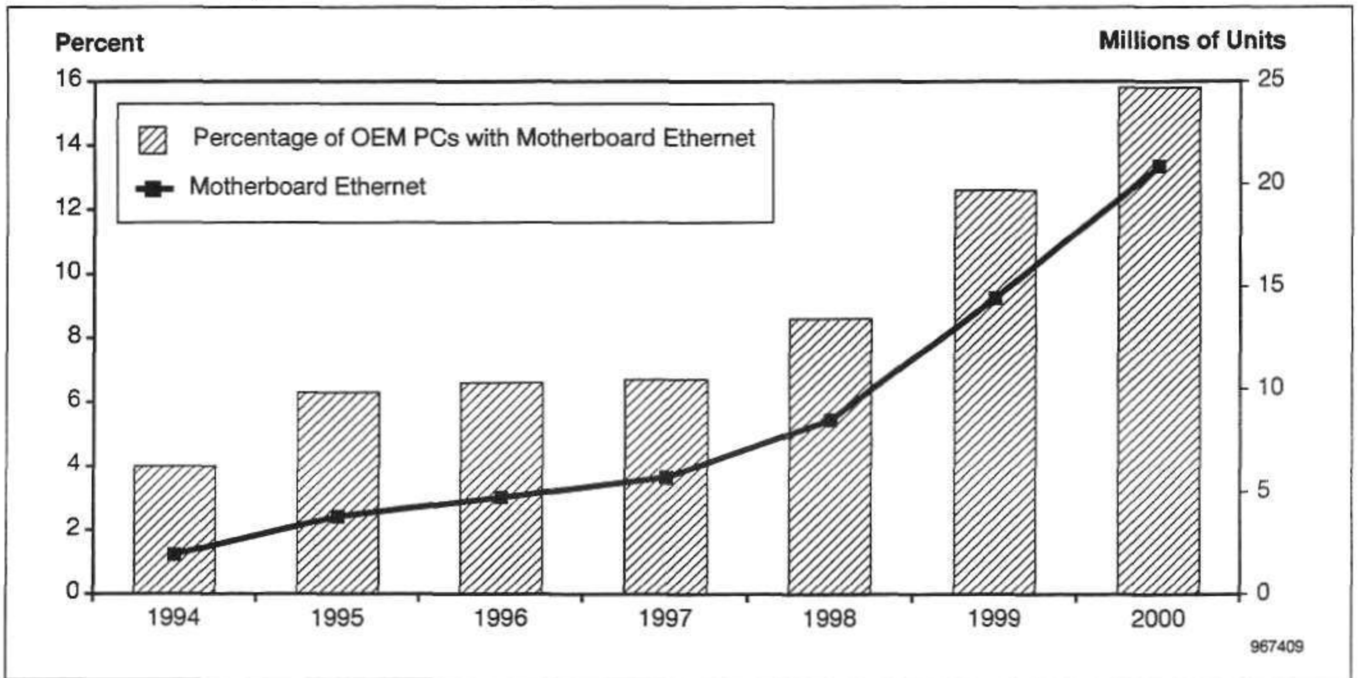
Figure 2 shows Dataquest's forecast for integrated networking in PCs through the year 2000. (The data for this figure is located in Table 3.)

Table 1
Several PC Product Lines Featuring Integrated Network Controllers

Brand	Product Line
Compaq	Deskpro 4000
	Deskpro 6000
Dell	Optiplex (some models)
Hewlett-Packard	Vectra XM2, XM3, XU
IBM	PC Power Series 830, 850
Apple	Quadra (some models)
	Power Macintosh (some models)
AST Research	Premmia GX
ICL	ErgoPRO
Siemens-Nixdorf	RM4000

Source: Dataquest (November 1996)

Figure 2
Forecast for Integrated Networking in PCs



Source: Dataquest (November 1996)

Integrated Networking Allows PC OEMs to Add Value and Differentiate Their Products

PC OEMs benefit in two ways from integrating networking ICs onto their motherboards. First, a PC with networking capabilities sells for a higher price, so the OEM gets a higher dollar margin on the sale of that PC. Motherboard implementations are less expensive than using ISA or PCI add-in cards, so OEMs get maximum economic benefit from integrating the network controller onto the motherboard.

Strategic benefits arise as well. Several PC OEMs use integrated networking to position themselves as solution providers rather than just equipment providers. The difference is that solution providers address cost-of-ownership issues. The message is "value" rather than "lowest price."

Some New Features Require Motherboard Implementation

Some new features available in network controllers are easier to implement on motherboards than on NICs. The Magic Packet technology, 3.3V operation, and user-visible status LEDs are some specific examples. (Magic Packet is a trademark of Advanced Micro Devices Inc.)

Magic Packet technology was developed by AMD and Hewlett-Packard as a way to turn on a PC remotely by sending a special message or "magic packet" over the network. This enables corporate IS staffs to remotely manage a number of functions, such as software or BIOS update, system backups, and other tasks, even if the PC is turned off. PC users can turn off their PCs at night to save electricity, and the IS staff can do its job without having to run around a building turning PCs on and off.

This technology requires that the network controller be powered up, although in a low-power sleep mode, when the PC is turned "off." The network controller must also be able to turn the PC "on" so that the PC boots up and is ready for operation. The PCI specification does not include these capabilities, so PC OEMs must enable these features through their motherboard designs. Special motherboard features require the network controller to be integrated into the motherboard design, even though the network controller may be soldered to a custom module or daughtercard. Hewlett-Packard and IBM are two PC OEMs that offer Magic Packet or similar features in their PC products.

Another benefit OEMs can realize by implementing network controllers on the motherboard is 3.3V operation. Some PCI motherboards do not include 3.3V power signals to the PCI connectors, so designers of PCI-based NICs must add a 3.3V voltage regulator if they want 3.3V signals on their card. The advantage of operating at 3.3V instead of 5V is lower power requirements.

Another opportunity for PC OEMs to differentiate their products is adding a simple network-activity LED, similar to the hard disk-activity LED and visible to the PC user. Many NICs have status LEDs today that are visible from the back of the PC, but few users can see the back of their PCs. Standard NICs do not provide an opportunity to route the LED signal to the front of the PC, so a motherboard implementation (and appropriate redesign of the PC case) would be necessary. This feature must be enabled through the controller itself for a true indication of network activity.

Feature Comparison of Several Ethernet Controllers

Suppliers of Ethernet controllers compete on features and price just like other chip vendors. Table 2 shows some of the basic features of several Ethernet controllers that are available today.

Table 2
Feature Comparison of Several Ethernet Controllers

	Product Family	Part Number	Speed (Mbps)	Integrated Transceiver?	Full-Duplex Operation?	Voltage	Bus Interface	Power-Saving Mode?	Package
AMD	PCnet-PCI	-	10	Yes	No	3.3, 5	PCI	Yes	PQFP-160
AMD	PCnet-PCI II	-	10	Yes	Yes	3.3, 5	PCI	Yes	PQFP-132, TQFP-144
AMD	PCnet-Fast	79C971	10/100	10 Mbps Only	Yes	3.3, 5	PCI	Yes	PQFP-160, TQFP-176
Digital	None	21041	10	Yes	Yes	3.3, 5	PCI	Yes	PQFP-120
Digital	None	21142	10/100	10 Mbps Only	Yes	3.3, 5	PCI CardBus	Yes	PQFP-144, TQFP-144
Digital	None	21143	10/100	10 Mbps Only	Yes	3.3, 5	PCI CardBus	Yes	PQFP-144, TQFP-144
Fujitsu	None	MB86965	10	Yes	No	5	ISA	Yes	QFP-160
Fujitsu	None	MB86965B	10	Yes	Yes	5	ISA	Yes	QFP-160
National Semiconductor	SONIC-T	DP83936	10	Yes	Yes	5	Direct to MPU	No	QFP-160
Standard Microsystems	None	SMC91C94	10	Yes	No	5	ISA	No	QFP-100, TQFP-100
Standard Microsystems	None	SMC91C100	10/100	10 Mbps Only	No	5	ISA PCMCIA	No	QFP-208
Texas Instruments	ThunderLAN	TNETE100	10/100	10 Mbps Only	No	3.3, 5	PCI	Yes	PQFP-144, TQFP-144
Texas Instruments	ThunderLAN	TNETE110	10	Yes	Yes	3.3, 5	PCI	Yes	PQFP-144, TQFP-144

Source: Dataquest (November 1996)

10/100-Mbps Controllers Provide an Upgrade Path

PC OEMs must balance the cost benefits of integrating peripherals versus configuration flexibility. Suppliers of Ethernet controllers have addressed this dilemma by offering 10/100-Mbps Ethernet controllers. These controllers offer 10-Mbps operation with a single chip, but are easily upgradable to 100-Mbps capability by adding a 100-Mbps transceiver chip.

Full-Duplex Operation Gives 10 Mbps a Boost

Full-duplex operation is a new feature for 10-Mbps Ethernet controllers that doubles the peak bandwidth to 20 Mbps (10 Mbps into the controller and 10 Mbps out). The performance increase is moderate (2x compared to the 10x increase offered by 100-Mbps Ethernet) but is compelling because of the low cost and single-chip configuration.

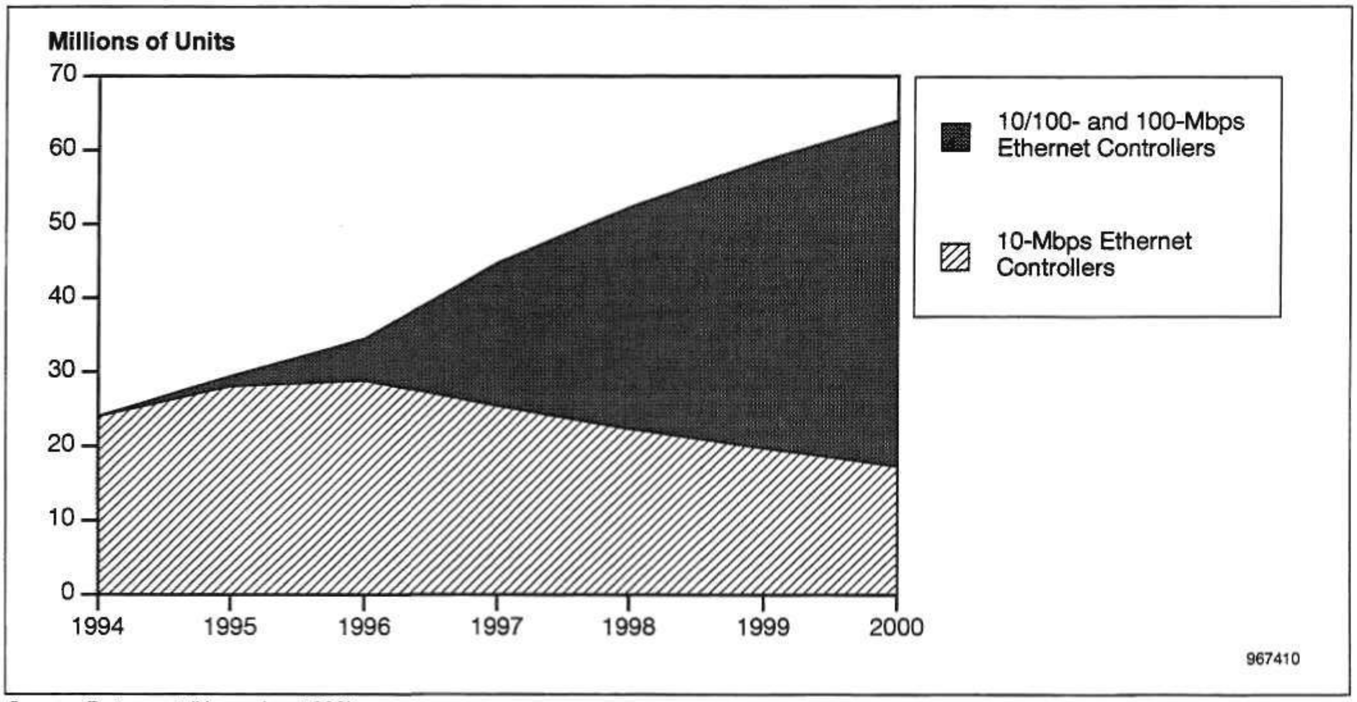
Power-Saving Modes Are a Requirement for Network Controllers in Mobile PCs

Most of the network controllers shown in Table 1 have some ability to go into a low power mode or sleep mode. This is a critical feature as semiconductor suppliers target the mobile PC market. Mobile PCs are frequently connected to networks when users are in their offices, so integrated networking makes sense, but battery life must be considered. Some mobile PCs from Hitachi have integrated network controllers today, and models from other vendors are sure to follow.

Forecast for Ethernet Controllers

Networking continues to be a critical function of the corporate PC. Dataquest's forecast for Ethernet controllers reflects this with almost a 17 percent compound annual growth rate (CAGR) from 1995 to 2000. Figure 3 and Table 3 show the actual forecast. This forecast shows a dramatic shift toward controllers capable of Fast Ethernet speeds (100 Mbps) as demand for network bandwidth continues to climb and the price premium for 10/100 Mbps gets smaller.

Figure 3
Forecast for Unit Shipments of Ethernet Controllers



Source: Dataquest (November 1996)

PCI will play a greater role for networking in the future, as system vendors want the performance and configuration benefits that that interface provides. True plug-and-play capability as well as lower CPU utilization are two tremendous advantages that PCI has over ISA.

Another major trend is the rising tide of application-specific standard products (ASSPs) in the Fast Ethernet category. Dataquest believes that ASSPs will increase from 30 percent of Fast Ethernet unit shipments to 70 percent over the next four years. ASIC vendors will enjoy higher unit growth from 1996 to 1997 if the total Ethernet controller market is considered, but subsequent years will bring slower growth for ASICs as ASSPs begin to dominate the Fast Ethernet category in addition to the 10-Mbps Ethernet category.

One ASIC vendor, 3Com, is selling chips directly to at least one PC OEM. In the past, 3Com has used its ASICs to sell board-level networking products and capture the added value of board-level integration. Dataquest believes that 3Com's willingness to sell chip-level products validates the trend toward integrated networking.

Table 3
Forecast for Revenue and Unit Shipments of Ethernet Controllers

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Ethernet (10 Mbps)								
Units (M)	24.00	28.00	28.80	25.40	22.30	19.70	17.30	-9.2
ASP ($)	11.8	10.4	9.1	8.7	8.5	8.3	8.2	-4.7
Revenue ($M)	283.0	291.0	263.0	220.0	190.0	164.0	141.0	-13.4
Percentage ASSP	77	78	80	83	87	95	98	
Percentage ASIC	23	22	20	17	13	5	2	
PCI I/F Units (M)	0.72	3.08	4.90	7.11	10.05	14.74	15.57	38.3
Motherboard Units (M)	1.92	3.78	4.61	4.57	4.02	3.54	3.11	-3.8
Fast Ethernet (100, 10/100 Mbps)								
Units (M)	0.03	1.42	5.68	19.31	29.93	38.91	46.70	101.1
ASP ($)	53.0	23.0	17.3	13.8	11.7	10.6	10.0	-15.3
Revenue ($M)	1.3	32.7	98.0	266.5	351.1	410.8	468.3	70.3
Percentage ASSP	20	25	30	40	50	60	70	
Percentage ASIC	80	75	70	60	50	40	30	
PCI I/F Units (M)	0.02	0.71	3.69	14.48	25.44	36.97	45.30	129.6
Motherboard Units (M)	0	0	0.11	1.13	4.49	10.90	17.74	NM
Total Ethernet (Sum of 10, 10/100, and 100 Mbps)								
Units (M)	24.03	29.42	34.48	44.71	52.23	58.61	64.00	16.8
ASP ($)	11.8	11.0	10.5	10.9	10.4	9.8	9.5	-2.9
Revenue ($M)	284.3	323.7	361.0	486.5	541.1	574.8	609.3	13.5
Percentage ASSP	77	75	72	64	66	72	78	
Percentage ASIC	23	25	28	36	34	28	22	
PCI I/F Units (M)	0.74	3.79	8.59	21.59	35.49	51.71	60.87	74.2
Motherboard Units (M)	1.92	3.78	4.72	5.70	8.51	14.44	20.85	40.7

NM = Not meaningful
Source: Dataquest (November 1996)

Dataquest Perspective

The market for Ethernet controllers in PCs will shift toward higher speeds and standard product (ASSP) solutions over the next five years. Many PC OEMs are integrating network controllers onto their motherboard designs, so they will increasingly buy chips instead of boards. This trend toward integrated networking favors standard products (ASSPs) for that reason. ASIC solutions sold at the board level will continue to have high volumes (about 14 million units in the year 2000) and will represent the leading edge in terms of performance.

As the market shifts toward motherboard designs, semiconductor suppliers have greater opportunity to add new features and differentiate their products. At least one chip supplier, Advanced Micro Devices, has integrated filters into the chip, removing this requirement from the inductor/isolator component shown in Figure 1. Features such as AMD's Magic Packet technology cannot be implemented across a PCI connector because the PCI specification does not provide connections for those signals. Motherboard implementations can use the standard PCI interface for standard functions but implement additional features however they like.

Semiconductor suppliers are encouraged to differentiate their products in ways that allow the PC OEM to add value. Integration reduces total cost, which is always nice, but PC OEMs are fighting for their own product differentiation to increase (or maintain) their gross margins. Network controllers that help PC OEMs position their own products as solutions with unique and value-oriented features should be in high demand.

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Market Analysis

CD-ROM Controllers Enable New Classes of CD Drives

Abstract: *Suppliers of CD-ROM controllers are adding new features to their chips that will change the dynamics of the CD-ROM drive market. CD-ROM drives are typically judged by data transfer rate and price, and CD-ROM controllers are a key component. The speed race from 2x- to 4x-speed and now 12x-speed drives is pushing several technology limits. Faster drives may require new features in the controller chips to improve overall performance without requiring faster motor speeds.*

Differentiation among CD-ROM controllers from the leading suppliers will continue to be performance oriented, but the integration of new features is essential for the higher speeds to be usable. Support for other types of compact disc drives such as CD-Recordable (CD-R) and CD-Rewritable (CD-RW, also called CD-Erasable or CD-E) is necessary for CD drives to compete with other mass storage options. Suppliers of CD-ROM controllers are aware of this and are integrating these features to make sure that CD drives can be competitive in the future. For the purposes of this document, the term "CD-ROM controller" will be used to describe controllers for CD drives that are CD-ROM compatible but may have CD-R or CD-RW capabilities, as well.

By Geoff Ballew

Basic Functions of a CD-ROM Controller

CD-ROM controllers are one of the major semiconductor components of CD-ROM drives. The basic functions of a CD-ROM controller include a decoder, error correction circuitry, a host interface (commonly SCSI or ATAPI), and interfaces to other components. The decoder functions are necessary for handling the different data formats such as CD-ROM, CD-Audio, CD-Interactive (CD-I), and others. Figure 1 shows a block diagram of CD-ROM drive, including the CD-ROM controller.

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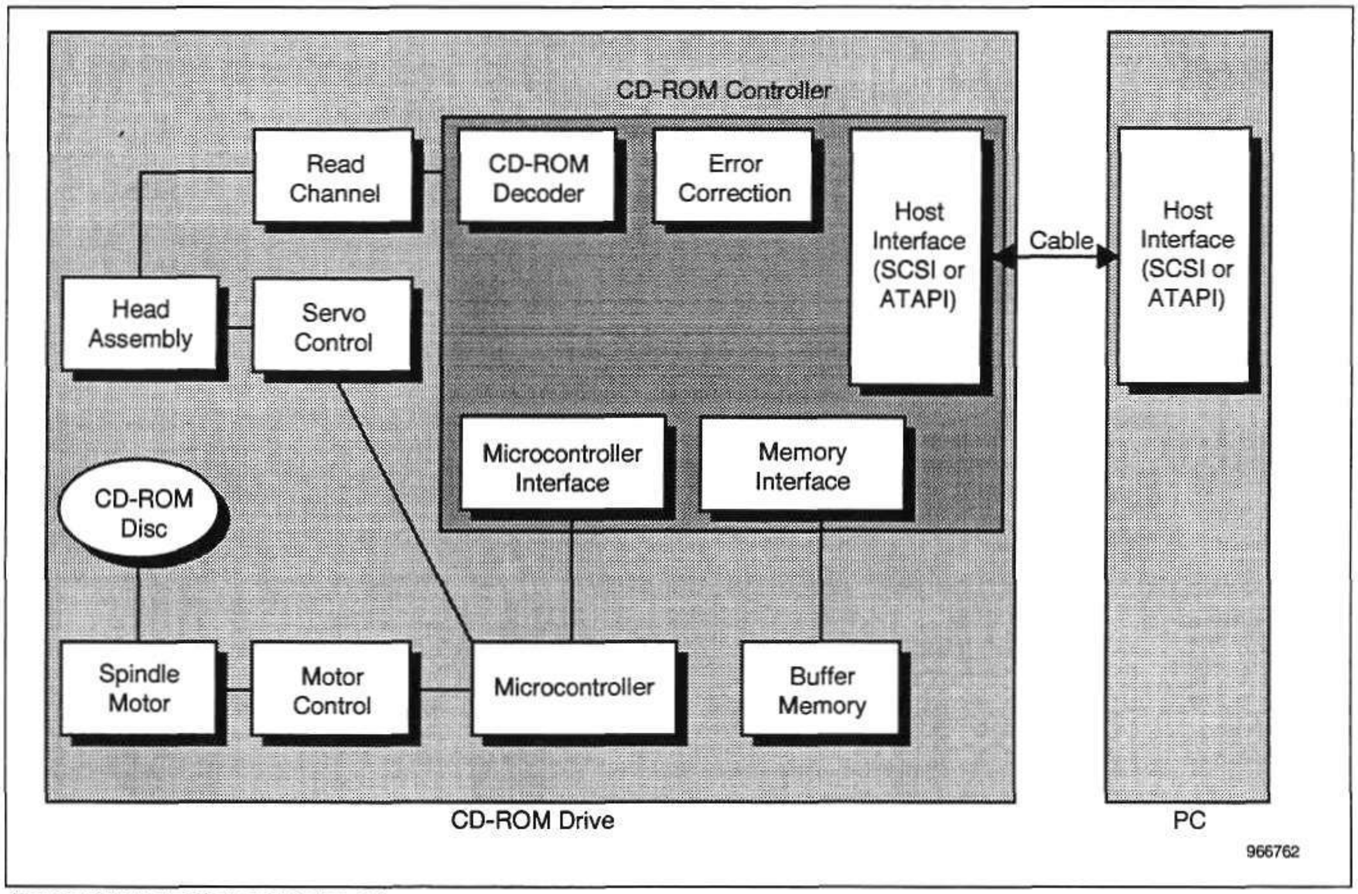
Additional functions are required for CD-Recordable (CD-R) and CD-Rewritable (CD-RW) capability. These include an encoder and a compact disc formatter, as well as circuitry for controlling the recording laser.

Figure 1
Block Diagram of a CD-ROM Drive



Source: Oak Technology and Dataquest

CD-ROM Drive Speed Issues

CD-ROM drive speed is often quoted as a whole-number multiple of the speed of the first, single-speed CD-ROM drives, for example 2x, 4x, 8x, and so on. An 8x drive can transfer data up to eight times as fast as a single-speed drive. These numbers reflect peak transfer rates rather than real application performance.

Until now, CD-ROM drive vendors have improved the peak transfer rates by simply spinning the disc faster and using faster ICs for the electronics part of the drive. The problem with this trend is that spinning the disc faster is becoming increasingly difficult. Dataquest believes that suppliers will introduce higher-speed drives (16x, 20x or faster), but the real performance of those drives may be no better than a 12x drive. Higher-speed designs will require significant redesign of the spindle motor and motor controls for reliable operation. Drive makers may find 12x-speed and faster drives difficult to manufacture in very high volume because of motor issues such as heat, vibration, and the time lag required for the motor to change speeds.

Performance may also be limited by physical imperfections of the discs. Many CDs are warped, dirty, scratched, or have a hole that is slightly off-center. These imperfections can cause data errors at higher speeds, particularly 12x and faster, even though they are readable at 2x or 4x speed. The consequence is that faster CD-ROM drives may not translate to better performance in real applications.

Another component of CD-ROM drive performance is access time. Typical access times for CD-ROM drives are 180ms to 250ms compared to 9ms to 12ms access times for rigid disk drives (RDDs). CD-ROM drive suppliers have downplayed access time in favor of promoting peak transfer rate, but this is changing. Overall performance, including access time, will receive greater attention in the future as faster motor speeds become increasingly difficult to achieve.

New Controllers Pave the Way for Better CD-ROM Drives

CD-ROM controllers are getting new features that will increase performance and make these drives more versatile by lowering the cost for CD-R and CD-RW capabilities. These improvements are important to keep the CD-ROM drive competitive with other mass storage options, such as DVD and other optical drives.

CAV Mode Helps to Solve CD-ROM Drive Speed Problems

Data rates are climbing to 20x-speed (3.0 MB/sec) and beyond, but true motor speeds may stagnate temporarily at 12x. Suppliers of CD-ROM controllers are addressing this performance mismatch by adding support for constant angular velocity (CAV) modes, in addition to the constant linear velocity (CLV) modes used in CD-ROM drives today. (See the glossary at the end of this document for a description of CAV and CLV.)

CAV mode will change the performance of CD-ROM drives in two ways. First, access time will be shorter when the drive is using CAV mode because the motor will not have to change speed. Access time is a combination of seek time, the time lag for the motor to stabilize at the appropriate rotational speed, and the time for the specific part of the disc to be read to pass over the optical head. For drives using CAV mode, the motor does not need to change speed, so that part of the access time is reduced to zero. The motor speed delays are most significant for interactive applications such as multimedia titles and are less significant for linear playback applications.

The second effect that CAV mode will have on CD-ROM drives is variable transfer rates. Transfer rates for drives using CLV are constant regardless of which part of the disc is being read. CAV causes the transfer rate to increase as the head moves outward from the center of the disc. For this reason, the transfer rate for a future CD-ROM drive might be 1.8MB/sec (12x) for the innermost part of the disc and 2.7MB/sec (18x) for the outermost part of the disc. At least one drive manufacturer expects to use CAV mode for reading the innermost part of the disc and CLV mode for reading the outermost part of the disk. Using this example, the drive would start reading the disc at 12x speed and the transfer rate would gradually increase to 18x speed, where it would stay for the rest of the disc. These are not exact numbers but serve to highlight an example. Figures 2 and 3 illustrate this relationship.

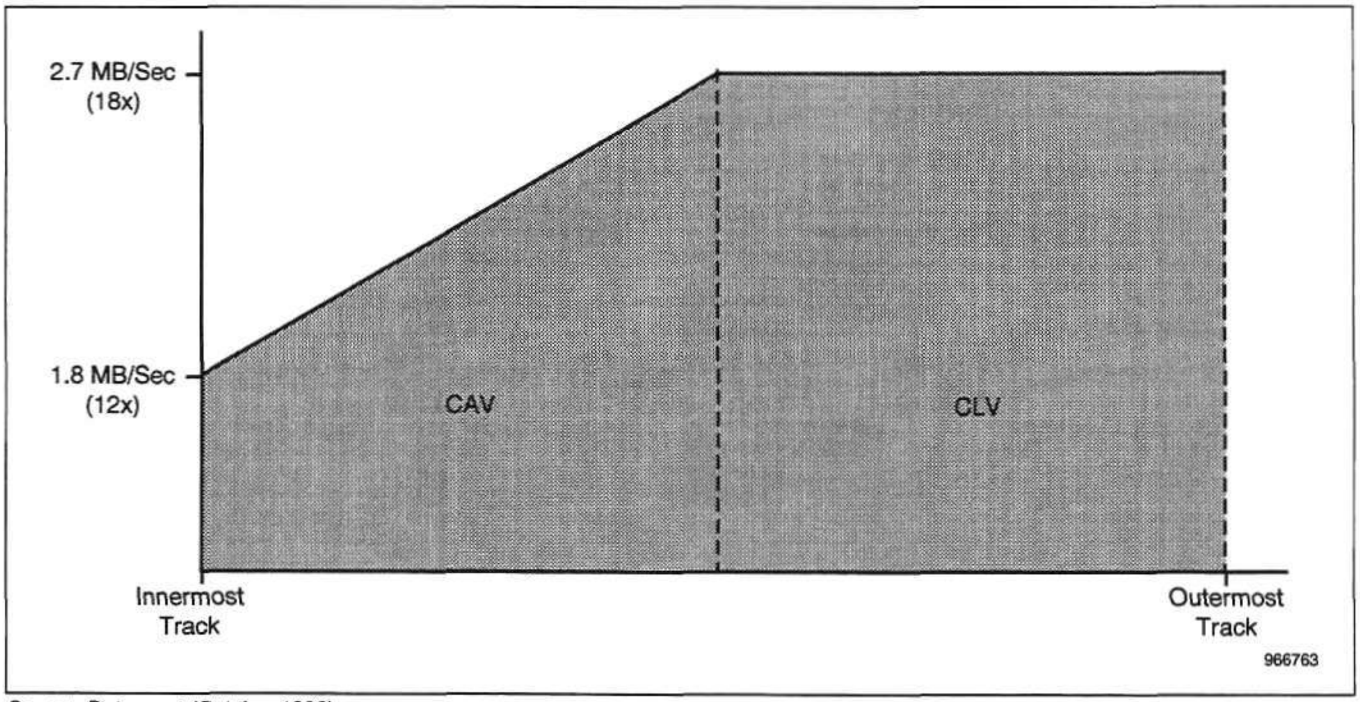
CAV mode will allow the higher data rates of new controllers to be used even if motor speeds do not increase. The example showed 18x peak transfer rate on a drive with an 12x speed motor. This 3:2 ratio applies to higher motor speeds as well: an 24x transfer rate can be achieved with a 16x speed motor. This is important because it will allow controller vendors to continue to differentiate their products on performance. Otherwise, CD-ROM drive performance could be limited by physical issues, and faster semiconductor components will not be necessary.

Integration Includes CD-R and CD-RW Features

The market for CD-ROM drives is dominated by drives that can only read discs rather than record data on them. CD-R and CD-RW drive shipments are growing at much faster rates than shipments of the read-only CD-ROM drives, but high costs are preventing the recordable drives from making the read-only drives obsolete.

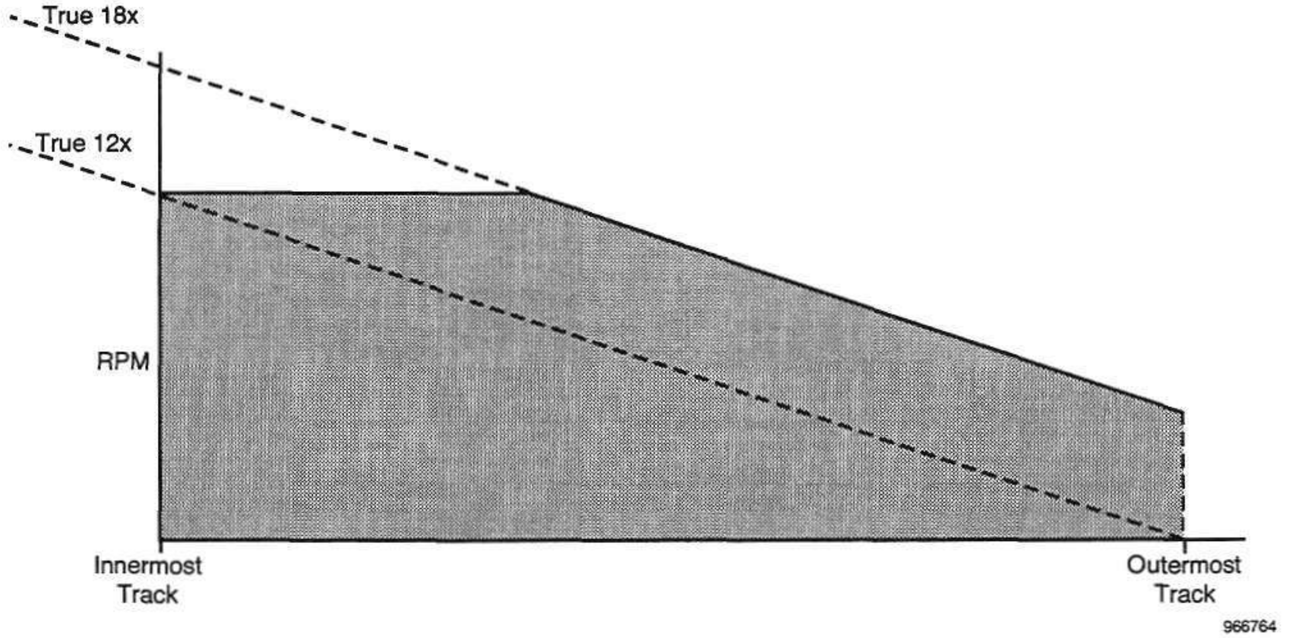
Semiconductor vendors are tackling this issue by integrating the CD-R and CD-RW features into the basic CD-ROM controller. The recordable drives require additional semiconductor content for CD-ROM data encoding, CD formatting, and control circuits for the recording laser.

Figure 2
Example of Transfer Rates Using a Dual-Mode Drive with a 12x-Speed Spindle Motor



Source: Dataquest (October 1996)

Figure 3
Example of Motor Speed Using a Dual-Mode Drive with a 12x-Speed Spindle Motor



Source: Dataquest (October 1996)

Current Products

The general specifications of current CD-ROM controllers show the trend toward higher performance and new features. Key differentiators are CAV support and CD-ROM speed. Table 1 lists the general features of several CD-ROM controllers that are shipping or have been announced by suppliers. CD-ROM speed is the peak data rate supported for read operations, and CD-R speed is the peak data rate supported for recording operations. The maximum host transfer rate is dependent on the type of interface, SCSI or ATAPI, and the specific host transfer modes that are used.

Cirrus Logic Inc. recently announced two new controller chips that are more highly integrated than competing products. The CL-CR3460 is the first CD-R/CD-RW controller chip with an ATAPI interface and follows the SCSI version of the chip. The ATAPI interface is critical for recordable drives to compete with the lower-cost read-only drives for high-volume shipments. Cirrus' new chips are a good step in reducing the costs for CD-R and CD-RW drives. Dataquest believes that Sony is Cirrus' biggest customer for CD-ROM controller chips. The advanced features of these new chips could help Cirrus win some new designs with other major CD-ROM drive OEMs.

Oak Technology Inc. is the volume leader in shipments of CD-ROM controllers. Estimates of Oak's market share for calendar 1995 are between 70 and 75 percent of the market on a unit basis. Having such a large part of the market is a double-edged sword. Oak's shipments suffered as the overproduction of 4x-speed drives last winter caused CD-ROM drive OEMs to postpone new orders for many components, including CD-ROM controllers. Those large inventories have since been worked through, and production of 8x and faster drives has ramped up for the Christmas buying season. Oak continues to have a good product line and is positioned to participate in the market transition to higher-speed drives. The company has not announced a single-chip CD-R controller, but Dataquest believes Oak will participate in the CD-R controller market as unit volumes increase in the future. CD-R is currently a relatively small market because of the high cost of CD-R drives, approximately $225 or $250 in OEM quantities, compared to less than $100 for fast CD-ROM drives in similar quantities.

It is important for new controllers to be faster than current drives. The drive OEMs need time to evaluate new controllers, and they want some "headroom" to allow for drives to get incrementally faster without having to change controllers. Oak needs to bring faster products to market to remain dominant in this market.

Philips Semiconductors Inc. has been slower to integrate functions than either Cirrus Logic or Oak Technology. As shown in Table 1, Philips' CD-ROM controller products do not include the decoder function, and the SAA7390 does not include a host interface. The SAA7385 does have an integrated microcontroller, but an external ROM is required, so the total chip count is not reduced. Philips does have a captive market for its controllers and may not be pushed competitively for that business. Philips' CD-ROM drives are more expensive than other leading brands. Relatively low levels of semiconductor integration could be a cause of higher manufacturing costs.

Table 1
Comparison of Several CD-ROM Controller Chips from Leading Vendors

Vendor	Part Number	On-Chip Decoder	CAV Support	Host Interface	CD-ROM Speed (MB/Sec)	CD-R Speed (MB/Sec)	Availability
Cirrus Logic	CL-CR3460	Yes	Yes	ATAPI	18x (2.7)	8x (1.2)	Q1/97
Cirrus Logic	CL-CR3560	Yes	Yes	SCSI	18x (2.7)	8x (1.2)	Q4/96
Cirrus Logic	CL-CR3410	Yes	No	ATAPI	10x (1.5)	NA	Now
Oak Technology	OTI-911	Yes	No	ATAPI	20x (3.0)	NA	Now
Oak Technology	OTI-910	Yes	No	ATAPI	9.5x (1.4)	NA	Now
Philips	SAA7390	No	No	None	8x (1.2)	4x (600KB/sec)	?
Philips	SAA7388	No	No	ATAPI	8x (1.2)	NA	Now
Philips	SAA7385	No	No	SCSI	8x (1.2)	NA	Now

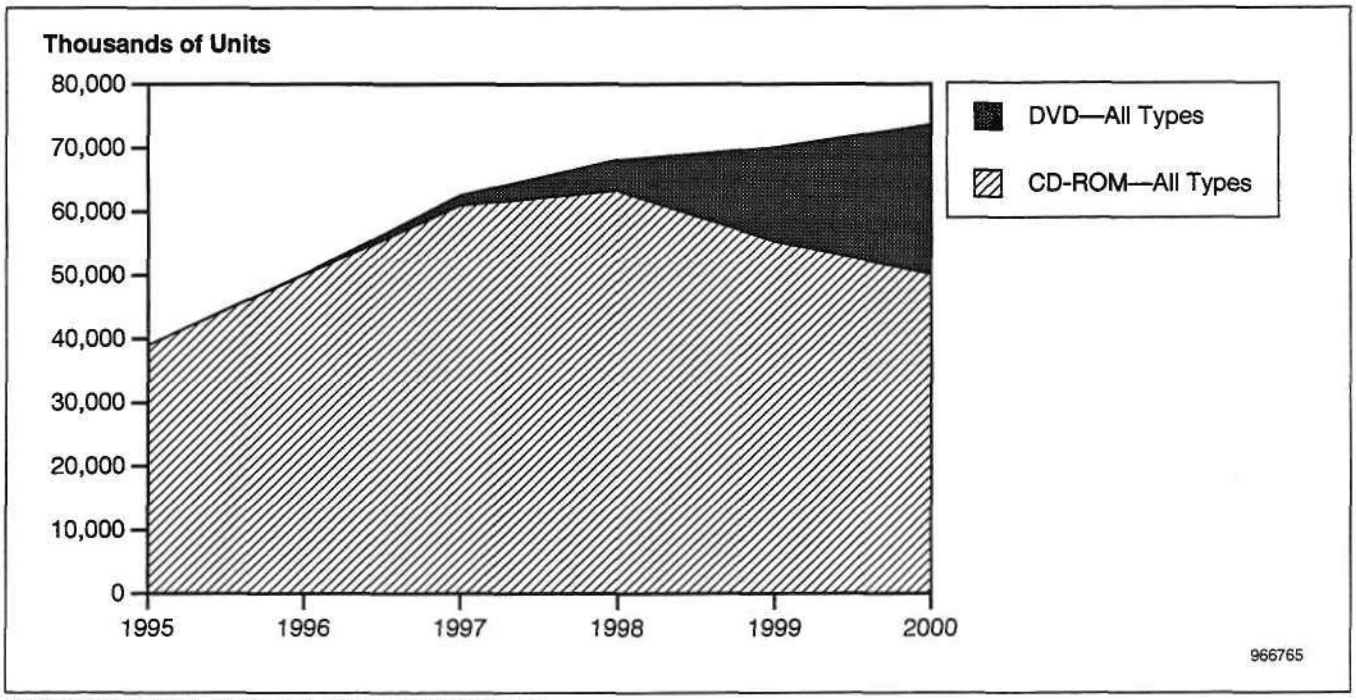
NA = Not applicable
Note: Sanyo Semiconductor is another supplier of CD-ROM controllers, but current product information was unavailable.
Source: Dataquest (October 1996)

Market Forecast

The market for CD-ROM controllers is tied to the market for the actual drives. Figure 4 and Table 2 show Dataquest's forecast for unit demand of all types of CD-ROM drives and DVD drives through the year 2000. The DVD drive forecast is shown because any delays in the ramp-up for DVD drives will impact the CD-ROM drive market positively.

The growth rate forecast for combined shipments of CD-ROM and DVD drives is slower from 1998 through 2000 than for 1996 and 1997 because of changes in the retail market. Dataquest expects that the attach rate of CD-ROM and DVD drives will continue to increase at the PC OEM level, but these increases will be largely offset by declines in the retail upgrade market for these drives.

Figure 4
Unit Shipment Forecast for All Types of CD-ROM and DVD Drives (Thousands of Units)



Note: Includes ROM, recordable, and rewritable versions)
Source: Dataquest (October 1996)

Table 2
Unit Shipment Forecast for All Types of CD-ROM and DVD Drives (Thousands of Units)

	1995	1996	1997	1998	1999	2000
CD-ROM—All Types	38,969	50,014	60,952	63,280	55,250	50,145
DVD—All Types	0	150	1,600	4,800	14,800	23,500

Source: Dataquest (October 1996)

Dataquest Perspective

Suppliers of CD-ROM controllers should continue their current strategies of enhancing performance and integrating CD-R and CD-RW features. Both of these improvements are necessary to ward off competition from competing mass-storage drives, such as Panasonic's PD drives. PD drives can read CD-ROM discs while offering rewritability on PD discs. DVD will eventually replace the CD-ROM, but cost is a major factor in the market dynamics. Any delays in bringing inexpensive DVD drives to market will create greater opportunity for CD-ROM drives.

As CD-ROM drives change from CLV devices to dual-mode devices supporting CAV and CLV, performance improvements can be made entirely through improvements in the semiconductor components. This is a boon for semiconductor vendors because it plays into their strengths of continually improving features and performance through improvements in circuit design and process technology.

Replacement of the CD-ROM platform is inevitable, so new product development should include controllers for DVD drives. Suppliers are advised to support both platforms because Dataquest believes the transition will take several years, with very high volumes of CD-ROM drives required through the year 2000. However, investment in DVD is important for long-term business growth.

Glossary

- CAV—Constant angular velocity (CAV) mode uses a constant motor RPM for reading all tracks of a disc, whether they are near the center of the disc or near the outer edge. Most disk-based mass-storage peripherals use a CAV mode. CD-ROM drives are the major exception. Using CAV mode reduces the requirements for the motor and its control system because it uses a constant motor speed.

- CLV—Constant linear velocity (CLV) uses a variable motor speed. The motor speed changes to ensure that the linear speed of the head over the track remains constant. As the head assembly moves outward from the center of the disc, the rotational speed is reduced in proportion to the circumference. CD-ROM drives use this mode because of the original Audio CD specification, which was designed for linear playback with limited random access capabilities. CLV is not well suited for applications requiring random access because it requires frequent changes to motor speed.

- CD-ROM—This stands for CD-read only memory. CD-ROM drives are playback drives for prerecorded discs, including audio CDs, standard CD-ROM discs, and others.

- CD-R—This stands for CD-recordable, that is, a type of CD drive that allow the user to write data to a CD. Special discs are required, and the data cannot be changed once it is written to the disc. CD-R discs can be read in a standard CD-ROM drive.

- CD-RW—This stands for CD-rewritable, that is, a type of CD drive that allows the user to write data to a CD, erase that data, and write to that disc again. These capabilities make CD-RW drives suitable for backup applications and other applications in which discs need to be reused as information changes. Special discs are required and are different from CD-R discs. CD-RW discs can be read in many newer CD-ROM drives, but older CD-ROM drives are not capable of reading those discs.

- DVD—This stands for digital versatile disc. DVD is essentially a high-density CD. DVD drives use discs that are the same size as a CD but hold about seven times as much information. Several different versions of DVD drives will be produced, including DVD-ROM (read-only memory), DVD-WORM (write once, read many), and DVD-RAM (random access memory). A DVD-WORM is similar to a CD-R, and a DVD-RAM is similar to a CD-RW.

- PD—This is an optical drive from Panasonic that can read, write, and erase information on PD discs as well as read CD-ROM discs.

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Market Analysis

PCs Will Consume $88 Billion of Semiconductor Content in the Year 2000

Abstract: *PCs are the largest application for semiconductors and represent over one-quarter of total semiconductor market revenue. This document provides an update to the PC semiconductor content forecast published earlier this year. The new forecast is based on Dataquest's latest PC forecast, which is also presented in this document. The semiconductor content of a typical PC peaked in 1995, and total revenue for the PC semiconductor market is forecast to decline significantly for 1996 in spite of nearly 20 percent growth in PC unit shipments. Dramatic (and well-publicized) changes in memory prices are the primary cause of the decline for 1996. Growth for the PC semiconductor market is forecast to resume in 1997 and continue through the year 2000.*
By Geoff Ballew

1996 PC Semiconductor Revenue Is Leaner than 1995, But Growth Will Return for 1997

PCs are the largest single application for semiconductors and continue to be the major driver of semiconductor growth. That growth does not always proceed unchecked, and 1996 clearly stands out as a year of decline. The PC semiconductor revenue forecast for 1996 is down primarily because of the dramatic declines in memory prices over the past year. PC OEMs have responded by stuffing more megabytes into each PC, but the increased bit consumption does not offset the declines in price per bit. Figure 1 shows Dataquest's latest forecast for the PC semiconductor market.

Overall, the PC market is forecast to consume $88 billion worth of semiconductor devices in the year 2000, up from $48 billion in 1995. This reflects a 12.9 percent compound annual growth rate (CAGR) despite the 14

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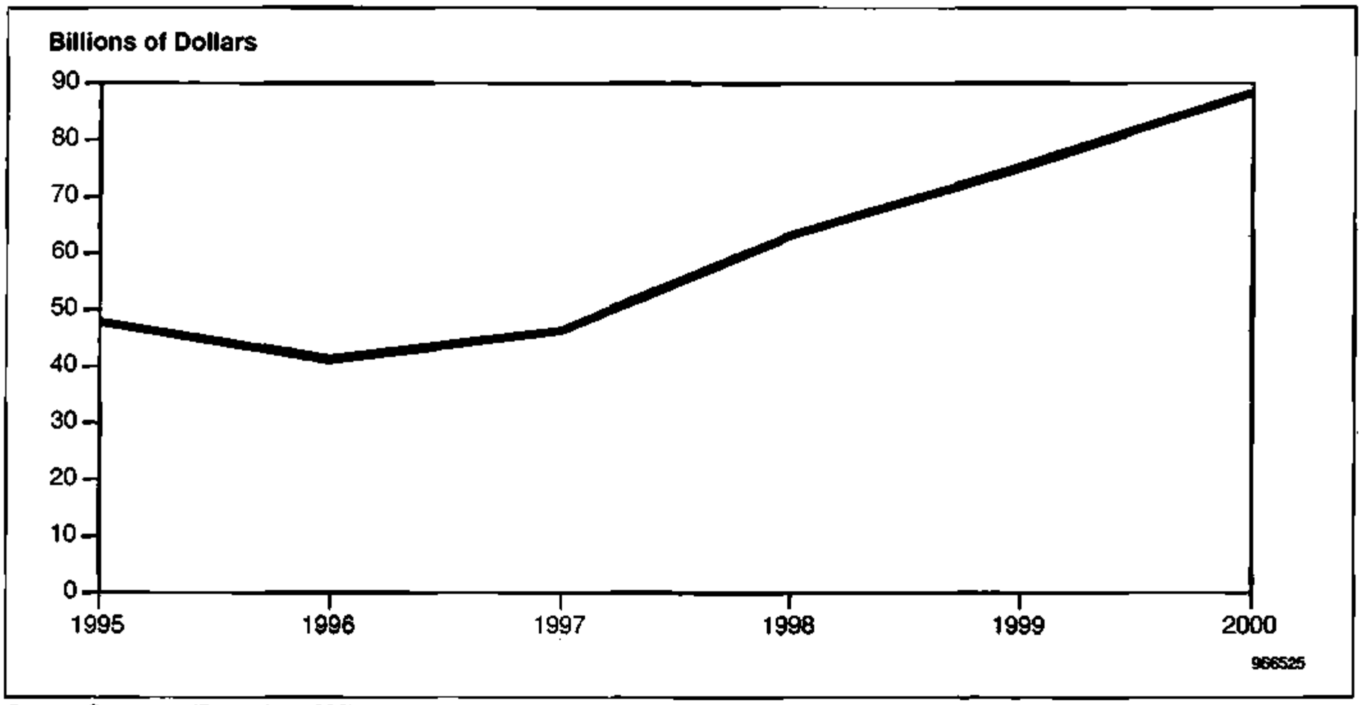
percent decline from 1995 to 1996. Table 1 includes the data from Figure 1. In 1997, revenue will show growth over 1996, but it is expected to be lower than 1995 revenue.

Figure 1
PC Semiconductor Revenue Forecast



Source: Dataquest (December 1996)

Table 1
PC Semiconductor Revenue Forecast

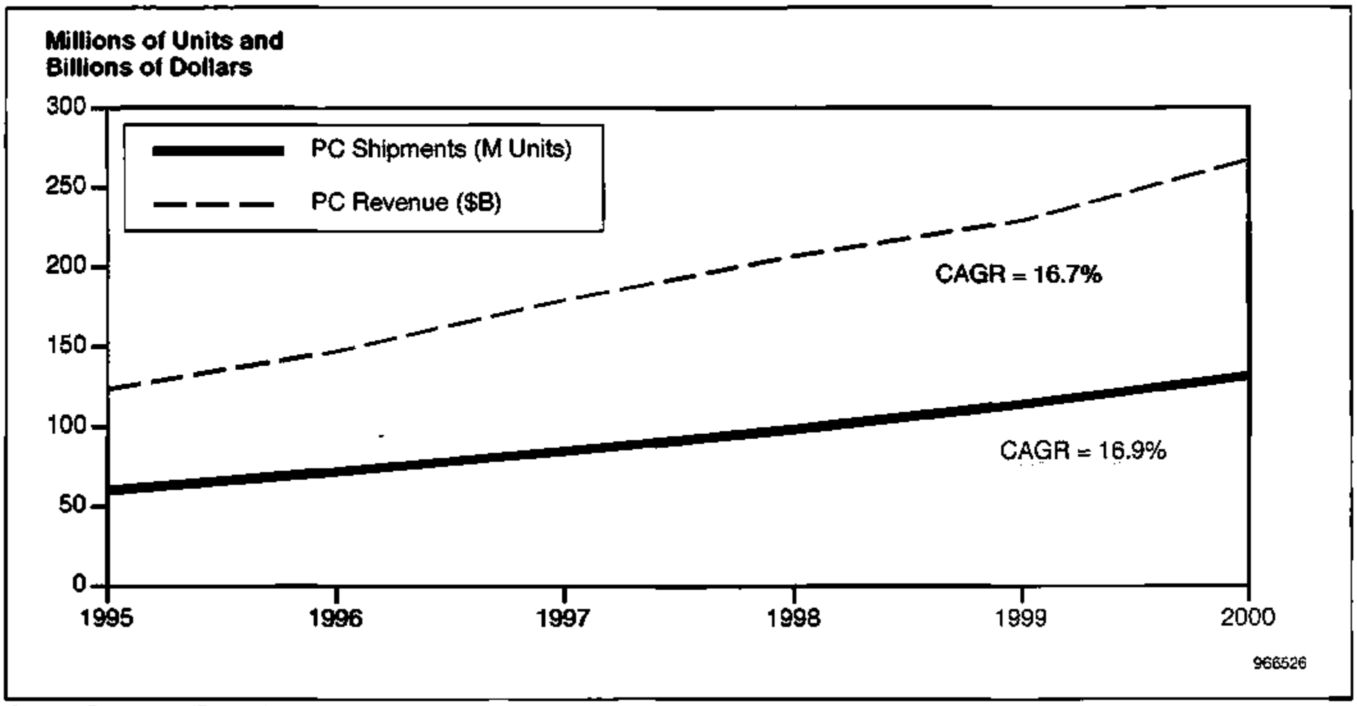
	1995	1996	1997	1998	1999	2000
PC Semiconductor Revenue ($B)	47.8	41.2	46.4	63.2	75.2	88.3
Growth over Previous Year (%)	-	-13.9	12.6	36.2	19.0	17.5

Source: Dataquest (December 1996)

The decline in PC semiconductor revenue is softened by the continued strong demand for PCs. PC shipments are on track to meet Dataquest's latest forecast of almost 20 percent unit growth for 1996. Figure 2 and Table 2 show Dataquest's most recent PC forecast. Note that unit shipments are expected to grow slightly faster than revenue over the forecast period.

The worldwide growth of the PC market is getting a boost from the markets in Japan and the Asia/Pacific region. Dataquest forecasts 40 percent unit growth for Japan and 35 percent for Asia/Pacific. These two markets are getting significant growth from home PC sales, just as the U.S. market was buoyed by sales of consumer PCs through most of the 1990s. The U.S. market is forecast to be a bit slower, at 15.5 percent unit growth. This is due in part to a level of saturation in the U.S. home PC market. Most consumers who want PCs (and can afford them) have purchased one, so the U.S. market is increasingly characterized by a replace-and-upgrade cycle rather than the dynamic of increasing market penetration. Economic issues in western Europe are limiting the unit growth there, and Dataquest expects only a 10.9 percent increase for that region.

Figure 2
PC Unit Shipment and Revenue Forecast



Source: Dataquest (December 1996)

Table 2
PC Unit Shipment and Revenue Forecast

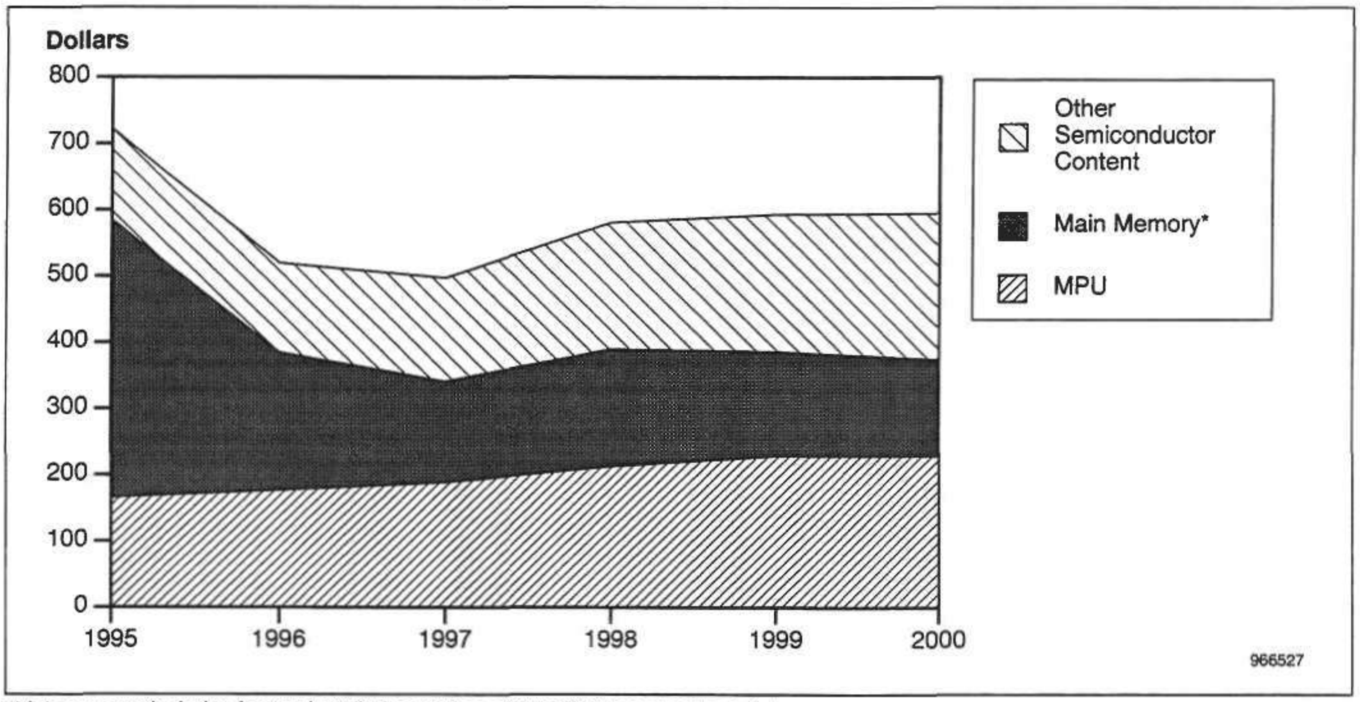
	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
PC Shipments (M Units)	60.2	72.0	84.8	98.5	114.1	131.5	16.9
PC Revenue ($B)	123.6	147.3	179.5	207.1	229.2	267.1	16.7
PC ASP ($K)	2.05	2.05	2.12	2.10	2.01	2.03	-0.2
Other Equipment Included in Semiconductor Consumption Forecast							
Additional PC Motherboards (M Units)	5.5	6.6	7.7	9.0	10.3	11.9	16.5
Handheld PCs (M Units)	0.5	0.6	0.8	1.3	2.4	5.1	60.0
Total Shipments (M Units)	66.2	79.2	93.4	108.8	126.8	148.5	17.5
PC Semiconductor Revenue ($B)	47.8	41.2	46.4	63.2	75.2	88.3	13.1
Semiconductor Revenue per Unit ($)	722	520	497	581	593	595	-3.8

Source: Dataquest (December 1996)

Semiconductor Content per PC Will Decline through 1997

Declining memory prices have driven the average semiconductor content of a PC from $722 in 1995 to $520 in 1996. This trend will continue into 1997 as semiconductor content falls to $497 before rebounding in 1998. Figure 3 shows the forecast for semiconductor content per PC through the year 2000. There is good news in these numbers for companies selling nonmemory devices rather than memory devices. The semiconductor content excluding main memory is forecast to grow each year through the year 2000. Table 3 provides the data from Figure 3.

Figure 3
Semiconductor Content of a Typical PC



*Main memory includes factory-installed as well as aftermarket memory upgrades.
Source: Dataquest (December 1996)

Table 3
Semiconductor Content per PC (Dollars per PC)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
MPU	165.6	176.3	188.3	212.6	228.6	228.4	6.6
Main Memory*	419.2	208.4	152.6	177.0	157.1	146.3	-19.0
Main Memory* (MB per System)	15.8	23.0	31.8	44.1	46.8	52.1	26.9
Cost per MB Assumption ($)	26.5	9.1	4.8	4.0	3.4	2.8	-36.1
Other Semiconductor Content	137.3	135.0	155.9	191.3	207.4	220.3	9.9
Total	722.2	519.8	496.8	581.0	593.1	595.1	-3.8

*Main memory includes factory-installed as well as aftermarket memory upgrades.
Source: Dataquest (December 1996)

Multimedia features and performance are the key drivers for PC semiconductor growth in the future. This trend is driven by peripheral chipsets but also includes microprocessors.

PC OEMs will spend significantly more dollars per PC on peripheral chipsets over the next few years as business PCs gain many of the multimedia features that characterize consumer PCs today. Audio and digital video features are penetrating the business PC market, particularly on mobile PCs. Networking is another driver as PC OEMs integrate Ethernet controllers onto many of their motherboard designs and make this a standard feature for many of their corporate PC product lines. The 9.9 percent growth of the Other Semiconductor Content line in Table 3 is due primarily to the growth of multimedia functions. 3-D graphics, higher-quality video and audio processing, and LAN/WAN peripheral chipsets are all part of this trend.

Consumer PCs will also get more new features that require additional semiconductor content. Examples are MPEG-2 and AC-3 decoding, new plug-and-play interfaces, 3-D graphics, and 3-D audio. These features will be added with a combination of fixed-logic and programmable devices. The programmable devices include media processors, as well as others that are not openly programmable but can be updated with software. One example is the U.S. Robotics 28.8-Kbps modem chipset that can be upgraded to 56-Kbps via software.

Microprocessor average selling prices (ASPs) continue to climb slowly. The higher prices are justified by advances in architecture (such as transition from Pentium-class to Pentium Pro-class MPUs) as well as new functionality, such as the multimedia instruction sets (for example, Intel's MMX) that all major MPU manufacturers are adding to their products. Demand for faster microprocessors is increasingly driven by requirements for processing multimedia types of data.

Dataquest Perspective

Demand for semiconductors in PCs is forecast to decline this year before resuming a pattern of growth. The revenue decline for 1996 is expected to be 14 percent, even though PC unit shipments are forecast to increase almost 20 percent. Higher unit shipments of PCs are necessary to offset in part the decline in dollars of semiconductor content per PC. PC OEMs are putting more megabytes of memory in PCs than ever before, but the larger memory sizes do not compensate entirely for the memory price erosion. PC semiconductor revenue growth is dependent on strong PC unit shipments.

Demand for PC semiconductors, excluding main memory, is much stronger and is forecast to grow at an 8.2 percent CAGR in terms of revenue per PC or 26.5 percent in actual revenue. The two growth rates are multiplied because the dollars per PC are growing at the same time that unit shipments are growing (that is, $1.082 \times 1.169 = 1.265$). The 8.2 percent growth rate is derived by adding the MPU revenue line and the Other Semiconductor Content revenue line from Table 3 and calculating the CAGR on the sum.

This is good news for microprocessor and peripheral chipset vendors because their products are the growth opportunities in the PC market. Memory suppliers will have a tougher time as the dollars per PC spent on main memory will decline at almost a 20 percent CAGR from 1995 to 2000.

PC semiconductor revenue will resume double-digit growth in 1997 and mirror the growth of PC revenue over the long term as supply and demand for semiconductor devices come back into balance.

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Dataquest Predicts

Quarterly x86 Compute Microprocessor Forecast

Abstract: *Dataquest has lowered its forecast of average selling prices (ASPs) to better reflect both our final 1995 estimates and Intel's ongoing, relentless price reductions intended to spur continued market growth (and succeeding). We have increased our first quarter 1997 estimate for Pentium Pro shipments to reflect Intel's recent decision to launch its Klamath design in the first quarter instead of the second quarter. We do not believe that Intel's decision to delay the P55C launch until early 1997 will have a material effect on Pentium unit shipments this year or next.*
By Nathan Brookwood

"Steady as She Goes"; Only Minor Tweaks to Our Prior Forecast

Dataquest has tuned its x86 computational processor forecast to reflect recent changes in market conditions and strategies of key vendors. The Computer Systems program stands by its earlier forecast for x86-based systems, and we have held steady our x86 unit shipment forecast (largely driven by PC unit shipment demand), as well. Based on our final roll-up of 1995 data, we have adjusted average selling prices (ASPs) downward for 1995 through 1999. These changes result in minor adjustments to factory revenue generated by x86 processor sales during the period.

Two recent Intel decisions cause minor perturbations to the forecast. First, Intel announced that it intends to forgo its customary November price adjustments for the Pentium (but not the Pentium Pro) line in the interest of maintaining market stability during the busiest season of the year for most system OEMs. Some of the price reductions we anticipated for November were incorporated in the August adjustments, and some will be deferred until February. Second, Intel announced a plan to delay the launch of its Pentium-class processor with MMX capabilities (the P55C) by a quarter, until

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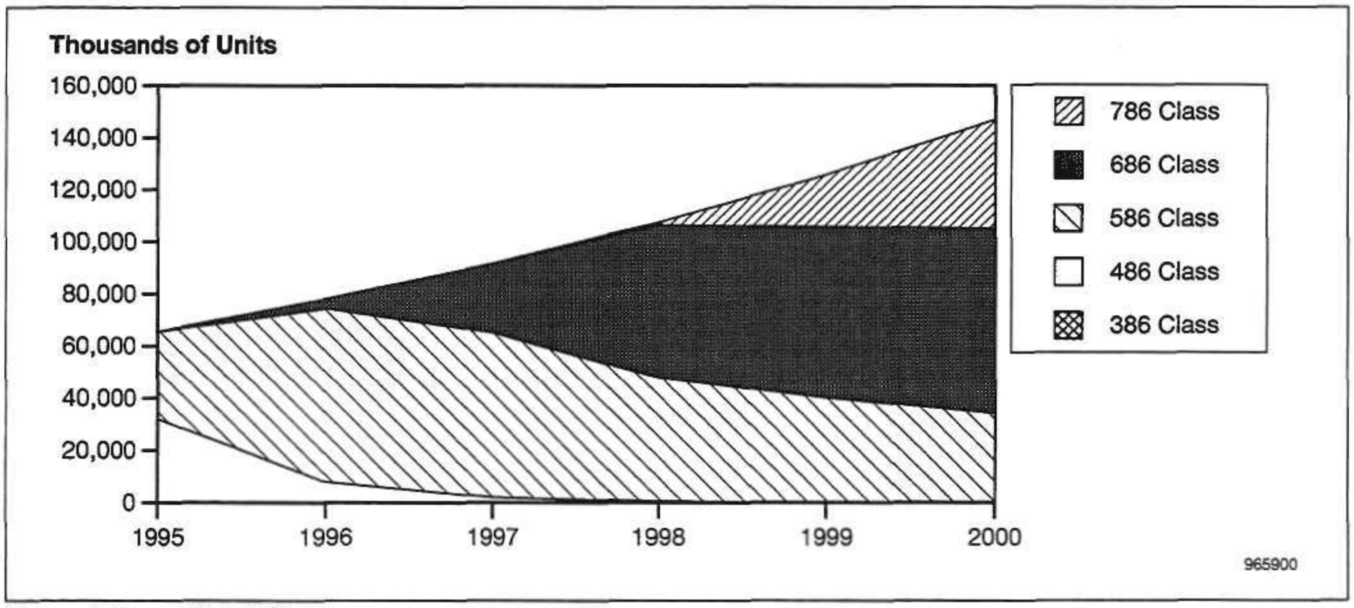
early 1997, again in the interest of market stability. It also announced its intent to pull in the release of its Pentium Pro-class product with MMX (Klamath) to early 1997, even though initial platforms may not be able to use all of the chip's performance potential. We see this pull-in increasing slightly the number of Pentium Pros sold in the first half of the year.

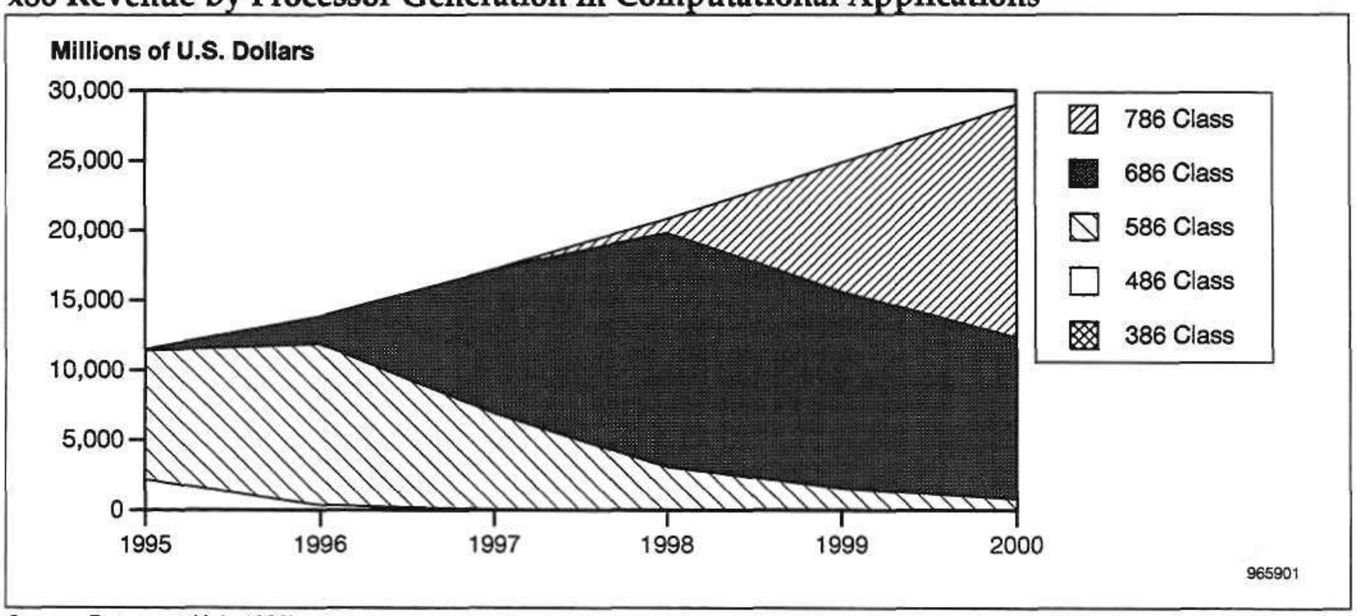
Figures 1, 2, and 3 and Table 1 illustrate Dataquest's projections for unit shipments, revenue, and ASPs over 1995 to 2000.

Figure 1
x86 Unit Shipments by Processor Generation in Computational Applications



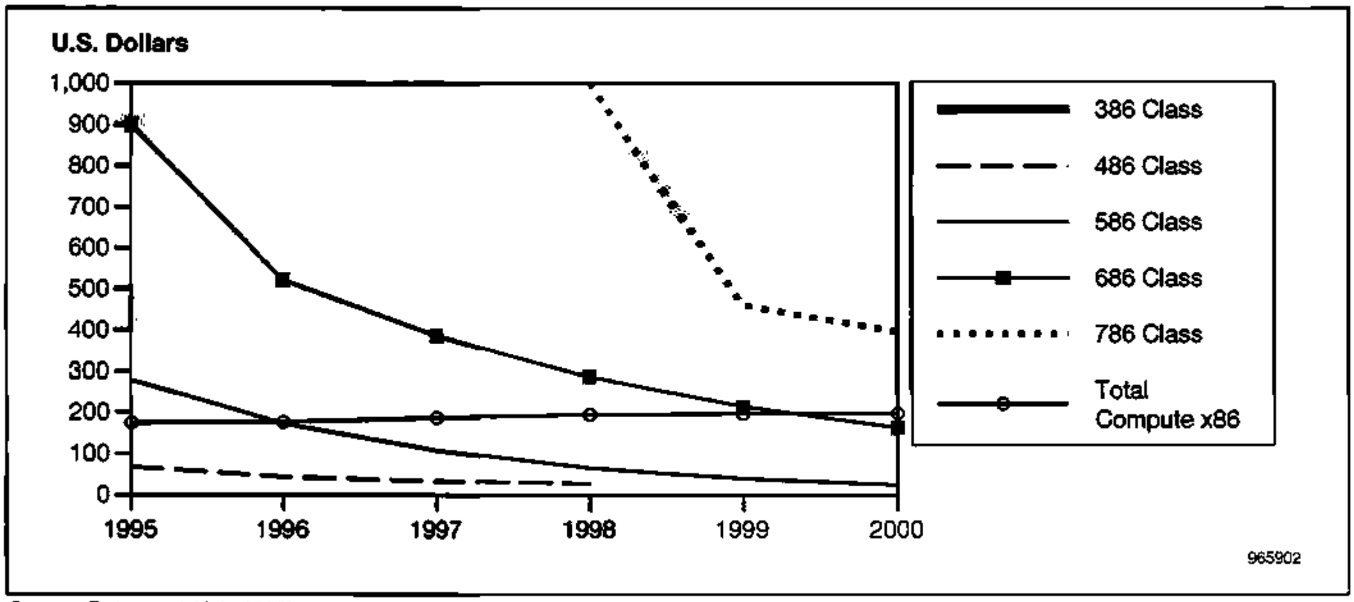
Source: Dataquest (July 1996)

Figure 2
x86 Revenue by Processor Generation in Computational Applications



Source: Dataquest (July 1996)

Figure 3
x86 Average Selling Prices by Processor Generation in Computational Applications



Source: Dataquest (July 1996)

Quarterly Projections: Strong PC Unit Growth to Continue

Dataquest projects that worldwide PC unit sales will continue to grow at an annual rate of about 19 percent over the next two years. Intel's reduced processor prices, combined with continued erosion in DRAM and hard disk prices, make this year's personal computers an incredible bargain by any standard, especially any standard more than two years old. The most successful vendors in the current market have learned how best to cope with the ever-decreasing product life cycles for systems and the need to manage assets and turn inventories as never before. This environment has produced incredible values for the consumer—and incredible headaches for PC system vendors. Dataquest regrets to report that it sees no letup in sight for these vendors, who have been dragged by Intel onto an ever-accelerating treadmill.

Table 2 and Figure 4 provide a quantitative view of Dataquest's forecast for x86 compute microprocessors over the next eight quarters.

Table 1
x86 Units, Revenue, and ASPs by Processor Generation in Computational Applications

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 Class							
Units (K)	290						-100
ASP ($)	20						-100
Revenue ($K)	5,771						-100
486 Class							
Units (K)	31,904	7,976	1,994	499			-100
ASP ($)	68	44	33	27			-100
Revenue ($K)	2,169,472	352,539	66,101	13,220			-100
586 Class							
Units (K)	33,214	66,428	63,107	47,330	40,231	34,196	1
ASP ($)	278	173	108	65	39	24	-39
Revenue ($K)	9,216,904	11,521,130	6,840,671	3,078,302	1,569,934	827,355	-38
686 Class							
Units (K)	95	3,800	26,600	58,520	65,542	70,786	275
ASP ($)	900	522	386	286	214	163	-29
Revenue ($K)	85,500	1,983,600	10,275,048	16,727,778	14,051,334	11,533,335	167
786 Class							
Units (K)				1,000	20,000	42,000	NM
ASP ($)				1,000	460	396	NM
Revenue ($K)				1,000,000	9,200,000	16,615,200	NM
Total Compute x86							
Units (K)	65,503	78,204	91,701	107,349	125,773	146,982	18
ASP ($)	175	177	187	194	197	197	2
Revenue ($K)	11,477,646	13,857,269	17,181,820	20,819,300	24,821,268	28,975,890	20

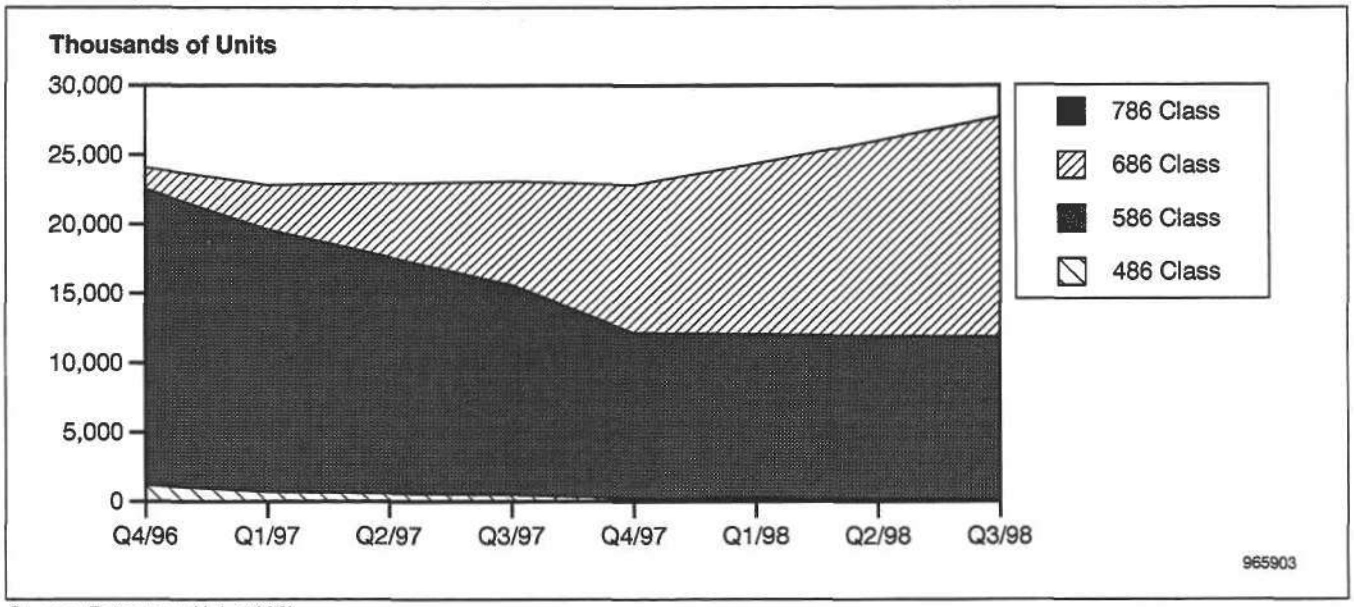
NM = Not meaningful
Source: Dataquest (July 1996)

Table 2
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications (Thousands of Units)

	Q4/96	Q1/97	Q2/97	Q3/97	Q4/97	Q1/98	Q2/98	Q3/98
486 Class	1,196	698	598	499	199	249	125	75
586 Class	21,384	18,932	17,039	15,146	11,990	11,833	11,833	11,833
686 Class	1,520	3,192	5,320	7,448	10,640	12,289	14,045	15,800
786 Class	0	0	0	0	0	0	0	50

Source: Dataquest (July 1996)

Figure 4
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications



Source: Dataquest (July 1996)

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Dataquest
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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Market Analysis

Quarterly x86 Compute Microprocessor Forecast

Abstract: *We have extended our quarterly forecast into 1998 and increased the rate of growth in unit shipments from 15 percent to 18 percent through the year 2000 to match the anticipated growth in personal computer unit shipments, as forecast by our PC systems group. We have increased the rate of average selling price erosion in 586 markets to reflect increased unit shipments by Cyrix and Advanced Micro Devices. We have slowed the rate of average selling price erosion for the Pentium Pro over this period to reflect Intel's recent decision to abandon its fourth quarter price adjustments and to reflect Cyrix's recent announcement that its 6x86 follow-on product will continue to use a Pentium-style bus. Cyrix's product thus will be categorized by Dataquest as a 586-class processor.*
By Nathan Brookwood

Lower System Prices Will Continue to Spur Growth in Unit Shipments

Dataquest has adjusted its x86 computational processor forecast to reflect recent changes in market conditions and strategies of key vendors. Compared with our x86 compute forecast issued last April, Dataquest now anticipates higher unit shipments—147 million units in the year 2000, compared with 130 million units before and slightly higher average selling prices (ASPs)—$198 in 1999, compared with $188 before. The result of higher unit shipments at higher ASPs is a larger projected market: $29 billion in the year 2000, compared with an earlier forecast of $24 billion. Several factors account for the slower rate of ASP erosion at the high end (Pentium Pro) of the line. One of these is technical; it now appears that the Cyrix competitor to the Pentium Pro will use a Pentium-style bus and thus be classified by Dataquest as a 586, rather than a 686, regardless of Cyrix's naming conventions. This also accounts for a slight decrease in our 686 forecast, along with a slight increase in the 586-class product forecast. Industry rumors abound that Intel may delay the introduction of its next Pentium Pro

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products by one or two quarters, and this too will slow the rate at which the Pentium Pro penetrates the market. Finally, we anticipate that Cyrix and Advanced Micro Devices will be forced to use pricing as a key weapon to drive their products into the market, and this, in turn, will lower ASPs for 586-class products.

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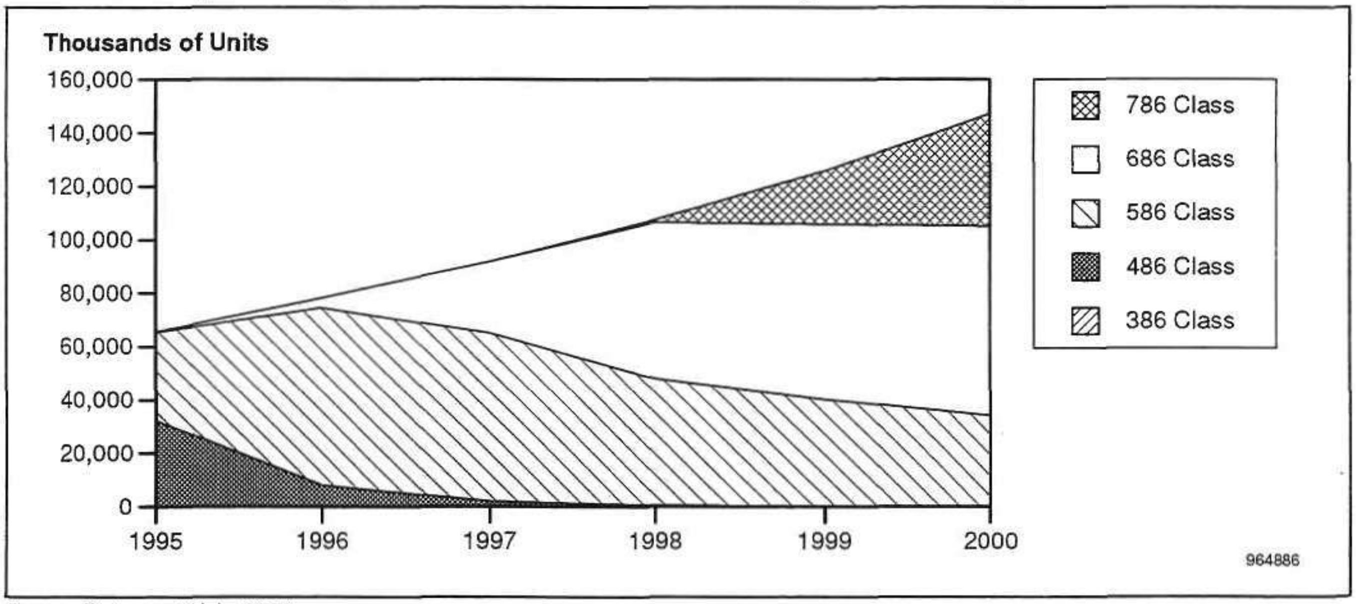
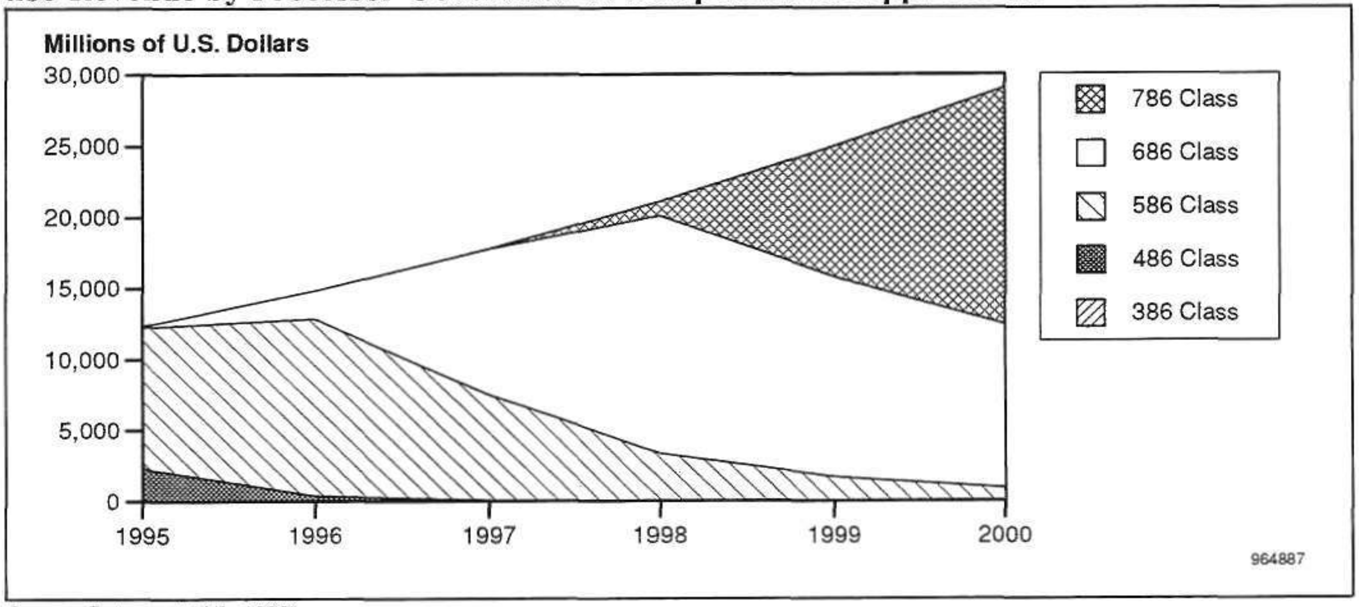
Figures 1, 2, and 3 and Table 1 illustrate Dataquest's projections for unit shipments, revenue, and ASPs from 1995 to 2000.

Figure 1
x86 Unit Shipments by Processor Generation in Computational Applications



Source: Dataquest (July 1996)

Figure 2
x86 Revenue by Processor Generation in Computational Applications



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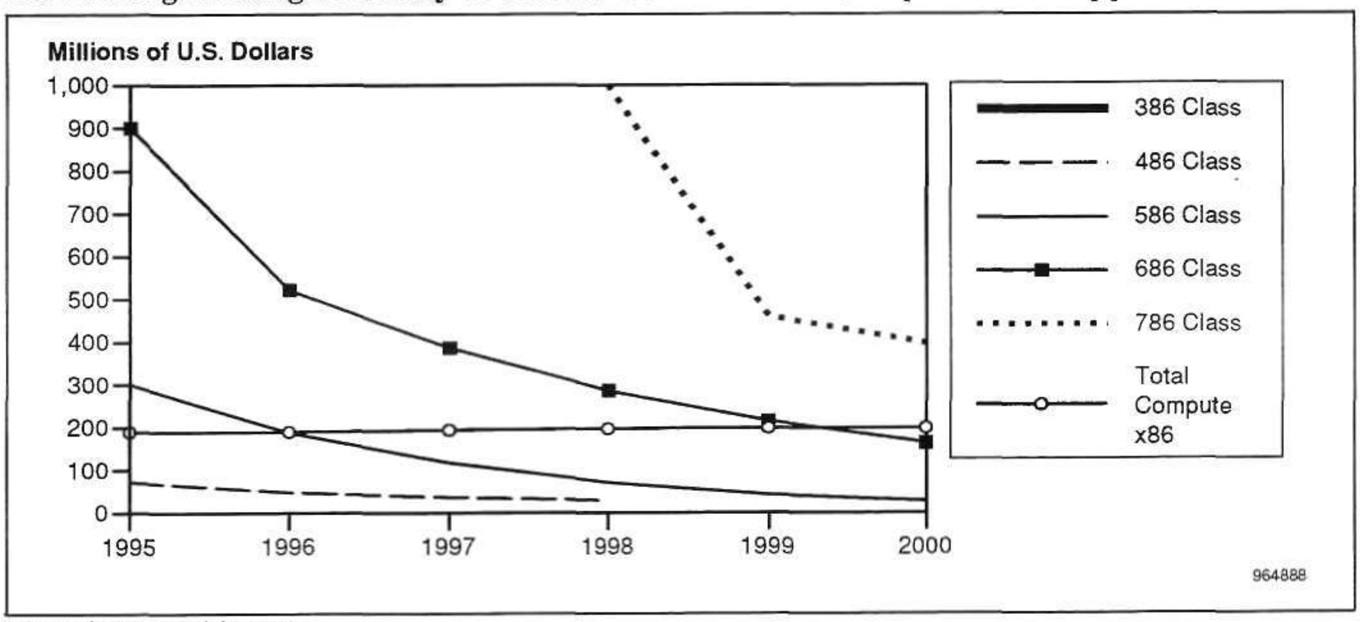

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x86 Units, Revenue, and ASPs by Processor Generation in Computational Applications

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 Class							
Units (K)	290						-100
ASP ($)	20						-100
Revenue ($K)	5,771						-100
486 Class							
Units (K)	31,904	7,976	1,994	499			-100
ASP ($)	72	47	35	28			-100
Revenue ($K)	2,297,088	373,277	69,989	13,998			-100
586 Class							
Units (K)	33,214	66,428	63,107	47,330	40,231	34,196	1
ASP ($)	300	188	117	70	42	26	-39
Revenue ($K)	9,964,220	12,455,275	7,395,320	3,327,894	1,697,226	894,438	-38
686 Class							
Units (K)	95	3,800	26,600	58,520	65,542	70,786	275
ASP ($)	900	522	386	286	214	163	-29
Revenue ($K)	85,500	1,983,600	10,275,048	16,727,778	14,051,334	11,533,335	167
786 Class							
Units (K)				1,000	20,000	42,000	NM
ASP ($)				1,000	460	396	NM
Revenue ($K)				1,000,000	9,200,000	16,615,200	NM
Total Compute x86							
Units (K)	65,503	78,204	91,701	107,349	125,773	146,982	18
ASP ($)	189	189	193	196	198	198	1
Revenue ($K)	12,352,579	14,812,152	17,740,357	21,069,670	24,948,560	29,042,973	19

NM = Not meaningful
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Dataquest projects that worldwide PC unit sales will continue to grow at an annual rate of about 19 percent over the next two years. The recent revenue and earnings shortfalls reported by several system vendors reflect a tremendously competitive pricing environment in 1996. Intel's recently announced results for the June quarter point to continued strong demand at the end-user level. The increased pressure on system vendors, caused in part by their inability to differentiate their products by other means, will only spur demand and should lead to greater increases in unit growth.

Figure 4 and Table 2 provide a quantitative view of Dataquest's forecast for x86 compute microprocessors over the next eight quarters.

Figure 4
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications

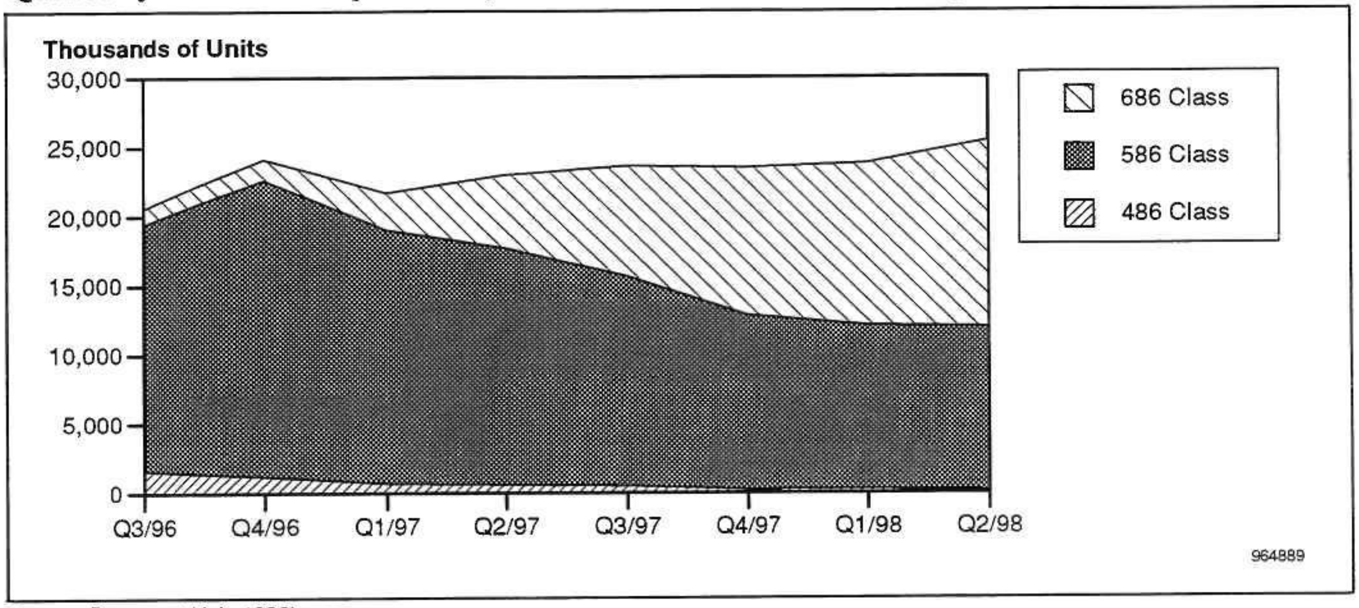

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Table 2
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications (Thousands of Units)

	Q3/96	Q4/96	Q1/97	Q2/97	Q3/97	Q4/97	Q1/98	Q2/98
486 Class	1,595	1,196	698	598	499	199	249	125
586 Class	17,820	21,384	18,301	17,039	15,146	12,621	11,833	11,833
686 Class	1,140	1,520	2,660	5,320	7,980	10,640	11,704	13,460
Total	20,555	24,100	21,659	22,957	23,624	23,461	23,786	25,417

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For More Information...
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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Market Analysis

Quarterly x86 Compute Microprocessor Forecast

Abstract: *We have extended our quarterly forecast into 1998 and increased the rate of growth in unit shipments from 15 percent to 18 percent through the year 2000 to match the anticipated growth in personal computer unit shipments, as forecast by our PC systems group. We have increased the rate of average selling price erosion in 586 markets to reflect increased unit shipments by Cyrix and Advanced Micro Devices. We have slowed the rate of average selling price erosion for the Pentium Pro over this period to reflect Intel's recent decision to abandon its fourth quarter price adjustments and to reflect Cyrix's recent announcement that its 6x86 follow-on product will continue to use a Pentium-style bus. Cyrix's product thus will be categorized by Dataquest as a 586-class processor.*
By Nathan Brookwood

Lower System Prices Will Continue to Spur Growth in Unit Shipments

Dataquest has adjusted its x86 computational processor forecast to reflect recent changes in market conditions and strategies of key vendors. Compared with our x86 compute forecast issued last April, Dataquest now anticipates higher unit shipments—147 million units in the year 2000, compared with 130 million units before and slightly higher average selling prices (ASPs)—$198 in 1999, compared with $188 before. The result of higher unit shipments at higher ASPs is a larger projected market: $29 billion in the year 2000, compared with an earlier forecast of $24 billion. Several factors account for the slower rate of ASP erosion at the high end (Pentium Pro) of the line. One of these is technical; it now appears that the Cyrix competitor to the Pentium Pro will use a Pentium-style bus and thus be classified by Dataquest as a 586, rather than a 686, regardless of Cyrix's naming conventions. This also accounts for a slight decrease in our 686 forecast, along with a slight increase in the 586-class product forecast. Industry rumors abound that Intel may delay the introduction of its next Pentium Pro

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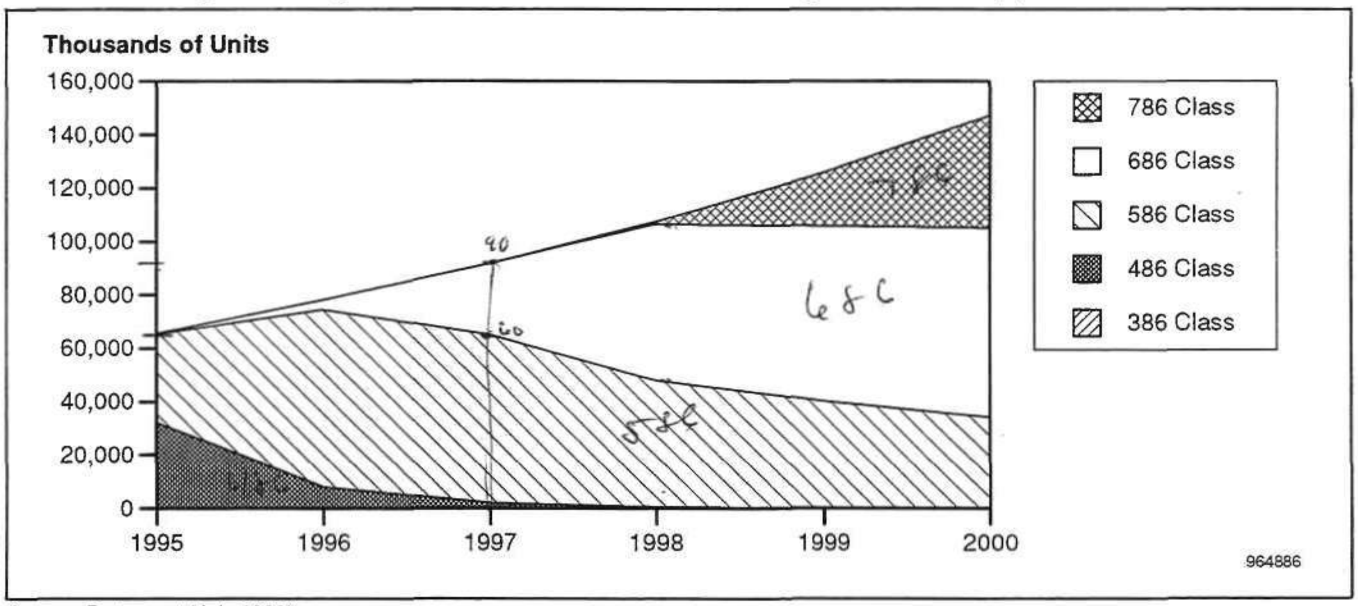

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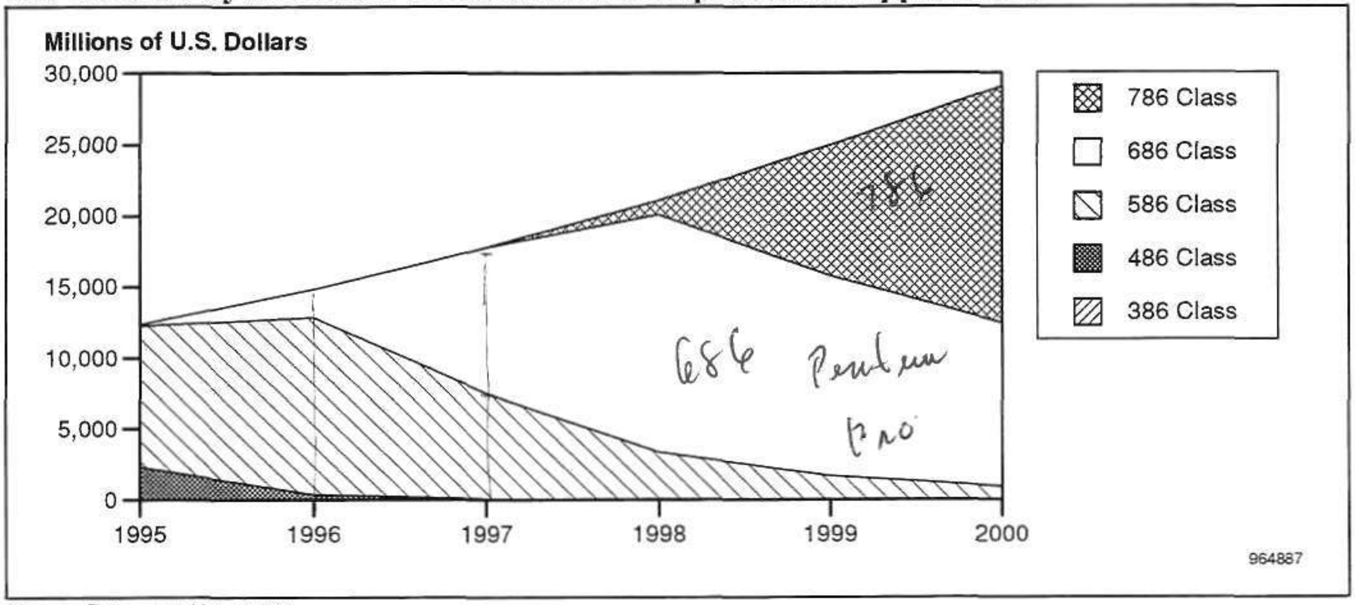

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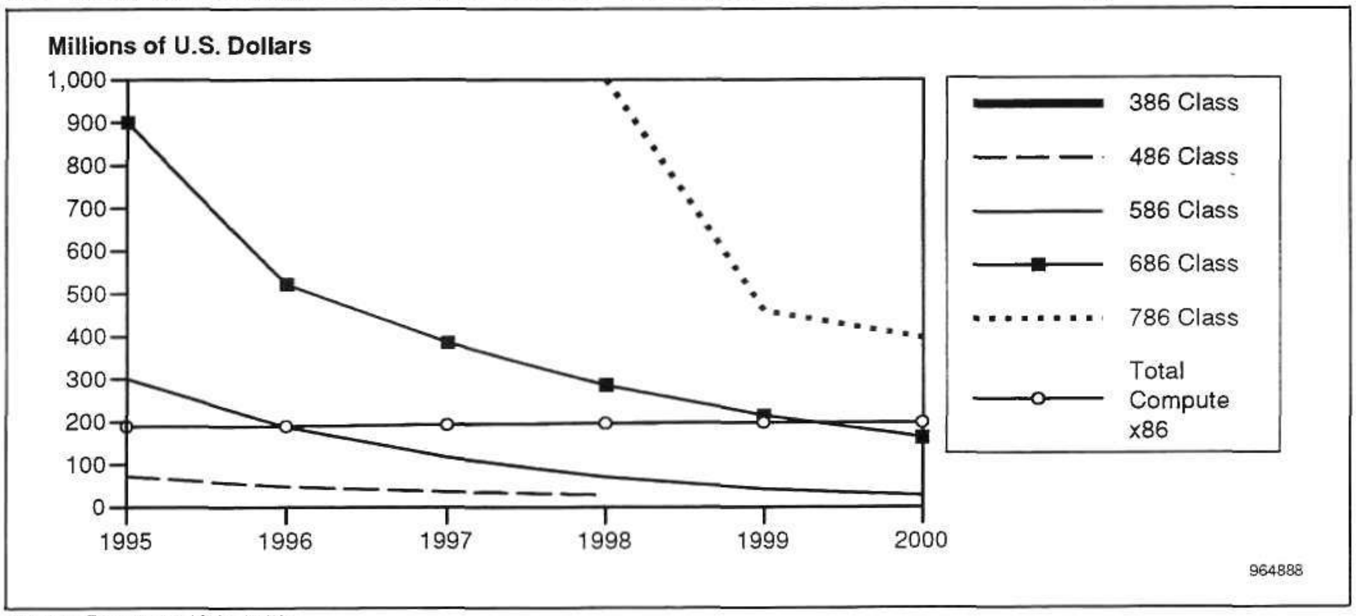

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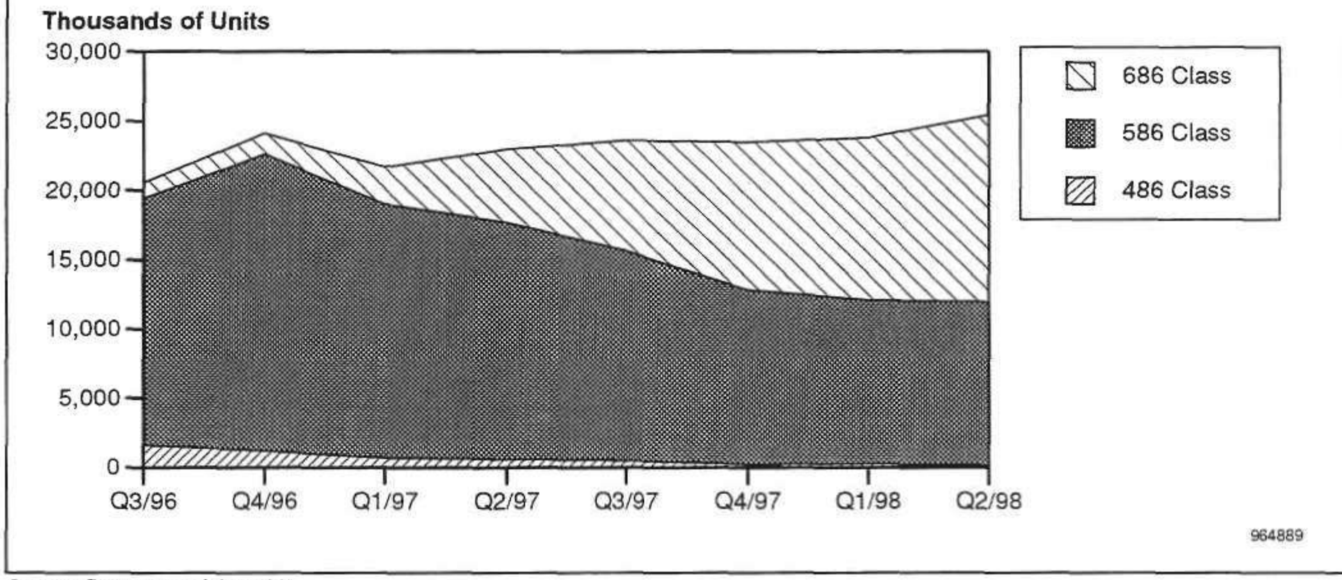

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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Dataquest Predicts

DVD Poised to Drive Market for Digital Video Chips to New Heights

Abstract: *Digital technologies and advanced semiconductors are reshaping the consumer electronics world. The introduction of exciting new products such as DVD-Video players and direct broadcast satellite (DBS) set-top boxes creates new destinations for chips such as microprocessors (MPUs), digital signal processors (DSPs), application-specific ICs (ASICs), application-specific standard products (ASSPs), and memory. Although these markets are still in their infancy, they are forecast to experience rapid growth. This report provides a brief overview of the market opportunity presented by DVD, along with some of the major hurdles that remain on the path to market. Forecasts of DVD production and the DVD semiconductor market are provided, along with a list of companies making early semiconductor product announcements.*

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By Dale Ford

The DVD Opportunity

Standing on the shoulders of major technological advances in areas such as video and audio compression, laser diode physics, and optical storage technology, DVD is poised to boost both the consumer electronics and personal computer markets to new heights. The exciting capabilities promised by

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DVD have captured the imagination and investment budgets of companies from at least seven major industries. The major players in the development of DVD continue to struggle with balancing the cooperative and competitive forces that have swirled around this promising product for over two years. Although all the players recognize that a coordinated, cooperative effort is essential for the creation of a successful market, their zeal to capitalize on one of the most exciting products of the 1990s has brought DVD to the brink of digital video disaster on a number of occasions.

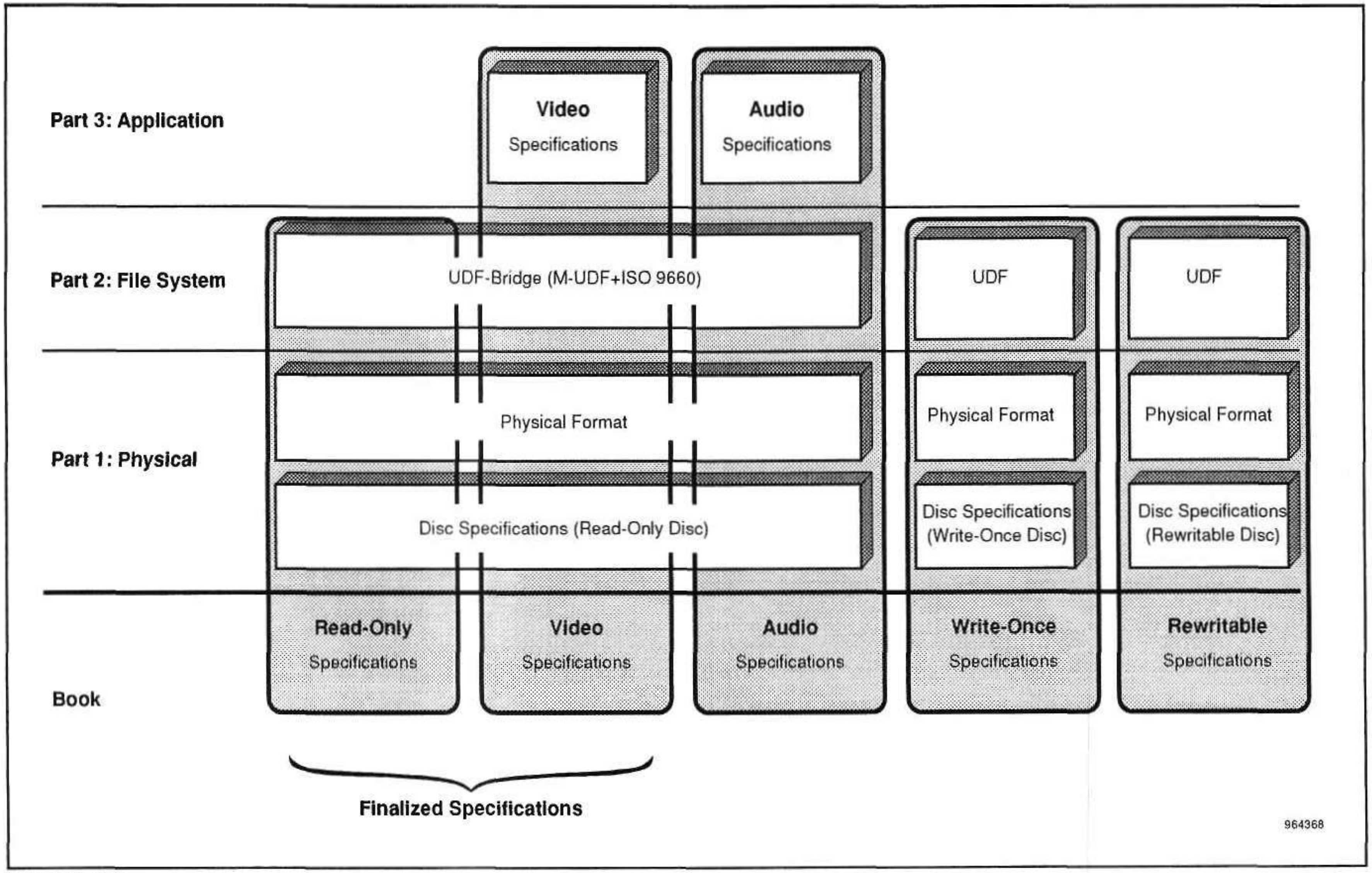
Dataquest is optimistic that the remaining hurdles on the path to the successful launch and growth of the DVD market will be overcome. Although it does not match the hyped expectations of some DVD proponents, Dataquest's forecast for the growth of the DVD market would make this one of the most successful products ever introduced in the consumer electronics and PC markets. After assessing the many factors that will influence the DVD market, Dataquest projects that market shipments of DVD-Video players and DVD optical drives will top 33 million by the year 2000. More than 2.3 million DVD systems are expected to ship between the first product introductions in October and November 1996 and the end of 1997. The semiconductor opportunity generated by the DVD market is forecast to exceed $3.6 billion by the year 2000.

DVD: What Is It? Where Is It Going?

Perhaps the easiest way to think of DVD is as a CD drive on steroids. With higher storage capacity, faster data transfer rates, interactive capabilities, and applications across computer, video, and audio markets, DVD has moved the capabilities of optical storage forward by an order of magnitude, and DVD supporters are already beginning to "feel the burn." In its incarnation as a video player, it offers the ability to view full-length movies in multiple aspect ratios, languages, and Motion Picture Association of America (MPAA) ratings (R, PG-13, PG, G), all stored on a single CD-ROM-size disc. As a PC peripheral, DVD offers new levels of interactivity for next-generation software titles and the storage capacity to handle more content than developers currently know what to do with. In reality, DVD is actually five separate standards, as shown in Figure 1. The physical specifications and file system for the first three standards are the same so that a common platform can be created for multiple applications in the video, audio, computer, and next-generation consumer electronics markets.

Books A, B, and C in the standard are "read-only memory standards" (ROM), while Book D will specify a "write-once, read-many" (WORM) standard, and Book E will offer the ability to read, write, and erase. Because of its ability to read and write, it is often called DVD-RAM, referring to a random access memory capability. Book A, also known as DVD-ROM, and Book B, DVD-Video or DVD-Movie, are close to final and should enable the launch of products based on these standards at the end of 1996. Manufacturers would say that the standards are final. They are close, but there are some details that remain to be decided, such as copy protection and encryption. The DVD-Audio standard, or Book C, is in the early stages of discussion, and some preliminary proposals have been presented for this standard. Although hardware manufacturers are eager to move to market as quickly as possible, the music industry is intent on protecting its interests and has signaled its intention to set a slower pace of development. The

Figure 1
The Five DVD Standards



Source: Toshiba

DVD-WORM and DVD-RAM standards will be established over the coming one to two years. In the meantime, the promoters of DVD have their hands full trying to bring the first DVD products to market.

The title of "convergence product" has been bestowed on DVD because of the common platform it will create for multiple applications across computer and consumer devices. Although obvious uses are found in TV, PC, and high-end audio systems, the set-top box, network computer, and video game console will also be impacted by DVD. Manufacturers of set-top boxes already have plans to leverage the common MPEG-2 chipset into a hybrid device that may provide the ability to record content sent over satellite or cable in the future. When the Bandai Pippen was introduced at the E3 1996 show, the manufacturer was already talking about the eventual replacement of the CD-ROM drive with a DVD drive in the next version. Even video game consoles will upgrade to DVD eventually.

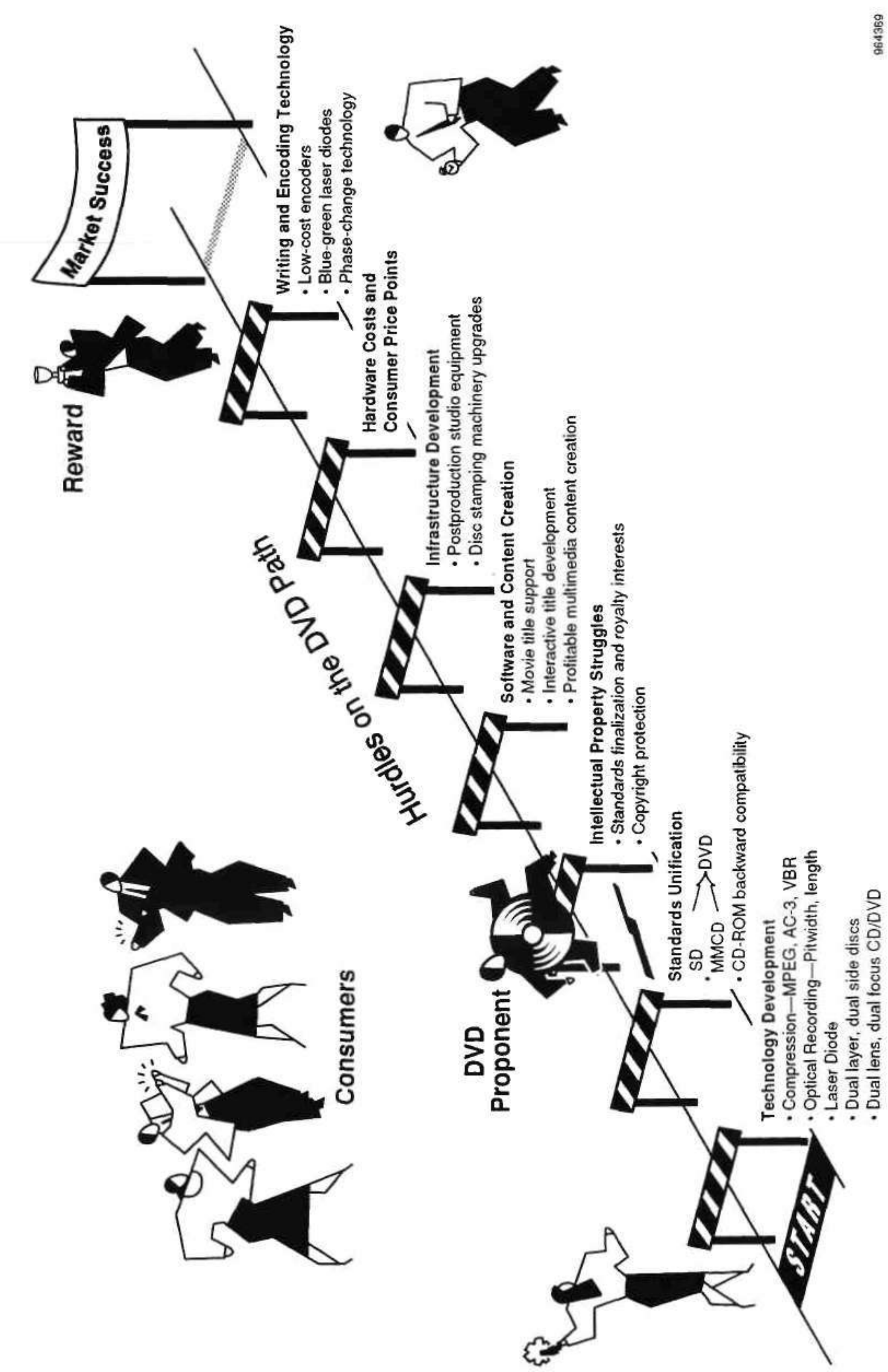
The success of DVD in the market is highly dependent on the ability of seven major industries to cooperate in translating this product concept into a market reality. If the major companies in any one of the industries decide that they are not benefiting sufficiently from DVD and decide to withdraw support, or if they fail to develop the necessary support infrastructure in a timely fashion, the near-term success of DVD would be seriously harmed. If disputes involving issues such as royalties and copyrights are not resolved soon, the launch of this market could be delayed. However, Dataquest is optimistic that present difficulties can be overcome and that the long-term prospects for DVD are very bright.

As they race to the market, DVD proponents will have to avoid being tripped up by some of the major hurdles shown in Figure 2. They have already overcome significant technological and standards hurdles, but they still do not have a clear sprint to the finish line. It is to be hoped that the potential rewards will provide the necessary momentum to allow the emerging DVD market to reach its full potential.

Based on an analysis of consumer market behavior and expected price trends, Dataquest has developed the market forecast for DVD-Video players, DVD optical storage drives, and DVD PC decode/encode add-in boards shown in Figure 3. This market forecast demonstrates Dataquest's optimism regarding the future of DVD. Our projections show the combined annual market shipments of DVD-Video players and DVD drives growing to over 33 million by the year 2000, making it one of the most successful products introduced in the 1990s. The combined market shipments of all DVD products, including decode/encode add-in boards, would drive factory revenue over $10 billion by the year 2000.

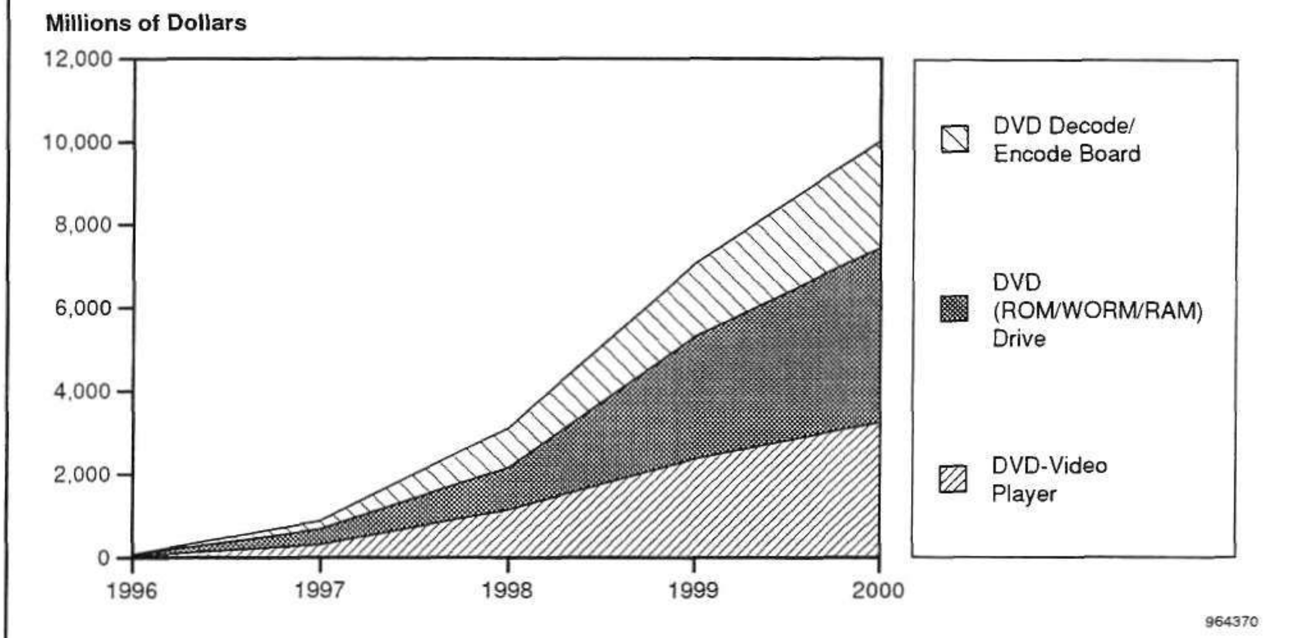
Certainly, there are factors that could drive the market above or below this forecast. If manufacturers are able to drive prices below Dataquest's expectations, this would stimulate higher growth. On the other hand, if the creative community fails to develop software products in a timely fashion that exploit the advanced capabilities of DVD, it will be hard to push the installed base of CD-ROM users and VCR owners to a more expensive platform. All the hurdles discussed earlier in this report could impact the growth of the DVD market.

Figure 2
Hurdles on the DVD Path



Source: Dataquest (June 1996)

Figure 3
DVD Market Revenue Forecast



Source: Dataquest (June 1996)

DVD Production Forecast and Semiconductor Opportunity

Based on the predicted market growth, Figure 4 and Table 1 present Dataquest's DVD production forecast.

The semiconductor community has invested in DVD technology early. Although the early DVD players that come to market will have little integration, they will be replaced in a matter of a few months by products that will take advantage of integrated chipsets that have already been announced. The second-generation chipsets will be ready before the first-generation systems have even shipped. Semiconductor manufacturers have outlined aggressive integration plans for DVD and other products that are based on MPEG-2 and AC-3 compression technology. Some companies have even presented plans to develop single-chip DVD processing solutions. Dataquest stops short of predicting this level of integration because of the belief that there are no cost or performance advantages to be gained from integrating the channel-processing function and audio/video coder/decoder (codec).

Announced chipsets for audio and video processing, the servo processor, and some channel demodulation functions will be based on a 0.35-micron CMOS process, which will migrate to 0.25-micron CMOS over the following two years. Other components in the DVD-drive electronics will be based on bipolar technology. As chipsets move along the integration path, a growing opportunity for BiCMOS will develop.

Figure 5 illustrates the semiconductor forecast for chips used in DVD applications. (The data for this figure is found in Table 1.) This forecast is based on the DVD production forecast and an analysis of semiconductor content

Figure 4
DVD Production Forecast

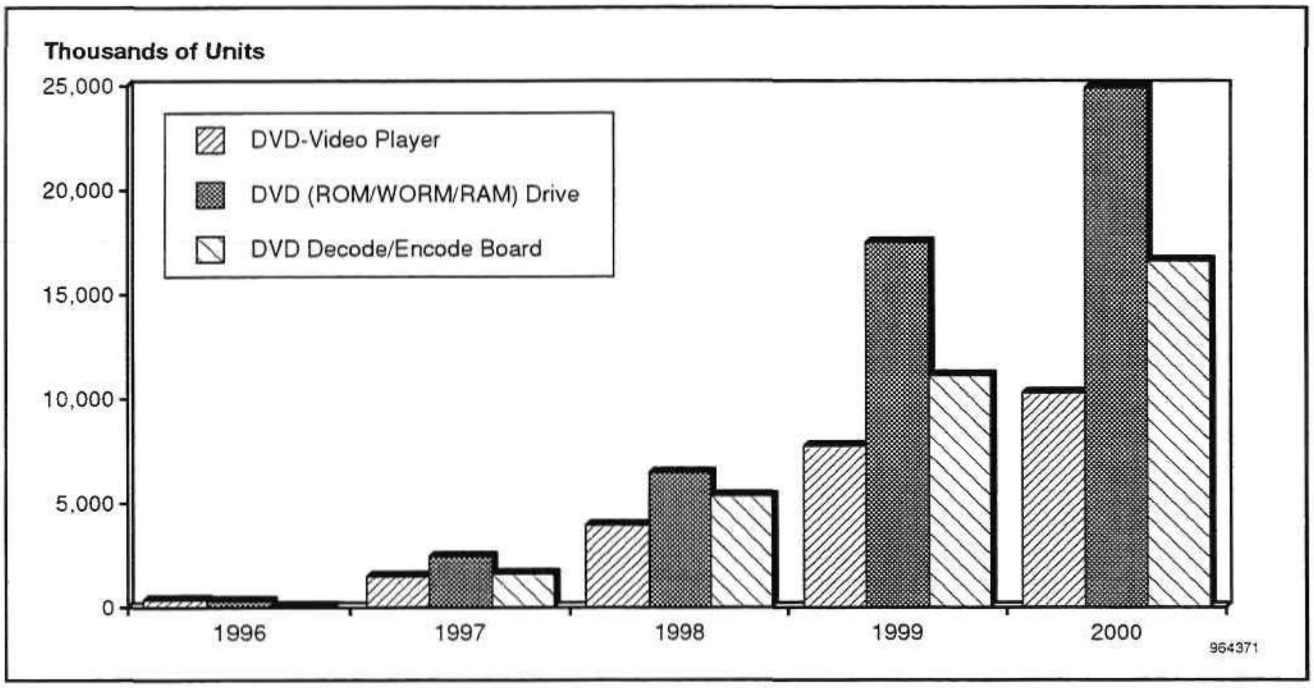


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Table 1
DVD Production Forecast

	1996	1997	1998	1999	2000	CAGR (%) 1996-2000
DVD-Video Player						
Units (K)	360	1,495	3,956	7,755	10,283	131.2
Factory ASP ($)	428	394	365	357	331	-6.2
Factory Revenue ($M)	154	589	1,443	2,772	3,406	116.9
Semiconductor Content ($)	146	133	122	116	108	-7.3
Semiconductor TAM ($M)	53	199	481	903	1,112	114.4
DVD Optical Drive						
Units (K)	295	2,440	6,467	17,500	24,898	203.1
Factory ASP ($)	230	218	204	194	175	-6.7
Factory Revenue ($M)	68	533	1,316	3,402	4,348	182.9
Semiconductor Content ($)	81	76	70	67	62	-6.6
Semiconductor TAM ($M)	24	185	451	1,170	1,532	183.1
DVD Decode/Encode Boards and Chipsets						
Units (K)	40	1,623	5,361	11,108	16,611	352.8
Factory ASP ($)	258	218	210	175	164	-10.7
Factory Revenue ($M)	10	354	1,125	1,941	2,720	304.3
Semiconductor Content ($)	85	77	75	64	60	-8.4
Semiconductor TAM ($M)	3	126	403	709	993	315.0

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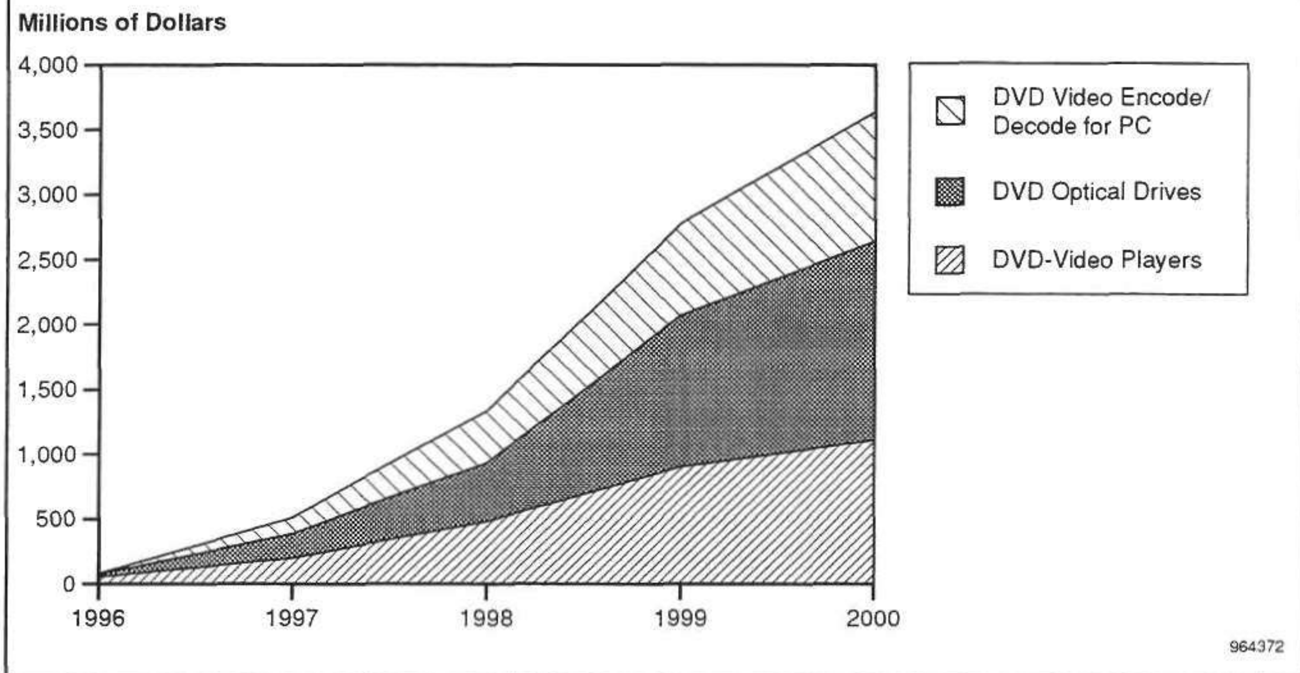
Figure 5
DVD Semiconductor Market Forecast by Platform



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and chip pricing trends. Dataquest forecasts the total DVD semiconductor market to grow from less than $80 million in 1996 to over $3.6 billion in just four years.

The following chip companies have been working with DVD manufacturers for many months leading up to the launch of DVD products.

- Motorola
- Hyundai
- Zoran
- Philips
- Texas Instruments
- Silicon Systems
- SGS-Thomson
- Oak Technology
- LSI Logic
- VLSI Technology
- Toshiba

Summary and Conclusions

The number of systems manufacturers and chip companies that will compete in the DVD arena will create a dynamic and highly competitive environment. Although the forecast market growth will create very profitable opportunities, the nature of the competition will lead to a number of casualties among systems and semiconductor players. Competitors should expect the consumer to be very demanding in terms of system performance and price. These demands will be reflected to the semiconductor companies, which will be placed under heavy price and performance pressures.

Because the technologies shaping this market will continue to develop over the forecast period, chip companies seeking to be successful in this market should be prepared to continue making major investments in their product development. As they seek to reduce their product development costs, systems manufacturers will value complete systems solutions from semiconductor manufacturers. Chip companies unable to provide a complete solution with their own product line should seek alliances with other companies to complement their strengths. Also, semiconductor manufacturers should develop strategies that will allow them to leverage their products across multiple next-generation consumer electronics products. This will allow them to maximize their profits and reduce their risks in this exciting, but turbulent, market segment.

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Filing: Perspective
(For Cross-Technology, file in the Semiconductor Application Markets, Volume 2, binder.)

DVD have captured the imagination and investment budgets of companies from at least seven major industries. The major players in the development of DVD continue to struggle with balancing the cooperative and competitive forces that have swirled around this promising product for over two years. Although all the players recognize that a coordinated, cooperative effort is essential for the creation of a successful market, their zeal to capitalize on one of the most exciting products of the 1990s has brought DVD to the brink of digital video disaster on a number of occasions.

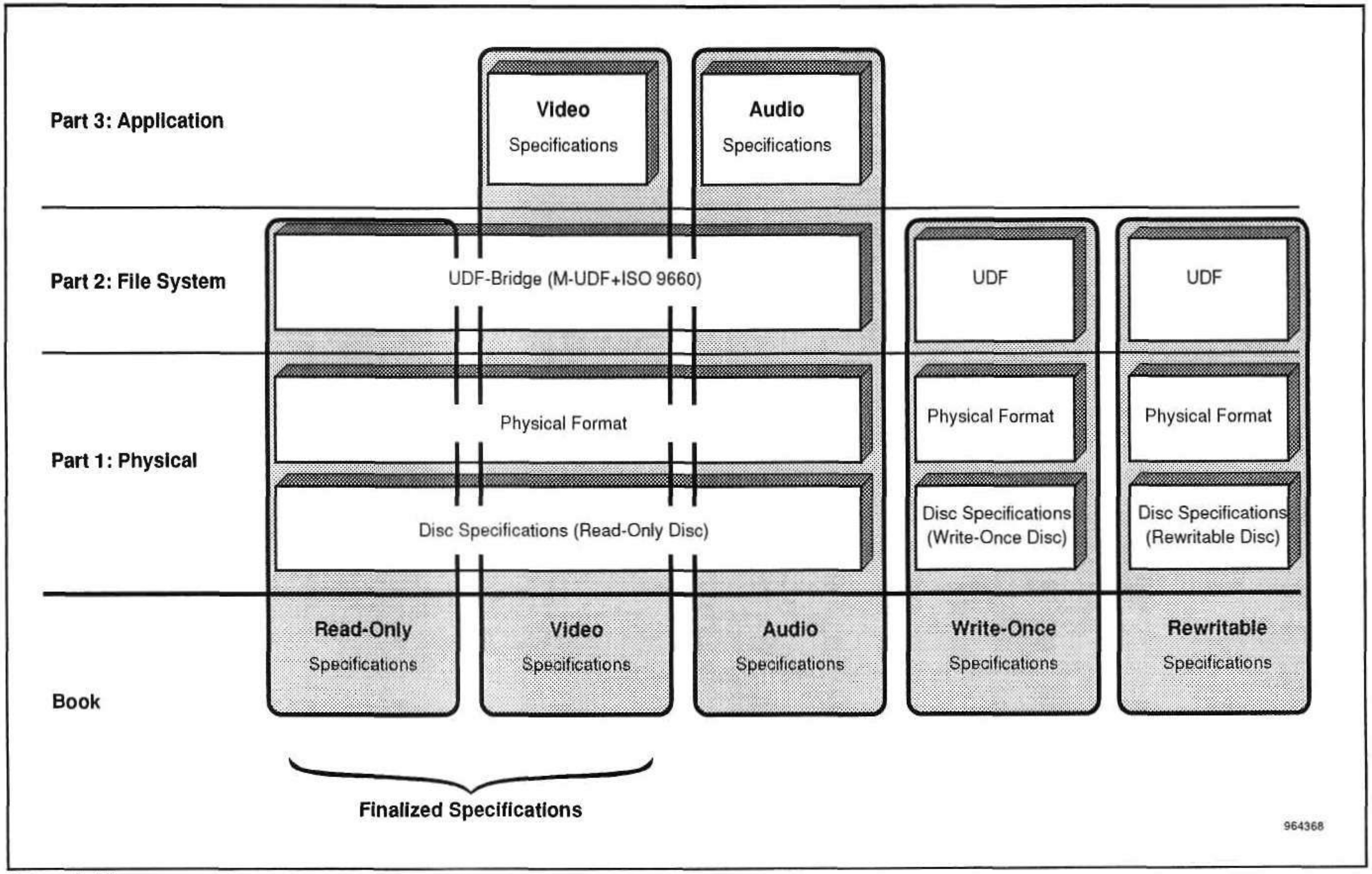
Dataquest is optimistic that the remaining hurdles on the path to the successful launch and growth of the DVD market will be overcome. Although it does not match the hyped expectations of some DVD proponents, Dataquest's forecast for the growth of the DVD market would make this one of the most successful products ever introduced in the consumer electronics and PC markets. After assessing the many factors that will influence the DVD market, Dataquest projects that market shipments of DVD-Video players and DVD optical drives will top 33 million by the year 2000. More than 2.3 million DVD systems are expected to ship between the first product introductions in October and November 1996 and the end of 1997. The semiconductor opportunity generated by the DVD market is forecast to exceed $3.6 billion by the year 2000.

DVD: What Is It? Where Is It Going?

Perhaps the easiest way to think of DVD is as a CD drive on steroids. With higher storage capacity, faster data transfer rates, interactive capabilities, and applications across computer, video, and audio markets, DVD has moved the capabilities of optical storage forward by an order of magnitude, and DVD supporters are already beginning to "feel the burn." In its incarnation as a video player, it offers the ability to view full-length movies in multiple aspect ratios, languages, and Motion Picture Association of America (MPAA) ratings (R, PG-13, PG, G), all stored on a single CD-ROM-size disc. As a PC peripheral, DVD offers new levels of interactivity for next-generation software titles and the storage capacity to handle more content than developers currently know what to do with. In reality, DVD is actually five separate standards, as shown in Figure 1. The physical specifications and file system for the first three standards are the same so that a common platform can be created for multiple applications in the video, audio, computer, and next-generation consumer electronics markets.

Books A, B, and C in the standard are "read-only memory standards" (ROM), while Book D will specify a "write-once, read-many" (WORM) standard, and Book E will offer the ability to read, write, and erase. Because of its ability to read and write, it is often called DVD-RAM, referring to a random access memory capability. Book A, also known as DVD-ROM, and Book B, DVD-Video or DVD-Movie, are close to final and should enable the launch of products based on these standards at the end of 1996. Manufacturers would say that the standards are final. They are close, but there are some details that remain to be decided, such as copy protection and encryption. The DVD-Audio standard, or Book C, is in the early stages of discussion, and some preliminary proposals have been presented for this standard. Although hardware manufacturers are eager to move to market as quickly as possible, the music industry is intent on protecting its interests and has signaled its intention to set a slower pace of development. The

Figure 1
The Five DVD Standards



Source: Toshiba

DVD-WORM and DVD-RAM standards will be established over the coming one to two years. In the meantime, the promoters of DVD have their hands full trying to bring the first DVD products to market.

The title of "convergence product" has been bestowed on DVD because of the common platform it will create for multiple applications across computer and consumer devices. Although obvious uses are found in TV, PC, and high-end audio systems, the set-top box, network computer, and video game console will also be impacted by DVD. Manufacturers of set-top boxes already have plans to leverage the common MPEG-2 chipset into a hybrid device that may provide the ability to record content sent over satellite or cable in the future. When the Bandai Pippen was introduced at the E3 1996 show, the manufacturer was already talking about the eventual replacement of the CD-ROM drive with a DVD drive in the next version. Even video game consoles will upgrade to DVD eventually.

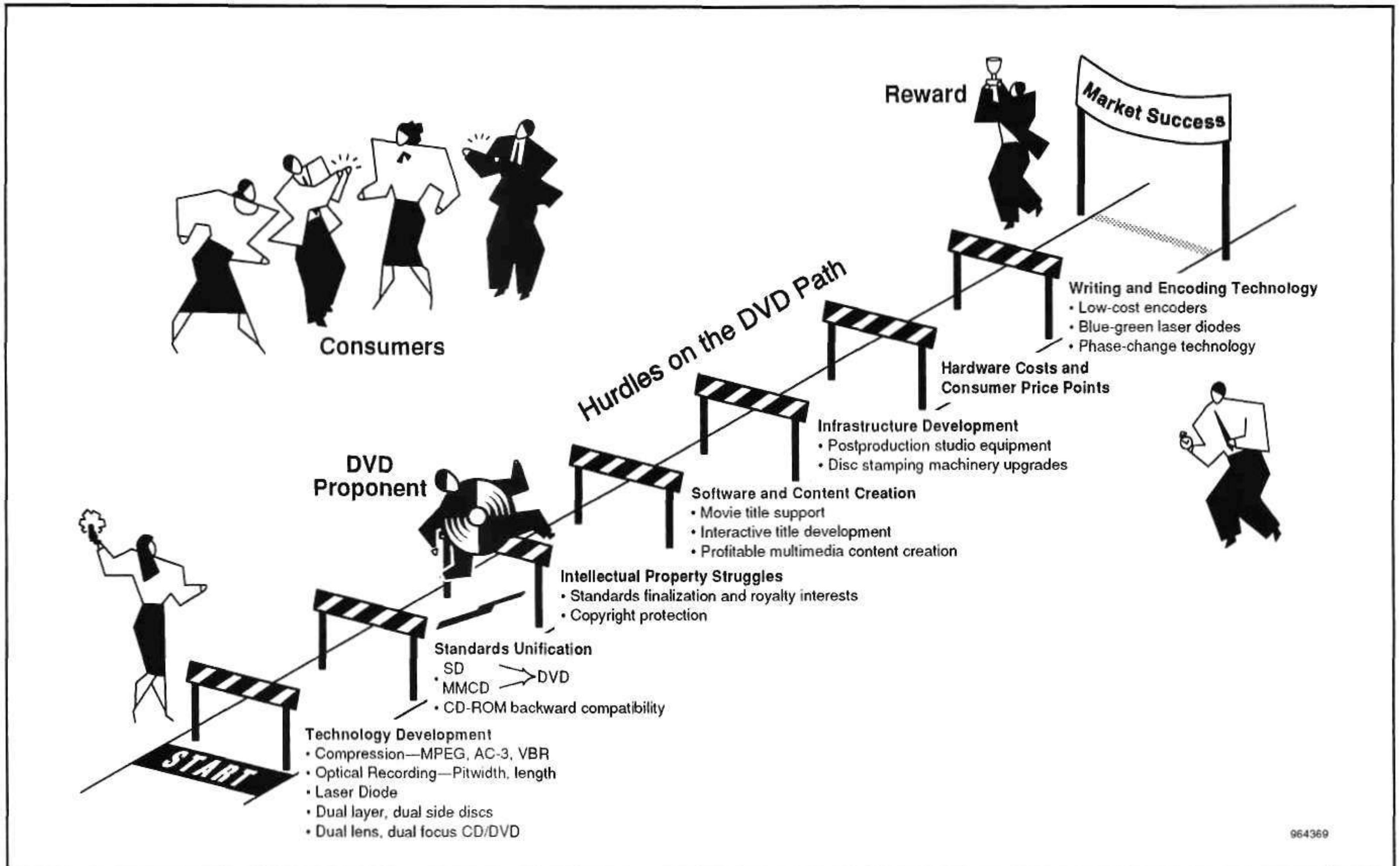
The success of DVD in the market is highly dependent on the ability of seven major industries to cooperate in translating this product concept into a market reality. If the major companies in any one of the industries decide that they are not benefiting sufficiently from DVD and decide to withdraw support, or if they fail to develop the necessary support infrastructure in a timely fashion, the near-term success of DVD would be seriously harmed. If disputes involving issues such as royalties and copyrights are not resolved soon, the launch of this market could be delayed. However, Dataquest is optimistic that present difficulties can be overcome and that the long-term prospects for DVD are very bright.

As they race to the market, DVD proponents will have to avoid being tripped up by some of the major hurdles shown in Figure 2. They have already overcome significant technological and standards hurdles, but they still do not have a clear sprint to the finish line. It is to be hoped that the potential rewards will provide the necessary momentum to allow the emerging DVD market to reach its full potential.

Based on an analysis of consumer market behavior and expected price trends, Dataquest has developed the market forecast for DVD-Video players, DVD optical storage drives, and DVD PC decode/encode add-in boards shown in Figure 3. This market forecast demonstrates Dataquest's optimism regarding the future of DVD. Our projections show the combined annual market shipments of DVD-Video players and DVD drives growing to over 33 million by the year 2000, making it one of the most successful products introduced in the 1990s. The combined market shipments of all DVD products, including decode/encode add-in boards, would drive factory revenue over $10 billion by the year 2000.

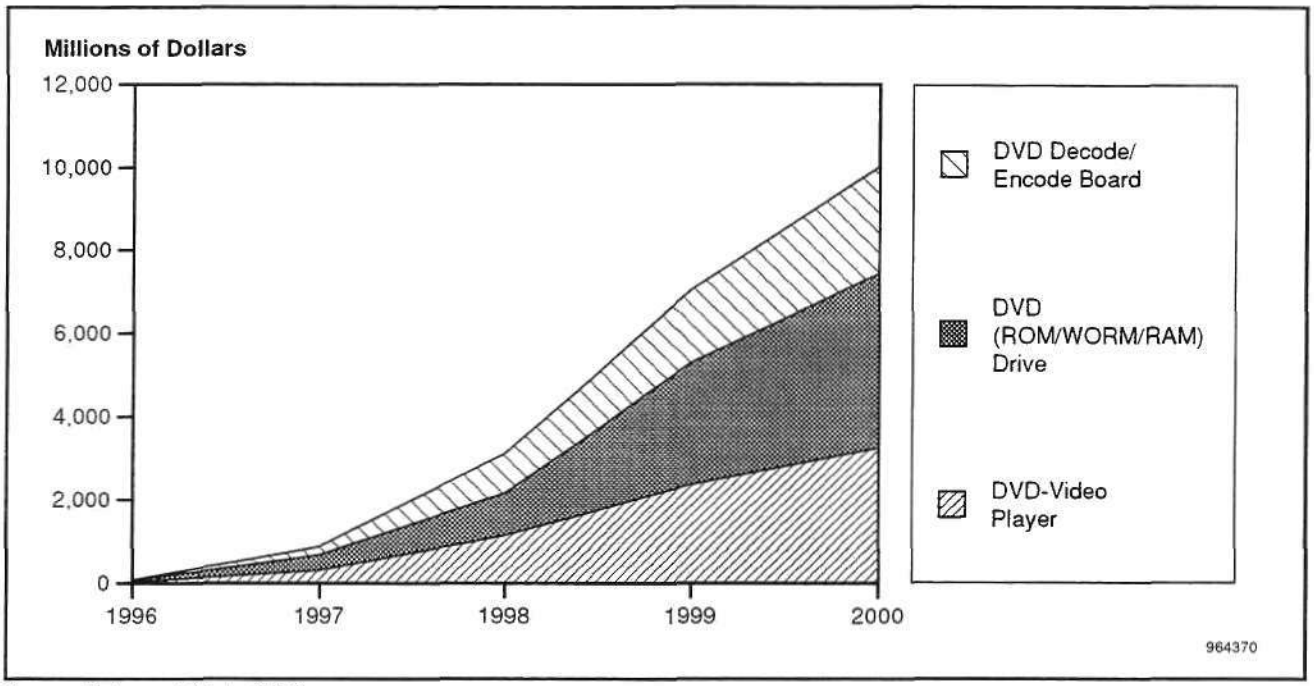
Certainly, there are factors that could drive the market above or below this forecast. If manufacturers are able to drive prices below Dataquest's expectations, this would stimulate higher growth. On the other hand, if the creative community fails to develop software products in a timely fashion that exploit the advanced capabilities of DVD, it will be hard to push the installed base of CD-ROM users and VCR owners to a more expensive platform. All the hurdles discussed earlier in this report could impact the growth of the DVD market.

Figure 2
Hurdles on the DVD Path



Source: Dataquest (June 1996)

Figure 3
DVD Market Revenue Forecast



Source: Dataquest (June 1996)

DVD Production Forecast and Semiconductor Opportunity

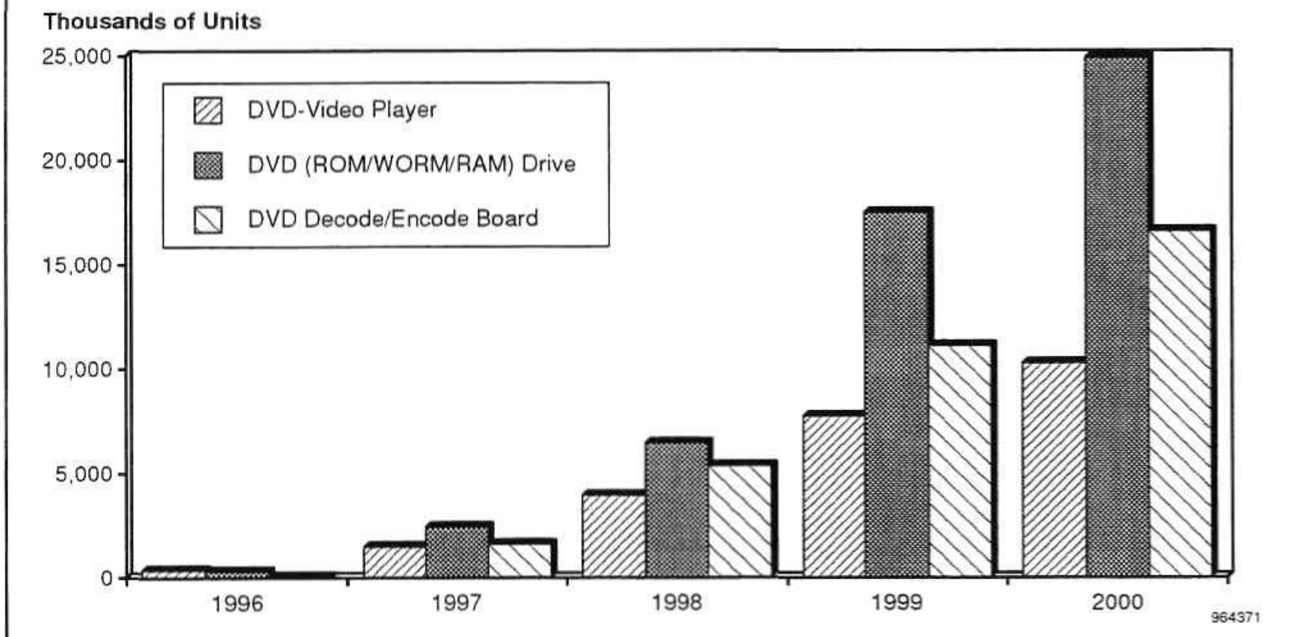
Based on the predicted market growth, Figure 4 and Table 1 present Dataquest's DVD production forecast.

The semiconductor community has invested in DVD technology early. Although the early DVD players that come to market will have little integration, they will be replaced in a matter of a few months by products that will take advantage of integrated chipsets that have already been announced. The second-generation chipsets will be ready before the first-generation systems have even shipped. Semiconductor manufacturers have outlined aggressive integration plans for DVD and other products that are based on MPEG-2 and AC-3 compression technology. Some companies have even presented plans to develop single-chip DVD processing solutions. Dataquest stops short of predicting this level of integration because of the belief that there are no cost or performance advantages to be gained from integrating the channel-processing function and audio/video coder/decoder (codec).

Announced chipsets for audio and video processing, the servo processor, and some channel demodulation functions will be based on a 0.35-micron CMOS process, which will migrate to 0.25-micron CMOS over the following two years. Other components in the DVD-drive electronics will be based on bipolar technology. As chipsets move along the integration path, a growing opportunity for BiCMOS will develop.

Figure 5 illustrates the semiconductor forecast for chips used in DVD applications. (The data for this figure is found in Table 1.) This forecast is based on the DVD production forecast and an analysis of semiconductor content

Figure 4
DVD Production Forecast



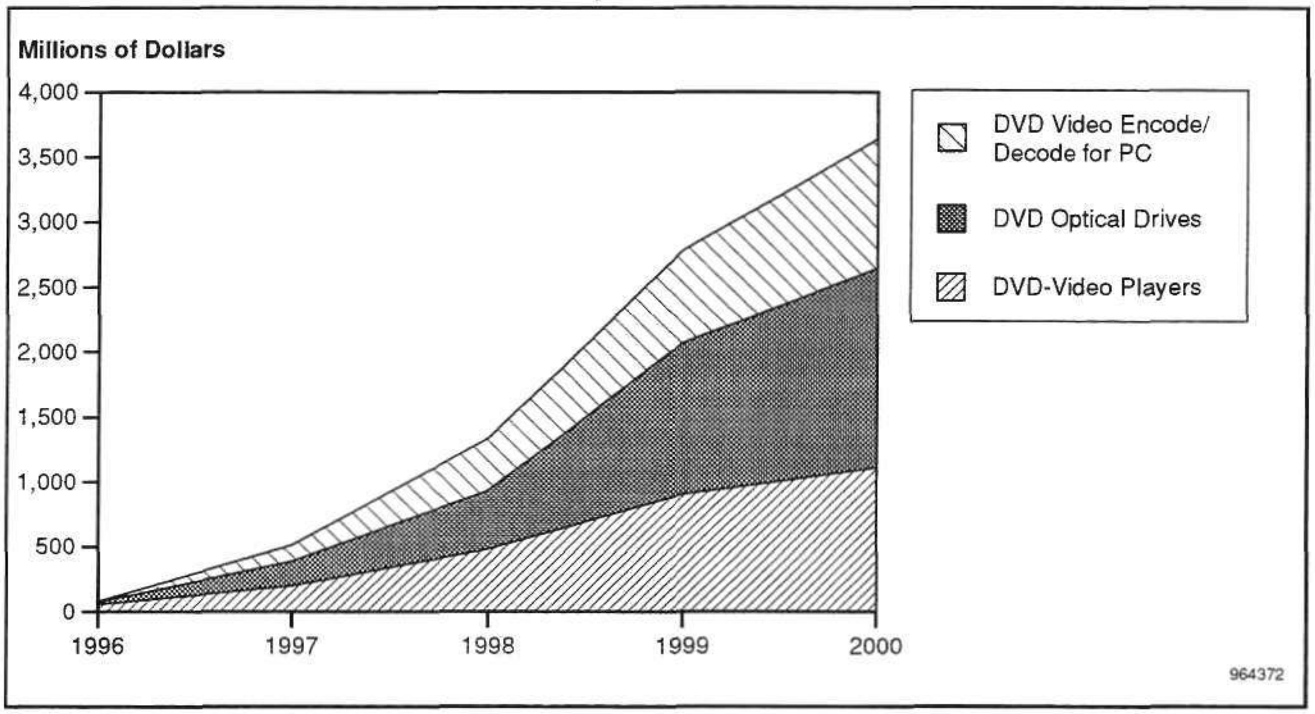
Source: Dataquest (June 1996)

Table 1
DVD Production Forecast

	1996	1997	1998	1999	2000	CAGR (%) 1996-2000
DVD-Video Player						
Units (K)	360	1,495	3,956	7,755	10,283	131.2
Factory ASP ($)	428	394	365	357	331	-6.2
Factory Revenue ($M)	154	589	1,443	2,772	3,406	116.9
Semiconductor Content ($)	146	133	122	116	108	-7.3
Semiconductor TAM ($M)	53	199	481	903	1,112	114.4
DVD Optical Drive						
Units (K)	295	2,440	6,467	17,500	24,898	203.1
Factory ASP ($)	230	218	204	194	175	-6.7
Factory Revenue ($M)	68	533	1,316	3,402	4,348	182.9
Semiconductor Content ($)	81	76	70	67	62	-6.6
Semiconductor TAM ($M)	24	185	451	1,170	1,532	183.1
DVD Decode/Encode Boards and Chipsets						
Units (K)	40	1,623	5,361	11,108	16,611	352.8
Factory ASP ($)	258	218	210	175	164	-10.7
Factory Revenue ($M)	10	354	1,125	1,941	2,720	304.3
Semiconductor Content ($)	85	77	75	64	60	-8.4
Semiconductor TAM ($M)	3	126	403	709	993	315.0

Source: Dataquest (June 1996)

Figure 5
DVD Semiconductor Market Forecast by Platform



Source: Dataquest (June 1996)

and chip pricing trends. Dataquest forecasts the total DVD semiconductor market to grow from less than $80 million in 1996 to over $3.6 billion in just four years.

The following chip companies have been working with DVD manufacturers for many months leading up to the launch of DVD products.

- Motorola
- Hyundai
- Zoran
- Philips
- Texas Instruments
- Silicon Systems
- SGS-Thomson
- Oak Technology
- LSI Logic
- VLSI Technology
- Toshiba

Summary and Conclusions

The number of systems manufacturers and chip companies that will compete in the DVD arena will create a dynamic and highly competitive environment. Although the forecast market growth will create very profitable opportunities, the nature of the competition will lead to a number of casualties among systems and semiconductor players. Competitors should expect the consumer to be very demanding in terms of system performance and price. These demands will be reflected to the semiconductor companies, which will be placed under heavy price and performance pressures.

Because the technologies shaping this market will continue to develop over the forecast period, chip companies seeking to be successful in this market should be prepared to continue making major investments in their product development. As they seek to reduce their product development costs, systems manufacturers will value complete systems solutions from semiconductor manufacturers. Chip companies unable to provide a complete solution with their own product line should seek alliances with other companies to complement their strengths. Also, semiconductor manufacturers should develop strategies that will allow them to leverage their products across multiple next-generation consumer electronics products. This will allow them to maximize their profits and reduce their risks in this exciting, but turbulent, market segment.

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Dataquest
A Gartner Group Company

Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Market Analysis

Semiconductor Vendors ... Start Your (Media) Engines!

Abstract: *New products called media engines and media processors could bring more multimedia performance to PCs for a lower price than conventional chipsets. These devices are too new to have been proven in the marketplace, but they offer some compelling benefits. Product positioning is squarely between application-specific standard products (ASSPs) and general microprocessors, leveraging the speed and programmability benefits of each of those products. Media processors must compete with ASSPs as well as with multimedia enhancement to general microprocessors, such as Intel's MMX, to be successful. The market for these products expands beyond PCs into consumer and communications equipment, but the scope of this document is limited to the PC market opportunity. This document defines what a media processor is, identifies key issues for these products, and provides a five-year forecast for the use of these devices in PCs.*

By Geoff Ballew

New Chips Provide More Bang for the Buck in Multimedia PCs

Multimedia. This one word has a tremendous impact on PC architecture because the simultaneous processing of graphics, audio, and video data places large demands on the major components in a PC. The trend toward more multimedia features and higher multimedia performance is pushing PCs harder than ever before. Today's PCs are much faster and better equipped for multimedia processing than they were just a few years ago, but they are clearly not powerful enough to handle new multimedia features such as 3-D audio, MPEG-2 decompression, and videoconferencing.

As PC OEMs strive to provide higher multimedia performance at low prices, they need to find efficient ways (on a price versus performance basis) to add additional multimedia muscle to a PC. So far there is no single answer; we have a variety of new solutions and old solutions that will compete. These include improving the application-specific standard products (ASSPs) or

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fixed-logic chipsets, making the CPU faster with special instructions (such as Intel's MMX) and higher clock speeds, and using an embedded processor that is optimized for multimedia data types. This last category includes chips such as programmable DSPs and a new class of embedded processor called a media processor or media engine. Media processors are the newest solution for boosting PC multimedia performance. They offer compelling benefits, but have some challenges to overcome if they are going to succeed in the PC semiconductor market. For the purposes of this document, media processors are not distinguished from media engines.

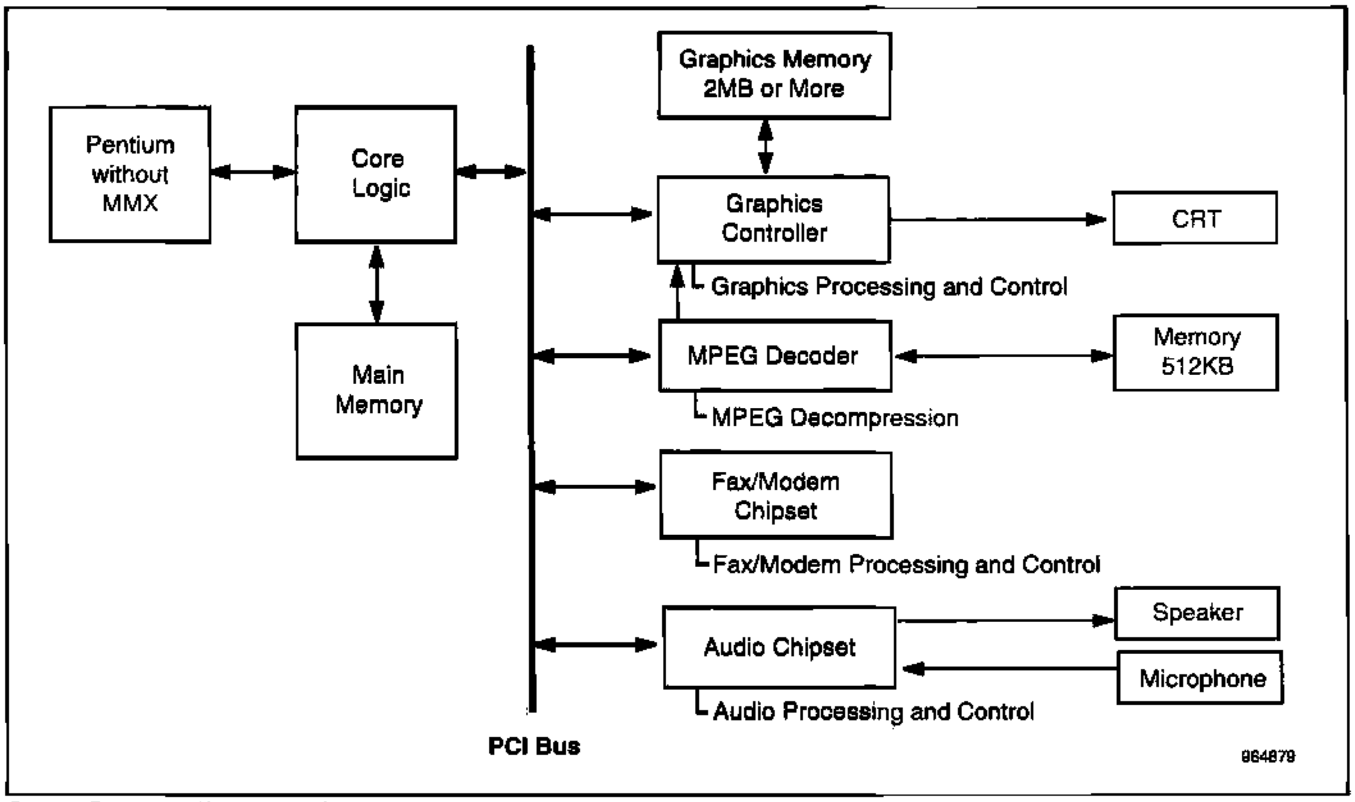
Each of these solutions has an impact on PC design, so a basic system diagram showing an example of each one is provided here. A bulleted list of the digital signal-processing tasks handled by each chip or chipset is provided, with the bullet located below the chip or chipset that performs that task. Figure 1 shows a typical multimedia PC with the multimedia features implemented with standard chipsets or ASSPs. Note that each subsystem (graphics, audio, and fax/modem) is implemented with a complete chipset. Figure 2 shows the same features using a CPU enhanced with Intel's MMX instruction set. This solution leverages the computing power of the CPU for signal processing and control functions instead of putting dedicated controllers in the peripheral chipsets. Figure 3 shows an implementation using a media processor called Mpact from Chromatic Research, a media processor company. This solution is similar to the one shown in Figure 2 but uses a dedicated processor rather than the CPU for signal processing and control. Each of these three solutions has price and performance advantages and disadvantages. Also, it is important to note that these solutions are not mutually exclusive. As Intel incorporates MMX into its entire x86 MPU product line, MMX will coexist with ASSPs and media processors in the same systems because the performance should be additive. This means that a system having MMX and a media processor will be more powerful than a system with a media processor but without MMX.

Media Processors: What Are They?

Media processors are a new class of semiconductor device. They have fixed-logic elements just like ASSPs or standard chipsets, but they also have a programmable signal processing core like a programmable digital signal processor (pDSP). These products are designed for processing digital signals just like a pDSP but have additional features that make them more suitable for PC and consumer electronics applications. These features include standard bus interfaces such as Peripheral Component Interconnect (PCI) and I^2C, integrated ASSP functions such as a VGA controller, greater processing power, and a high degree of concurrency for handling multiple real-time processes. A general definition of a media processor is a device that meets the following criteria:

- Media processors are programmable. This separates them from highly integrated, multiple-function logic chipsets, such as integrated audio and fax/modem chipsets.

Figure 1
System Diagram of a Multimedia PC with 3-D Graphics, MPEG, Telephony, and Audio Features Implemented with ASSPs



Source: Dataquest (August 1996)

- Media processors must have a high degree of concurrency. The ability to handle three or more real-time processes simultaneously is essential.
- Media processors have a dedicated purpose. The addition of application-specific bus interfaces, such as PCI or I^2C, targets these devices to communications and multimedia applications in PCs and consumer electronics rather than other applications for digital signal processing. This also distinguishes media processors from general-purpose microprocessors with multimedia functions, such as Intel's MMX.

These requirements are very general, but so is the media processor product category. These devices straddle the abyss between fixed logic implementations such as ASSPs (which are fast but not flexible) and general-purpose microprocessors (which are flexible but not fast.) Figure 4 shows this positioning.

Software Defines the Functionality

Media processors require software to define their functionality. The hardware provides computational power for processing digital signals, but software is required for compatibility with various data types, standards, and protocols such as V.34 for modems, Sound Blaster compatibility for audio processing, and even digital video decoding standards such as

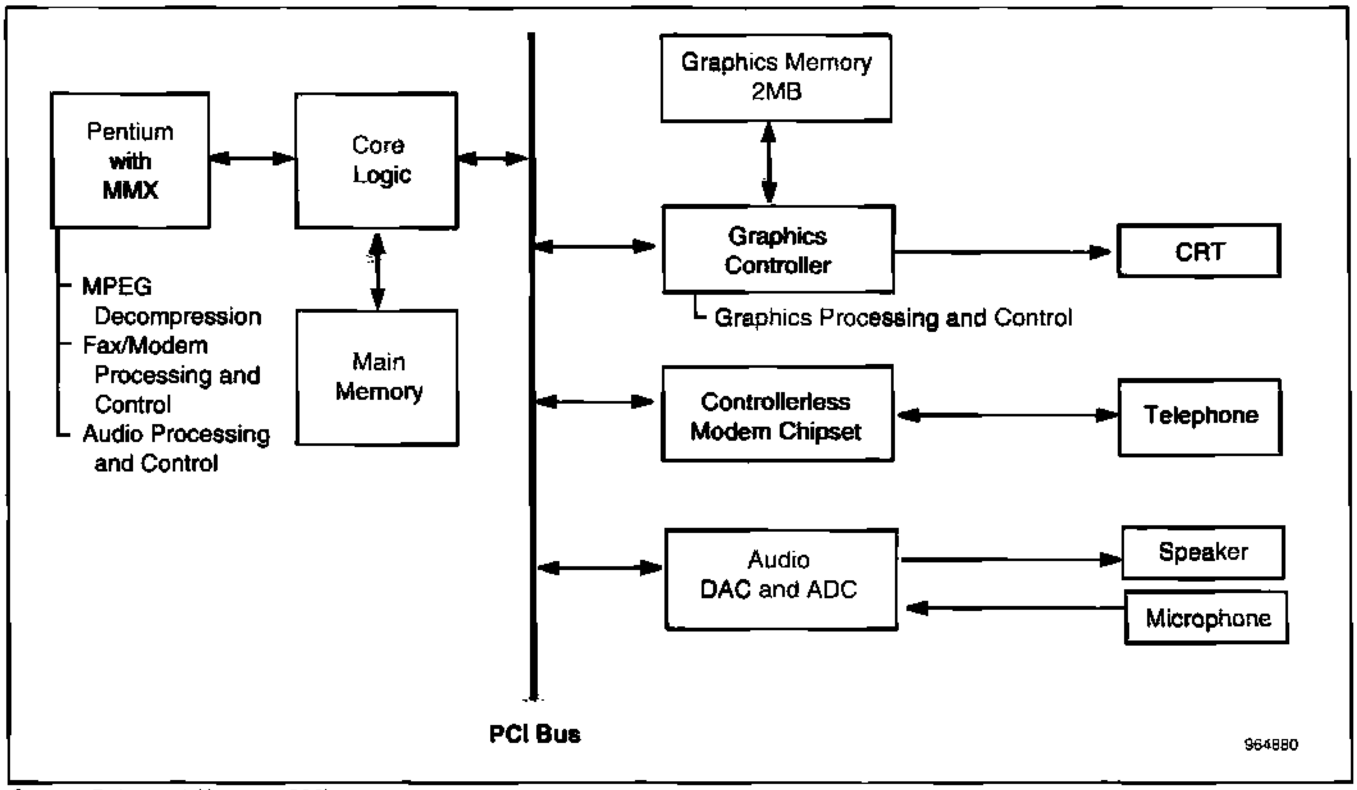
MPEG-1. This is in sharp contrast to ASSPs because those products have the required standards and protocols implemented in the chips rather than requiring software to provide compatibility. Of course both media processors and ASSPs require software drivers to interface with the PC operating system, such as Windows 95. Figure 5 highlights the division between hardware and software for media processors compared with ASSPs.

The Advantages of Media Processors

The major advantages of using media processors over alternative solutions are discussed after this bulleted list:

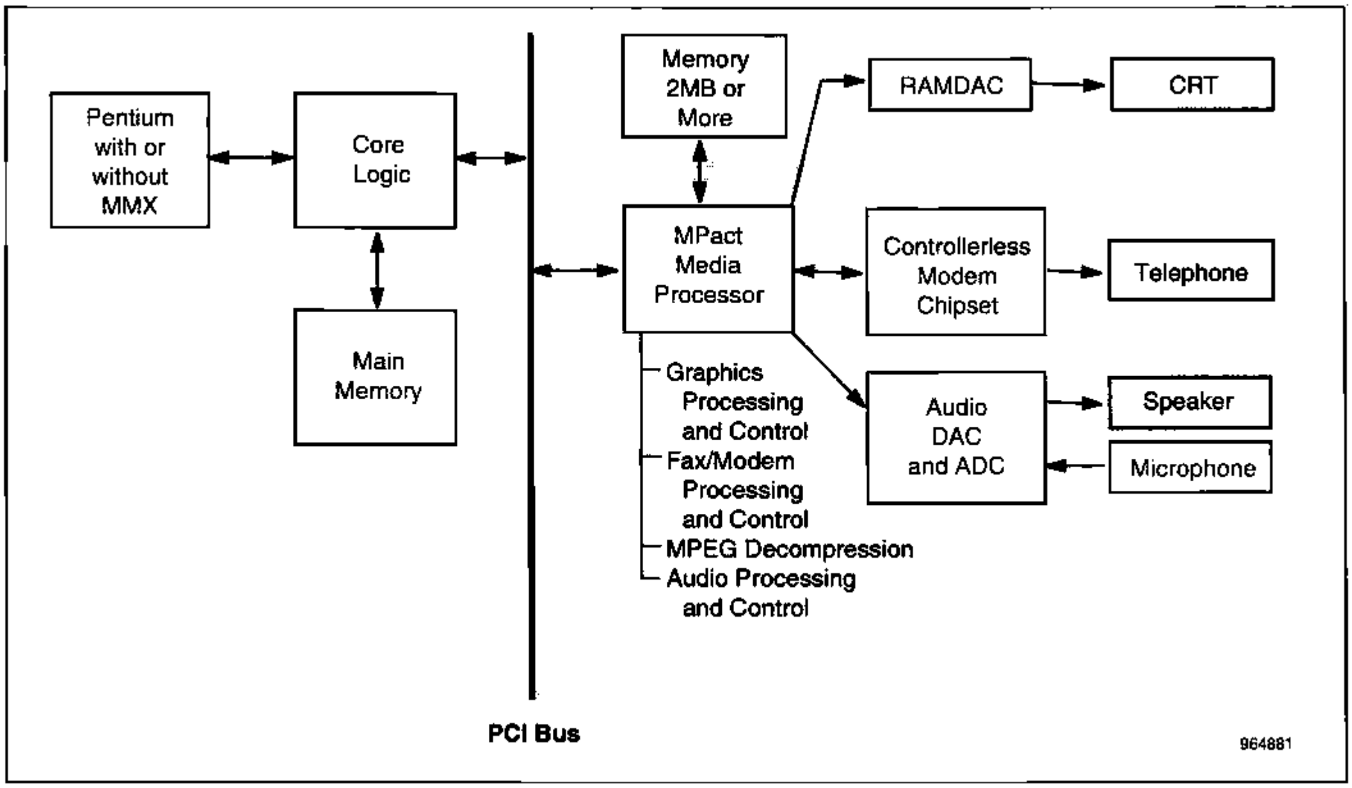
- Media processors centralize signal processing to reduce redundant functions (and therefore redundant cost) across multiple subsystems, such as audio processing, fax/modem, networking, graphics, and video processing.
- Media processors enable functional upgrades through software rather than hardware changes. This benefits PC OEMs by reducing the risk of inventory and design obsolescence, and it benefits PC users because features and performance can be enhanced without the challenges of opening the PC and changing hardware.

Figure 2
System Diagram of a Multimedia PC with 3-D Graphics, MPEG, Telephony, and Audio Features Implemented with MMX



Source: Dataquest (August 1996)

Figure 3
System Diagram of a Multimedia PC with 3-D Graphics, MPEG, Telephony and Audio Features Implemented with a Media Processor

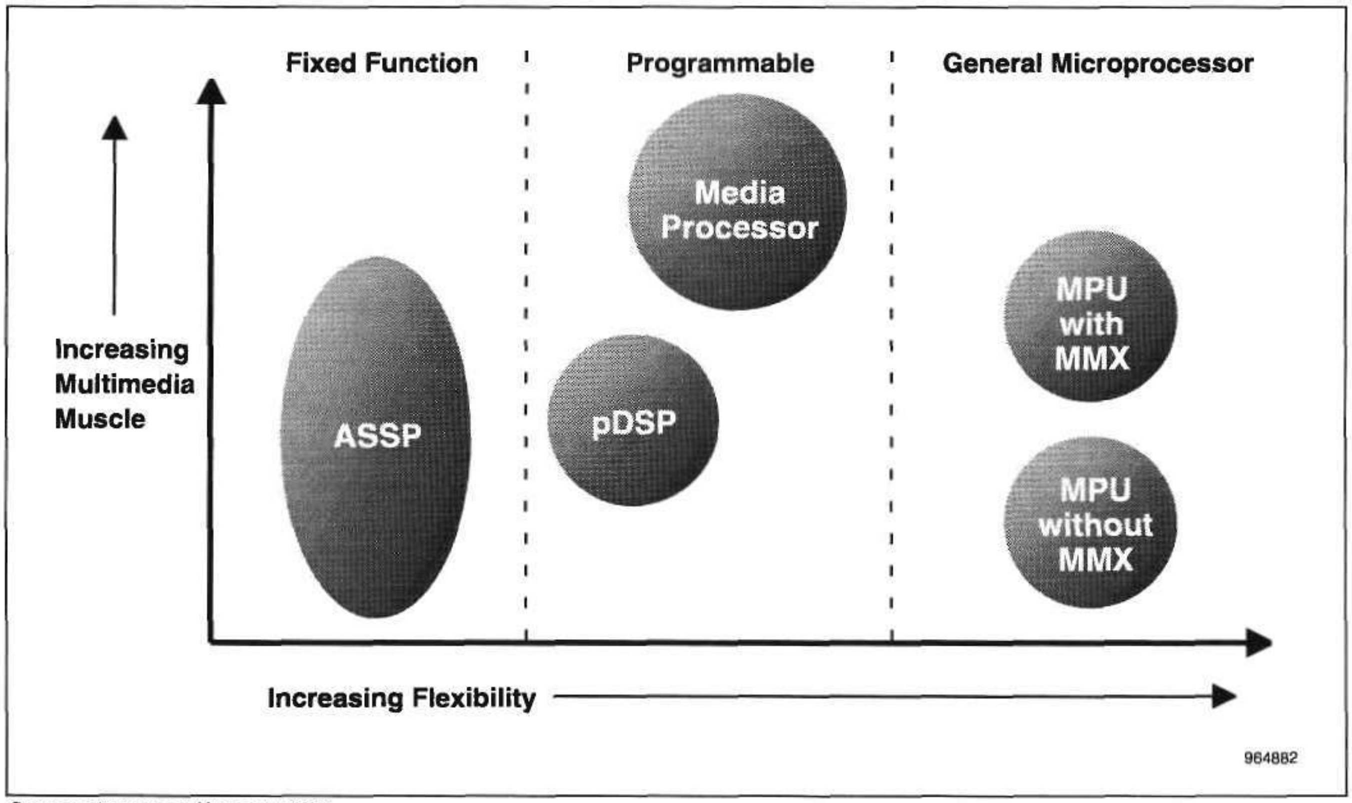


Note: This example uses Chromatic Research's Mpact product to illustrate the point because it has an integrated VGA controller.
Source: Dataquest (August 1996)

- Scalability allows functions to use as much processing power as possible on a real-time basis.
- Lower total system costs are possible. The potential for cost savings increases dramatically when high-end functions such as MPEG-2 decompression, Dolby AC-3 decoding, and videoconferencing are included.
- Media processors are more powerful than multimedia enhancements to microprocessors.

Media processors have the potential to provide many benefits for PC OEMs and PC users by making hardware designs more flexible without incurring a large cost penalty. The traditional way to add features to PCs has been to add a new chipset for each new subsystem—for example, adding a modem chipset for modem functions or an audio chipset for sound processing. The problem with this method is simply that adding another major function requires another standalone chipset. All the functions for a given subsystem are integrated into a compact chipset, but there is little integration across subsystems to minimize the total number of chips (and more specifically the total number of gates) for the whole PC. Media processors are designed to leverage processing power across multiple functions by separating the control elements of peripheral chipsets from the interface elements of peripheral chipsets. Processing power is centralized and can be allocated to various functions (such as MPEG decode, audio processing, or communications processing) on a real-time basis. Media processors do require support chips, such as analog-to-digital conversion (ADC) and digital-to-analog conversion (DAC), to interface with external peripherals. However, the cost of these interface chips is significantly lower than the cost of complete chipsets.

Figure 4
Relative Positioning of Media Processors



Source: Dataquest (August 1996)

A second benefit of using media processors instead of fixed-logic chipsets is software upgradability. A PC user today who wants to upgrade a modem must take the old modem out and put a new modem in. If a PC has a media processor, its multimedia functions can be upgraded just by installing new software, rather than by opening the box and changing the hardware. In the same way, a PC OEM that designs around a media processor rather than ASSPs will be able to reconfigure inventory and work in process more easily by changing software rather than hardware. This helps protect the OEM against the risks of product obsolescence and having a large inventory of undesirable products in the midst of a technology shift.

Figure 5
Media Processors Rely on Software for Compatibility

	ASSPs	Media Processors
Interface to Operating System Such as Windows 95	**Software**	**Software**
Compatibility with Standards and Data Types	**Hardware**	**Software**
Processing Power	**Hardware**	**Hardware**

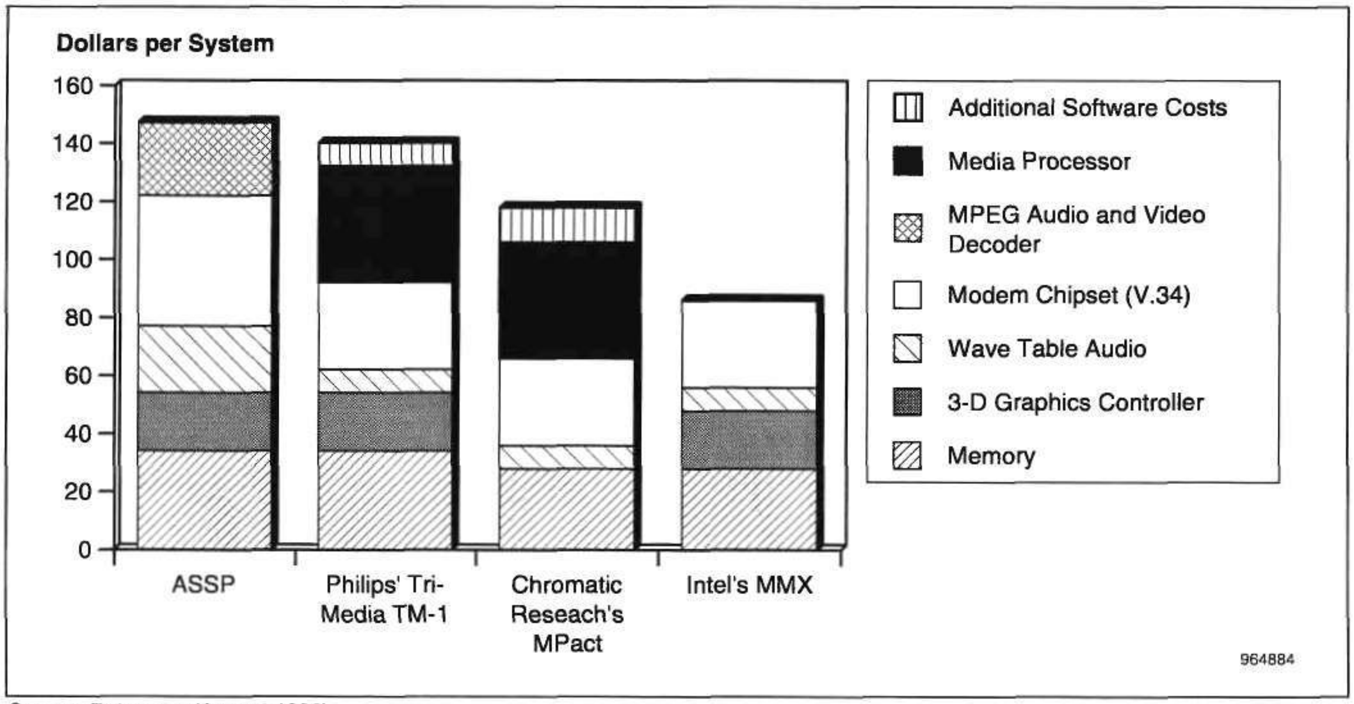
964883

Source: Dataquest (August 1996)

A third benefit of media processors is scalability. All of a media processor's processing power is divided among the functions in use on a real-time basis. When only one or two functions are used simultaneously, those functions receive more processing power and therefore show higher performance than they would have in an average ASSP. When the user requires multiple functions in demanding applications such as Internet gaming (a simultaneous use of modem, audio, graphics, and probably motion video decoding) each function receives only its share of the total processing power. For this reason, media processors must be powerful enough to process multiple data streams concurrently.

A fourth benefit of using a media processor is the opportunity for a lower total bill-of-materials cost to implement a feature-rich, multimedia PC. A PC with a media processor requires only a controllerless chipset, rather than a standard chipset, for a given subsystem such as a fax/modem. A controllerless chipset is a subset of a standard chipset; it does not include the microcontroller and DSP functions, which makes it less expensive than a standard chipset. The media processor provides the microcontroller and DSP functions in place of having those functions in the peripheral chipset. If enough subsystems are added with these lower-cost controllerless chipsets, then the cost saving from buying less-expensive chipsets will exceed the cost of buying the media processor. A rule of thumb is that four or more subsystems must be added to make a media processor cost-effective. If an OEM will use the media processor for only one or two functions, then ASSPs will provide a lower total cost. Figure 6 shows some Dataquest estimates of the semiconductor costs for implementing a multimedia subsystem with the following four functions: accelerated 3-D graphics, MPEG-1 decompression, wave table audio, and V.34 modem functions. Media processors offer more dramatic cost savings if high-end functions like MPEG-2 decoding, Dolby AC-3 decoding, and videoconferencing are added to a PC design.

Figure 6
Cost Comparison between Media Processors and Other Solutions for Adding 3-D Graphics, MPEG, Telephony, and Audio Functions to a Multimedia PC



Source: Dataquest (August 1996)

The fifth advantage is simply that higher performance can be achieved by using a media processor than by relying solely on MMX or other MPU multimedia enhancements for signal-processing power. If a media processor is added to a system with MMX, the available multimedia processing power will be approximately additive. Although the two resources (MMX and a media processor) will not work cooperatively on a single task, the list of tasks can be divided between them to maximize performance.

The Disadvantages of Media Processors

The potential disadvantages of using media processors versus alternative solutions are discussed after this bulleted list:

- Functional redundancy with MMX puts vendors in partial competition with Intel for low-end PC designs.
- There is risk in adopting new design strategies.
- Higher total system costs are possible.

Functional redundancy with MMX and other multimedia enhancements to microprocessors is a potential barrier to getting design-wins in low-end PCs. Media processor vendors are not the only advocates of centralizing multimedia processing. Intel evangelizes the centralized model because it creates greater demand for new microprocessors. The MMX instruction set is one step Intel is taking to make its microprocessors able to process multimedia data more efficiently. Other MPU vendors are implementing similar multimedia enhancements to their own designs. Two examples are Sun Microsystems' Visual Instruction Set (VIS) and Cyrix's own implementation of the MMX instruction set. Media processors and multimedia enhancements to general-purpose MPUs are variations on the same theme. Media processor vendors must position their products carefully against MMX because MMX will be shipping for "free" as it becomes a standard feature in all Intel's Pentium and Pentium Pro microprocessors and as the non-MMX versions are discontinued.

As PC OEMs strive to differentiate their products, there is risk associated with adopting a new design strategy such as using a media processor instead of ASSPs. OEMs that use ASSPs can choose each chipset from a different vendor, so their audio chipset vendor can be independent from their fax/modem chipset vendor. This will change slowly, because higher levels of integration are necessary for minimizing costs, but media processors make this transition much more immediate. Of course, there is also potential gain by adopting a new strategy because it does differentiate one OEM from another.

The issue of total system cost was mentioned as a possible advantage as well as a possible disadvantage. Media processors are new products, so the actual cost of implementation is not established. The total cost of implementation must be competitive compared with ASSP implementations because PCs are sold on the basis of price, performance, and features. Media processor vendors must make the chip and software available at a volume price that makes it competitive even if an OEM does not include high-end functions such as videoconferencing, MPEG-2 decompression, or Dolby AC-3 decoding.

Company Highlights

Two companies, Chromatic Research and Philips Semiconductors, are leading the race to bring media processors to the PC market. Below is a brief description of each company's media processor strategy.

Chromatic Research

Chromatic is bringing a new business model—the "chipless semiconductor company"— to the market. The company's media processor is named Mpact, but will not be manufactured or sold by Chromatic. Strategic partners will make and sell the chip, while Chromatic will sell the software to use the chip. The company has announced two partners so far, LG Semicon and Toshiba, and may add one additional partner.

As a chipless semiconductor company, Chromatic will design new versions of the Mpact chip, as well as write and sell software for the chip. In fact, Chromatic will be the sole source of software "modules" for the Mpact chip. These modules are required for any implementation and will consist of a basic set of functions as well as optional functions so OEMs can tailor their purchases to their needs. This strategy keeps Chromatic focused on product technology and marketing rather than manufacturing and allows it to leverage the manufacturing expertise and process technology of its partners.

Chromatic is making good progress on the software modules for the Mpact chip and expects to release the first software versions this fall. The hardware design is finalized and appears to be robust and manufacturable. The progress in both hardware and software indicates that technical issues will not be a barrier to Chromatic. Market issues such as design-wins into leading OEMs and sell-through to the end user are the next step. Chromatic expects to announce several key design-wins over the next 12 months, but this information is not yet public.

Philips Semiconductors

This consumer electronics giant has been a market leader in digital video chips but until recently did not actively participate in the PC semiconductor market. Philips is now pursuing the PC market more aggressively with PC graphics products as well as its TriMedia TM-1 media processor, a family of media processors that it plans to bring to market. TM-1 is the first actual product in the TriMedia family. The company plunged into the PC graphics market in the fall of 1995 by acquiring the multimedia products group from Western Digital. That acquisition gave Philips immediate access to PC graphics technology, as well as giving it the Paradise brand name for board-level graphics products.

Philips is using its expertise in signal processing (most notably video encoders, decoders, ADCs, and DACs) to gain a larger role in the PC semiconductor market. TM-1 is focused on signal processing for the PC but does not include a VGA controller. This makes it highly complementary to the graphics products acquired from Western Digital. Future products in the TriMedia family will be tailored for consumer applications other than PCs. Those products are likely to include VGA or TV output as well as greater capability to act as the system microprocessor rather than just as a coprocessor like the TM-1.

Others

Several other companies have announced development efforts for media processors. IBM is developing a product called MFast. NEC and VideoLogic have announced a joint development effort. Mitsubishi and Samsung have each announced their intention of bringing media processors to market. Also, a number of companies are developing products that are similar to media processors but fall into other product categories. These include programmable DSPs like IBM's MWave chip and products from Analog

Devices, as well as multifunction chipsets like NVidia's NV1 and NV3 products. These products will compete with media processors for PC design-wins, but they offer varying levels of performance and programmability.

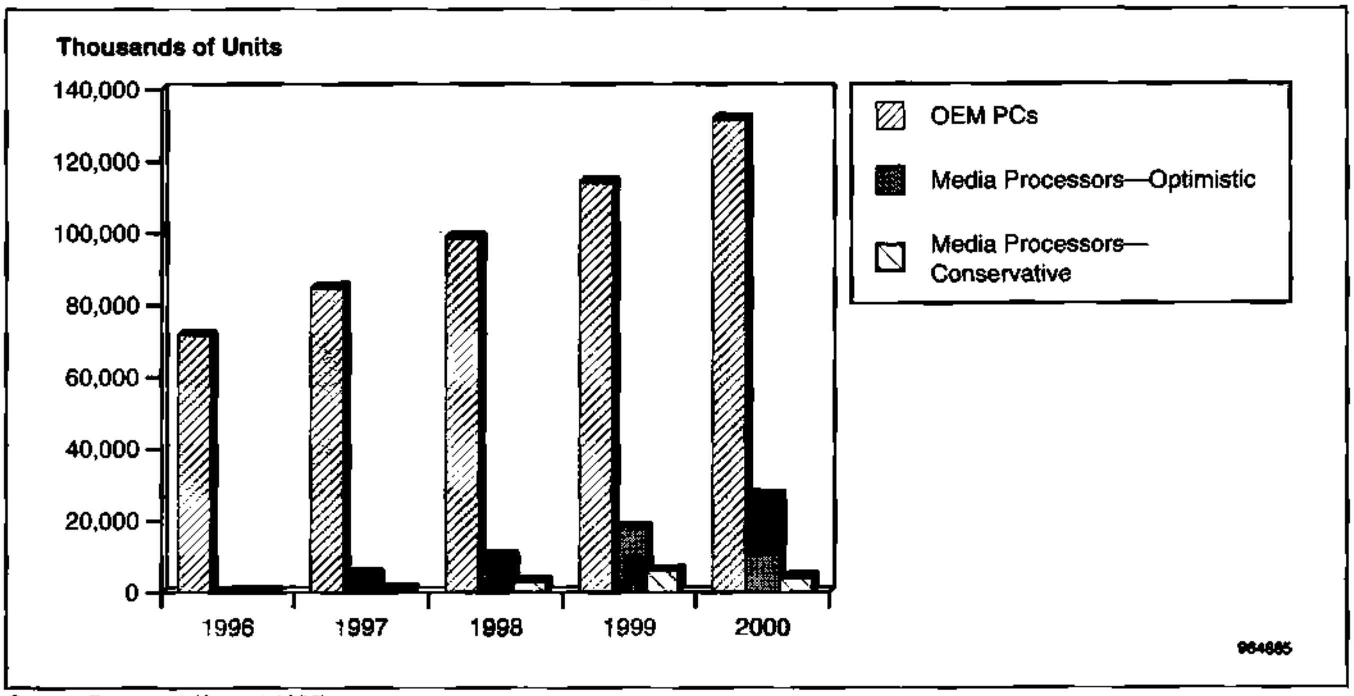
Five-Year Forecast

Media processors are a new product that will bring new levels of flexibility to the PC market. These devices are becoming available at a critical time in the PC market, because expectations for multimedia processing are increasing faster than microprocessor performance. Multimedia functions can always be implemented in ASSPs, but the cost of adding multiple chipsets can be prohibitive and this approach does not take advantage of redundancies across chipsets. Media processors have the opportunity to balance this equation by providing lots of processing power tailored for multimedia data types (audio, video, communications, and graphics) at a competitive price versus performance level. However, the adoption of media processors into a product does require a shift in product design and configuration. For media processors, 1996 will be an interesting year, with some exciting announcements of design-wins, but it will not be a strong indicator of long-term acceptance. Philips is not scheduled to reach volume production until first quarter 1997, and other vendors will take even longer. Greater competition between media processor vendors will develop as they bring new products to market through 1997 and 1998.

Media processors are a new product and had not started shipping as of the date of this forecast. At this early stage in the market, Dataquest has forecast media processor shipments based upon the best of its knowledge and information and has provided two scenarios (optimistic and conservative). Actual shipments are expected to fall somewhere between these two scenarios. This forecast will be updated as more information becomes available and as these products begin to ship into the PC marketplace. Figure 7 shows a forecast for media processors as well as for PCs. Tables 1 and 2 provide the forecast for units and revenue. Critical factors that will affect media processor shipments are:

- Willingness of ASSP vendors to compete in a price war
- Willingness of OEMs to embrace programmable solutions versus ASSPs
- Introduction of media processors from additional vendors to increase competition
- Real demand for high-performance multimedia features such as MPEG-2 decompression, AC-3 decoding, and videoconferencing

Figure 7
Five-Year Forecast for Media Processor Shipments in PCs



Source: Dataquest (August 1996)

Table 1
Five-Year Unit Forecast for Media Processor Shipments for PCs (Thousands of Units)

	1996	1997	1998	1999	2000	CAGR (%) 1996-2000
OEM PCs	71,651	84,694	98,693	114,178	131,700	16.4
Optimistic Forecast	200	5,000	10,000	18,000	27,000	240.9
Conservative Forecast	100	1,000	3,000	6,000	4,000	151.5

Source: Dataquest (August 1996)

Table 2
Five-Year Revenue Forecast for Media Processor Shipments for PCs (Thousands of Dollars)

	1996	1997	1998	1999	2000	CAGR (%) 1996-2000
Optimistic Forecast	8,000	190,000	360,000	630,000	945,000	229.7
Conservative Forecast	4,000	38,000	108,000	210,000	140,000	143.2
Dataquest Estimated ASP ($)	40	38	36	35	35	-3.3

Source: Dataquest (August 1996)

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Dataquest
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Perspective

Semiconductor Directions in PCs and PC Multimedia

Market Analysis

Quarterly x86 Compute Microprocessor Forecast

Abstract: *We have extended our forecast through the year 2000. The rate of unit shipment growth has been increased to reflect Intel's strategy of driving prices lower to keep its increased manufacturing capacity fully loaded. 586-class processors will comprise the vast majority of CPU shipments in 1996 and 1997, given the waning presence of the 486, the growth of Pentium Pro shipments from a tiny base in 1995, and the ability of both AMD and Cyrix, after a seemingly never-ending series of delays, to ship Pentium-class products.*
By Nathan Brookwood

Aggressive Price Reductions Spur Increased Unit Shipments and Decreased Average Selling Prices

Dataquest has extended its x86 computational processor forecast through the turn of the century, and adjusted it to reflect changes in market conditions and strategies of key vendors. Compared with our previous x86 compute forecast issued last November, we now anticipate higher unit shipments of 115.8 million units in 1999, compared with 105.5 million units before, but lower average selling prices (ASPs) of $179 in 1999, compared with $305 before. The key to these changes is Intel's dramatically increased production capacity, resulting from a substantial capital investment program over the past three years. It has been a very long time since demand, rather than supply, constrained Intel's growth, but we are now entering such a period. Intel's new manufacturing muscle produces value only when flexed, and Intel has demonstrated that it will price its products aggressively to spur market demand. Thus the 100-MHz Pentium that commanded a $900 price two years ago now sells for less than $200. Intel

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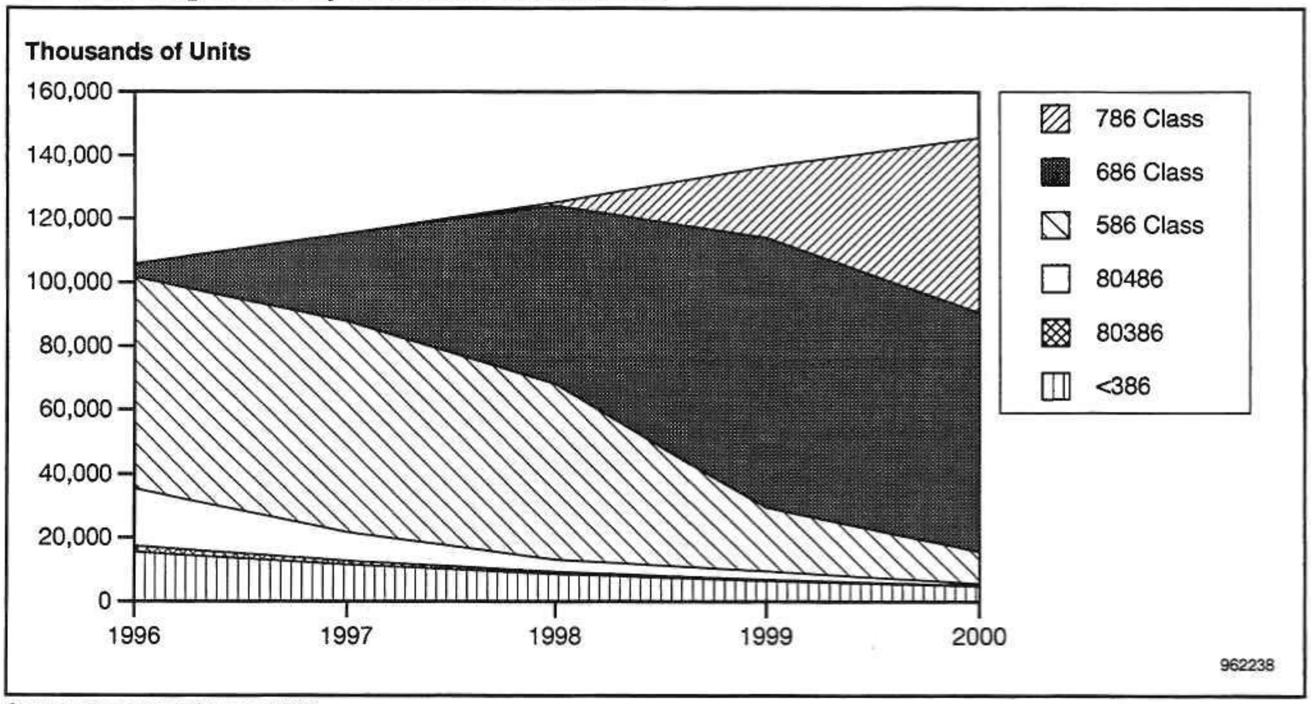
did not lower these prices for competitive reasons—there has been no Pentium-class competition until recently. Now that such competition has arrived from both Cyrix and AMD, we anticipate an even greater reduction in x86 ASPs.

Dataquest projects that the ASP for all x86 microprocessors sold into both compute and embedded market segments will continue to increase at a compound annual growth rate (CAGR) of 8 percent, from $118 in 1995 to $156 in the year 1999. One of the paradoxes that makes the x86 microprocessor market so profitable for those companies that can participate is that this overall ASP *increases*, while the ASP for each individual microprocessor generation *decreases* over time. The key challenge for x86 vendors is to continually shift the mix of products sold toward the high end. So far, they have always met this challenge.

Figures 1, 2, and 3, along with Table 1, illustrate Dataquest's projections for unit shipments, revenue, and ASPs from 1995 to 2000. During this period, Pentium and 586-class products will grow from 35 percent to 63 percent of unit shipments, and then shrink to only 7 percent; they will account for 65 percent of sales in 1995, 77 percent in 1996, but only 1 percent in the year 2000. Pentium Pro and 686-class products will be introduced, grow to over 60 percent market share, and begin to wane. The 786-class products will just be reaching their ascendancy at the turn of the century.

Figure 1
x86 Unit Shipments by Processor Generation



Source: Dataquest (March 1996)

Figure 2
x86 Revenue by Processor Generation

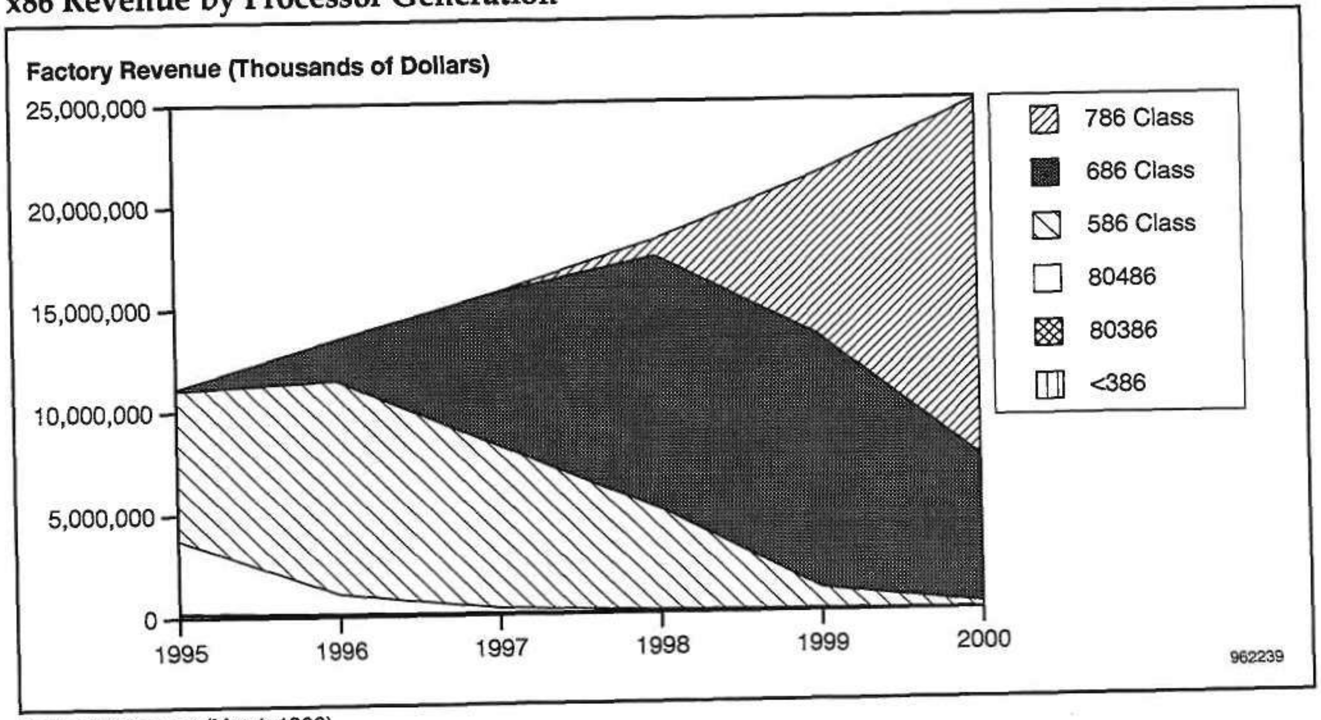


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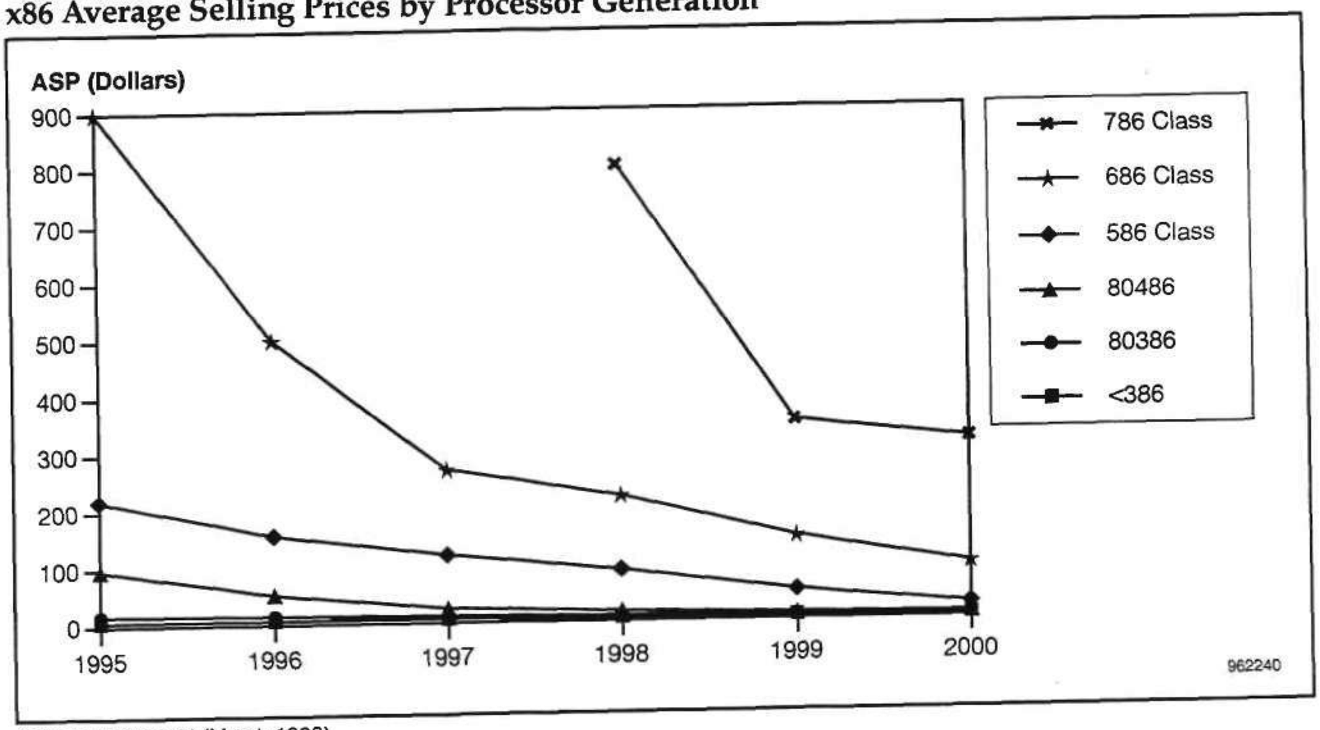
Figure 3
x86 Average Selling Prices by Processor Generation



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x86 Units, ASP, and Revenue by Processor Generation
(Units in Thousands, ASP in U.S. Dollars, Revenue in Thousands of U.S. Dollars)

Processor		1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
<386	Units	20,816	15,481	11,518	8,602	6,437	4,822	-25
(8086/8088	ASP	7	7	7	6	6	5	-6
186/188/286)	Revenue	154,235	107,821	75,411	52,939	37,237	26,220	-30
80386	Units	4,050	1,900	1,235	741	445	267	-42
	ASP	18	15	12	9	7	6	-20
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	Revenue	3,527,455	948,618	236,197	64,295	26,263	4,091	-74
586 Class	Units	33,295	66,250	66,000	55,000	20,000	10,000	-21
	ASP	219	157	120	90	51	24	-36
	Revenue	7,274,958	10,371,438	7,920,000	4,950,000	1,020,000	237,500	-50
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	ASP	900	500	270	220	146	96	-36
	Revenue	90,000	2,000,000	7,425,000	12,320,000	12,358,125	7,200,000	140
786 Class	Units				1,000	22,500	55,000	NM
	ASP				800	350	316	NM
	Revenue				800,000	7,875,000	17,400,000	NM
886 Class	Units							
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	ASP	118	127	136	145	156	171	8
	Revenue	11,121,220	13,455,613	15,671,031	18,194,157	21,319,947	24,869,406	17

NM = Not meaningful
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The astute observer will note that Dataquest has pushed back its anticipated introduction of Intel's 786-class processor until late in 1998, based on our understanding of Intel's current road map. This change in turn delays the 886 generation until after the turn of the century, and out of the current forecast period. Although the interval between the onset of each new generation continues to hover around three years, the period from introduction to mainstream shipments has decreased over time and is now under 18 months. This shrinking period, combined with the dramatically increased unit shipment volume of today's very large market, has forced processor and system vendors into ever higher rates of manufacturing acceleration. Today's market moves at such a high speed that even a minor hiccup in development programs can have major impacts on revenue and profits.

x86 Microprocessors in Computational Applications

Dataquest divides the microprocessor world into two major categories. Processors used in devices whose functional characteristics can be changed by software the user selects at any particular point in time are considered "compute" microprocessors. Processors used in devices where the functional characteristics are determined by the device manufacturer are considered "embedded" microprocessors. x86-based microprocessors dominate the "compute" category but also participate in the "embedded" segment. This document focuses on those used in computational applications, including personal computers, mobile PCs, workstations, and servers.

Dataquest projects that 586-class processors, including the Intel Pentium, Cyrix 6x86, and AMD 5K86, will continue to dominate unit shipments through the end of 1997, when the 686 class (Pentium Pro) will reach dominance. The lifespan of the 586 generation will be prolonged by the introduction of midlife architectural kickers, including multimedia instruction set enhancements, in early 1997. As we noted last fall, the Pentium Pro's market share growth will be somewhat constrained by its need for 32-bit environments in order to reach its full performance potential. The desktop PC world has migrated to such environments at a slower pace than Intel's planners envisioned five years ago. Fortunately (for Intel), Windows NT provides such an environment and is now gaining rapid acceptance in commercial environments, spurred somewhat by decreased memory costs, along with a reluctance on the part of MIS managers to migrate to Windows 95, despite the massive hype that surrounded this product last summer and fall. Intel has indicated an intent to lower Pentium Pro prices substantially by the end of 1996, and Dataquest anticipates that this, too, will spur demand. Consequently, we have increased our forecast for Pentium Pro shipments in 1996 from 2.5 million to 4 million units.

Although there has been much recent discussion regarding saturation of PC markets in the home and office, Dataquest believes that such views apply only to the U.S. market, if they apply at all. Ample opportunity still exists for market growth in the Asia/Pacific area, and we anticipate that this region will drive much of the continued growth of the PC industry, and consequently, the semiconductor industry.

In 1996, the computational x86 market will experience something it lacked in 1995—competition at the middle and high-end of desktop systems. After an agonizing series of delays on the part of both Cyrix and AMD, both vendors now can deliver meaningful quantities of 586-class products this year. Cyrix has positioned its 6x86 as a Pentium Pro competitor by name and as a Pentium by its price, but the 6x86 really falls between the Pentium and Pentium Pro by its architecture. Cyrix and its partners (IBM Microelectronics and SGS-Thomson) can produce over 5 million units in calendar 1996. AMD has positioned its K5 product, now known as the 5K86, at the lower end of the performance range, but still in the Pentium performance ballpark. AMD's offering should appeal primarily to OEMs and resellers, which can increase their gross profit dollars by substituting a lower-cost AMD processor for an Intel device of equivalent performance. AMD estimates that it can produce between 3.5 million and 4 million 5K86 devices during 1996.

Dataquest anticipates that ASPs for x86 processors in computational markets will continue to inch up overall, despite the decreasing ASP for each individual generation. ASP growth will be constrained by Intel's need to drive market growth via aggressive pricing, along with the ever more difficult problems associated with increasing the production rates for new products from a standing start to tens of millions of units in less and less elapsed time.

Table 2 and Figures 4, 5, and 6 contain Dataquest's quantitative views of the x86 computational market through the year 2000, with regard to unit shipments, revenue, and average selling prices.

Quarterly Projections: Can We Sustain Five Consecutive Quarterly Increases?

Dataquest projects that unit shipments of x86 compute microprocessors will show positive growth from the fourth quarter of 1995 through the fourth quarter of 1996. This is a rare event; normally first quarter sales fall off a bit from higher sales at the prior year-end. The combination of a somewhat weaker-than-hoped-for final quarter of 1995, along with a strong international market early in 1996, should break this trend, and we expect demand to build throughout the year. During 1996, we expect 486 shipments to decline at almost the same rate that Pentium Pro shipments build. Pentium Pro sales should accelerate sharply early in 1997, when Intel introduces its next P6 implementation, code-named Klamath. If AMD/NexGen is ready with its K6 processor, and if Cyrix is ready with its M2 design, then 1997 might be a very interesting year.

Table 3 and Figure 7 provide a quantitative view of Dataquest's forecast for x86 compute microprocessors over the next eight quarters.

Microprocessor and PC System Forecast Alignment

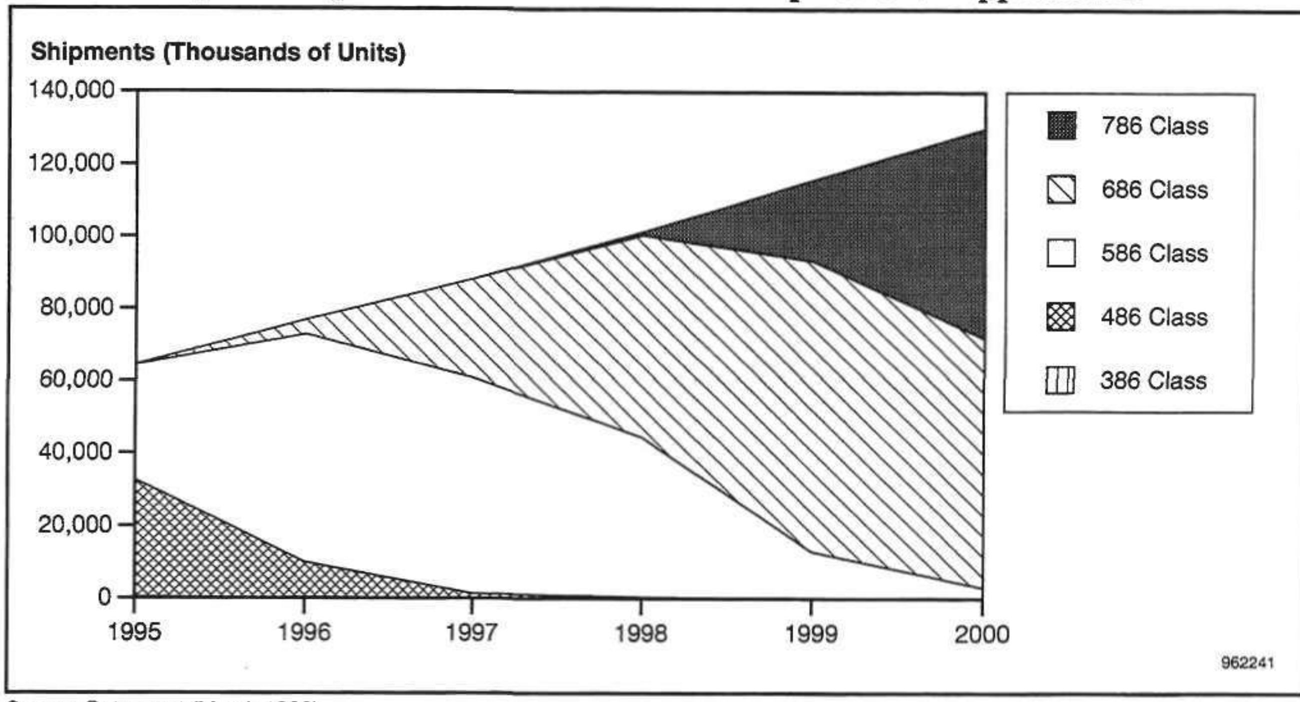
Dataquest tracks and forecasts personal computer system shipments along with microprocessor shipments. Our forecasting methodology forces an alignment of x86 microprocessor forecasts by CPU and speed grade with anticipated PC system sales by CPU and speed grade. Given that every x86-compatible PC contains at least one (and usually no more than one) x86 compute processor, Dataquest attempts to balance anticipated PC demand with projected microprocessor availability.

Table 2
x86 Units, ASP, and Revenue by Processor Generation in Computational Applications (Units in Thousands, ASP in U.S. Dollars, Revenue in Thousands of U.S. Dollars)

		1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 Class								
	Units	405						-100
	ASP	20	14	11	2			-100
	Revenue	8,059	0	0	0			-100
486 Class								
	Units	32,310	9,900	1,350	380			-100
	ASP	101	66	49	39			-100
	Revenue	3,258,205	648,918	66,367	14,945			-100
586 Class								
	Units	31,630	62,938	59,400	44,000	13,000	3,000	-38
	ASP	230	159	125	100	65	33	-32
	Revenue	7,274,958	10,007,063	7,425,000	4,400,000	845,000	97,500	-58
686 Class								
	Units	100	4,000	27,500	56,000	80,275	69,000	270
	ASP	900	500	270	220	150	100	-36
	Revenue	90,000	2,000,000	7,425,000	12,320,000	12,041,250	6,900,000	138
786 Class								
	Units				1,000	22,500	58,000	NM
	ASP				800	350	300	NM
	Revenue				800,000	7,875,000	17,400,000	NM
Total Compute x86								
	Units	64,445	76,838	88,250	101,380	115,775	130,000	15
	ASP	165	165	169	173	179	188	3
	Revenue	10,631,221	12,655,981	14,916,367	17,534,945	20,761,250	24,397,500	18
	U/U (%)	23	19	15	15	14	12	
	$/$ (%)	21	19	18	18	18	18	

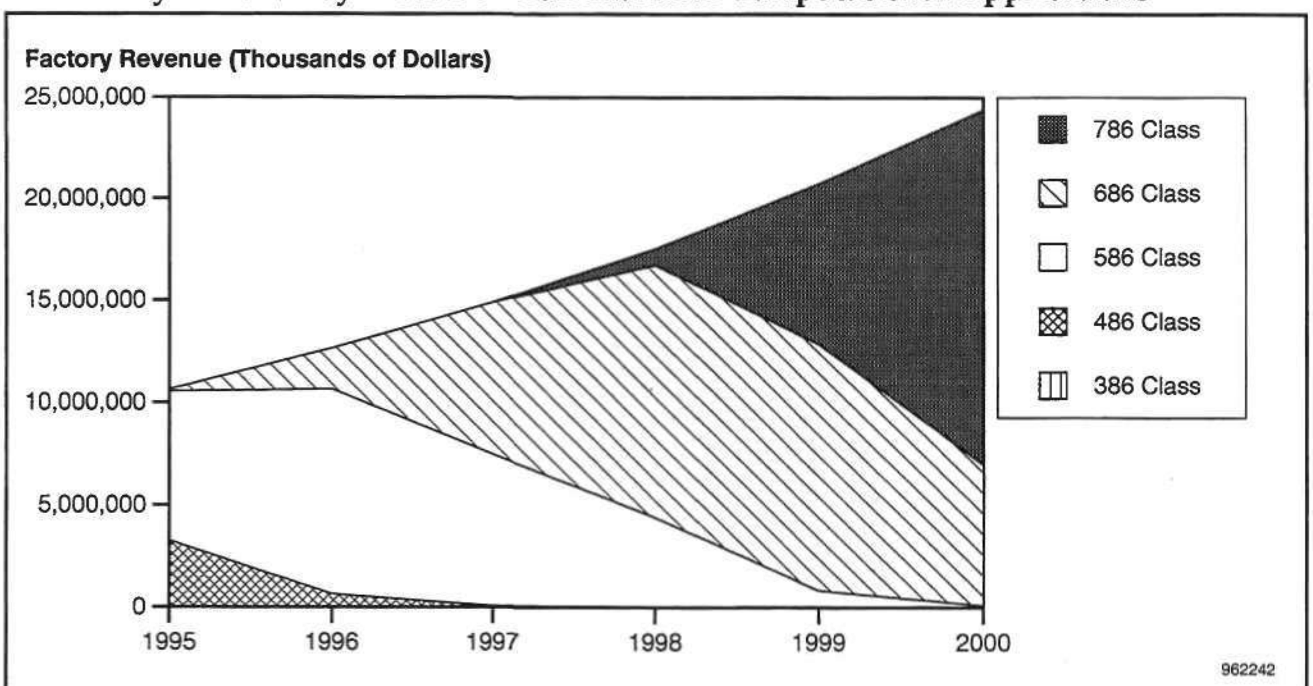
NM = Not meaningful
Source: Dataquest (March 1996)

Figure 4
x86 Unit Shipments by Processor Generation in Computational Applications



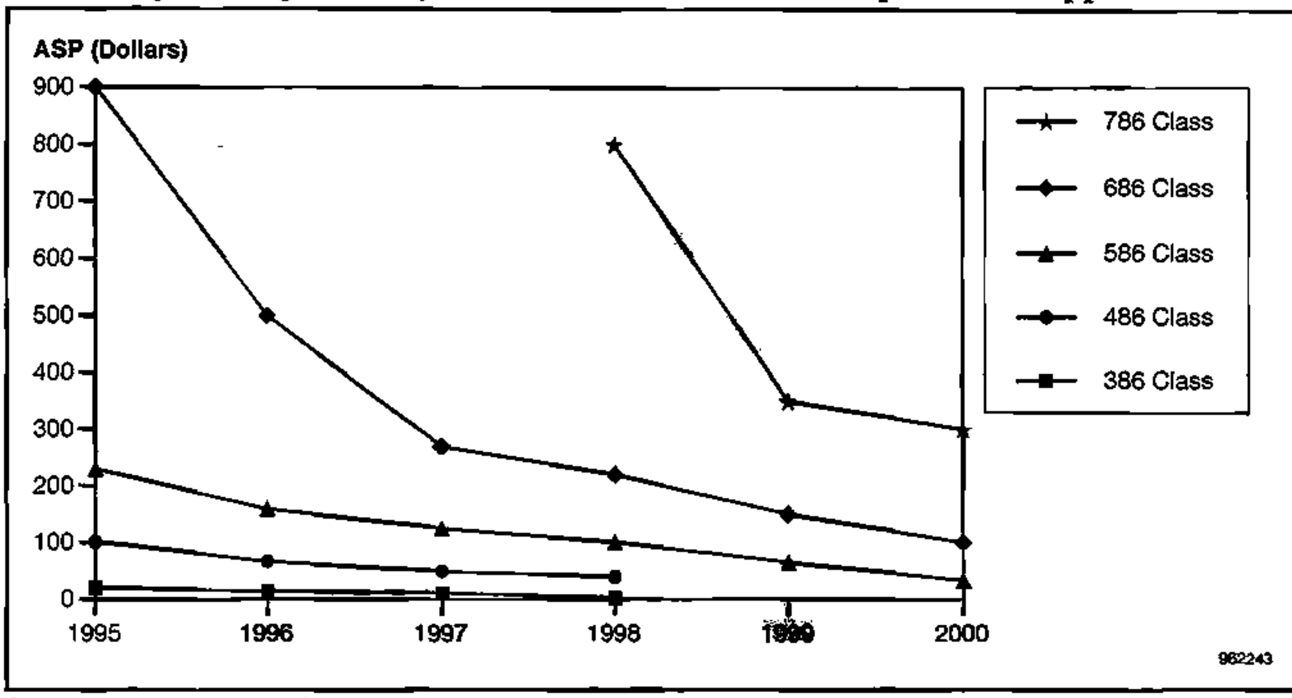
Source: Dataquest (March 1996)

Figure 5
x86 Factory Revenue by Processor Generation in Computational Applications



Source: Dataquest (March 1996)

Figure 6
x86 Average Selling Prices by Processor Generation in Computational Applications



Source: Dataquest (March 1996)

Table 3
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications (Units in Thousands)

	Q1/96	Q2/96	Q3/96	Q4/96	Q1/97	Q2/97	Q3/97	Q4/97
486	3,465	2,970	1,980	1,485	473	405	338	135
586	11,725	14,069	16,883	20,260	17,226	16,038	14,256	11,880
686	400	800	1,200	1,600	2,750	5,500	8,250	11,000
All x86	15,590	17,839	20,063	23,345	20,449	21,943	22,844	23,015

Source: Dataquest (March 1996)

Table 4 and Figure 8 provide the latest worldwide PC systems forecast, by CPU speed class, as recently released by our systems group. In all years and all speed grades, there is an excess of processors over systems. This excess, labeled "CPUs without Systems" in the table and figure, includes processors (in all speed grades) sold as upgrades, or to individuals assembling their own systems. This category also includes the inventory "float" that accounts for processors sold by the chip vendor to the system vendor, but not yet sold by the system vendor to an end user.

Figure 7
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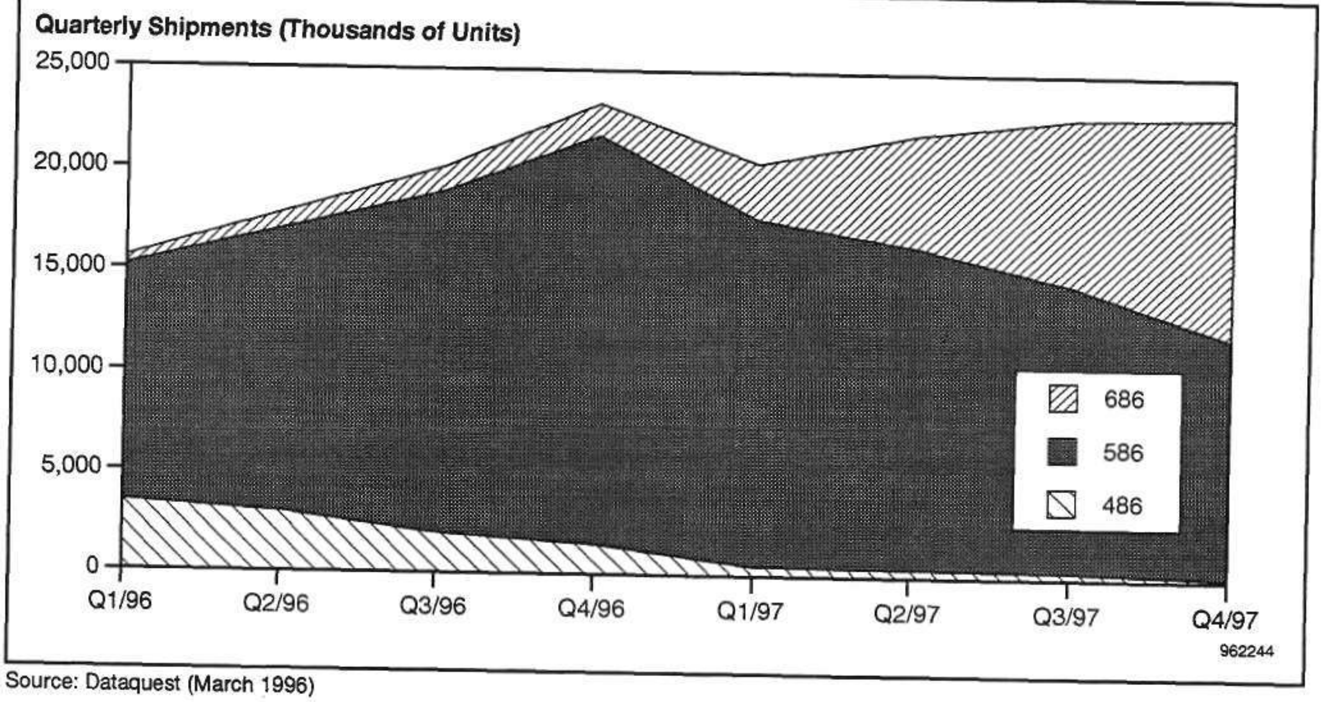


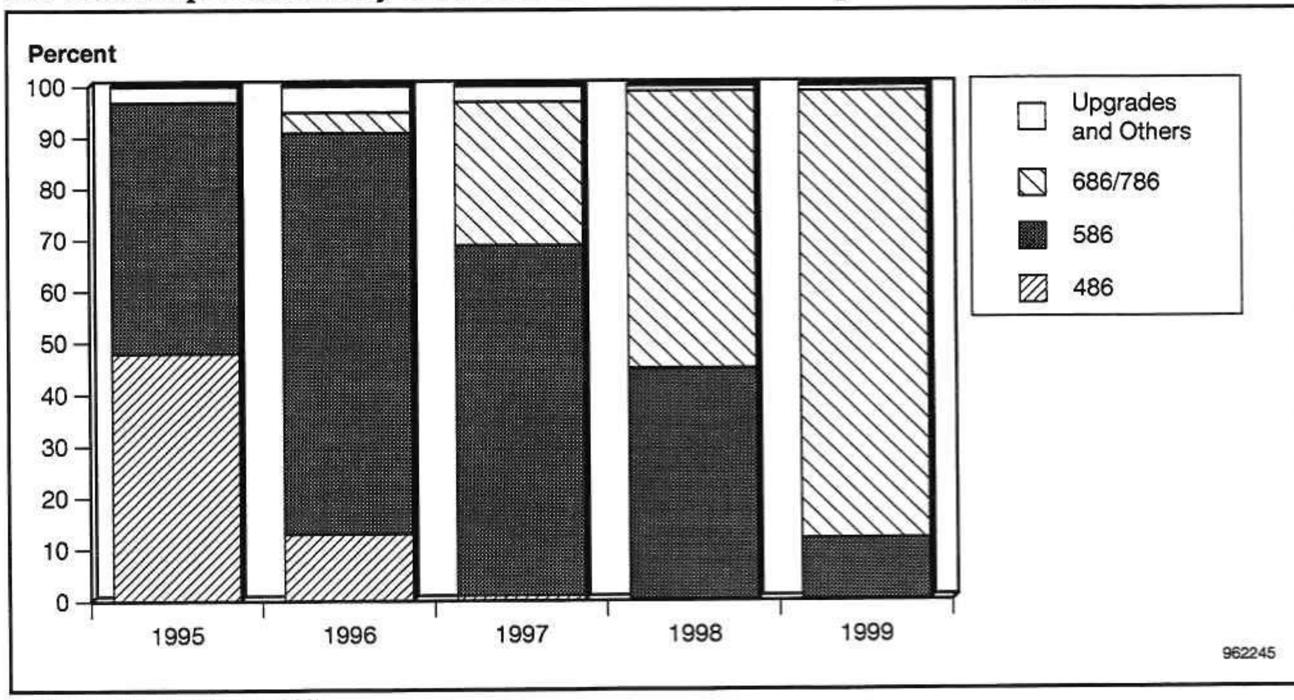
Source: Dataquest (March 1996)

Table 4
Worldwide x86 Unit Shipments by Processor Generation in Computational Applications (Units in Thousands)

	1995	1996	1997	1998	1999
386 PC	74				
486 PC	30,823	9,684	718		
586 PC	31,469	60,548	60,096	45,612	13,905
686/786 PC	12	2,861	25,120	54,943	100,416
CPUs without Systems	2,067	3,745	2,316	825	1,454

Source: Dataquest (March 1996)

Figure 8
x86 Unit Shipment Mix by Processor Generation in Computational Applications



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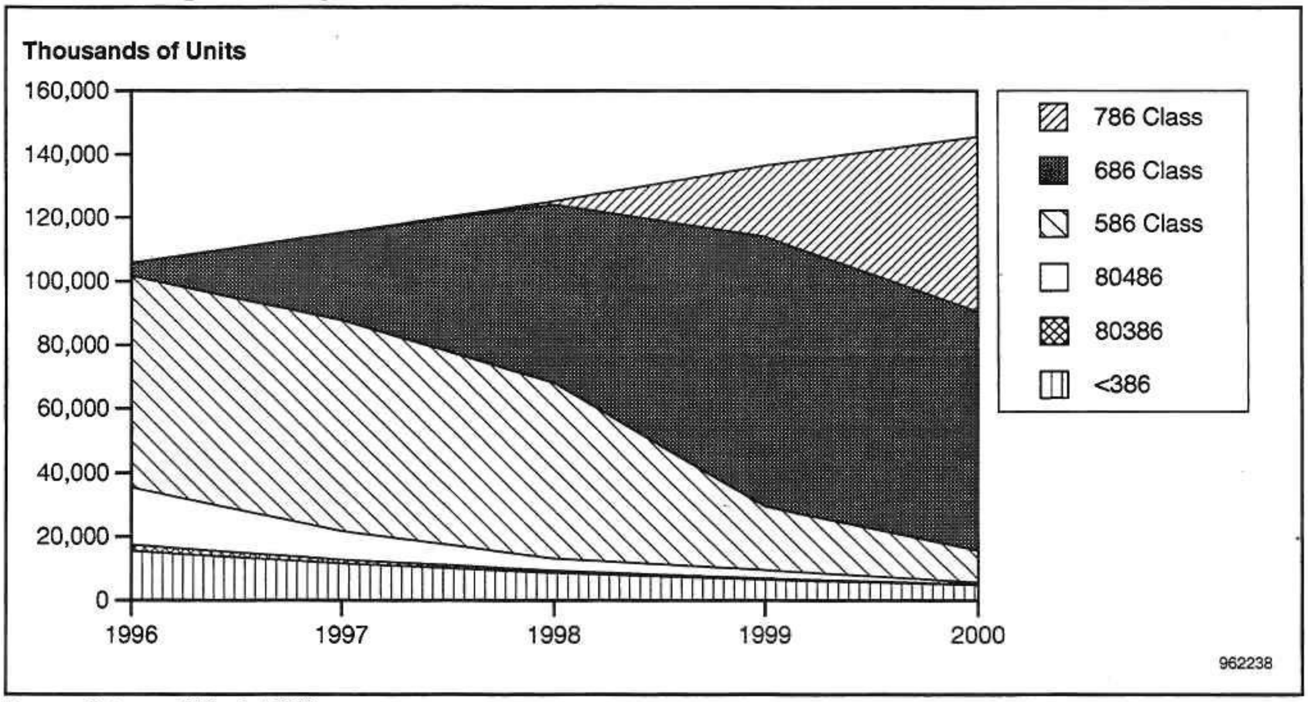

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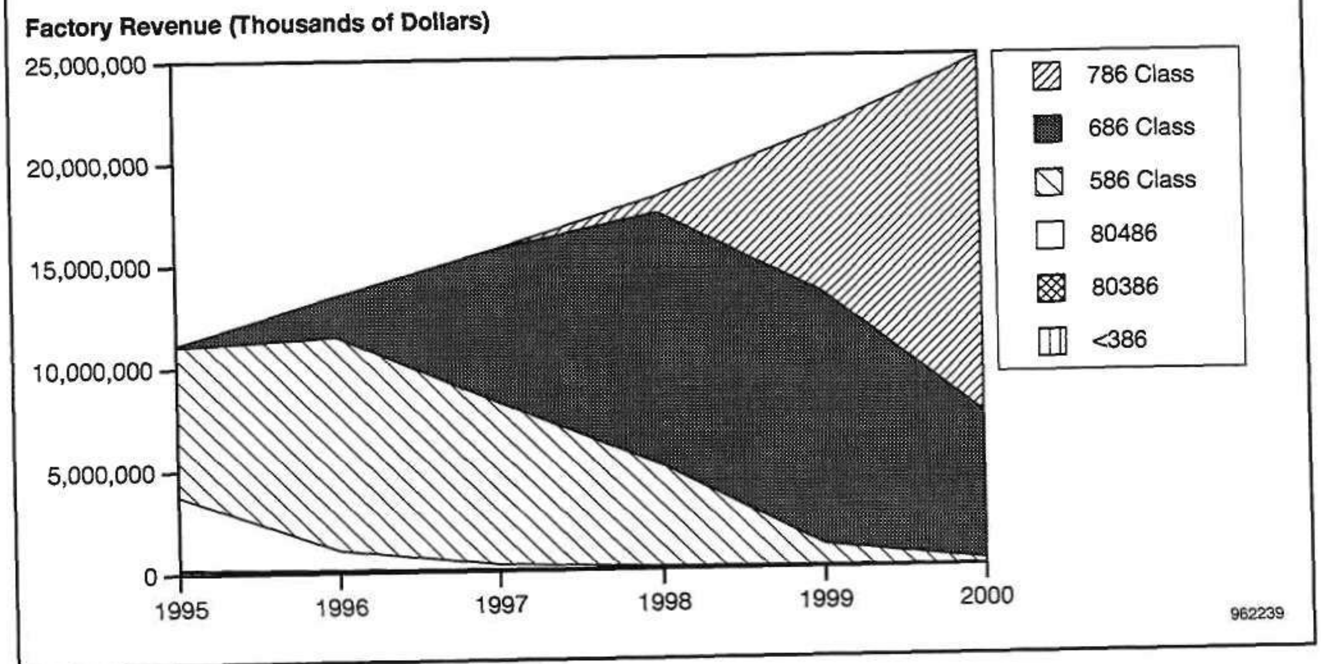

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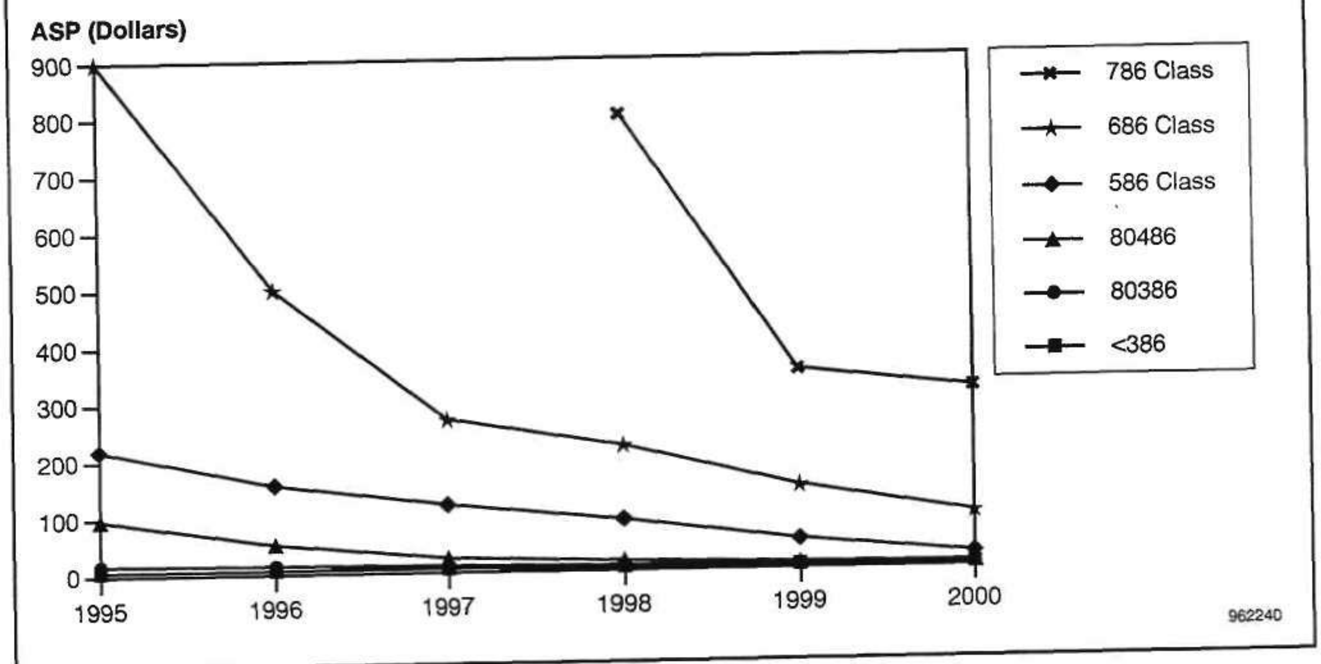

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x86 Microprocessors in Computational Applications

Dataquest divides the microprocessor world into two major categories. Processors used in devices whose functional characteristics can be changed by software the user selects at any particular point in time are considered "compute" microprocessors. Processors used in devices where the functional characteristics are determined by the device manufacturer are considered "embedded" microprocessors. x86-based microprocessors dominate the "compute" category but also participate in the "embedded" segment. This document focuses on those used in computational applications, including personal computers, mobile PCs, workstations, and servers.

Dataquest projects that 586-class processors, including the Intel Pentium, Cyrix 6x86, and AMD 5K86, will continue to dominate unit shipments through the end of 1997, when the 686 class (Pentium Pro) will reach dominance. The lifespan of the 586 generation will be prolonged by the introduction of midlife architectural kickers, including multimedia instruction set enhancements, in early 1997. As we noted last fall, the Pentium Pro's market share growth will be somewhat constrained by its need for 32-bit environments in order to reach its full performance potential. The desktop PC world has migrated to such environments at a slower pace than Intel's planners envisioned five years ago. Fortunately (for Intel), Windows NT provides such an environment and is now gaining rapid acceptance in commercial environments, spurred somewhat by decreased memory costs, along with a reluctance on the part of MIS managers to migrate to Windows 95, despite the massive hype that surrounded this product last summer and fall. Intel has indicated an intent to lower Pentium Pro prices substantially by the end of 1996, and Dataquest anticipates that this, too, will spur demand. Consequently, we have increased our forecast for Pentium Pro shipments in 1996 from 2.5 million to 4 million units.

Although there has been much recent discussion regarding saturation of PC markets in the home and office, Dataquest believes that such views apply only to the U.S. market, if they apply at all. Ample opportunity still exists for market growth in the Asia/Pacific area, and we anticipate that this region will drive much of the continued growth of the PC industry, and consequently, the semiconductor industry.

In 1996, the computational x86 market will experience something it lacked in 1995—competition at the middle and high-end of desktop systems. After an agonizing series of delays on the part of both Cyrix and AMD, both vendors now can deliver meaningful quantities of 586-class products this year. Cyrix has positioned its 6x86 as a Pentium Pro competitor by name and as a Pentium by its price, but the 6x86 really falls between the Pentium and Pentium Pro by its architecture. Cyrix and its partners (IBM Microelectronics and SGS-Thomson) can produce over 5 million units in calendar 1996. AMD has positioned its K5 product, now known as the 5K86, at the lower end of the performance range, but still in the Pentium performance ballpark. AMD's offering should appeal primarily to OEMs and resellers, which can increase their gross profit dollars by substituting a lower-cost AMD processor for an Intel device of equivalent performance. AMD estimates that it can produce between 3.5 million and 4 million 5K86 devices during 1996.

Dataquest anticipates that ASPs for x86 processors in computational markets will continue to inch up overall, despite the decreasing ASP for each individual generation. ASP growth will be constrained by Intel's need to drive market growth via aggressive pricing, along with the ever more difficult problems associated with increasing the production rates for new products from a standing start to tens of millions of units in less and less elapsed time.

Table 2 and Figures 4, 5, and 6 contain Dataquest's quantitative views of the x86 computational market through the year 2000, with regard to unit shipments, revenue, and average selling prices.

Quarterly Projections: Can We Sustain Five Consecutive Quarterly Increases?

Dataquest projects that unit shipments of x86 compute microprocessors will show positive growth from the fourth quarter of 1995 through the fourth quarter of 1996. This is a rare event; normally first quarter sales fall off a bit from higher sales at the prior year-end. The combination of a somewhat weaker-than-hoped-for final quarter of 1995, along with a strong international market early in 1996, should break this trend, and we expect demand to build throughout the year. During 1996, we expect 486 shipments to decline at almost the same rate that Pentium Pro shipments build. Pentium Pro sales should accelerate sharply early in 1997, when Intel introduces its next P6 implementation, code-named Klamath. If AMD/NexGen is ready with its K6 processor, and if Cyrix is ready with its M2 design, then 1997 might be a very interesting year.

Table 3 and Figure 7 provide a quantitative view of Dataquest's forecast for x86 compute microprocessors over the next eight quarters.

Microprocessor and PC System Forecast Alignment

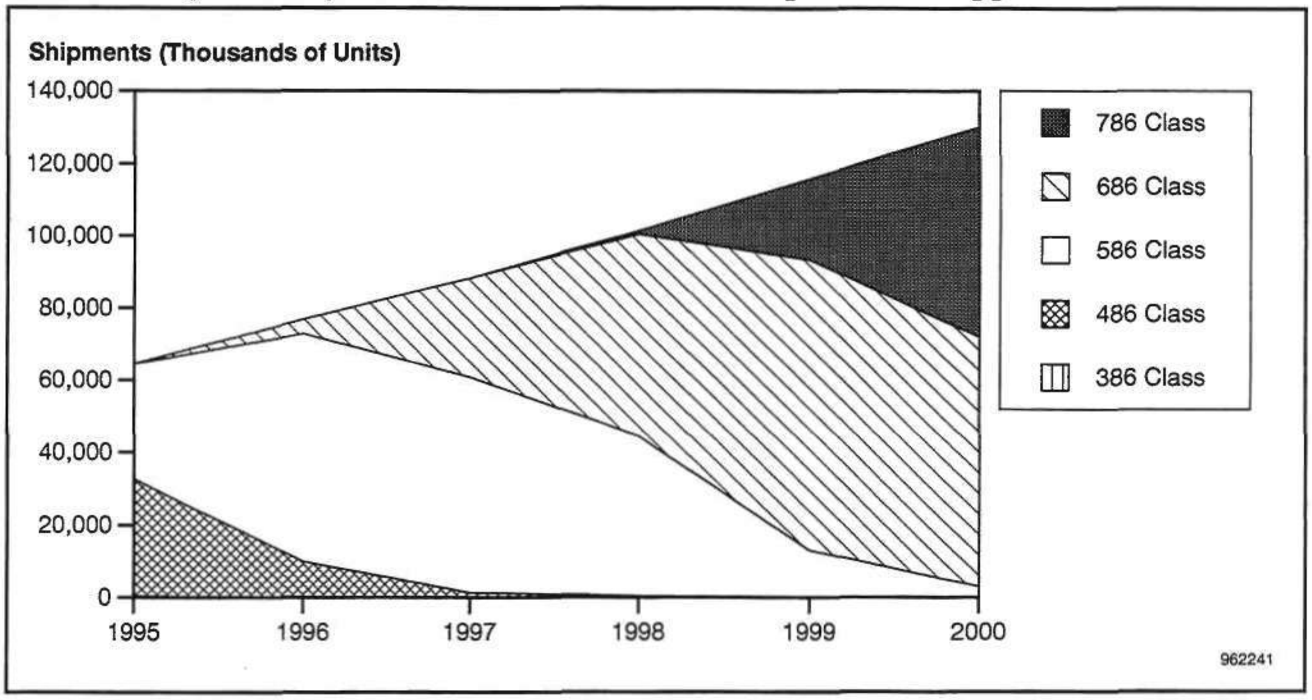
Dataquest tracks and forecasts personal computer system shipments along with microprocessor shipments. Our forecasting methodology forces an alignment of x86 microprocessor forecasts by CPU and speed grade with anticipated PC system sales by CPU and speed grade. Given that every x86-compatible PC contains at least one (and usually no more than one) x86 compute processor, Dataquest attempts to balance anticipated PC demand with projected microprocessor availability.

Table 2
x86 Units, ASP, and Revenue by Processor Generation in Computational Applications (Units in Thousands, ASP in U.S. Dollars, Revenue in Thousands of U.S. Dollars)

		1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 Class								
	Units	405						-100
	ASP	20	14	11	2			-100
	Revenue	8,059	0	0	0			-100
486 Class								
	Units	32,310	9,900	1,350	380			-100
	ASP	101	66	49	39			-100
	Revenue	3,258,205	648,918	66,367	14,945			-100
586 Class								
	Units	31,630	62,938	59,400	44,000	13,000	3,000	-38
	ASP	230	159	125	100	65	33	-32
	Revenue	7,274,958	10,007,063	7,425,000	4,400,000	845,000	97,500	-58
686 Class								
	Units	100	4,000	27,500	56,000	80,275	69,000	270
	ASP	900	500	270	220	150	100	-36
	Revenue	90,000	2,000,000	7,425,000	12,320,000	12,041,250	6,900,000	138
786 Class								
	Units				1,000	22,500	58,000	NM
	ASP				800	350	300	NM
	Revenue				800,000	7,875,000	17,400,000	NM
Total Compute x86								
	Units	64,445	76,838	88,250	101,380	115,775	130,000	15
	ASP	165	165	169	173	179	188	3
	Revenue	10,631,221	12,655,981	14,916,367	17,534,945	20,761,250	24,397,500	18
	U/U (%)	23	19	15	15	14	12	
	$/$ (%)	21	19	18	18	18	18	

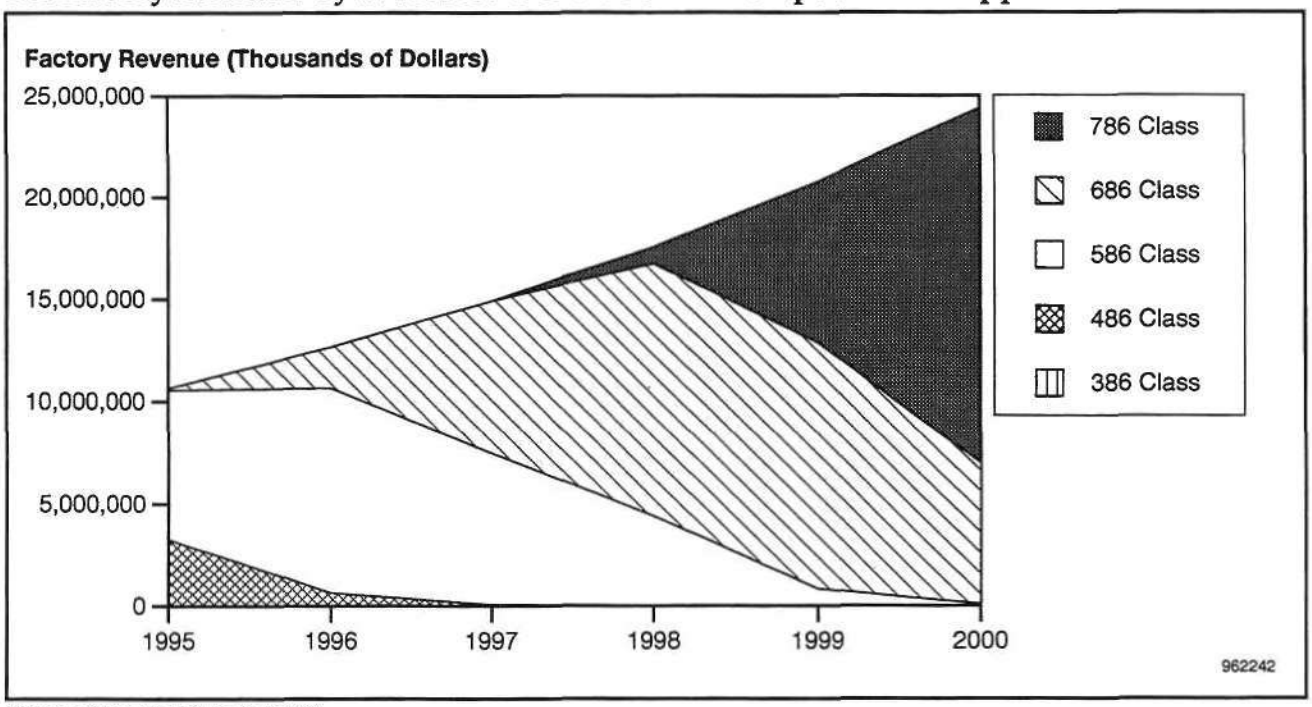
NM = Not meaningful
Source: Dataquest (March 1996)

Figure 4
x86 Unit Shipments by Processor Generation in Computational Applications



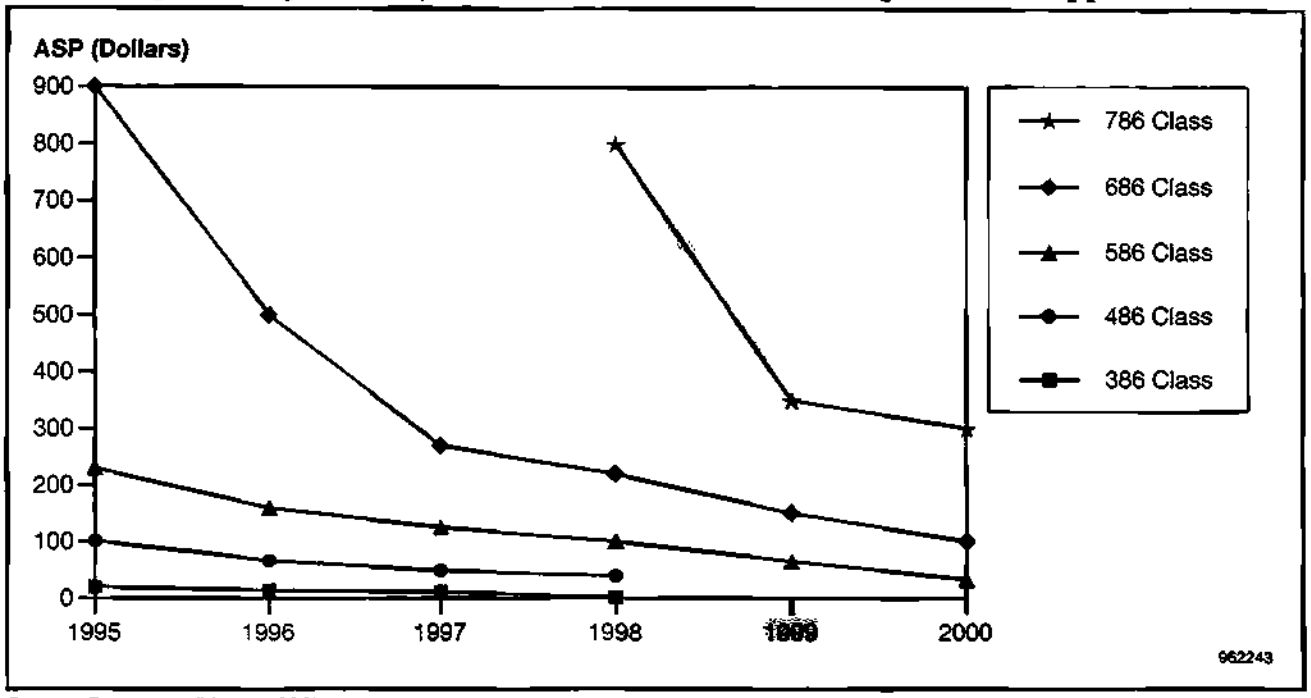
Source: Dataquest (March 1996)

Figure 5
x86 Factory Revenue by Processor Generation in Computational Applications



Source: Dataquest (March 1996)

Figure 6
x86 Average Selling Prices by Processor Generation in Computational Applications



Source: Dataquest (March 1996)

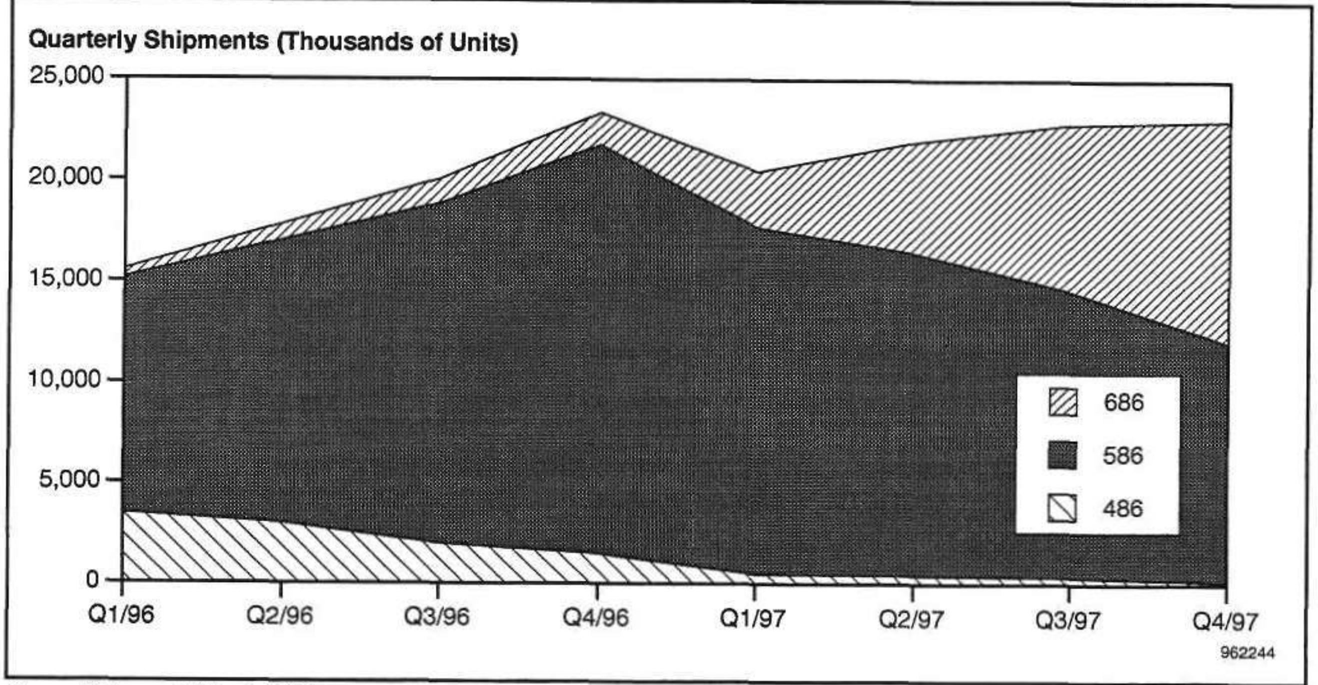
Table 3
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications (Units in Thousands)

	Q1/96	Q2/96	Q3/96	Q4/96	Q1/97	Q2/97	Q3/97	Q4/97
486	3,465	2,970	1,980	1,485	473	405	338	135
586	11,725	14,069	16,883	20,260	17,226	16,038	14,256	11,880
686	400	800	1,200	1,600	2,750	5,500	8,250	11,000
All x86	15,590	17,839	20,063	23,345	20,449	21,943	22,844	23,015

Source: Dataquest (March 1996)

Table 4 and Figure 8 provide the latest worldwide PC systems forecast, by CPU speed class, as recently released by our systems group. In all years and all speed grades, there is an excess of processors over systems. This excess, labeled "CPUs without Systems" in the table and figure, includes processors (in all speed grades) sold as upgrades, or to individuals assembling their own systems. This category also includes the inventory "float" that accounts for processors sold by the chip vendor to the system vendor, but not yet sold by the system vendor to an end user.

Figure 7
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications



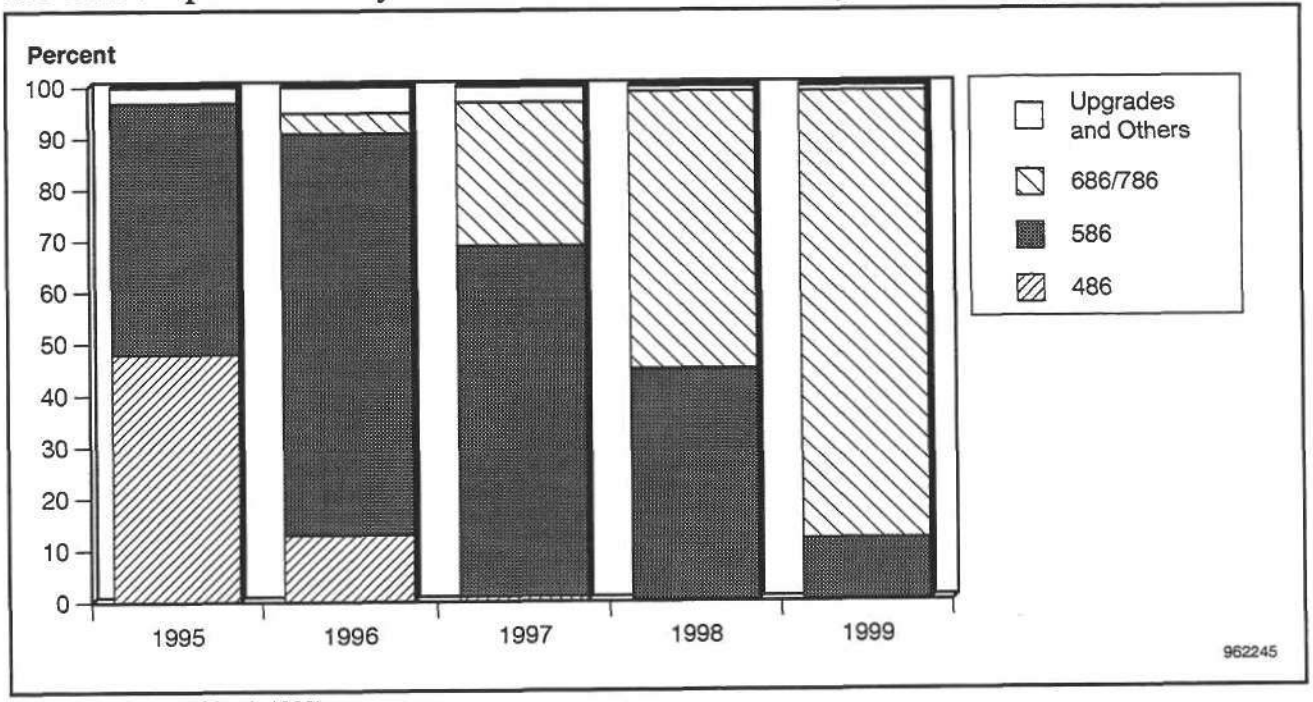
Source: Dataquest (March 1996)

Table 4
Worldwide x86 Unit Shipments by Processor Generation in Computational Applications (Units in Thousands)

	1995	1996	1997	1998	1999
386 PC	74				
486 PC	30,823	9,684	718		
586 PC	31,469	60,548	60,096	45,612	13,905
686/786 PC	12	2,861	25,120	54,943	100,416
CPUs without Systems	2,067	3,745	2,316	825	1,454

Source: Dataquest (March 1996)

Figure 8
x86 Unit Shipment Mix by Processor Generation in Computational Applications



Source: Dataquest (March 1996)

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Perspective

Semiconductor Directions in PCs and PC Multimedia

Market Analysis

Core Logic Market Share: Preliminary 1995 Statistics

Abstract: *This document provides a preliminary look at Dataquest's 1995 core logic market share statistics. The year 1995 brought few surprises, with only one new name in the top 10 list for the overall market. The biggest gain was made by Intel, which seized the No. 1 position, displacing VLSI Technology. The market for mobile PC core logic also has a new leader as Pico Power displaced VLSI Technology. The purpose of this newsletter is to communicate the unit market share rankings for core logic. A more exhaustive analysis of the core logic market will be published in May 1996.*
By Geoff Ballew

It's No Surprise—Intel Seizes Top Spot in Core Logic Market

Intel's dominance of the Pentium motherboard market and popular Triton chipset propelled the company to the top of the core logic supplier list. Intel's strength lies in the ability to supply varying levels of assembly/integration at a compelling price as well as chipset performance. The synergy between core logic and MPU gives Intel a time-to-market advantage for core logic, which the company exploits quite well. Dataquest expects Intel to retain the title of biggest core logic supplier for 1996 for the same reasons that Intel's market share grew in 1995.

All of the other core logic vendors fought for market share with few changes in rank order outside of Intel's jump. VLSI's SuperCore 590 chipset was an early entrant to the Pentium chipset market and won several big design wins in 1994, only to lose many of them to Triton in 1995. In Taiwan, SIS and UMC kept their unit shipments growing by relying heavily on the 486 PC market as the Asian market shifted to Pentium more slowly than did other regions. Only two of the top 10 suppliers other than Intel increased their overall market share, and both did so on the mobile PC side of the market.

Dataquest

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The overall core logic market grew almost 36 percent in terms of unit shipments, which is faster than the 25 percent unit growth for PC shipments. Several issues caused this faster growth. Chip sales precede PC sales, and aggressive forecasting in 1995 by the PC OEMs accelerated chip purchases in fall 1995. Those "extra" chips will be sold to consumers in 1996 PCs instead of 1995 PCs. On the mobile side, unit shipments rose 45 percent as the shift toward standard product chipsets continued. Only two companies, Toshiba and Apple, still rely on custom logic to differentiate their mobile PC products.

The mobile PC side of the core logic market promises excitement in 1996 as Intel enters the market. Intel's Mobile Triton chipset will compete in this market for 1996, but was not a factor in 1995. The mobile PC market is more difficult for Intel to penetrate than the desktop market for two reasons: The mobile PC market shifted to Pentium later than the desktop market and Intel is not able to leverage chipset sales from its motherboard division the way it can for desktop PCs. However, the current leader Pico Power in the mobile core logic market faces organizational challenges at the corporate level. Cirrus Logic, which owns Pico Power, announced a restructuring on March 19 and omitted core logic from its list of critical programs. Pico Power has a substantial lead over all of its competitors, but faces heavy competition from Intel, ACC Microelectronics, and OPTi for 1996.

Table 1 shows the market share rankings of the top 10 vendors for the total PC core logic market, combining shipments for desktop as well as mobile PCs. Table 2 shows the market share rankings of the top 10 vendors for the desktop PC core logic market. Table 3 shows the market share rankings of the top six vendors for the mobile PC core logic market.

Table 1
Preliminary Market Share for the Total PC Core Logic Market (Thousands of Units)

1995 Rank	1994 Rank		1994 Total	1995 Total	Market Share (%)	Unit Growth (%)
1	5	Intel	5,300	20,600	30.2	288.7
2	1	VLSI	9,047	9,280	13.6	2.6
3	2	SIS	8,600	9,150	13.4	6.4
4	3	UMC	8,200	8,730	12.8	6.5
5	4	OPTi	7,775	6,800	10.0	-12.5
6	6	Acer Labs	4,200	4,800	7.0	14.3
7	8	Pico Power	1,850	2,950	4.3	59.5
8	7	ACC Micro	2,563	2,750	4.0	7.3
9	10	Symphony	860	925	1.4	7.6
10	9	Chips & Technologies	1,700	750	1.1	55.9
		Others	0	1,555	2.3	NM
		Total	50,630	68,290	100.0	35.9

NA = Not applicable
NM = Not meaningful
Source: Dataquest (March 1996)

Table 2
Preliminary Market Share for the Desktop PC Core Logic Market (Thousands of Units)

1995 Rank	1994 Rank		1994 Desktop	1995 Desktop	Market Share (%)	Unit Growth (%)
1	5	Intel	5,300	20,600	34.1	288.7
2	1	SIS	8,510	9,000	14.9	5.8
3	2	UMC	8,200	8,600	14.2	4.9
4	4	VLSI	7,152	8,130	13.4	13.7
5	3	OPTi	7,396	6,000	9.9	-18.9
6	6	Acer Labs	4,000	4,400	7.3	10.0
7	7	ACC Micro	1,774	1,750	2.9	-1.4
8	9	Symphony	850	900	1.5	5.9
9	8	Chips & Technologies	1,700	750	1.2	-55.9
10	NA	Via	0	100	0.2	NM
		Others	0	220	0.4	NM
		Total	44,882	60,450	100.0	34.7

NA = Not applicable
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Table 3
Preliminary Market Share for the Mobile PC Core Logic Market (Thousands of Units)

1995 Rank	1994 Rank		1994 Mobile	1995 Mobile	Market Share (%)	Unit Growth (%)
1	2	Pico Power	1,850	2,950	37.6	59.5
2	1	VLSI	1,895	1,150	14.7	-39.3
3	3	ACC Micro	789	1,000	12.8	26.7
4	5	OPTi	379	800	10.2	111.1
5	4	Western Digital	500	500	6.4	0
6	6	Acer Labs	200	400	5.1	100.0
		Others	135	1,040	13.3	670.4
		Total	5,748	7,840	100.0	36.4

Source: Dataquest (March 1996)

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7	7	ACC Micro	1,774	1,750	2.9	-1.4
8	9	Symphony	850	900	1.5	5.9
9	8	Chips & Technologies	1,700	750	1.2	-55.9
10	NA	Via	0	100	0.2	NM
		Others	0	220	0.4	NM
		Total	44,882	60,450	100.0	34.7

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5	4	Western Digital	500	500	6.4	0
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		Others	135	1,040	13.3	670.4
		Total	5,748	7,840	100.0	36.4

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Perspective

Semiconductors in PCs and PC Multimedia Worldwide

Market Analysis

Graphics Market Share: Preliminary 1995 Statistics

Abstract: *The perennial graphics giants top this year's market share ranking list again. Actual rankings among the top companies did change, with impressive gains by S3 in desktop PC graphics and Chips & Technologies in mobile PC graphics. These market statistics are preliminary and will be finalized in the graphics Market Trends document to be published in April.*

By Geoff Ballew

Cirrus Logic Retains the Top Ranking Despite Loss of Market Share

Cirrus Logic is still the largest supplier of graphics controllers to the PC market, despite losing market share in 1995 to competitors such as S3 Inc. and Chips & Technologies. Cirrus' growth was limited throughout most of the year by supply constraints, which eased near the end of the year only to be offset by canceled orders from a major customer. Those canceled orders left Cirrus with too much inventory, some of which was 32-bit controllers, at a time when prices for 32-bit graphics controllers were sharply eroding.

S3 showed strong unit growth in the desktop market as the Trio family of graphics controllers ramped to volume with an impressive list of design-wins including Compaq Computer's Presario line. S3 led the shift to 64-bit controllers from the older 32-bit designs as access to manufacturing capacity limited the ability to support both product lines. S3 wisely chose to support the higher-margin, 64-bit products and reaped the benefits of higher average selling prices and relative immunity from price erosion in the 32-bit market.

Chips & Technologies seized the No. 1 position in the mobile graphics market, beating Western Digital with an array of higher-performance graphics

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products. Chips & Technologies grew its unit shipments with an impressive number of design-wins for the 65545 and related graphics controllers. Dataquest expects Chips & Technologies to retain the No. 1 market share position for mobile PC graphics in 1996.

Table 1 shows the market share rankings of the top 10 vendors for the total PC graphics market, combining shipments for desktop and mobile PCs. Table 2 shows the market share rankings of the top 10 vendors for the desktop PC graphics market. Table 3 shows the market share rankings of the top six vendors for the mobile PC graphics market.

Table 1
Preliminary Market Share for the Total PC Graphics Market (Unit Shipments)

	1994	1995	1995 Rank	1994 Rank	Growth (%)	Market Share (%)
Cirrus Logic	26,000	27,900	1	1	7	37.4
S3	6,000	12,000	2	3	100	16.1
Trident Microsystems	7,903	10,791	3	2	37	14.5
Chips & Technologies	2,013	6,825	4	7	239	9.1
ATI Technologies	2,500	5,000	5	6	60	6.7
Tseng Labs	4,600	3,000	6	4	-35	4.0
Western Digital (Philips)	3,175	2,000	7	5	-37	2.7
Avance Logic	1,250	1,417	8	8	13	1.9
Ark Logic	100	1,300	9	Not ranked	1,200	1.7
Sierra Semiconductor	750	1,253	10	9	67	1.7
Others	4,549	3,182			-30	4.3
Total	58,840	74,668				100.0

Source: Dataquest (March 1996)

Table 2
Preliminary Market Share for the Desktop PC Graphics Market (Unit Shipments)

	1994	1995	1995 Rank	1994 Rank	Growth (%)	Market Share (%)
Cirrus Logic	24,500	26,000	1	1	6	41.0
S3 Inc.	6,000	12,000	2	3	100	18.9
Trident Microsystems	7,903	10,381	3	2	31	16.4
ATI Technologies	2,500	5,000	4	5	60	7.9
Tseng Labs	4,600	3,000	5	4	-35	4.7
Avance Logic	1,250	1,417	6	6	13	2.2
Ark Logic	100	1,300	7	Not ranked	1,200	2.1
Sierra Semiconductor	750	953	8	7	27	1.5
Silicon Integrated Systems	0	896	9	Not ranked	NA	1.4
Chips & Technologies	513	876	10	9	71	1.4
Others	2,695	1,567			-42	2.5
Total	50,811	63,390				100.0

NA = Not applicable
Source: Dataquest (March 1996)

Table 3
Preliminary Market Share for the Mobile PC Graphics Market (Unit Shipments

	1994	1995	1995 Rank	1994 Rank	Growth (%)	Market Share (%)
Chips & Technologies	1,500	5,949	1	3	297	52.7
Western Digital (Philips)	3,175	2,000	2	1	-37	17.7
Cirrus Logic	1,500	1,800	3	2	20	16.0
Trident Microsystems	0	410	4	Not ranked	NA	3.6
S-MOS Systems	500	300	5	4	-40	2.7
OPTi	100	100	6	5	0	0.9
Others	1,254	719			-43	6.4
Total	8,029	11,278				

NA = Not applicable
Source: Dataquest (March 1996)

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Dataquest
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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Dataquest Predicts

Can Any Microprocessor Vendor Compete with Intel in 1996?

Abstract: *Intel entered 1996 in an extremely strong position relative to its competitors. This document reviews the company's major achievements during 1995, discusses the major factors affecting competition in the computational microprocessor market, and projects the 1996 fortunes of Intel's major microprocessor competitors, including Advanced Micro Devices, Cyrix, IBM, Digital Equipment, and Sun Microsystems.*
By Nathan Brookwood

The Playing Field in January 1996

Intel entered 1996 in its strongest position ever with regard to the so-called competition in the microprocessor arena. In 1995, it drove its Pentium line into the mainstream PC market and left the 486 market in tatters. It launched its Pentium Pro line while competitors struggled to introduce Pentium-class products. It began a transition to 0.35-micron semiconductor technology that improved performance and reduced die size. In this Perspective, Dataquest examines what actions microprocessor vendors must take if they hope to compete with Intel in the future. We assess both alternative x86 vendors (principally Advanced Micro Devices, Cyrix, and IBM), and purveyors of computational reduced-instruction-set computing (RISC) architectures, including the PowerPC coalition, Alpha, and SPARC.

Before addressing the issue of which (if any) vendor can compete with Intel, examination of the dimensions of the battlefield is in order. Dataquest considers that a number of factors weigh heavily in the microprocessor purchase decisions of system vendors, which greatly determine which products will be offered to end users.

Dataquest

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Performance

Throughout the history of the computer industry, customers have tended to purchase as much performance as they could at whatever price they could afford and/or justify. The purchase of an Intel-based system represents the lowest risk for most purchasers—"nobody ever got fired for buying Intel." Intel's competitors must either offer superior performance or equivalent performance at a lower price in order to compete successfully. For most, this proved too difficult in 1995. Many RISC competitors could offer superior performance in their "native" (that is, RISC) mode, but none could do so when running Windows 3.1, 95, or NT applications via emulation. They could not even achieve this by throwing larger, more expensive configurations at the problem. As we discuss later, delivering equivalent performance at a lower price also proved elusive.

x86 Compatibility

Like it or not, the Wintel standard dominates today's computer market. Software developers typically create the Windows versions of their products first in order to reach the largest possible market. Only when Wintel cannot deliver the minimum features or performance do these developers turn their sights elsewhere. Today's RISC vendors have universally missed this point and deliver abysmal x86 performance, if they address the issue at all. Such a strategy satisfies only the continually shrinking segment of the market that has not made a significant investment in Wintel-based software. As long as Wintel platforms deliver superior performance for most x86 applications, end users will have few reasons to switch to an alternative.

System Economics

In the past, vendors unable to match Intel's performance at the high end could compete by offering a superior "value proposition," that is, lower performance at a substantially lower price. The weak fourth quarter performances of Advanced Micro Devices (AMD) and Cyrix suggest that this approach does not work as well as it used to, and Dataquest doubts that it will soon regain its effectiveness. Three factors account for the demise of this formula: the shrinking gap (in absolute dollar terms) between the cost of high- and low-performance processors; the high impact of CPU performance on overall system performance; and the total system cost required to construct non-Intel-based systems.

The shrinking gap between the cost of high and low-performance processors results from Intel's recent practice of pricing its products to drive market demand. Andy Grove has not had to pay much attention to the pricing strategies of Jerry Sanders or Gerry Rogers, but he still heeds Adam Smith. Intel now sells its entry-level 75-MHz Pentium for less than $100. A mainstream $2,000 PC includes purchased components with a combined (OEM) price of about $1,400. Even if an Intel competitor were to give away the CPU, it would impact system material costs by only 7 percent. Consumers appear increasingly unwilling to sacrifice 50 percent of potential performance to save less than 10 percent on their system purchases. On the contrary, their behavior during the past holiday season (when they opted for the 100-MHz Pentium over the less expensive 75-MHz variety) suggests they may be willing to spend more for a marginal performance benefit. Finally, Intel's aggressive pricing for chipsets and motherboards further reduces the differential for the combined cost of the processor and motherboard offered by Intel, compared with the same cost for non-Intel variants. (This is one of several factors that makes the NexGen Nx586 increasingly problematic.)

Manufacturing Technology and Capacity

Vendors lacking access to 0.5-micron, four-layer metal interconnect manufacturing technology cannot hope to compete in a market in which the typical processor has over 3 million transistors. In a processor market amounting to more that 100 million units per year, a vendor that cannot produce at least 5 million units cannot, by definition, have a major impact. Intel has driven its process technology forward with impressive speed and has made substantial investments in increased capacity. To become or remain competitive, Intel competitors must do likewise.

Technological Infrastructure

The PC industry has evolved to include a variety of hardware, firmware, and software companies whose primary purpose is make Intel (and Intel-compatible) processors useful in computer systems. These companies provide the chipsets and motherboards, the BIOS firmware, operating systems, device drivers, and utility and communications software, not to mention the application software, that turn hunks of silicon and metal into useful machines. Almost all of this infrastructure focuses on products for the x86 world. Processor vendors that cannot ride on Intel's coattails must provide equivalent technology because vendors assembling and selling systems are increasingly unable or unwilling to provide these components themselves. Intel's recent activities in many parts of this infrastructure have weakened earlier participants, many of whom are searching for markets in which Intel competes less actively.

Sales and Marketing Infrastructure

Not only can Intel depend on a highly developed infrastructure to fill in any of the elements of technology needed for using its chips in systems, but it also has the advantage of a complete infrastructure to sell and distribute its products downstream, at both component and system levels. It has spent several hundred million dollars to reinforce its own name and its Pentium brand in the minds of consumers around the world. Prospective computer system purchasers need not look very far to find a seller of Intel-based products. Here, too, vendors of x86-compatibles get an almost-free ride on Intel's coattails, although consumer awareness of the Intel and Pentium brands may bias some prospective buyers away from non-Intel solutions. As if a reminder were needed, Compaq's recent decision to rejoin the "Intel Inside" campaign serves as yet another mark of Intel's commanding presence with top-tier system vendors.

Intel's Position in the Microprocessor Market

According to Dataquest's preliminary figures for 1995, Intel rang up sales of $10.9 billion in processors last year. This figure includes all of Intel's processors—x86, other complex-instruction-set computing (CISC), and RISC—but x86 products make up the bulk of these shipments. Given an x86 market of $12.9 billion, a 32-bit CISC market of $14.4 billion, and a 32-bit processor market of $15.7 billion, Intel's share of these markets comes to 84 percent, 76 percent and 69.4 percent, respectively. By the end of the year, Intel had converted the mainstream market to its Pentium processor; vendors without Pentium equivalents found themselves at a serious competitive disadvantage. AMD, Intel's largest microprocessor competitor, had MPU sales just 10 percent of Intel's, in part because it lacked such a Pentium alternative. Figure 1 shows the worldwide revenue history for 32-bit microprocessors by company.

Intel launched its next-generation processor, Pentium Pro, in 1995. This product displays impressive performance in the 32-bit worlds of Windows NT and UNIX, but its performance in the mixed 16-bit/32-bit world of Windows 95 and Windows 3.1 seems less compelling. Dataquest believes the Pentium Pro will remain a niche product (although in a multimillion-unit niche) in 1996 and will begin to ramp in volume in 1997.

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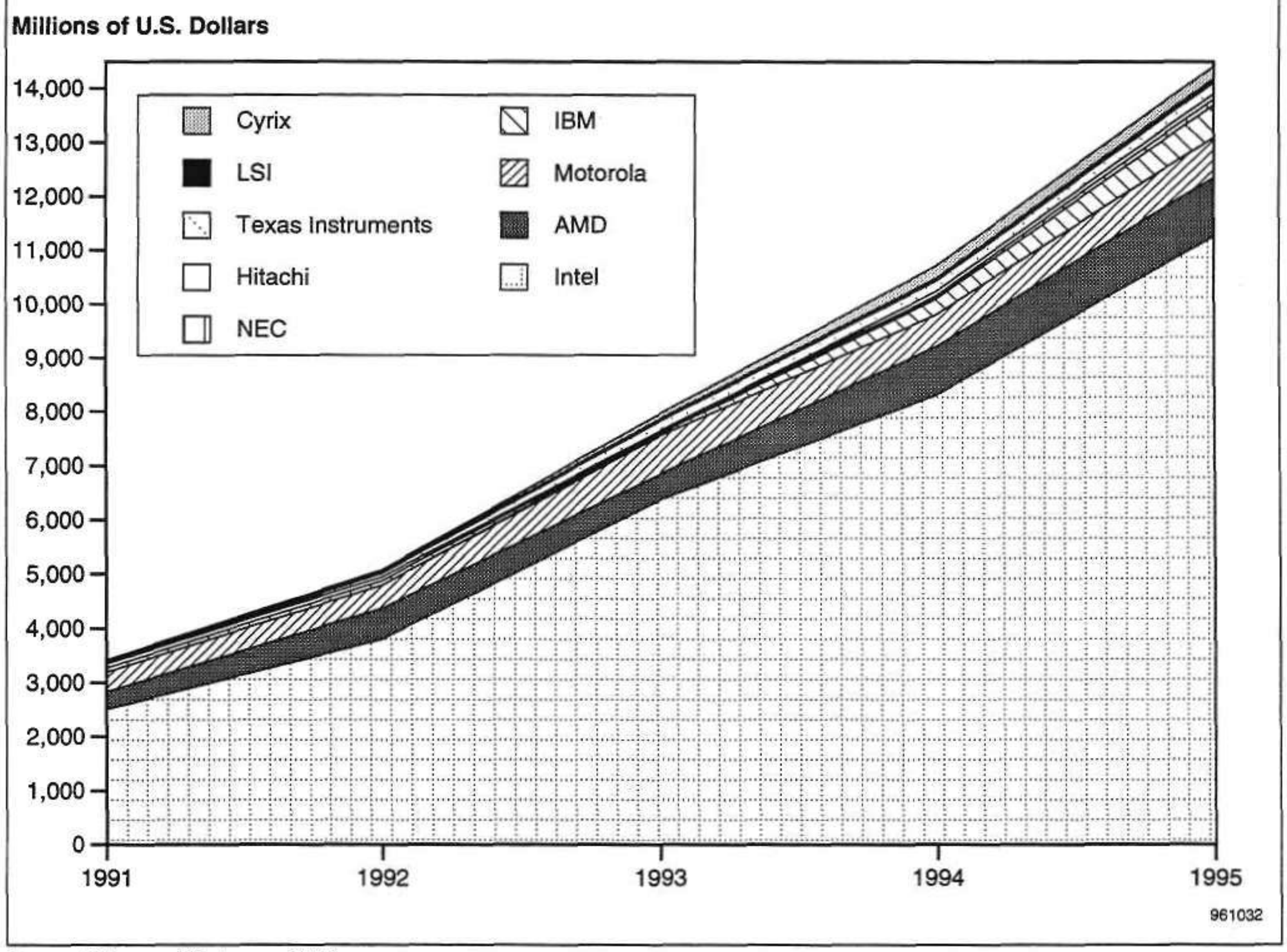

Source: Dataquest (February 1996)

Intel also continued to increase its presence in the chipset and motherboard businesses. The economic rationale for Intel's chipset activities makes these products a win for everyone except other chipset vendors. The rationale for Intel's participation in the motherboard business appears to rest on issues other than strict economics, and this seems problematic. The long-term impact of Intel's participation in these businesses on the existing market players remains to be seen.

All in all, 1995 was a very good year for Intel. Given its size and the complexity of its products, the company executed its strategy with astounding precision. It was a far less auspicious year for Intel's competitors in the processor market.

AMD's Position in the Microprocessor Market

Dataquest estimates that AMD's microprocessor sales amounted to $1 billion in 1995, about 8 percent of the overall 32-bit CISC market. The collapse of the 486 market leaves AMD without a competitive processor offering at the start of 1996; this situation will continue until AMD can launch a K5-based design that can compete with mainstream Pentium processors.

AMD's new Fab 25 in Austin, Texas, certainly has the capacity to produce a meaningful number of microprocessors, but its current CS34 process provides only three-layer metal interconnect. Future designs require four and/or five layers, plus local interconnect capability, which AMD intends to add this year. We regard this as a challenging proposition for the company.

Although 1996 will be problematic for AMD's microprocessor business, there is light at the end of the tunnel. If AMD can complete the development of the NexGen Nx686 design, which has been modified to use a Pentium-compatible pinout and bus structure, and if the company can put the enhanced processes in place at Fab 25 to build this product in volume, then AMD will be well positioned in 1997 when Intel begins to move its Pentium Pro line into high-volume production. The change from a proprietary NexGen pinout to the more standard Pentium pinout will allow AMD to leverage the technology infrastructure that supports Intel-based designs. The enhanced manufacturing processes will be needed to transfer production from IBM's Essex Junction fab. If AMD cannot accomplish these two tasks, then the light at the end of the tunnel may prove to be on the front of Intel's train.

Cyrix's Position in the Microprocessor Market

Cyrix limped through the second half of 1995, impacted by the collapse of the 486 market and delays in getting M1, its Pentium alternative, into volume production. Its saving grace was its 5x86 processor, a small M1 derivative that fits into a 486-socket and delivers low-end Pentium performance. Cyrix said it shipped thousands of its 400-mil 6x86 device, but this failed to have any impact on the market or the company's performance. Dataquest estimates Cyrix 1995 sales to be under $230 million, consisting entirely of x86 microprocessors. This amounts to less than 2 percent of the overall 32-bit CISC market.

Cyrix is one of the few Intel competitors poised to increase its sales and market share in 1996. Its foundry arrangements with IBM and SGS-Thomson should allow for the production of over 5 million 6x86 units this year, some of which will be marketed directly by IBM.

Cyrix needs to find additional capacity during 1996 to support growth, and it needs to track the clock-rate scaling that Dataquest anticipates will drive Intel's Pentium performance throughout the year. If Cyrix meets these goals, it will have earned the opportunity to compete with Intel's future processor generations.

IBM Microelectronics Division's Position in the Microprocessor Market

IBM competes both in the x86 market, in which it uses Cyrix designs, and in the RISC market, in which it uses PowerPC designs that it has created with Motorola. Dataquest estimates that IBM's x86 sales to the merchant market were under $100 million in 1995; less than 1 percent of the overall 32-bit CISC market. We estimate IBM's PowerPC sales at about $525 million (32 percent of the 32-bit RISC market) in the same period.

IBM's x86 programs ride on the coattails of Cyrix's designs and Intel's infrastructure in the x86 market. In both regards, 1996 should be a good year as the Cyrix 6x86 design finally hits its stride and the Intel infrastructure seeks CPU alternatives in the wake of Intel's entry into chipsets and boards. IBM has announced several major fab expansion projects, which should eventually alleviate the capacity constraints that limited its production last year.

IBM's PowerPC programs ride on the coattails of Apple's Macintosh activities, which have lagged noticeably of late. Dataquest anticipates that three major forces may converge to spark PowerPC demand in the second half of 1996. First, the Common Hardware Reference Platform, recently renamed the PowerPC Platform, will enable prospective cloners to build one machine that can be sold into Macintosh environments (the present PowerPC market) and Windows NT environments (the future PowerPC market). Second, Apple must follow through on its threats to open its Macintosh technology to all comers, not just to those posing no threat to Apple. Third, the Windows NT market may finally begin its volume ramp after three years of incubation. It remains for the PowerPC alliance (Apple, IBM, and Motorola) to demonstrate that it can deliver performance and/or value superior to Intel's designs if it is to benefit from Windows NT's emergence as a major platform.

Digital Equipment's Position in the Microprocessor Market

Digital Equipment has demonstrated performance leadership in RISC markets for several years but has little to show for this leadership in merchant chip sales or market share. Dataquest estimates Digital's Alpha sales to be under $40 million in 1995, giving the company less than 3 percent of the 32-bit and greater RISC market.

In the past, weak market share has been the death knell for microprocessor architectures because software developers do not willingly port software to unpopular platforms. Digital's FX!32 x86 emulation technology addresses this problem directly and allows high-end Alpha systems to execute x86-based Windows applications faster than they run on an Intel platform. This technology has been demonstrated but will not be shipped as a product until later this year. If it works as promised, Digital will be the first RISC vendor to demonstrate performance superior to Intel's in both native and x86 emulation modes, and this could provide a key advantage for Digital.

Digital has also placed a major bet on Windows NT, which has developed more slowly than anticipated. As Windows NT acceptance grows, and it appears to be growing dramatically in 1996, this too could boost Digital's fortunes.

Although Alpha has the smallest market share of any microprocessor architecture, Digital does not lack resources, and Digital's FX!32 strategy may make a significant difference. Dataquest sees Alpha as the dark horse in the 1996 microprocessor derby.

Sun Microsystems' Position in the Microprocessor Market

Sun's SPARC architecture lagged in RISC performance for several years, but its recently introduced UltraSPARC design makes up for lost time. UltraSPARC's Visual Instruction Set (VIS) provides an impressive demonstration of the performance benefits that multimedia extensions provide to traditional architectures. (Dataquest anticipates that vendors failing to add such extensions to their own architectures will be at a serious competitive disadvantage in 1997.) Dataquest estimates that SPARC sales amounted to $180 million (11 percent of the RISC market) in 1995.

UltraSPARC should continue to have a good run in the Solaris (UNIX) market, but SPARC lacks an entree into the growing Windows NT market. This omission has not yet affected Sun materially, given the slow rate of market acceptance of Windows NT to date. Dataquest anticipates that as Windows NT gains momentum in 1996, Sun will be at an increasing disadvantage unless it formulates an acceptable response in this regard.

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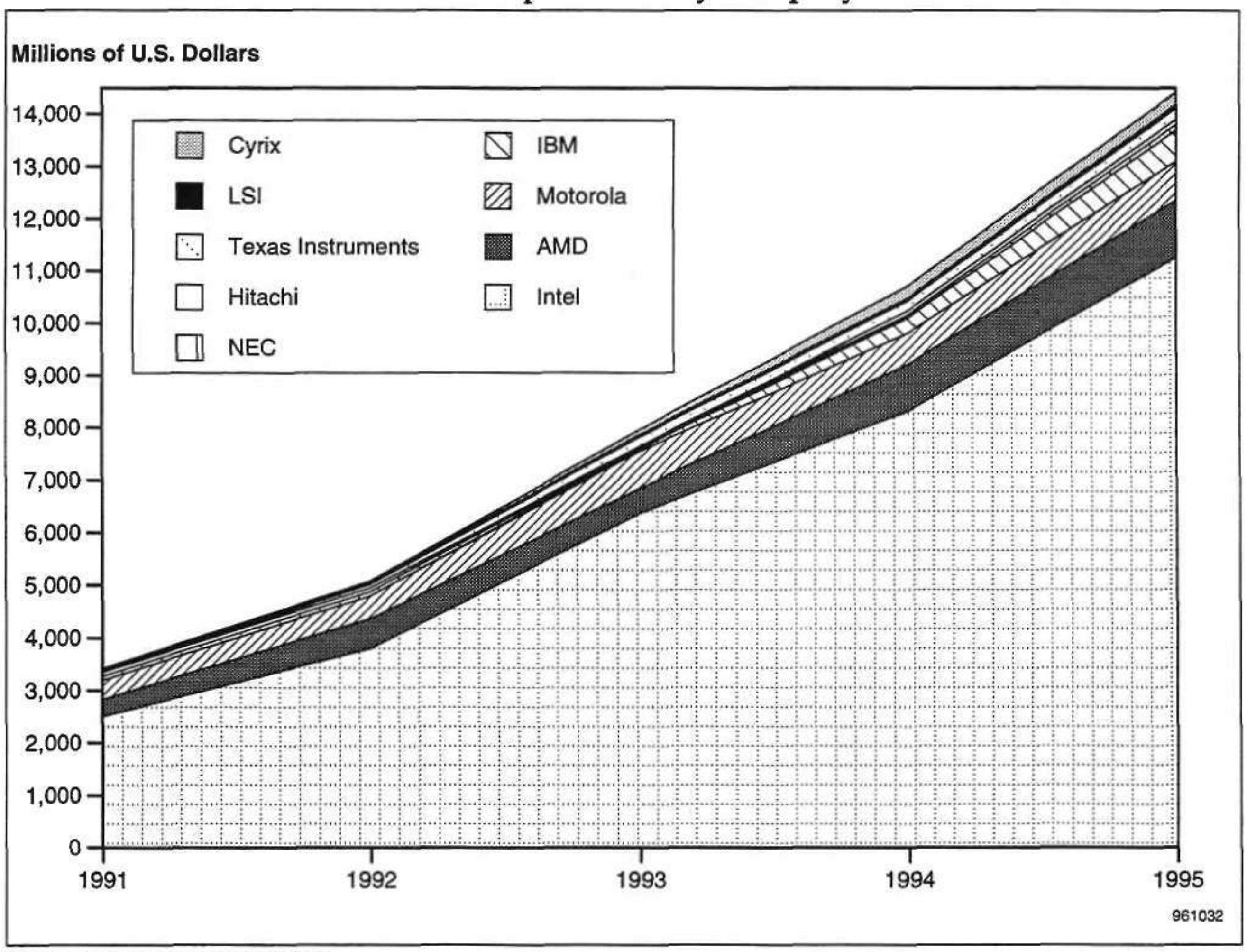

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UMA—A Good Idea Whose Time Has Not Quite Come

Abstract: *A memory architecture known as Unified Memory Architecture (UMA) has come to life for x86 PCs with a flurry of product announcements and a lot of attention from the press. The impact of UMA for 1996 will probably be small, but its prospects will grow as the negative issues are addressed and the positives become stronger through the next two years. This document provides an overview of UMA and its impact on PC design and performance. By Geoff Ballew and Jim Handy*

What Is UMA?

Unified Memory Architecture (UMA) is a means of using a single bank of memory to replace two separate banks of memory in a PC. The recent explosion of articles and product announcements has made UMA one of the latest buzzwords in the PC semiconductor industry. It is not a new idea, having been used in graphics-oriented PCs since Apple's Macintosh, but UMA is getting new attention as a feature for future PCs.

Figure 1 shows a typical PC. There are two memory systems: system memory and graphics memory. The system memory stores the programs the processor executes, as well as the data being processed by the program. Historically, the terms "system memory" and "main memory" have been largely interchangeable because most computers were designed with a split memory architecture. These terms can be misleading when UMA is considered, however. For this article, Dataquest uses "system memory" to denote the portion of the main memory bank that is available to the operating system. System memory is always less than main memory for a UMA PC and equal to main memory for a split-memory architecture. Graphics

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The use of UMA is not so easy, however. The graphics controller and the processor in a UMA design are put into competition with each other for memory bandwidth, a precious resource. If the graphics processor is not allowed to have access to the DRAM exactly when it needs it, the display will appear to have really bad static. Little dots and lines will jump around all over the screen. Since the graphics controller cannot be prevented from using the bus at any time, the processor must be forced to take a back seat every time its needs conflict with those of the graphics controller. The net result is that the processor must frequently wait for access to the system memory, rather than having first priority.

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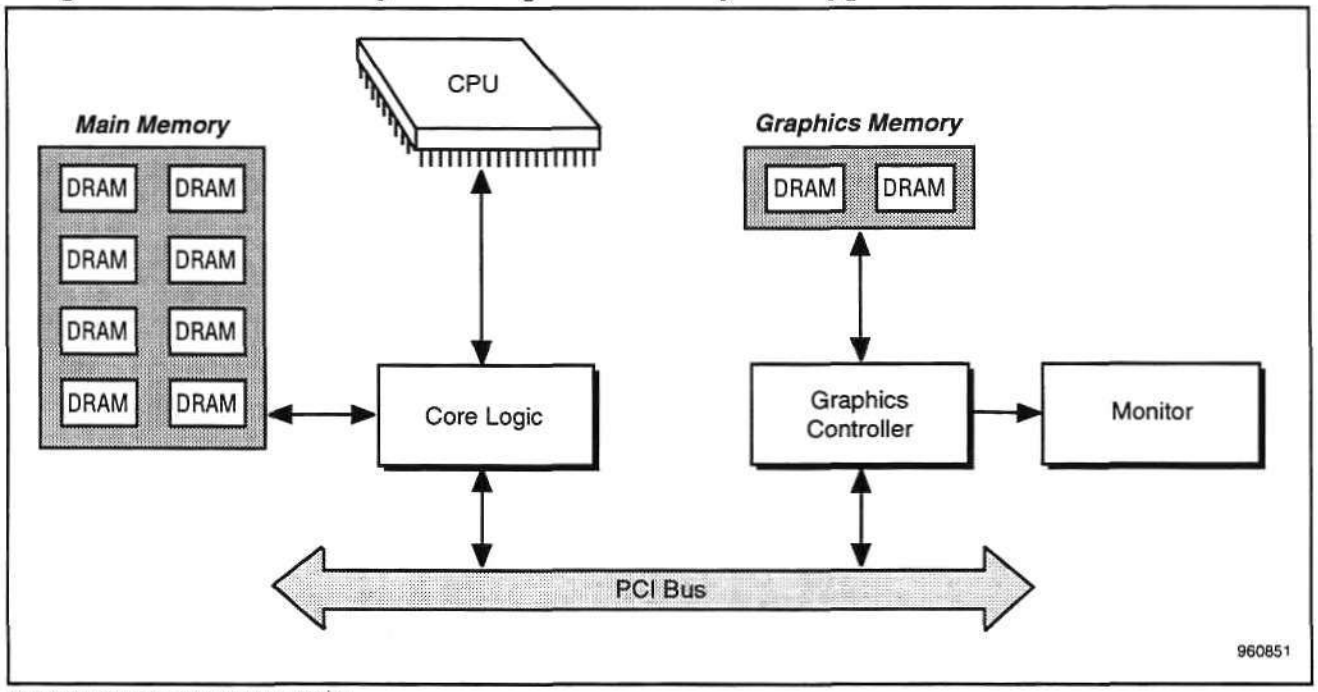

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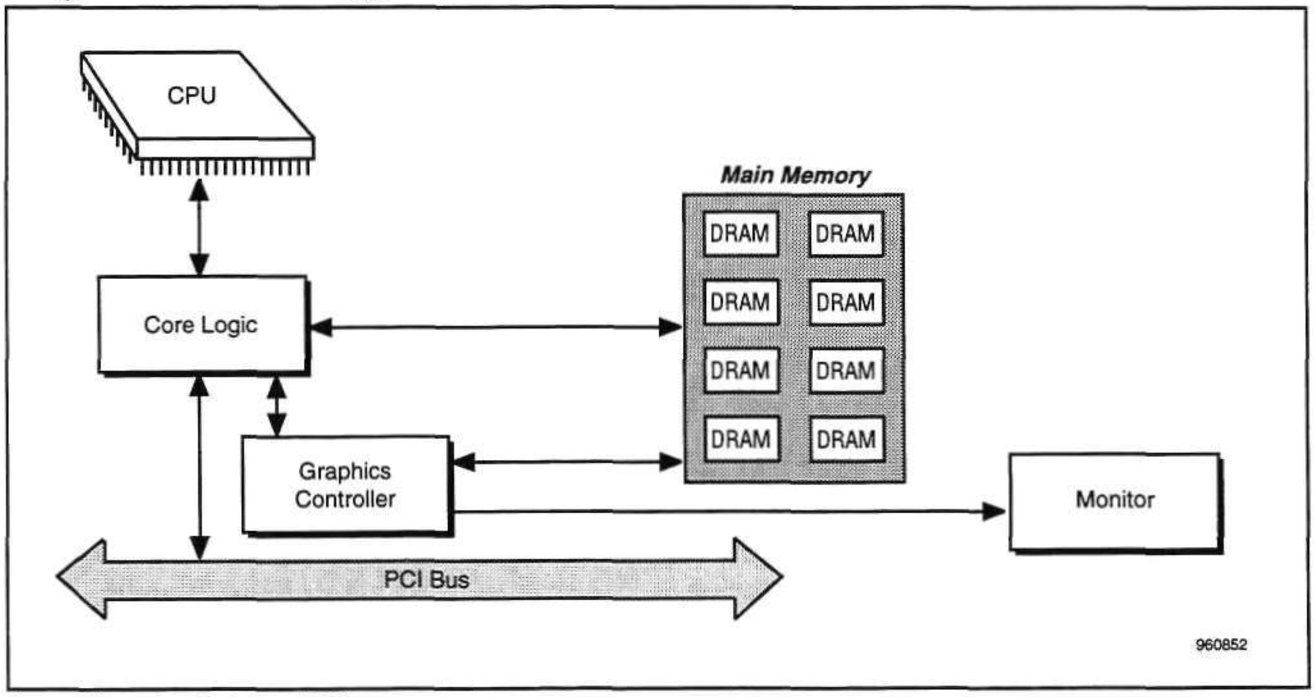

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UMA Looks Better as Time Marches On

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Dataquest
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Perspective

Semiconductor Directions in PCs and PC Multimedia Worldwide

Dataquest Predicts

UMA—A Good Idea Whose Time Has Not Quite Come

Abstract: *A memory architecture known as Unified Memory Architecture (UMA) has come to life for x86 PCs with a flurry of product announcements and a lot of attention from the press. The impact of UMA for 1996 will probably be small, but its prospects will grow as the negative issues are addressed and the positives become stronger through the next two years. This document provides an overview of UMA and its impact on PC design and performance.*
By Geoff Ballew and Jim Handy

What Is UMA?

Unified Memory Architecture (UMA) is a means of using a single bank of memory to replace two separate banks of memory in a PC. The recent explosion of articles and product announcements has made UMA one of the latest buzzwords in the PC semiconductor industry. It is not a new idea, having been used in graphics-oriented PCs since Apple's Macintosh, but UMA is getting new attention as a feature for future PCs.

Figure 1 shows a typical PC. There are two memory systems: system memory and graphics memory. The system memory stores the programs the processor executes, as well as the data being processed by the program. Historically, the terms "system memory" and "main memory" have been largely interchangeable because most computers were designed with a split memory architecture. These terms can be misleading when UMA is considered, however. For this article, Dataquest uses "system memory" to denote the portion of the main memory bank that is available to the operating system. System memory is always less than main memory for a UMA PC and equal to main memory for a split-memory architecture. Graphics

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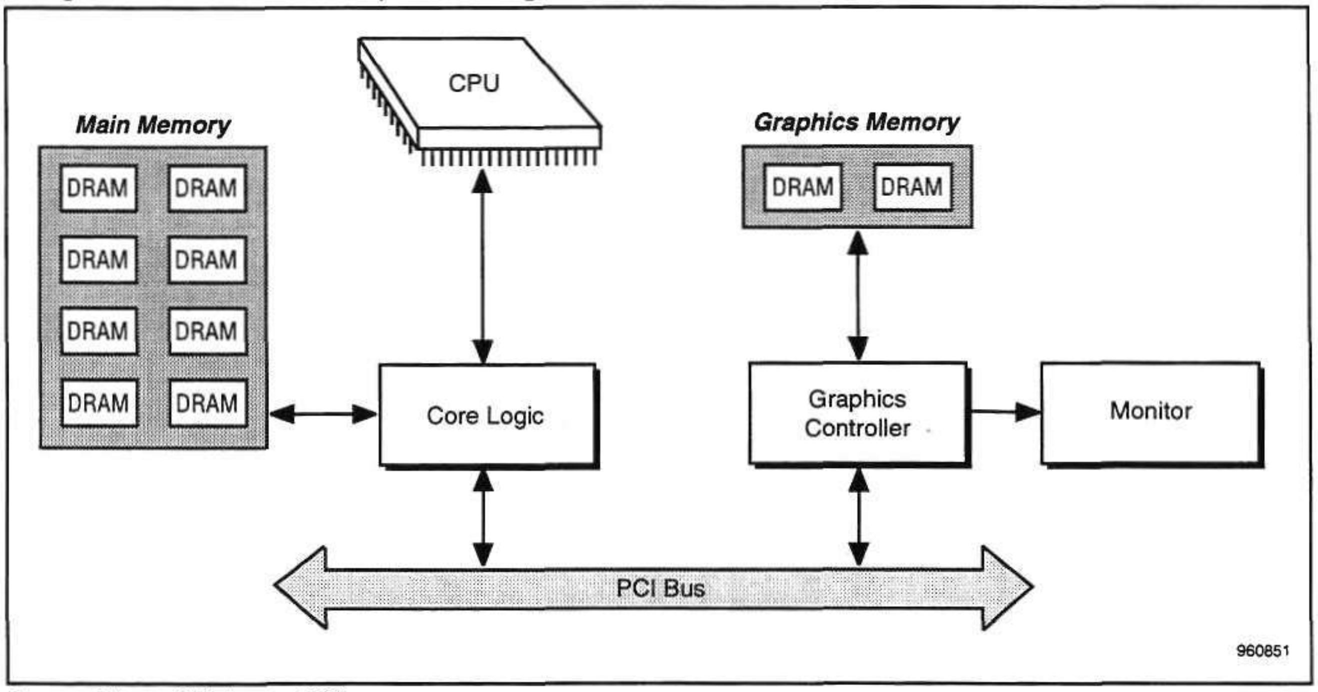

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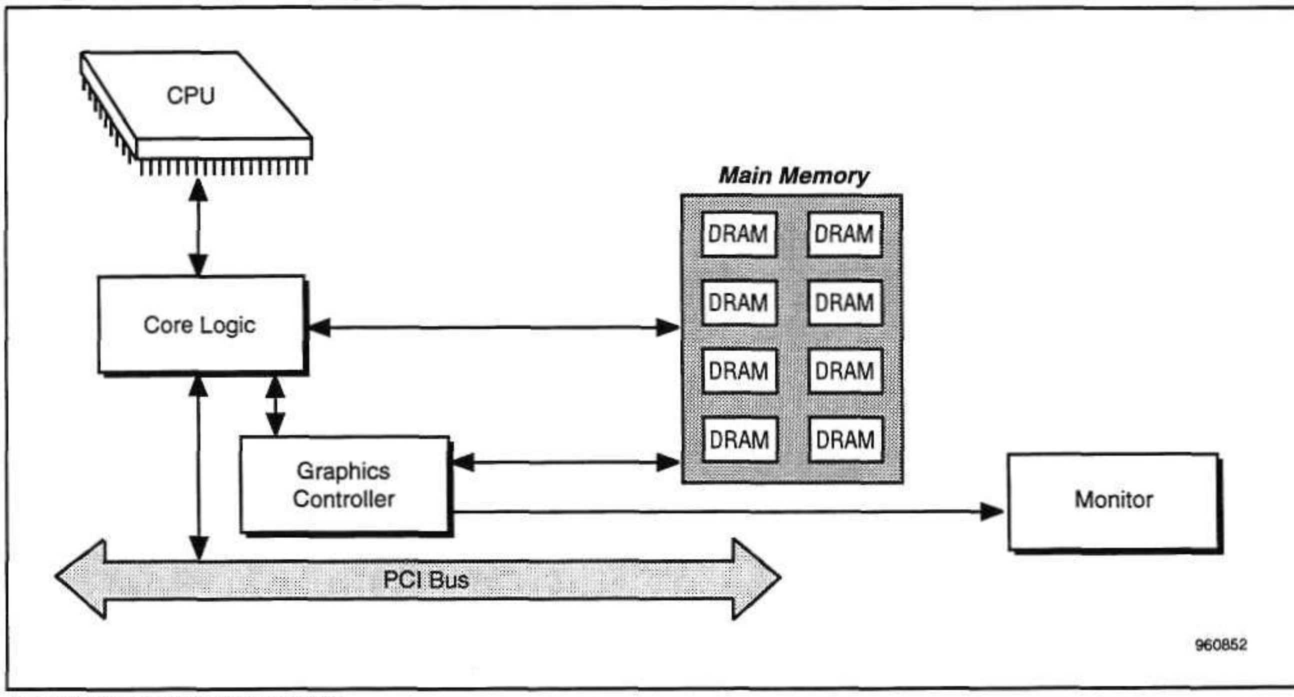

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Dataquest
A Gartner Group Company

Perspective

Semiconductor Directions in PCs

Technology Analysis

Digital Video on PCs Is Getting Better and Cheaper

Abstract: *Digital video on PCs is changing. New graphics controllers and faster MPUs are making advanced digital video features more economical as well as easier to design onto motherboards and add-in cards. As digital video features become standard on PCs, graphics vendors are growing into multimedia vendors. These vendors are introducing new products to tackle the video processing bottlenecks head-on. For product purposes, digital video features are being segmented into two major groups: video acceleration and video decompression. This document highlights industry trends in the graphics market and provides an overview of why video compression is so important.*
By Geoff Ballew

Graphics Vendors Are Becoming Multimedia Vendors

Increasing demand for digital video on PCs, combined with the relatively poor performance of digital video, is driving graphics vendors to broaden their horizons. Graphics subsystems are growing into multimedia subsystems that process graphics, digital video, and sound. These functions are becoming tightly knit as consumers demand better digital video performance from their PCs. Historically, graphics and digital video have been separate markets, each with a different list of semiconductor vendors. The leap from graphics or video to a combination of both is not trivial. Figure 1 shows the major bottlenecks in playing digital video on a PC.

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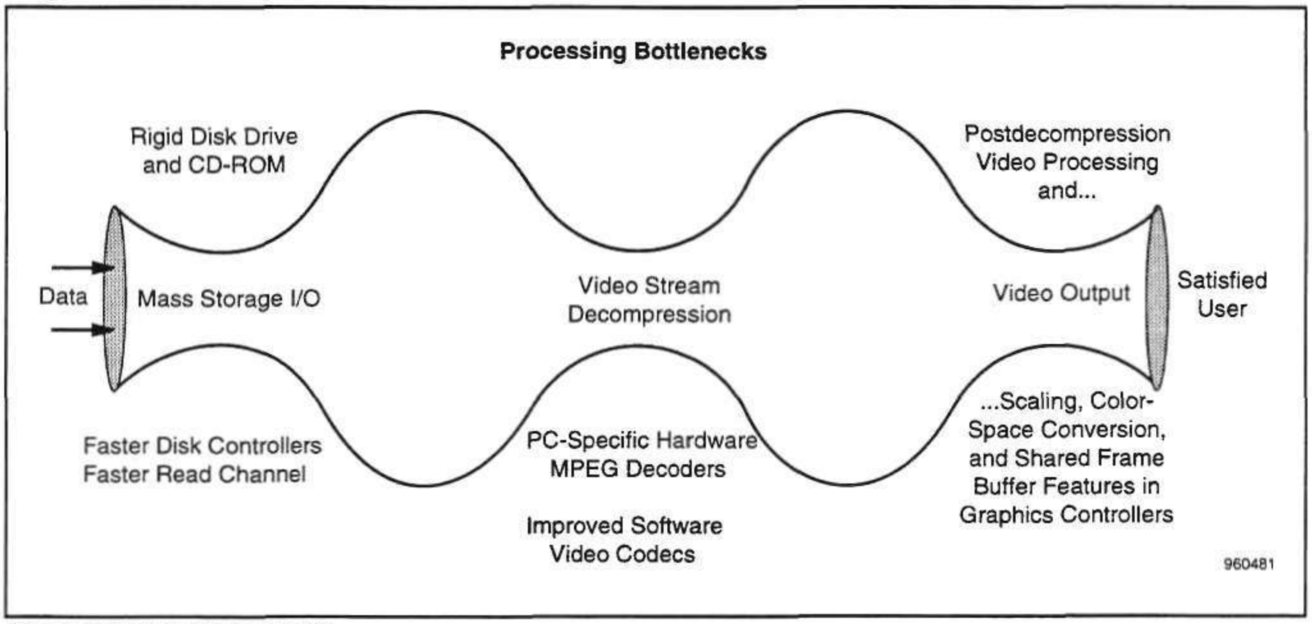
Figure 1
Digital Video Bottlenecks in PCs



Source: Dataquest (January 1996)

The good news is that leading PC graphics companies are addressing two of the three bottlenecks: digital video acceleration and decompression. (Disk I/O bandwidth is the third bottleneck and is also being addressed, but that discussion is beyond the scope of this document.) To make this transition manageable, graphics vendors have divided the problem into two parts. Two key trends punctuate these changes: Most new graphics controllers have video acceleration features, and the traditional graphics vendors are introducing hardware codecs with standard PC interfaces.

Graphics Controllers Get Digital Video Features

Most graphics vendors have now added digital video acceleration features to their graphics controllers. The new features were chosen to provide the greatest performance gains possible while minimizing the impact on cost. Three common features are scaling, color space conversion, and the ability to use the graphics buffer for both RGB and YUV data. These two standard color encoding schemes are described later in this document under the subheading "Data Formats." Graphics controllers are the logical location for these features because they are useful whether the user has additional digital video hardware or not. By integrating these features onto the graphics controller, chip vendors have added a lot of value without a big increase in cost. The quality of these features in standard graphics controllers is lower than in dedicated video chips, but the gap is closing.

Image scaling features in graphics controllers allow the image resolution to be increased for viewing, even though the resolution of the stored image is lower. Interpolation and filtering are important features for maximizing quality as images are scaled. Otherwise, blockiness from large pixels and color banding become more noticeable. Color banding is a common image defect in which a color intended to change gradually, such as a blue sky changing from light to dark, appears instead as large stripes that change abruptly. Bidirectional scaling is important, but scaling an image to a higher resolution is more common than scaling to a lower resolution.

Color-space conversion is a key feature because digital video is usually encoded in some variation of YUV format. The YUV digital video stream must be converted to RGB format before going through the RAMDAC and out to the display. However, the YUV formats commonly used in PCs, 4:2:2 and 4:2:0, are more compact than standard 24-bit RGB format, so it is beneficial to leave the digital video data in YUV format until it is ready to be displayed.

The third common feature is the ability to share the graphics memory between RGB data and YUV data. Most PCs do not use the entire frame buffer for graphics, so the unused memory can be used for digital video data. This reduces the need for additional graphics memory beyond the standard 1MB, although the total amount of graphics memory required depends on color depth and resolution. Only graphics controllers with color-space conversion capabilities can use the shared frame buffer feature. The largest benefit to system OEMs is simply keeping costs at a minimum. The ability to share the existing graphics memory reduces the need to install additional memory in the system. Without this feature, graphics subsystems may need additional memory for the digital video acceleration functions. That increased cost is unacceptable to many PC OEMs, so shared memory is effectively a required feature.

The combination of a graphics controller with these digital video acceleration features and a midrange (100-MHz or faster) Pentium for software video decompression provides compelling, yet inexpensive, digital video playback capabilities on a PC. The biggest threat to the hardware decompression market may very well be the combination of these features with faster and faster MPUs. Dataquest expects that this combination will render hardware decompression unnecessary for most PC users.

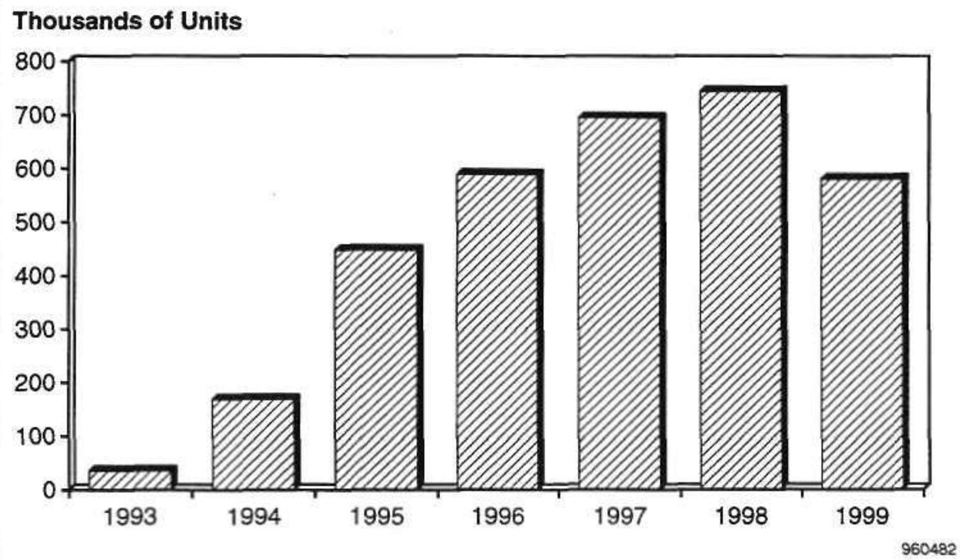
Graphics Vendors Are Making Video Codecs

Many graphics vendors are introducing hardware video codecs to complement their traditional graphics products. These companies are leveraging their expertise in PC semiconductors to create MPEG decoders tailored specifically for the PC market. The new chips are designed to work cooperatively with graphics controllers and have glueless interfaces to standard PC buses such as PCI, ISA, and VAFC as well as proprietary interfaces to graphics controllers from the same vendor. Two examples of vendor-specific interfaces are Cirrus Logic's V-Port and S3's Scenic Highway.

These new MPEG decoders are making playback boards less expensive than previous designs by eliminating the glue logic and bus interface chips. However, the question is whether or not they are reducing costs sufficiently to drive higher market growth. Hardware MPEG decoders are overwhelmingly an add-in card market because PC OEMs are reluctant to burden their motherboards with the added cost of these chips. In 1995, Compaq and IBM introduced PCs with MPEG decoders on the motherboard, but both companies now appear to be moving back to an add-in card strategy.

Dataquest believes that the digital video board market for hardware decompression is growing steadily but remains a niche market. Interestingly, this market is divided between users of high-end and low-end PCs. Some users of high-end PCs will find software video decompression inadequate and will pay for the extra performance and higher quality of a hardware codec. Also, some users of relatively low-end PCs (all 486s and possibly Pentiums of 75 MHz or slower) may choose to buy a digital video board rather than upgrade to a faster machine. Users with those machines may not be happy with the performance of software codecs and are potential buyers of dedicated hardware. Figure 2 shows Dataquest's forecast for digital video boards.

Figure 2
Forecast for Digital Video Boards with Hardware Decompression



Note: The 1994-to-1999 compound annual growth rate is 5.3 percent.
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Note that the unit shipments of digital boards with hardware decompression are projected to grow at 28 percent from 1994 to 1999, which exceeds the 20 percent unit growth for PCs. This digital video board market is expected to peak during that period, with some market contraction in 1999. Dataquest believes that software video decompression will meet the requirements of most PC users, leaving only the high end of the market for hardware decompression, with relatively low prospects for growth after the next few years. The competition from software solutions will prevent boards with hardware decompression from breaking the million-unit mark. Hardware decompression is not expected to migrate onto the motherboard, so implementations will be either software solutions or add-in cards.

Why Is Video Compression So Important?

Video compression is an absolute necessity for delivering digital video to PCs. The surprisingly high data rate of broadcast TV may be the biggest problem for displaying comparable digital video on a PC. For example, full resolution of the CCIR-601 standard at 30 frames per second (fps) is 720 x 480 active pixels. If every pixel is sampled and digitally encoded in a YUV 4:4:4 format with 8-bit resolution each for Y, U, and V, the data rate is a shocking 29.7 MB/sec. (YUV 4:4:4 format is a standard for digital video information, which stores complete information about every single pixel.) This high data rate is a problem because of capacity and transfer rates of mass storage devices. If digital video is recorded onto a CD-ROM disk at 30 MB/sec, that disk would hold less than 30 seconds of information. Transfer rates are another limiting factor; rigid disk drives typically have sustained transfer rates of 2 MB/sec to 5 MB/sec, and CD-ROM drives are typically 150 KB/sec to 600 KB/sec. Obviously, these common mass storage solutions cannot begin to deliver uncompressed digital video at full resolution and color depth.

The challenge for compression is to reduce the 30 MB/sec video data stream to the sustainable transfer rate for a typical CD-ROM drive. For the purpose of this example, assume that the sustainable transfer rate for a CD-ROM drive is 150 KB/sec, which is the transfer rate for a single-speed CD-ROM drive and the limiting factor for the Constrained Parameters Bitstreams conformance point for MPEG-1. For full-screen, full-color digital video to be delivered by this CD-ROM drive, the data must be compressed by a factor of 200. Current compression standards cannot achieve that level of compression in a single pass, so a combination of methods must be used. These methods fall into two general categories, video image compression and subsampling. Subsampling can be considered a compression method but is discussed separately for the purposes of this document to distinguish between simply discarding information versus mathematically compressing information.

Video Image Compression

Video image compression relies on a high degree of redundancy from one frame to the next. The overall idea is simply to encode changes to a reference frame rather than storing all of the information for each frame. MPEG is discussed here to illustrate some of the mechanics of video image compression.

MPEG encoding includes a mixture of three different types of frames known as I, B, and P. I frames, also known as intraframes, are reference frames. They contain the most information and are quite similar to a compressed JPEG image. B and P frames must be compared to other frames for reconstruction. P frames are reconstructed in relation to a previous frame. B frames can be constructed from previous frames, subsequent frames, or a combination of the two. Because some B frames are reconstructed in relation to subsequent frames, frame information is sometimes stored out of order. For example, assume the second frame of a video sequence is encoded in relation to both the first and the third frames. Then both the first and third frames must be reconstructed before it is possible to reconstruct the second frame.

This level of flexibility means that a single video stream may be encoded differently by hardware from different vendors, resulting in variable quality and compression ratios. The MPEG standard does not rigidly define the encoding techniques nor does it define the frame sequences; it does define the data syntax within frames.

Subsampling

One method of reducing bandwidth requirements is simply to discard some of the information. This is known as subsampling. Discarding data is simple, but discarding data without significantly degrading image quality is more difficult. The missing data may have a large impact on image quality. Some very simple techniques for discarding data are reducing the image resolution and frame rate and using different data formats.

Resolution and Frame Rate

Digital video on PCs is usually delivered at a much lower resolution and frame rate than full CCIR-601. Full CCIR-601 is 720 x 480 active pixels at 30 fps and requires bandwidth of almost 30 MB/sec. The amount of data in a video stream can be significantly reduced by using a lower frame rate, lower resolution, or both. The data requirements scale linearly with the frame rate but exponentially with resolution. For example, reducing the frame rate from 30 fps to 15 fps cuts the data stream in half, but reducing the resolution from 720 x 480 to 360 x 240 cuts the data stream by 75 percent because the pixel count is reduced by 75 percent. The most common resolution and frame rate for digital video on PCs are 320 x 240 pixels at 30 frames per second, which is part of the Constrained Parameters Bitstreams conformance point for MPEG-1.

During playback of digital video, the frame rate may be artificially reduced if the system hardware cannot process the video stream quickly enough. Relatively few PCs today have hardware decompression chips; most rely on software codecs running on the host CPU. When digital video clips are played on these machines, video frames are often dropped unless the CPU is a 100-MHz Pentium or faster.

Data Formats

Fortunately, the human eye is more sensitive to small changes in brightness than small changes in hue or color. This means that some data points are more valuable than others for judging image quality by standards of human perception. As a result, some data formats are more suitable for compression than others. Two popular standards, RGB and YUV, are discussed here.

RGB Format

RGB format stores the combined chrominance, or color, and luminance, or brightness, values for each of three colors (red, green, and blue). Unfortunately, this combines the most valuable data (luminance) with less valuable data (chrominance), which makes it difficult to discard the chrominance data alone. Subsampling options are essentially limited to dropping complete pixels, so RGB is not commonly used for storing digital video on PCs.

RGB is important for playing digital video on PCs because most computer monitors are driven with an analog RGB signal. Graphics are stored in the frame buffer in digital RGB and converted to analog RGB by the RAMDAC before being displayed on the screen. If digital video is stored in the graphics buffer in YUV format, then it must be converted to digital RGB before it is passed through the RAMDAC.

YUV Format

YUV stores the luminance data of the pixel separately from the chrominance data. This separation of the luminance and chrominance data makes YUV data much more convenient than RGB for discarding data while minimizing the impact on image quality. YUV may also be written as YCrCb. Cr is short for *chrominance red* and Cb is short for *chrominance blue*. These two formats carry the same amount of information but are not identical. U and V do not equal Cr and Cb but are, in fact, different by the value of Y. Specifically, U = Cr-Y and V = Cb-Y. For these formats, there is no green component as there is in an RGB format. The green component in YUV must be calculated from a formula that defines Y as a combination of the red, green, and blue values.

One subsampling technique used with YUV format is known as 4:2:2. It essentially means that the luminance of every pixel is recorded, but actual color is recorded for only half of the pixels. This reduces the total information recorded by 33 percent, because both U and V are chrominance data, while Y is the luminance data. The data sequence for two pixels then becomes YYUV, or 4 bytes of data, rather than YUVYUV, or 6 bytes of data. See Figure 3 for a graphical representation of these two encoding schemes.

Other encoding schemes for YUV data include 4:1:1 and 4:2:0, which offer more substantial reductions in data rate than 4:2:2. These two schemes reduce the data rate by discarding even more data points. The 4:1:1 encoding scheme stores the luminance data for every pixel but stores the chrominance data for only one-quarter of the pixels. The 4:2:0 encoding scheme breaks the mold, because it does not store the chrominance data for any single pixel. It does store the average chrominance of a 2 x 2 block of pixels. See Figure 4 for a graphical representation of these two encoding schemes.

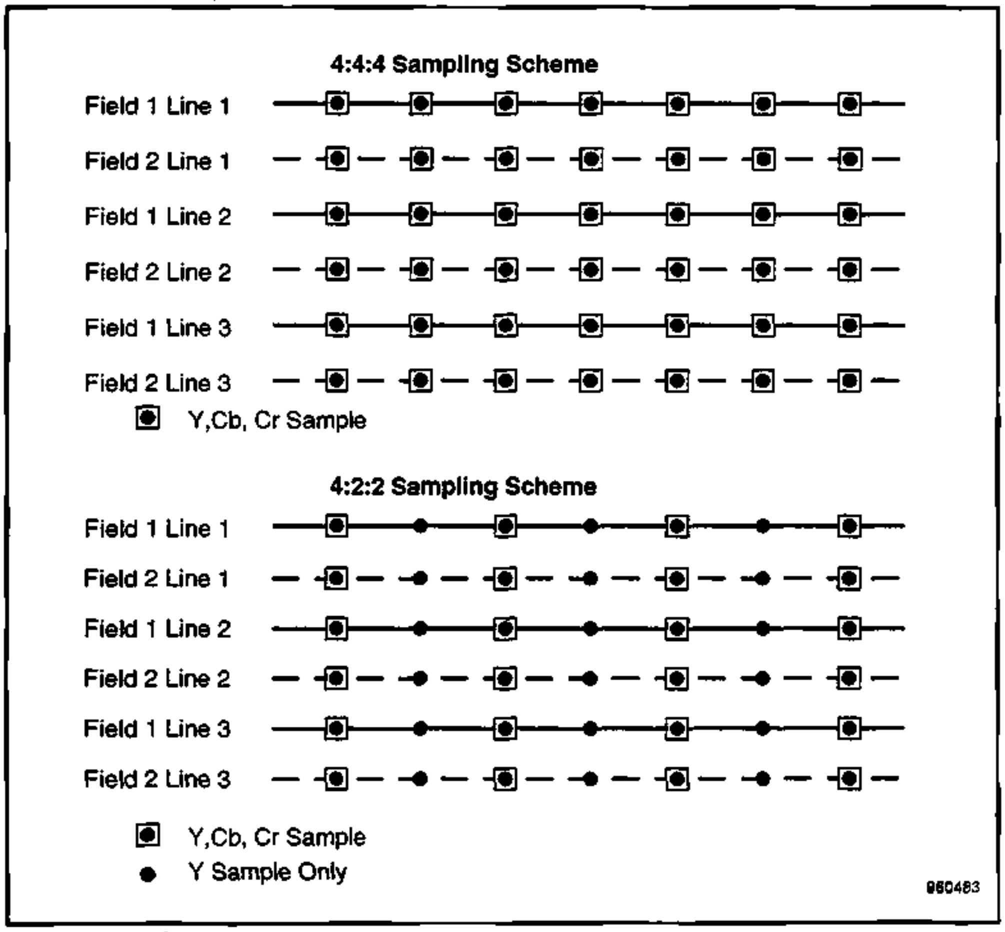
Table 1 shows the actual data rates necessary to support each of these four variations of YUV encoding.

As Table 1 shows, common data formats for YUV can reduce the required bandwidth by 25 percent or 50 percent. These different encoding methods are effectively different subsampling techniques and are designed to balance the trade-off between data rate and image quality.

Dataquest Perspective

The graphics market is evolving into a multimedia market. Demand for digital video on PCs is driving digital video functions and some audio functions into what has traditionally been the graphics subsystem. As this transition continues, Intel is pushing microprocessors to new price/performance heights. Semiconductor vendors in the PC graphics market should consider these trends when adjusting their product strategies.

Figure 3
Two Sampling Variations of Digital YUV Data

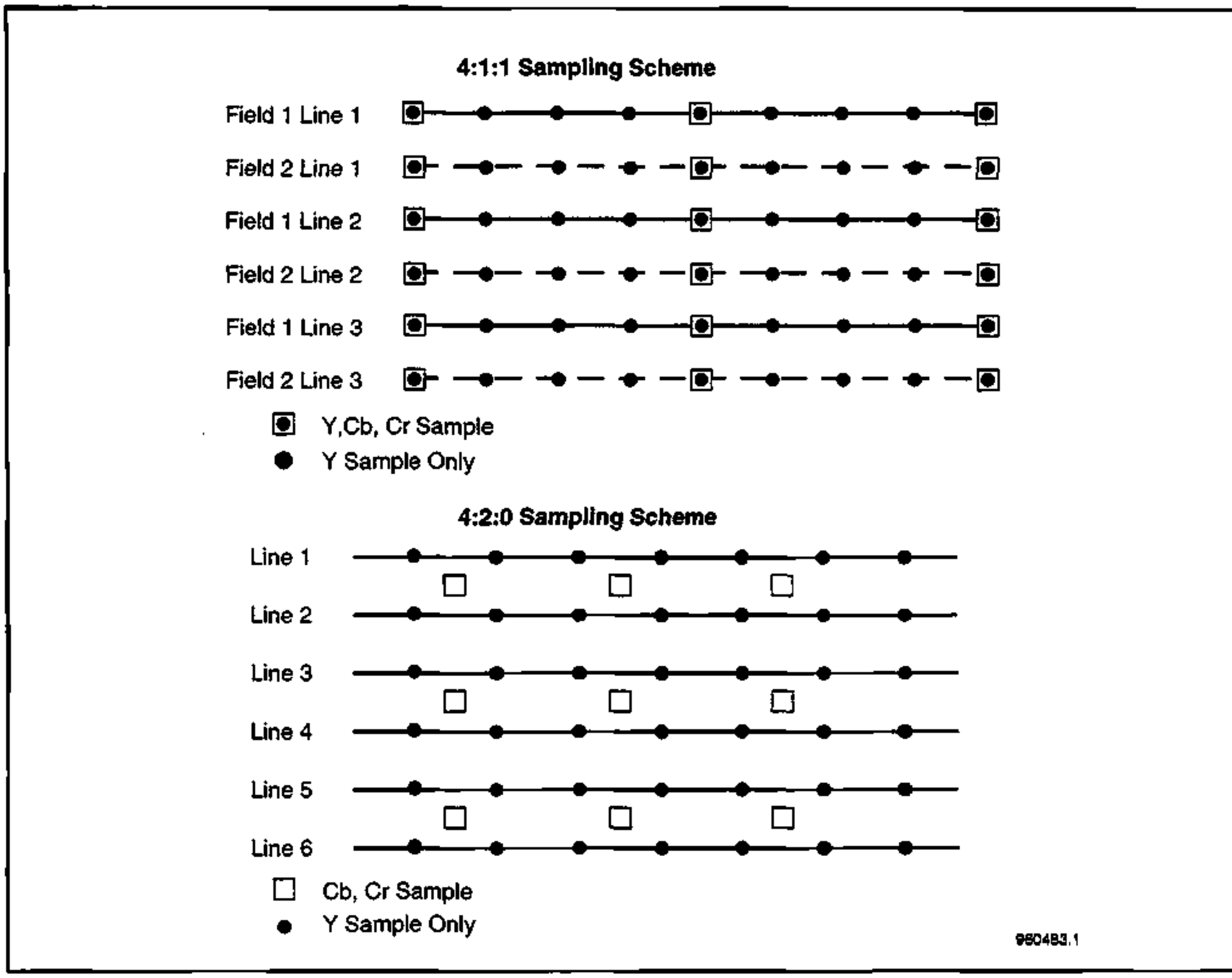


Source: Philips Semiconductors

Graphics vendors are advised to enhance the digital video acceleration features in their graphics controller products. These features are complementary to both hardware and software video decoders, and their quality level has a strong impact on video playback quality. Digital video acceleration is rapidly becoming a de facto feature of graphics controllers targeted at both the business and consumer PC markets.

As for hardware codecs, semiconductor companies developing new products for hardware video decompression in PCs may want to re-evaluate the market opportunity. The market for hardware decompression boards in PCs is expected to grow moderately to a volume of 744,000 units per year by 1998. That relatively low unit forecast, compared with the market opportunity for graphics controllers, may make hardware codecs low-profit or no-profit products for many vendors. The hardware codec market for consumer equipment such as set-top boxes and digital video discs presents a different opportunity but will demand different levels of integration.

Figure 4
Two Additional Sampling Variations of Digital YUV Data



Source: Philips Semiconductors

Table 1
Data Rates for Four YUV Sampling Schemes

Format	Sequence for Four Pixels	Data Rate (MB/sec)	Bandwidth Reduction Compared with 4:4:4 (%)
4:4:4	YYYYUVUVUVUV	6.6	0
4:2:2	YYUVYYUV	4.4	25
4:1:1	YYYYUV	3.3	50
4:2:0	YYYYUV	3.3	50

Note: Image parameters are 320 x 240 pixels and 30 frames per second with 8-bit resolution for each of Y, U, and V.
Source: Dataquest (January 1996)

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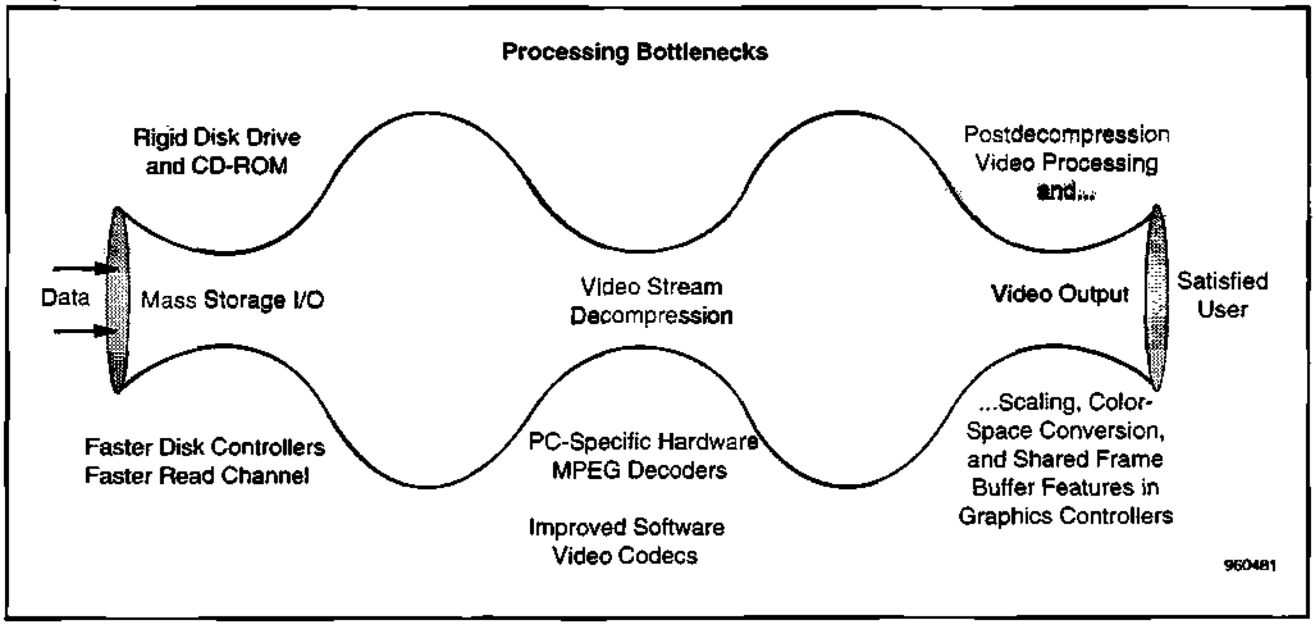

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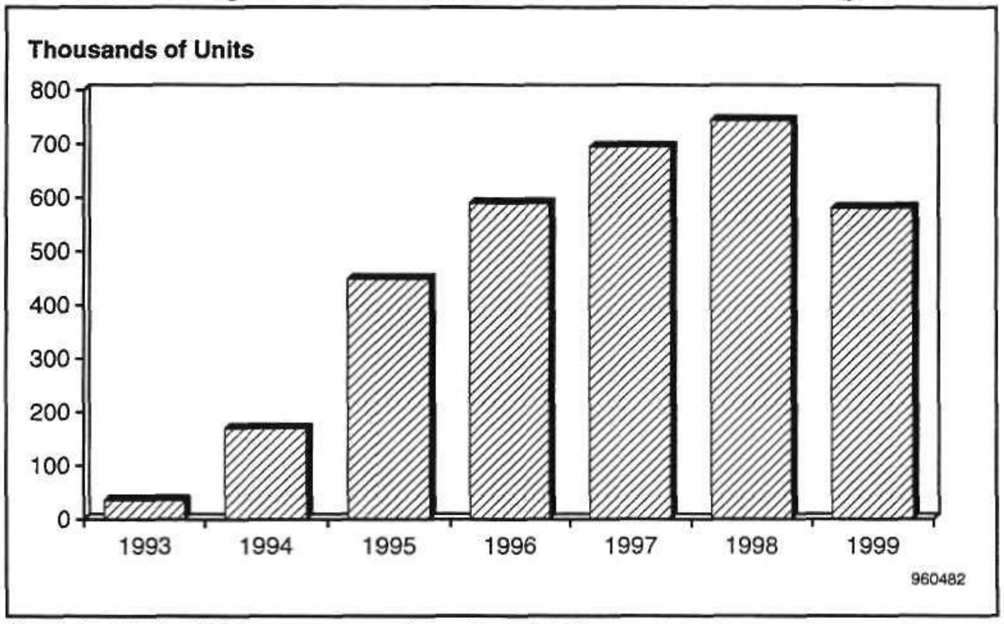

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Data Formats

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YUV Format

YUV stores the luminance data of the pixel separately from the chrominance data. This separation of the luminance and chrominance data makes YUV data much more convenient than RGB for discarding data while minimizing the impact on image quality. YUV may also be written as YCrCb. Cr is short for *chrominance red* and Cb is short for *chrominance blue*. These two formats carry the same amount of information but are not identical. U and V do not equal Cr and Cb but are, in fact, different by the value of Y. Specifically, U = Cr-Y and V = Cb-Y. For these formats, there is no green component as there is in an RGB format. The green component in YUV must be calculated from a formula that defines Y as a combination of the red, green, and blue values.

One subsampling technique used with YUV format is known as 4:2:2. It essentially means that the luminance of every pixel is recorded, but actual color is recorded for only half of the pixels. This reduces the total information recorded by 33 percent, because both U and V are chrominance data, while Y is the luminance data. The data sequence for two pixels then becomes YYUV, or 4 bytes of data, rather than YUVYUV, or 6 bytes of data. See Figure 3 for a graphical representation of these two encoding schemes.

Other encoding schemes for YUV data include 4:1:1 and 4:2:0, which offer more substantial reductions in data rate than 4:2:2. These two schemes reduce the data rate by discarding even more data points. The 4:1:1 encoding scheme stores the luminance data for every pixel but stores the chrominance data for only one-quarter of the pixels. The 4:2:0 encoding scheme breaks the mold, because it does not store the chrominance data for any single pixel. It does store the average chrominance of a 2 x 2 block of pixels. See Figure 4 for a graphical representation of these two encoding schemes.

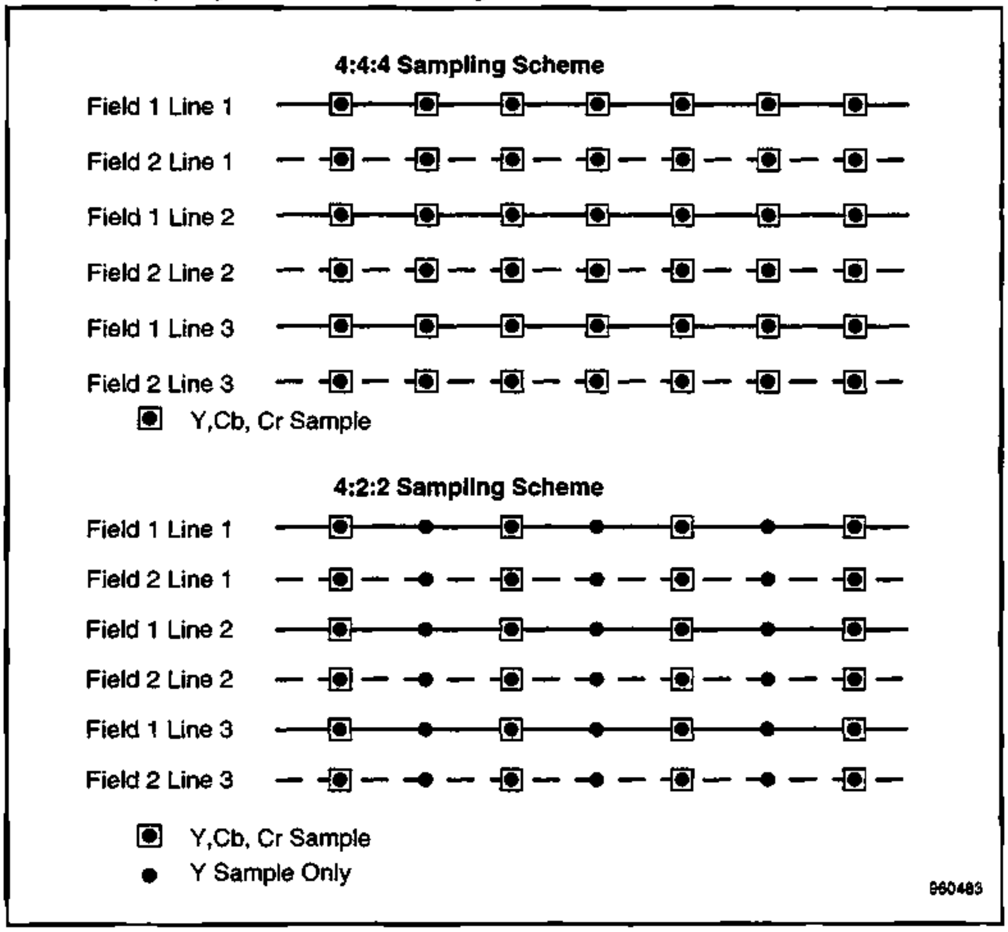
Table 1 shows the actual data rates necessary to support each of these four variations of YUV encoding.

As Table 1 shows, common data formats for YUV can reduce the required bandwidth by 25 percent or 50 percent. These different encoding methods are effectively different subsampling techniques and are designed to balance the trade-off between data rate and image quality.

Dataquest Perspective

The graphics market is evolving into a multimedia market. Demand for digital video on PCs is driving digital video functions and some audio functions into what has traditionally been the graphics subsystem. As this transition continues, Intel is pushing microprocessors to new price/performance heights. Semiconductor vendors in the PC graphics market should consider these trends when adjusting their product strategies.

Figure 3
Two Sampling Variations of Digital YUV Data

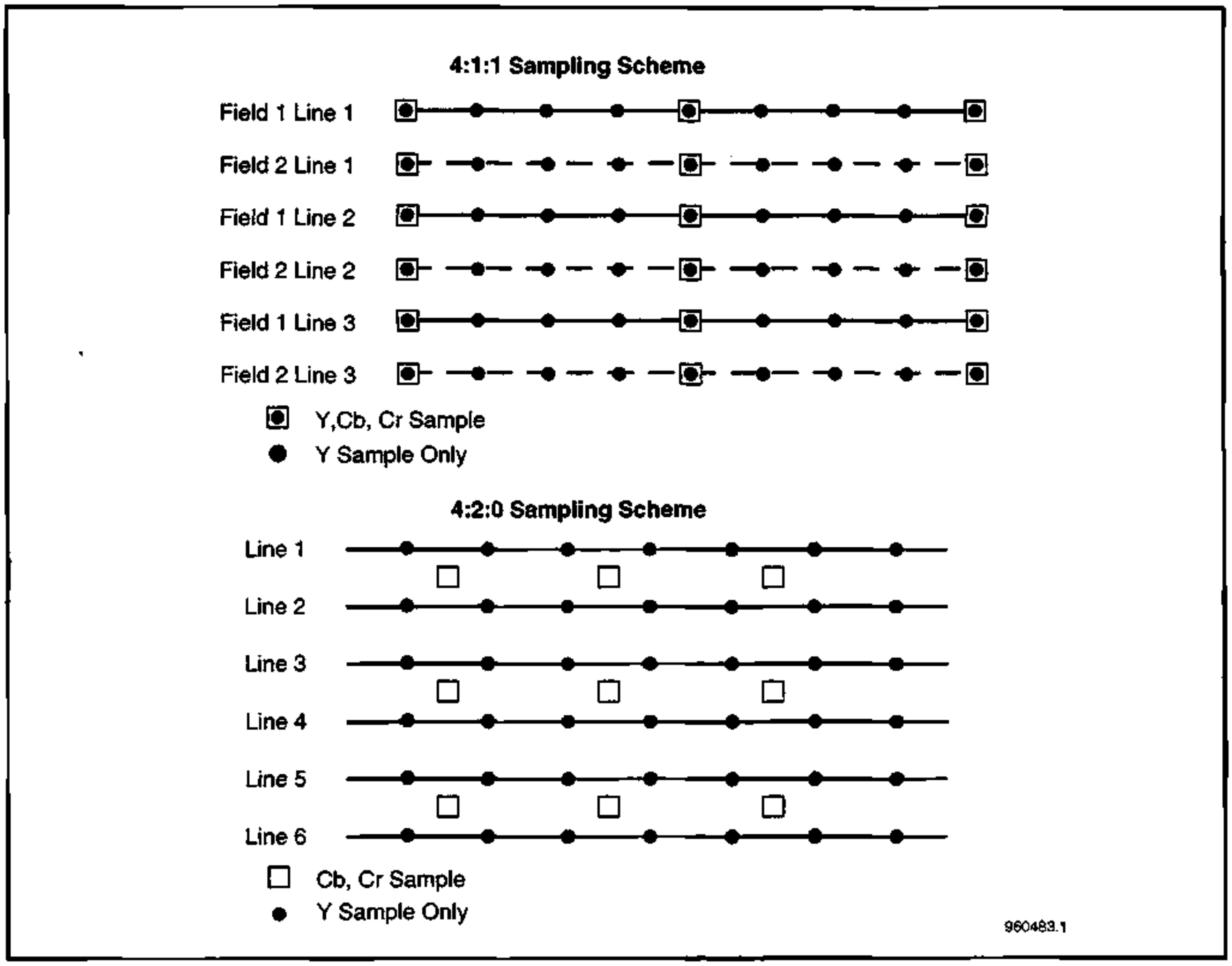


Source: Philips Semiconductors

Graphics vendors are advised to enhance the digital video acceleration features in their graphics controller products. These features are complementary to both hardware and software video decoders, and their quality level has a strong impact on video playback quality. Digital video acceleration is rapidly becoming a de facto feature of graphics controllers targeted at both the business and consumer PC markets.

As for hardware codecs, semiconductor companies developing new products for hardware video decompression in PCs may want to re-evaluate the market opportunity. The market for hardware decompression boards in PCs is expected to grow moderately to a volume of 744,000 units per year by 1998. That relatively low unit forecast, compared with the market opportunity for graphics controllers, may make hardware codecs low-profit or no-profit products for many vendors. The hardware codec market for consumer equipment such as set-top boxes and digital video discs presents a different opportunity but will demand different levels of integration.

Figure 4
Two Additional Sampling Variations of Digital YUV Data



Source: Philips Semiconductors

Table 1
Data Rates for Four YUV Sampling Schemes

Format	Sequence for Four Pixels	Data Rate (MB/sec)	Bandwidth Reduction Compared with 4:4:4 (%)
4:4:4	YYYYUVUVUVUV	6.6	0
4:2:2	YYUVYYUV	4.4	25
4:1:1	YYYYUV	3.3	50
4:2:0	YYYYUV	3.3	50

Note: Image parameters are 320 x 240 pixels and 30 frames per second with 8-bit resolution for each of Y, U, and V.
Source: Dataquest (January 1996)

Qty: 1

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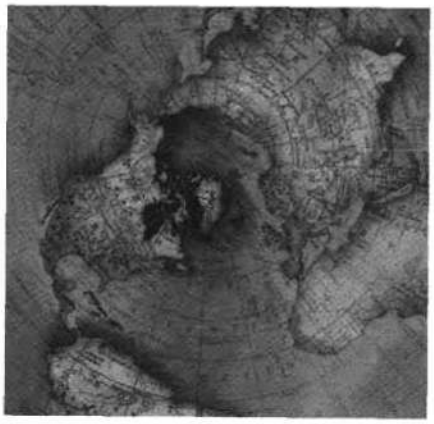
Market Trends

Dataquest



Dataquest

Compute Microprocessor Market Trends and Forecast

Market Trends

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-MT-9604
Publication Date: September 2, 1996
Filing: Market Trends

Compute Microprocessor Market Trends and Forecast

Market Trends

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Table of Contents

List of Figures

List of Tables

Chapter 1
Executive Summary

The worlds of compute and embedded microprocessors continued to drift further apart in 1995. Revenue of x86 compute microprocessors increased 24 percent to $11.5 billion on a 25 percent increase in unit volumes, driven by an overheated personal computer market, as consumers rushed to add on-ramps for the information superhighway. Unit shipments of PowerPC microprocessors increased almost 70 percent, but revenue grew only 54 percent, as the major consumer of PowerPCs (Apple) played its suppliers against one another. Even this clever purchasing activity did not prevent Apple from reporting a vast loss, throwing the future of the company, the Macintosh, and (indirectly) the PowerPC into some doubt.

Although suppliers of compute microprocessors sold only 30 percent of all microprocessor units last year, they collected 88 percent of all MPU revenue. To accomplish this, they charged over 16 times more for their average chip ($177) than embedded vendors charged for their average device ($11). The lion's share (93 percent) of compute microprocessors are compatible with Intel's x86 architecture and run programs engineered for that standard. This has proven to be an insurmountable barrier for vendors offering architectural alternatives claimed to be superior to, but incompatible with, the x86 standard. Vendors that adopt the x86 standard for their own designs must outengineer, outmanufacture, and out-market Intel, and this too has proven to be a difficult undertaking, at best. Dataquest believes that the economic benefits that accrue to successful vendors in this market are too great to ignore and expects to see a continual series of challengers to Intel in future years.

The complex-instruction-set computing (CISC) approach to processor design encompasses most computer architectures developed before 1980 or their direct descendants. Early microprocessors, based on this design approach, got a head start in amassing a software base and have held onto that lead. The Intel x86 and Motorola 68000 have become so numerous that they dwarf everything else in the market. Apple remained the last and most important user of computational 68000s, and its conversion to the PowerPC, which will largely be complete by the end of 1996, marks the end of the 68000's life in computational markets.

Intel dominates the narrow world of compute microprocessors. Its aggressive pricing of Pentium processors, along with its aggressive advertising to end users and its aggressive rollout of new products, drove the market and kept its factories humming, even as they transitioned from 0.6-micron to 0.35-micron manufacturing processes, shrinking die size and increasing performance while lowering per-unit costs. Late in the year, Intel rolled out its Pentium Pro line, which offers impressive performance when used with 32-bit applications under Windows NT and somewhat less impressive performance in combination with 16-bit applications and Windows 3.1 or Windows 95. Intel's principal x86 competitors, Advanced Micro Devices and Cyrix Corporation, were unable to capitalize on this rare opportunity to gain a product advantage over Intel, as they encountered delays in their own development programs for Pentium- and Pentium Pro-class products.

Intel refused to give its RISC-based competitors any chance to catch their collective breath. Its Pentium Pro closes and, in some cases, eliminates the performance gap between personal computers and workstations and thus places increased price and margin pressure on vendors of the latter class of products. This pressure will only increase in 1996 and 1997 as new personal computer architectural initiatives for enhanced I/O performance and 3-D computing enter the market. The PowerPC, often considered the principal challenger to the x86 compute monopoly, lost much momentum because its proponents were unable to match Intel's aggressive scaling of clock rates, microarchitectural enhancements, and platform enhancements during the year.

Among the major system purveyors of non-x86 systems, only Digital Equipment Corporation and Hewlett-Packard showed signs of recognizing and preparing to exploit the opportunities Microsoft's Windows NT environment will create over the intermediate term. Vendors ignore these opportunities at their own peril. Dataquest anticipates that an accelerating migration to Windows NT in 1996 and 1997 will drive a major round of hardware upgrades in commercial accounts. NT's "architectural neutrality" makes it possible, although never easy, for vendors to promote, and end users to deploy, mixed-platform environments. In the limiting case, architecture neutrality could make the competitive picture in the compute microprocessor market resemble that of the embedded market. Dataquest considers this to be an unlikely scenario.

The RISC compute segment is entering a period of consolidation and attrition. Strong unit growth will continue in 1996, as Apple completes the conversion from the 68000 CISC architecture to the PowerPC. Dataquest anticipates that once this conversion is complete, growth in PowerPC units will drop below the market average, resulting in a slowly eroding market share. Similarly, unit shipments of proprietary RISC compute microprocessors will also be below the market average. Users already committed to these platforms will continue to purchase additional units to support increased user populations and greater performance requirements. Occasionally a group of users will opt to switch from its preferred RISC platform to a Wintel-based standard. Far fewer, if any, users committed to the Wintel platform will switch to a RISC environment; thus the RISC segment will slowly shrink as it loses stalwart supporters and attracts few replacements. This trend will accelerate as software developers place more of their attention on high-volume mainstream architectures, causing the RISC environments to become even less compelling.

Chapter 2
The Year That Was

Review of the 1995 Compute Microprocessor Market

Beneath the calm surface of the microprocessor market lie two vastly different submarkets. Vendors fortunate enough to have gained admission to the mainstream compute microprocessor market have all the privileges that accrue to members of any elite society. They collect the highest revenue per square inch of delivered silicon accorded any semiconductor vendor. Their customers, and more importantly, their customers' customers, continue to show even greater brand loyalty (or at least architectural loyalty) than almost any other consumer group. As long as these vendors and their partners can find new customers, or persuade old customers that their old systems are too slow, the sun continues to shine on them.

The denizens of the embedded microprocessor market, who live across the tracks on the other side of town, lead a much more difficult life. Their customers care little about issues like software compatibility and are unwilling to pay a premium for such niceties. Once the customer delivers a piece of equipment that includes an embedded microprocessor, his customers are unlikely to buy another until the first wears out. Except in rare instances, a new release of Windows or UNIX is unlikely to spur demand for his products. Unlike customers of compute microprocessors, purchasers of embedded microprocessors pay close attention to price and little, if any, attention to features and performance. Vendors in this segment must be on the lookout continuously for new customers, because they have no assurance that the customer who designs their processor into this year's video game, modem, or printer will be motivated to incorporate the new improved microprocessor they plan to introduce next year—in fact, he might even decide to use some other vendor's new, improved product instead. Prices and margins in this segment are acceptable by traditional manufacturing measures, but do not come close to approaching the rents that compute microprocessor vendors get to collect.

The worlds of compute and embedded microprocessors continued to drift further apart in 1995. Revenue of x86 compute microprocessors increased 24 percent, to $11.5 billion, on a 25 percent increase in unit volumes, driven by an overheated personal computer market, as consumers rushed to add on-ramps for the information superhighway. Unit shipments of PowerPC microprocessors increased almost 70 percent, but revenue grew more slowly, as the major consumer of PowerPC (Apple) played off its suppliers against one another. Even this clever purchasing activity did not prevent Apple from reporting a vast loss, throwing the future of the company, the Macintosh, and (indirectly) the PowerPC into some doubt.

> Why, man, he doth bestride the narrow world
> Like a Colossus, and we petty men
> Walk under his huge legs and peep about
> To find ourselves dishonourable graves.
>
> (William Shakespeare, *Julius Caesar*)

Like Caesar, Intel dominates the narrow world of microprocessors. Its aggressive pricing of Pentium processors, along with its aggressive advertising to end users, and its aggressive rollout of new products drove the market and kept its factories humming, even as they transitioned from 0.6-micron to 0.35-micron manufacturing processes, shrinking die size and increasing performance while lowering per-unit costs. Late in the year, Intel rolled out its Pentium Pro line, which offers impressive performance when used with 32-bit applications under Windows NT and somewhat less impressive performance in combination with 16-bit applications and Windows 3.1 or Windows 95. Intel's principal x86 competitors, Advanced Micro Devices and Cyrix, were unable to capitalize on this rare opportunity to gain a product advantage over Intel because they encountered delays in their own development programs for Pentium-class and Pentium Pro-class products.

Intel also refused to give its RISC-based competitors any chance to catch their collective breath. Its Pentium Pro closes and, in some cases, eliminates the performance gap between "personal computers" and "workstations" and thus places increased price and margin pressure on vendors of the latter class of products. This pressure will only increase in 1996 and 1997 as new personal computer architectural initiatives for enhanced I/O performance and 3-D computing enter the market. The PowerPC, often considered the principal challenger to the x86 compute monopoly, lost much momentum; its proponents were unable to match Intel's aggressive scaling of clock rates, microarchitectural enhancements, and platform enhancements during the year.

Among the major system purveyors of non-x86 systems, only Digital Equipment Corporation and Hewlett-Packard showed signs of recognizing and preparing to exploit the opportunities Microsoft's Windows NT environment will create over the intermediate term. Vendors ignore these opportunities at their own peril. Dataquest anticipates that an accelerating migration to Windows NT in 1996 and 1997 will drive a major round of hardware upgrades in commercial accounts. NT's "architectural neutrality" makes it possible, although never easy, for vendors to promote, and end users to deploy, mixed-platform environments. This, in turn, may allow end users to become more architecturally fickle, like their embedded microprocessor counterparts. (When was the last time an end user inquired about the microprocessors used within a car or a home appliance?) In the limiting case, architecture neutrality could make the competitive picture of the compute microprocessor market resemble that of the embedded market. Dataquest considers this to be an unlikely scenario.

The Compute Microprocessor Market

Of the 236.1 million microprocessors consumed across the world in 1995, only 71.1 million were lucky enough to end up in compute environments. These fortunate devices got to reside in environments generally safe for human habitation and often engaged in a variety of tasks in their day-to-day activities. Their embedded counterparts, 164.5 million in all, resided in hot, dark engine compartments, dangerous factory machines, and in a variety of consumer devices. They encountered little variety in their daily activities and were often driven by programs stored in some form of read-only memory.

Although suppliers of compute microprocessors sold only 30 percent of all microprocessor units, they collected over 87 percent of all MPU revenue. To accomplish this, they charged over 16 times more for their average chip ($177) than embedded vendors charged for their average device ($11). The fact that so many customers voluntarily (even eagerly, in some cases) paid these tolls says much about the value proposition offered by today's personal computers. The lion's share (93 percent) of compute microprocessors are compatible with Intel's x86 architecture and run programs engineered for that standard. This has proven to be an insurmountable barrier for vendors offering architectural alternatives claimed to be superior to, but incompatible with, the x86 standard. Vendors that have chosen to adopt the x86 standard for their own designs must then outengineer, outmanufacture, and outmarket Intel, and this too has proven to be a difficult undertaking, at best. Dataquest believes that the economic benefits that accrue to successful vendors in this market are too great to ignore and expects to see a continual series of challengers to Intel in future years.

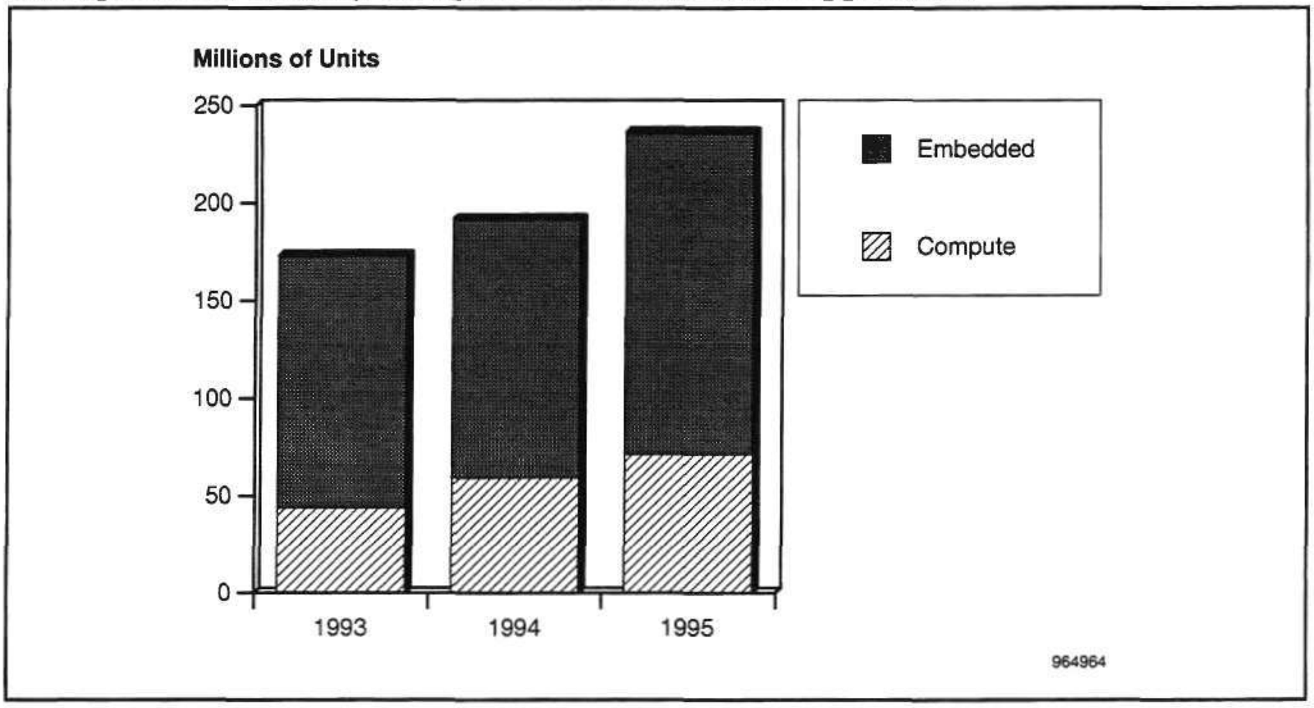
Table 2-1 and Figures 2-1, 2-2, 2-3, and 2-4 indicate the total size of the microprocessor market over the past three years, in terms of unit shipments and factory revenue. The reader will note the degree to which CISC processors sold into compute markets dominate the revenue generated in this market.

Table 2-1
The Microprocessor Market

	1993	1994	1995
All Microprocessors			
Units (K)	172,520	191,437	236,066
ASP ($)	51	61	61
Revenue ($K)	8,860,303	11,603,980	14,465,398
Compute Microprocessors			
Units (K)	44,123	59,645	71,590
ASP ($)	173	172	177
Revenue ($K)	7,637,840	10,254,761	12,650,237
CISC Compute Microprocessors			
Units (K)	43,236	56,557	66,616
ASP ($)	169	168	173
Revenue ($K)	7,310,864	9,473,351	11,522,767
RISC Compute Microprocessors			
Units (K)	887	3,088	4,974
ASP ($)	369	253	227
Revenue ($K)	326,976	781,411	1,127,470
Embedded Microprocessors			
Units (K)	128,397	131,792	164,476
ASP ($)	10	10	11
Revenue ($K)	1,222,463	1,349,219	1,815,161

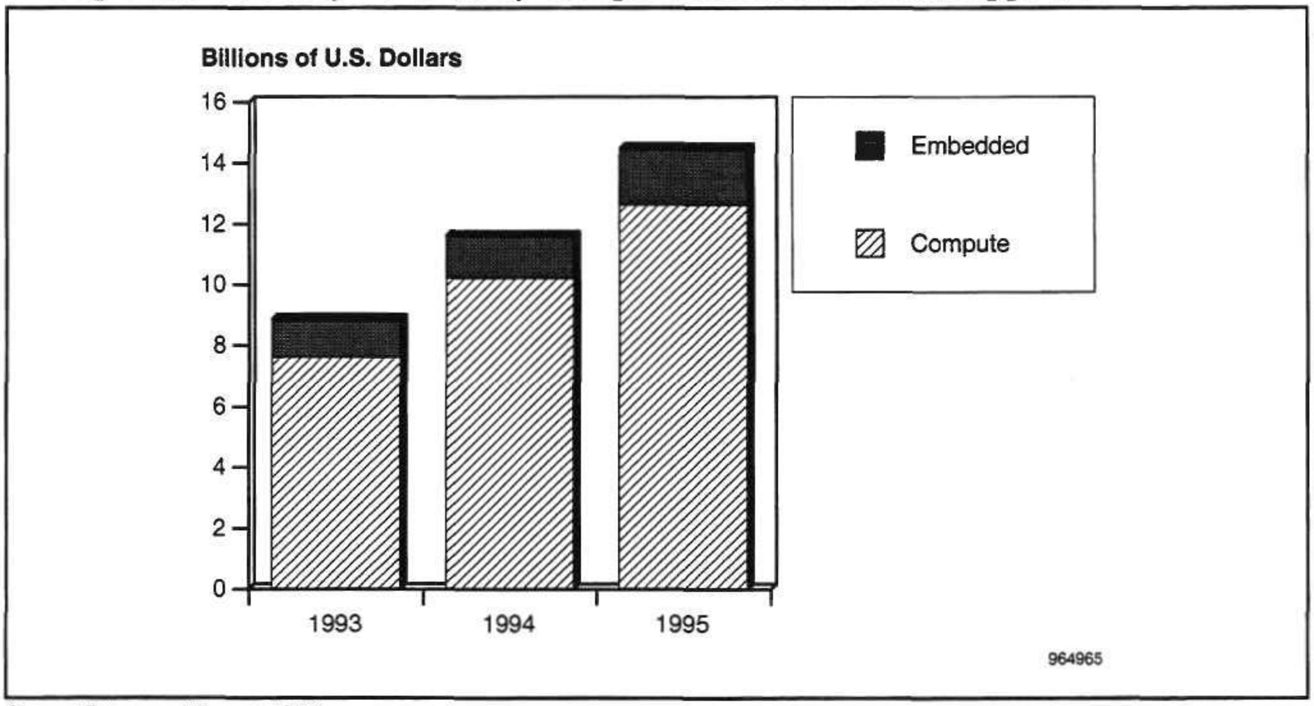
Source: Dataquest (August 1996)

Figure 2-1
Microprocessor Units by Compute versus Embedded Application



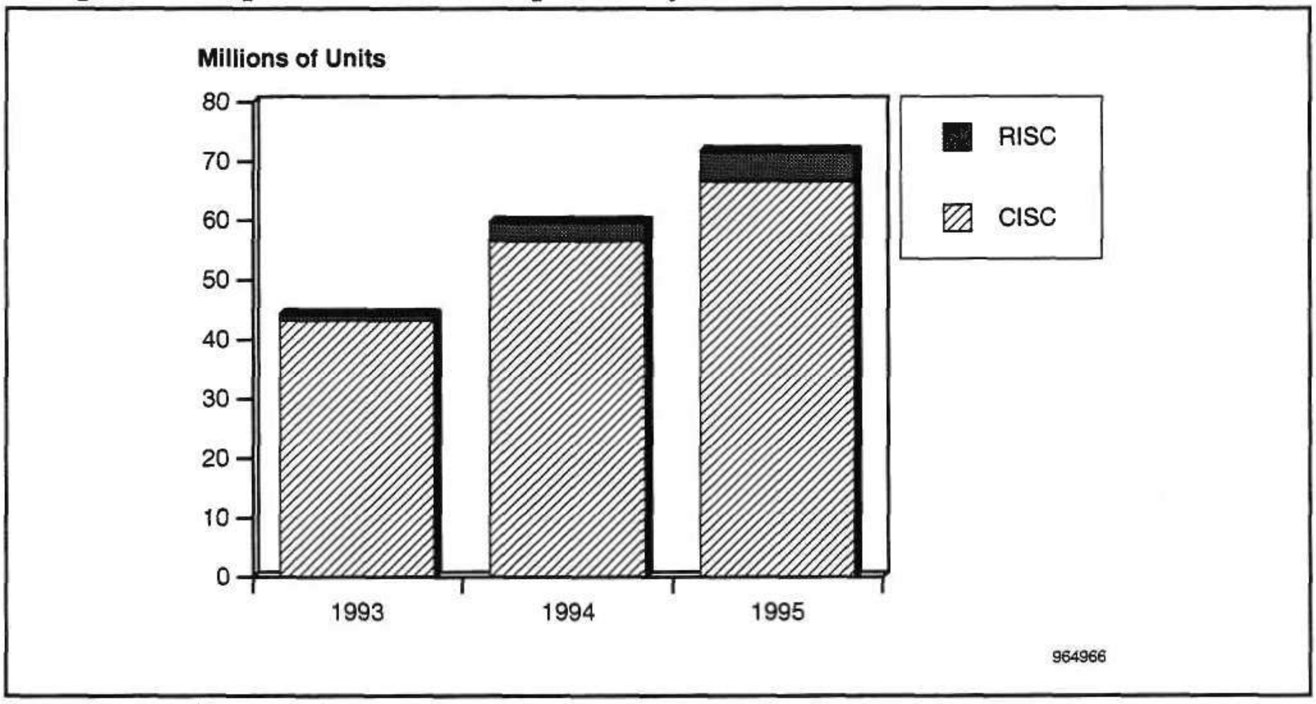
Source: Dataquest (August 1996)

Figure 2-2
Microprocessor Factory Revenue by Compute versus Embedded Application



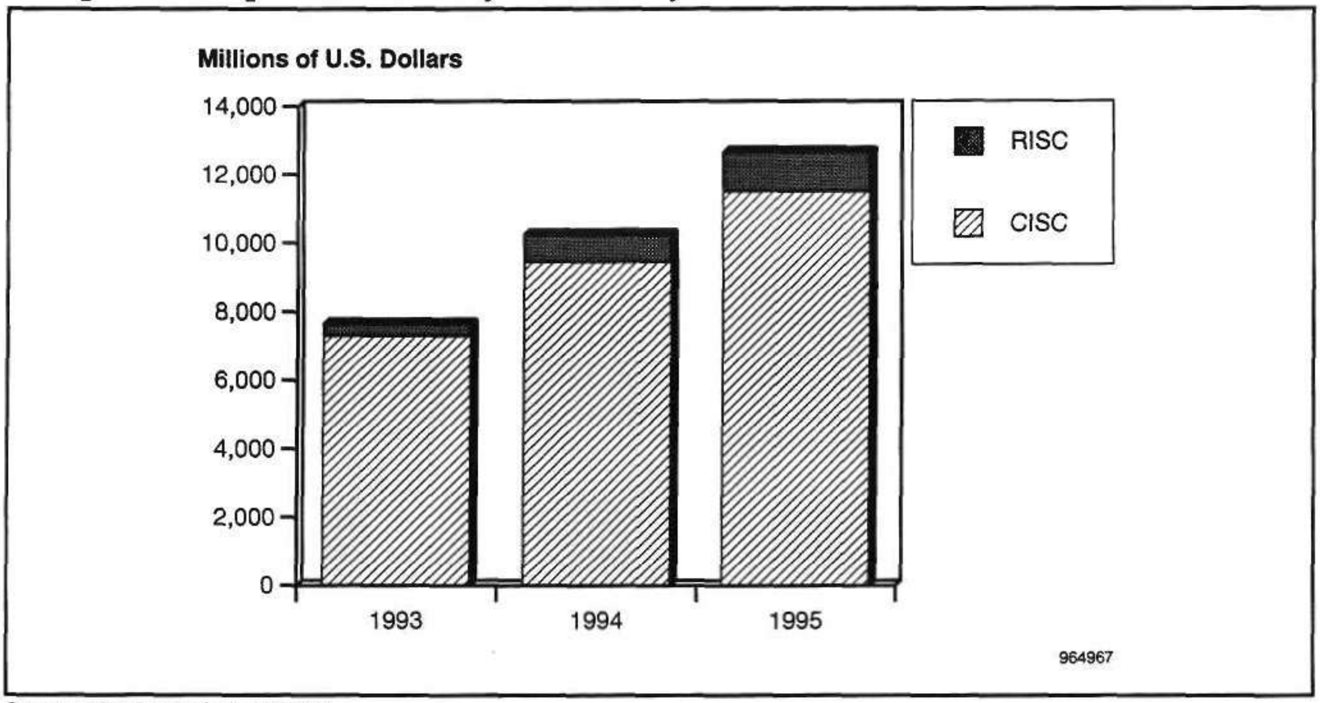
Source: Dataquest (August 1996)

Figure 2-3
Compute Microprocessor Units Shipments by RISC versus CISC Architecture



Source: Dataquest (August 1996)

Figure 2-4
Compute Microprocessor Factory Revenue by RISC versus CISC Architecture



Source: Dataquest (August 1996)

The CISC Compute Microprocessor Market in 1995

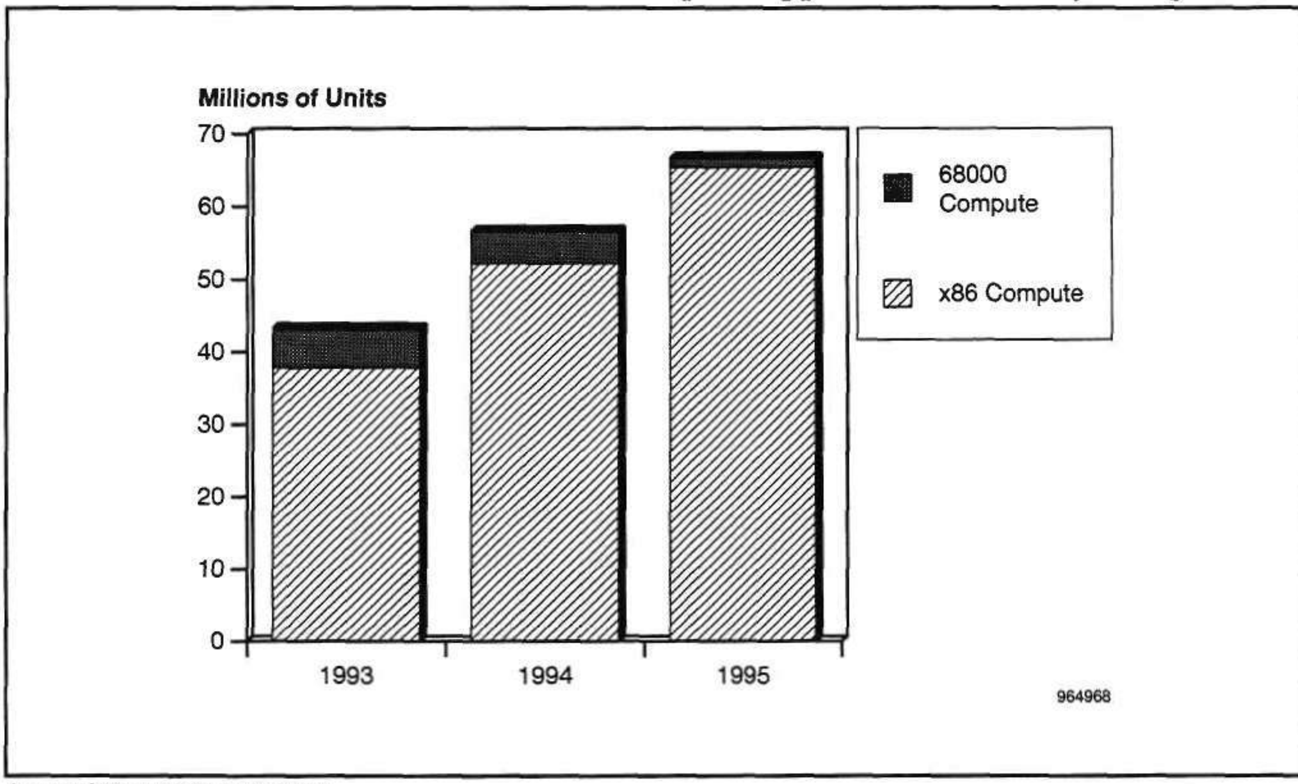
The CISC approach to processor design encompasses most computer architectures developed before 1980 or their direct descendants, including the architecture of IBM's mainframes and Digital's VAX minicomputers. Early microprocessors, based on this design approach, got a head start in amassing a software base and have held onto that lead. The Intel x86 (8086, 286, ..., Pentium, and Pentium Pro) and Motorola 68000 (68000, 68010, 68020, ..., 68060, and derivatives) have become so numerous that they dwarf everything else in the market and are the only CISC compute MPUs, for all intents. In the mid-1980s, over 100 companies in Silicon Valley were rumored to have been developing their own versions of 68000-based systems running UNIX. Neither of the two that emerged from that crop, Sun Microsystems and Silicon Graphics Inc., today uses the 68000 in its computational products. Apple remained the last and most important user of computational 68000s, and its conversion to the PowerPC, which will largely be complete by the end of 1996, marks the end of the 68000's life in computational markets. Table 2-2 and Figure 2-5 illustrate the extent to which the x86 design continues to dominate the CISC compute market. Table 2-3 provides a ranking by unit shipments of all suppliers of CISC compute MPUs.

Table 2-2
The CISC Compute Microprocessor Market

	1993	1994	1995
x86 Compute			
Units (K)	37,863	52,259	65,503
ASP ($)	182	177	175
Revenue ($K)	6,887,740	9,240,356	11,477,646
68000 Compute			
Units (K)	5,373	4,298	1,113
ASP ($)	79	54	41
Revenue ($K)	423,124	232,995	45,120
CISC Compute			
Units (K)	43,236	56,557	66,616
ASP ($)	169	168	173
Revenue ($K)	7,310,864	9,473,351	11,522,767

Source: Dataquest (August 1996)

Figure 2-5
The Demise of the 68000 Architecture in Compute Applications Is Nearly Complete



Source: Dataquest (August 1996)

Table 2-3
CISC Compute Microprocessor Supplier Rankings, 1993-1995

1995 Rank	1994 Rank		1993 Units	1994 Units	1995 Units	Percentage Change	1995 Market Share (%)
1	1	Intel	27,975	38,440	50,806	32	76
2	2	Advanced Micro Devices	6,790	8,210	9,482	15	14
3	4	Cyrix	900	2,382	3,404	43	5
4	6	IBM	872	1,515	1,685	11	3
5	3	Motorola	5,373	4,298	1,165	-73	2
6	5	Texas Instruments	1,200	1,540	116	-92	0
7	8	United Microelectronics Corp.	0	25	10	-60	0
8	7	Chips & Technologies	126	147	0	-100	0
		All CISC Compute	43,236	56,557	66,668	18	100

Source: Dataquest (August 1996)

The RISC Compute Microprocessor Market in 1995

The mid-to-late 1980s saw the introduction and proliferation of new RISC designs, as system vendors sought to differentiate their microprocessor-based designs via instruction-set architectures, much as they had done with the mainframes and minicomputers that preceded contemporary desktop systems. Today, the concept that any of these designs poses a serious threat to the domination of the x86 architecture has largely been discounted. Unlike the CISC segment, where only the x86 survives, the RISC segment remains fragmented; this fragmentation allows several vendors to continue in the market, although none has a clear road to long-term success. Most of the architectural techniques that allowed early RISCs to easily surpass x86 performance have now been incorporated into the design of newer x86 chips, with corresponding performance benefits. In 1996, RISC offers minor performance advantages over x86-based designs, but software migration issues have precluded any mass migration away from x86. Any vendor hoping to continue in the market with a proprietary microprocessor offering must offer a solution to the software migration issue. Digital appears to have aimed its FX!32 x86-to-Alpha translation utility directly at this problem.

Table 2-4 and Figures 2-6 and 2-7 illustrate the current state of the RISC compute market. The PowerPC now represents over 60 percent of this market, based on its use in the Macintosh line. PowerPC deployment has grown rapidly within Apple's installed base. As this user community completes its migration, the PowerPC must attract new customers. IBM and Motorola have taken slightly different approaches to this problem, which must be solved to ensure the long-term success of the architecture.

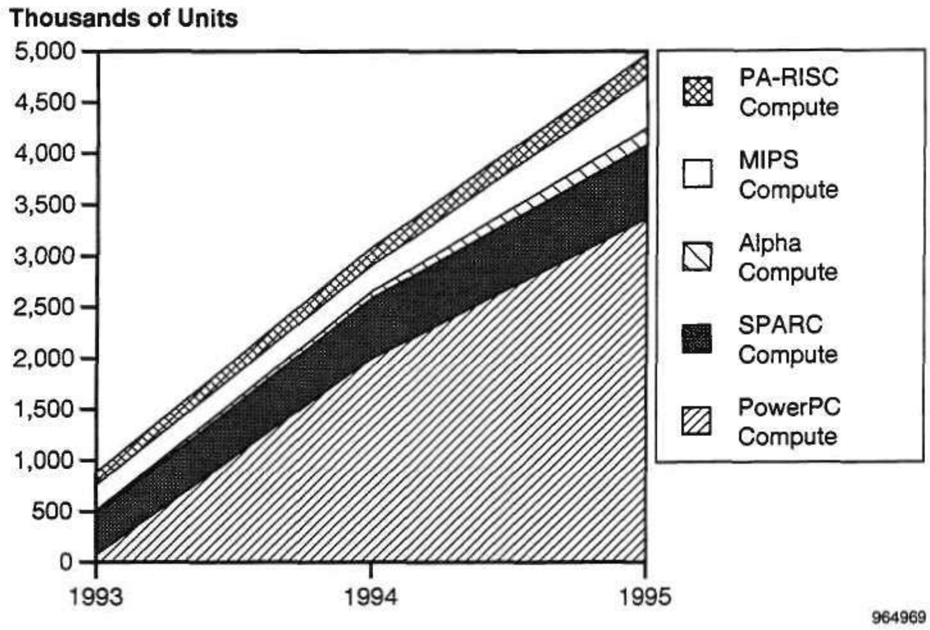
Table 2-5 provides a ranking of all suppliers that have participated in the RISC compute marketplace over the past three years. IBM leads this category, based on its early involvement with the PowerPC. (The PPC 601 used in Apple's initial generation of Power Macintoshes was manufactured only by IBM. The second-generation Power Macintosh products use the PPC 603, manufactured by both companies.) The competition between IBM and Motorola for the single major customer for PowerPC devices caused significant erosion in PowerPC average selling prices in 1995; Dataquest expects this to continue in 1996.

Table 2-4
The RISC Compute Market by Architectural Family

	1993	1994	1995
PowerPC Compute			
Units (K)	75	2,000	3,371
ASP ($)	390	224	205
Revenue ($K)	29,250	447,471	691,055
SPARC Compute			
Units (K)	408	590	715
ASP ($)	350	280	275
Revenue ($K)	142,800	165,200	196,625
Alpha Compute			
Units (K)	30	65	165
ASP ($)	650	475	350
Revenue ($K)	19,500	30,875	57,750
MIPS Compute			
Units (K)	249	258	498
ASP ($)	340	280	230
Revenue ($K)	84,660	72,240	114,540
PA-RISC Compute			
Units (K)	125	175	225
ASP ($)	406	375	300
Revenue ($K)	50,766	65,625	67,500
RISC Compute			
Units (K)	887	3,088	4,974
ASP ($)	369	253	227
Revenue ($K)	326,976	781,411	1,127,470

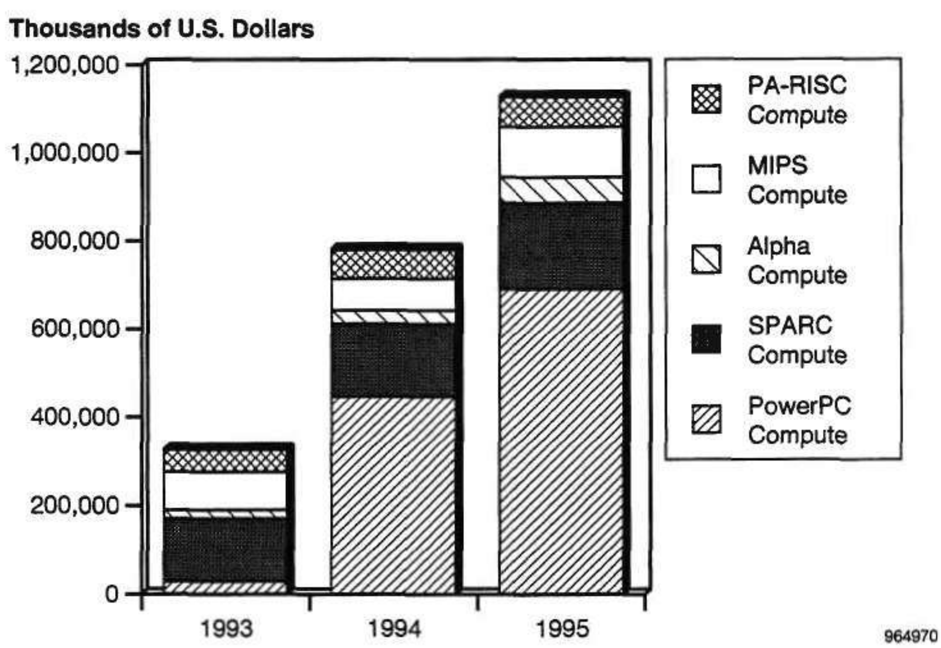
Source: Dataquest (August 1996)

Figure 2-6
The RISC Compute Market by Architectural Family



Source: Dataquest (August 1996)

Figure 2-7
RISC Compute Factory Revenue by Architectural Family



Source: Dataquest (August 1996)

Table 2-5
RISC Compute Microprocessor Supplier Rankings, 1993-1995

1995 Rank	1994 Rank		1993 Units	1994 Units	1995 Units	Percentage Change	1995 Market Share (%)
1	1	IBM	75	2,000	2,121	6	43
2	9	Motorola	71	32	1,250	3,806	25
3	2	Texas Instruments	275	400	445	11	9
4	3	Fujitsu	78	180	270	50	5
5	4	NEC	95	120	268	123	5
6	12	Hewlett-Packard	0	0	225	NM	5
7	7	Digital Equipment Corporation	30	65	165	154	3
8	8	Integrated Device Technology	64	64	125	95	3
9	6	Toshiba	61	74	105	42	2
10	5	Intel	70	85	0	-100	0
11	10	Weitek	30	10	0	-100	0
12	11	Cypress Semiconductor	25	0	0	NM	0
13	13	LSI Logic	25	0	0	NM	0
14	14	Performance Semiconductor	4	0	0	NM	0
		All RISC Compute	903	3,030	4,974	64	100

NM = Not meaningful
Source: Dataquest (August 1996)

Chapter 3
The Years That Will Be

The Compute Microprocessor Market through the Turn of the Century

Dataquest estimates that the market for compute microprocessors will more than double between 1995 and the year 2000, to more than 155,000 units sold for $30 billion. Compute microprocessors will continue to garner over 90 percent of microprocessor revenue, although they account for less than half of unit shipments.

Key Assumptions

- Worldwide personal computer shipments will increase from 60 million, as measured by Dataquest in 1995, to 130 million in 2000. PC ASPs will continue to fall in the range of $1,500 to $2,000.
- New applications will continue to drive demand for higher-performance systems, with most users upgrading their systems every two to three years. The concept that demand for increased computing performance is essentially insatiable is central to the continued growth of the market.
- A major shift from Pentium-based systems to Pentium Pro will begin in 1997 and continue for at least two years.
- Intel will introduce its P7 design (the Merced) late in 1998, but this product will not proliferate until early in the next decade.
- The so-called network computer will end up having only limited markets and will not seriously impact PC market growth during the forecast period.
- The Apple Macintosh line will slowly lose market share as current customers defect to the Wintel platform while fewer Wintel customers migrate to Macintosh.
- UNIX-based systems from Sun, Silicon Graphics, and IBM will slowly lose market share as current customers defect to the Wintel platform while fewer Wintel customers migrate to UNIX platforms.
- Hewlett-Packard will successfully transition its PA-RISC customers to P7-based platforms, running either HP-UX or Windows NT, beginning in 1998. The PA-8000 and its derivatives will be the last dedicated PA-RISC platforms.
- Shipments of Digital's Alpha-based products will grow more rapidly than the overall market, based on Alpha's performance advantages and its ability to run most x86 applications with good performance.

The Compute Microprocessor Market Forecast: 1996-2000

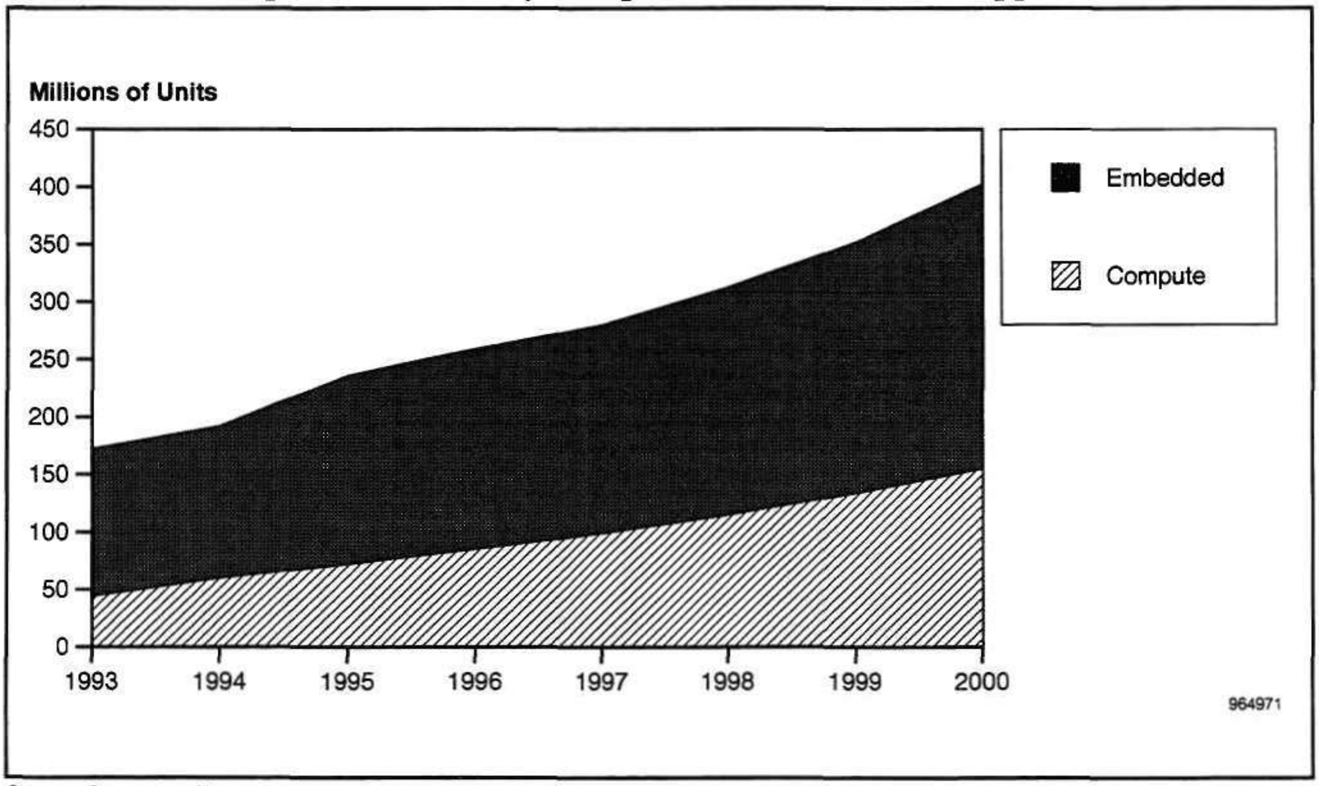
Table 3-1 and Figures 3-1 and 3-2 look at the split in unit shipments and revenue between the compute and embedded segments of the total MPU market.

Table 3-1
Forecast of the Microprocessor Market by Compute versus Embedded Applications

	1993	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
All Compute									
Units (K)	44,123	59,645	71,590	85,282	98,722	114,781	133,702	155,475	17
ASP ($)	173	172	177	179	188	194	196	196	2
Revenue ($K)	7,637,840	10,254,761	12,650,237	15,250,583	18,546,745	22,217,740	26,260,107	30,471,498	19
All Embedded									
Units (K)	128,397	131,792	164,476	164,576	180,233	203,296	228,998	262,054	10
ASP ($)	10	10	11	11	12	12	12	12	2
Revenue ($K)	1,222,463	1,349,219	1,815,161	1,872,615	2,096,919	2,393,482	2,762,319	3,219,450	12
All Microprocessors									
Units (K)	172,520	191,437	236,066	249,858	278,955	318,077	362,700	417,529	12
ASP ($)	51	61	61	69	74	77	80	81	6
Revenue ($K)	8,860,303	11,603,980	14,465,398	17,123,198	20,643,664	24,611,221	29,022,426	33,690,948	18

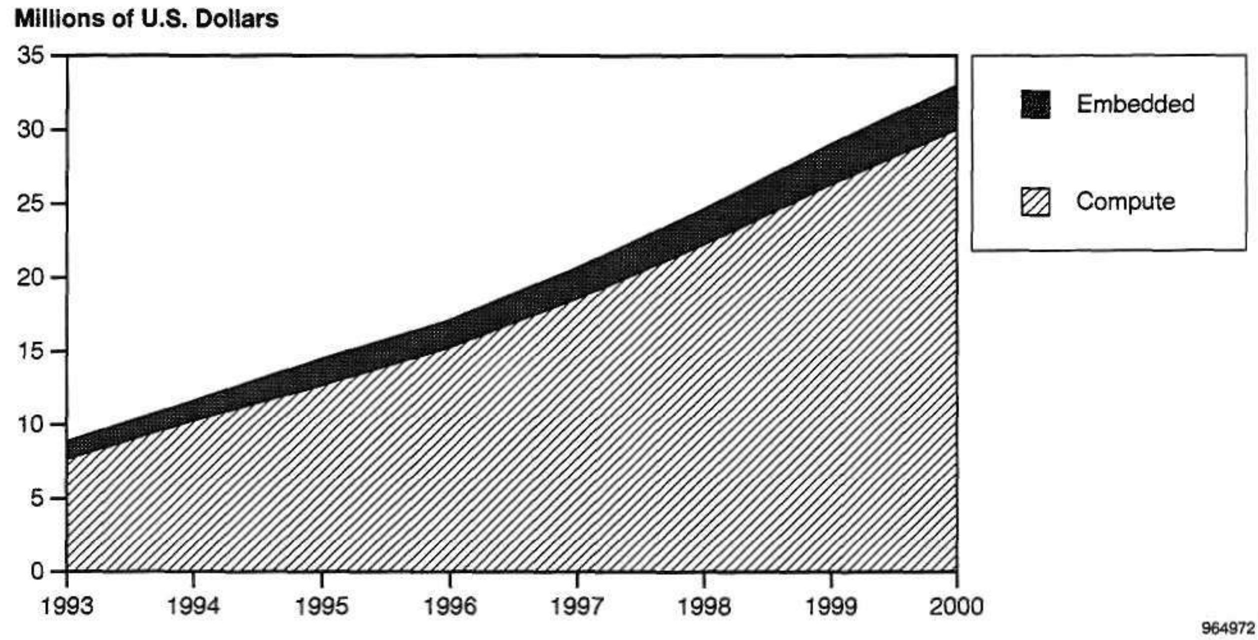
Source: Dataquest (August 1996)

Figure 3-1
Forecast of Microprocessor Units by Compute versus Embedded Application



Source: Dataquest (August 1996)

Figure 3-2
Forecast of Microprocessor Factory Revenue by Compute versus Embedded Application



Source: Dataquest (August 1996)

Table 3-2 and Figures 3-3 and 3-4 project compute microprocessor shipments by major architectural family and show that x86 designs continue to dominate during the period. The conversion of Apple's Macintosh base from CISC to RISC causes Dataquest to project that the RISC portion of the overall mix will grow to 8 percent in units and 9 percent in revenue in 1996. Then, as the Macintosh base grows more slowly than the overall market, RISC slides to 5 percent of the units and revenue by the year 2000.

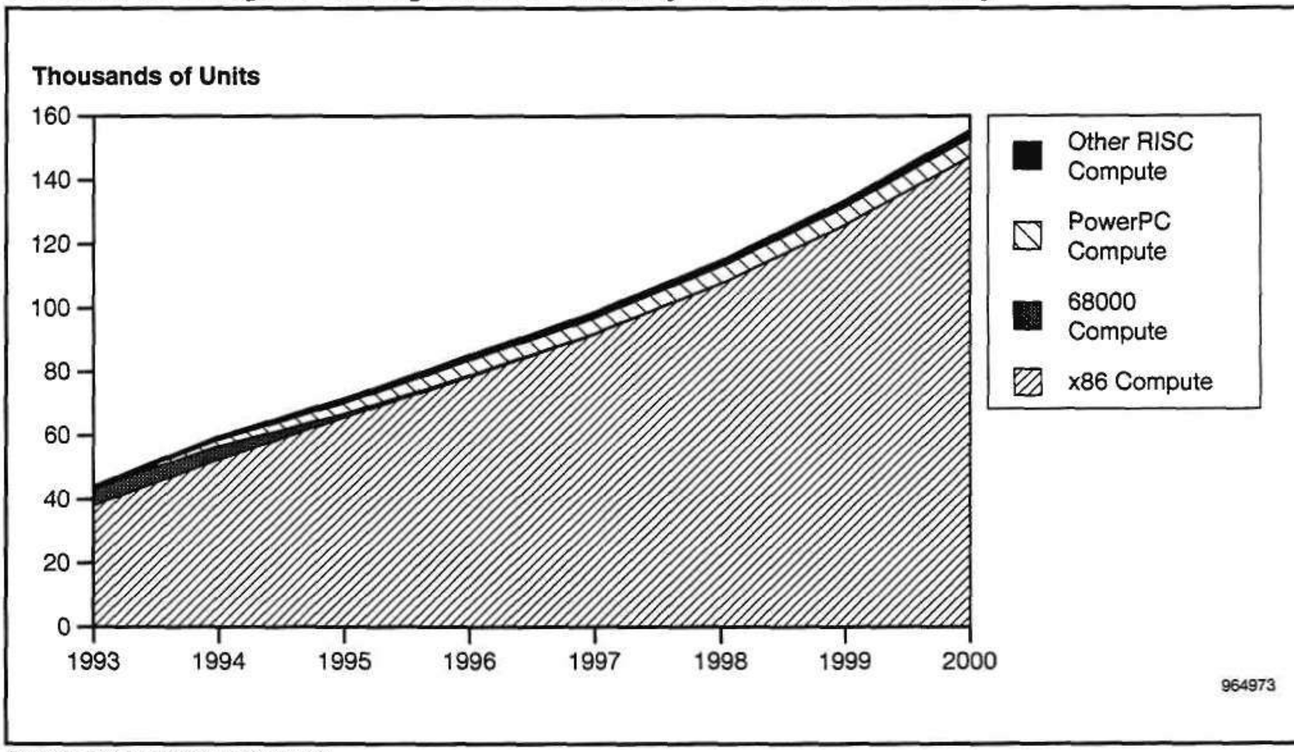
Average selling prices (ASPs) for compute microprocessors will continue to inch upward as these devices incorporate more of the functions previously handled by separate chips within the computing system. It is a given that new devices will be faster than their predecessors and little more expensive to build. These properties enable the market to continue growing beyond the point where the installed base of systems exceeds the user population. ASPs for RISC compute microprocessors have tended to decrease over the past several years and will continue in this direction. Dataquest expects CISC and RISC ASPs to meet (at about $200 in 1998), with CISC (that is, x86) increasing beyond that point, while RISC continues to decrease. Figure 3-5, based on data in Table 3-2, illustrates this phenomenon.

Table 3-2
Forecast of the Compute Microprocessor Market by Architectural Family

	1993	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
x86 Compute									
Units (K)	37,863	52,259	65,503	78,204	91,701	107,349	125,773	146,982	18
ASP ($)	182	177	175	177	187	194	197	197	2
Revenue ($K)	6,887,740	9,240,356	11,477,646	13,857,269	17,181,820	20,819,300	24,821,268	28,975,890	20
68000 Compute									
Units (K)	5,373	4,298	1,113	624	366	253	218	193.07	-30
ASP ($)	79	54	41	37	41	48	54	62	9
Revenue ($K)	423,124	232,995	45,120	23,180	14,943	12,244	11,822	11,993	-23
PowerPC Compute									
Units (K)	75	2,000	3,371	4,626	4,729	5,173	5,542	5,773	11
ASP (S)	390	224	205	195	187	181	178	176	-3
Revenue ($K)	29,250	447,471	691,055	901,001	884,182	938,062	984,965	1,015,746	8
Other RISC Compute									
Units (K)	812	1,088	1,603	1,827	1,926	2,007	2,169	2,527	10
ASP ($)	367	307	272	257	242	223	204	185	-7
Revenue ($K)	297,726	333,940	436,415	469,133	465,799	448,133	442,052	467,870	1
CISC Compute									
Units (K)	43,236	56,557	66,616	78,828	92,067	107,602	125,991	147,175	17
ASP ($)	169	168	173	176	187	194	197	197	3
Revenue ($K)	7,310,864	9,473,351	11,522,767	13,880,449	17,196,763	20,831,544	24,833,090	28,987,883	20
RISC Compute									
Units (K)	887	3,088	4,974	6,453	6,655	7,179	7,711	8,300	11
ASP ($)	369	253	227	212	203	193	185	179	-5
Revenue ($K)	326,976	781,411	1,127,470	1,370,134	1,349,982	1,386,195	1,427,017	1,483,615	6
Total Compute									
Units (K)	44,123	59,645	71,590	85,282	98,722	114,781	133,702	155,475	17
ASP ($)	173	172	177	179	188	194	196	196	2
Revenue ($K)	7,637,840	10,254,761	12,650,237	15,250,583	18,546,745	22,217,740	26,260,107	30,471,498	19

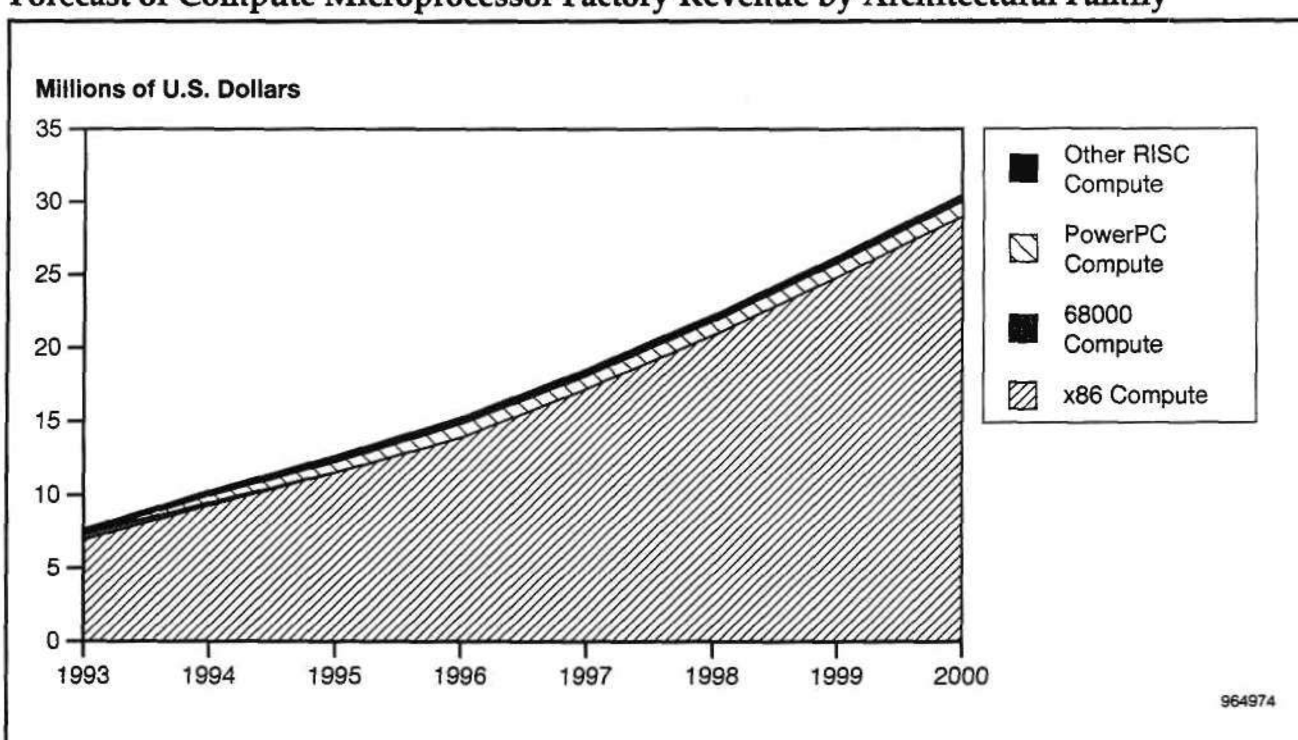
Source: Dataquest (August 1996)

Figure 3-3
Forecast of Compute Microprocessor Units by Architectural Family



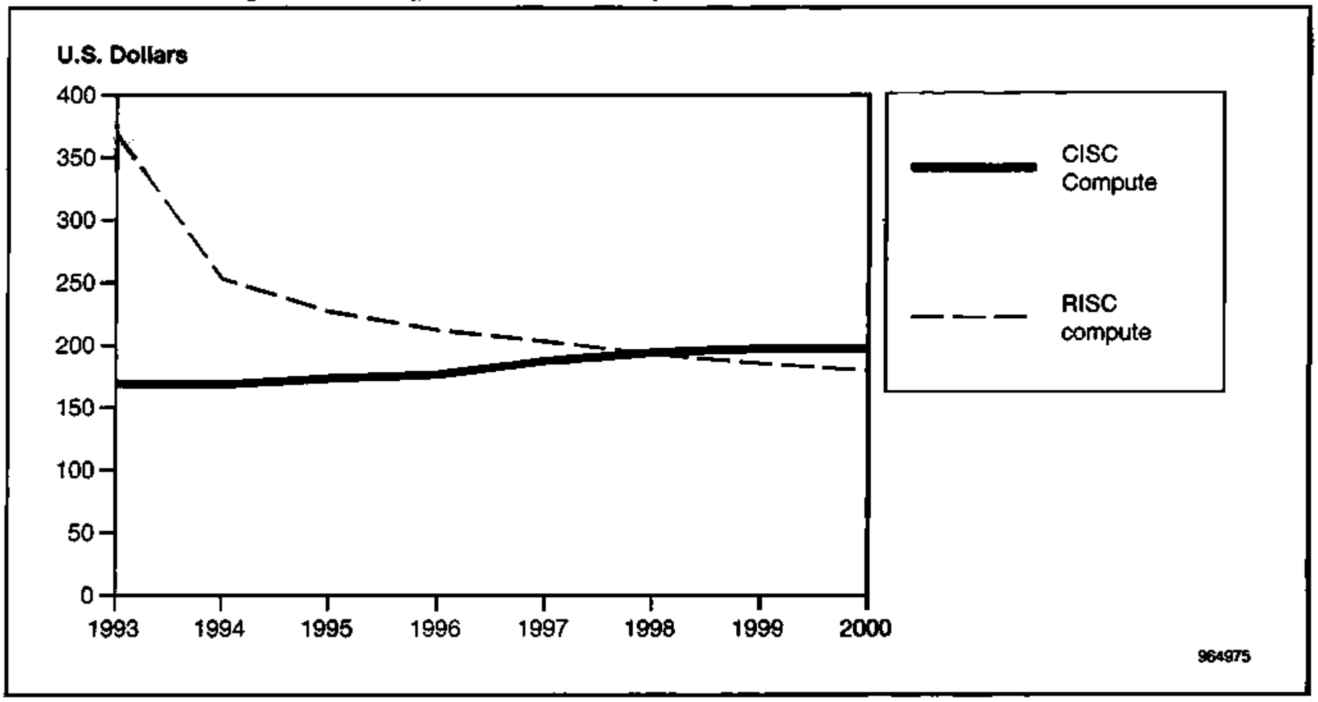
Source: Dataquest (August 1996)

Figure 3-4
Forecast of Compute Microprocessor Factory Revenue by Architectural Family



Source: Dataquest (August 1996)

Figure 3-5
Forecast of Compute Microprocessor ASP by RISC versus CISC Architecture



Source: Dataquest (August 1996)

The CISC Compute Microprocessor Market Forecast: 1996-2000

Market Trends

CISC architectures—the x86 and the 68000—will continue to dominate the microprocessor landscape through the forecast period. The 32-bit x86 processors, primarily Pentium and Pentium Pro from Intel, account for the vast majority of compute microprocessors, while 16-bit x86 processors retain an important, but slowly eroding, portion of the embedded market. During this period, the 68000 continues as a strong player in embedded markets.

Tables 3-3 and 3-4 and Figures 3-6 and 3-7 provide a view of the total CISC MPU market, including both compute and embedded application segments. The x86 and (to a lesser extent) 68000 span both segments; the other 8-bit, 16-bit, and 32-bit CISC architectures continue only in embedded applications.

In the early part of the forecast period, 586-class processors dominate the computational landscape (see Table 3-5). Intel's Pentium Pro design will begin to proliferate in the mass market in 1997, and, by 1999, it will constitute the majority of Intel's processor shipments. Other x86 vendors, notably Cyrix and AMD, plan to use the current Pentium bus design for their next-generation products and thus are classified by Dataquest as 586-class rather than 686-class processors. As a result of this classification, Dataquest expects the 586-class market to continue beyond the normal x86 generation's life span, and ASPs for computational products in this class will erode more slowly than has typically been the case for "prior-generation" processors. If Cyrix and AMD deliver on their promises, users will

Table 3-3
Shipment Forecast of the CISC Microprocessor Market by Architectural Family (Thousands of Units)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
x86	99,109	112,855	129,979	149,763	172,818	198,320	15
68000	54,446	56,100	64,470	75,548	89,473	105,742	14
Other 32-Bit CISC	2,514	1,131	679	407	244	147	-43
Other 16-Bit CISC	673	303	182	109	76	53	-40
Other 8-Bit CISC	52,125	44,306	41,311	41,180	38,113	35,355	-7
Total CISC	208,867	214,695	236,620	267,007	300,726	339,618	10

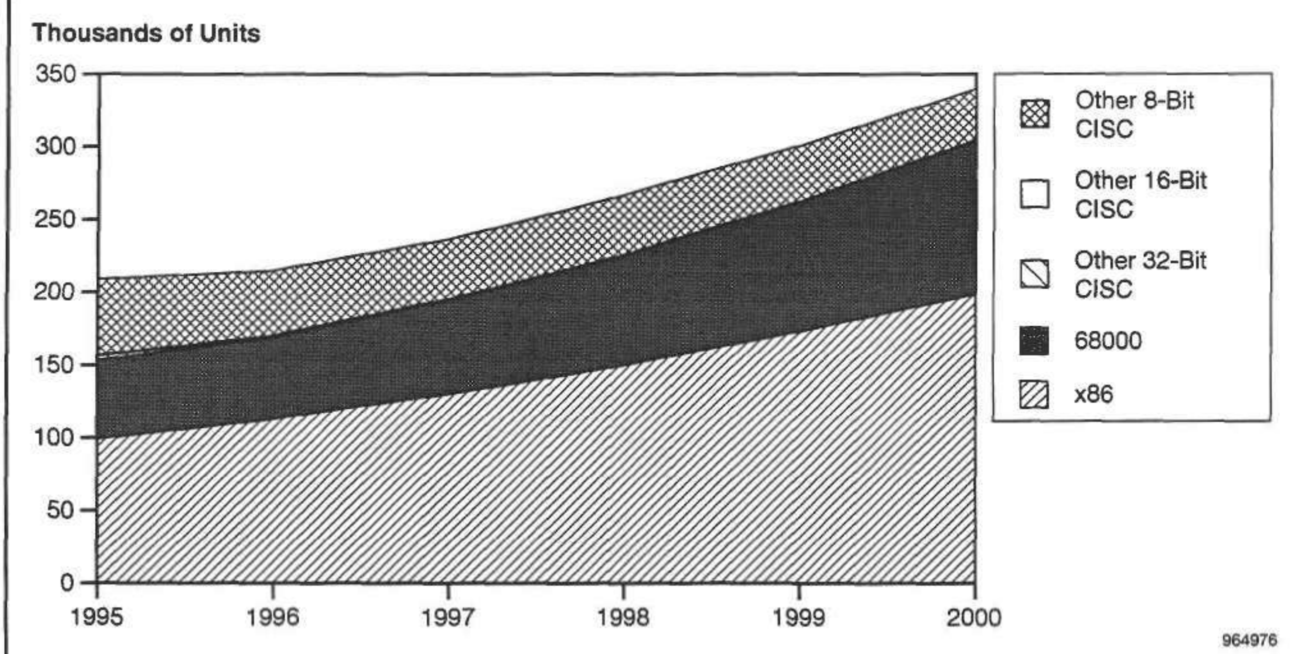
Source: Dataquest (August 1996)

Table 3-4
Revenue Forecast of the CISC Microprocessor Market by Architectural Family (Thousands of U.S. Dollars)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
x86	11,833,548	14,191,798	17,571,287	21,272,891	25,346,978	29,553,103	20
68000	495,524	501,020	597,718	736,484	933,310	1,173,667	19
Other 32-Bit CISC	55,308	25,137	15,837	9,977	6,286	3,960	-41
Other 16-Bit CISC	4,866	2,212	1,393	878	645	474	-37
Other 8-Bit CISC	294,418	300,307	276,146	269,559	243,693	220,765	-6
Total CISC	12,683,664	15,020,474	18,462,381	22,289,789	26,530,912	30,951,968	20

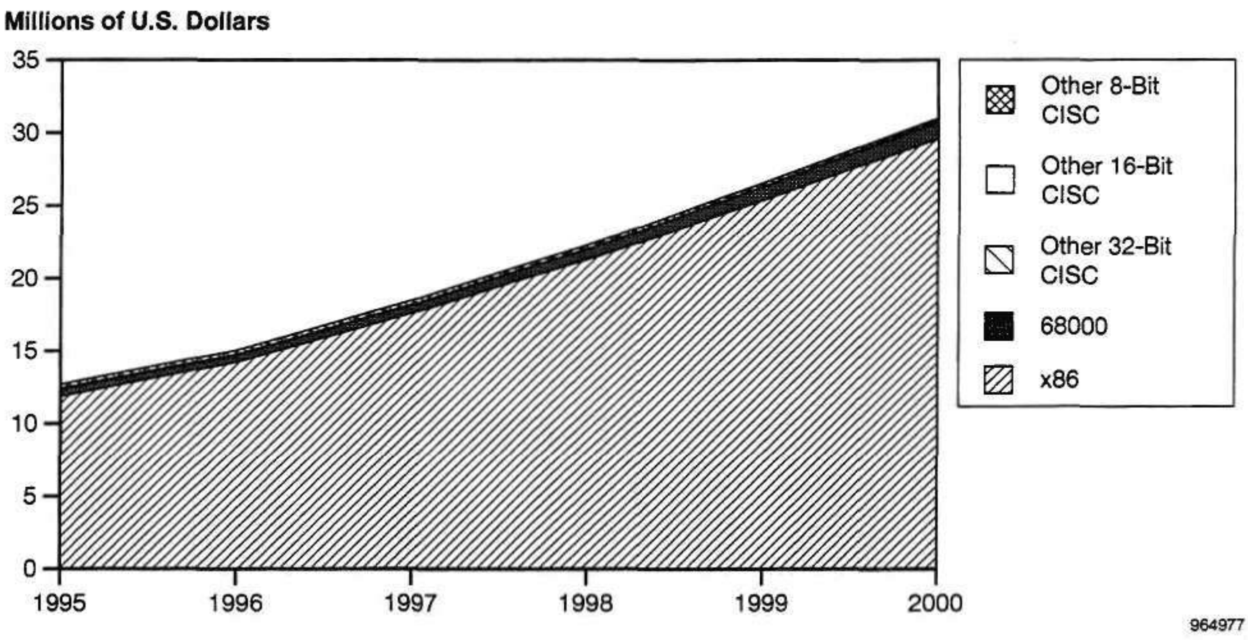
Source: Dataquest (August 1996)

Figure 3-6
Shipment Forecast of the CISC Microprocessor Market by Architectural Family



Source: Dataquest (August 1996)

Figure 3-7
Revenue Forecast of the CISC Microprocessor Market by Architectural Family



Source: Dataquest (August 1996)

have a choice of pursuing increased performance via entirely new platforms (using Pentium Pro technology) or via extensions and upgrades to existing platforms based on the Pentium processor. Figures 3-8 and 3-9 show Dataquest's forecast of the x86 compute microprocessor market.

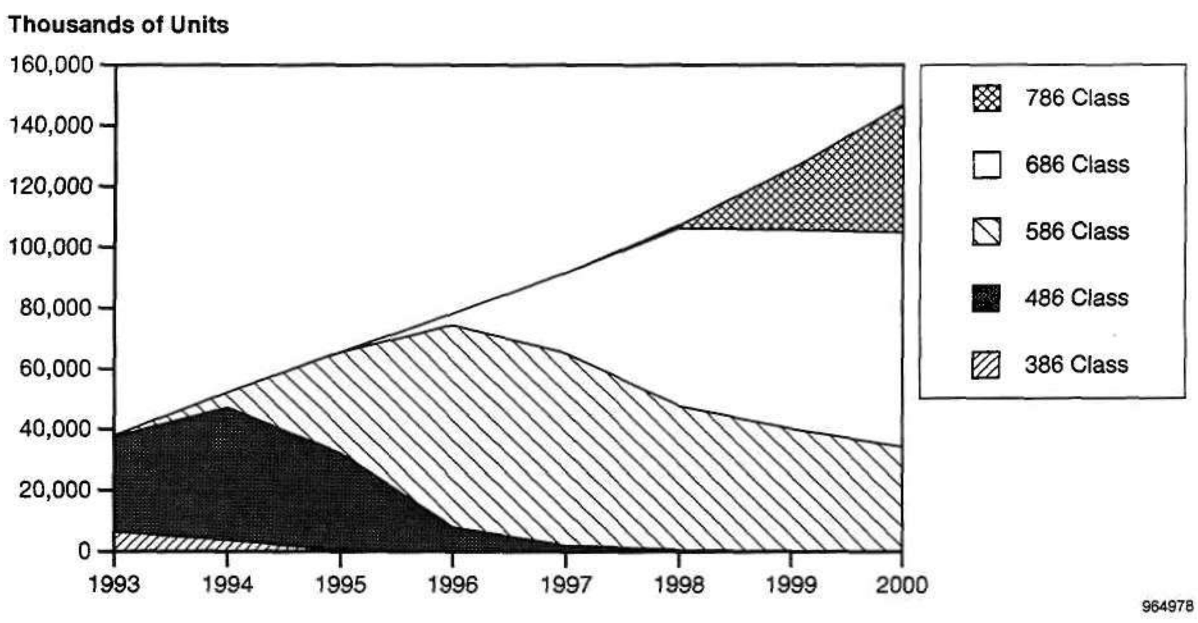
The average selling price for x86 compute microprocessors has inched up over the years, and Dataquest expects this trend to continue (see Figure 3-10). Many observers are puzzled by the seeming paradox of product prices that fall rapidly, accompanied by an overall increase in average price. This is not a paradoxical as it might seem; there has been a long-term shift to users moving up and buying products in the middle and high end of the line instead of the low end, and this shifting mix drives the ASP higher. This effect is consistent with survey data that indicates that first-time computer buyers often buy on price, but when the same users become more knowledgeable and purchase follow-on systems, they tend to be more sensitive to features and performance.

Table 3-5
Forecast of the x86 Compute Microprocessor Market

	1993	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 Class									
Units (K)	6,366	3,632	290	0	0	0	0	0	-100
ASP ($)	33	23	20	0	0	0	0	0	-100
Revenue ($K)	209,293	82,860	5,771	0	0	0	0	0	-100
486 Class									
Units (K)	31,172	43,587	31,904	7,976	1,994	499	0	0	-100
ASP ($)	206	147	68	44	33	27	0	0	-100
Revenue ($K)	6,415,198	6,385,496	2,169,472	352,539	66,101	13,220	0	0	-100
586 Class									
Units (K)	325	5,040	33,214	66,428	63,107	47,330	40,231	34,196	1
ASP ($)	810	550	278	173	108	65	39	24	-39
Revenue ($K)	263,250	2,772,000	9,216,904	11,521,130	6,840,671	3,078,302	1,569,934	827,355	-38
686 Class									
Units (K)	0	0	95	3,800	26,600	58,520	65,542	70,786	275
ASP ($)	0	0	900	522	386	286	214	163	-29
Revenue ($K)	0	0	85,500	1,983,600	10,275,048	16,727,778	14,051,334	11,533,335	167
786 Class									
Units (K)	0	0	0	0	0	1,000	20,000	42,000	NM
ASP ($)	0	0	0	0	0	1,000	460	396	NM
Revenue ($K)	0	0	0	0	0	1,000,000	9,200,000	16,615,200	NM
Total x86 Compute									
Units (K)	37,863	52,259	65,503	78,204	91,701	107,349	125,773	146,982	18
ASP ($)	182	177	175	177	187	194	197	197	2
Revenue ($K)	6,887,740	9,240,356	11,477,646	13,857,269	17,181,820	20,819,300	24,821,268	28,975,890	20

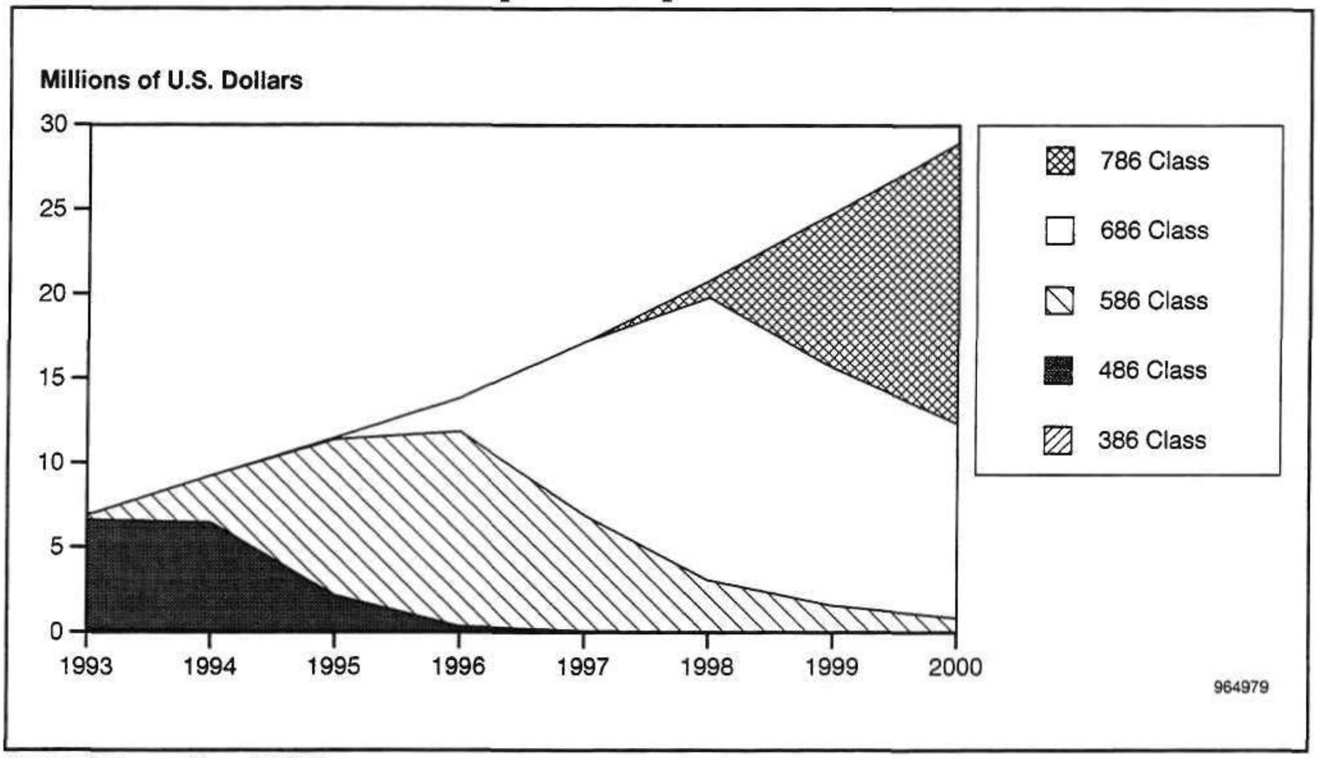
NM = Not meaningful
Source: Dataquest (August 1996)

Figure 3-8
Shipment Forecast of the x86 Compute Microprocessor Market



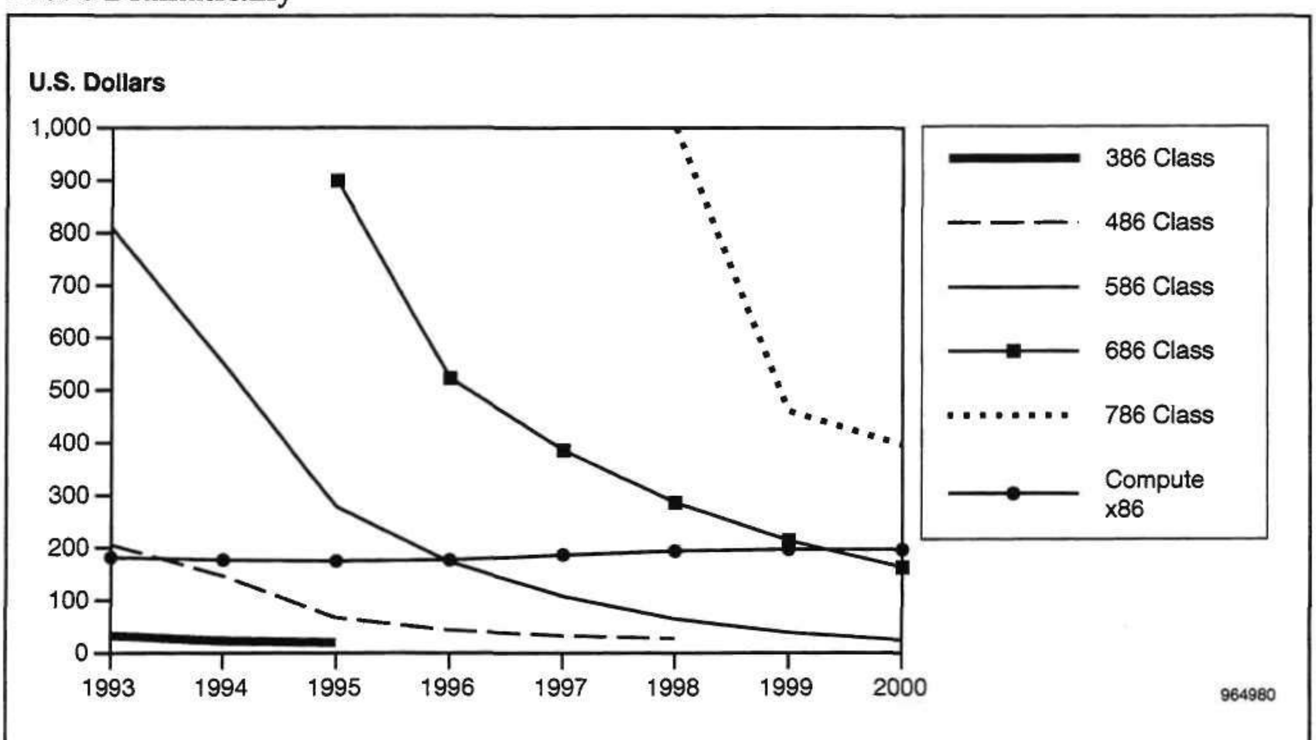
Source: Dataquest (August 1996)

Figure 3-9
Revenue Forecast of the x86 Compute Microprocessor Market



Source: Dataquest (August 1996)

Figure 3-10
Overall x86 Compute Family ASP Continues to Rise as ASPs for Individual Products Erode Dramatically



Source: Dataquest (August 1996)

The RISC Compute Microprocessor Market Forecast: 1996-2000

The RISC compute segment is entering a period of consolidation and attrition. Strong unit growth will continue in 1996 as Apple completes the conversion of its entire Macintosh line from the 68000 CISC architecture to the PowerPC. Dataquest anticipates that once this conversion is complete, growth in PowerPC units will drop below the market average, resulting in a slowly eroding market share. Similarly, unit shipments of proprietary RISC compute microprocessors will also be below the market average. Users already committed to these platforms will continue to purchase additional units to support increased user populations and greater performance requirements. Occasionally, a group of users will opt to switch from its preferred RISC platform to a Wintel-based standard. Far fewer, if any, users committed to the Wintel platform will switch to a RISC environment; thus, the RISC segment will slowly shrink as it loses stalwart supporters and attracts few replacements. This trend will accelerate as software developers place more of their attention on high-volume mainstream architectures, causing the RISC environments to become even less compelling.

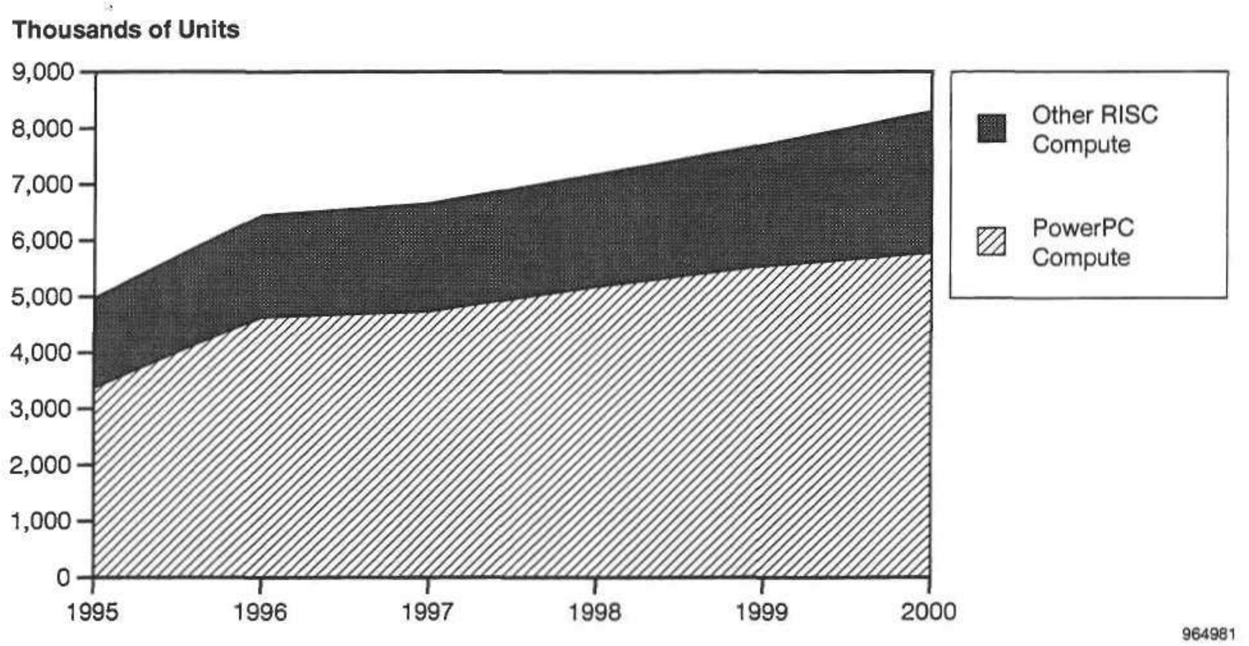
Table 3-6, Figures 3-11 and 3-12, and Figure 3-6, shown above, illustrate Dataquest's somewhat gloomy scenario for the gradual disappearance of the RISC compute market. As RISC loses its performance advantage relative to x86 architectures, its ASP will slowly fall until the ASP of the average RISC compute processor converges with that of the average CISC compute processor; about $200, at the end of 1997. Thereafter, RISC ASPs will fall below those of CISC (x86) processors in computational applications, reflecting both the performance parity between the two approaches and the lack of applications software available on the RISC platforms.

Table 3-6
Forecast of the RISC Compute Microprocessor Market

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
PowerPC Compute							
Units (K)	3,371	4,626	4,729	5,173	5,542	5,773	11
ASP ($)	205	195	187	181	178	176	-3
Revenue ($K)	691,055	901,001	884,182	938,062	984,965	1,015,746	8
Other RISC Compute							
Units (K)	1,603	1,827	1,926	2,007	2,169	2,527	10
ASP ($)	272	257	242	223	204	185	-7
Revenue ($K)	436,415	469,133	465,799	448,133	442,052	467,870	1
All RISC Compute							
Units (K)	4,974	6,453	6,655	7,179	7,711	8,300	11
ASP ($)	227	212	203	193	185	179	-5
Revenue ($K)	1,127,470	1,370,134	1,349,982	1,386,195	1,427,017	1,483,615	6

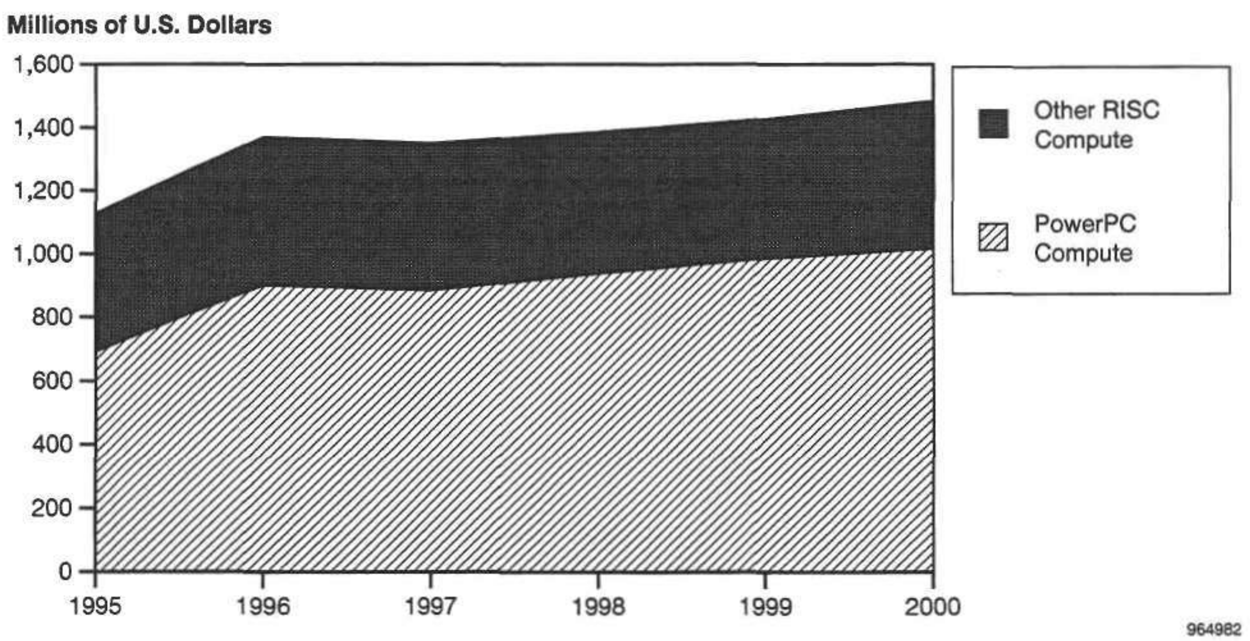
Source: Dataquest (August 1996)

Figure 3-11
Shipment Forecast for the RISC Compute Microprocessor Market



Source: Dataquest (August 1996)

Figure 3-12
Revenue Forecast for the RISC Compute Microprocessor Market



Source: Dataquest (August 1996)

Appendix A
Methodology

Dataquest surveys microprocessor suppliers to gain information regarding their microprocessor shipments and the revenue generated by these shipments. Our revenue survey captures sales by major product line; because these lines can easily be classified as CISC or RISC, we have the ability to report market share as measured by revenue along this classification. It is far more difficult to identify processor revenue by compute versus embedded application segment, especially when a product (like many x86 MPUs) is sold into both segments. Often, the suppliers themselves cannot identify the market segment into which their product is sold.

Dataquest does not automatically classify all x86 microprocessors sold in personal computers as compute microprocessors. Rather, the intended use of the personal computer system determines this decision. We consider personal computers embedded in various manufacturing automation, retail automation, and communications applications to be embedded rather than computational applications and categorize the processors in such systems accordingly.

The difficulty in reliably identifying the ultimate market for a given processor precludes our ability to collect meaningful revenue data by application segment. We do, however, capture unit shipment data by application segment. We incorporate both sets of data in our overall market analysis, but we are unable to translate vendor market shares in specific application segments, as measured in units, into market shares measured by revenue for those same segments, since average selling prices vary considerably by segment.

Appendix B

Factory Revenue for Vendors of 32-Bit CISC Microprocessors

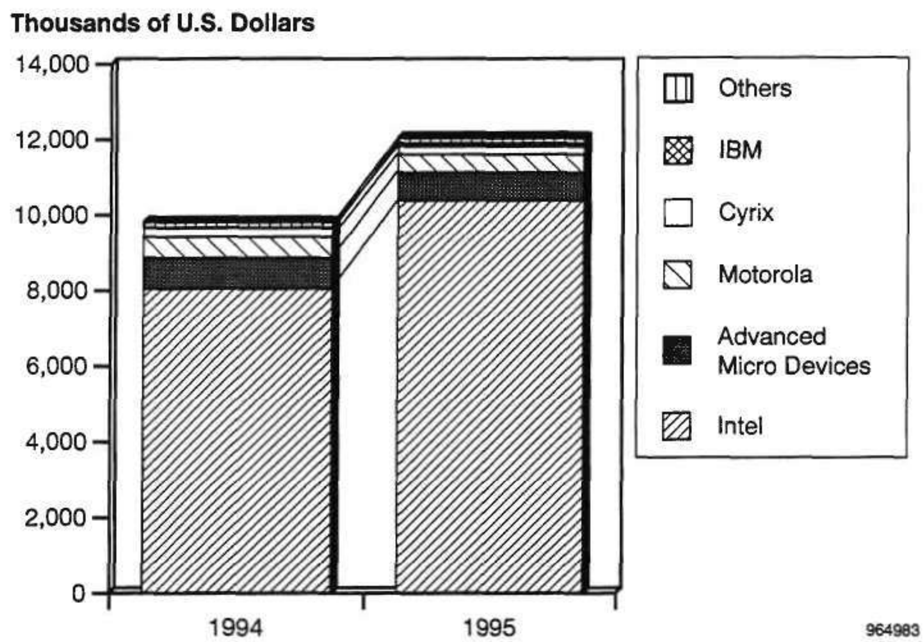
Table B-1 and Figure B-1 provide Dataquest's estimates of factory revenue generated by sales of 32-bit CISC microprocessors to both compute and embedded application segments. Figure B-2 shows changes in market share from 1994 to 1995.

Table B-1
Rankings of Vendors of 32-Bit CISC Microprocessors (Thousands of Dollars)

1995 Rank	1994 Rank		1994 Revenue	1995 Revenue	Percentage Change	1995 Market Share (%)
1	1	Intel	8,050	10,386	29	86.2
2	2	Advanced Micro Devices	823	750	-9	6.2
3	3	Motorola	561	479	-15	4.0
4	4	Cyrix	231	212	-8	1.8
5	28	IBM	0	75	NA	0.6
6	5	National Semiconductor	46	43	-8	0.4
7	6	Texas Instruments	41	30	-27	0.2
8	7	NEC	25	25	2	0.2
9	9	United Microelectronics Corp.	10	15	50	0.1
10	8	TCS	10	14	40	0.1
11	19	Mitsubishi	0	6	NA	0
12	11	Performance Semiconductor	4	6	40	0
13	13	Fujitsu	1	1	27	0
14	12	Hitachi	3	1	-67	0
15	10	Chips & Technologies	7	0	-100	0
		All Others	0	0	NA	NA
		Americas Companies	9,763	11,980	23	99.5
		Japanese Companies	29	34	16	0.3
		European Companies	10	14	40	0.1
		Asia/Pacific Companies	10	15	50	0.1
		Total Market	9,812	12,043	23	100.0

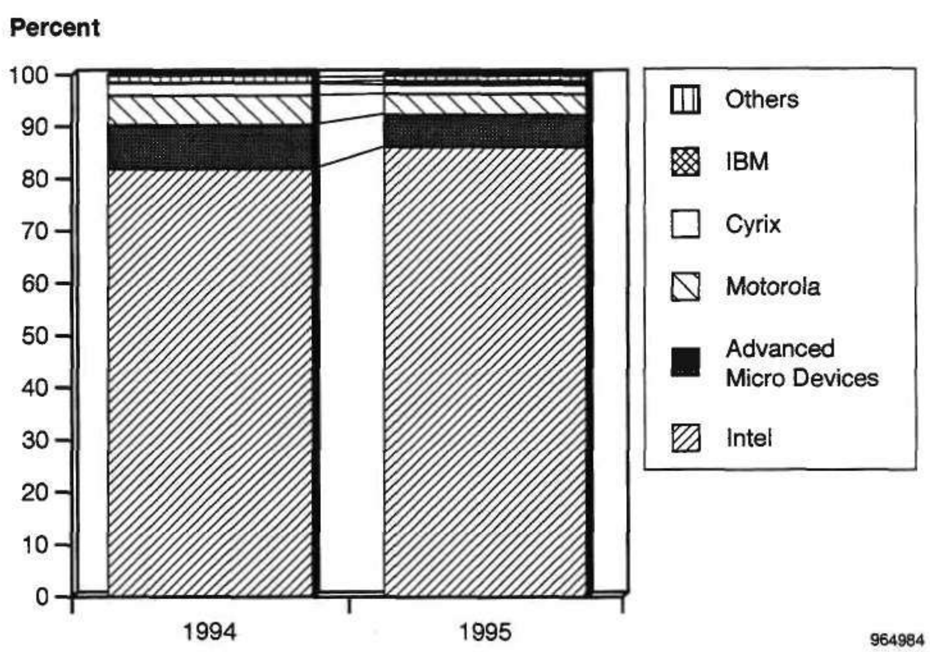
NA = Not available
Source: Dataquest (August 1996)

Figure B-1
CISC Microprocessor Supplier Revenue, 1994-1995



Source: Dataquest (August 1996)

Figure B-2
Market Share Analysis of CISC Microprocessor Suppliers by Revenue



Source: Dataquest (August 1996)

Appendix C

Factory Revenue for Vendors of RISC Microprocessors

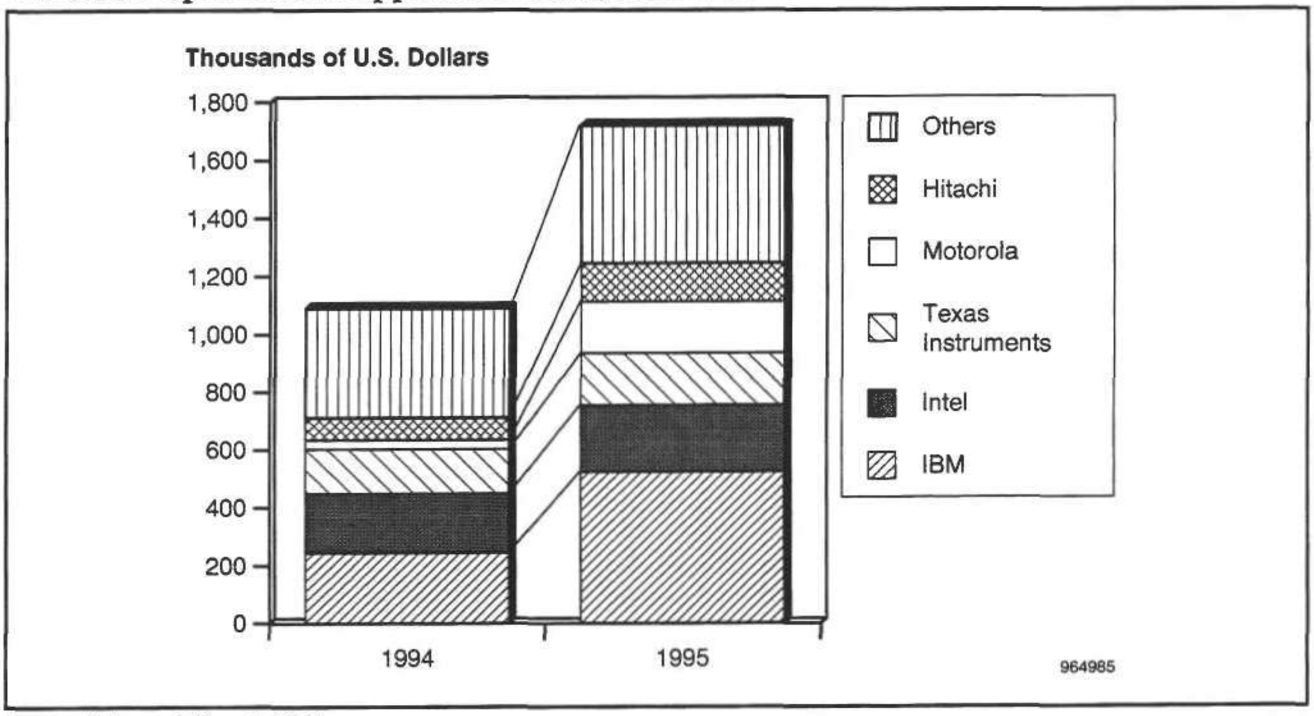
Table C-1 and Figure C-1 provide Dataquest's estimates of factory revenue generated by sales of RISC microprocessors to both compute and embedded application segments. Figure C-2 shows changes in market share from 1994 to 1995.

Table C-1
Rankings of Vendors of RISC Microprocessors (Thousands of Dollars)

1995 Rank	1994 Rank		1994 Revenue	1995 Revenue	Percentage Change	1995 Market Share (%)
1	1	IBM	246	525	113	30.5
2	2	Intel	205	231	13	13.4
3	3	Texas Instruments	153	180	18	10.5
4	12	Motorola	31	177	471	10.3
5	5	Hitachi	77	132	71	7.7
6	11	NEC	34	84	147	4.9
7	4	Advanced Micro Devices	81	74	-8	4.3
8	7	SGS-Thomson	51	68	34	4.0
9	9	Fujitsu	47	68	45	4.0
10	6	Integrated Device Technology	51	63	24	3.7
11	10	Toshiba	38	52	37	3.0
12	8	LSI Logic	51	36	-29	2.1
13	13	Weitek	14	20	40	1.1
14	16	VLSI Technology	2	4	86	0.2
15	14	GEC Plessey	6	3	-50	0.2
16	15	Matsushita	2	3	33	0.2
		All Others	0	0	NA	0
		Americas Companies	834	1,310	57	76.2
		Japanese Companies	198	339	71	19.7
		European Companies	57	71	25	4.1
		Asia/Pacific Companies	0	0	NA	0
		Total Market	1,089	1,720	58	100.0

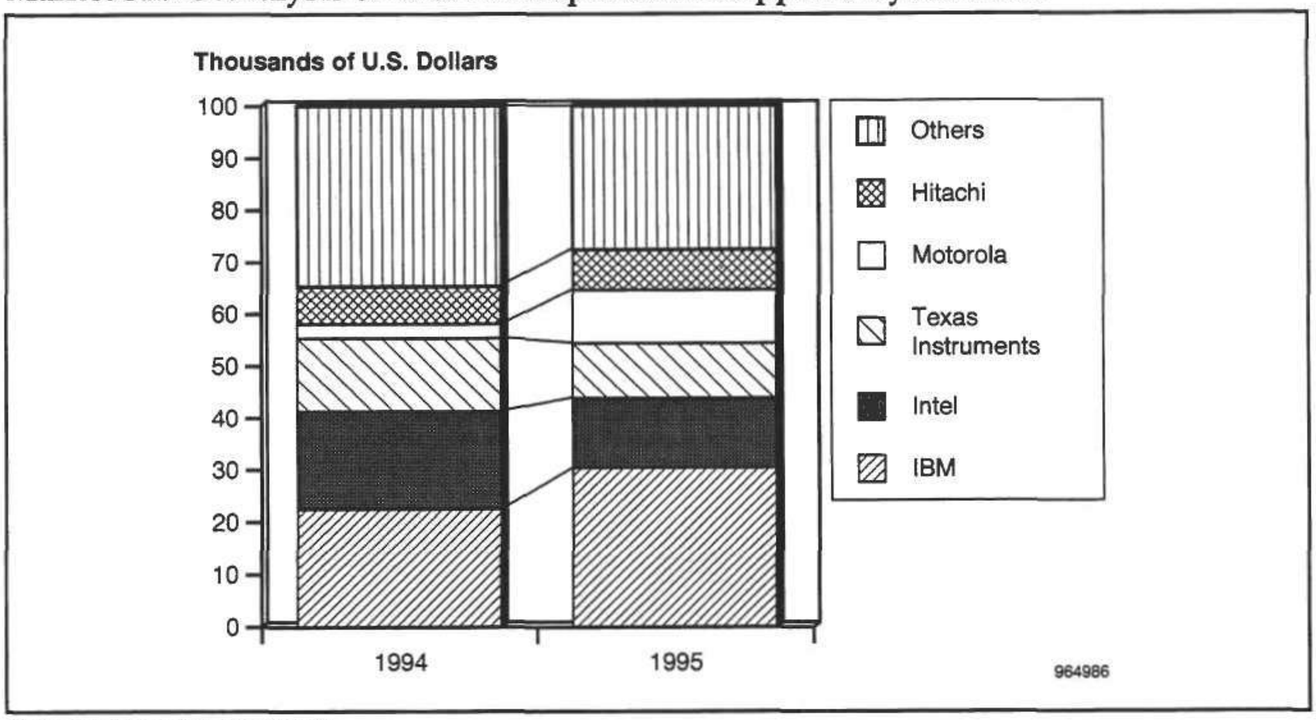
NA = Not available
Source: Dataquest (August 1996)

Figure C-1
RISC Microprocessor Supplier Revenue, 1994-1995



Source: Dataquest (August 1996)

Figure C-2
Market Share Analysis of RISC Microprocessor Suppliers by Revenue



Source: Dataquest (August 1996)

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Dear Dataquest Customer,

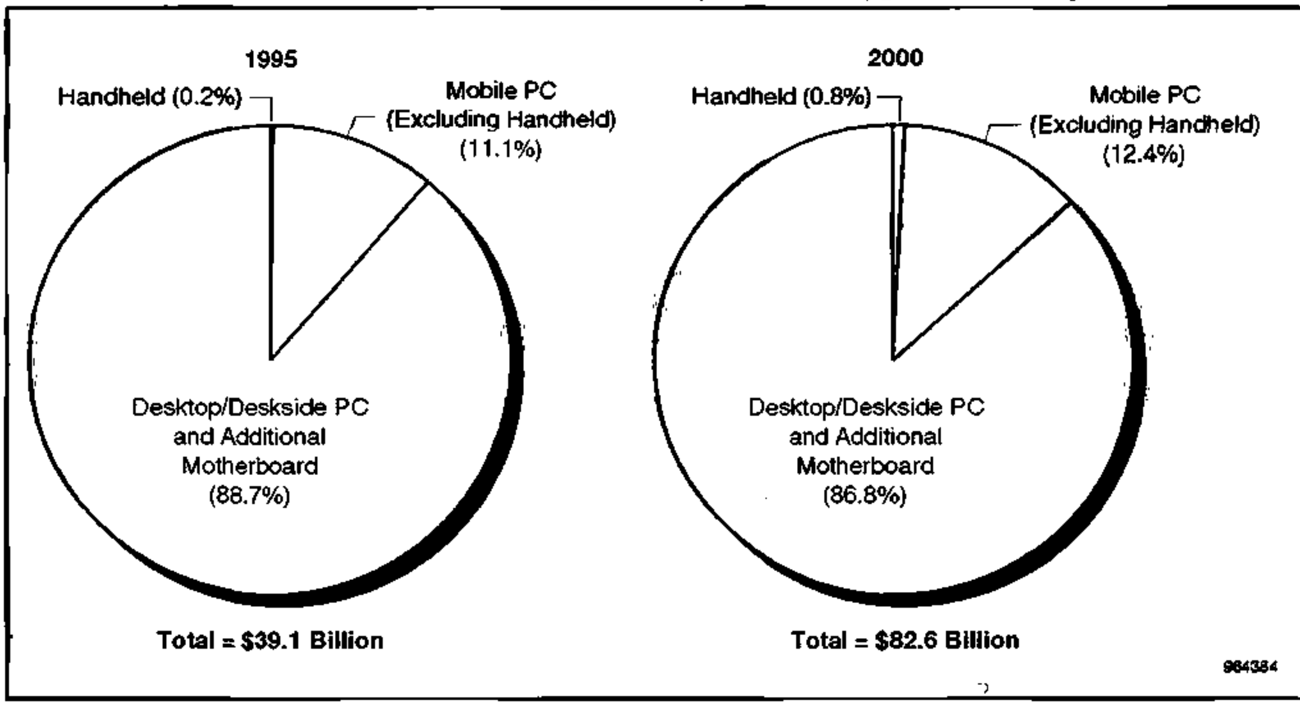
In Dataquest's Market Trends document *Trends in the Semiconductor Content of PCs and Workstations* (PSAM-WW-MT-9603) some of the data in Table 5-1 and Figure 5-2 were incorrect. Please insert the pages enclosed into your current copy of this document and place this letter in the front pocket of your binder.

Dataquest regrets the error and apologizes for any inconvenience this might have caused. For further information, contact Geoff Ballew at (408) 468-8676 or at gballew@dataquest.com.

Ben Southern

Ben Southern
Publications Coordinator

Figure 5-2
Worldwide PC Semiconductor Consumption by Product Type (Percentage)



Source: Dataquest (June 1996)

Table 5-1
Worldwide PC Production and Semiconductor Market (Less Peripherals; Includes Standard Handhelds)

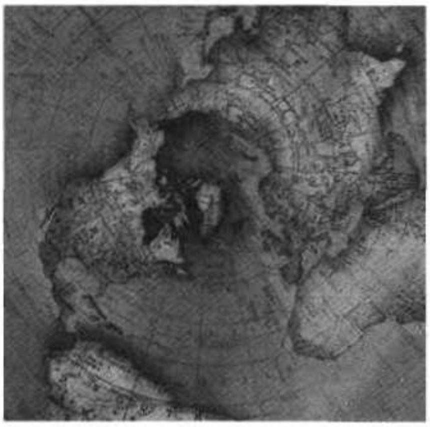
	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Complete PC Systems								
Units (K)	48,284	60,652	72,262	85,544	100,030	116,530	136,752	17.7
Factory ASP ($K)	1.98	2.06	2.06	2.07	2.05	2.01	1.95	-1.2
Factory Revenue ($M)	95,775	125,027	148,544	177,288	205,106	234,805	266,046	16.3
Semiconductor Content per System ($)	490	574	497	485	507	505	539	-1.2
Semiconductor TAM ($M)	23,678	34,836	35,941	41,481	50,704	58,855	73,761	16.2
Desktop/Deskside PC Systems								
Units (K)	39,252	50,259	59,043	69,651	80,847	93,610	108,012	16.5
Factory ASP ($K)	1.88	1.95	1.99	2.01	2.01	1.99	1.95	0
Factory Revenue ($M)	73,937	98,000	117,575	139,907	162,558	186,484	210,500	16.5

(Continued)

Table 5-1 (Continued)
Worldwide PC Production and Semiconductor Market
(Less Peripherals; Includes Standard Handhelds)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Semiconductor Content per System ($)	519	605	519	502	531	536	582	-0.8
Semiconductor TAM ($M)	20,368	30,417	30,667	34,949	42,931	50,213	62,887	15.6
Mobile PC Systems								
Units (K)	9,032	10,394	13,219	15,893	19,183	22,920	28,741	22.6
Factory ASP ($K)	2.42	2.60	2.34	2.35	2.22	2.11	1.93	-5.8
Factory Revenue ($M)	21,838	27,026	30,970	37,381	42,548	48,321	55,546	15.5
Semiconductor Content per System ($)	366	425	399	411	405	377	378	-2.3
Semiconductor TAM ($M)	3,310	4,420	5,275	6,532	7,774	8,642	10,874	19.7
Additional Motherboards								
Units (K)	4,404	7,036	8,266	9,752	11,318	13,105	15,121	16.5
Factory ASP ($K)	1.18	1.00	0.82	0.69	0.70	0.68	0.76	-5.4
Factory Revenue ($M)	5,178	7,018	6,805	6,776	7,889	8,957	11,422	10.2
Semiconductor Content per System ($)	519	605	519	502	531	536	582	-0.8
Semiconductor TAM ($M)	2,285	4,258	4,294	4,893	6,010	7,030	8,804	15.6
Total Production								
Units (K)	52,689	67,688	80,528	95,296	111,348	129,635	151,873	17.5
Factory ASP ($K)	1.92	1.95	1.93	1.93	1.91	1.88	1.83	-1.3
Factory Revenue ($M)	100,952	132,044	155,350	184,064	212,996	243,762	277,468	16.0
Semiconductor Content per System ($)	493	578	500	487	509	508	544	-1.2
Semiconductor TAM ($M)	25,963	39,094	40,235	46,375	56,715	65,885	82,565	16.1

Source: Dataquest (June 1996)



Dataquest

Trends in the Semiconductor Content of PCs and Workstations

Market Trends

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-MT-9603
Publication Date: July 29, 1996
Filing: Reports

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Table of Contents

List of Figures

List of Tables

List of Tables

Chapter 1
Executive Summary

The PC market and semiconductor markets are inherently linked by the simple fact that PCs consume more semiconductors than any other single application. The growth of the semiconductor market depends on a robust PC market just as the PC market depends on new semiconductor devices to differentiate the latest models from older designs. This relationship is symbiotic—profits from the semiconductor industry are funneled back into product and process development, driving more features and more performance into microprocessors, graphics chips, memory devices and all the other semiconductor devices in PCs.

The PC market, including motherboards and handheld PCs, is forecast to grow at a cumulative annual growth rate of 16.3 percent on a revenue basis from 1995 to the year 2000, with Japan and Asia/Pacific exhibiting higher growth than other regions. The semiconductor content of that total PC market, including motherboards and handheld PCs, is forecast to grow at a 16.1 percent cumulative annual growth rate for the same period. So the semiconductor content of the typical PC will remain steady as a percentage of factory selling price.

This document provides market data, market forecasts, and market trend information for both the PC market and the PC semiconductor market. Chapter 2 provides an introduction and discussion of methodology. Chapter 3 provides Dataquest's latest PC forecast with breakouts by form factor, regional demand, and microprocessor type. Chapter 4 provides trend information about the semiconductor market for PCs and workstations. Chapter 5 has market size and forecast information for the PC and workstation semiconductor markets. Chapter 6 provides market forecast and semiconductor content information about several standard input/output (I/O) peripherals.

Chapter 2
Introduction and Methodology

This document is the third in a series of four that provide reference information and analysis about the markets for semiconductor devices in personal computers. The four books cover graphics controllers, core logic chipsets, microprocessors, and an overview that includes a model of total semiconductor content for PCs. Specific areas of information include:

- PC system market size (in production terms) in revenue, units, and average selling price (ASP)
- PC system market and product feature trends
- Hardware architecture trends and semiconductor device opportunities
- Semiconductor content and market forecast
- Listings of key OEMs

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers, as well as analyst knowledge and opinions. Secondary sources include government and trade sources on sales, production, trade, and public spending. Semiconductor content assumptions are based on both surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative personal computers.

The forecast methodology is based on various methods and assumptions, depending on the specific market. To form a solid basis for projecting system demand and capital, government, and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes and government policies are also considered. Semiconductor content forecasts are based on interviews of system marketers and designers (including makers of enabling semiconductor technology), along with an analysis of historical trends.

Project Analyst: Geoff Ballew

Chapter 3
Personal Computer and Workstation Markets

Market and Production Trends

Personal Computers

Market and production trends in PCs and workstations are as follows:

- Although notebook and subnotebook computers have enjoyed strong growth, desktop systems will continue to dominate the computing platform because of their lower manufacturing costs, their ability to handle robust configurations with large amounts of storage, and their role in offering the fastest and latest computing technologies.
- Notebooks have enjoyed solid unit growth and even higher revenue growth because of their ability to replicate desktop environments. Larger LCDs, bigger hard disks and integrated CD-ROM drives continue to narrow the performance gap between desktop and notebook PCs.
- Ultraportable and notepad shipments continue to grow but may be surpassed by handheld PCs as the second-largest mobile category, behind notebooks.
- Shipments of laptops and transportable units declined again for 1995 but are forecast to remain steady in terms of unit volume through the forecast period.
- In the world of mobile computing, handheld devices continue to promise function and mobility but face size, weight, and cost issues. Dataquest has defined two categories for these handheld devices, but only the handheld computer category is covered in this document.
  - Expandable organizers: These are computers that typically measure 3.0 x 6.0 x 0.75 inches and weigh less than a pound. They are distinguished by their ability to allow the user to add applications and memory and by the fact that expansion is proprietary to a particular device or family. The operating systems typically are proprietary. The market for these devices is expected to peak at more than 0.5 million unit shipments in 1995 and then slowly shrink to fewer than 0.4 million by 1999.
  - Handheld computers: These devices typically measure 4.0 x 7.0 x 1.0 inches and weigh about one pound. They are distinguished from expandable organizers by their adherence to hardware and software compatibility standards. The operating systems are open and licensed, and application development and memory expansion are open to third-party developers and may be distributed in a standard format (such as PCMCIA). Personal digital assistants (PDAs) fall into this category.

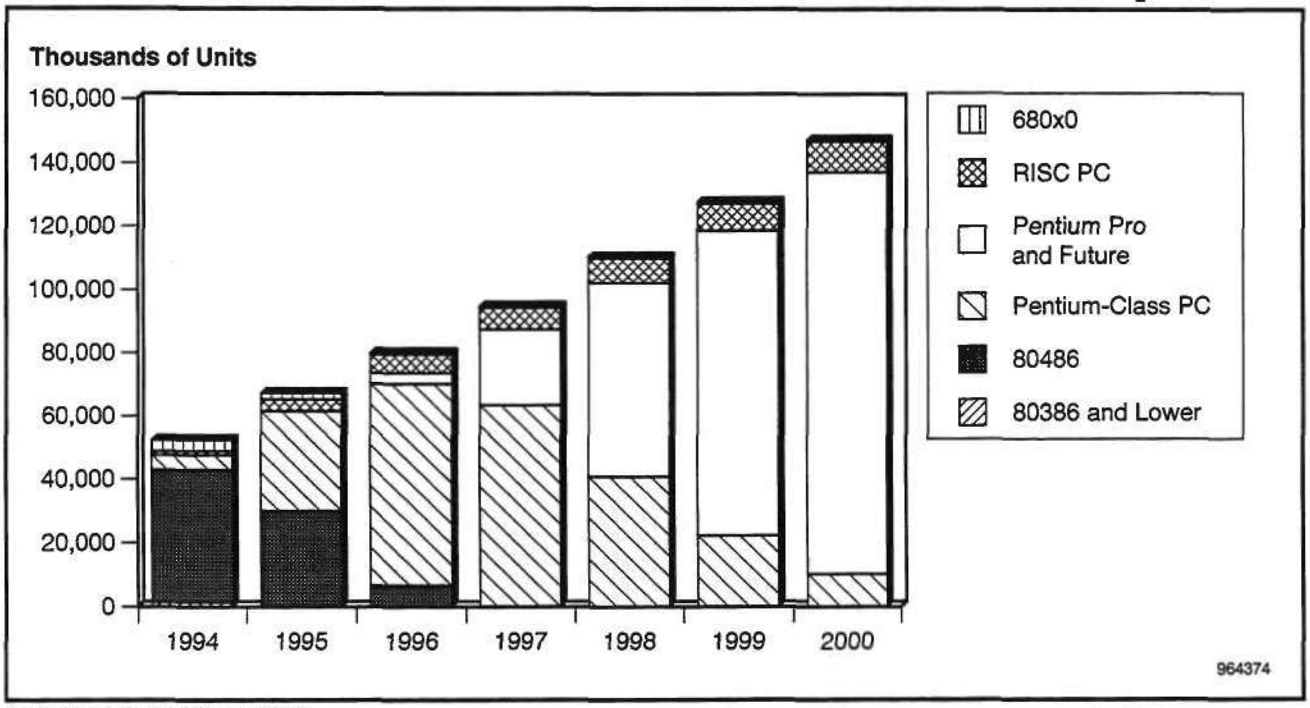
- Strong growth in the worldwide home PC market will continue across all regions of the world except for the U.S. home market, which shows early signs of saturation. Price elasticity is a key issue in reaching lower-income homes in all regions of the world.
- Microsoft's Windows 95 operating system was launched in the second half of 1995 with actual product sales beginning on August 24. Its most significant impact on hardware is the need to upgrade to 16MB of main memory.
- Emerging markets and regions will account for a sharply increased proportion of shipments by 1998.
- The multimedia PC market continued its torrid growth in 1995. Shipments of complete multimedia systems doubled from 1994 to 1995, reaching 20.9 million shipments.
- Major PC manufacturers will continue to place a strong emphasis on the branding of PCs.
- Manufacturing strategies are dictated by economies of scale, with strong influence from free trade zones, the availability of components, and the quality and price of labor. For desktop PCs, the trend is toward assembling units close to the end market or at least having the final configuration (including CPU and main memory installation) executed on demand close to the end market. For mobile PCs, production is largely focused in Japan and other Asian countries. A rising tide of OEM notebooks from Taiwanese vendors will maintain Asia/Pacific's growing influence on the mobile PC market.
- Motherboard production will depend more heavily on the Asia/Pacific region as suppliers regain some of the market share they lost because of Intel's rapid growth in the motherboard business in 1994 and 1995.

Figures 3-1 to 3-3 and Tables 3-1 to 3-7 present Dataquest's worldwide PC market forecasts. Figure 3-4 shows the regional variation in markets from 1994 to 2000.

OEMs

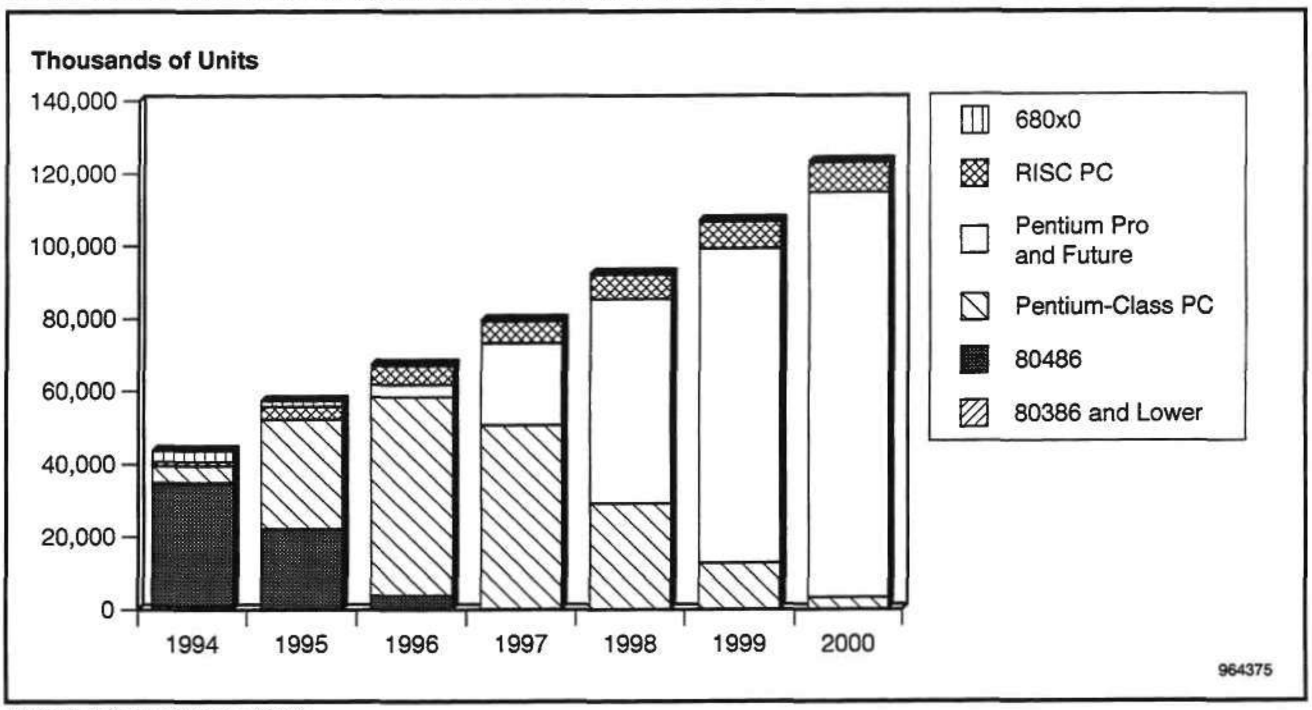
Tables 3-8 and 3-9 list the key OEMs ranked by revenue and unit shipment market share. Compaq retained the No. 1 spot despite fierce competition from the smaller OEMs but lost just a bit of market share on a revenue basis. Compaq faces a challenge in keeping the top spot for 1996 because the merger between NEC and Packard Bell has created a larger competitor. The combined shipments of NEC and Packard Bell make the new company the largest PC company in the world, based on 1995 unit shipments. Hewlett-Packard posted the largest gain in market share of all of the top 10 OEMs with the rapid growth of its Pavilion line of multimedia PCs.

Figure 3-1
Worldwide Personal Computer Shipments by Microprocessor Type (Includes OEM PCs and Additional Motherboards; Excludes Handheld Computers)



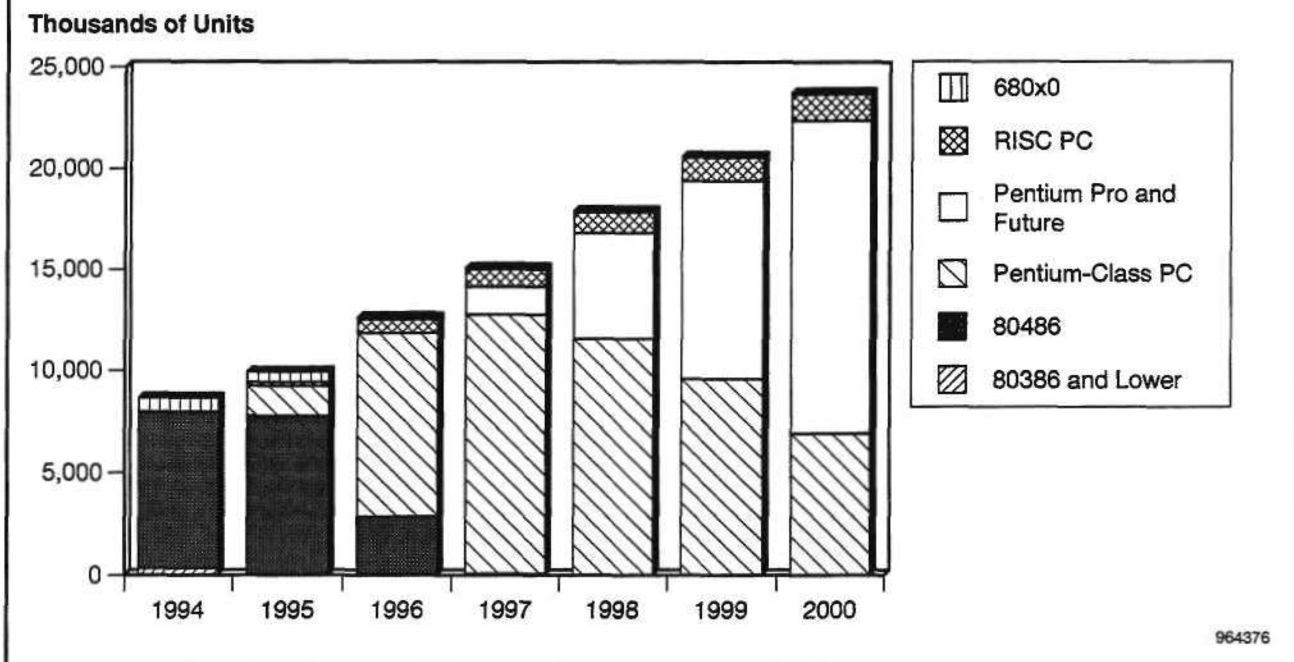
Source: Dataquest (June 1996)

Figure 3-2
Worldwide Desktop/Deskside Personal Shipments by Microprocessor Type (Includes OEM PCs and Additional Motherboards)



Source: Dataquest (June 1996)

Figure 3-3
Worldwide Mobile Personal Computer Shipments by Microprocessor Type (Excludes Handheld Computers)



Source: Dataquest (June 1996)

Table 3-1
Worldwide Personal Computer Market by Product Type*

Product Type	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Desktop/Deskside								
Units (K)	39,252	50,259	59,043	69,651	80,847	93,610	108,012	16.5
ASP ($K)	1.88	1.95	1.99	2.01	2.01	1.99	1.95	0
Factory Revenue ($M)	73,937	98,000	117,575	139,907	162,558	186,484	210,500	16.5
Transportable/Laptop								
Units (K)	166	44	42	45	44	43	43	-0.9
ASP ($K)	6.25	5.41	6.35	5.90	5.52	5.53	5.26	-0.6
Factory Revenue ($M)	1,035	240	269	263	243	240	224	-1.4
Notebook/Tablet								
Units (K)	7,480	8,649	11,116	13,049	14,965	16,709	18,979	17.0
ASP ($K)	2.49	2.71	2.44	2.47	2.37	2.34	2.31	-3.2
Factory Revenue ($M)	18,653	23,464	27,119	32,283	35,531	39,055	43,804	13.3

(Continued)

Table 3-1 (Continued)
Worldwide Personal Computer Market by Product Type*

Product Type	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Ultraportable/Notepad								
Units (K)	997	1,219	1,450	1,950	2,838	3,816	4,667	30.8
ASP ($K)	1.84	2.49	2.24	2.26	2.18	2.12	2.09	-3.4
Factory Revenue ($M)	1,832	3,034	3,246	4,411	6,173	8,085	9,750	26.3
Handheld								
Units (K)	390	481	611	850	1,336	2,352	5,052	60.0
ASP ($K)	0.82	0.60	0.55	0.50	0.45	0.40	0.35	-10.2
Factory Revenue ($M)	318	289	336	425	601	941	1,768	43.7
Additional Motherboards								
Units (K)	4,404	7,036	8,266	9,752	11,318	13,105	15,121	16.5
ASP ($K)	1.18	1.00	0.82	0.69	0.70	0.68	0.76	-5.4
Factory Revenue ($M)	5,178	7,018	6,805	6,776	7,889	8,957	11,422	10.2
Total PC (Including Handheld and Additional Motherboards)								
Units (K)	52,689	67,688	80,528	95,296	111,348	129,635	151,873	17.5
ASP ($K)	1.92	1.95	1.93	1.93	1.91	1.88	1.83	-1.3
Factory Revenue ($M)	100,952	132,044	155,350	184,064	212,996	243,762	277,468	16.0
Workstation								
Units (K)	735	841	937	1,027	1,105	1,204	1,307	9.2
ASP ($)	15.06	15.79	15.08	14.64	14.42	14.16	13.75	-2.7
Factory Revenue ($M)	11,070	13,287	14,133	15,036	15,936	17,050	17,975	6.2

*ASP and factory revenue include standard peripherals and memory upgrades installed by the factory or PC assembler.
Source: Dataquest (April 1996)

Table 3-2
Worldwide Personal Computer Shipments by Microprocessor Type (Thousands of Units) (Includes Additional Motherboards; Excludes Handheld Computers)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	1,491	76	0	0	0	0	0	-100.0
486	41,553	30,007	6,778	295	0	0	0	-100.0
Pentium Class	4,605	31,543	63,496	63,289	40,847	22,453	10,317	-20.0
Pentium Pro and Future	0	4	3,478	23,940	61,433	96,262	126,982	680.0
RISC PC	1,153	3,738	5,862	6,903	7,731	8,567	9,523	20.6
680x0	3,495	1,838	304	20	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	52,298.3	67,206.5	79,917.6	94,445.9	110,011.9	127,282.8	146,821.4	16.9

NA = Not applicable
Source: Dataquest (April 1996)

Table 3-3
Worldwide Desktop/Deskside Personal Computer Shipments by Microprocessor Type (Thousands of Units) (Includes Additional Motherboards)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	1,139	63	0	0	0	0	0	-100.0
486	33,929	22,231	3,913	210	0	0	0	-100.0
Pentium Class	4,583	30,082	54,509	50,589	29,259	12,837	3,361	-35.5
Pentium Pro and Future	0	4	3,478	22,558	56,213	86,476	111,549	660.1
RISC PC	1,153	3,547	5,176	6,025	6,694	7,402	8,223	18.3
680x0	2,851	1,367	234	20	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	43,655.8	57,294.1	67,309.6	79,402.3	92,165.3	106,715.3	123,132.8	16.5

NA = Not applicable
Source: Dataquest (June 1996)

Table 3-4
Worldwide Mobile Personal Computer Shipments by Microprocessor Type (Thousands of Units) (Excludes Handheld Computers)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	352	13	0	0	0	0	0	-100.0
486	7,624	7,776	2,865	85	0	0	0	-100.0
Pentium Class	22	1,461	8,987	12,700	11,588	9,616	6,956	36.6
Pentium Pro and Future	0	0	0	1,381	5,221	9,786	15,432	NM
RISC PC	0	191	685	877	1,038	1,165	1,300	46.7
680x0	644	471	71	0	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	8,642.5	9,912.4	12,608.1	15,043.6	17,846.6	20,567.5	23,688.6	19.0

NM = Not meaningful
NA = Not applicable
Source: Dataquest (June 1996)

Table 3-5
Worldwide Personal Computer Revenue by Microprocessor Type (Millions of Dollars) (Includes Additional Motherboards; Excludes Handheld Computers)*

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	1,480	58	0	0	0	0	0	-100.0
486	76,725	52,457	10,366	351	0	0	0	-100.0
Pentium Class	13,879	68,620	121,653	113,622	69,078	36,608	16,890	-24.5
Pentium Pro and Future	0	19	12,090	56,090	129,249	190,752	241,521	558.7
RISC PC	2,808	7,768	10,487	13,554	14,067	15,461	17,289	17.4
680x0	5,741	2,832	418	22	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	100,634.1	131,755.6	155,013.8	183,639.1	212,394.2	242,820.9	275,699.8	15.9

*Factory revenue includes standard peripherals and memory upgrades installed by the factory or PC assembler.
NA = Not applicable
Source: Dataquest (April 1996)

Table 3-6
Worldwide Desktop/Deskside Personal Computer Revenue by Microprocessor Type*
(Millions of Dollars) (Includes Additional Motherboards)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	978	42	0	0	0	0	0	-100.0
486	57,365	33,077	5,250	221	0	0	0	-100.0
Pentium Class	13,691	62,792	97,997	83,565	44,406	17,769	4,223	-41.7
Pentium Pro and Future	0	19	12,090	51,697	114,537	165,051	203,562	536.6
RISC PC	2,808	7,294	8,757	11,178	11,506	12,621	14,136	14.1
680x0	4,273	1,794	286	22	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	79,114.3	105,017.9	124,379.9	146,682.8	170,447.9	195,441.1	221,921.9	16.1

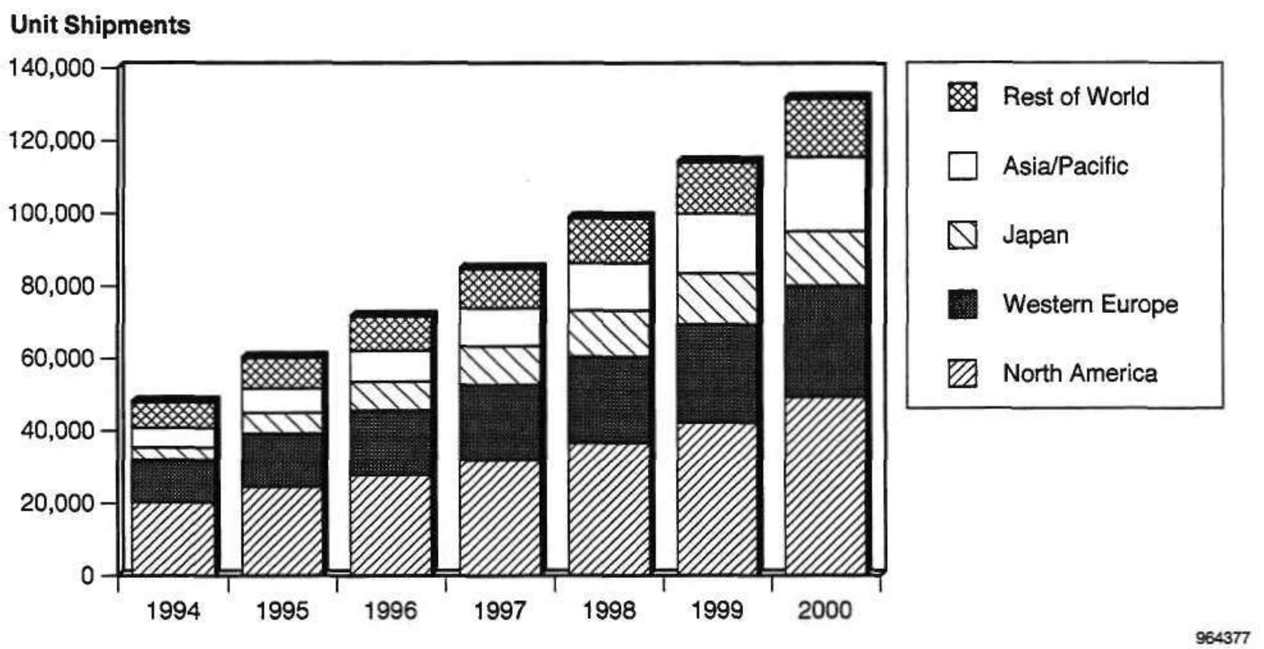
*Factory revenue includes standard peripherals and memory upgrades installed by the factory or PC assembler.
NA = Not applicable
Source: Dataquest (April 1996)

Table 3-7
Worldwide Mobile Personal Computer Revenue by Microprocessor Type*
(Millions of Dollars) (Excludes Handheld Computers)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	502	17	0	0	0	0	0	-100.0
486	19,360	19,381	5,116	130	0	0	0	-100.0
Pentium Class	189	5,828	23,656	30,057	24,673	18,839	12,666	16.8
Pentium Pro and Future	0	0	0	4,394	14,712	25,701	37,959	NA
RISC PC	0	474	1,730	2,376	2,561	2,840	3,153	46.1
680x0	1,469	1,039	132	0	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	21,519.8	26,737.7	30,633.9	36,956.3	41,946.3	47,379.9	53,777.9	15.0

NA= Not applicable
*Factory revenue includes standard peripherals and memory upgrades installed by the factory or PC assembler.
Source: Dataquest (April 1996)

Figure 3-4
Regional Personal Computer Markets (Unit Shipments)



Note: This document does not include regional PC production data because that data was not finalized in time for publication. Regional PC production data will be published in a document when finalized later this summer.
Source: Dataquest (June 1996)

Table 3-8
Personal Computers—Worldwide Revenue Market Share (Percent)*

	1994	1995
Compaq Computer Corporation	10.4	10.2
IBM	8.9	8.0
Apple Computer	8.4	7.7
NEC	5.4	5.5
Packard Bell	3.9	4.5
Hewlett-Packard	2.7	3.6
Dell Computer Corporation	3.2	3.6
Toshiba	3.6	3.4
Acer	2.3	2.7
Gateway 2000	2.7	2.7
Others	48.6	48.0
Total	100.0	100.0

*Does not include motherboard upgrade revenue
Source: Dataquest (April 1996)

Table 3-9
Personal Computers—Worldwide Unit Market Share (Percent)*

	1994	1995
Compaq Computer Corporation	10.0	10.0
IBM	8.2	7.9
Apple Computer	8.3	7.8
Packard Bell	5.2	5.3
NEC	4.1	4.8
Hewlett-Packard	2.7	3.7
Acer	2.6	3.1
Dell Computer Corporation	2.7	3.0
Toshiba	2.5	2.5
AST Research	2.7	2.3
Others	51.0	49.5
Total	100.0	100.0

*Does not include motherboard upgrade revenue
Source: Dataquest (April 1996)

Systems Technology and Architecture Trends

The technology road maps of PCs and workstations are principally driven by the twin factors of economy and improved end-user features. PC makers typically try to give the buyer more features with each new product generation while maintaining price points. Workstation makers are known more for emphasizing performance and other features, although the low end of the workstation market is forced to compete directly with the high end of the PC range. Some specific trends are listed in the following sections.

Personal Computers

Trends in PCs are as follows:

- Desktop power demand will come from servicing graphical user interface (GUI) and WYSIWYG-oriented applications, including processing (compressing and decompressing); store, forward, and read multimedia (OLE-enabled); and real-time multimedia such as desktop videoconferencing. Networking support increasingly will require faster servicing as transfer rates climb (for example, toward 100 Mbps over Ethernet) and the size and frequency of transferred files and e-mail increase as well.
- Pentium-class microprocessors will continue to dominate as multimedia features and higher clock frequencies give these processors a midlife boost in performance. Next-generation microprocessors (MPUs) such as Pentium Pro will grow in importance and are expected to match unit shipments of Pentium-class MPUs at the end of 1997 or early 1998.
- The PowerPC alliance will continue to be a major element for Apple and IBM but may suffer from Motorola's decision to pursue process development independently.

- Peripheral Component Interconnect (PCI) and Industry Standard Architecture (ISA) combinations are the overwhelming standard for backplane buses. PCI will be enhanced with Accelerated Graphics Port (AGP) in 1997. ISA will continue to exist for some time to maintain compatibility with the vast bulk of legacy add-in cards.
- Plug-and-play PCs, with support from major players such as Microsoft, Intel, Compaq, Advanced Micro Devices, and others, will be a significant feature in the drive to make PCs more user-friendly. Universal serial bus (USB) and IEEE 1394 will be the standards for external plug-and-play devices, with USB shipments starting in 1996.
- The green PC, stimulated by the Energy Star program and similar requirements coming out of Europe, is being recycled with new emphasis on desktop PC power management. Advanced configuration power interface (ACPI) and Microsoft's OnNow are critical elements of renewed efforts to make desktop PCs more efficient.
- Enhanced Integrated Development Environment (EIDE) will remain the dominant interface to mass storage, with parallel SCSI the choice for connecting external mass-storage devices. Parallel SCSI will face increasing pressure from serial SCSI standards (predominately IEEE 1394, with fiber channel arbitrated loop making inroads in the workstation market).
- Serial and parallel I/O have remained fairly constant, but now new technologies such as 1394/Firewire, Access.bus, and USB are vying to displace those trusted standbys.
- USB ports will appear on PCs this year, with rapid growth in 1997 and 1998. This local bus for the PC will provide a common standard for communicating among PCs, modems, scanners, joysticks, keyboards, mice, monitors, and printers.
- Mobile computers will be enhanced with 32-bit CardBus slots rather than the standard PCMCIA slots, but the average number of slots per mobile PC may decline as modems and network controllers become standard equipment on more notebook designs.
- Other key trends in mobile computing will include commercialized low-power-consuming components, standardization of operating voltage for circuits and components at 3V/3.3V, continued increases in sophistication of battery management, improved battery technology, and effective handwriting/voice recognition capabilities.

Table 3-10 highlights projected trends in PC technology.

Figure 3-5 shows areas that offer opportunities for enhancement.

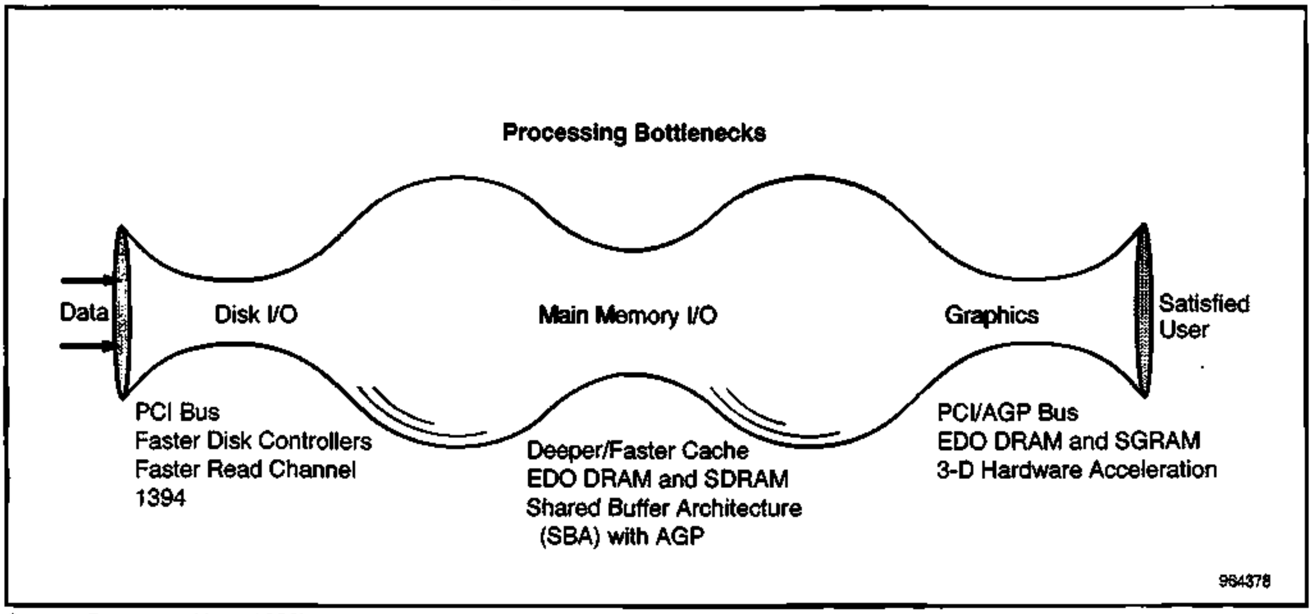
Tables 3-11 through 3-15 provide forecasts for key PC and workstation technologies.

Table 3-10
The Evolving PC

	1994	1996	1998	Trend
Main Memory (Factory-Installed)	8MB to 10MB FPM DRAM	14MB to 16MB EDO DRAM	20MB to 24MB SDRAM	Toward synchronous types of DRAM
CPU	486 DX2/DX4	Pentium 100 MHz to 133 MHz	Pentium 200 MHz/ Pentium Pro; with MMX	Rapid adoption of MMX; shift from Pentium to Pentium Pro
Cache (Factory-Configured)	128KB	0KB/256KB	256KB/512KB	Cacheless Pentium Pro systems are unlikely; minimum increases to 256KB
Peripheral Buses	VL/ISA	PCI/ISA	PCI/AGP	Rise of AGP for graphics; systems will have some support for legacy ISA peripherals
Graphics and Video	32-bit, 2-D acceleration, 1MB buffer	64-bit, 2-D and video acceleration, 2MB buffer	64-bit, 2-D, 3-D and video acceleration, 2.5MB dedicated, sharing of main memory via AGP	Rapid growth of 3-D as graphics vendors strive to continue to add value
Storage	EIDE (5MB/sec)/SCSI	EIDE (13MB/sec)/SCSI-2	EIDE (20MB/sec)/SCSI-2/ 3/1394	EIDE likely to remain in-box interface; rise of 1394
Local I/O	RS-232/422	RS-232/422, beginning of shift to USB	USB, RS-232/422	USB will become primary interface; RS-232/422 for legacy items

Source: Dataquest (April 1996)

Figure 3-5
PC Performance Enhancement Opportunities



Source: Dataquest (June 1996)

Table 3-11
Worldwide PC Bus Requirements (Percentage of Total or Category)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
VL/ISA	66.9	49.2	15.6	0.6	0	0	0	-100.0
PCI/ISA	16.6	44.0	81.4	63.1	24.7	5.0	0	-100.0
PCI/AGP/ISA	0	0	0	35.0	75.0	95.0	100.0	NM
Other	16.5	6.8	3.0	1.3	0.3	0	0	-100.0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 3-12
Worldwide Penetration of PCMCIA/PC Card/CardBus Slot Forecast (Thousands of Slots)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
With One or More Type II Slots	10,389	13,175	14,411	11,529	6,917	2,767	0	-100.0%
With One or More Type III Slots	4,040	4,831	5,139	5,115	4,804	4,408	5,000	0.7%
With One or More CardBus slots	0	0	2,522	3,153	3,783	4,540	5,448	NM
Total	14,429	18,005	22,072	19,796	15,504	11,714	10,448	-10.3%

NM = Not meaningful
Source: Dataquest (June 1996)

Table 3-13
Worldwide PC (Host) Storage Interface Requirement (Percentage of Category)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
All PCs								
EIDE/ATA	85	86	88	85	72	44	15	-29.5
SCSI (I/II/III)	15	14	12	10	8	6	5	-18.6
1394/SSA/FC-AL	0	0	0	5	20	50	80	NM
Pentium Pro and Future								
EIDE/ATA	0	20	50	70	60	50	40	14.9
SCSI (I/II/III)	0	80	49	25	20	20	20	-24.2
1394/SSA/FC-AL	0	0	1	5	20	30	40	NM
RISC PC								
EIDE/ATA	2	10	10	10	10	10	10	0
SCSI (I/II/III)	98	90	90	75	60	30	15	-30.1
1394/SSA/FC-AL	0	0	0	15	30	60	75	NM

NM = Not meaningful
Source: Dataquest (June 1996)

Table 3-14
Worldwide PC Graphics Standard Penetration (Motherboard-Based or Add-In) (Percent)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Std VGA	28.9	9.4	0.8	0	0	0	0	-100.0
2-D Acceleration	68.3	66.2	28.9	4.1	0	0	0	-100.0
2-D Acceleration with Video Acceleration	2.8	24.3	66.9	73.0	44.9	14.9	1.6	-41.7
2-D, 3-D, and Video Acceleration	0	0.1	3.4	22.9	55.1	85.1	98.4	325.6

Source: Dataquest (June 1996)

Table 3-15
Worldwide Embedded Communications and Multimedia in PCs (Percentage of Total)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Overall PC								
Analog Modem	1.5	1.6	1.9	2.3	2.8	3.2	3.6	18.3
LAN	0.9	1.7	8.6	21.3	21.4	21.6	21.8	66.1
USB	0	0	8.7	46.0	91.9	100.0	100.0	NM
Sound I/O	3.5	22.4	28.9	37.2	39.7	40.5	41.3	13.0
Graphics	44.9	57.4	57.9	66.4	66.5	66.5	66.5	3.0
MPEG Decoder	0.0	0.6	1.2	2.0	2.0	2.0	2.0	28.4
General-Purpose DSP	0.1	0.5	1.0	1.7	2.3	3.0	3.7	49.7
Desktop/Deskside PC								
Analog Modem	1.4	1.5	1.7	2.0	2.4	2.7	3.0	14.9
LAN	1.0	2.0	10.0	15.0	20.0	25.0	25.0	65.7
USB	0	0	10.0	50.0	100.0	100.0	100.0	NM
Sound I/O	1.2	21.4	25.0	30.0	35.0	40.0	50.0	18.5
Graphics	34.0	50.0	50.0	60.0	60.0	60.0	60.0	3.7
MPEG Decoder	0	0.5	1.0	2.0	2.0	2.0	2.0	32.0
General-Purpose DSP	0.1	0.4	0.8	1.6	2.3	3.2	4.0	58.5
Mobile PC (Excluding Handhelds)								
Analog Modem	2.0	2.0	4.0	6.0	10.0	12.0	14.0	28.5
LAN	0.1	0.1	1.0	2.0	3.0	4.0	5.0	118.7
USB	0	0	2.0	25.0	50.0	100.0	100.0	NM
Sound I/O	15.0	28.3	50.0	75.0	90.0	95.0	100.0	28.7
Graphics	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0
MPEG Decoder	0	1.0	2.0	2.0	2.0	2.0	2.0	14.9
General-Purpose DSP	0	1.0	2.0	2.0	2.0	2.0	2.0	14.9

Source: Dataquest (June 1996)

Chapter 4
Semiconductor Market Trends for PCs and Workstations

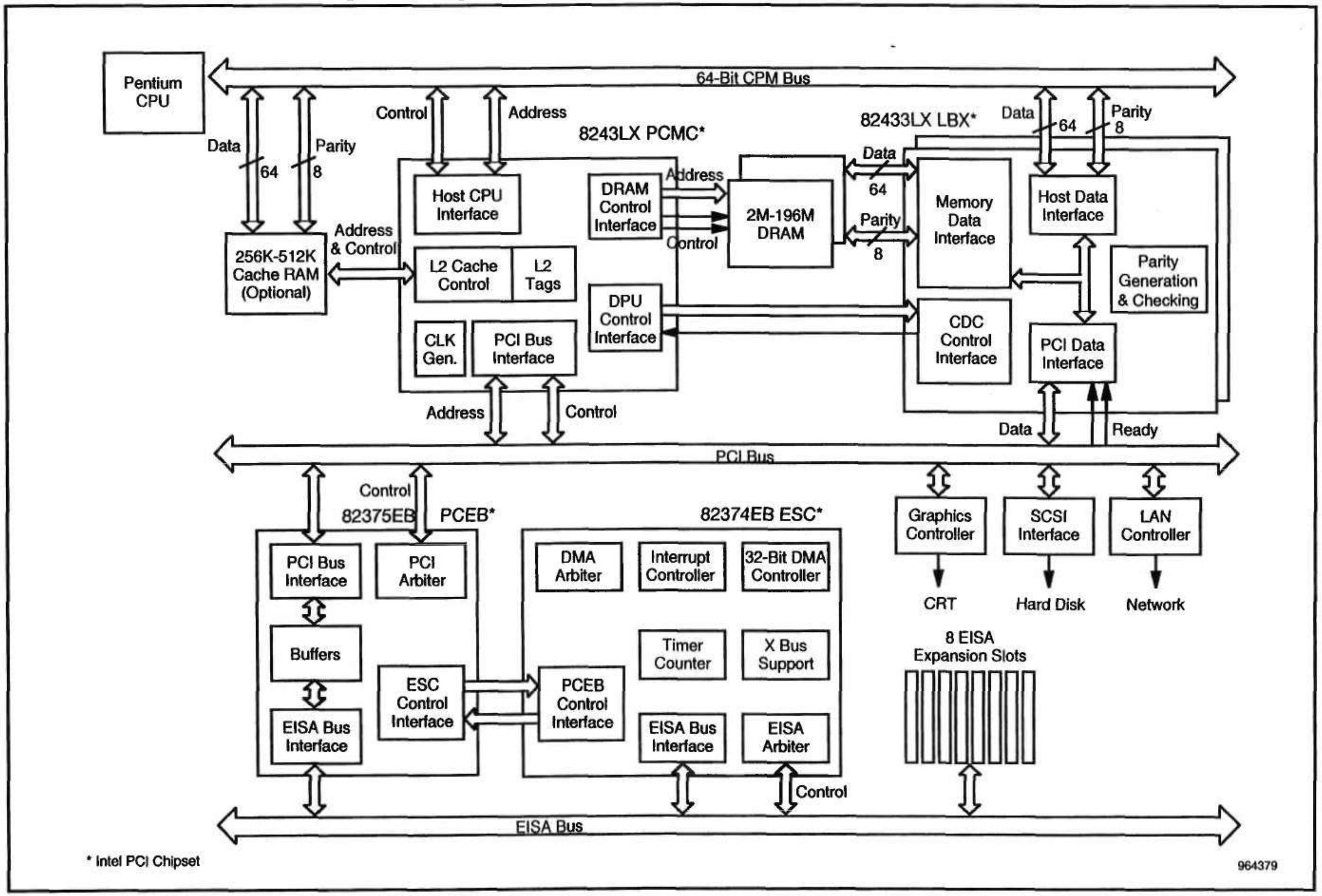
Semiconductor Market Opportunities and Technology Trends

Semiconductor market opportunities and technology trends are as follows:

- New generations of Pentium, Pentium Pro, PowerPC, Alpha, PA-RISC, SPARC, and MIPS processors will drive future PCs, workstations, and servers. Future trends include internal frequencies climbing past the current 200-MHz offerings for PCs and 400-MHz offerings for workstations. Multiprocessing features will also be available in many workstations and high-end PCs using Pentium Pro MPUs.
- Proprietary processors such as Advanced RISC Machines' ARM will continue to be used in palmtop devices and other communications-based applications.
- PCs with an average of 14MB to 16MB DRAM main memory in 1995 will move to 32MB DRAM in 1998.
- Increased opportunities will emerge for synchronous DRAM (SDRAM) as MPU speeds outstrip conventional memory architectures.
- Bursting, MPU-specific SRAM will be used for cache design. Static RAM (SRAM) modules were becoming more popular, but are costly compared to soldered-down designs.
- New chipsets to support MPUs and the new buses (USB and the AGP enhancement to PCI) will continue to emerge.
- Mixed-signal accelerated window graphics on a single chip (with RAMDAC) will be mainstream. High-resolution (1024 x 768, 16-color) 3-D graphics (OpenGL for workstations; Direct3D for consumer PCs) and digital video features will become more prevalent.
- Mixed-signal I/O chips will support high-speed storage and peripherals communications (EIDE, SCSI, IEEE 1394/Firewire). Chips integrating LAN and SCSI control will complement existing super I/O functions.
- Sound and video coder/decoders (codecs) and I/O functions will be used in multimedia systems. Microsoft, IBM, and Apple are continuing to provide multimedia and telephony interfaces to their operating systems.

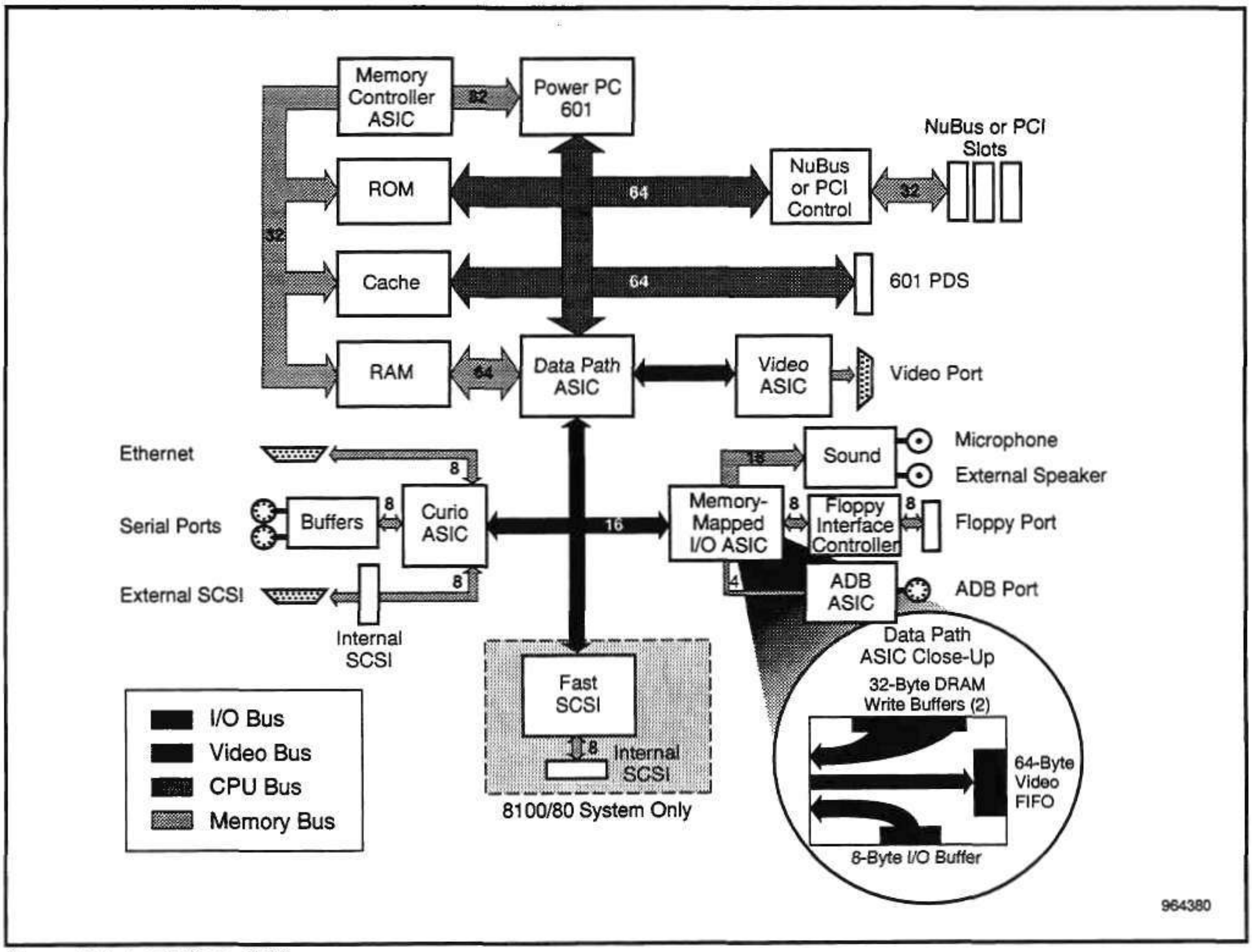
Figures 4-1 to 4-4 provide block diagrams for generic Pentium desktop, Power Macintosh, generic notebook, and Apple Newton systems.

Figure 4-1
Generic Pentium-Based Desktop PC Using PCI Bus



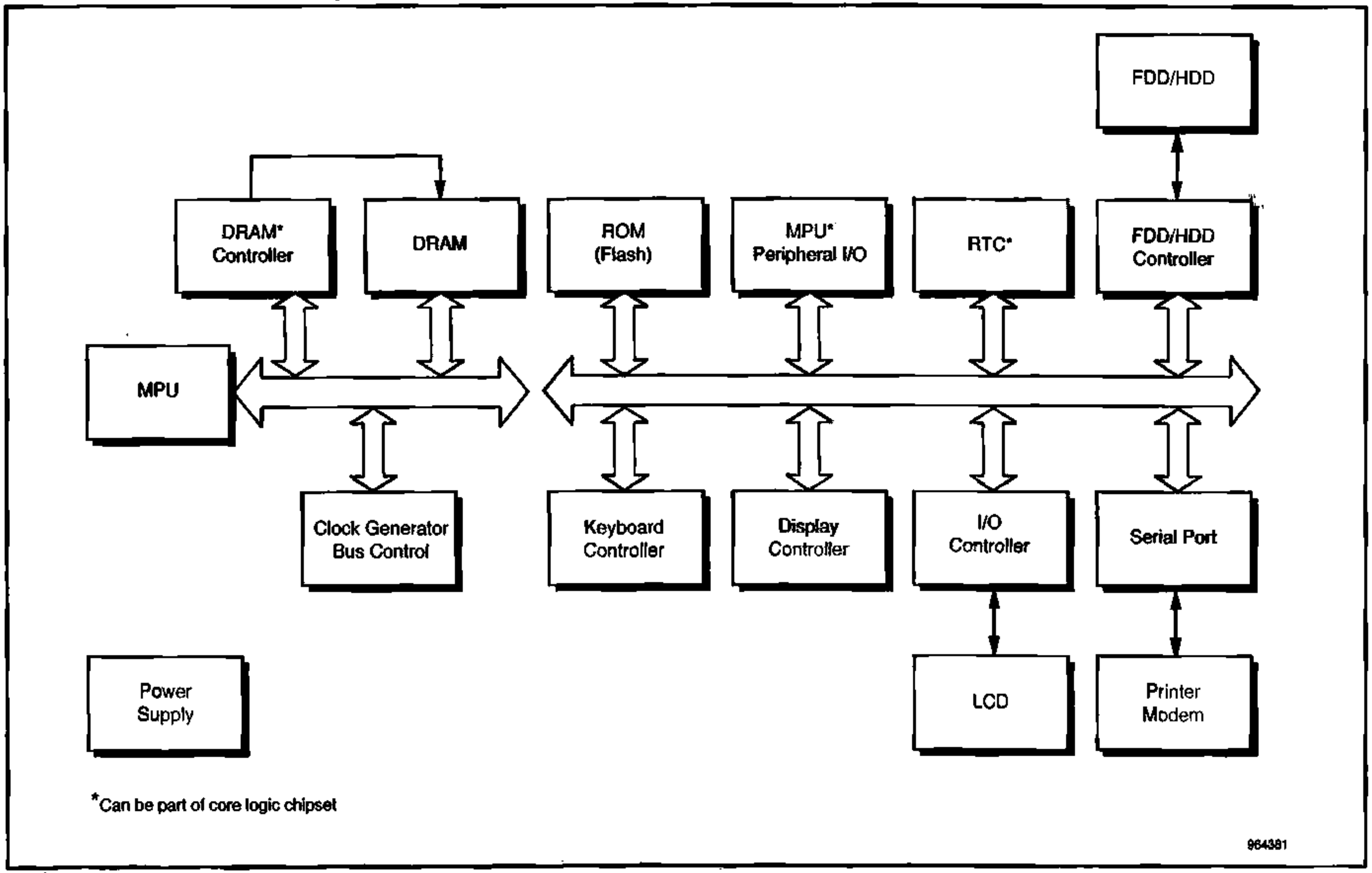
Source: Intel

Figure 4-2
Power Macintosh Hardware Architecture



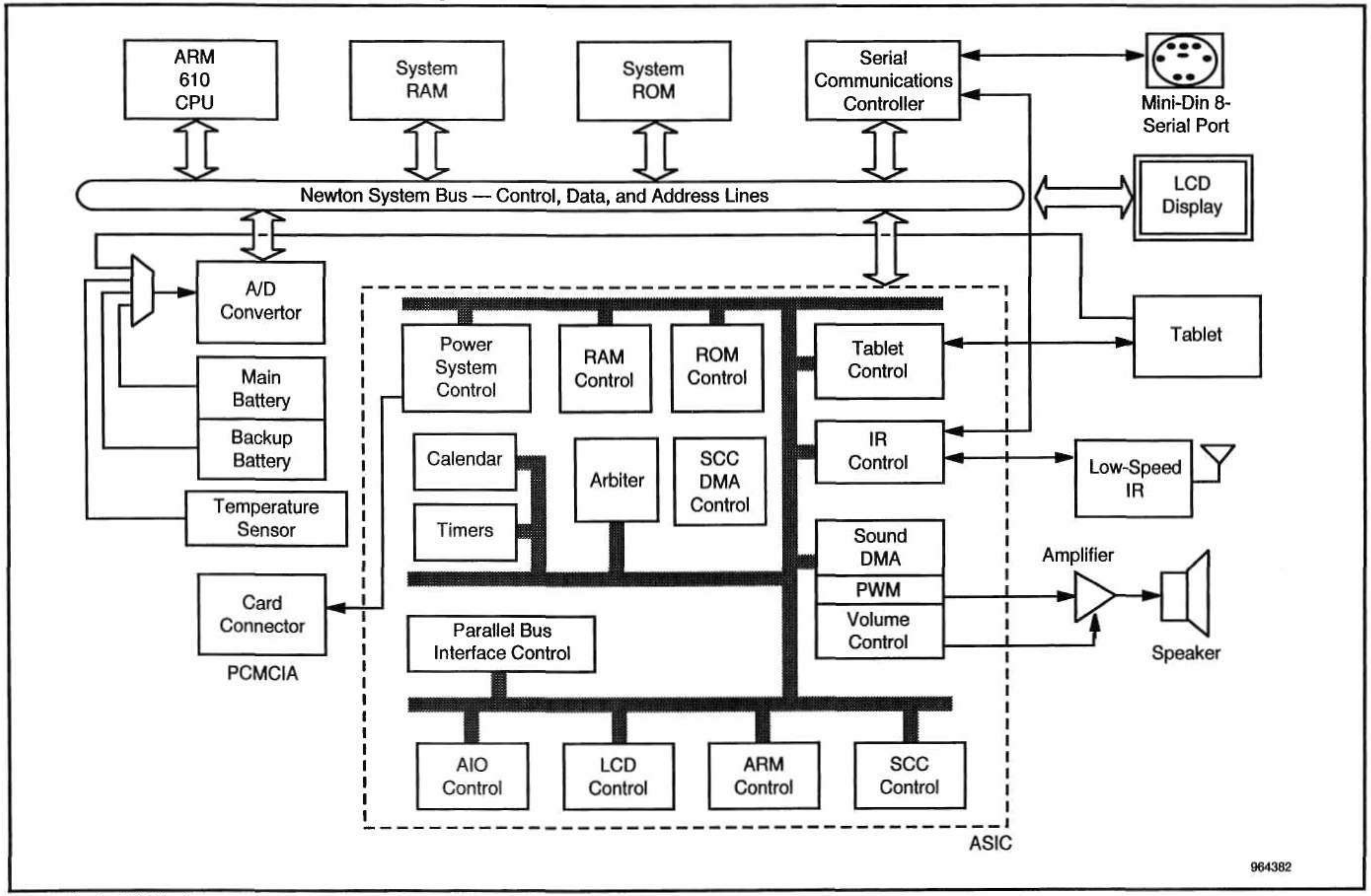
Source: Dataquest (June 1996)

Figure 4-3
Generic Notebook Block Diagram



Source: Dataquest (April 1996)

Figure 4-4
Apple Newton MessagePad Block Diagram

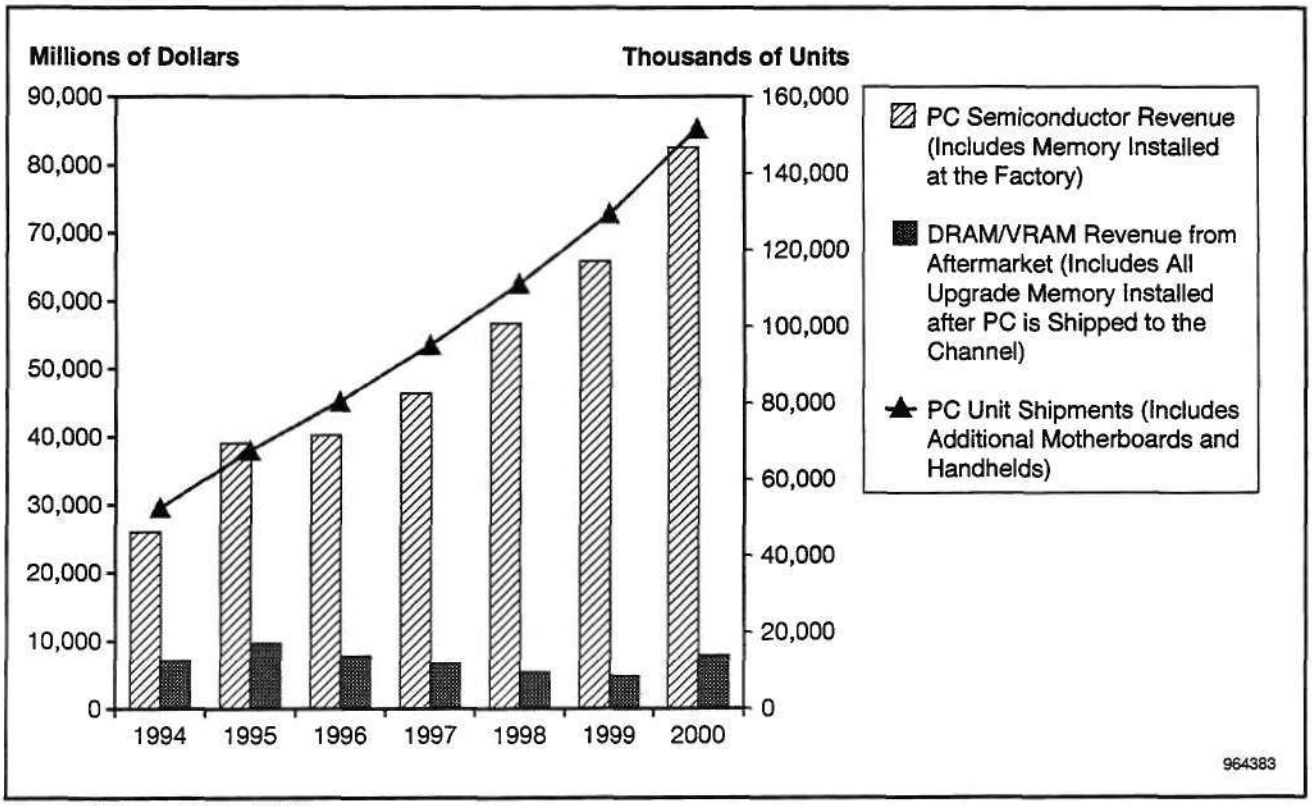


Source: Apple, PC Week

Chapter 5
Market Size and Forecast for PC and Workstation Semiconductors

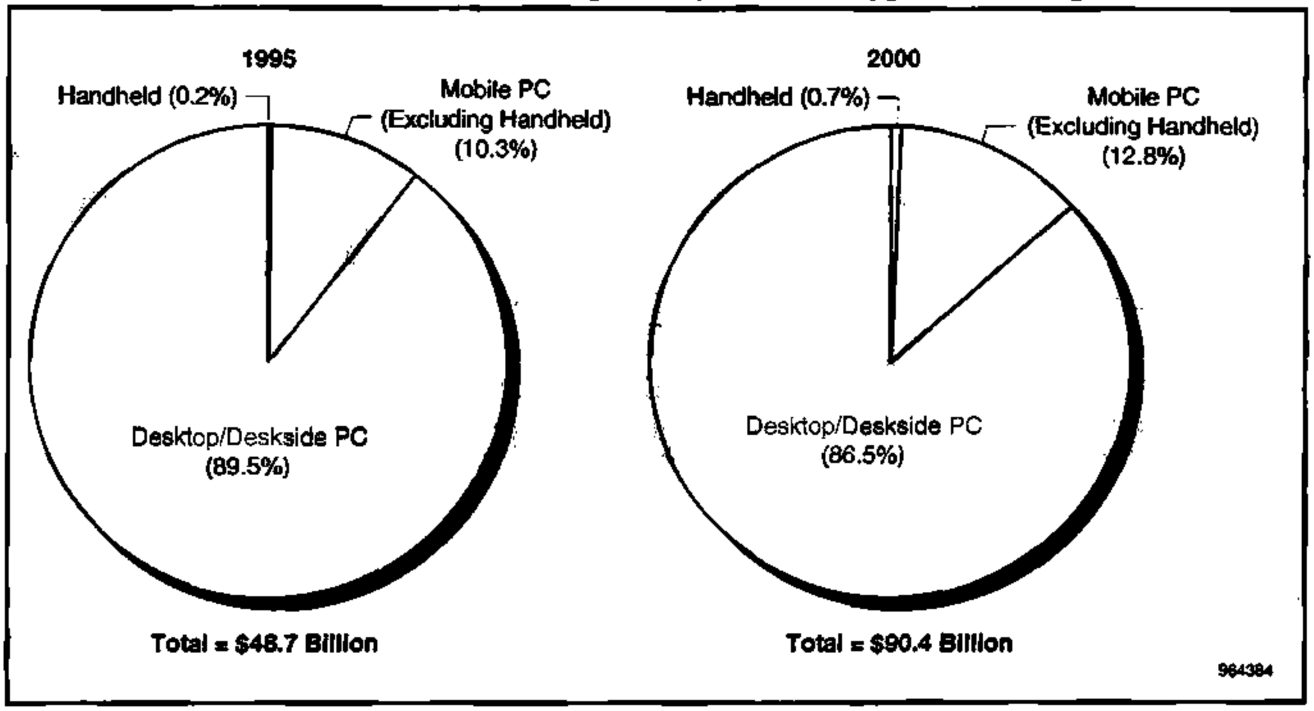
Figures 5-1 and 5-2 and Tables 5-1 and 5-2 provide forecasts and illustrations of semiconductor opportunities in the PC and workstation markets, including a focus on opportunities by region, system type, and semiconductor device type.

Figure 5-1
Worldwide PC Semiconductor Market (Revenue in Millions of Dollars, Shipments in Thousands of Units)



Source: Dataquest (June 1996)

Figure 5-2
Worldwide PC Semiconductor Consumption by Product Type (Percentage)



Source: Dataquest (June 1996)

Table 5-1
Worldwide PC Production and Semiconductor Market (Less Peripherals; Includes Standard Handhelds)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Complete PC Systems								
Units (K)	48,284	60,652	72,262	85,544	100,030	116,530	136,752	17.7
Factory ASP ($K)	4.30	4.55	4.33	4.36	4.23	4.10	3.88	-3.1
Factory Revenue ($M)	95,775	125,027	148,544	177,288	205,106	234,805	266,046	16.3
Semiconductor Content per System ($)	497	586	503	489	510	510	549	-1.3
Semiconductor TAM ($M)	24,016	35,551	36,330	41,812	51,030	59,382	75,138	16.1
Desktop/Deskside PC Systems								
Units (K)	39,252	50,259	59,043	69,651	80,847	93,610	108,012	16.5
Factory ASP ($K)	1.88	1.95	1.99	2.01	2.01	1.99	1.95	0
Factory Revenue ($M)	73,937	98,000	117,575	139,907	162,558	186,484	210,500	16.5

(Continued)

Table 5-1 (Continued)
Worldwide PC Production and Semiconductor Market (Less Peripherals; Includes Standard Handhelds)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Semiconductor Content per System ($)	519	605	519	502	531	536	582	-0.8
Semiconductor TAM ($M)	20,368	30,417	30,667	34,949	42,931	50,213	62,887	15.6
Mobile PC Systems								
Units (K)	9,032	10,394	13,219	15,893	19,183	22,920	28,741	22.6
Factory ASP ($K)	2.42	2.60	2.34	2.35	2.22	2.11	1.93	-5.8
Factory Revenue ($M)	21,838	27,026	30,970	37,381	42,548	48,321	55,546	15.5
Semiconductor Content per System ($)	404	494	428	432	422	400	426	-2.9
Semiconductor TAM ($M)	3,647	5,134	5,663	6,863	8,099	9,169	12,251	19.0
Additional Motherboards								
Units (K)	4,404	7,036	8,266	9,752	11,318	13,105	15,121	16.5
Factory ASP ($K)	1.18	1.00	0.82	0.69	0.70	0.68	0.76	-5.4
Factory Revenue ($M)	5,178	7,018	6,805	6,776	7,889	8,957	11,422	10.2
Semiconductor Content per System ($)	519	605	519	502	531	536	582	-0.8
Semiconductor TAM ($M)	2,285	4,258	4,294	4,893	6,010	7,030	8,804	15.6
Total Production								
Units (K)	52,689	67,688	80,528	95,296	111,348	129,635	151,873	17.5
Factory ASP ($K)	1.92	1.95	1.93	1.93	1.91	1.88	1.83	-1.3
Factory Revenue ($M)	100,952	132,044	155,350	184,064	212,996	243,762	277,468	16.0
Semiconductor Content per System ($)	499	588	504	490	512	512	553	-1.2
Semiconductor TAM ($M)	26,301	39,809	40,624	46,705	57,040	66,412	83,942	16.1

Source: Dataquest (June 1996)

Table 5-2
Worldwide PC Semiconductor Market by System (Millions of Dollars)

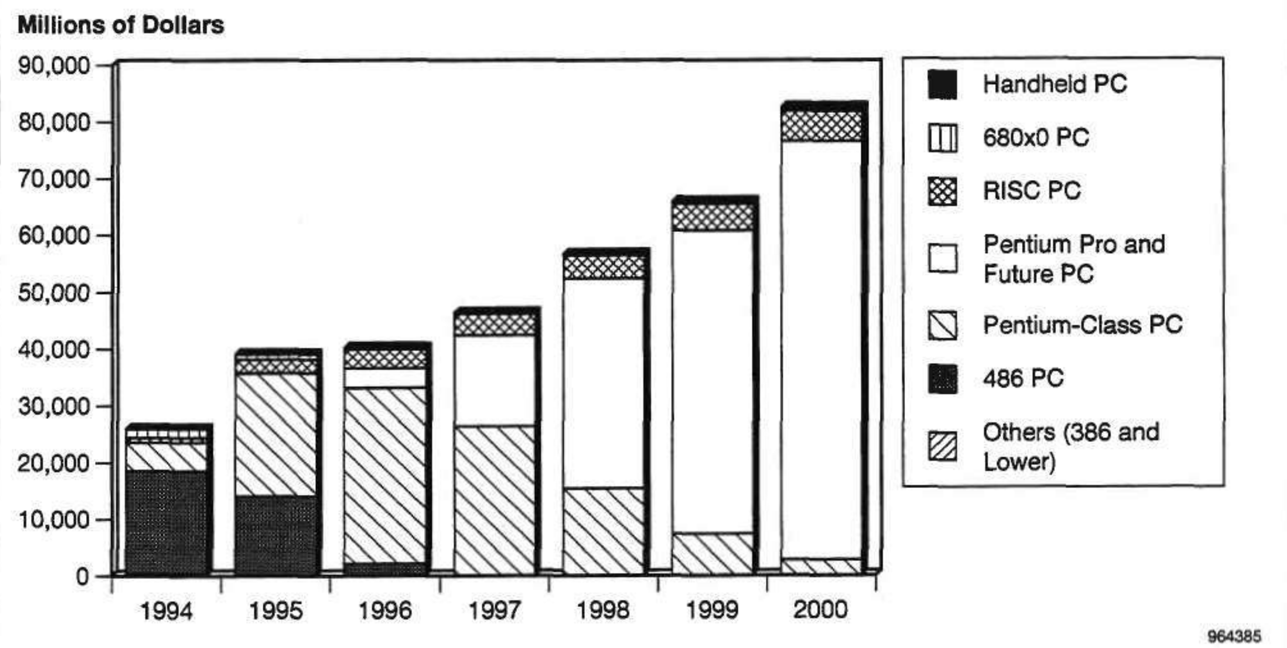
	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Other (386 and Lower)	388	17	0	0	0	0	0	-100.0
486 PC	18,249	14,152	2,201	73	0	0	0	-100.0
Pentium-Class PC	4,955	21,623	31,003	26,379	15,515	7,374	2,791	-33.6
Pentium Pro and Future PC	0	7	3,475	16,072	36,954	53,490	73,855	532.5
RISC PC	901	2,397	3,345	3,693	4,027	4,676	5,256	17.0
680x0 PC	1,396	803	83	8	0	0	0	-100.0
Handheld PC	74	94	128	149	219	344	663	47.8
Total	25,963	39,094	40,235	46,375	56,715	65,885	82,565	16.1
Year-to-Year Growth (%)		50.6	2.9	15.3	22.3	16.2	25.3	

Source: Dataquest (June 1996)

Semiconductor Opportunities by System

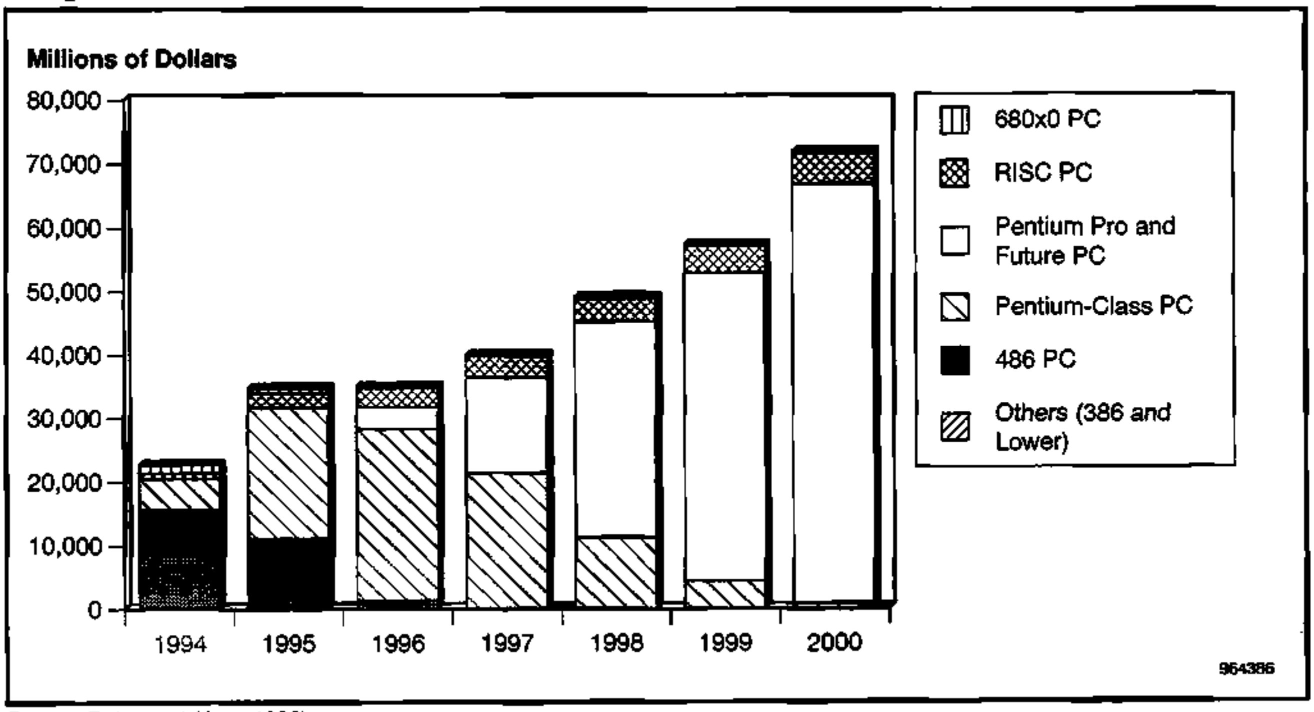
Figures 5-3 through 5-12 and Tables 5-2 through 5-4 detail semiconductor opportunities by system.

Figure 5-3
Worldwide PC Semiconductor Market by Microprocessor Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



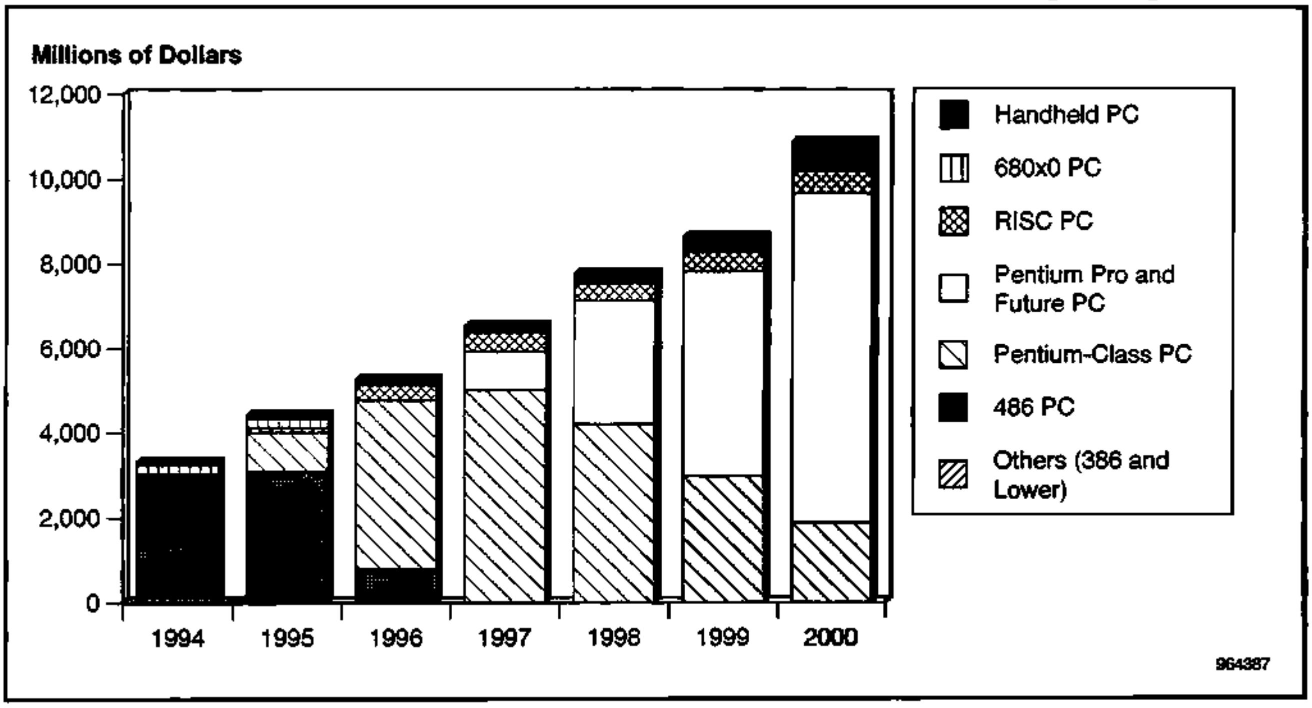
Source: Dataquest (June 1996)

Figure 5-4
Worldwide Desktop/Deskside PC Semiconductor Market by Microprocessor Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



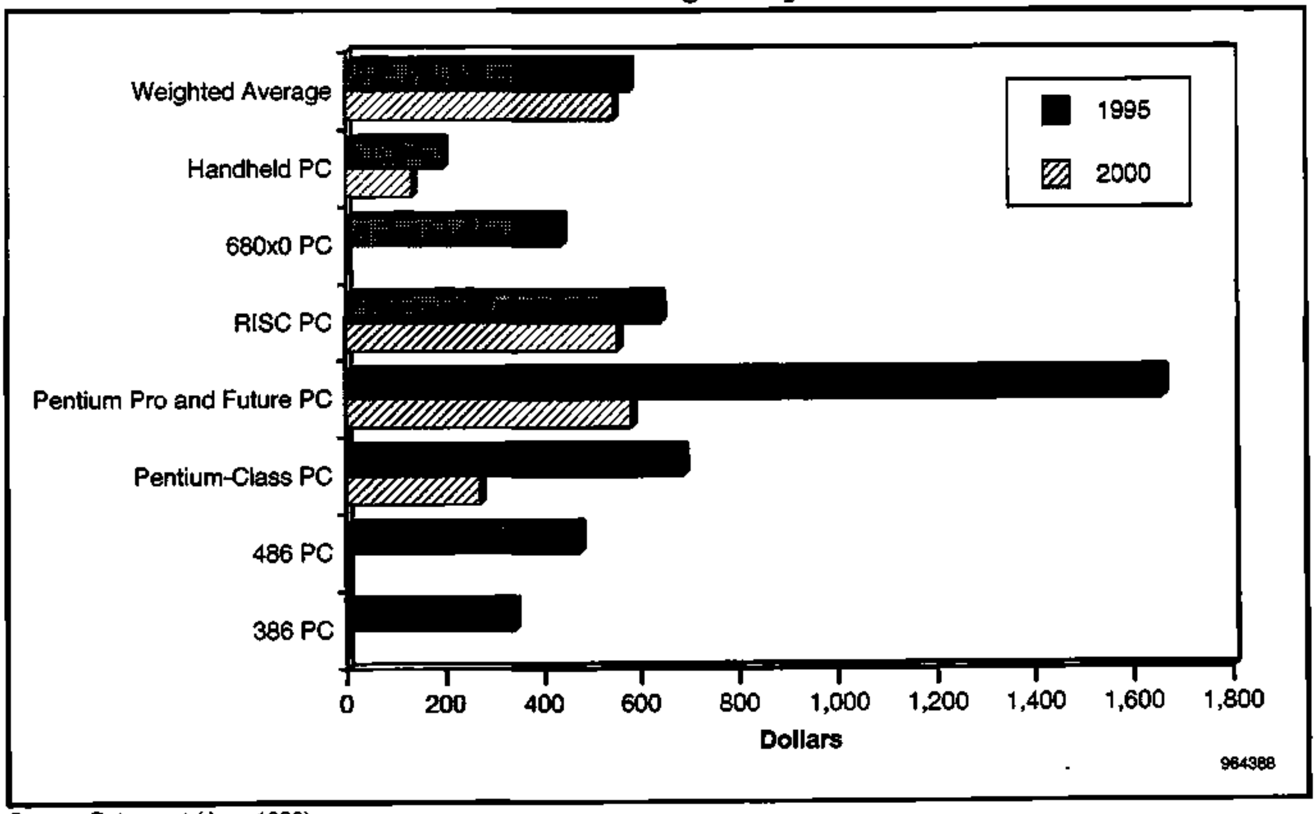
Source: Dataquest (June 1996)

Figure 5-5
Worldwide Mobile PC Semiconductor Market by Microprocessor Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



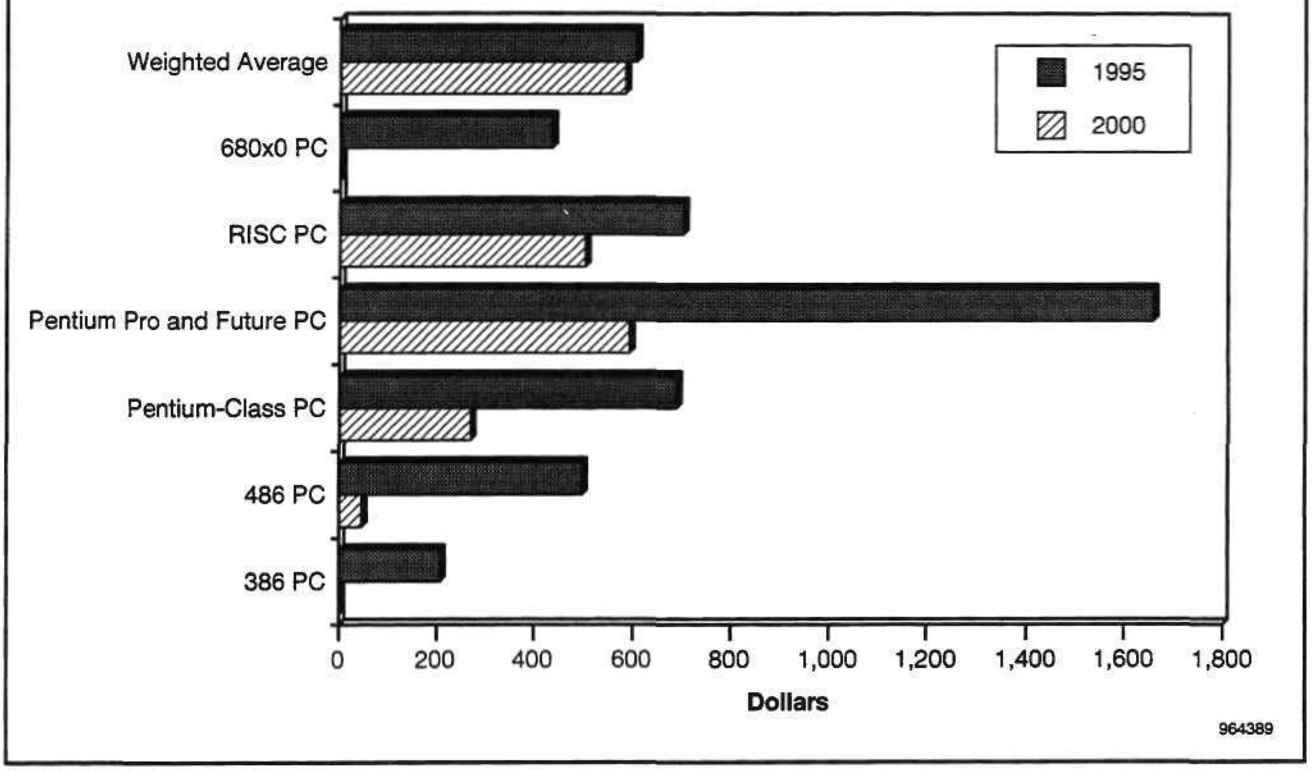
Source: Dataquest (June 1996)

Figure 5-6
Average Overall PC System Semiconductor Content (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



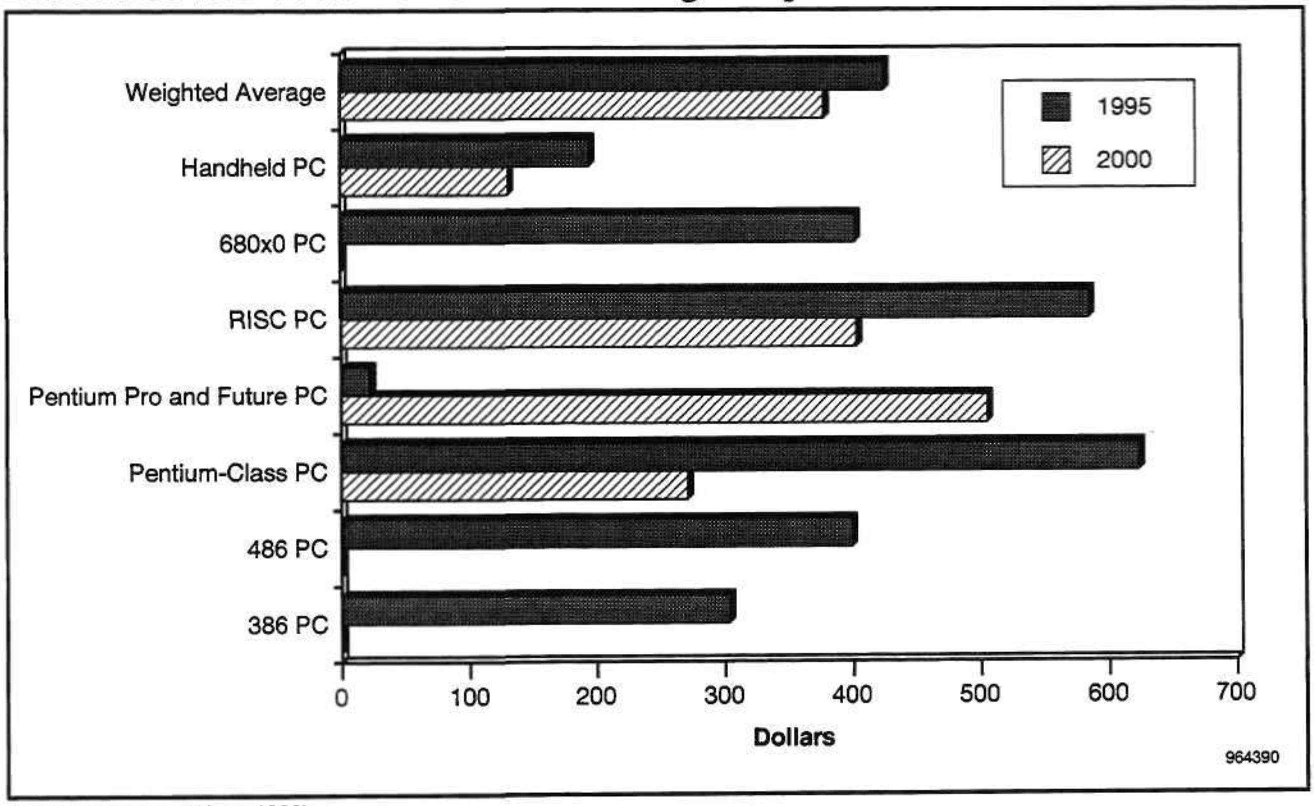
Source: Dataquest (June 1996)

Figure 5-7
Average Desktop/Deskside PC System Semiconductor Content (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



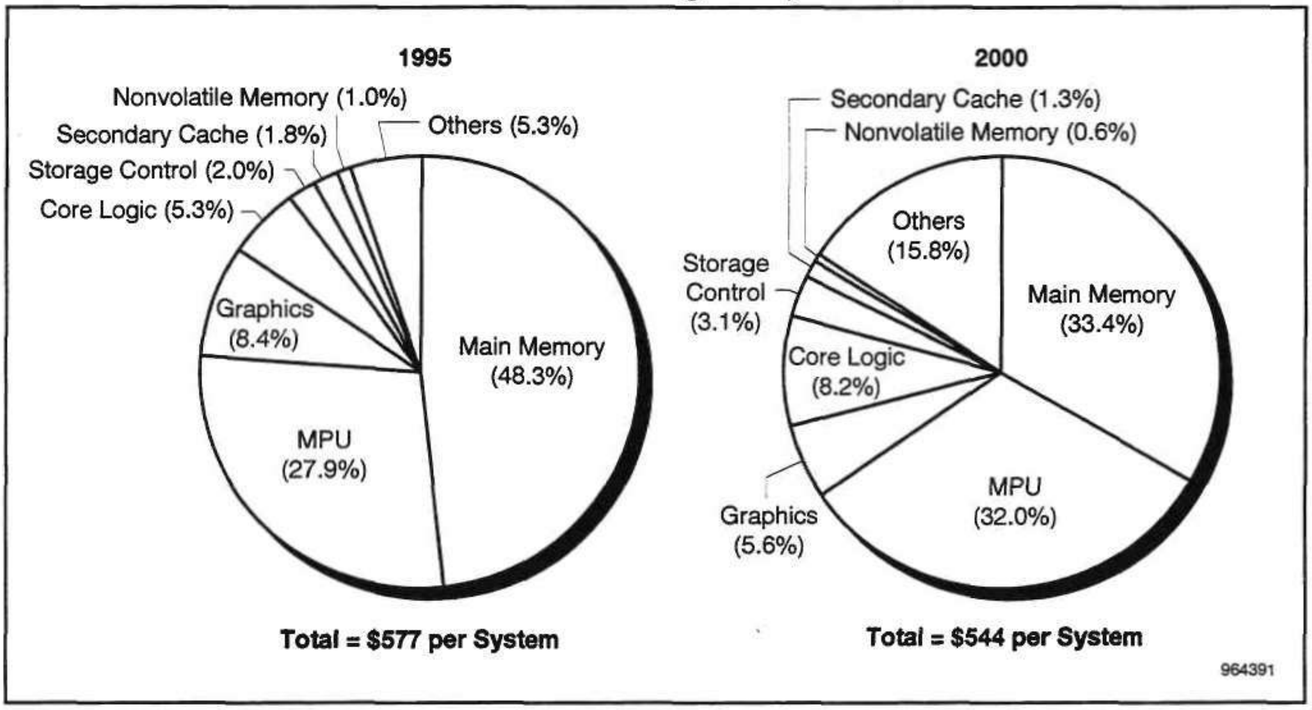
Source: Dataquest (June 1996)

Figure 5-8
Average Mobile PC System Semiconductor Content (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



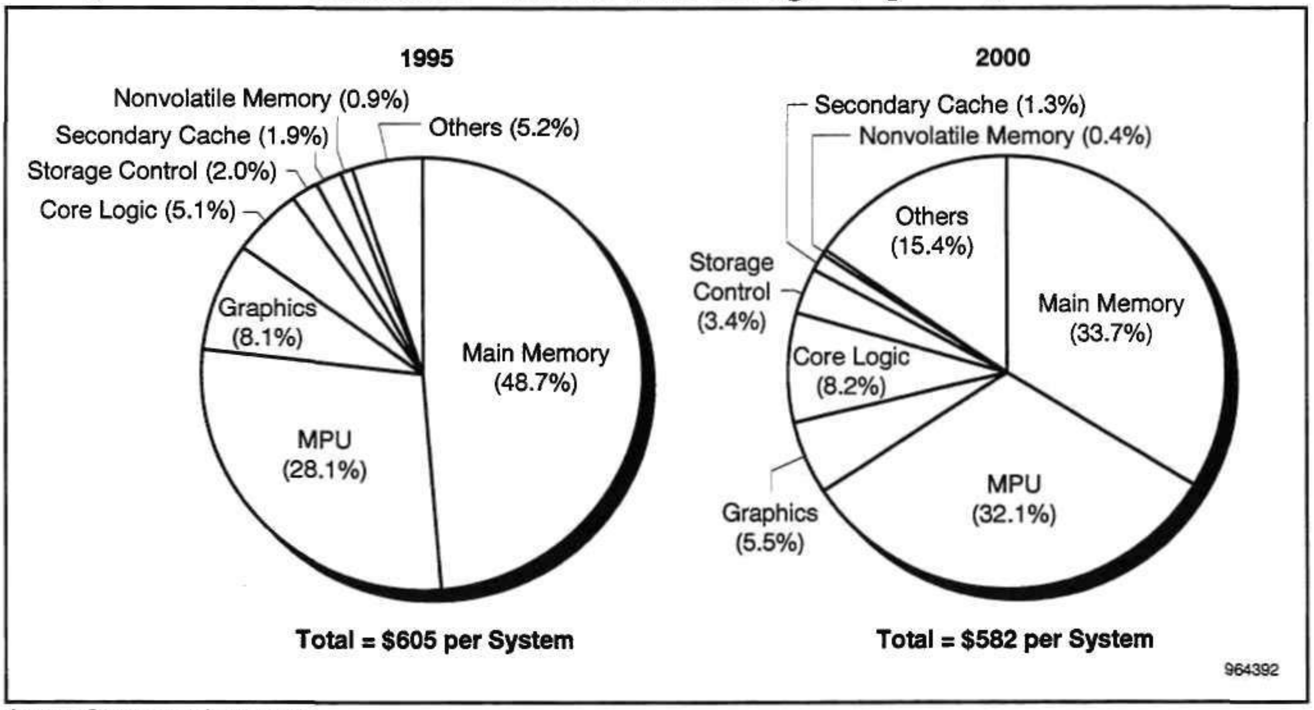
Source: Dataquest (June 1996)

Figure 5-9
Overall PC Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



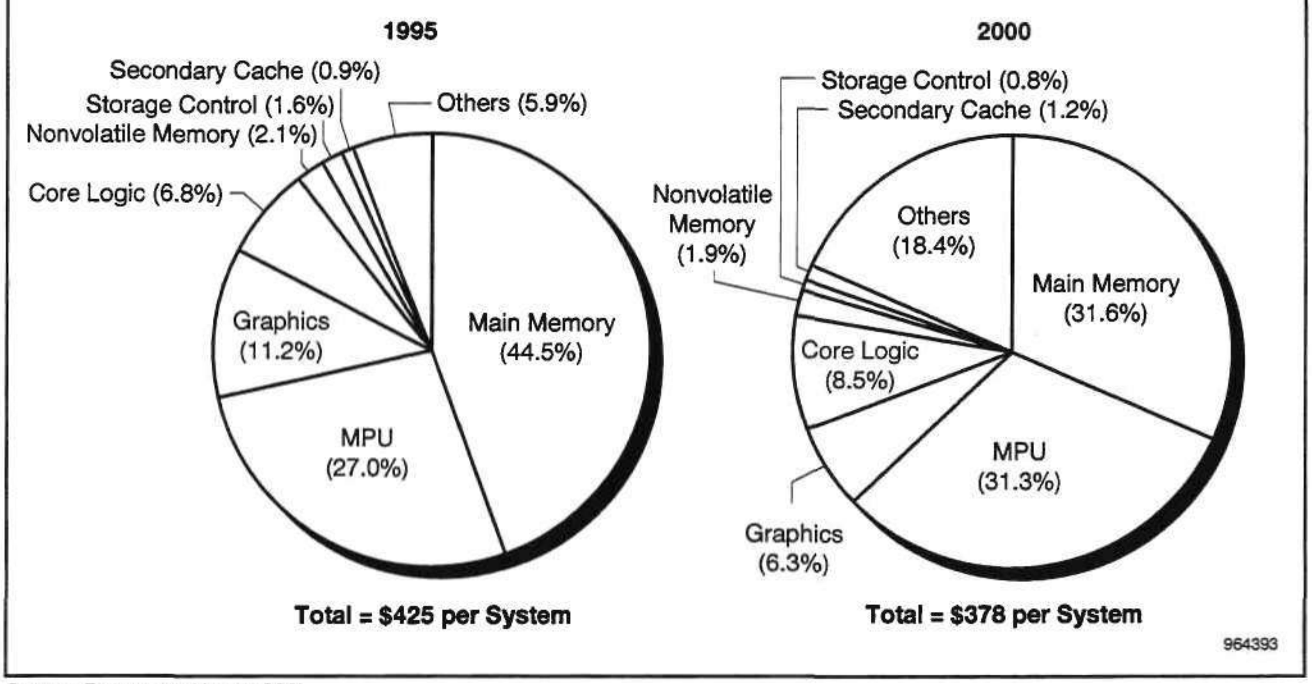
Source: Dataquest (June 1996)

Figure 5-10
Overall Desktop/Deskside PC Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



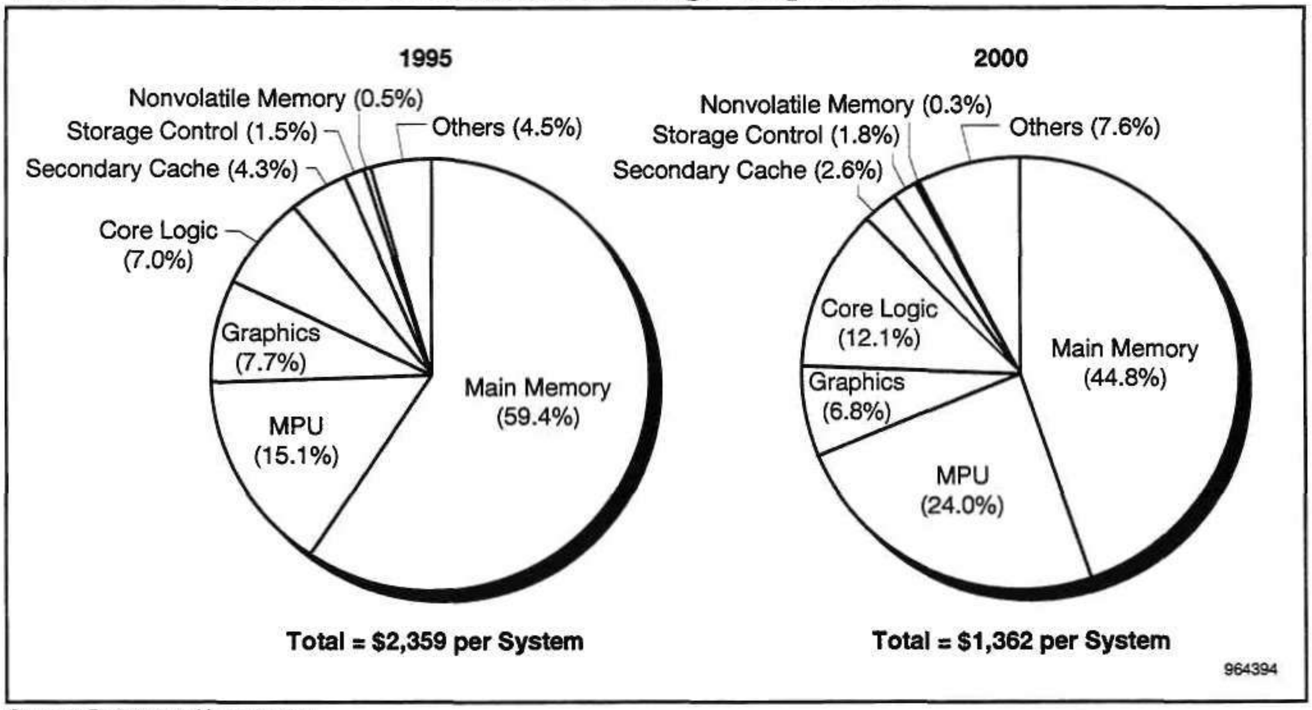
Source: Dataquest (June 1996)

Figure 5-11
Overall Mobile PC Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



Source: Dataquest (June 1996)

Figure 5-12
Overall Workstation Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



Source: Dataquest (June 1996)

Table 5-3
Worldwide Desktop/Deskside PC Semiconductor Market by System (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Others (386 and Lower)	259	13	0	0	0	0	0	-100.0
486 PC	15,372	11,051	1,402	54	0	0	0	-100.0
Pentium-Class PC	4,935	20,713	27,023	21,369	11,304	4,386	905	-46.5
Pentium Pro and Future PC	0	7	3,475	15,168	34,028	48,637	66,054	518.6
RISC PC	901	2,285	2,981	3,244	3,609	4,220	4,731	15.7
680x0 PC	1,187	605	79	8	0	0	0	-100.0
Total	22,654	34,674	34,960	39,842	48,941	57,243	71,691	15.6
Year-to-Year Growth (%)		53.1	0.8	14.0	22.8	17.0	25.2	

Source: Dataquest (June 1996)

Table 5-4
Worldwide Mobile PC Semiconductor Market by System (Millions of Dollars)

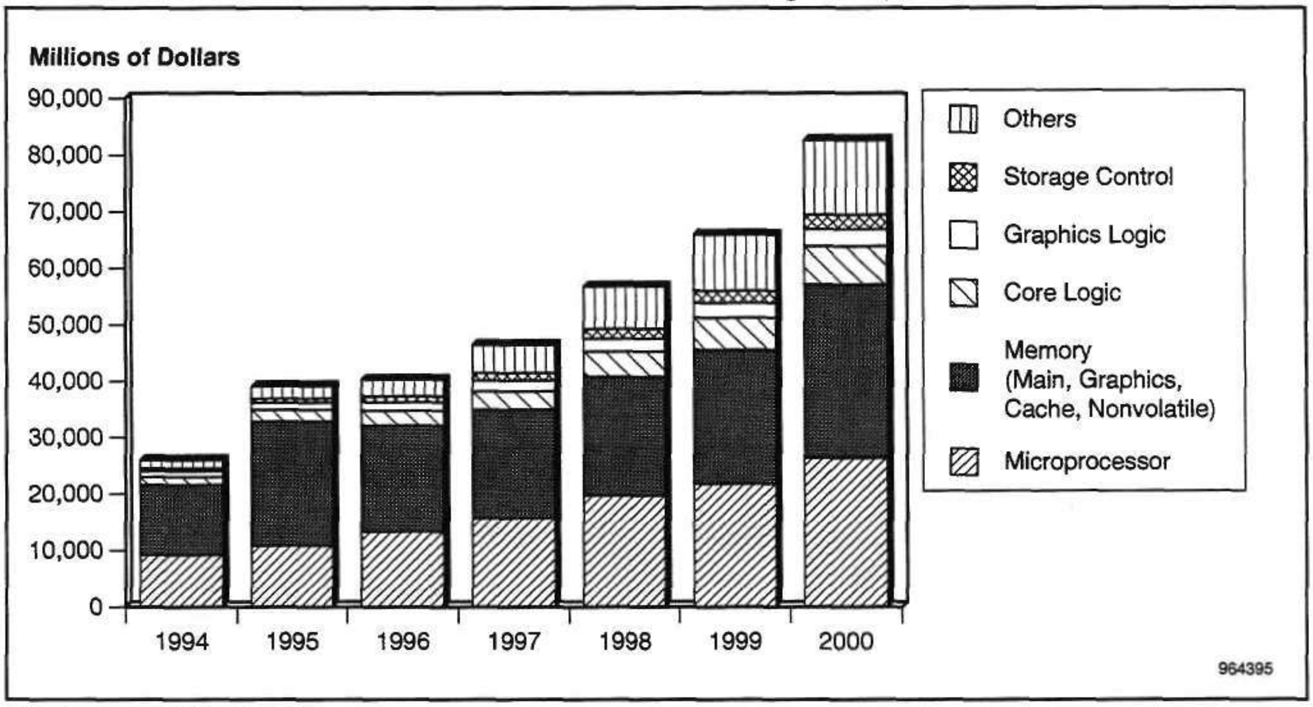
	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Others (386 and Lower)	129	4	0	0	0	0	0	-100.0
486 PC	2,878	3,101	799	19	0	0	0	-100.0
Pentium-Class PC	20	911	3,980	5,011	4,211	2,989	1,886	15.7
Pentium Pro and Future PC	0	0	0	904	2,926	4,853	7,801	NM
RISC PC	0	112	364	448	417	456	525	36.2
680x0 PC	209	198	3	0	0	0	0	-100.0
Handheld PC	74	94	128	149	219	344	663	47.8
Total	3,310	4,420	5,275	6,532	7,774	8,642	10,874	19.7
Year-to-Year Growth (%)		33.5	19.3	23.8	19.0	11.2	25.8	

NM = Not meaningful
Source: Dataquest (June 1996)

Semiconductor Opportunities by Device Type

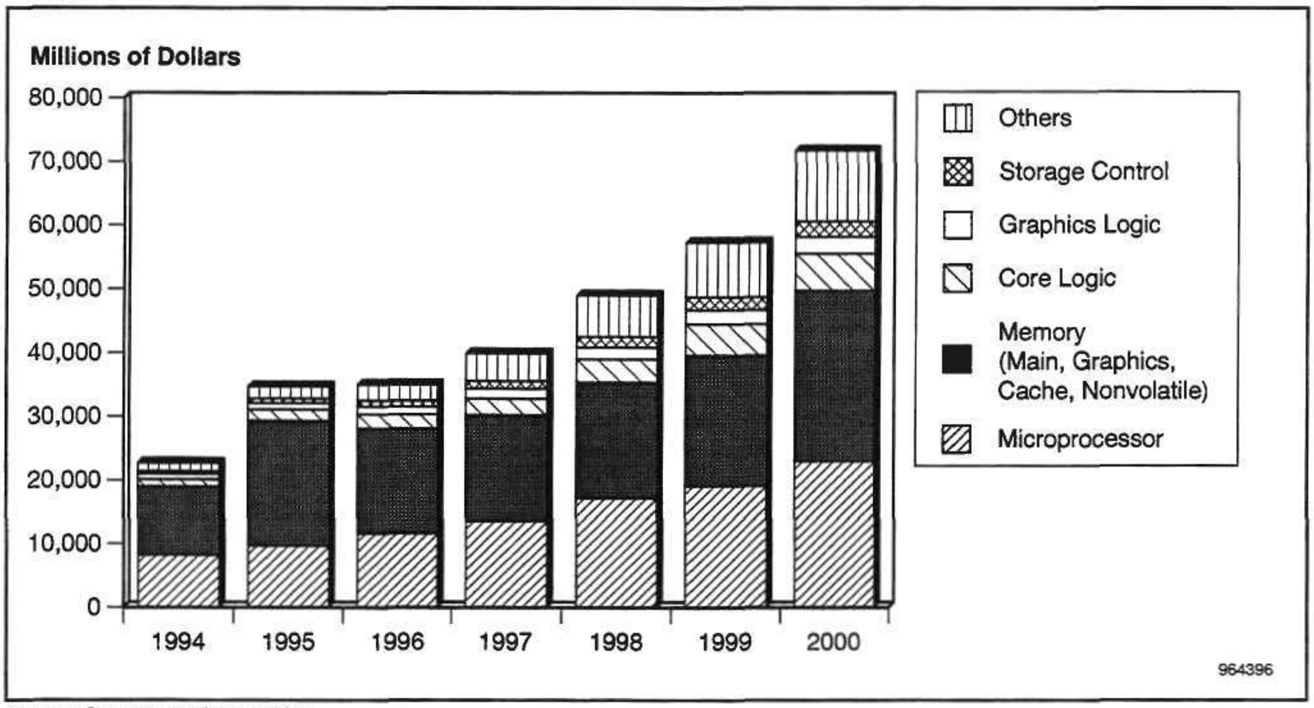
Figures 5-13 through 5-24 and Tables 5-5 through 5-17 detail semiconductor opportunities by device type.

Figure 5-13
Worldwide Total PC Semiconductor Market by Device Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



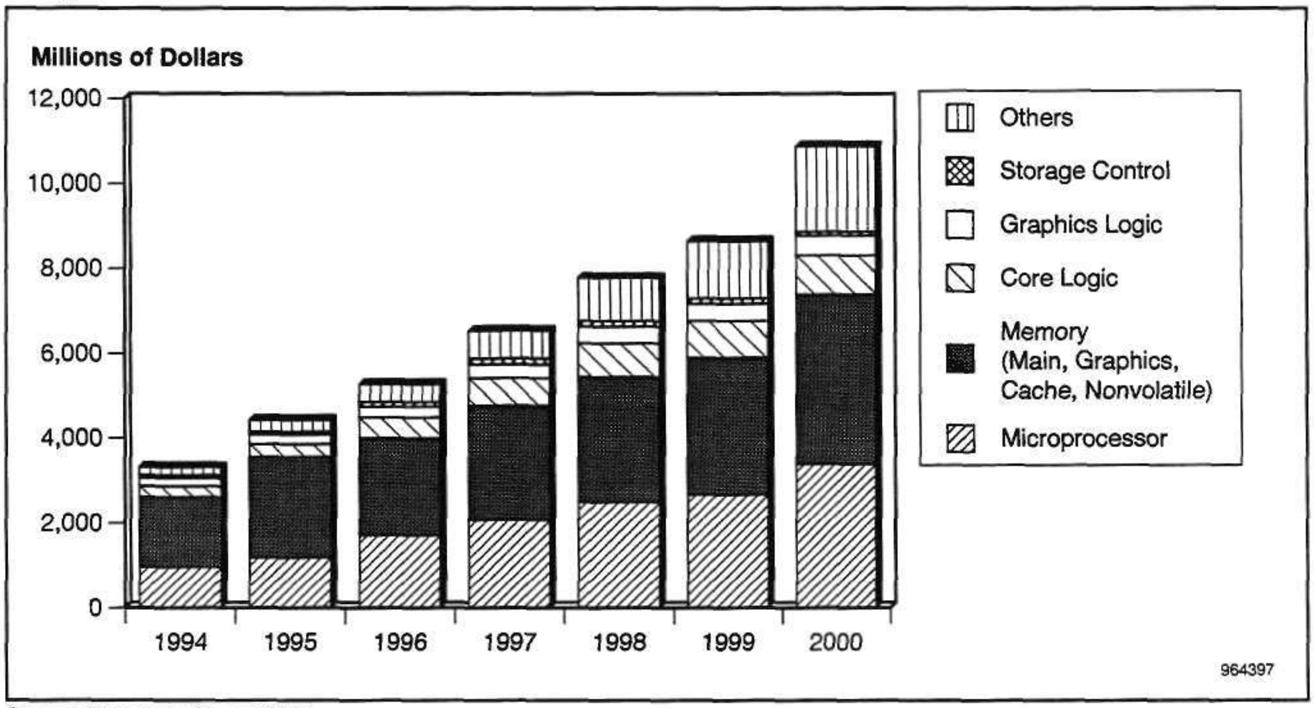
Source: Dataquest (June 1996)

Figure 5-14
Worldwide Desktop/Deskside PC Semiconductor Market by Device Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



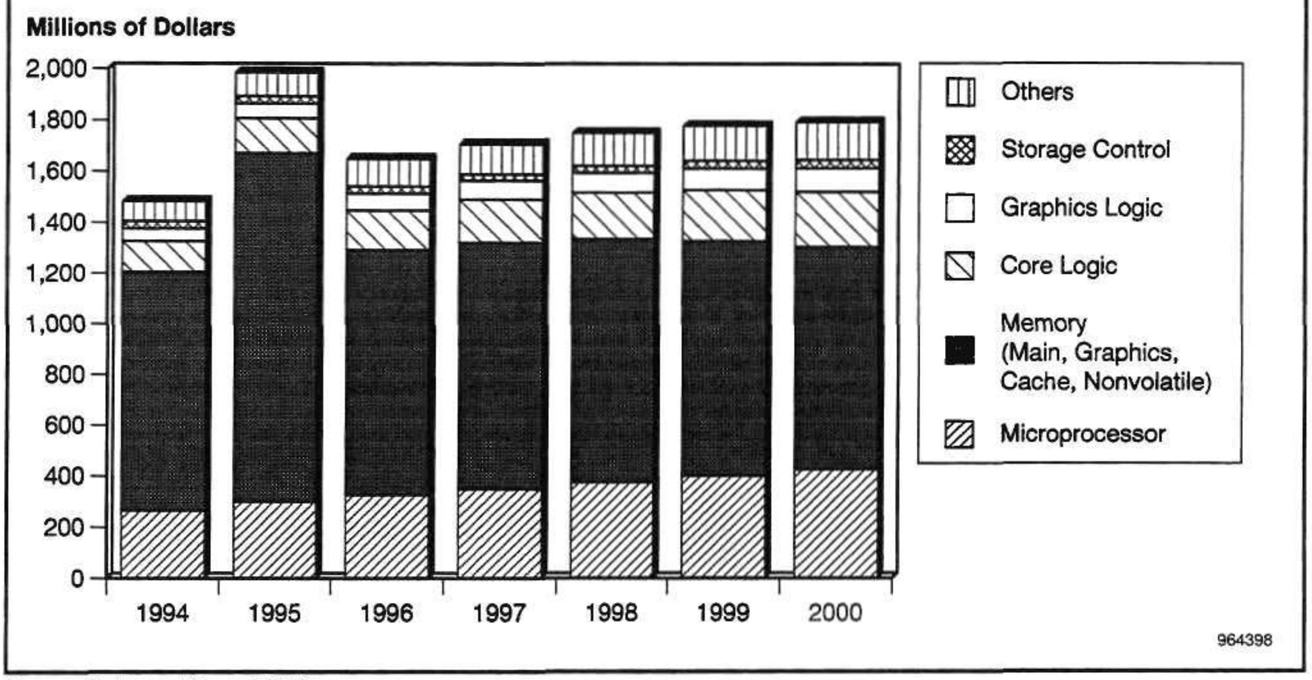
Source: Dataquest (June 1996)

Figure 5-15
Worldwide Mobile PC Semiconductor Market by Device Type
(Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



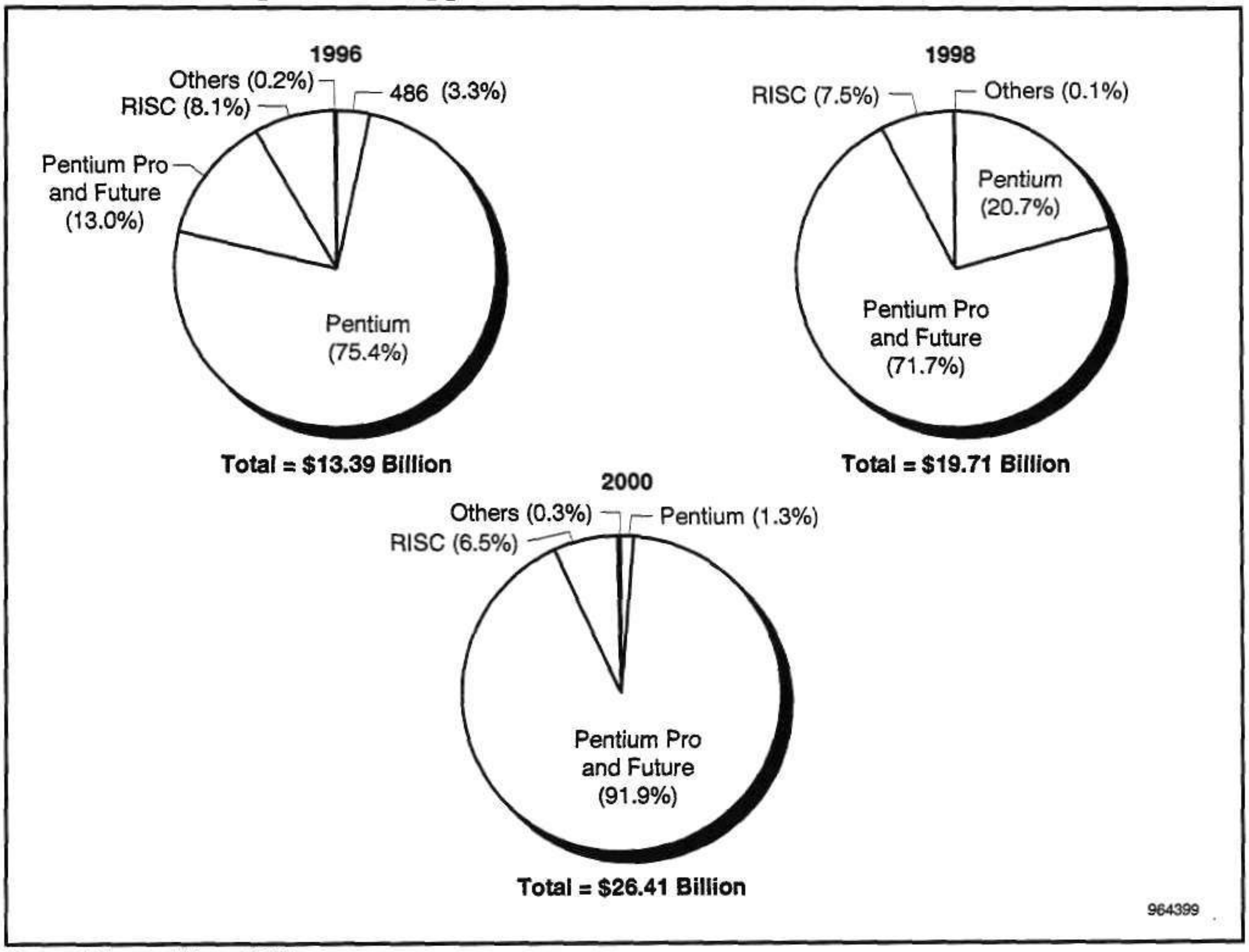
Source: Dataquest (June 1996)

Figure 5-16
Worldwide Workstation Semiconductor Market by Device Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



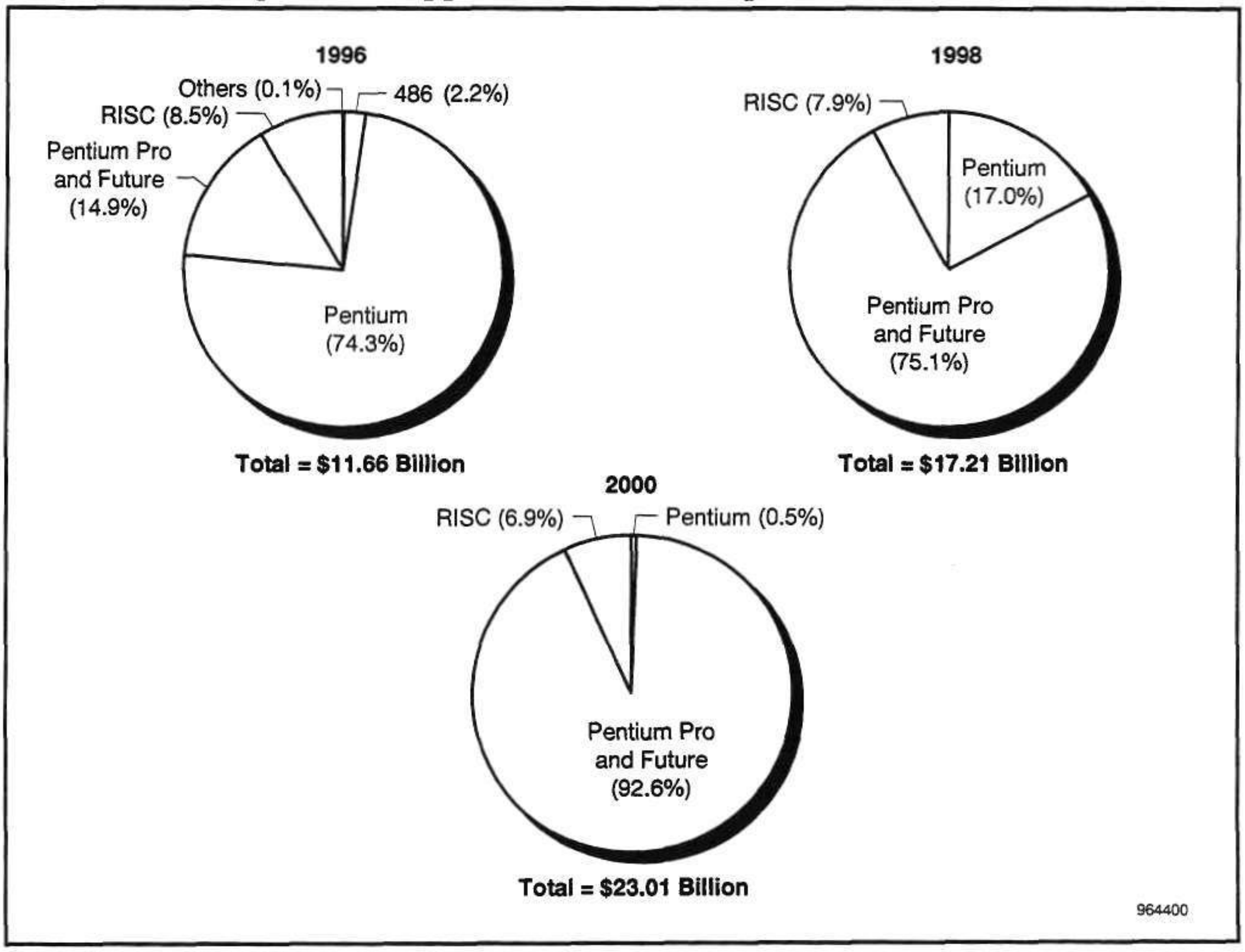
Source: Dataquest (June 1996)

Figure 5-17
Worldwide Microprocessor Opportunities in PCs



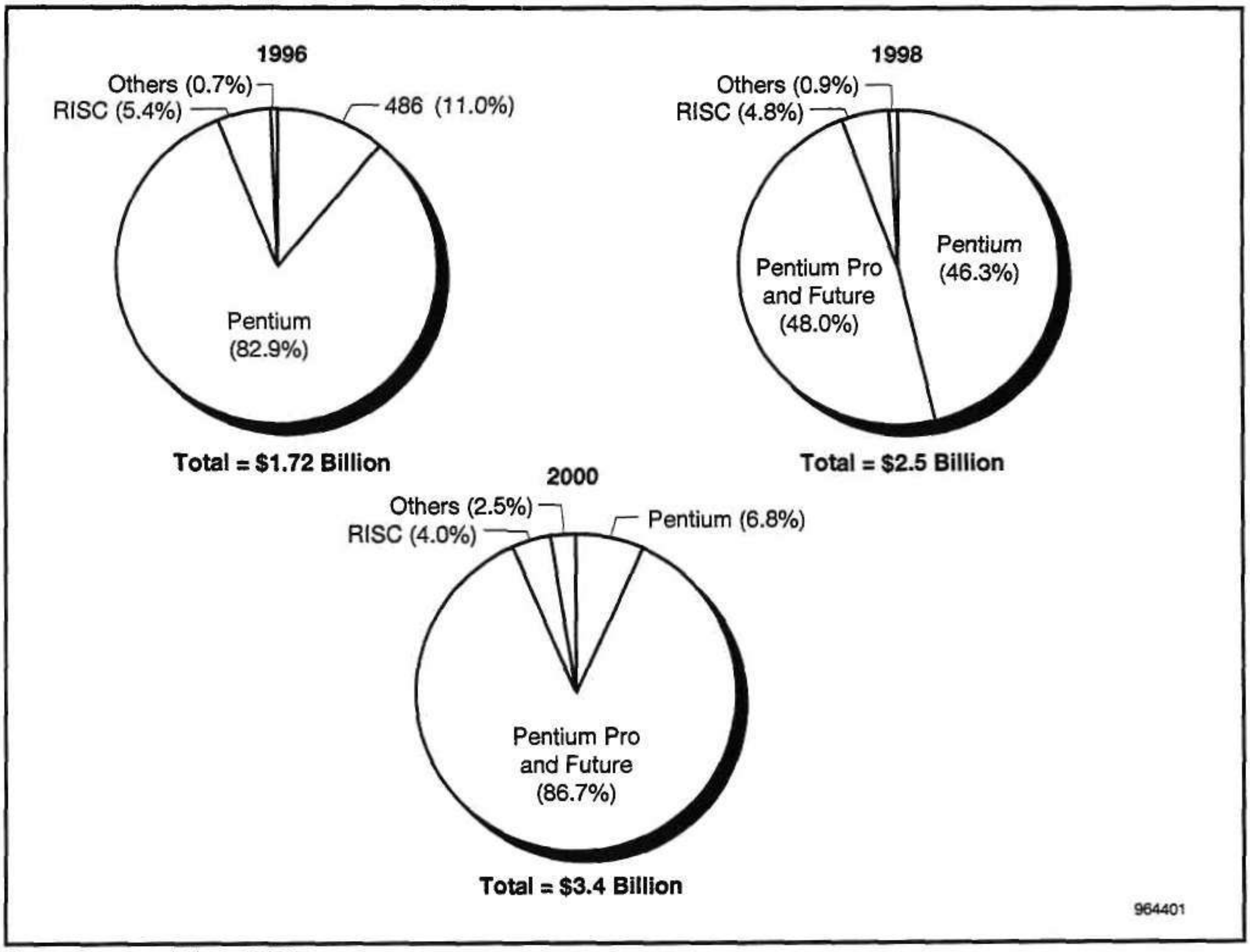
Source: Dataquest (June 1996)

Figure 5-18
Worldwide Microprocessor Opportunities in Desktop/Deskside PCs



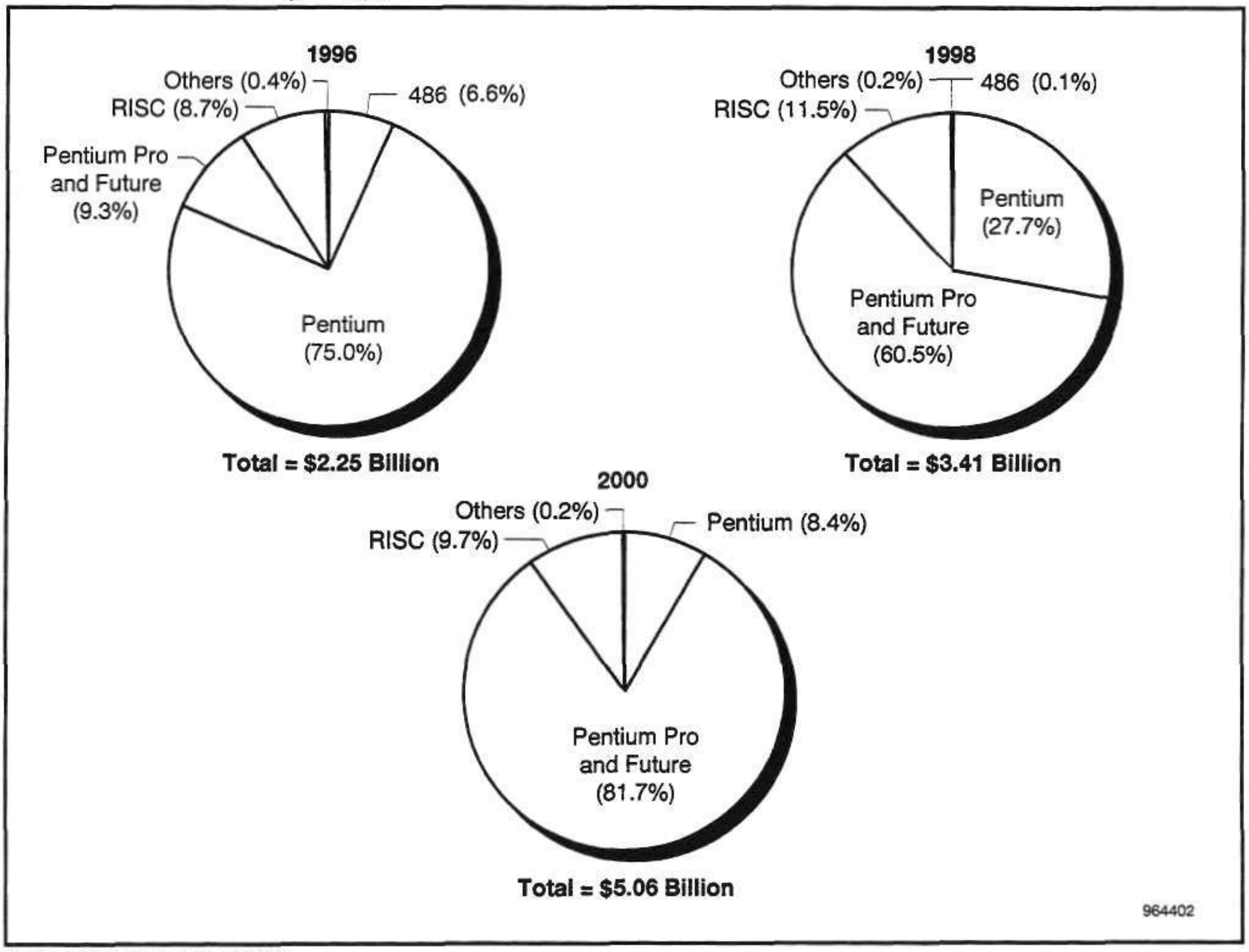
Source: Dataquest (June 1996)

Figure 5-19
Worldwide Microprocessor Opportunities in Mobile PCs



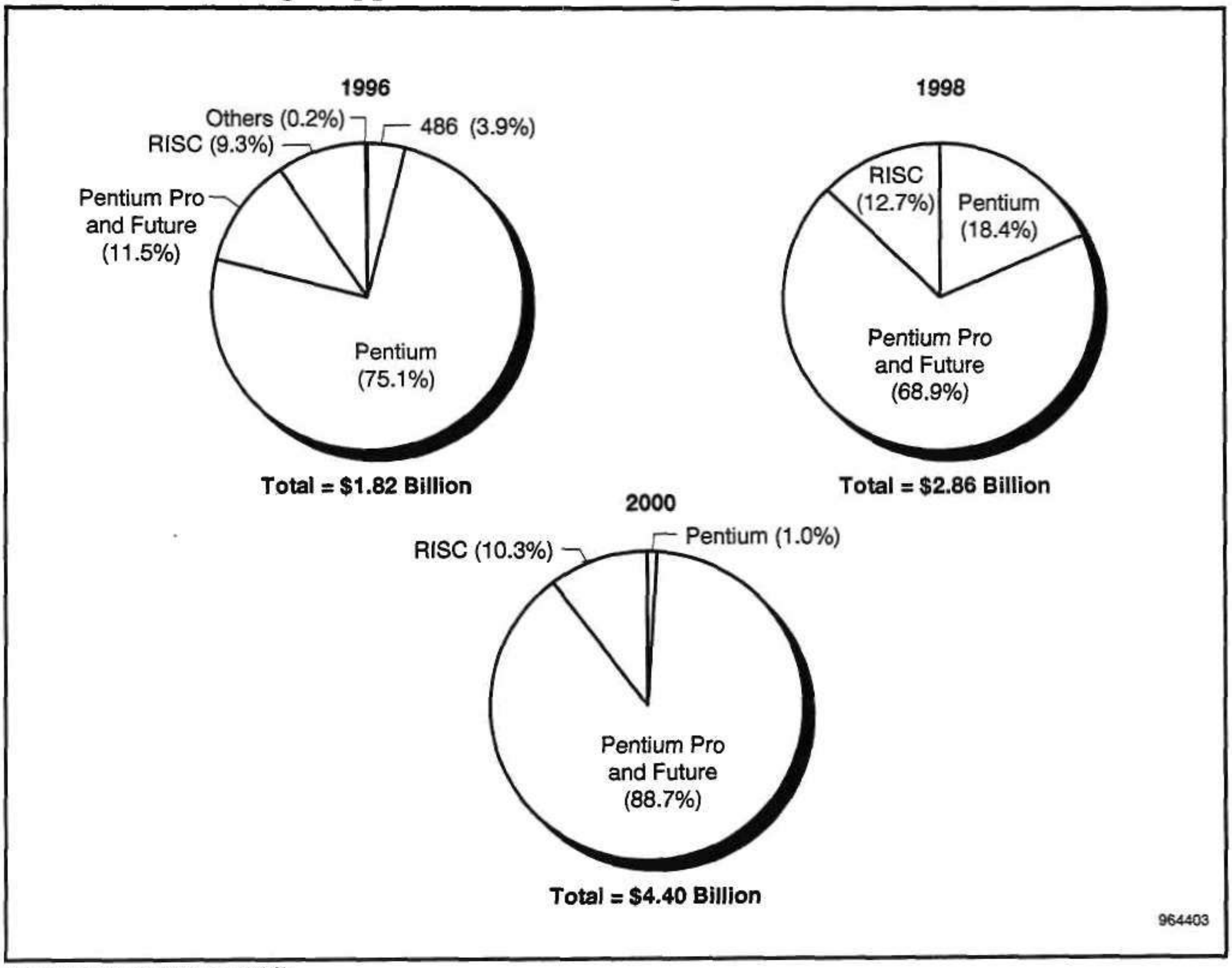
Source: Dataquest (June 1996)

Figure 5-20
Worldwide Core Logic Opportunities in PCs



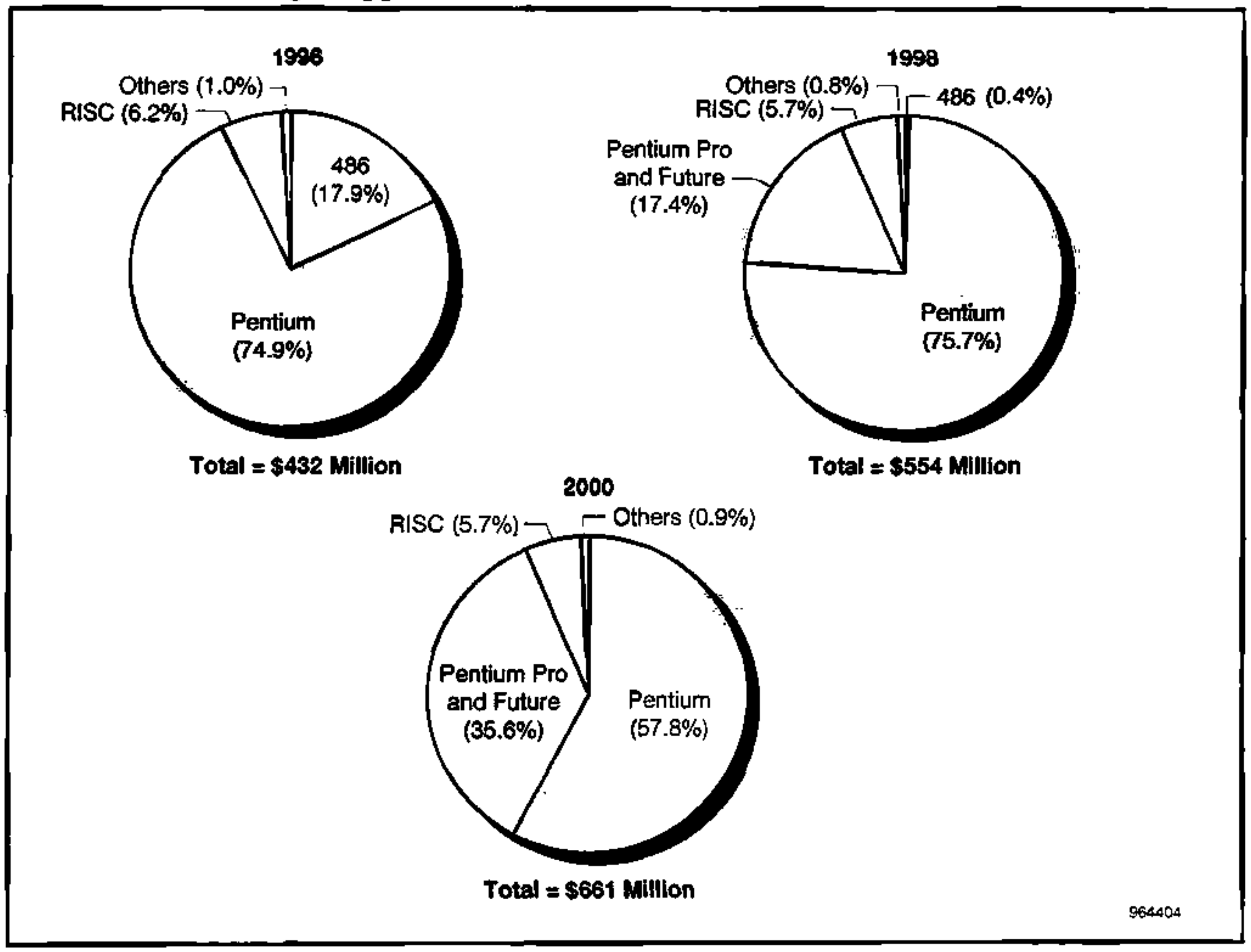
Source: Dataquest (June 1996)

Figure 5-21
Worldwide Core Logic Opportunities in Desktop/Deskside PCs



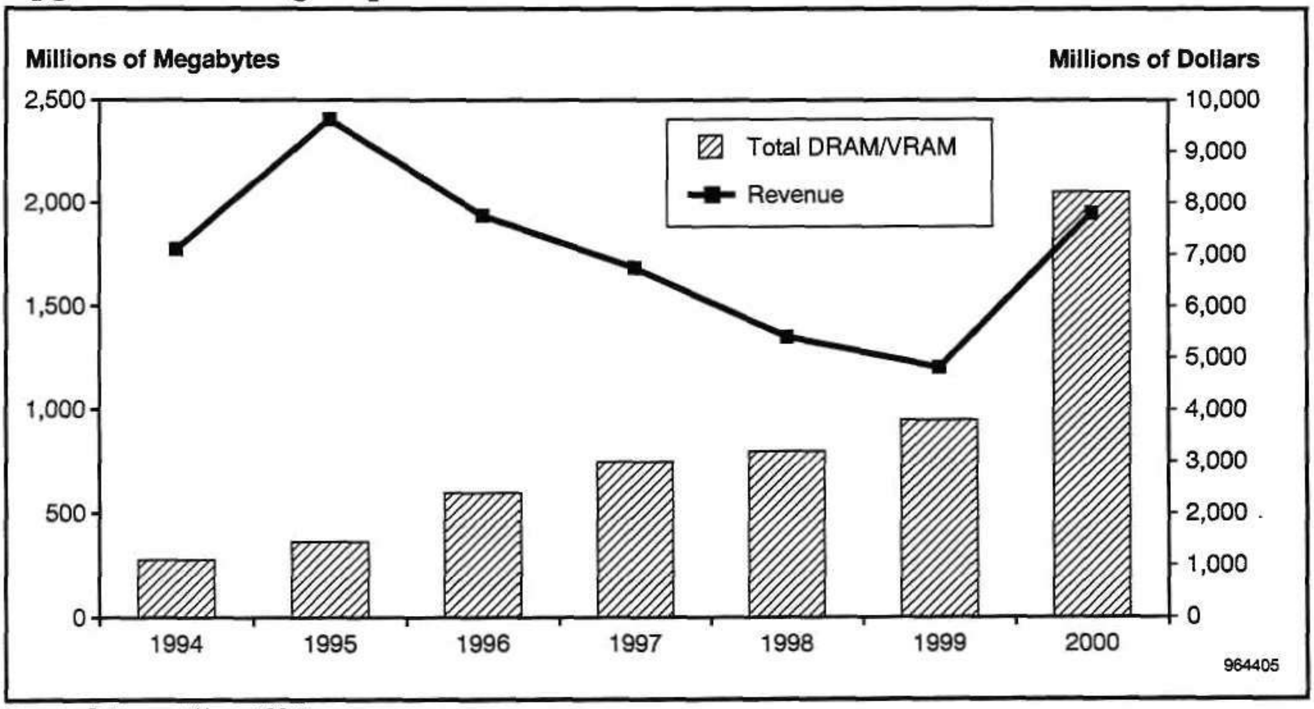
Source: Dataquest (June 1996)

Figure 5-22
Worldwide Core Logic Opportunities in Mobile PCs



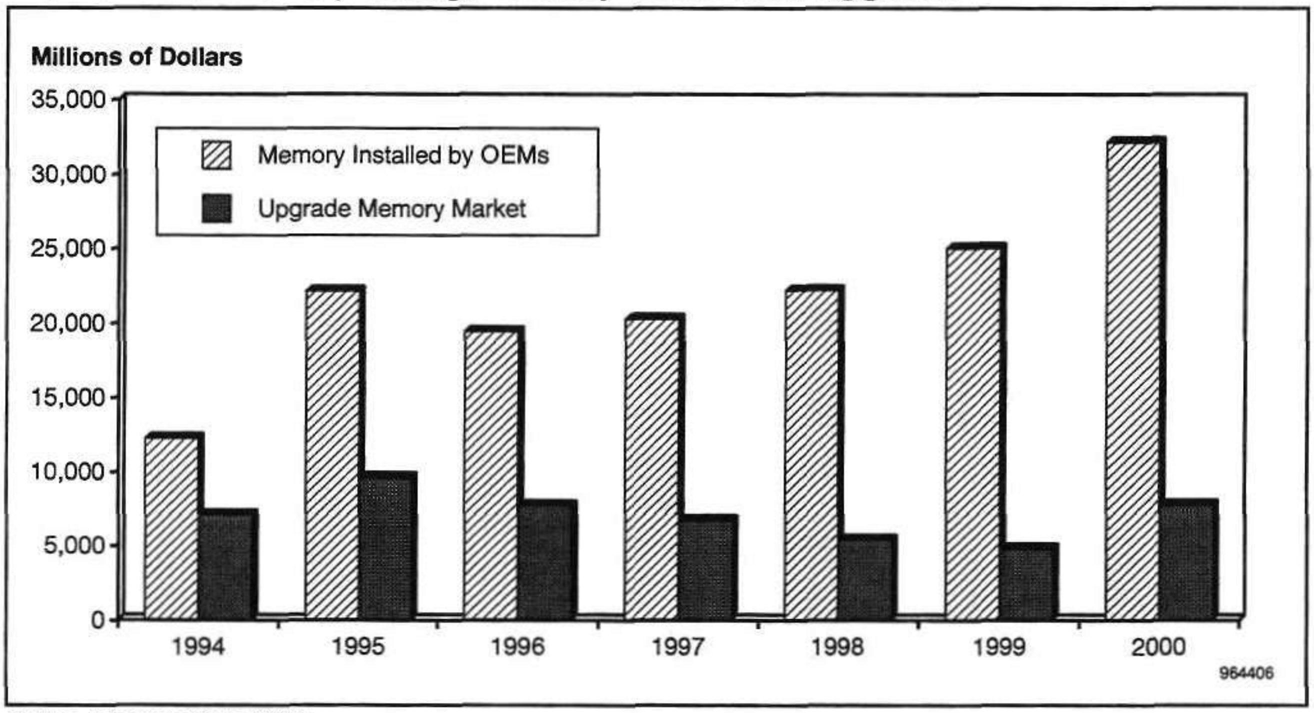
Source: Dataquest (June 1996)

Figure 5-23
Worldwide Aftermarket DRAM/VRAM Memory Demand in PCs (Includes All Memory Upgrades Following Shipment of PC from OEM to Sales Channel)



Source: Dataquest (June 1996)

Figure 5-24
Breakdown of Memory Configuration by OEM versus Upgrades



Source: Dataquest (June 1996)

Table 5-5
Worldwide Total PC Semiconductor Market by Device Type (Millions of Dollars) (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Microprocessor	9,269	10,927	13,386	15,660	19,711	21,789	26,405	19.3%
Memory (Main, Graphics, Cache, Nonvolatile)	12,369	22,017	18,791	19,365	21,079	23,761	30,712	6.9%
Core Logic	1,390	2,059	2,679	3,249	4,512	5,763	6,797	27.0%
Graphics Logic	1,045	1,242	1,464	1,898	2,267	2,583	3,046	19.7%
Storage Control	511	775	1,061	1,349	1,761	2,172	2,541	26.8%
Others	1,380	2,074	2,854	4,854	7,385	9,818	13,064	44.5%
Total Semiconductors	25,963	39,094	40,235	46,375	56,715	65,885	82,565	16.1%
Year-to-Year Growth (%)		50.6	2.9	15.3	22.3	16.2	25.3	

Source: Dataquest (June 1996)

Table 5-6
Worldwide Desktop/Deskside PC Semiconductor Market by Device Type (Millions of Dollars) (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Microprocessor	8,306	9,734	11,663	13,574	17,210	19,113	23,005	18.8
Memory (Main, Graphics, Cache, Nonvolatile)	10,717	19,641	16,514	16,676	18,129	20,530	26,722	6.4
Core Logic	1,137	1,757	2,183	2,590	3,715	4,889	5,867	27.3
Graphics Logic	844	1,022	1,212	1,581	1,873	2,184	2,578	20.3
Storage Control	449	703	943	1,204	1,623	2,046	2,452	28.4
Others	1,201	1,817	2,446	4,218	6,392	8,481	11,066	43.5
Total Semiconductors	22,654	34,674	34,960	39,842	48,941	57,243	71,691	15.6
Year-to-Year Growth (%)		53.1	0.8	14.0	22.8	17.0	25.2	

Source: Dataquest (June 1996)

Table 5-7
Worldwide Mobile PC Semiconductor Market by Device Type (Millions of Dollars) (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Microprocessor	962	1,192	1,723	2,086	2,502	2,676	3,400	23.3
Memory (Main, Graphics, Cache, Nonvolatile)	1,653	2,376	2,277	2,690	2,950	3,231	3,990	10.9
Core Logic	253	303	497	659	796	874	930	25.2
Graphics Logic	200	220	253	317	394	399	468	16.3
Storage Control	63	72	118	145	138	125	89	4.4
Others	179	257	408	636	994	1,336	1,998	50.7
Total Semiconductors	3,310	4,420	5,275	6,532	7,774	8,642	10,874	19.7
Year-to-Year Growth (%)		33.5	19.3	23.8	19.0	11.2	25.8	

Source: Dataquest (June 1996)

Table 5-8
Worldwide Semiconductor Memory Demand in PCs and Workstations by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	12,094	22,188	18,872	19,294	20,846	23,319	29,939	6.2
SRAM	873	782	571	719	791	912	1,127	7.6
EPROM/OTP/ROM	137	63	16	7	8	9	10	-30.0
Flash	206	355	298	319	395	448	514	7.7
Total	13,311	23,387	19,757	20,338	22,039	24,688	31,590	6.2

Source: Dataquest (June 1996)

Table 5-9
Worldwide Semiconductor Memory Demand in Desktop/Deskside PCs by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	9,677	18,669	15,845	15,866	17,178	19,449	25,460	6.4
SRAM	811	657	461	595	671	769	947	7.6
EPROM/OTP/ROM	92	47	10	4	6	6	6	-33.2
Flash	137	268	198	211	274	305	309	2.9
Total	10,717	19,641	16,514	16,676	18,129	20,530	26,722	6.4

Source: Dataquest (June 1996)

Table 5-10
Worldwide Semiconductor Memory Demand in Mobile PCs by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	1,531	2,243	2,134	2,528	2,774	3,001	3,653	10.2
SRAM	18	39	45	59	59	90	132	27.7
EPROM/OTP/ROM	41	14	5	2	2	3	4	-21.8
Flash	62	80	92	101	115	138	201	20.3
Total	1,653	2,376	2,277	2,690	2,950	3,231	3,990	10.9

Source: Dataquest (June 1996)

Table 5-11
Worldwide Semiconductor Memory Demand in Workstations by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	885.5	1,276	893	900	894	868	826	-8.3
SRAM	44	85	65	65	60	53	47	-11.3
EPROM/OTP/ROM	5	1	0	0	0	0	0	-41.6
Flash	7	8	8	7	6	5	5	-10.1
Total	941	1,370	966	973	960	927	878	-8.5

Source: Dataquest (June 1996)

Table 5-12
Worldwide Semiconductor Memory Demand by System for PCs and Workstations (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	6,749	7,323	908	30	0	0	0	-100.0
Upgrade Memory	6,305	3,703	323	10	0	0	0	-100.0
Display Buffer	1,064	936	220	5	0	0	0	-100.0
Cache	630	377	58	0	0	0	0	-100.0
Nonvolatile	194	164	47	2	0	0	0	-100.0
Total	14,942	12,502	1,556	47	0	0	0	-100.0
Pentium-Class PC								
Main OEM	1,769	9,899	12,031	10,024	5,909	2,857	1,306	-33.3
Upgrade Memory	254	5,352	6,257	3,871	1,736	682	157	-50.6
Display Buffer	118	830	2,186	1,503	878	450	132	-30.8
Cache	135	219	369	409	111	7	0	-100.0
Nonvolatile	36	172	181	125	62	29	14	-39.1
Total	2,313	16,473	21,023	15,933	8,696	4,025	1,609	-37.2

(Continued)

Table 5-12 (Continued)
Worldwide Semiconductor Memory Demand by System for PCs and Workstations (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Pentium Pro and Future PC								
Main OEM	0	2	904	4,817	10,641	16,165	24,153	564.7
Upgrade Memory	0	2	723	2,536	3,366	3,798	7,107	420.4
Display Buffer	0	0	114	431	1,019	1,218	1,206	439.9
Cache	0	0	0	172	511	761	1,004	NM
Nonvolatile	0	0	15	126	255	318	334	574.1
Total	0	4	1,757	8,081	15,792	22,260	33,805	509.8
RISC PC								
Main OEM	383	1,167	1,219	1,274	1,210	1,427	1,803	9.1
Upgrade Memory	140	479	439	325	299	335	536	2.3
Display Buffer	48	197	295	249	201	188	210	1.3
Cache	35	84	78	73	109	90	75	-2.2
Nonvolatile	9	16	18	15	12	10	9	-9.7
Total	615	1,942	2,049	1,936	1,831	2,050	2,633	6.3
Workstation								
Main OEM	808	1,180	837	853	851	833	797	-7.5
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	77	96	56	47	44	36	29	-21.2
Cache	44	85	65	65	60	53	47	-11.3
Nonvolatile	12	9	8	7	6	5	5	-12.6
Total	941	1,370	966	973	960	927	878	-8.5
Others								
Main OEM	842	471	91	61	93	146	303	-8.5
Upgrade Memory	401	94	13	0	0	0	0	-100.2
Display Buffer	237	87	10	0	0	0	0	-99.9
Cache	29	16	1	0	0	0	0	-100.0
Nonvolatile	92	57	45	51	67	95	162	23.2
Total	1,600	725	161	112	160	241	466	-8.5
Total PC and Workstation								
Main OEM	10,551	20,042	15,991	17,058	18,704	21,427	28,362	7.2
Upgrade Memory	7,100	9,630	7,756	6,742	5,402	4,814	7,800	-4.1
Display Buffer	1,543	2,146	2,881	2,235	2,142	1,892	1,577	-6.0
Cache	873	782	571	719	791	912	1,127	7.6
Nonvolatile	343	417	314	325	403	457	524	4.7
Total	20,411	33,017	27,513	27,080	27,441	29,502	39,390	3.6

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-13
Worldwide Semiconductor Memory Demand for Desktop/Deskside PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	5,596	5,882	610	23	0	0	0	-100.0
Upgrade Memory	5,969	3,177	203	8	0	0	0	-100.0
Display Buffer	869	731	148	4	0	0	0	-100.0
Cache	613	359	54	0	0	0	0	-100.0
Nonvolatile	134	121	34	1	0	0	0	-100.0
Total	13,181	10,270	1,050	36	0	0	0	-100.0
Pentium-Class PC								
Main OEM	1,764	9,552	10,629	8,195	4,345	1,689	460	-45.5
Upgrade Memory	252	5,174	6,023	3,642	1,580	487	51	-60.3
Display Buffer	117	792	2,057	1,366	761	353	92	-34.9
Cache	135	203	341	379	103	7	0	-100.0
Nonvolatile	36	164	142	81	29	8	2	-58.5
Total	2,304	15,884	19,192	13,664	6,818	2,543	605	-48.0
Pentium Pro and Future PC								
Main OEM	0	2	904	4,568	9,865	14,877	22,042	552.6
Upgrade Memory	0	2	723	2,436	3,225	3,501	5,934	402.0
Display Buffer	0	0	114	406	949	1,094	1,060	426.1
Cache	0	0	0	159	474	684	882	NM
Nonvolatile	0	0	15	121	241	297	306	562.6
Total	0	4	1,757	7,690	14,754	20,452	30,225	496.3
RISC PC								
Main OEM	383	1,126	1,077	1,085	1,084	1,273	1,625	7.6
Upgrade Memory	140	469	404	325	271	300	437	-1.4
Display Buffer	48	187	260	217	174	163	181	-0.6
Cache	35	80	65	56	94	78	65	-4.0
Nonvolatile	9	15	15	12	9	7	7	-13.5
Total	615	1,876	1,821	1,695	1,633	1,821	2,315	4.3
Others								
Main OEM	709	332	36	2	0	0	0	-99.9
Upgrade Memory	401	94	13	0	0	0	0	-100.1
Display Buffer	191	65	9	0	0	0	0	-100.0
Cache	28	16	1	0	0	0	0	-100.0
Nonvolatile	50	15	2	0	0	0	0	-100.1
Total	1,379	522	62	3	0	0	0	-99.9

(Continued)

Table 5-13 (Continued)
Worldwide Semiconductor Memory Demand for Desktop/Deskside PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Total Desktop/Deskside PC								
Main OEM	8,452	16,894	13,257	13,873	15,295	17,840	24,127	7.4
Upgrade Memory	6,762	8,915	7,367	6,412	5,076	4,287	6,423	-6.3
Display Buffer	1,225	1,775	2,588	1,993	1,883	1,610	1,333	-5.6
Cache	811	657	461	595	671	769	947	7.6
Nonvolatile	229	315	208	215	279	311	315	0.0
Total	17,479	28,556	23,881	23,088	23,205	24,817	33,145	3.0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-14
Worldwide Semiconductor Memory Demand for Mobile PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	1,153	1,440	298	7	0	0	0	-100.0
Upgrade Memory	335	527	119	2	0	0	0	-100.0
Display Buffer	195	205	72	2	0	0	0	-100.0
Cache	17	18	4	0	0	0	0	-100.0
Nonvolatile	60	42	12	0	0	0	0	-100.0
Total	1,761	2,232	506	11	0	0	0	-100.0
Pentium-Class PC								
Main OEM	5	348	1,402	1,829	1,564	1,168	846	19.4
Upgrade Memory	2	178	234	229	156	195	106	-9.9
Display Buffer	1	39	129	137	117	97	40	0.5
Cache	1	16	28	30	8	0	0	-100.0
Nonvolatile	0	8	39	44	32	21	12	9.3
Total	9	589	1,831	2,269	1,879	1,481	1,004	11.3
Pentium Pro and Future PC								
Main OEM	0	0	0	249	775	1,287	2,111	NM
Upgrade Memory	0	0	0	99	141	297	1,173	NM
Display Buffer	0	0	0	25	70	124	147	NM
Cache	0	0	0	13	37	77	122	NM
Nonvolatile	0	0	0	5	15	22	28	NM
Total	0	0	0	391	1,038	1,808	3,580	NM

(Continued)

Table 5-14 (Continued)
Worldwide Semiconductor Memory Demand for Mobile PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
RISC PC								
Main OEM	0	41	143	190	126	153	178	34.4
Upgrade Memory	0	10	36	0	28	35	99	57.7
Display Buffer	0	10	34	32	27	26	29	23.2
Cache	0	4	13	16	15	12	10	19.0
Nonvolatile	0	1	3	3	3	3	2	17.4
Total	0	66	229	241	199	229	318	36.9
Handhelds								
Main OEM	23	32	55	59	93	146	303	56.4
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	0	0	0	0	0	0	0	NM
Cache	0	0	0	0	0	0	0	NM
Nonvolatile	31	37	43	50	67	95	162	34.6
Total	54	69	98	109	160	241	466	46.5
Others								
Main OEM	110	107	0	0	0	0	0	-99.8
Upgrade Memory	0	0	0	0	0	0	0	-47.0
Display Buffer	46	22	0	0	0	0	0	-99.9
Cache	1	0	0	0	0	0	0	-99.6
Nonvolatile	12	5	0	0	0	0	0	-99.9
Total	167	134	0	0	0	0	0	-99.8
Total Mobile PC								
Main OEM	1,290	1,968	1,897	2,333	2,559	2,755	3,438	11.8
Upgrade Memory	338	715	388	330	325	527	1,377	14.0
Display Buffer	241	275	237	195	215	247	215	-4.8
Cache	18	39	45	59	59	90	132	27.7
Nonvolatile	103	94	97	103	117	140	205	16.9
Total	1,990	3,091	2,665	3,020	3,276	3,759	5,367	11.7

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-15
Worldwide Semiconductor Memory Configuration Assumptions by System for PCs and Workstations (Megabytes per System; Kilobytes per System for Cache)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	5.53	8.16	8.15	9.90	0	0	0	-100.0
Upgrade Memory	5.16	4.13	2.90	3.35	0	0	0	-100.0
Display Buffer	1.00	1.19	1.29	1.00	0	0	0	-100.0
Cache	132.04	142.89	175.90	3.33	0	0	0	-100.0
Nonvolatile	0.15	0.25	0.39	0.43	0	0	0	-100.0
Pentium-Class PC								
Main OEM	13.07	10.50	11.53	15.64	19.05	22.35	29.60	23.0
Upgrade Memory	1.88	5.67	5.99	6.04	5.60	5.33	3.56	-8.9
Display Buffer	1.00	1.00	1.53	1.84	2.22	2.29	1.83	12.8
Cache	256.00	79.17	118.94	176.55	98.95	14.64	0	-100.0
Nonvolatile	0.25	0.25	0.16	0.14	0.14	0.15	0.20	-4.8
Pentium Pro and Future PC								
Main OEM	0	14.16	15.82	19.87	22.81	29.50	44.49	25.7
Upgrade Memory	0	14.16	12.65	10.46	7.22	6.93	13.09	-1.6
Display Buffer	0	2.00	2.00	2.00	2.46	2.50	2.50	4.6
Cache	0	0	0	195.69	302.85	384.00	512.00	NM
Nonvolatile	0	0.25	0.25	0.38	0	0	0	-100.0
RISC PC								
Main OEM	11.30	10.44	12.65	18.23	20.62	29.26	44.28	33.5
Upgrade Memory	4.14	4.29	4.56	4.66	5.09	6.87	13.17	25.2
Display Buffer	1.50	2.00	2.00	2.50	2.50	2.50	2.50	4.6
Cache	262.14	256.00	270.97	288.54	512.00	512.00	512.00	14.9
Nonvolatile	0.25	0.19	0.18	0.15	0.14	0.13	0.14	-6.4
Workstation								
Main OEM	40.00	53.00	68.70	92.30	114.00	136.60	160.50	24.8
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	2.50	3.00	3.00	3.50	4.00	4.00	4.00	5.9
Cache	512.00	752.00	926.00	1,127.00	1,285.00	1,402.00	1,508.00	14.9
Nonvolatile	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-16
Worldwide Semiconductor Memory Configuration Assumptions by System for Desktop/Deskside PCs (Megabytes per System; Kilobytes per System for Cache)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	6.00	10.00	12.00	12.00	12.00	12.00	12.00	3.7
Upgrade Memory	6.40	5.40	4.00	4.00	4.00	4.00	4.00	-5.8
Display Buffer	1.00	1.25	1.50	1.00	1.00	1.00	1.00	-4.4
Cache	157.29	183.50	283.12	0	0	0	0	-100.0
Nonvolatile	0.13	0.25	0.50	0.50	0	0	0	-100.0
Pentium-Class PC								
Main OEM	14.00	12.00	15.00	18.00	22.00	26.00	36.00	24.6
Upgrade Memory	2.00	6.50	8.50	8.00	8.00	7.50	4.00	-9.3
Display Buffer	117.32	791.76	2,057.17	1,365.89	760.74	353.01	92.42	-34.9
Cache	256.00	76.80	128.00	204.80	128.00	25.60	0	-100.0
Nonvolatile	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0
Pentium Pro and Future PC								
Main OEM	0	16.00	20.00	22.50	26.00	34.00	52.00	26.6
Upgrade Memory	0	16.00	16.00	12.00	8.50	8.00	14.00	-2.6
Display Buffer	0	2.00	2.00	2.00	2.50	2.50	2.50	4.6
Cache	0	0	0	192.00	307.20	384.00	512.00	NM
Nonvolatile	0	0.25	0.25	0.38	0.38	0.38	0.38	9.0
RISC PC								
Main OEM	12.00	12.00	16.00	20.00	24.00	34.00	52.00	34.1
Upgrade Memory	4.14	5.00	6.00	6.00	6.00	8.00	14.00	22.9
Display Buffer	1.50	2.00	2.00	2.50	2.50	2.50	2.50	4.6
Cache	256.00	256.00	256.00	256.00	512.00	512.00	512.00	14.9
Nonvolatile	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-17
Worldwide Semiconductor Memory Configuration Assumptions by System for Mobile PCs (Megabytes per System; Kilobytes per System for Cache)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	5.50	7.00	8.00	9.00	0	0	0	-100.0
Upgrade Memory	1.60	2.56	3.20	3.20	0	0	0	-100.0
Display Buffer	1.00	1.00	1.00	1.00	0	0	0	-100.0
Cache	19.66	26.76	29.49	11.62	0	0	0	-100.0
Nonvolatile	0.25	0.25	0.25	0.25	0	0	0	-100.0
Pentium-Class PC								
Main OEM	8.00	9.00	12.00	16.00	20.00	24.00	32.00	28.9
Upgrade Memory	4.00	4.60	2.00	2.00	2.00	4.00	4.00	-2.8
Display Buffer	1.00	1.00	1.10	1.20	1.50	2.00	1.50	8.4
Cache	256.00	128.00	64.00	64.00	25.60	0	0	-100.0
Nonvolatile	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0
Pentium Pro and Future PC								
Main OEM	0	0	16.00	20.00	22.00	26.00	36.00	NM
Upgrade Memory	0	0	8.00	8.00	4.00	6.00	20.00	NM
Display Buffer	0	0	2.00	2.00	2.00	2.50	2.50	NM
Cache	0	0	0	256.00	256.00	384.00	512.00	NM
Nonvolatile	0	0	0	0.25	0.25	0.25	0.25	NM
RISC PC								
Main OEM	6.00	8.00	16.00	24.00	18.00	26.00	36.00	35.1
Upgrade Memory	0	2.00	4.00	0	4.00	6.00	20.00	58.5
Display Buffer	1.00	2.00	2.00	2.50	2.50	2.50	2.50	4.6
Cache	256.00	256.00	384.00	512.00	512.00	512.00	512.00	14.9
Nonvolatile	0	0.25	0.25	0.25	0.25	0.25	0.25	0
Handhelds								
Main OEM	1.25	1.60	2.50	3.25	4.00	4.00	4.00	20.1
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	0	0	0	0	0	0	0	NM
Cache	0	0	0	0	0	0	0	NM
Nonvolatile	2.50	3.50	4.00	4.25	4.50	4.50	4.50	5.2

NM = Not meaningful
Source: Dataquest (June 1996)

Chapter 6

Input/Output and Dedicated Systems

Tables 6-1 through 6-6 detail system and semiconductor market data on selected computer I/O systems.

Table 6-1
Worldwide Sound Board Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Board Units (M)	13.7	11.5	12.1	12.7	13.4	14.0	14.7	0.1
Board ASP ($)	64.6	66.3	66.3	66.3	66.3	66.3	66.3	0
Board Factory Revenue ($M)	883.1	765.0	803.2	843.4	885.6	929.8	976.3	0
16-Bit and Higher Penetration (%)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0
Semiconductor Content ($)	16.1	17.0	17.5	18.0	18.0	18.0	18.0	0
Semiconductor Market ($M)	220.8	196.3	212.2	229.1	240.6	252.6	265.3	0.1
ASSP/ASIC ($M)	94.9	82.1	86.2	90.6	95.1	99.8	104.8	0.1
Synthesis ($M)	81.7	70.7	74.2	78.0	81.9	85.9	90.2	0.1
Analog/Discrete ($M)	33.1	28.6	30.1	31.6	33.2	34.8	36.6	0.1
Memory/Others ($M)	11.0	14.8	21.6	29.1	30.5	32.0	33.6	0.2

Source: Dataquest (June 1996)

Table 6-2
Worldwide Sound Board OEMs (1995 Unit Share; Percent)

Creative	61.1
Aztech	36.5
Diamond	0.5
Turtle Beach	0.3
Others	1.6

Source: Dataquest (June 1996)

Table 6-3
Worldwide Graphics Board Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Board Units (K)	12,634.5	16,677.5	20,013.0	23,815.5	27,673.6	31,741.7	35,836.3	16.5
Board ASP ($)	160.00	152.00	160.00	152.00	148.96	145.98	143.06	-1.2
Board Factory Revenue ($M)	2,021.5	2,535.0	3,202.1	3,620.0	4,122.3	4,633.7	5,126.8	15.1
Semiconductor Content ($)	57.00	55.00	58.00	60.00	59.00	58.00	57.00	0.7
Semiconductor Market ($M)	720.2	917.3	1,160.8	1,428.9	1,632.7	1,841.0	2,042.7	17.4

Source: Dataquest (June 1996)

Table 6-4
Worldwide Digital Video Board Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Board Units (K)	605.0	1,080.3	1,188.3	1,307.1	1,437.8	1,581.6	1,739.8	10.0
With Hardware Compression and/or Decompression	169.0	351.5	369.0	387.5	406.8	427.2	448.5	5.0
With TV Tuner	100.0	189.0	236.3	295.3	369.1	461.4	576.8	25.0
Board ASP ($)	310.00	227.98	216.58	205.75	195.46	185.69	176.40	-5.0
Board Factory Revenue ($M)	187.6	246.3	257.4	268.9	281.0	293.7	306.9	4.5
Semiconductor Content ($)	87.80	79.79	78.20	76.63	75.10	73.60	72.12	-2.0
Semiconductor Market ($M)	53.1	86.2	92.9	100.2	108.0	116.4	125.5	7.8
TV Signal Processing ($M)	1.5	3.8	4.7	5.9	7.4	9.2	11.5	25.0
Video Scaling/ Processing ($M)	20.0	27.0	28.4	29.8	31.3	32.8	34.5	5.0
Compression/ Decompression ($M)	5.9	17.6	18.5	19.4	20.3	21.4	22.4	5.0
Memory (DRAM/VRAM) ($M)	22.7	27.0	28.4	29.8	31.3	32.8	34.5	5.0
Others ($M)	3.0	10.8	13.0	15.3	17.7	20.2	22.6	15.8

Source: Dataquest (June 1996)

Table 6-5
Worldwide Monitor Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
System Units (K)	41,227.0	54,419.6	65,303.6	77,711.2	90,300.5	103,574.6	116,935.8	16.5
System ASP ($)	352.00	316.80	285.12	256.61	230.95	207.85	187.07	-10.0
System Factory Revenue ($M)	14,494.0	17,240.1	18,619.4	19,941.3	20,854.6	21,528.2	21,874.8	4.9
Semiconductor Content ($)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	0
Semiconductor Market ($M)	188.0	272.1	326.5	388.6	451.5	517.9	584.7	16.5

Source: Dataquest (June 1996

Table 6-6
Worldwide Keyboard Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
System Units (K)	55,961.6	73,869.3	88,643.2	105,485.4	122,574.0	140,592.4	158,728.8	16.5
Semiconductor Content ($)	2.45	2.50	2.50	2.50	2.50	2.50	2.50	0
Semiconductor Market ($M)	137.1	184.7	221.6	263.7	306.4	351.5	396.8	16.5

Source: Dataquest (June 1996)

Key Trends

Sound Boards

Key trends in sound boards are as follows:

- The sound board market faces increasing competition from integrated designs with sound chips on the motherboard or on custom daughter-card modules. Integrated sound chips are primarily used for mobile and consumer PCs, although a few business desktops have integrated sound capability.
- Microsoft has adopted DSP Group's TrueSpeech technology as a compression standard. Several vendors already support ADPCM for compression.
- Movement to 16-bit is nearly complete. Wave-table synthesis is gaining market share.
- Key chip functions include FM and wave-table synthesis (512KB to 4MB ROM-based), ASSP/ASICs (mixed-signal and digital CMOS), audio amplifiers, and mixers. SCSI host adapters have declined in popularity compared to EIDE or proprietary variants of EIDE.

Graphics Boards

Key trends in graphics boards are as follows:

- May receive a boost from the 3-D graphics market until mid-1997 when several new graphics controllers make 3-D hardware more attractive for motherboard implementations.
- Boards are moving to greater than 1000 x 1000-pixel resolutions; accelerated BitBLT-based, 64-bit data paths; and RAMDAC technology moving from 85 MHz to 135 MHz. Also, digital video, 3-D, and sound capability are appearing in the high-end boards.
- Extended data out (EDO) DRAM will be the dominant memory for 1996 but will be replaced with SDRAM/SGRAM in 1997. Minimal buffers start at 1MB and move to 4MB with optional single in-line memory modules (SIMMs). Most high-end add-in boards have a separate RAMDAC, and digital video acceleration functions are being integrated into virtually every design.

Digital Video Boards

Key trends in digital video boards are as follows:

- There will be continued penetration into the multimedia content creator market (software title development, market communications, and training). Playback board growth will be limited to full-screen 15-fps to 30-fps acceleration. Other opportunities exist for TV tuner, capture pass-through, and integrated audio and graphics boards.
- MPEG-1 hardware shifted partly to the motherboard in 1995 but has already reverted to add-in cards, creating greater opportunities for video board OEMs.

- Key semiconductor opportunities include compression decoders for MPEG-1 and JPEG, among others (and encoders for real-time algorithms), decoders and encoders between various video standards such as PAL, NTSC, and CCIR , ASICs (CMOS), digital video processors (scaling, among other functions), and DRAM/VRAM pixel buffers.

Leading digital video board OEMs worldwide are ATI, Creative Technologies, Diamond Multimedia, FutureTel, IBM, Intel, Matrox, Media Vision, Optibase, Optivision, Orchid, Sigma Designs, SuperMac, and Video Logic.

Monitors

Key trends in monitors are as follows:

- Color will grow to 98 percent of the market in 1999.
- 15-inch tubes will be the predominant size in 1996; 17-inches tubes will be predominant in 1997.
- There will be a chip content of about $5 for primarily video amplifier controls (moving to 135 MHz) and CRT controls.

Keyboards

The trend in keyboards is commodity items moving toward ergonomic and wireless versions.

Leading keyboard OEMs worldwide are Keytronic, Silitek, and MaxiSwitch.

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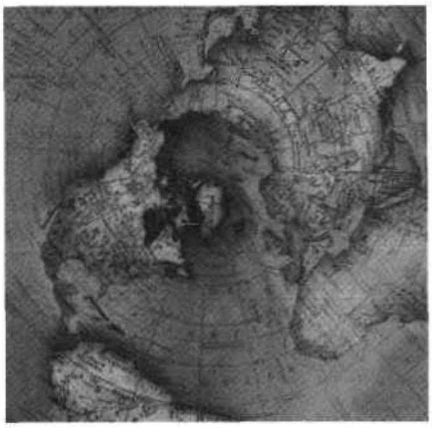

Dataquest

PC Semiconductor Application Markets—Core Logic

Market Trends

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-MT-9602
Publication Date: June 17, 1996
Filing: Market Trends

PC Semiconductor Application Markets—Core Logic

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Table of Contents

List of Figures

List of Tables

Chapter 1
Executive Summary

The personal computer core logic market grew 38 percent to $1.38 billion in 1995, compared with $999 million in 1994. This growth in sales was driven by both a 36 percent increase in unit shipments to 75.6 million units and a 2 percent increase in average selling price (ASP) to $18.21. The desktop core logic segment comprised 68.8 million units that sold for $1.24 billion. Desktop ASPs increased, driven by the shift from 486-based systems to Pentium-based systems that occurred during the year. The mobile core logic market comprised almost 6.8 million units that sold for $137 million, essentially flat with regard to revenue, as an 18 percent increase in units was offset by eroding ASPs that shrank 15 percent over the year.

Intel clearly has become the dominant player in core logic and shows no sign of retreating from this position. Systems based on its Triton chipset, introduced early in 1995, and ramped aggressively in the second quarter, continued to win performance benchmarks throughout the year. Core logic production allows Intel to recycle manufacturing facilities, since this core logic generation's process requirements tend to track those of the prior CPU generation. Intel has brought Triton chipset production in-house after using contract manufacturing sources for the earlier Saturn, Mercury, and Neptune generations. The next-generation P6 chipset, known as the 440FX, will also be produced in-house.

As the market completes its transition to Pentium-based PCI systems, core logic suppliers must formulate their strategies for Pentium Pro, along with sixth-generation processors from Cyrix and AMD. It appears unlikely that these latter vendors will attempt to be plug compatible with the Pentium Pro bus and pinout. Rather, they will maintain compatibility with the current Pentium (P54C) bus design. As Intel directs more of its resources toward Pentium Pro core logic, there will be opportunities for other vendors to focus on chipsets for Pentium-compatible chipsets that optimize the performance of the AMD K5 and K6 and the Cyrix M1 and M2. To date, VIA Technologies is the only core logic vendor (other than Intel) to introduce a product aimed at the emerging Pentium Pro market. The continuing evolution of personal computer architecture creates many opportunities for innovation and product enhancement with regard to core logic.

Chapter 2
Introduction and Methodology

This document is the second in a series of four that provide reference information and analysis about the markets for semiconductor devices in personal computers. The four books cover graphics controllers, core logic chipsets, microprocessors, and an overview that includes a model of total semiconductor content for PCs.

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers, as well as analyst knowledge and opinions. Secondary sources include government and trade sources on sales, production, trade, and public spending. Semiconductor content assumptions are based both on surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative personal computers.

The forecast methodology is based on various methods and assumptions, depending on the specific market. To form a solid basis for projecting system demand and capital, government, and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes, and government polices are also considered. Semiconductor content forecasts are based upon interviews of system marketers and designers (including makers of enabling semiconductor technology), along with an analysis of historical trends.

Project Analyst: Nathan Brookwood

Chapter 3
Market Analysis

1995: A Good Year for Core Logic Vendors, Especially Intel

The personal computer core logic market grew 38 percent to $1.38 billion in 1995, compared with $999 million in 1994. This growth in sales was driven by both a 36 percent increase in unit shipments to 75.6 million units and a 2 percent increase in average selling price to $18.21. This unusual increase in ASP resulted from the larger number of chips needed in most Pentium designs, compared with 486 designs, and from the enhanced function offered by the latest chipset generation.

Dataquest divides the core logic market into two segments: chipsets for desktops and chipsets for mobile products. Tables 3-1, 3-2, and 3-3 and Figures 3-1, 3-2, and 3-3 describe the overall core logic market, in terms of factory revenue, unit shipments, and average selling prices, as estimated by Dataquest. Table 3-4 ranks these vendors by 1995 revenue and provides market share information. Dataquest has restated its 1994 data to include devices from VIA Technologies, a major industry participant that failed to participate in our 1994 survey but provided 1994 and 1995 data as part of this year's survey.

Table 3-1
Personal Computer Core Logic Factory Revenue, 1993-1995 (Millions of Dollars)

	Desktop			Mobile			Total		
	1993	1994	1995	1993	1994	1995	1993	1994	1995
Acer Laboratories	52.7	48.0	52.8	0	2.2	4.0	52.7	50.2	56.8
ACC Microelectronics	20.2	21.3	20.9	11.8	14.2	13.0	32.1	35.5	33.8
Chips & Technologies	26.6	28.9	13.6	0	0	0	26.6	28.9	13.6
Cirrus Logic	0	0	0	8.8	42.6	58.5	8.8	42.6	58.5
Cypress	0	0	0	0	0	0	0	0	0
Intel	53.0	186.0	445.5	0	0	0	53.0	186.0	445.5
Oak	0	0	0	0	0.8	0	0	0.8	0
OPTi	107.7	112.4	116.3	2.6	7.6	8.8	110.2	120.0	125.1
Silicon Integrated Systems	62.8	102.1	128.8	0	1.3	1.3	62.8	103.4	130.0
Symphony	4.8	10.2	12.0	0.1	0.1	0.2	4.9	10.3	12.2
UMC	91.8	98.4	108.0	0	0	1.4	91.8	98.4	109.4
VIA Technologies	0	76.5	138.0	0	0.4	2.0	0	76.9	140.0
VLSI Technology	205.3	178.8	202.4	10.9	56.9	26.3	216.2	235.7	228.7
Weitek	0	0	0.6	0	0	0	0	0	0.6
Western Digital	0	0	0	20.0	11.0	22.0	20.0	11.0	22.0
Total	624.9	862.6	1,238.8	54.2	137.0	137.5	679.1	999.6	1,376.3

Source: Dataquest (May 1996)

Table 3-2
Personal Computer Core Logic Unit Shipments, 1993-1995 (Thousands of Units)

	Desktop			Mobile			Total		
	1993	1994	1995	1993	1994	1995	1993	1994	1995
Acer Laboratories	3,900	4,000	4,400	0	200	350	3,900	4,200	4,750
ACC Microelectronics	1,446	1,774	1,490	537	789	720	1,983	2,563	2,210
Chips & Technologies	1,400	1,700	800	0	0	0	1,400	1,700	800
Cirrus Logic	0	0	0	325	1,850	3,000	325	1,850	3,000
Cypress	0	0	0	0	0	0	0	0	0
Intel	1,500	5,300	16,500	0	0	0	1,500	5,300	16,500
Oak	0	0	0	0	35	0	0	35	0
OPTi	6,241	7,396	7,500	103	379	400	6,344	7,775	7,900
Silicon Integrated Systems	4,652	8,510	10,100	0	90	98	4,652	8,600	10,198
Symphony	400	850	1,000	10	10	15	410	860	1,015
UMC	6,800	8,200	9,000	0	0	130	6,800	8,200	9,130
VIA Technologies	0	5,100	9,200	0	20	100	0	5,120	9,300
VLSI	7,080	7,152	8,800	312	1,895	975	7,392	9,047	9,775
Weitek	0	0	20	0	0	0	0	0	20
Western Digital	0	0	0	800	500	1,000	800	500	1,000
Totals	33,419	49,982	68,810	2,087	5,768	6,788	35,506	55,750	75,598

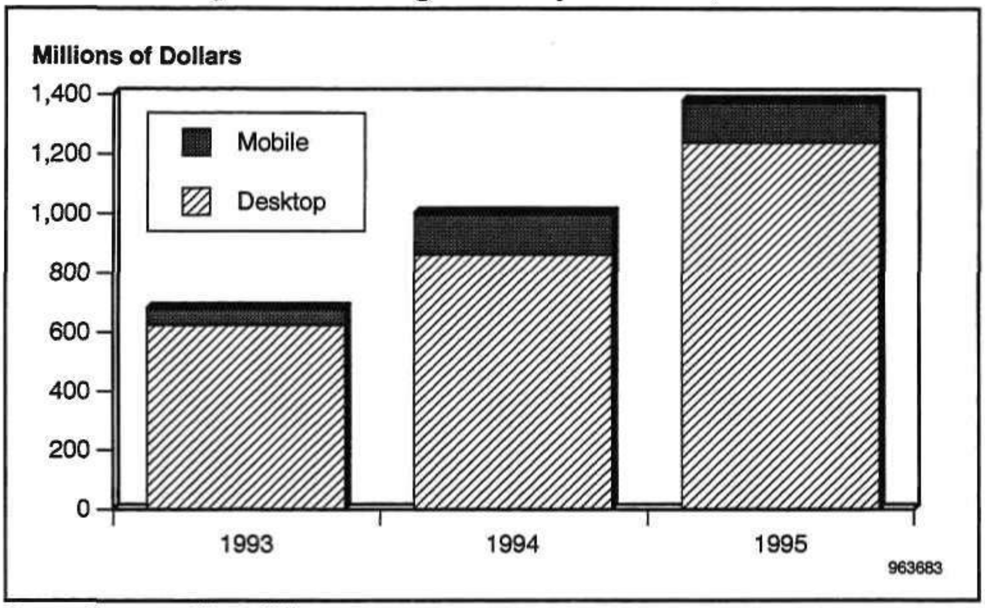
Source: Dataquest (May 1996)

Table 3-3
Personal Computer Core Logic Average Selling Price, 1993-1995 (Dollars)

	Desktop			Mobile			Total		
	1993	1994	1995	1993	1994	1995	1993	1994	1995
Acer Laboratories	13.50	12.00	12.00	0	11.00	11.50	13.50	11.95	11.96
ACC Microelectronics	14.00	12.00	14.00	22.00	18.00	18.00	16.17	13.85	15.30
Chips & Technologies	19.00	17.00	17.00	0	0	0	19.00	17.00	17.00
Cirrus Logic	0	0	0	27.00	23.00	19.50	27.00	23.00	19.50
Cypress	0	0	0	0	0	0	NM	NM	NM
Intel	35.33	35.09	27.00	0	0	0	35.33	35.09	27.00
Oak	0	0	0	0	22.50	0	NM	22.50	NM
OPTi	17.25	15.20	15.50	25.00	20.00	22.00	17.38	15.43	15.83
Silicon Integrated Systems	13.50	12.00	12.75	0	14.00	13.00	13.50	12.02	12.75
Symphony	12.00	12.00	12.00	14.00	14.00	14.00	12.05	12.02	12.03
UMC	13.50	12.00	12.00	0	0	10.75	13.50	12.00	11.98
VIA Technologies	0	15.00	15.00	0	20.00	20.00	NM	NM	NM
VLSI	29.00	25.00	23.00	35.00	30.00	27.00	29.25	26.05	23.40
Weitek	0	0	30.00	0	0	0	NM	NM	30.00
Western Digital	0	0	0	25.00	22.00	22.00	25.00	22.00	22.00
Totals	18.70	17.26	18.00	25.98	23.75	20.26	19.13	17.93	18.21

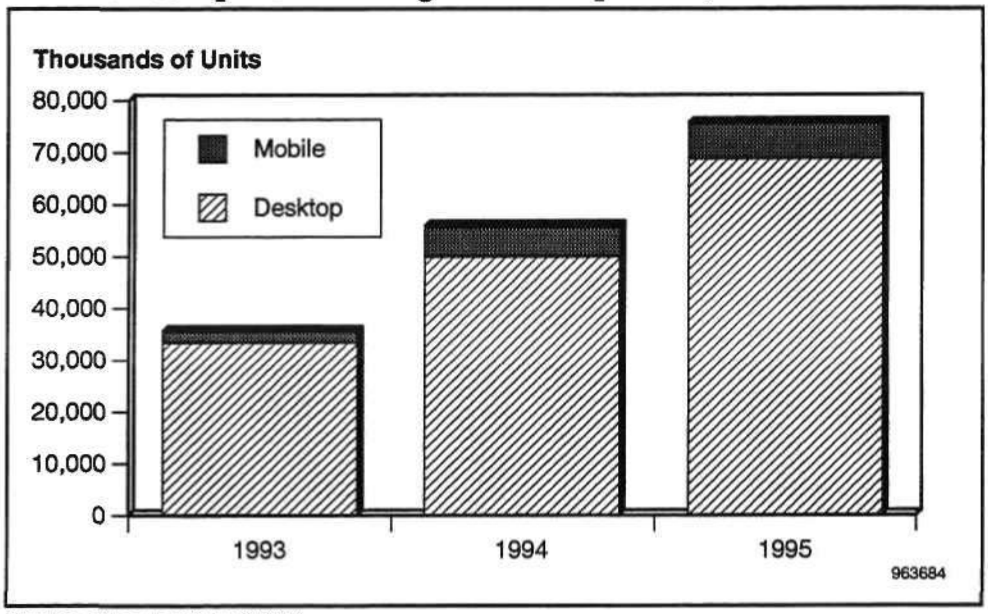
NM = Not meaningful
Source: Dataquest (May 1996)

Figure 3-1
Personal Computer Core Logic Factory Revenue, 1993-1995



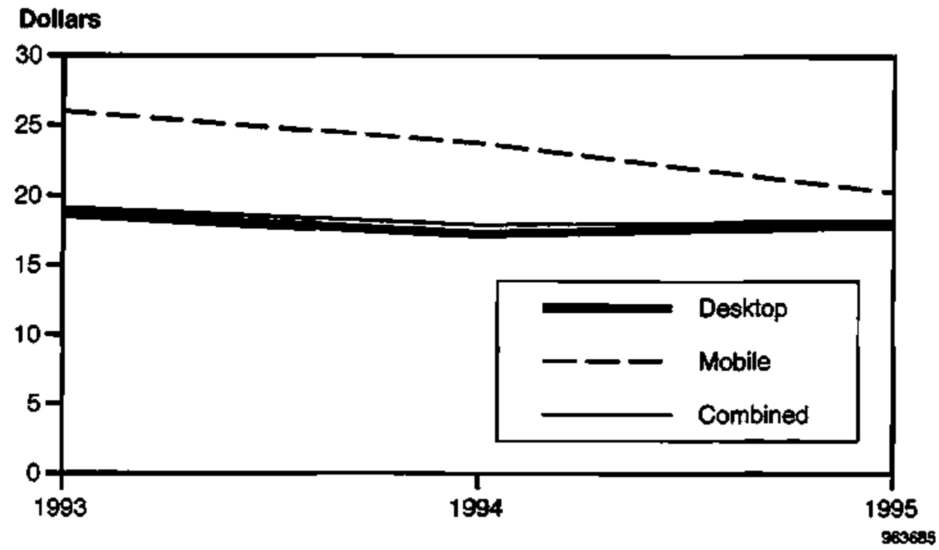
Source: Dataquest (May 1996)

Figure 3-2
Personal Computer Core Logic Unit Shipments, 1993-1995



Source: Dataquest (May 1996)

Figure 3-3
Personal Computer Core Logic Average Selling Price, 1993-1995



Source: Dataquest (May 1996)

Table 3-4
Core Logic Vendors, Ranked by 1995 Factory Revenue (Millions of Dollars)

1995 Rank	1994 Rank		1994 Revenue	1995 Revenue	1994 Market Share (%)	1995 Market Share (%)	Growth (%)
1	2	Intel	186.0	445.5	19	32	140
2	1	VLSI	235.7	228.7	24	17	-3
3	6	VIA Technologies	76.9	140.0	8	10	82
4	4	Silicon Integrated Systems	103.4	130.0	10	9	26
5	3	OPTi	120.0	125.1	12	9	4
6	5	UMC	98.4	109.4	10	8	11
7	8	Cirrus Logic	42.6	58.5	4	4	37
8	7	Acer Laboratories	50.2	56.8	5	4	13
9	9	ACC Microelectronics	35.5	33.8	4	2	-5
10	11	Western Digital	11.0	22.0	1	2	100
11	10	Chips & Technologies	28.9	13.6	3	1	-53
12	12	Symphony	10.3	12.2	1	1	18
13	15	Weitek	0	0.6	0	0	NM
14	13	Oak	0.8	0	0	0	NM
		Total	999.6	1,376.3	100	100	38

NM = Not meaningful
Source: Dataquest (May 1996)

The core logic market also divides naturally by processor type; chipsets designed for 486-class processors cannot be used with Pentium CPUs and vice versa. These two dimensions (CPU type and mobility) define four market segments, each of which displayed different dynamics during 1995. Table 3-5 illustrates the distinctive attributes of these segments.

Table 3-5
Core Logic Market Segmentation

	486	Pentium
Desktop	Shrank rapidly from large base	Grew rapidly from small base
	Falling ASP	Rising ASP
	Cost focus	Performance/feature focus
Mobile	Large, rapidly shrinking niche	Small, rapidly growing niche
	Falling ASP	Flat ASP
	Cost focus	Cost focus

Source: Dataquest (May 1996)

Core Logic for Desktop Systems

In 1995, twelve companies provided virtually all the core logic components used by all major marketers of desktop products; none of the major system vendors still designs its own core logic components. The desktop core logic segment comprised 68.8 million units that sold for $1.24 billion in 1995. It should come as no surprise that this number (68.8 million) exceeds both the number of x86-based personal computers (55.2 million) and the number of x86 processors (64.4 million) sold into computational environments during 1995. Dataquest's data collection methodology does not distinguish core logic sold into computational markets from that sold into embedded markets, and the same core logic chips can often be used in both applications. Dataquest does collect and report data on microprocessors sold into compute and embedded segments separately. The core logic figure tends to fall between sales of all x86 processors (16-bit and 32-bit versions, sold into compute and embedded applications—about 93 million units in 1995) and 32-bit x86 sales (64.4 million units, sold primarily into computational markets at this time).

The Pentium desktop market grew rapidly, driven by a dramatic shift in system mix from 486 to Pentium as the year progressed. Average selling prices increased slightly in this segment as vendors integrated new features into the core logic that added value but decreased the overall bill of materials cost of the resulting systems. The most common new feature in this category was an enhanced integrated drive electronics (EIDE) controller, although some vendors also integrated keyboard controllers or real-time clocks. The good news was that this large market grew rapidly; the bad news (for all except Intel) was that Intel's 430FX product, popularly known as Triton, dominated the segment.

The 486 desktop core logic market provided the most challenges for its participants, which faced declining markets for 486-based systems as the year progressed. There was little opportunity here for innovation or differentiation. Weitek introduced a differentiated product here and promoted a Unified Memory Architecture for the 486, but the company met with little success. Dataquest anticipates that vendors in this segment must reposition their products for "embedded" x86 applications or exit the market. Such embedded applications often incorporate general-purpose personal computer hardware features but are deployed into special-purpose environments, such as display kiosks and PBX system controllers.

Tables 3-6 and 3-7 rank desktop core logic vendors by revenue and unit shipments, respectively, and Figures 3-4 and 3-5 display these results graphically. Intel was the clear winner in this segment. Its revenue grew by 140 percent, and it more than tripled its unit shipments over the prior year. Intel controlled 36 percent of the desktop core logic market. Among the other vendors in this category, only VIA Technologies was able to exceed the segment's 44 percent growth rate. Silicon Integrated Systems (SiS) and VLSI Technology both had double-digit growth but lost share overall as they failed to keep up with Intel's torrid growth.

Table 3-6
Desktop Personal Computer Core Logic Factory Revenue, 1994-1995 (Millions of Dollars)

1995 Rank	1994 Rank		1994	1995	1994 Market Share (%)	1995 Market Share (%)	Growth (%)
1	1	Intel	186.0	445.5	22	36	140
2	2	VLSI	178.8	202.4	21	16	13
3	6	VIA Technologies	76.5	138.0	9	11	80
4	4	Silicon Integrated Systems	102.1	128.8	12	10	26
5	3	OPTi	112.4	116.3	13	9	3
6	5	UMC	98.4	108.0	11	9	10
7	7	Acer Laboratories	48.0	52.8	6	4	10
8	9	ACC Microelectronics	21.3	20.9	2	2	-2
9	8	Chips & Technologies	28.9	13.6	3	1	-53
10	10	Symphony	10.2	12.0	1	1	18
11	14	Weitek	0	0.6	0	0	NM
		Total	862.6	1,238.8	100	100	44

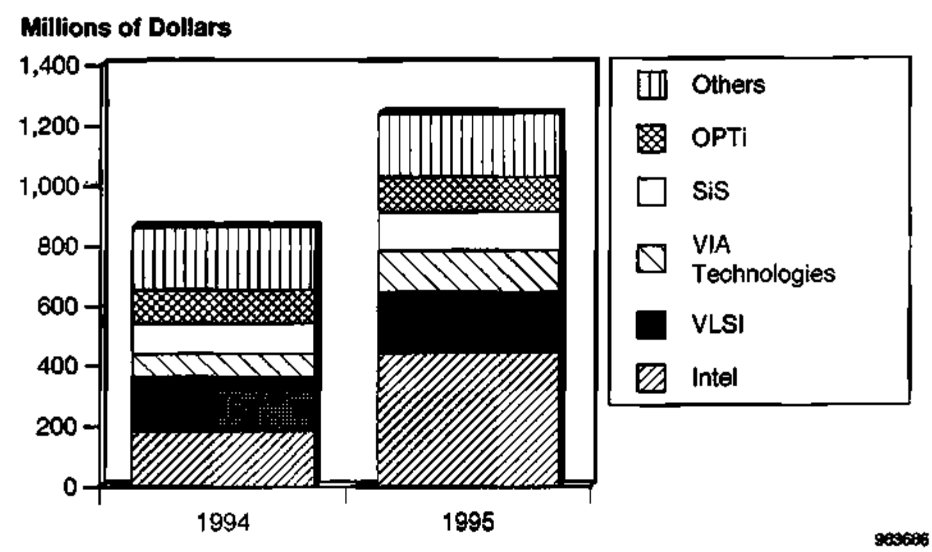
NM = Not meaningful
Source: Dataquest (May 1996)

Table 3-7
Desktop Personal Computer Core Logic Unit Shipments, 1994-1995 (Thousands of Units)

1995 Rank	1994 Rank		1994	1995	1994 Market Share (%)	1995 Market Share (%)	Growth (%)
1	5	Intel	5,300	16,500	11	24	211
2	1	Silicon Integrated Systems	8,510	10,100	17	15	19
3	6	VIA Technologies	5,100	9,200	10	13	80
4	2	UMC	8,200	9,000	16	13	10
5	4	VLSI	7,152	8,800	14	13	23
6	3	OPTi	7,396	7,500	15	11	1
7	7	Acer Laboratories	4,000	4,400	8	6	10
8	8	ACC Microelectronics	1,774	1,490	4	2	-16
9	10	Symphony	850	1,000	2	1	18
10	9	Chips & Technologies	1,700	800	3	1	-53
11	14	Weitek	0	20	0	0	NM
		Total	49,982	68,810	100	100	38

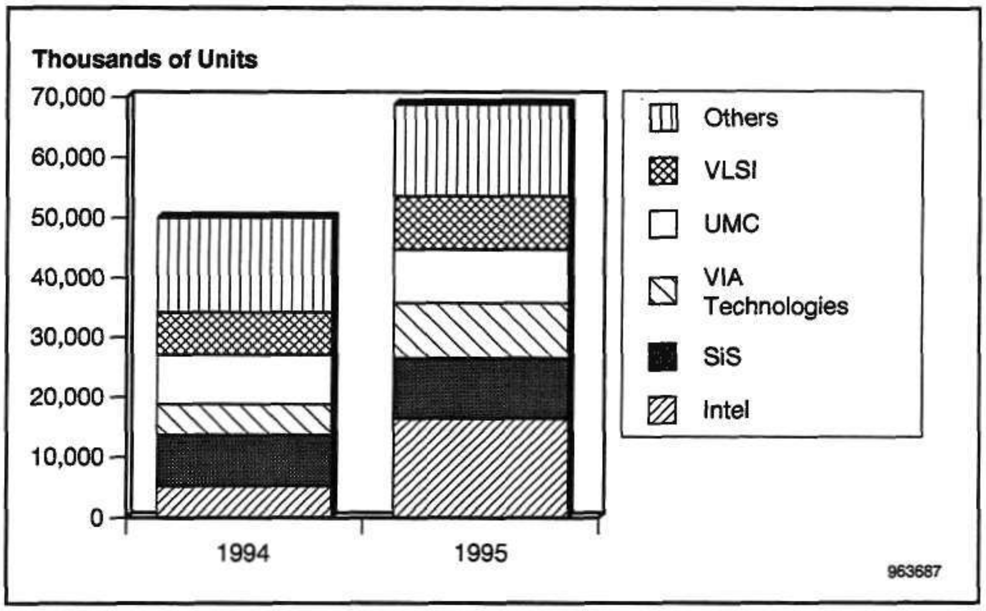
NM = Not meaningful
Source: Dataquest (May 1996)

Figure 3-4
Desktop Personal Computer Core Logic Factory Revenue, 1994-1995



Source: Dataquest (May 1996)

Figure 3-5
Desktop Personal Computer Core Logic Unit Shipments, 1994-1995



Source: Dataquest (May 1996)

Intel clearly has become the dominant player in core logic and shows no sign of retreating from this position. Its core logic operation, headquartered in Folsom, California, supports Intel's strategy of rapidly evolving PC technology and performance to drive market growth. It facilitates the introduction of new I/O architectures like the Peripheral Component Interconnect (PCI) bus, the Universal Serial Bus (USB), and the forthcoming Accelerated Graphics Port (AGP). The Folsom operation also allows Intel to recycle manufacturing facilities, since this core logic generation's process requirements tend to track the prior CPU generation's requirements. Consequently, Intel has brought chipset production in-house after using contract manufacturing sources for the earlier Saturn, Mercury, and Neptune generations. Orion, the relatively low-volume Pentium Pro chipset, is manufactured externally, but the company's next-generation P6 chipset, known over time as Mars, Natoma, and 440FX, will be produced in-house.

Core Logic for Mobile Systems

Ten core logic vendors provided about half the chipsets used in mobile computers; several vendors of mobile systems still use proprietary core logic devices. As system complexity increases, because of more severe power management issues and more complex memory system and I/O structures, this approach becomes less and less practical, and Dataquest anticipates increased penetration of off-the-shelf devices into this class of product. The mobile core logic market comprised almost 6.8 million units that sold for $137 million in 1995.

The Pentium mobile market grew rapidly but from a very small base. In 1995 most mobile systems continued to be built around 486-class CPUs. Mobile Pentium-based products tended toward the high-end in 1995, making this market less price sensitive than others; ASPs remained flat, even with the heavy mix of 486-based mobile products. Intel did not introduce its "mobile Triton" (430TX) product until late in the year, thus leaving opportunities for other vendors to jump in earlier.

The 486 mobile segment provided limited opportunities for product differentiation via power management and grew to over 6 million units. Standard core logic vendors still confronted homegrown solutions in this segment and often cut prices to displace internal designs; the net effect was ASP erosion that led to flat dollar sales on increased unit volumes.

VLSI Technology and Cirrus Logic's PicoPower division traded the No. 1 and No. 2 positions in the mobile segment. VLSI's position depended largely on its mobile 386-based chipset, where sales fell off as the 386 CPU faded from the mobile scene. PicoPower gained the top position as sales of its mobile 486-based chipsets grew substantially and it commenced shipments of its first mobile Pentium products. Despite its success in 1995, PicoPower represented but a minor portion of Cirrus' overall revenue, and the division was rumored to be up for sale as Cirrus tried to focus its energies following a weak finish to 1995.

Tables 3-8 and 3-9 rank mobile core logic vendors by revenue and unit shipments, respectively, and Figures 3-6 and 3-7 display these results graphically.

Table 3-8
Mobile Personal Computer Core Logic Factory Revenue, 1994-1995 (Millions of Dollars)

1995 Rank	1994 Rank		1994	1995	1994 Market Share (%)	1995 Market Share (%)	Growth (%)
1	2	Cirrus Logic	42.6	58.5	31	43	37
2	1	VLSI	56.9	26.3	42	19	-54
3	4	Western Digital	11.0	22.0	8	16	100
4	3	ACC Microelectronics	14.2	13.0	10	9	-9
5	5	OPTi	7.6	8.8	6	6	16
6	6	Acer Laboratories	2.2	4.0	2	3	83
7	9	VIA Technologies	0.4	2.0	0	1	400
8	14	UMC	0	1.4	0	1	NM
9	7	Silicon Integrated Systems	1.3	1.3	1	1	1
10	10	Symphony	0.1	0.2	0	0	50
11	8	Oak	0.8	0	1	0	-100
		Total	137	137	100	100	0

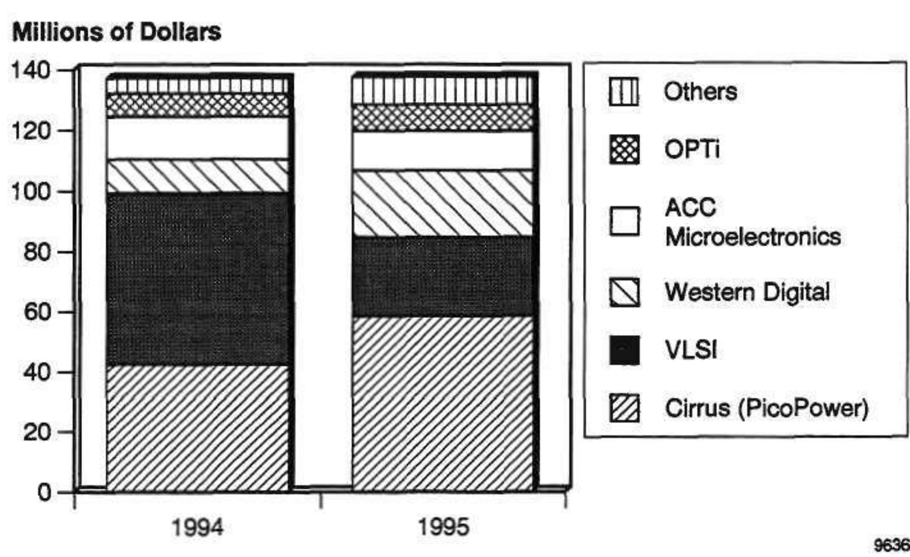
NM = Not meaningful
Source: Dataquest (May 1996)

Table 3-9
Mobile Personal Computer Core Logic Unit Shipments, 1994-1995 (Thousands of Units)

1995 Rank	1994 Rank		1994	1995	1994 Market Share (%)	1995 Market Share (%)	Growth (%)
1	2	Cirrus Logic	1,850	3,000	32	44	62
2	4	Western Digital	500	1,000	9	15	100
3	1	VLSI	1,895	975	33	14	-49
4	3	ACC Microelectronics	789	720	14	11	-9
5	5	OPTi	379	400	7	6	6
6	6	Acer Laboratories	200	350	3	5	75
7	14	UMC	0	130	0	2	NM
8	9	VIA Technologies	20	100	0	1	400
9	7	Silicon Integrated Systems	90	98	2	1	9
10	10	Symphony	10	15	0	0	50
11	8	Oak	35	0	1	0	-100
		Total	5,768	6,788	100	100	18

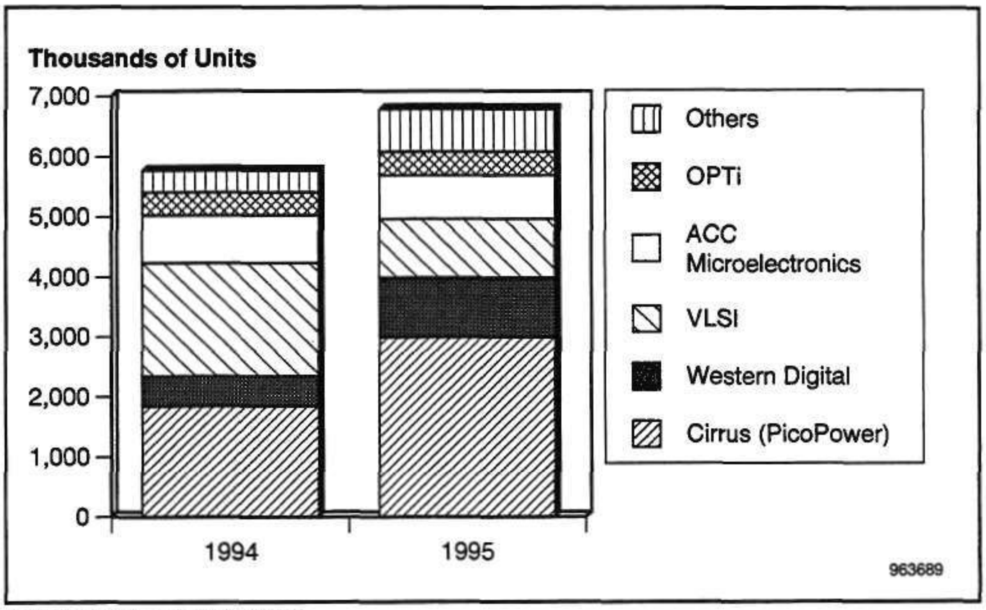
NM = Not meaningful
Source: Dataquest (May 1996)

Figure 3-6
Mobile Personal Computer Core Logic Factory Revenue, 1994-1995



Source: Dataquest (May 1996)

Figure 3-7
Mobile Personal Computer Core Logic Unit Shipments, 1994-1995



Source: Dataquest (May 1996)

Chapter 4

Trends in PC Core Logic Features

Processor Support

Intel's increasing presence in core logic markets creates both problems and opportunities for other core logic suppliers. The biggest problem they face is that Intel's reuse of CPU manufacturing facilities to produce core logic allows it to eliminate much depreciation expense, making Intel the low-cost producer in a market that is highly price competitive. Because it controls many of the key technologies with which the core logic must deal, including CPU, PCI, and USB interfaces, Intel often has a time-to-market advantage as well, a key issue as product cycles continue to shrink. Intel's impending transition from Pentium to P6 processor technology forces independent vendors to confront several key strategic issues. Intel has obtained patents on several unique aspects of its P6 bus design, and it appears unlikely that alternate x86 vendors (that is, Cyrix and AMD) will incorporate the P6 bus into their next-generation designs. Chipset suppliers must decide whether they want to pursue the larger P6 opportunity, where they must go head-to-head with Intel, or whether to focus their efforts on supporting the next-generation processors from AMD and Cyrix, which will likely utilize the current Pentium bus and pinout specifications, but place far greater demands on I/O bandwidth than any existing Pentium processor.

Memory Technology

Most vendors of Pentium-class core logic added support for extended data out (EDO) memory early in 1995, and the system market's rapid transition to EDO in the second half of the year contributed to the supply imbalance that drove the price of fast page mode (FPM) DRAM down at the end of the year.

Memory system bandwidth requirements will continue to be stressed by applications like 3-D rendering and motion video. This is especially true at the low end of the market, where cost concerns dictate that many of the functions handled by outboard subsystems in high-end systems be handled by the main system processor. The processor vendors happily supply the execution engines to drive such devices, but this approach taxes memory bandwidth. SDRAM and Rambus DRAM (RDRAM) will take on increasing significance in this regard.

The use of pipelined burst SRAM (PBSRAM) grew rapidly during the year as core logic vendors added this capability to their products, and memory vendors ramped production of these devices. Supply imbalances kept the price of PBSRAM high in the first half, but brought prices in line with the traditional asynchronous SRAM by year's end. Given the overall system performance benefit provided by a secondary cache in the Pentium environment, especially at higher processor clock rates, Dataquest anticipates that all but the lowest-end desktop systems will incorporate this feature. Fujitsu has demonstrated a device similar to a multichip module (MCM) that contains a Pentium CPU, Mobile Triton chipset, and 256KB of

PBSRAM, all mounted as raw dice on a small daughtercard suitable for use in mobile environments.

The debate that raged in 1995 over Unified Memory Architectures, or UMA, (see Dataquest Perspective PSAM-WW-DP-9602) has now abated, largely because of Microsoft's active lobbying against the concept and the changing economics of the cost of system memory and frame buffer memory toward the end of the year. The 8MB Windows 95 systems with UMA appear in retrospect to have been a marginal proposition at best. Dataquest anticipates that this debate will resurface in 1997, when entry-level systems contain 16MB of memory and the economics of building dedicated frame buffers of 1MB to 2MB, using relatively low-density DRAM components, once again favors UMA approaches.

Input/Output Bus Support

For all intents and purposes, the local bus battle is over. PCI designs have taken hold, even in mobile markets. The next major issue is support for Intel's proposed Accelerated Graphics Port (AGP), which significantly ups the bandwidth between a graphics accelerator and main memory. Intel has driven the AGP definition but indicates that it will make the specification available on a royalty-free basis. Intel has stated that Pentium Pro core logic slated for 1997 will contain support for AGP, but it has said nothing about Pentium core logic during this time. There may be opportunities for third parties to provide such enhancements for processors using the Pentium bus architecture, which include not only the P55C, but sixth-generation designs from Cyrix and AMD as well.

The new Universal Serial Bus interface will take on increasing significance in the second half of 1996 and beyond, and competitive new core logic designs must provide support for this feature.

Integration of Enhanced Features

The classic approach to adding value to core logic products is to absorb functions handled by separate support chips in current designs. EIDE, supporting PCI master mode transfers, has now been incorporated into most chipsets, and Microsoft has indicated its intention to add standard support for this feature in the next release of Windows 95. Some vendors have chosen to integrate real-time clock and/or keyboard controller functions as well. Dataquest expects to see at least one vendor offer "Super I/O" features in core logic during the next year.

Power Management

Power management features, long a requirement in chipsets targeted at mobile applications, will take on increased importance in desktop environments as well. At the WinHEC '96 conference, Microsoft unveiled its Simply Interactive PC (SIPC) initiative, which makes the personal computer more appliance-like by enabling it to transition from a mostly powered-down state to an active state in less than 10 seconds. This would allow a sleeping PC to wake up and answer a ringing phone in time to take a message or receive a fax. The SIPC program has significant implications for core logic and BIOS vendors, as well as for operating system and application program designers.

Packaging

The nature of the functions core logic performs tends to cause many such devices to be limited more by interconnect mechanisms than by silicon density or performance. The cost-sensitive nature of the application precludes expensive solutions to this problem. Several vendors have recently introduced core logic in ball-grid array (BGA) packages in order to increase the number of signals entering the device without significantly increasing its packaging cost. Dataquest anticipates increased use of this approach over the next two years.

Chapter 5
Competitive Analysis

The following section provides a brief overview of the top three core logic vendors, as measured by 1995 factory revenue.

Intel

Intel's core logic operation, headquartered in Folsom, California, supports Intel's strategy of rapidly evolving PC technology and performance to drive market growth. It facilitates the introduction of new I/O architectures like the Peripheral Component Interconnect (PCI) bus, the Universal Serial Bus (USB), and the forthcoming Accelerated Graphics Port (AGP). Systems based on its Triton chipset, introduced early in 1995 and ramped aggressively in the second quarter, continued to win performance benchmarks throughout the year.

Intel used contract manufacturing sources for its Saturn, Mercury, and Neptune Pentium chipsets, as well as for Orion, its first-generation Pentium Pro core logic. In 1995, Intel began in-house production of its Triton (430FX) chipsets, and this continues in 1996 with in-house manufacture of Triton II (430HX), Triton VX (430VX), and Natoma (440FX). The Folsom operation allows Intel to recycle manufacturing facilities, since this year's core logic process requirements tend to track the prior year's CPU process needs. This eliminates much of the equipment depreciation expense for this class of product and allows Intel to compete with vendors having far lower overhead expenses.

Before Intel's participation, this market tended to have a high-price (over $50) segment that addressed high-performance markets and a lower-price segment (under $20) for customers willing to trade performance for cost. Intel's entry compressed these price points, forcing high-end chipsets into the $20-to-$30 range and low-end devices below $15.

Dataquest estimates that more than half the chipsets Intel manufactures are consumed by the company's motherboard operation, which in turn sells most of its output on an OEM basis to major PC suppliers.

VLSI Technology

Last year's top core logic supplier, VLSI Technology's Personal Computer Division (PCD), headquartered in Tempe, Arizona, had a difficult year in the face of Intel's aggressive growth in this segment. Growth in desktop revenue was constrained by price erosion and delays in the company's Wildcat program, the successor to the earlier Pentium Supercore product. Shipments of its mobile products declined as OEM customers for its 386-based mobile designs selected other vendors for their 486-based products. More than most other vendors, VLSI suffered from the price compression at the high end of the market. It had neither the low overhead structure of offshore vendors nor Intel's access to depreciated equipment.

VIA Technologies

VIA Technologies, based in Fremont, California, was the only vendor able to increase its market share from 1994 to 1995 in the face of Intel's dramatic growth in this area. The company's core logic revenue grew 82 percent to $140 million in 1995. Via has emphasized highly integrated designs that include EIDE controller, keyboard controller, and real-time clock, thus lowering the bill of materials cost for systems built around its core logic. Via has been quick to jump on new technologies, and at last fall's COMDEX show it demonstrated a Pentium chipset that supported burst EDO (BEDO) DRAM, synchronous DRAM, and a Unified Memory Architecture. Via is the only company (outside of Intel) to develop and market core logic for the Pentium Pro. The company's initial three-chip version of this set, introduced in January, provided a compact and inexpensive alternative to Intel's seven-chip Orion DT configuration. Via followed this with a recent announcement of a two-chip version that supports BEDO and SDRAM memory technologies.

Chapter 6

Market Forecast

Dataquest derives its core logic forecast from a combination of the Semiconductor group's worldwide x86 microprocessor forecast and its worldwide personal computer forecast. The personal computer forecast drives the unit mix between desktop and mobile systems, which remains steady at 18 percent mobile, 80 percent desktop, and 2 percent server. The PC forecast also plays a key role in the mix among different processor generations.

The core logic unit forecast tracks overall demand for x86 processors, including those sold into both compute and embedded applications. (As noted earlier, Dataquest classifies many personal computer hardware configurations as embedded only because a general-purpose personal computer or PC motherboard is installed within a fixed-function device, such as a display kiosk. Such systems nevertheless consume standard PC core logic.) This classification scheme leads to the interesting anomaly that allows us to report core logic unit shipments in excess of personal computer shipments and also in excess of microprocessors used in personal computers.

The forecasting problem is further complicated by differing processor model mixes in mobile computational, nonmobile computational, and embedded applications. Our model reflects our estimates of these CPU mixes over time.

Table 6-1 and Figure 6-1 provide Dataquest's forecast for core logic chipsets by x86 processor generation, from 1996 through 2000. It is important to note that for tracking and forecasting purposes, Dataquest defines these generations primarily by MPU pinout considerations. Thus, we classify the Cyrix 5X86 and the AMD 5X86, both of which fit into 486-type sockets, as 486 from a core logic perspective. Similarly, the Cyrix 6x86 and the AMD 5K86, neither of which shipped in meaningful quantities in 1995, will both be counted in 586 core logic families, even though they contain many of the architectural features found in Intel's Pentium Pro design.

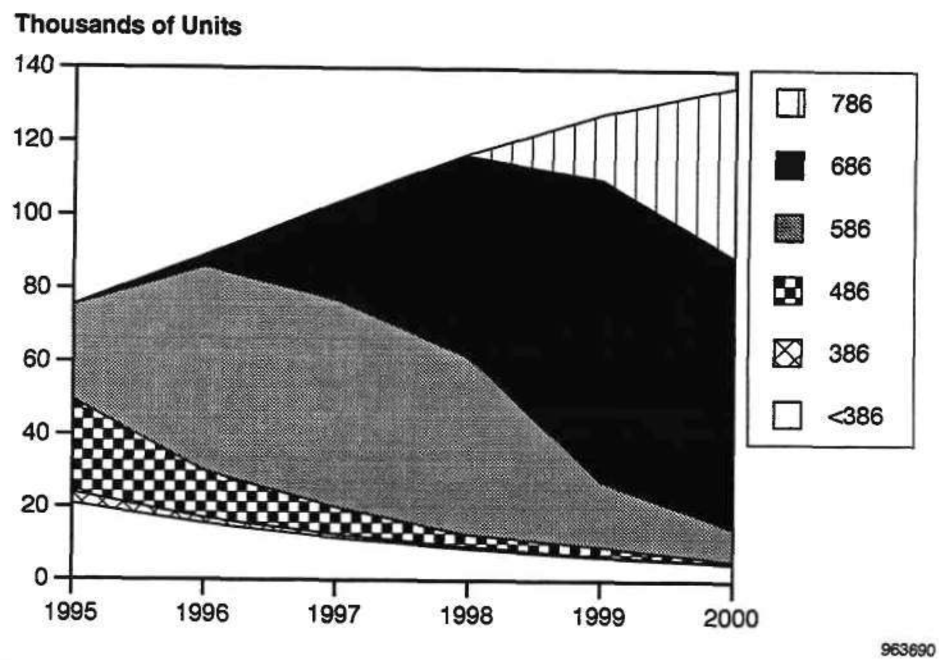
Table 6-2 and Figure 6-2 describe Dataquest's forecast in terms of target markets. The segment named "fixed" refers to desktop and deskside computational applications. "Mobile" refers to systems containing x86 devices used in mobile applications. "Embedded" refers to x86 systems used in nongeneral-purpose environments, which include both mobile and fixed applications.

Table 6-1
Core Logic Unit by x86 Processor Generation, 1996-2000 (Thousands of Units)

CPU Type	1995	1996	1997	1998	1999	2000
<386	20,816	15,481	11,518	8,602	6,437	4,822
386	3,078	1,520	988	593	356	213
486	25,597	12,996	7,502	3,359	2,470	513
586	25,937	55,849	57,024	48,620	18,000	9,060
686	80	3,200	26,400	54,880	82,472	74,400
786	0	0	0	800	18,000	46,400
Total	75,507	89,045	103,432	116,854	127,734	135,408

Source: Dataquest (May 1996)

Figure 6-1
Core Logic Unit Forecast for Desktop Systems, 1996-2000



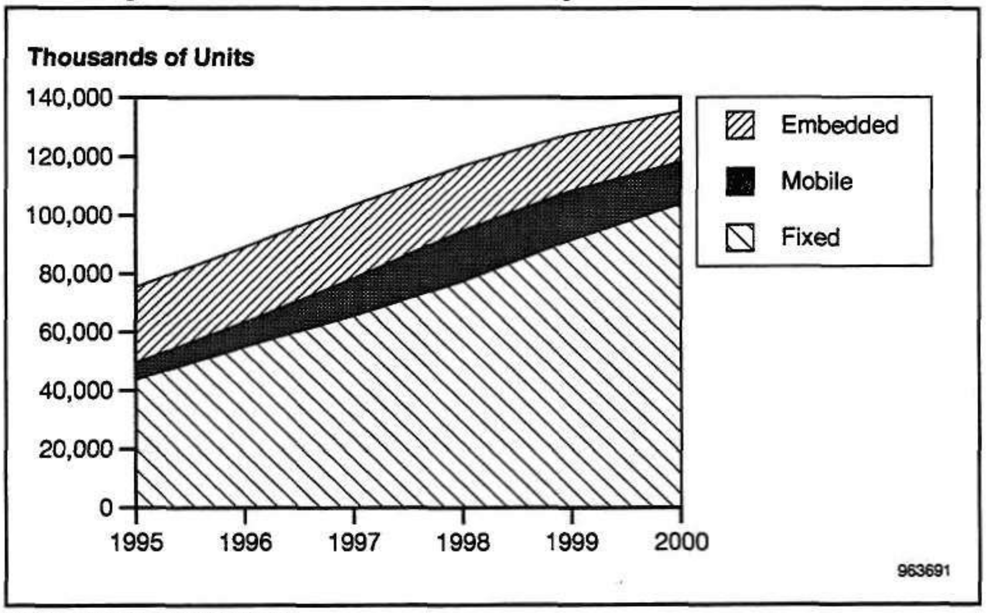
Source: Dataquest (May 1996)

Table 6-2
Core Logic Unit Forecast by Application, 1996-2000 (Thousands of Units)

Application	1995	1996	1997	1998	1999	2000
Embedded	26,065	25,652	24,949	22,173	19,365	17,248
Mobile	5,748	8,543	12,851	17,158	16,790	14,400
Fixed	43,694	54,851	65,632	77,523	91,580	103,760
Total	75,507	89,045	103,432	116,854	127,734	135,408

Source: Dataquest (May 1996)

Figure 6-2
Core Logic Unit Forecast for Mobile Systems, 1996-2000



Source: Dataquest (May 1996)

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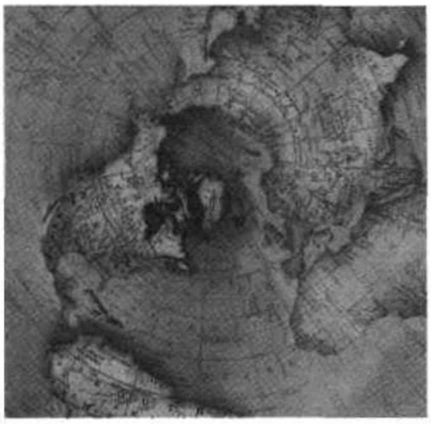

Dataquest

PC Semiconductor Application Markets: Graphics Controllers

Market Trends

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-MT-9601
Publication Date: May 27, 1996
Filing: Market Trends

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Table of Contents

List of Figures

List of Tables

Chapter 1

Executive Summary

The market for graphics controllers in PCs grew to $1.32 billion in 1995. The year was characterized by tight supply of graphics controllers, as well as most other semiconductor devices, through most of the year, with a dramatic shift in the fourth quarter to abundant supply coupled with softening demand for PCs.

Cirrus Logic is still the largest supplier of graphics controllers but did lose market share. S3 and ATI Technologies gained market share in the desktop market by emphasizing their 64-bit graphics products. Chips & Technologies was the big mover on the mobile graphics side of the market, posting tremendous 270 percent unit growth and breaking the $100-million-dollar mark in that market alone.

Trends in features include wider adoption of video acceleration features, which shipped in 26 percent of desktop PC graphics controllers in 1995. Interface standards are still coupled with microprocessor sales as PCI follows Pentium shipments and Intel's Accelerated Graphics Port will follow Pentium Pro shipments starting in the second half of 1997. Graphics memory is shifting to EDO DRAM from FPM DRAM now, but SGRAM is on the horizon with good prospects for widespread use in graphics.

The future will be exciting for graphics vendors as market growth slows in 1996 to 7.1 percent on a revenue basis before rebounding to 20.8 percent revenue growth in 1997 as shipments of 3-D graphics accelerators soar past the 20-million-unit mark, up from 3 million units in 1996. Software compatibility issues, including the delays of Microsoft's Direct3D, will limit the number of 3-D games on the retail shelves this year and subsequently postpone the widespread adoption of 3-D graphics accelerators into 1997. Price competition for 2-D accelerators with video features, coupled with the relatively small numbers of more expensive 3-D accelerators (a few million units this year), is the reason for slow revenue growth expectations in 1996.

Chapter 2
Introduction and Methodology

This document is the first in a series of four that provide reference information and analysis about the markets for semiconductor devices in personal computers. The four books discuss graphics controllers, core logic chipsets, microprocessors, and an overview that includes a model of total semiconductor content for PCs.

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers, as well as analyst knowledge and opinions. Secondary sources include government and trade sources on sales, production, trade, and public spending. Semiconductor content assumptions are based on both surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative personal computers.

The forecast methodology is based on various methods and assumptions, depending on the specific market. To form a solid basis for projecting system demand and capital, government and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes, and government policies are also considered. Semiconductor content forecasts are based on interviews of system marketers and designers (including makers of enabling semiconductor technology), along with an analysis of historical trends.

Project Analyst: Geoff Ballew

Chapter 3

Market Analysis

1995: In Like a Lion, Out Like a Lamb

The PC graphics controller market grew to $1.32 billion in 1995, with 22.2 percent growth over 1994's $1.08 billion size. Unit shipments rose 26.9 percent over this same period as the average selling price (ASP) fell because of competition. This market is driven primarily by demand for PCs but was not quite as strong as the PC market last year. Factory revenue for PCs grew by 30.7 percent even though unit shipments of PCs grew by only 25.6 percent.

The ASP for graphics controllers fell slightly in 1995 while the ASP for finished PCs increased. Supply constraints through most of 1995 forced vendors to do a balancing act between new products and more mature ones. Graphics chip vendors wanted the higher prices that new products fetch but faced lower manufacturing yields as production ramped up. Volume commitments kept capacity allocated to the mature products, slowing the adoption of new features, as vendors struggled to meet demand for chips. Capacity constraints eased near the end of the year, but slower PC demand coupled with relatively high inventories reduced demand for graphics controllers as well as other components. PC OEMs and add-in board OEMs did not place as many new orders for graphics controllers because their inventory levels were full from previous orders. The result was a year that finished with a sigh rather than a bang as graphics vendors were largely unable to benefit from the greater availability of manufacturing capacity near the end of the year.

Cirrus Logic Retains the No. 1 Ranking

Cirrus Logic is still the largest supplier of graphics controllers to the PC market, despite losing market share in 1995 to competitors such as S3, ATI, and Chips & Technologies. Cirrus' revenue came close to $0.5 billion, with over 90 percent from the desktop graphics market. Cirrus' growth was limited by supply constraints, which eased just about the same time that a major customer canceled some orders. Those canceled orders left Cirrus with too much inventory when prices for 32-bit controllers were sharply eroding. Table 3-1 shows the unit shipments and revenue for PC graphics controllers. Figure 3-1 shows the unit shipment data graphically.

The real winners for 1995 were S3 and ATI. Both these companies doubled their unit shipments while maintaining the highest ASPs of the high-volume graphics chip vendors. S3 led the shift to 64-bit controllers from the older 32-bit designs as access to manufacturing capacity limited its ability to support both product lines. Both S3 and ATI reaped the benefits of emphasizing the 64-bit products like S3's Trio64 and ATI's Mach64 with higher prices and relative immunity from price erosion in the 32-bit graphics market near the end of the year. Note that these two companies have the highest ASPs in the list of top vendors. The race for market share in 1996 will be heated as the 3-D graphics becomes more important. ATI and S3 have complete product portfolios that include fast 2-D graphics and video acceleration as well as pin-compatible 3-D accelerators. 2-D performance coupled with pin-compatible 3-D accelerators will win designs for these two companies. Cirrus Logic has promised that it will have

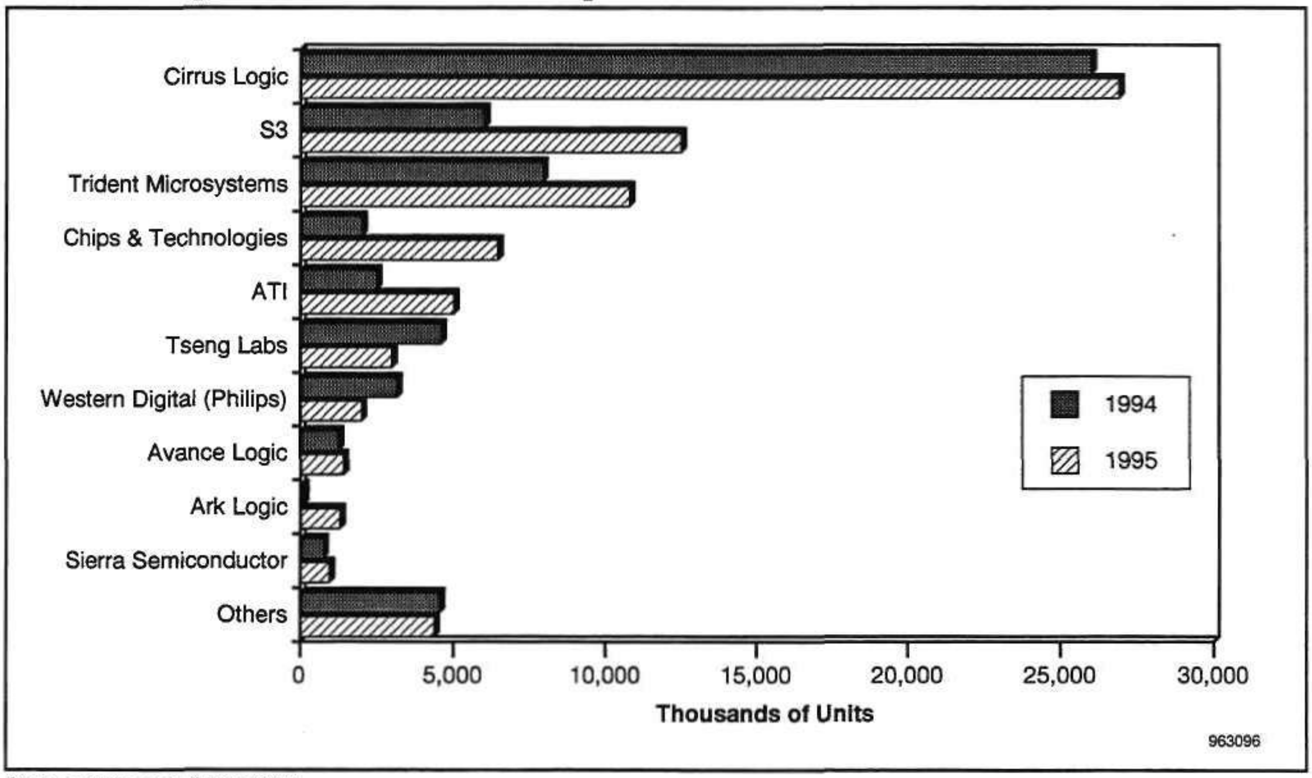
3-D accelerators in time for Christmas 1996 products but has not announced details. Table 3-2 shows the unit shipments and revenue for desktop PC graphics controllers. Figure 3-2 shows the unit shipment data graphically.

Table 3-1
Vendor Market Share for PC Graphics Controllers (Units in Thousands, Revenue in Millions)

1995 Rank	1994 Rank	Company	1994 Units	1995 Units	1995 Revenue	Market Share (%)
1	1	Cirrus Logic	26,000	26,900	488.1	37.0
2	3	S3	6,000	12,500	288.0	21.8
3	2	Trident Microsystems	7,903	10,791	132.8	10.1
4	7	Chips & Technologies	2,013	6,425	115.9	8.8
5	6	ATI Technologies	2,500	5,000	100.0	7.6
6	4	Tseng Labs	4,600	3,000	39.0	3.0
7	5	Western Digital (Philips)	3,175	2,000	38.0	2.9
8	8	Avance Logic	1,250	1,417	18.4	1.4
9	NR	Ark Logic	100	1,300	15.6	1.2
10	9	Sierra Semiconductor	750	953	14.3	1.1
		Others	4,549	4,382	69.3	5.3
		Total	58,840	74,668	1,319.4	

NR = Not ranked
Source: Dataquest (May 1996)

Figure 3-1
Total PC Graphics Controllers Unit Shipments



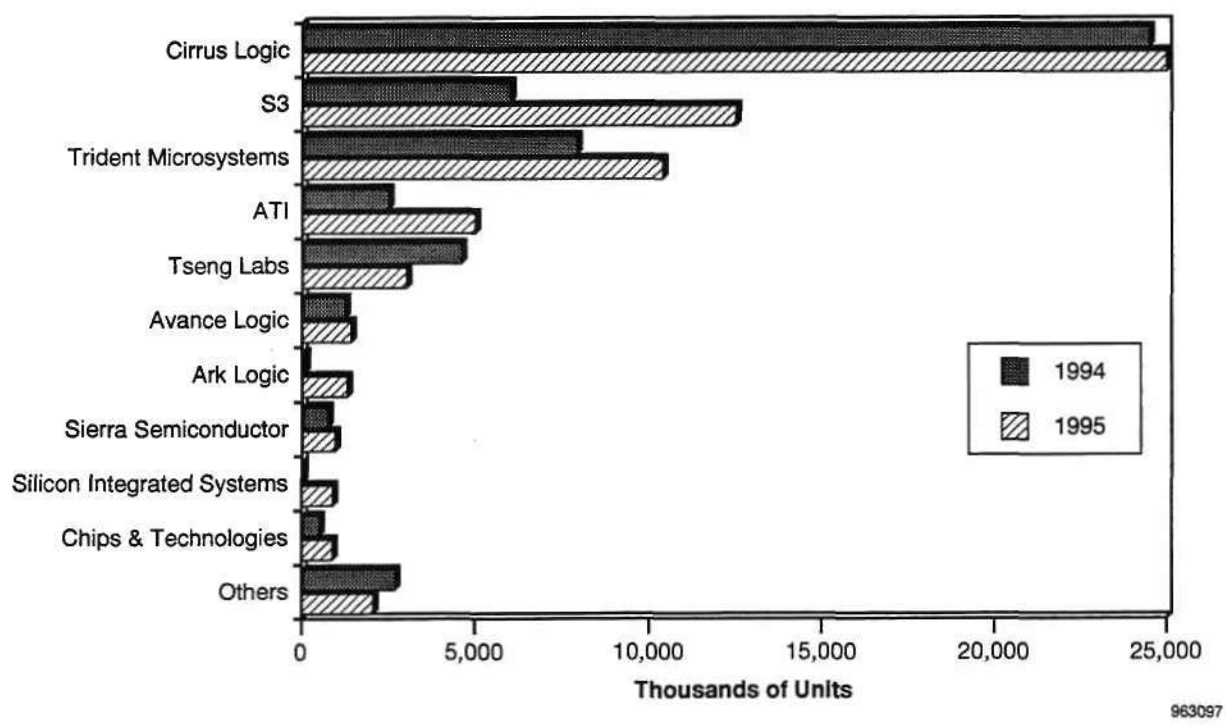
Source: Dataquest (May 1996)

Table 3-2
Vendor Market Share for Desktop PC Graphics Controllers (Units in Thousands, Revenue in Millions)

1995 Rank	1994 Rank	Company	1994 Units	1995 Units	1995 Revenue	Market Share (%)
1	1	Cirrus Logic	24,500	25,000	446.3	40.7
2	3	S3	6,000	12,500	288.0	26.2
3	2	Trident Microsystems	7,903	10,381	124.6	11.3
4	5	ATI Technologies	2,500	5,000	100.0	9.1
5	4	Tseng Labs	4,600	3,000	39.0	3.6
6	6	Avance Logic	1,250	1,417	18.4	1.7
7	NR	Ark Logic	100	1,300	15.6	1.4
8	7	Sierra Semiconductor	750	953	14.3	1.3
9	NR	Silicon Integrated Systems	0	896	11.6	1.1
10	9	Chips & Technologies	513	876	10.5	1.0
		Others	2,695	2,067	29.3	2.7
		Total	50,811	63,390	1,097.6	

NR = Not ranked
Source: Dataquest (May 1996)

Figure 3-2
Desktop PC Graphics Controllers Unit Shipments



Source: Dataquest (May 1996)

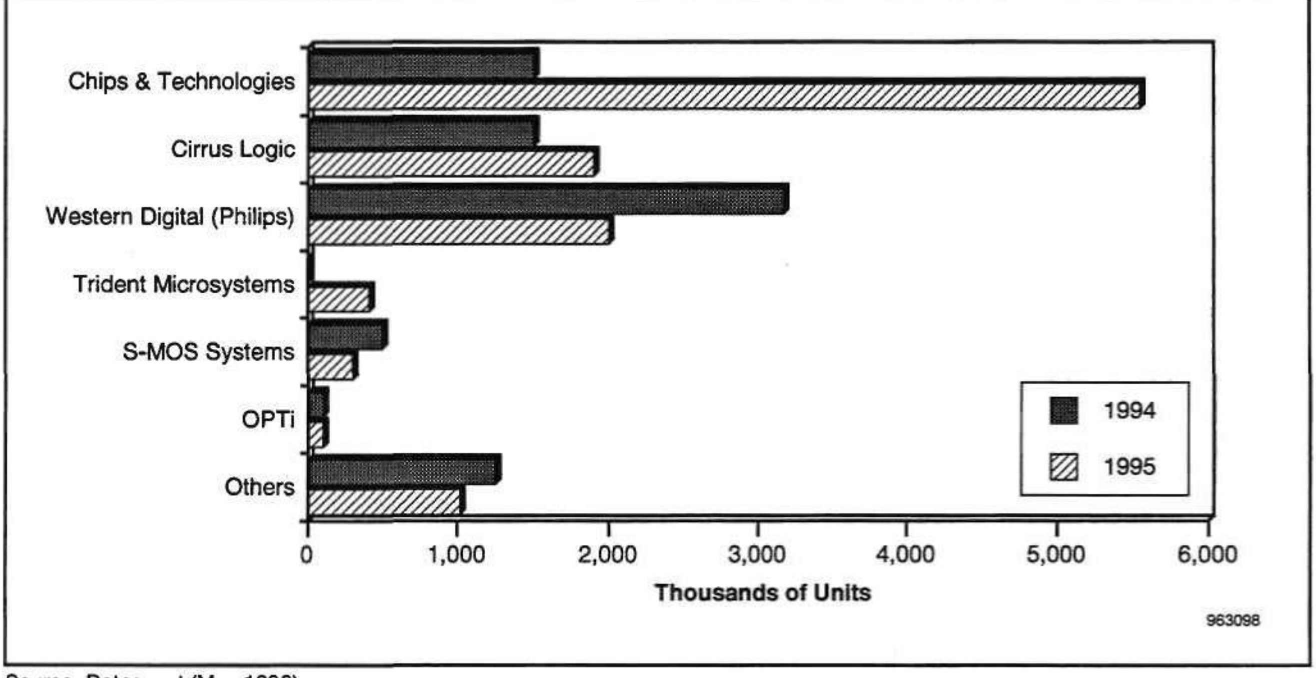
Chips & Technologies seized the No. 1 position in the mobile graphics market, beating Western Digital with an array of higher-performance controllers. Chips & Technologies grew its unit shipments and revenue with an impressive number of design-wins for the 65545 family of controllers. The year 1996 will be interesting because S3, the second-largest PC graphics vendor, introduced a family of products for mobile computers last January. Even with the new competition, Dataquest expects Chips & Technologies to retain the No. 1 position for mobile graphics controllers in 1996. Table 3-3 shows the unit shipments and revenue for mobile PC graphics controllers. Figure 3-3 shows the unit shipment data graphically.

Table 3-3
Vendor Market Share for Mobile PC Graphics Controllers (Units in Thousands, Revenue in Millions)

1995 Rank	1994 Rank	Company	1994 Units	1995 Units	1995 Revenue	Market Share (%)
1	3	Chips & Technologies	1,500	5,549	105.4	47.5
2	2	Cirrus Logic	1,500	1,900	41.8	18.8
3	1	Western Digital (Philips)	3,175	2,000	38.0	17.1
4	NR	Trident Microsystems	0	410	8.2	3.7
5	4	S-MOS Systems	500	300	6.0	2.7
6	5	OPTi	100	100	2.0	0.9
		Others	1,254	1,019	20.4	9.2
		Total	8,029	11,278	221.8	

NR = Not ranked
Source: Dataquest (May 1996)

Figure 3-3
Mobile PC Graphics Controller Unit Shipments



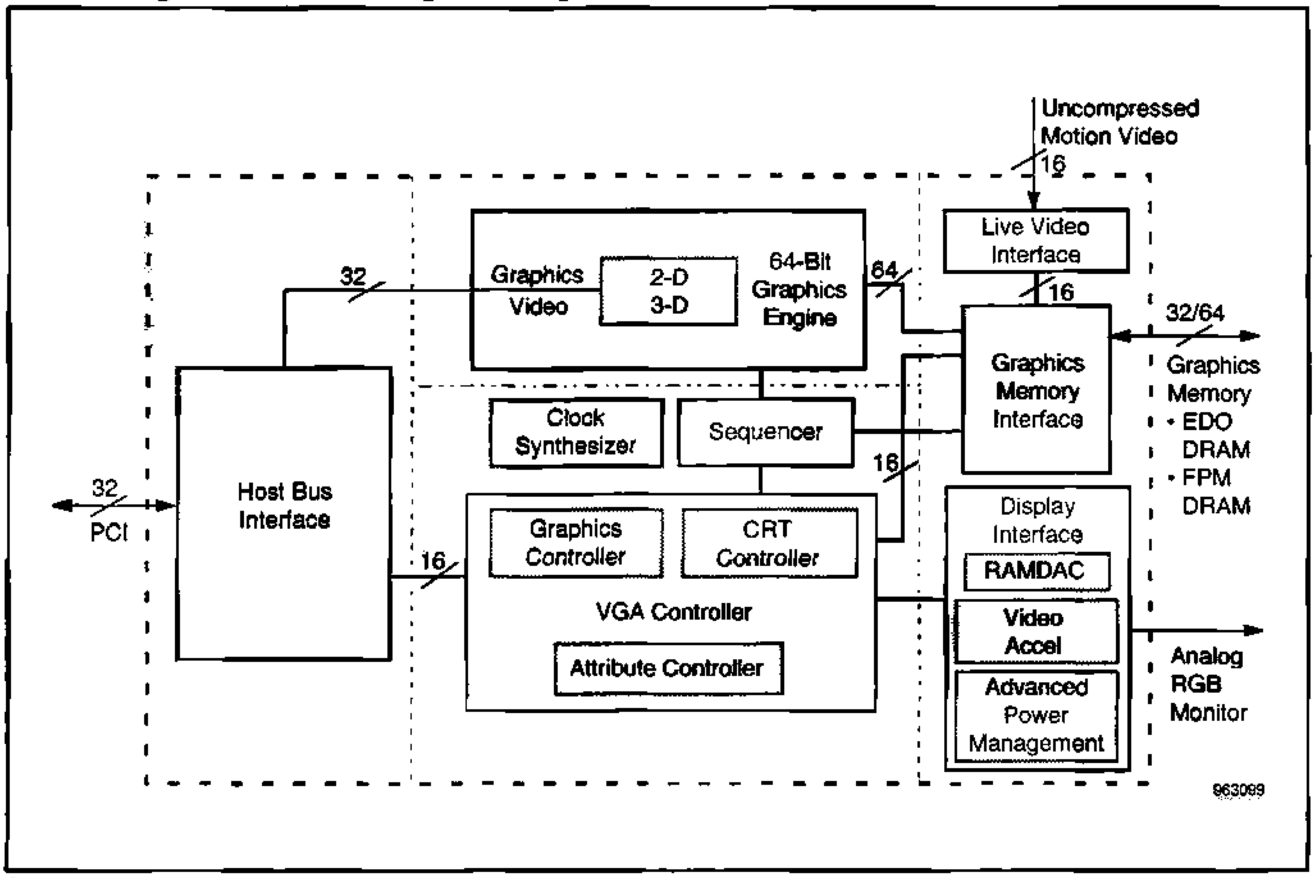
Source: Dataquest (May 1996)

Chapter 4
Trends in Features of PC Graphics Controllers

Higher Levels of Integration

Figure 4-1 shows the level of feature integration for a desktop graphics controller today. The most significant additions in 1995 were the live video interface and 3-D graphics acceleration. The live video interface is more sophisticated than the video pass-through connectors that graphics controllers have had in the past because it feeds video data into the graphics memory rather than straight to the video accelerator. This enables live video to share the existing graphics memory and makes effective use of the control functions in the graphics chip to mix the video and graphics data streams.

Figure 4-1
Block Diagram for a Desktop PC Graphics Controller



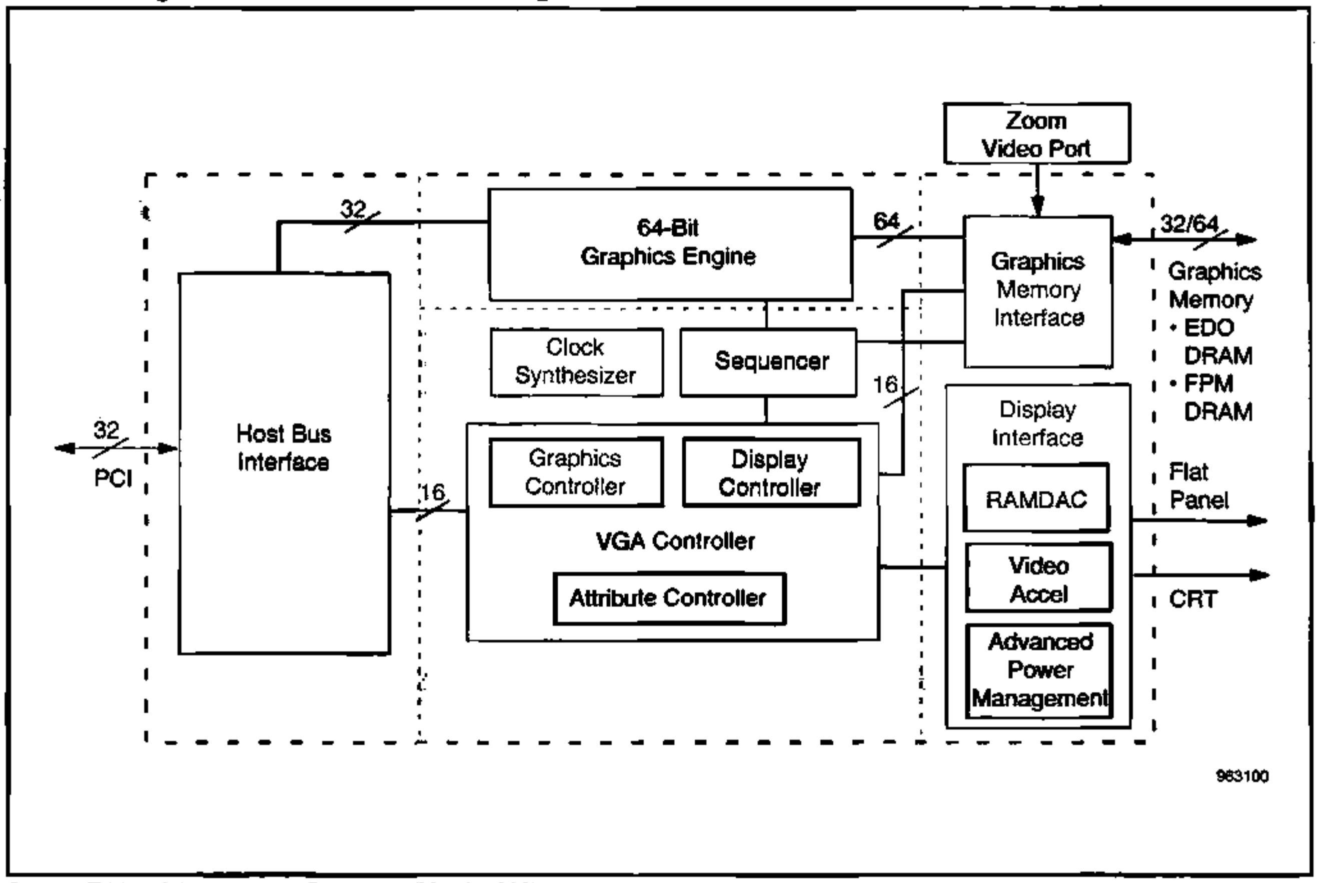
Source: Trident Microsystems, Dataquest (March 1996)

Figure 4-2 shows the level of feature integration for a mobile PC graphics controller today. The most significant changes in 1995 were the shift to a 64-bit graphics engine, the addition of video acceleration features, and the Zoom Video (ZV) port. The ZV port is effectively the mobile PC equivalent of the live video interface added to desktop controllers. It allows video data to stream through the PC Card or PCMCIA connector to the graphics controller, but it does require support logic in the PC Card or PCMCIA controller as well as the graphics controller.

Video Acceleration

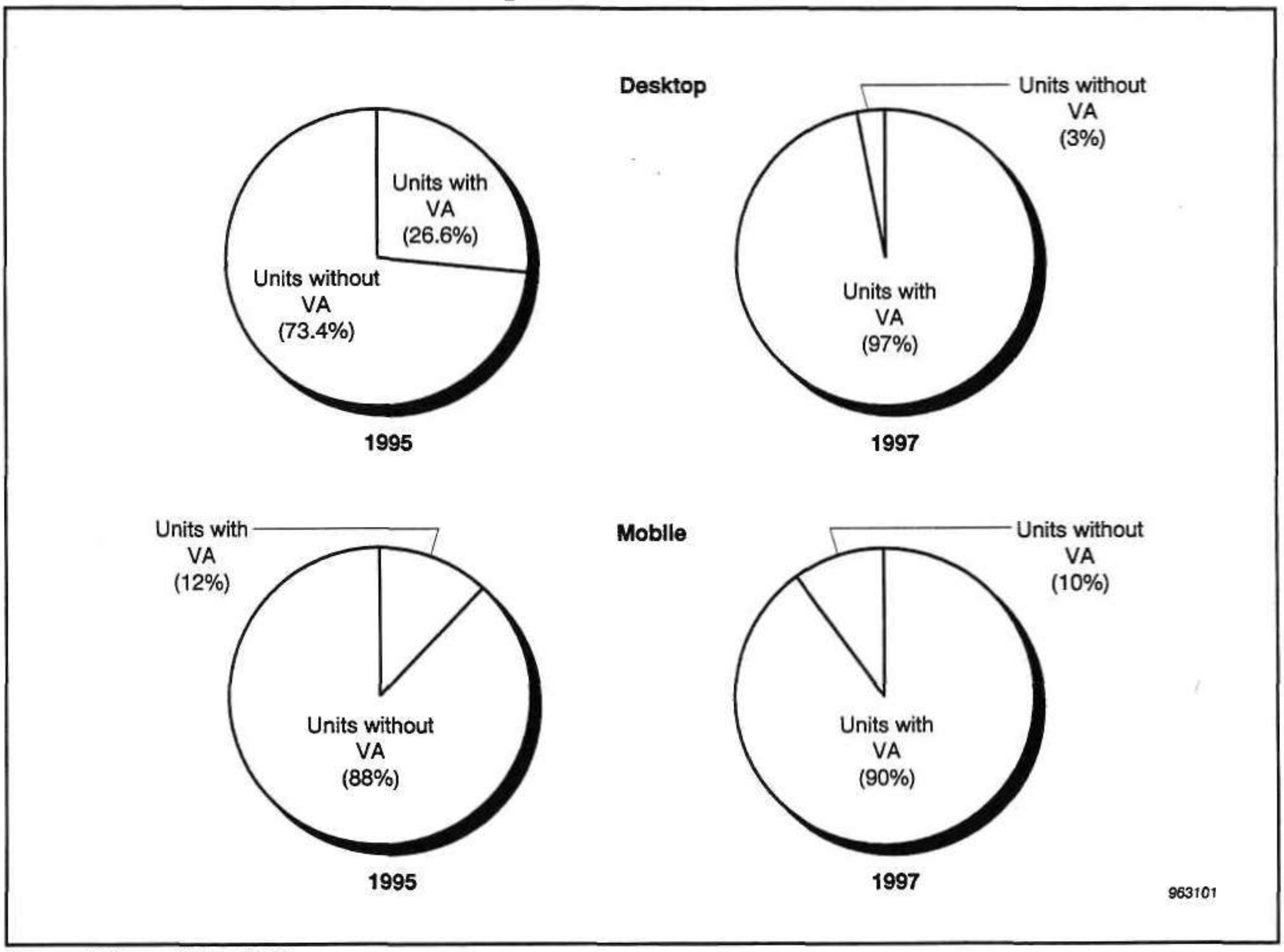
PC graphics controllers now include features for accelerating digital video playback. Research shows that video acceleration (VA) features shipped in 26 percent of desktop PC graphics controllers in 1995, up from 3 percent in 1994. The mobile PC graphics market is a half-step behind the desktop market, with 12 percent of graphics controllers shipping with video acceleration in 1995, up from zero percent in 1994. These features will spread to nearly 100 percent of unit shipments for desktop PC graphics controllers in 1997 and 90 percent of mobile PC graphics controllers in that same year. Figure 4-3 shows this trend graphically.

Figure 4-2
Block Diagram for a Mobile PC Graphics Controller



Source: Trident Microsystems, Dataquest (March 1996)

Figure 4-3
Video Acceleration (VA) in PC Graphics Controllers

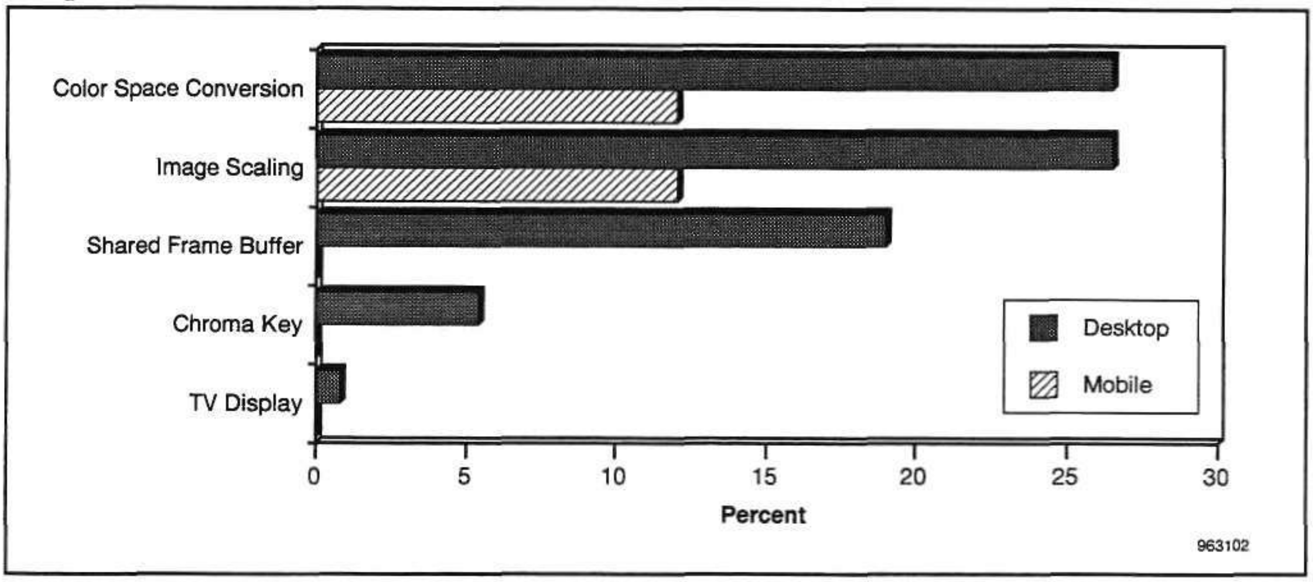


Source: Dataquest (May 1996)

Within the broad definition of video acceleration, there is room for graphics vendors to differentiate their products on specific acceleration features as well as quality. Figure 4-4 shows the percentage of graphics controllers that shipped in 1995 with specific video acceleration features, broken out by desktop and mobile markets.

These will quickly become standard features that ship in almost all graphics controllers. The mobile graphics market will continue to lag the desktop market in adoption rate for these features, but the lag time is less than one year. Color space conversion, scaling with both vertical and horizontal interpolation, and the ability to share the frame buffer for YUV and RGB data will increase to nearly 100 percent of unit shipments by the end of 1997. Chroma key may lag those features slightly, but it is a key feature for interactive multimedia titles, particularly games. TV display will lag a bit more as demand for these features is now focused in Asian markets where TV/PC combinations are more popular because of space considerations. Demand for TV display features in the U.S. and European home PC markets is low but will increase. Initiatives to make the PC a home appliance for the living room, such as Microsoft's Simply Interactive PC (SIPC), require TV display features to blur the difference between monitors and TVs.

Figure 4-4
Relative Shipments of Specific Video Acceleration Features in Desktop and Mobile PC Graphics Controllers in 1995



Source: Dataquest (May 1996)

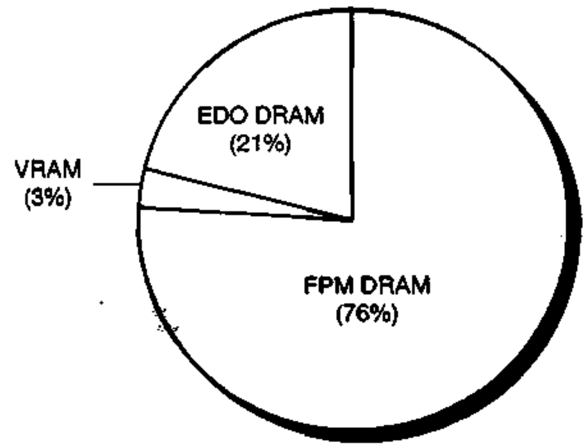
Graphics Memory

Most graphics controllers today use fast page mode (FPM) DRAM for the graphics memory, with VRAM reserved for high-end applications that are less cost-sensitive. New types of memory are necessary as 3-D graphics and higher-resolution displays push the performance limits of FPM DRAM. The transition is difficult because PC OEMs do not want their cost per megabyte to rise, but they need the benefits offered by new types of memories. The first alternative is extended data out (EDO) DRAM, which offers higher performance at a small price premium. Over 21 percent of graphics controllers shipped last year could use EDO DRAM. Figure 4-5 shows the types of memory supported by graphics controllers that shipped in 1995.

Other types of memory that could become more popular for use as graphics memory are synchronous graphics RAM (SGRAM), Rambus DRAM (RDRAM), MoSys DRAM (MDRAM), window RAM (WRAM), and 3DRAM. Each of these memory types has its strengths, and each one has graphics controllers designed to use it today. Adoption of these new memories is slow, however, as PC OEMs are reluctant to bet on any of these memory types. For PC OEMs, choosing the "wrong" memory means facing higher prices because of limited sourcing. Two of the memories listed have much broader acceptance than the others. SGRAM is being used in several new 3-D graphics controllers and appears to have enough manufacturers to ensure commodity pricing. RDRAM has a number of design-wins, but only one in the PC graphics market. Cirrus Logic chose RDRAM for its Laguna family of PC graphics controllers.

Dataquest expects EDO DRAM to be the most widely used memory for the next two years, with support for SGRAM increasing as more graphics controllers ship with 3-D graphics acceleration. All the other memory types mentioned above have technical merit but may not gain broad acceptance because of marketing or supply issues.

Figure 4-5
Memory Support for Graphics Controllers in 1995



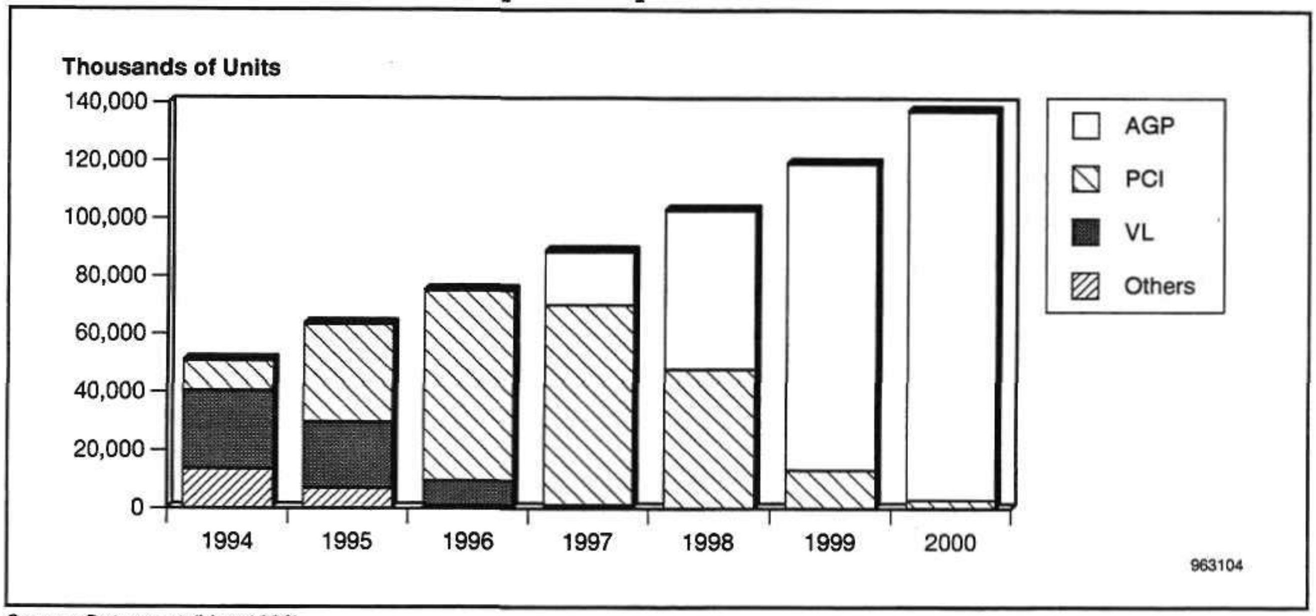
Source: Dataquest (May 1996)

One additional solution to the graphics memory problem is to integrate the memory onto the same chip as the graphics controller. Some Dell Latitude notebooks are already shipping with a graphics controller from NeoMagic that has integrated memory. The challenges of integrating memory and logic are significant, but so are the benefits of a wider interface and single-chip (memory and logic) design. Integrated memories are a product to watch, but they were more attractive when memory prices were higher. Price declines for memory in late 1995 and early 1996 make integrated memories relatively more expensive. Integrated memories will become more interesting as DRAMs shift to the 64Mb size from the current 16Mb size, leaving plenty of space on a single die for a large graphics memory (4MB) as well as graphics logic.

Bus Interface

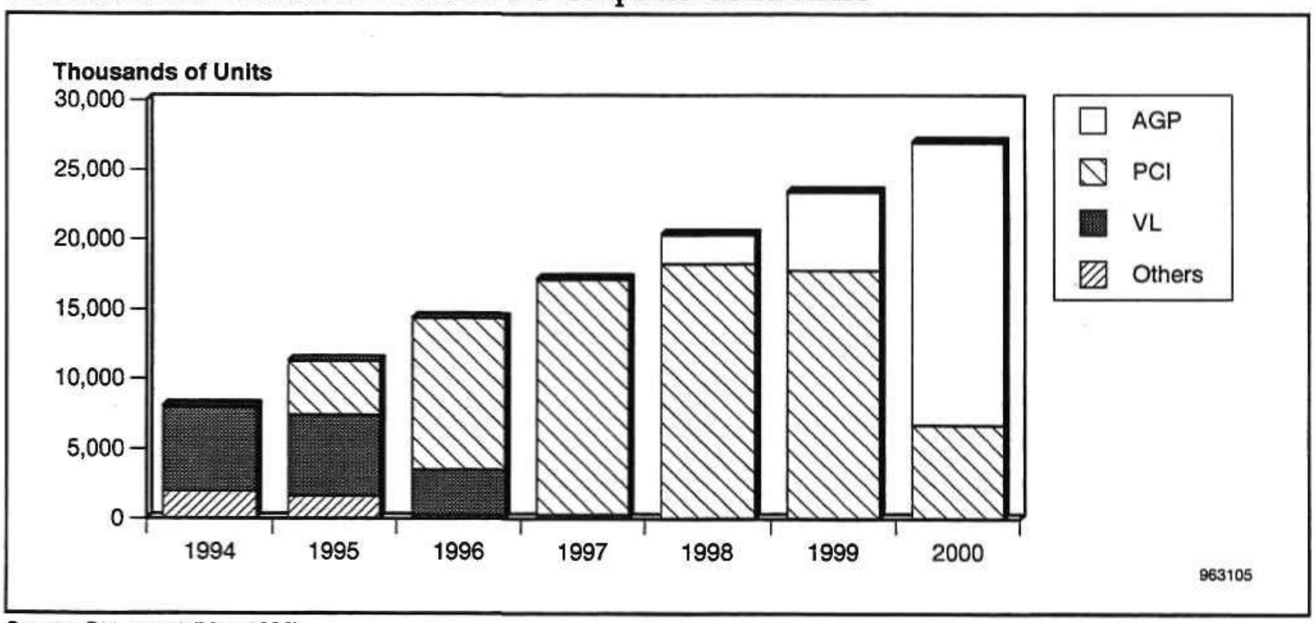
The bus interface is a critical element of graphics performance in PCs. Graphics controllers are typically the first peripherals to adopt any new and faster interface standards. The bus interface forecast continues the shift to PCI as VL-bus fades with the 486 microprocessor and a subsequent shift to Intel's Accelerated Graphics Port (AGP). Intel introduced AGP at the WinHEC show in 1996, with actual products expected in the second half of 1997. The company plans to include AGP in core logic chipsets for the Pentium Pro microprocessor but not the Pentium. Dataquest anticipates that graphics controllers with AGP will ship at about two-thirds the volume of Pentium Pro microprocessors in 1997 and 95 percent of the Pentium Pro microprocessor volume in 1998. Performance is the primary market driver for AGP. This continues the cycle of upgrading the peripheral bus with each new generation of microprocessors. Figure 4-6 shows the bus interface forecast for desktop PC graphics controllers through the year 2000. Figure 4-7 shows the bus interface forecast for mobile PC graphics controllers through the year 2000.

Figure 4-6
Bus Interface Forecast for Desktop PC Graphics Controllers



Source: Dataquest (May 1996)

Figure 4-7
Bus Interface Forecast for Mobile PC Graphics Controllers



Source: Dataquest (May 1996)

For additional reading on AGP, see the Dataquest Perspective, "Intel's Accelerated Graphics Port" (PSAM-WW-DP-9606) in the Semiconductor Directions in PCs and PC Multimedia Worldwide binder.

3-D Graphics

3-D graphics is the next big feature for PC graphics controllers. Initial shipments of consumer-level 3-D graphics accelerators started in 1995, but those products appealed only to the early adopter and were priced accordingly. A broader range of 3-D graphics products is available this year at lower price points, but software compatibility issues will very likely keep unit shipments of 3-D graphics accelerators to a 3-million-unit level despite latent demand for PCs and add-in boards with 3-D acceleration. Software compatibility is hindered by the lack of a common application programming interface (API), so software must be modified to recognize and use each 3-D graphics accelerator chip, which subsequently limits the number of game titles available.

The market for 3-D graphics accelerators will expand rapidly in 1997. New single-chip controllers with 3-D acceleration will also come to market in 1997, making 3-D graphics on the motherboard absolutely compelling for multimedia PCs. See Chapter 6 for the market forecast for PC graphics controllers with 3-D acceleration. Current 3-D accelerators can be grouped into three categories: low-end, midrange, and high-end. Table 4-1 outlines the basic parameters for these categories.

For a more thorough analysis of the market opportunity for 3-D graphics controllers, refer to the report titled "3-D Graphics Adds Sizzle and Semiconductor Content to Multimedia PCs" (PSAM-WW-FR-9601) in the Semiconductor Directions in PCs and PC Multimedia Worldwide binder.

Table 4-1
General Categories for 3-D Accelerators

Category	Number of Chips (Counting Any External RAMDAC)	Integrated VGA, 2-D Acceleration, and Video Acceleration	List Price for Quantities of 10,000 ($)	Performance in 1996	Example
Low End	One	Yes	30-40	Up to 300 polygons/second	S3's ViRGE
				Up to 20M pixels/second	ATI's 3D RAGE
Midrange	Two	Yes	40-60	300 to 500 polygons/second	3Dlabs' PERMEDIA
				20M to 40M pixels/second	Rendition's Verite
High End	Three or more	No	50-80	500 or more polygons/second 40M to 80M pixels/second	3Dfx's VooDoo Graphics

Source: Dataquest (May 1996)

UMA and SBA

Unified memory architecture (UMA) is a means of eliminating the dedicated graphics memory from a system and allocating a portion of the main memory for graphics. Most graphics and core logic vendors support some form of UMA in at least one product, but a lack of support from Intel and Microsoft have largely suppressed the adoption of UMA for the near future. A variation of UMA known as shared buffer architecture (SBA) is included in Intel's Accelerated Graphics Port (AGP) proposal and involves using a dedicated graphics memory for some graphics functions but allows the graphics controller special access to main memory as well. This provides the flexibility of UMA without the performance problem of tying up the main memory for screen refresh. For additional reading on UMA, see the Dataquest Perspective "UMA: A Good Idea Whose Time Has Not Quite Come" (PSAM-WW-DP-9602) in the Semiconductor Directions in PCs and PC Multimedia Worldwide binder.

Chapter 5
Competitive Analysis

The following section offers a brief comment on each of the top five vendors in the PC graphics controller market. The vendors are listed in rank order by revenue as detailed in Table 3-1.

Cirrus Logic

Cirrus Logic, based in Fremont, California, is the giant among the PC graphics companies, with 37 percent market share by revenue. The company posted total revenue of $1.187 billion for calendar year 1995. Cirrus is a diverse company, having acquired a number of other companies to expand its product line. Pico Power, Crystal Semiconductor, and PCSI are all owned by Cirrus Logic and represent core logic, audio, and wireless communications product lines, respectively.

The slowdown in the PC industry has affected Cirrus more than the other graphics companies. After restating the third quarter of fiscal year 1996 for a loss, the company announced a restructuring with a layoff affecting one in seven employees. Cirrus' fiscal year runs April to March, so the third quarter of fiscal year 1996 is the fourth quarter of calendar year 1995. The slowdown that Cirrus experienced in its third quarter continued into its fourth quarter of fiscal year 1996, resulting in a fiscal year 1996 revenue total of $1.147 billion, about $40 million less than calendar year 1995 revenue. Cirrus appears to have lost focus as it expanded beyond its core market, which is graphics controllers.

Cirrus' product line for graphics is technically strong but lacks a 3-D accelerator. The company is teaming with 3DO to bring that company's 3-D technology to the PC market, but Cirrus needs to deliver on promises of 3-D accelerators. The year 1996 will be transitional for the graphics market, but 1997 will bring double-digit revenue growth, and 3-D graphics are the fuel for that growth. Cirrus Logic needs 3-D accelerators that are pin-compatible with other Cirrus graphics chips to participate in that market growth.

S3 Inc.

S3, based in Santa Clara, California, posted a tremendous year of growth in both units and revenue, with graphics controllers representing over 90 percent of total revenue. The company's Trio family of graphics controllers, particularly the Trio64 and Trio64V+, won many designs through the year, including Compaq Computer's Presario line of home PCs, which previously used Cirrus Logic graphics chips.

S3 is also early to the 3-D graphics market with a single-chip product called ViRGE, short for Video and Rendering Graphics Engine. ViRGE is pin-compatible with the Trio64V+, and several add-in boards based on ViRGE won the Best Multimedia Product award at the CeBIT show.

The company grew to be the second-largest PC graphics vendor without shipping a single product for the mobile PC market. That should change, as S3 introduced the Aurora family of mobile graphics controllers in January 1996. If Aurora is successful, the new market will help S3 continue its path of aggressive growth. However, repeating last year's growth (greater than 100 percent) this year will be a daunting task.

Trident Microsystems

Trident, based in Mountain View, California, is consistently near the top of the PC graphics vendor rankings and depends on graphics controllers for almost 100 percent of its revenue. The company fares better in unit shipment comparisons than revenue comparisons because it has a lower ASP than the other top-tier graphics companies. The company relies heavily on the Asia/Pacific region for revenue, selling almost 70 percent of its unit volume in that region. Trident's latest products cater to the Asia/Pacific markets, with greater emphasis on TV display features. Those features could distinguish Trident's products in the Americas and Europe if the "living room" PC, such as Microsoft's Simply Interactive PC, becomes a reality in those markets.

Trident entered the mobile graphics market in 1995 and won designs at NEC and IBM. Unit shipments neared 0.5 million in that first year with good momentum from those design-wins for 1996.

Chips & Technologies

Chips & Technologies, based in San Jose, California, is the undisputed leader in graphics controllers for mobile PCs but also sells desktop graphics controllers as well as core logic chipsets. The company has successfully transitioned itself from a core logic company to a graphics company over the past several years.

Graphics is the largest segment of Chips' business, representing $116 million of about $133 million in total revenue for calendar 1995.

ATI Technologies

ATI, based in Thornhill, Ontario, is unique in several ways. First, it is based in Canada rather than Silicon Valley. It is the only top-five graphics vendor to sell chips as well as board-level products using those chips. ATI historically relied on the Macintosh market for its sales but successfully leveraged its products across multiple platforms as PCI became the interface bus for those platforms. Graphics products, at the semiconductor-device level and at the add-in-board level, represent all of ATI's revenue.

ATI, like S3, is early to the 3-D graphics market with a single-chip 3-D product, called 3D RAGE. 3D RAGE has already won designs in IBM's Aptiva line of multimedia PCs for 1996. 3D RAGE is pin-compatible with ATI's Mach64 graphics controller, which happens to be designed onto the Intel Atlantis motherboard.

Chapter 6
Market Forecast

The year 1996 is transitional for graphics controllers in PCs. Competition is driving down the ASP for controllers with 2-D acceleration and video acceleration, and software issues have delayed the widespread adoption of 3-D accelerators into 1997. The result is a forecast of 7 percent revenue growth despite an almost 20 percent growth in unit shipments. The market will rebound in 1997 with nearly 21 percent revenue growth as the ASP slowly returns to historical levels by the year 2000. The return to the higher, historical ASP will be driven largely by higher prices justified by 3-D graphics. The shift to 3-D will be aggressive in 1997 as today's midrange 3-D performance (currently a two-chip set) is packed into single-chip designs and software compatibility is no longer an issue. 3-D graphics will receive another boost in 1998 as AGP and Pentium Pro microprocessors move into the volume sweet spot of the PC market.

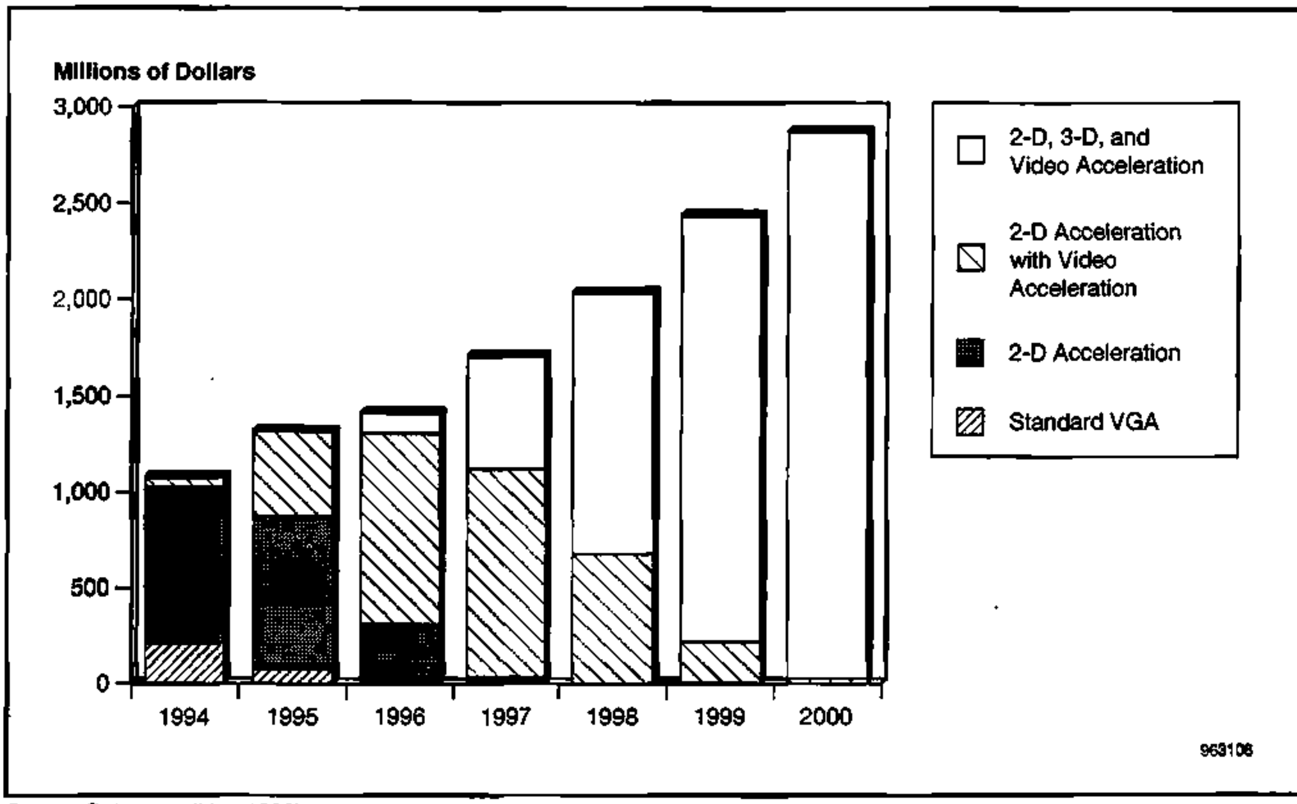
Table 6-1 shows the PC graphics market revenue forecast by functional category through the year 2000. Figure 6-1 shows the revenue forecast graphically. Table 6-2 shows the PC graphics controller unit shipment forecast by functional category through the year 2000 as well as the PC unit shipment forecast for the same period. Figure 6-2 shows the graphics controller unit shipment forecast graphically. Figure 6-3 shows the PC unit shipment forecast graphically.

Table 6-1
PC Graphics Controller Revenue Forecast to the Year 2000 (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Desktop								
Standard VGA	136.5	26.8	0	0	0	0	0	-100.0
2-D Acceleration	692.5	665.3	172.7	15.9	0	0	0	-100.0
2-D Acceleration with Video Acceleration	49.5	403.2	877.2	861.2	452.5	107.2	0	-100.0
2-D, 3-D, and Video Acceleration	0	2.4	105.1	520.5	1203.2	1875.4	2335.7	297.0
Total	878.5	1,097.6	1,155.1	1,397.6	1,655.7	1,982.6	2,335.7	16.3
Mobile								
Standard VGA	77.0	46.9	7.9	0	0	0	0	-100.0
2-D Acceleration	124.0	139.7	129.1	20.5	0	0	0	-100.0
2-D Acceleration with Video Acceleration	0	35.2	120.5	227.0	227.4	112.3	27.0	-5.2
2-D, 3-D, and Video Acceleration	0	0	0	61.6	152.3	344.0	509.4	NM
Total	201.1	221.8	257.5	309.1	379.7	456.3	536.3	19.3
Total								
Standard VGA	213.5	73.7	7.9	0	0	0	0	-100.0
2-D Acceleration	816.5	805.0	301.8	36.5	0	0	0	-100.0
2-D Acceleration with Video Acceleration	49.5	438.3	997.7	1,088.1	679.9	219.5	27.0	-42.8
2-D, 3-D, and Video Acceleration	0	2.4	105.1	582.1	1,355.5	2,219.4	2,845.1	313.0
Total PC Graphics Market	1,079.5	1,319.4	1,412.6	1,706.7	2,035.4	2,438.9	2,872.0	16.8
Year-to-Year Growth		22.2	7.1	20.8	19.3	19.8	17.8	

NM = Not meaningful
Source: Dataquest (May 1996)

Figure 6-1
PC Graphics Controller Revenue Forecast to the Year 2000 (Millions of Dollars)



Source: Dataquest (May 1996)

Table 6-2
PC Graphics Controller Unit Shipment Forecast to the Year 2000 (Thousands of Units)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Desktop								
Standard VGA	13,649	4,120	0	0	0	0	0	-100.0
2-D Acceleration	35,512	42,419	17,274	2,658	0	0	0	-100.0
2-D Acceleration with Video Acceleration	1,650	16,798	54,826	63,790	41,135	11,907	0	-100.0
2-D, 3-D, and Video Acceleration	0	53	3,004	22,149	61,703	107,166	137,392	382.4
Total Units	50,811	63,390	75,104	88,597	102,838	119,073	137,392	16.7
Mobile								
Standard VGA	3,349	2,932	717	0	0	0	0	-100.0
2-D Acceleration	4,680	6,992	8,607	1,712	0	0	0	-100.0
2-D Acceleration with Video	0	1,353	5,021	13,351	14,214	9,360	2,695	14.8
2-D, 3-D, and Video Acceleration	0	0	0	2,054	6,092	14,041	24,257	NM
Total Units	8,029	11,278	14,345	17,116	20,305	23,401	26,952	19.0

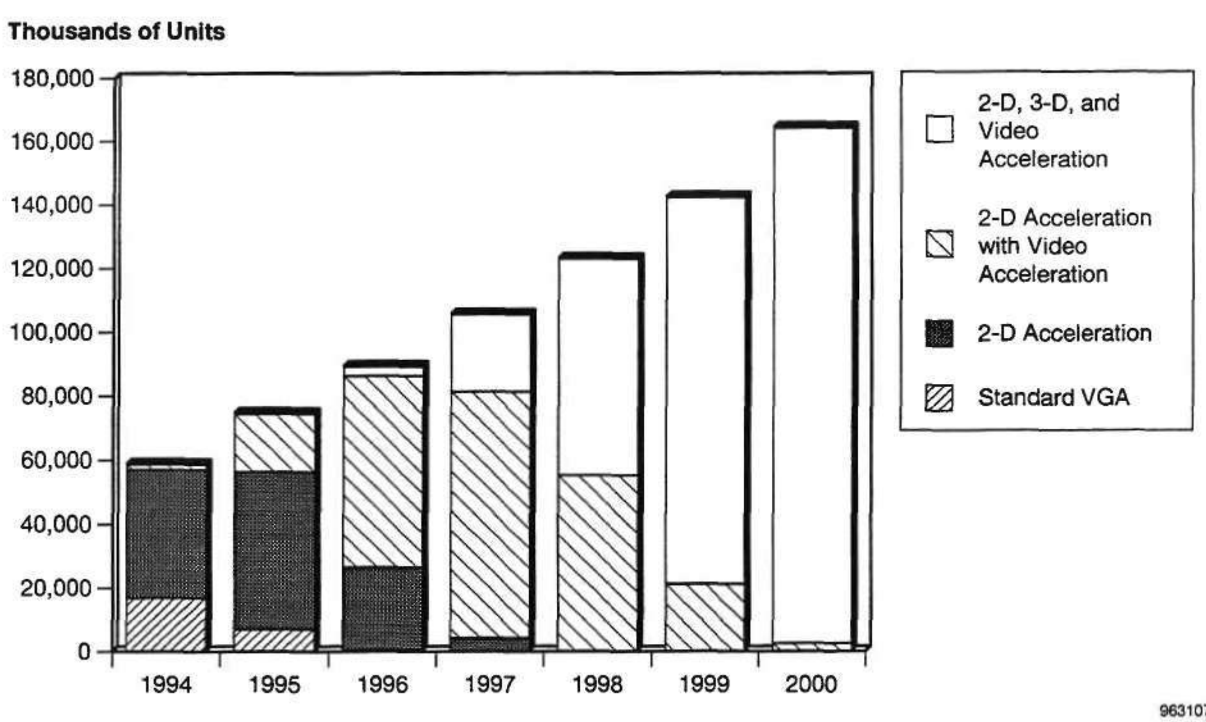
(Continued)

Table 6-2 (Continued)
PC Graphics Controller Unit Shipment Forecast to the Year 2000 (Thousands of Units)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Total								
Standard VGA	16,998	7,053	717	0	0	0	0	-100.0
2-D Acceleration	40,192	49,411	25,881	4,370	0	0	0	-100.0
2-D Acceleration with Video Acceleration	1,650	18,152	59,846	77,140	55,349	21,268	2,695	-31.7
2-D, 3-D, and Video Acceleration	0	53	3,004	24,203	67,795	121,207	161,649	398.3
Total Units	58,840	74,668	89,449	105,713	123,144	142,474	164,344	17.0
PCs								
Mobile OEM PC Units*	8,642	9,912	12,608	15,044	17,847	20,568	23,689	19.0
Desktop/Deskside OEM PC Units*	39,252	50,259	59,043	69,651	80,847	93,610	108,011	16.5
Total OEM PC Units*	47,894	60,171	71,651	84,694	98,693	114,178	131,700	17.0
Additional Motherboard Shipments	4,404	5,528	6,495	7,662	8,893	10,297	11,881	16.5
Total OEM PC and Motherboard Shipments	52,298	65,699	78,146	92,356	107,587	124,475	143,581	16.9

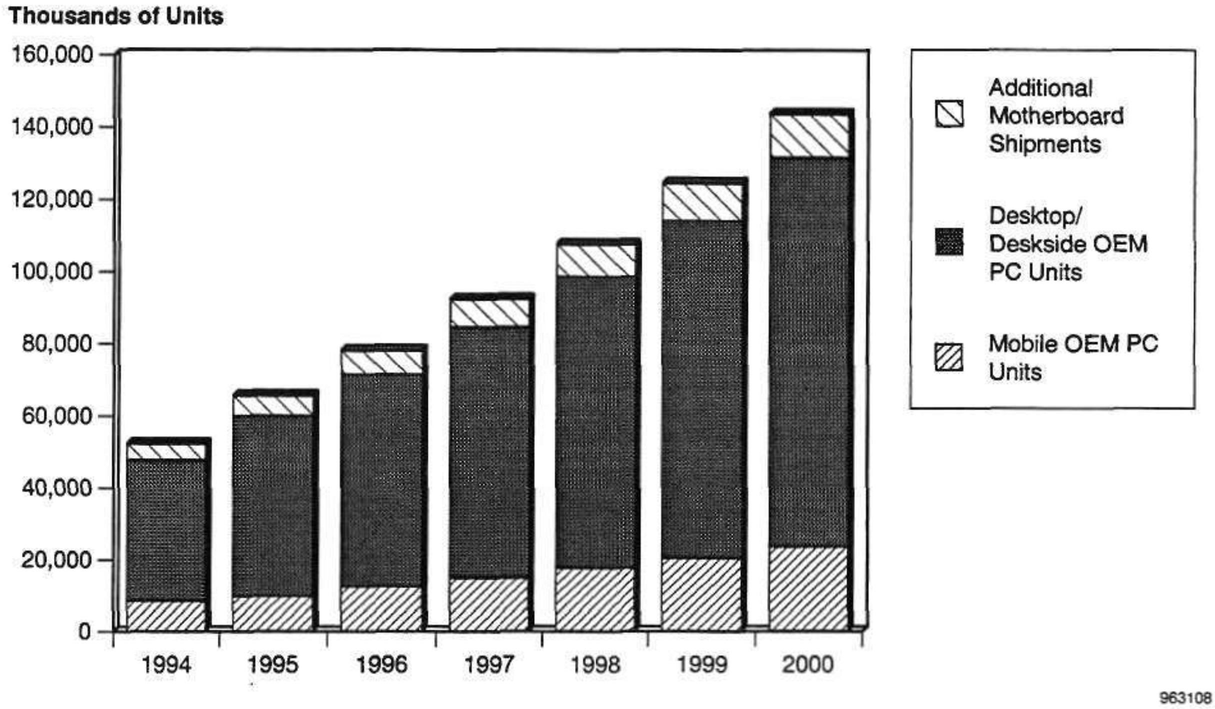
NM = Not meaningful
*OEM PC shipment numbers are from Dataquest's Spring 1996 PC forecast.
Source: Dataquest (May 1996)

Figure 6-2
PC Graphics Controller Unit Shipment Forecast to the Year 2000 (Thousands of Units)



Source: Dataquest (May 1996)

Figure 6-3
PC Unit Shipment Forecast to the Year 2000 (Thousands of Units)



Source: Dataquest (May 1996)

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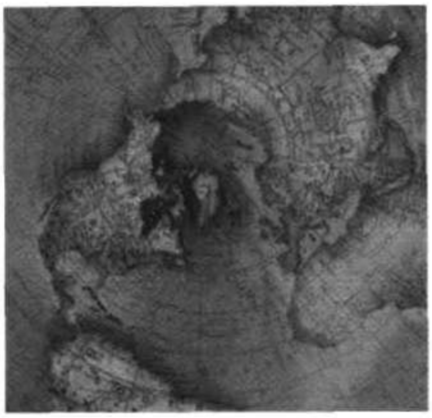

Dataquest

Microcomponent Market Definitions

Dataquest Guide

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-GU-9601
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Table of Contents

List of Tables

Chapter 1
Market Share Survey Overview

Each year, Dataquest surveys microcomponent vendors to estimate their unit shipments and the revenue derived from the sale of those devices. The 1996 survey covers microcomponent vendors worldwide. This exercise helps Dataquest maintain its dynamic database of microcomponent supply by company. The information gained is supplemented by, and cross-checked with, Dataquest's various other information sources.

The microcomponent market share survey takes place after the end of the calendar year under review. The results are summarized and analyzed in several Dataquest reports.

The categories for which microcomponent unit shipments are reported are defined comprehensively for the purpose of clarity and guidance to survey participants. These definitions may occasionally be revised, altered, or expanded to reflect changes in the industry. To support these definitions, Dataquest will issue an annual survey guide to all participants in its microcomponent market share survey program. This document is the 1996 survey guide.

Note that the definition for word width for microprocessors, microcontrollers, and digital signal processors has changed for 1996 and beyond.

Chapter 2
Microcomponent Companies Surveyed Worldwide for 1996

In 1996, Dataquest surveyed microcomponent companies worldwide.

American Companies

The following North American companies are surveyed:

- Advanced Micro Devices
- Analog Devices
- Atmel
- California Micro Devices
- C-Cube
- Chips & Technologies
- Cirrus Logic
- Cypress Semiconductor
- Cyrix Semiconductor
- Dallas Semiconductor
- Digital Equipment Corporation
- DSP Group
- Harris Semiconductor
- Hewlett-Packard Company
- Hughes Microelectronics
- IBM Microelectronics
- Integrated Device Technology
- Integrated Information Technology
- Intel Corporation
- Intergraph Corporation
- LSI Logic
- Lucent Technologies
- Microchip Technology
- Motorola
- National Semiconductor
- Oak Technology
- Performance Semiconductor
- Rockwell International
- S3
- Symbios Logic

- Texas Instruments
- Trident Microsystems
- Tseng Labs
- VLSI Technology
- Weitek
- Zilog
- Zoran

European Companies

The following European companies are surveyed:

- GEC Plessey
- Matra MHS
- NV Philips BV
- SGS-Thomson Microelectronics
- Siemens AG
- TEMIC
- TMS

Japanese Companies

The following Japanese companies are surveyed:

- Fujitsu
- Hitachi
- Mitsubishi Electric
- NEC
- Oki Electric Industry
- Ricoh
- Rohm
- Sanyo Electric
- Seiko Epson
- Sharp
- Sony
- Toshiba
- Yamaha

Asia/Pacific Companies

The following Asia/Pacific companies are surveyed:

- Acer
- LG Semicon
- Samsung

Chapter 3

General Sales Definitions

Unit Shipments

This is the volume or number of finished units shipped by manufacturers to users, equipment manufacturers, or distributors. The units must include operating silicon and are generally assembled into packages, tested, and shipped in protective packaging. A manufacturer's own inventory is not included. Often reported in thousands (K) or millions (M) of units. Similar terms are units and volume.

Revenue

This is the total revenue value of the finished units shipped by manufacturers to users or distributors. In Dataquest's worldwide services, revenue is reported in equivalent U.S. dollars, unless otherwise noted. Often reported in millions of dollars ($M) or billions of dollars ($B).

Average Selling Price

The average selling price (ASP) is the average price for which a product sells when considering all the sales of the product in total, from very small quantities to large-volume orders. ASP is determined by dividing the total revenue derived from the sale of all of the category of products by the number of units that make up all of that category (ASP = revenue/units). It is quite possible that no sale of product ever takes place at a reported ASP. It is also possible that any one sale of product takes place at more than 50 percent variation from an ASP. ASPs are not intended to be the manufacturers' suggested retail prices, one-piece prices, volume-discount prices, or the best possible prices. In Dataquest's worldwide services, ASPs are reported in equivalent U.S. dollars unless otherwise noted.

Compound Annual Growth Rate

Compound annual growth rate (CAGR) is a measure of the growth of an industry over time, usually a five-year span (N = 5). A positive number indicates a growing market. The CAGR is associated with revenue unless noted as units or ASP. CAGR is defined as follows and is usually expressed as a percentage:

$$CAGR = \sqrt[N]{\frac{Value}{Value_{t=0}}} - 1$$

Market Share

Market share refers to the revenue of the desired product, vendor, or region divided by the revenue for all products, vendors, or regions in the same category, usually expressed as a percentage. Market share of units is also a valid measurement but is only used where explicitly stated. No implication should be made as to the "availability" of the market shared within the category.

Merchant versus Captive Consumption

Dataquest includes all revenue, both merchant and captive, for semiconductor suppliers selling to the merchant market. The data excludes completely captive suppliers where devices are manufactured solely for the company's own use. A product that is used internally is valued at market price rather than at transfer or factory price.

Chapter 4
Exchange Rate Definitions

When converting a company's local currency sales into U.S. dollars, or vice versa, it is important to use the preliminary 1996 exchange rates provided in Table 4-1. This will prevent inconsistencies in the conversion of offshore sales between each company. The preliminary 1996 exchange rate estimate uses actual exchange rates through September 1996 and assumes that the September rate applies throughout the months of October through December.

The annual rate is estimated as the arithmetic mean of the 12 monthly rates. Table 4-1 outlines these rates. Exchange rates for historical years are available on request.

Table 4-1
Average 1995 and 1996 Exchange Rates per U.S. Dollar

Country	1995 Rate	1996 Rate	U.S. Dollar Appreciation (%) 1996
Australia (Dollar)	1.35	1.28	-5.21
Austria (Schilling)	10.06	10.55	4.82
Belgium (Franc)	29.42	30.84	4.84
Canada (Dollar)	NA	1.37	NM
China (Renminbi)	NA	8.34	NM
Denmark (Krone)	5.59	5.80	3.64
EU (ECU)	0.77	0.80	3.20
Finland (Markka)	4.37	4.58	4.86
France (Franc)	4.97	5.10	2.69
Germany (Mark)	1.43	1.50	4.77
Great Britain (Pound)	0.63	0.65	2.47
Greece (Drachma)	231.34	240.42	3.92
Hong Kong (Dollar)	7.74	7.73	-0.02
India (Rupee)	32.38	35.52	9.71
Ireland (Punt)	0.62	0.63	0.97
Italy (Lira)	1,628.21	1,542.35	-5.27
Japan (Yen)	93.90	108.06	15.08
Malaysia (Ringgit)	2.51	2.51	-0.09
Mexico (Peso)	6.41	7.53	17.49
Netherlands (Guilder)	1.60	1.68	4.79
New Zealand (Dollar)	1.52	1.46	-4.29
Norway (Krone)	6.33	6.46	2.18
Portugal (Escudo)	149.77	154.13	2.91
Singapore (Dollar)	1.43	1.41	-1.05
South Africa (Rand)	NA	4.28	NM

(Continued)

Table 4-1 (Continued)
Average 1995 and 1996 Exchange Rates per U.S. Dollar

Country	1995 Rate	1996 Rate	U.S. Dollar Appreciation (%) 1996
South Korea (Won)	770.57	802.37	4.13
Spain (Peseta)	124.40	126.24	1.48
Sri Lanka (Rupee)	NA	55.08	NM
Sweden (Krona)	7.14	6.70	-6.14
Switzerland (Franc)	1.18	1.22	3.66
Taiwan (Dollar)	26.48	27.46	3.73
Thailand (Baht)	24.91	25.33	1.68

NA = Not tracked until 1996
NM = Not meaningful
Source: Dataquest (November 1996)

Chapter 5

Microcomponent Product Category Hierarchy

The microcomponent product category hierarchy in Table 5-1 begins with total microcomponent and indents each subcategory in the left-hand column according to its position in the hierarchy. At each level in the hierarchy, all subcategories that contribute to this level are shown as a subcategory summation in the right-hand column. Any level in the hierarchy that does not depend on any subcategory is marked as a "Data Point."

Table 5-1
Microcomponent Product Category Hierarchy

Total MOS Digital Microcomponent Integrated Circuit (IC):	Microprocessor + Microcontroller + Digital Signal Processor + Microperipheral
Microprocessor (MPU):	8-Bit and 16-Bit CISC MPU + 32-Bit and Greater CISC MPU + 32-Bit and Greater RISC MPU
8-Bit and 16-Bit CISC MPU:	Data Point
32-Bit and Greater CISC MPU:	Data Point
32-Bit and Greater RISC MPU:	Data Point
Microcontroller (MCU):	4-Bit MCU + 8-Bit MCU + 16-Bit and Greater MCU
4-Bit MCU:	Data Point
8-Bit MCU:	Data Point
16-Bit and Greater MCU:	Data Point
Digital Signal Processor (DSP):	Data Point
Microperipheral (MPR):	System Core Logic Chipsets + Graphics and Imaging Controllers + Communications Controllers + Mass Storage Controllers + Audio/Other Controllers
System Core Logic Chipsets:	Data Point
Graphics and Imaging Controllers:	Data Point
Communications Controllers:	Data Point
Mass Storage Controllers:	Data Point
Audio/Other Controllers:	Data Point

Source: Dataquest (November 1996)

Chapter 6
Microcomponent Product Category Definitions

The microcomponent product category definitions in Table 6-1 begin with total microcomponent and continue through each subcategory in the same order as shown in the preceding microcomponent product category hierarchy. At each level in the hierarchy, all subcategories that contribute to this level are shown as a subcategory summation in the right-hand column. Comprehensive definitions are given at every level.

Table 6-1
Microcomponent Product Category Definitions

Total Microcomponent IC	(Microprocessor + Microcontroller + Digital Signal Processor + Microperipheral) Microcomponents are a category of metal oxide semiconductor (MOS) digital integrated circuits made up of the microprocessor (MPU), microcontroller (MCU), programmable digital signal processor (DSP), and microperipheral (MPR) product families.
Microprocessor	(8-Bit and 16-Bit CISC MPU + 32-Bit and Greater CISC MPU + 32-Bit and Greater RISC MPU) An MPU is a MOS digital integrated circuit that includes an instruction decoder, arithmetic logic unit (ALU), registers, and additional logic. It may contain instruction, data, or unified caches, memory management systems, and auxiliary ALUs for floating point and other special data types. An MPU's functions are determined by fetching and executing instructions and manipulating data held in registers, internal cache, or external memory. MPUs operate out of external memory systems typically ranging from 1MB to 64MB of RAM and often backed by secondary memory systems (like disks). More highly integrated versions of MPUs may contain on-chip peripherals, interface, and support circuits. The MPU category includes MPUs incorporating or originating from an ASIC design. MPUs are divided into complex-instruction-set computer (CISC) or reduced-instruction-set computer (RISC) implementations having 8-bit, 16-bit, or 32-bit and greater word width. MPUs are designed into computational applications or into embedded applications.

(Continued)

Table 6-1 (Continued)
Microcomponent Product Category Definitions

Microcontroller	(4-Bit MCU + 8-Bit MCU + 16-Bit and Greater MCU) An MCU is a MOS digital integrated circuit designed for standalone operation, that includes a programmable processing unit, program memory, read/write data memory, and some input/output capability. The processing unit contains an instruction decoder, arithmetic logic unit (ALU), registers, and additional logic. The MCU's functions are determined by fetching and executing instructions and manipulating data held in on-chip program and data memory (not including cache memories). MCU devices must be available with on-chip program or data store. As an option, some MCU devices can be purchased without on-chip memory for use during the debug and development phase of the system. Peripherals may be included on chip to assist in sophisticated input, output, and control functions. The MCU category includes MCUs incorporating or originating from an ASIC design. Standalone digital signal processors are not included with MCUs. MCUs are divided into 4-bit, 8-bit, or 16-bit and greater word width. All MCUs are designed into embedded applications.
Digital Signal Processor	A DSP is a programmable MOS digital integrated circuit designed for standalone operation, consisting of a high-speed arithmetic unit (typically a multiplier-accumulator unit) designed to perform complex mathematical operations such as Fourier transforms in real time to generate, manipulate, or interpret digital representations of analog signals. Modern DSPs typically access multiple pieces of data in different locations of on-chip memory over separate data paths using specialized addressing modes. Most DSP functions, such as the multiply-and-accumulate function, complete in a single instruction clock. DSPs usually include peripherals, which may include analog circuits like analog-to-digital converters. DSPs typically operate on 16 bits or 24 bits of fixed point data or 32 bits of floating point data, although Dataquest does not currently subdivide DSPs into these categories. DSPs that have no version that can be reprogrammed by the user in assembly language or a higher-level language are not included but are classified as application-specific standard products (ASSPs) or microperipherals. DSPs integrated on chip with an independent microprocessor or microcontroller are classified as either an MPU or MCU, respectively. All DSPs are designed into embedded applications. A similar term is pDSP.

(Continued)

Table 6-1 (Continued)
Microcomponent Product Category Definitions

Microperipheral	(System Core Logic Chipsets + Graphics and Imaging Controllers + Communications Controllers + Mass Storage Controllers + Audio/ Other Controllers) An MPR is a MOS digital integrated circuit that serves as a dedicated logical support function to a microprocessor or microcontroller in a system. Microperipherals are not programmable from assembly language, although they are often highly configurable by software or electrical signals. This definition includes MPRs comprising more than one device, such as PC or core logic chipsets. The MPR category includes MPRs incorporating, or originating from, an ASIC design. MPRs might be implemented using microprocessor, microcontroller, or digital signal processing elements, although this is generally not evident to the user.
System Core Logic Chipsets	Devices dedicated to a particular microprocessor interface that perform some of the basic interface functions such as memory management, DRAM control, cache control, bus interface control, DMA control, and interrupt control.
Graphics and Imaging Controllers	Devices that typically interface to some form of system bus to interpret, control, and display the visual output of systems (computer-generated graphics, live video, and other images).
Communications Controllers	Devices that control, format, and perform handshaking for the serial transmission and reception of information between systems or intelligent devices, including network controllers, integrated fax/modem chips, serial UARTs, and other communications interfaces.
Mass Storage Controllers	Devices that are used to control data storage into and retrieval from all forms of mass storage media (magnetic, optical, and others), which include controllers used within host computers (host-side) and within mass storage drives (device-side).
Audio/Other Controllers	Devices used to input or output information through other forms, including audio input/output controllers, keyboard controllers, pen input controllers, parallel port controllers, and various other devices.

Source: Dataquest (November 1996)

Word Width

This is the width, in bits, of the primary on-chip integer arithmetic and logic unit (ALU). This measurement is independent of the data bus width or any other bus associated with the device. The processor might operate on wider and narrower data types, with multiple passes through the ALU or with special hardware. The word width classification is not influenced by the existence of additional integer units or of floating point and other special data type processors. Table 6-2 shows the Dataquest word width category into which typical microcomponents are placed. A similar term is bit size.

Table 6-2
Microcomponent Word Widths

	4-Bit	8-Bit	16-Bit	24-Bit	32-Bit	64-Bit
MCU	4-bit	8-bit	16-bit and greater	-	16-bit and greater	-
MPU	-	8-bit and 16-bit	8-bit and 16-bit	-	32-bit and greater	32-bit and greater
DSP	-	-	DSP	DSP	DSP	-

Source: Dataquest (November 1996)

Chapter 7
Worldwide Geographic Region Definitions and Regional Roll-Ups

Americas

North America
Includes Canada, Mexico, and the United States (50 states).

South America

Central America

Japan

Japan is the only single-country region.

Europe, Africa, and Middle East

Europe

Western Europe
Includes Austria, Belgium, Denmark, Eire (Ireland), Finland, France, Germany (including former East Germany), Greece, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and Rest of Western Europe (Andorra, Cyprus, Gibraltar, Liechtenstein, Monaco, San Marino, Vatican City, Iceland, Malta, and Turkey).

Eastern Europe
Includes Albania, Bulgaria, the Czech Republic and Slovakia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, the republics of the former Yugoslavia, and the republics of the former USSR (Belarus, Russian Federation, Ukraine, Georgia, Moldova, Armenia, Azerbaijan, Kazakhstan, Uzbekistan, Tajikistan, Kyrgyzstan, and Turkmenistan).

Africa

Middle East

Asia/Pacific

Includes Asia/Pacific's newly industrialized economies (NIEs) and the rest of Asia/Pacific regions. NIEs include Hong Kong, Singapore, South Korea, and Taiwan. The rest of Asia/Pacific region includes Australia, Bangladesh, Cambodia, China, India, Indonesia, Laos, Malaysia, Maldives, Myanmar, Nepal, New Zealand, Pakistan, the Philippines, Sri Lanka, Thailand, and Vietnam.

Chapter 8
Application Segment Definitions

Data Processing

Defined as computer systems, data storage, input/output (I/O) devices, dedicated systems, and other data processing equipment:

- Computer systems: The computer estimate does not include the value of the rigid disk drives, flexible disk drives, keyboards, and displays. Computer estimate does include the value of aftermarket sales of graphics boards, motherboards, memory cards and single in-line memory modules (SIMMs), storage host adapters, and serial and parallel I/O boards. Worldwide computer systems production has been re-estimated and revalued to equal the value of worldwide (factory) revenue and shipments of computer systems as estimated by the Dataquest Computer Systems and Peripherals Worldwide group and to eliminate double-counting of system sales of storage devices, keyboards, and displays. Computer systems include supercomputers, mainframe computers, midrange computers (also known as superminicomputers and minicomputers), workstations, and personal computers (including portable computers). Includes the value of central processing units (that is, boxes) only.
- Data storage includes rigid disk drives, flexible disk drives, optical disk drives, and tape drives.
- Input/output devices include alphanumeric terminals and graphics terminals (for example, X terminals), monitors, and funds transfer terminals; and printers, media-to-media data conversion, magnetic ink character recognition, optical scanning equipment, plotters, mice, keyboards, and digitizers.
- Dedicated systems include electronic copiers, electronic calculators and personal organizers, smart cards (IC cards), dictation/transcribing equipment, electronic typewriters and dedicated word processors, point-of-sale terminals and electronic cash registers, and mailing/letter-handling/addressing equipment.
- Other data processing includes sound/audio boards, digital video boards, accelerator boards, and embedded CPU boards.

Communications

Defined as premises telecom equipment, public telecom equipment, mobile communications equipment, broadcast and studio equipment, and other telecom equipment:

- Premises telecom equipment includes image and text communication, such as facsimile and facsimile cards, and video teleconferencing; data communications equipment such as modems and modem cards, statistical multiplexers, T1 multiplexers, front-end processors, DSU/CSU, protocol converters, local area network (LAN) interface cards, LAN hubs and internetworking equipment, and packet data switching systems; premises switching equipment, such as PBX telephone equipment, and key telephone systems; call processing equipment, such as voice messaging, interactive voice response systems, and automatic call distributors; and desktop terminal equipment, such as telephone sets/pay telephones and cordless telephones, and teleprinters.

- Public telecom equipment includes transmission equipment, such as multiplexers, carrier systems, microwave radio, laser and infrared transmission equipment, and satellite communications equipment; and central office switching equipment.
- Mobile communications equipment includes mobile radio systems such as cellular telephones, microcellular telephones, mobile radios, mobile radio base station equipment, and pagers; portable radio receivers and transmitters; and radio checkout equipment.
- Broadcast and studio equipment includes audio equipment, video equipment, transmitters and radio frequency (RF) power amplifiers, studio transmitter links, cable TV (head-end) equipment, closed-circuit TV equipment, and other equipment, such as studio and theater equipment.
- Other telecom equipment includes intercom equipment, electrical amplifiers, and communications equipment not elsewhere classified.

Industrial

Defined as security/energy management systems, manufacturing systems/instruments, medical equipment, and other industrial equipment:

- Security/energy management includes alarm systems, such as intrusion detection and fire detection systems, and energy management systems.
- Manufacturing systems/instruments include microcomponent production equipment, controls, process controls, and control and processing displays and robots, as well as test and measuring equipment such as microcomponent-dedicated automatic test equipment (ATE), other test and measurement equipment, and nuclear electronics.
- Medical equipment includes diagnostic equipment, therapeutic equipment, patient monitoring equipment, surgical support systems, and irradiation equipment.
- Other industrial equipment includes vending machines, power supplies, traffic control equipment, and industrial equipment not elsewhere classified.

Consumer

Defined as audio equipment, video equipment, personal electronics, appliances, and other consumer equipment:

- Audio equipment includes compact disc players, radios, stereo components, musical instruments, and tape recorders.

- Video equipment includes VCRs and VTRs, video cameras and camcorders, video disc players, color and monochrome TVs, and cable/satellite set-top decoders.
- Personal electronics includes electronic games and toys (systems and cartridges), cameras, watches, and clocks.
- Appliances includes air conditioners, microwave ovens, washers and dryers, refrigerators, dishwashers, and ranges and ovens.
- Other consumer equipment includes automatic garage door openers and consumer equipment not elsewhere classified.

Military and Civil Aerospace

Defined as military and civil aerospace electronic equipment.

- Military/civil aerospace: North American military/civil aerospace production has been re-estimated and revalued to reflect U.S. Department of Commerce estimates of U.S. defense and civil (aerospace) electronics. Military/civil aerospace includes radar/sonar/reconnaissance systems, missile/space-related electronics, navigation equipment, electronic warfare, aircraft flight systems, and command and control systems.

Transportation

Defined as in-car entertainment, body control electronics, power train systems, and safety and convenience systems.

- In-car entertainment includes systems such as AM/FM radios, cassette and compact disc players, and radio/cassette combination systems.
- Body control electronics includes four-wheel steering control, two-wheel drive/four-wheel drive control; multiplex systems such as driver's door console, door locks, windshield wipers, heated rear windows, memory seats, memory steering wheel, remote security systems, and suspension control and traction control systems; lighting controls including automatic headlight systems, timers, reminders, and sequential signal controls; and other body control electronics, including aerodynamic aid control and power roof/window controls; driver information systems, including electronic dashboard/instrument clusters, analog or digital clusters, electronic analog/digital clocks and compasses, electronic thermometers, head-up displays, navigation and location systems, signal and warning lights, and trip computers.
- Power train systems include engine management systems, power train sensors, ignition control, fuel injection systems, fuel flow, engine temperature, air temperature, coolant level, wheel speed sensors, and transmission control.
- Safety and convenience systems include climate control systems (air conditioning/heating), air purifier systems, air bag control systems, antilock braking systems, collision warning systems, and cruise control.

Applications

Computational Applications

Computational applications of microprocessors are designed to be highly programmable by the end user while the manufacturer has only a vague idea of the final use of the system. The microprocessor is the central processor in the system, running an operating system performing task scheduling, system administration, and resource allocation according to the needs of the programs scheduled or initiated to execute. The programs are typically executed by the central processor, although they may be dispatched to subservient processors. The programs typically reside on mass storage media such as floppy or hard disks or may be downloaded over networks.

The programs executed may vary greatly according to user demands on the product, so the system is designed to handle a wide variety of potential applications. The operating system might be DOS, Windows 95, Mac OS, UNIX, OS/2, Solaris, or any other, although it is rarely designed for real-time response. The application programs are normally computational in nature. Computational applications must be programmable by the end user of the equipment in a higher-level language such as BASIC or FORTRAN.

The most common computational applications are personal computers, workstations, and servers. Most computational MPUs can also be used in embedded applications. Computational systems may have many embedded microcomponents in subsystems that support the central processor, such as the monitor, keyboard, mouse, disk drive, network interface, and modem, among others.

Embedded Applications

Embedded applications of microcomponents are designed to perform a fixed set of functions once the system is shipped from the manufacturer. Those functions typically define the end product. The system may be reconfigurable by the end user but cannot be reprogrammed by a high-level language such as BASIC or FORTRAN. Usually the end user would not even know what type of processor was in the equipment.

The processor will typically run a real-time operating system (although real time is not a requirement, nor is any operating system) and a set of instructions that perform functions critical to the operation of the end product. Programs run by the processor may perform system monitoring, system control, data processing, peripherals interfacing, data movement, and motion control, among other functions. Programs often exist in ROM, although they may load from secondary storage, such as disks. Each processor or microcontroller in the system typically has a fairly narrow range of responsibilities.

Examples of embedded applications are many and varied but include feature phones, cellular phones, cellular infrastructure, telephone switches, bridges, routers, network cards, point of sale terminals, modems, arcade games, cameras, camcorders, VCRs, satellite receivers, set-top boxes, remote controls, audio equipment (personal, home, and professional), keyboards, disk drives, CD drives, laser printers, other computer peripherals, fax machines, copiers, medical instruments, motor control, industrial process control, robotics, engine control, airbags, antilock braking systems, and global positioning systems. Although personal digital assistants (PDA), video games, and organizers can be fed external programs, the purpose of the device is still primarily the same, and so they are considered embedded applications. All microcontrollers and all digital signal processors, as well as many microprocessors, are designed into embedded applications.

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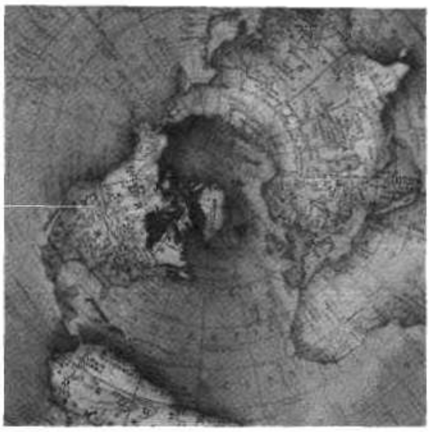

Dataquest

Audio Chips Let PCs Be Heard and Not Just Seen

Focus Report

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-FR-9602
Publication Date: September 9, 1996
Filing: Reports

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Table of Contents

List of Figures

List of Tables

Chapter 1
Executive Summary

The market for PC audio chips is driven by high levels of competition and PC buyers' lust for the latest features at the lowest prices. Those same PC buyers demand backward compatibility with their favorite applications from yesteryear, which has an impact on how quickly the market shifts to new standards for generating sound in the PC. Wavetable synthesis promises higher fidelity but must be implemented with legacy hardware functions for backward compatibility with a huge installed base of entertainment software. Spatial enhancement promises to improve music playback as well as sound effects and is a stepping stone to immersive, 3-D positional audio. Intel's AC-97 will most likely end the trend toward single-chip audio in favor of dividing digital and analog functions between two chips and could help to speed up the integration of PC audio and PC telephony.

Implementation trends include a rising tide of motherboard and daughterboard designs as OEMs strive to minimize costs. This trend fuels demand for audio chips rather than the ISA-based cards that have dominated the audio market in the past. Legacy compatibility issues rear their ugly heads again as vendors look to move audio subsystems from the ISA bus to the PCI bus. The move is compelling for performance and flexibility issues, but requires additional standards for dealing with ISA's direct memory access (DMA) and interrupt request (IRQ) requirements.

The battle for market share in the PC audio chip market is led by Crystal Semiconductor because it dominates the market for audio codecs. As the codec is integrated with other audio components, Crystal faces pressure from ESS Technology and Creative Technologies. Creative dominates the add-in card segment of the PC audio market and has leveraged its strong brand name and expertise into the market for PC audio chips, as well, to become the third-largest PC audio chip vendor. The success of Intel's AC-97 initiative could dramatically affect the market share rankings as the codec once again becomes a separate chip and dedicated hardware controllers compete with software controllers running on the CPU for low-end systems. This market change back toward separate codecs will favor those companies with high-quality mixed-signal products.

The market forecast for PC audio chip unit shipments is robust, calling for a compound annual growth rate (CAGR) of 34 percent for 1995 to 2000. Revenue will grow a little more slowly at just under 21 percent owing to moderate ASP erosion over the forecast period. Unit growth will be more modest if Intel's AC-97 initiative is unsuccessful because single-chip audio solutions will lower the chip count per PC compared with Intel's two-chip solution. Either way, demand for audio subsystems will increase as audio features increase their penetration of the growing PC market.

Chapter 2
Introduction

Audio features in PCs have come a long way since the early beeping and buzzing noises in the first PCs. In the late 1980s, sound cards became popular for game enthusiasts to add audio features to their PCs. The rise of the multimedia PC through the early 1990s brought PC audio into the mainstream as "edutainment," and some business applications validated the need for PC audio beyond just playing games. Now, in 1996, audio subsystems are standard equipment for most PCs targeted at the consumer or small office/home office (SOHO) markets. The corporate desktop is the last major PC category that does not generally have sound capability, but that will slowly change. Future applications such as desktop videoconferencing and greater computer/telephony integration create demand for audio features in corporate markets.

The market growth for PC audio chips is driven by lower costs and compelling new features. High levels of integration have shrunk costs and reduced the chip count as well as the board space required for an audio subsystem. These trends have given PC OEMs greater flexibility and have made motherboard implementations feasible. Audio chip vendors must also compete on features and are adding spatial enhancement, wavetable synthesis, and 3-D positioning to their products.

This document provides an overview of the market for PC audio chips. Chapter 3 shows a generic block diagram for an audio subsystem. Chapter 4 identifies major trends for new features in these chips. Chapter 5 highlights the changing ways that PC OEMs are adding audio chips to their systems. Chapter 6 provides an overview of the five largest PC audio chip vendors. Chapter 7 holds the market share statistics and analysis. Chapter 8 presents the forecast for PC audio chips through the year 2000.

Chapter 3

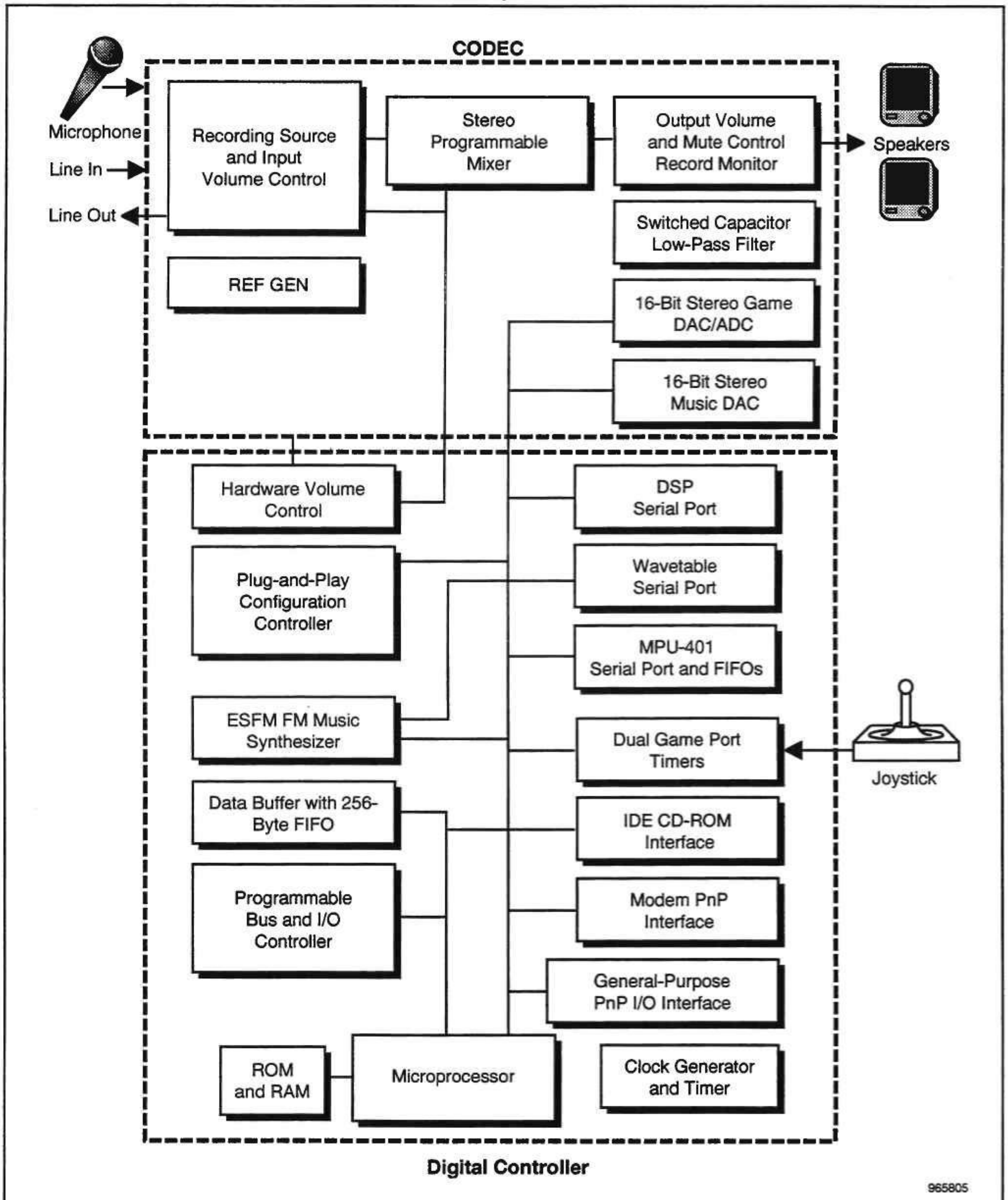
What Is in a PC Audio Subsystem?

The major functional elements of a PC audio subsystem can be lumped into two general categories: digital functions and analog functions. The digital functions are typically integrated into a chip called a digital controller. The digital controller includes all the peripheral control and interface functions, at a minimum, but can also include synthesis functions. FM synthesis is a digital function that was not integrated until recently because of intellectual property issues. All the analog functions, such as digital-to-analog conversion, are typically integrated into a mixed-signal chip called a codec, short for coder/decoder. The terms digital controller and codec will be used throughout this document to represent groups of functions within the audio subsystem. The digital controller and codec may be separate chips or may be integrated onto a single chip. Figure 3-1 shows the specific functions that are commonly included in codecs and digital controllers for the PC audio market.

The core functions of the digital controller are the interface to the ISA bus and the general control functions of moving data between the various parts of the audio subsystem as well as into and out of the PC. The list of functions has grown over time to include a wide variety of interfaces to peripherals such as CD-ROM drives, joysticks, or game pads through the game port, musical instrument digital interface (MIDI) devices, and modems.

Codecs have also gathered new features as higher levels of integration allowed chip designers to add analog mixing, amplifiers, and compression and decompression to the basic functions of converting between analog and digital formats.

Figure 3-1
Generic Block Diagram of a PC Audio Subsystem



Source: ESS Technology and Dataquest (August 1996)

Chapter 4
Audio Feature Trends

Migration from FM Synthesis to Wavetable Synthesis

FM synthesis has been the de facto standard for producing sound effects on PCs since the early success of Creative Labs with its Sound Blaster series of PC sound cards. Wavetable synthesis is a newer technology that is poised to replace FM synthesis with the promise of higher fidelity. Wavetable synthesis uses brief digital recordings called samples that are modified to create the desired sounds. FM synthesis recreates a sound based on a mathematical formula rather than starting from a recorded sample. The migration to wavetable synthesis is slow because of two major issues: backward compatibility with the popular Sound Blaster standard, which uses FM synthesis, and cost of implementation.

Sound Blaster compatibility is still an important feature for PC audio chipsets. Many PC buyers want to run legacy applications such as DOS-based games and Sound Blaster compatibility is the surest way to do it. Sound Blaster applications need specific hardware features in the audio chips for proper operation and these hardware features are very difficult to emulate with software. As a result, audio chips are burdened with legacy hardware requirements that increase the total cost and effectively slow down the acceptance of new standards.

The cost of implementation is also a barrier to moving from FM synthesis to wavetable synthesis. Wavetable synthesis is more expensive because it requires memory for storing the samples, or digital recordings. Memory requirements vary, but 512KB or 1MB of ROM is considered a minimum, and many add-in cards are sold with 2MB to 4MB of ROM as well as 512KB or more of RAM. Most wavetable implementations can be expanded by the user with additional ROM or RAM for storing more samples, but this increases the total cost. The dramatic declines in memory prices through the early part of 1996 have reduced the cost of adding wavetable audio to PCs and should increase demand for wavetable audio chips.

Waveguide synthesis is a more advanced technique than wavetable synthesis and produces higher quality music. It does require more processing power than wavetable synthesis and therefore will provide a growth path for audio subsystems in the future. Waveguide synthesis will be used in conjunction with wavetable synthesis on high-end PC audio subsystems in 1997 and will migrate into the average PC by the end of the decade.

Software Wavetable Synthesis

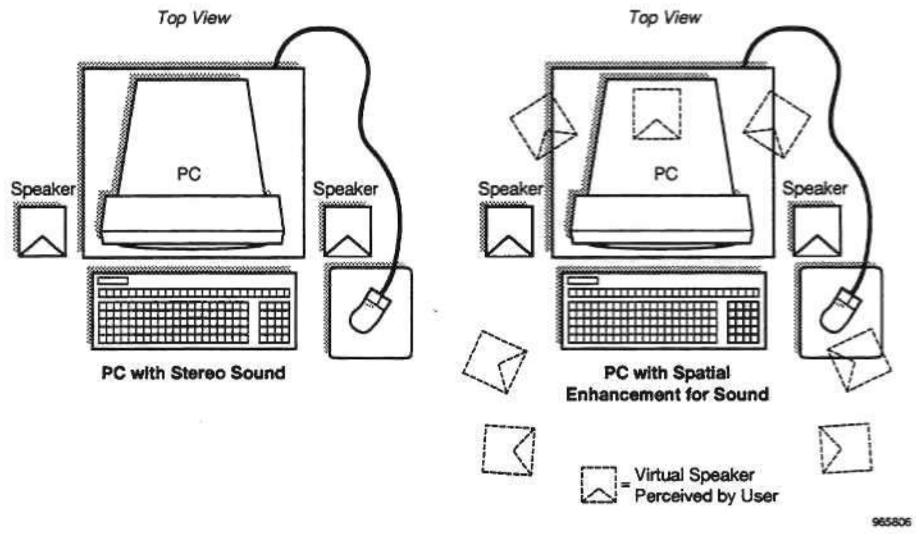
The transition from FM synthesis to wavetable synthesis is being spurred by software wavetable implementations. Software wavetable synthesis costs less than hardware wavetable synthesis because it uses the CPU for the digital signal processing and the PC main memory for storing the samples rather than requiring dedicated hardware. The cost savings do not come without a compromise: software wavetable is lower in quality than hardware solutions. That trade-off is important because PC OEMs cannot substitute wavetable synthesis for FM synthesis without compromising software compatibility. A PC OEM that adds wavetable synthesis to a PC is basically paying for wavetable synthesis in addition to FM synthesis. Software wavetable is compelling because it allows the PC OEM to enhance the audio subsystem at a lower incremental cost than adding dedicated hardware.

Spatial Enhancement Goes Beyond Plain Old Stereo

Spatial enhancement, sometimes called stereo enhancement, is an improvement on stereo sound because it makes the sound appear to come from a 180-degree arc of many speakers rather than just two speakers. In fact, it produces this effect using only two speakers by modifying the audio signals sent to each speaker. A variety of techniques are used. Some involve digital signal processing, while others use analog filters to modify the signals between the digital-to-analog converter (DAC) and the amplifier for the speakers.

Spatial enhancement dramatically improves the quality of music playback on PCs. These features are added to PCs at both the chip level and the board level. The cost of spatial enhancement ranges from under $1 to several dollars or more depending on the level of sophistication. Figure 4-1 shows how spatial enhancement improves the listener's experience by creating the impression that sounds are coming from many speakers rather than just two. Some companies promote spatial enhancement as 3-D sound, but that is misleading because it is really two-dimensional sound.

Figure 4-1
Spatial Enhancement Creates the Impression of Many Speakers Rather than Just Two



Source: Dataquest and Spatializer (August 1996)

Several companies, such as QSound Labs, SRS Laboratories, Spatializer Audio Laboratories, and Binaura, have developed spatial enhancement techniques. These companies are bringing their different technologies to the PC market by licensing specific designs as well as selling chips.

3-D Positioning

3-D positioning of sounds is the newest audio feature for PCs and is the next step beyond spatial enhancement. The ability to position and move sounds in three dimensions using only two speakers enhances the PC user's experience and requires a significant amount of signal-processing capability. 3-D positioning is a major step toward higher levels of realism and creates a more immersive, virtual reality experience. It is available today in both software-only versions and software/hardware combinations and will become mainstream in the second half of 1997 as it becomes integrated with standard audio chips. As PC OEMs design their products for the Christmas 1997 buying season, 3-D positioning will be a major differentiator between audio chip companies.

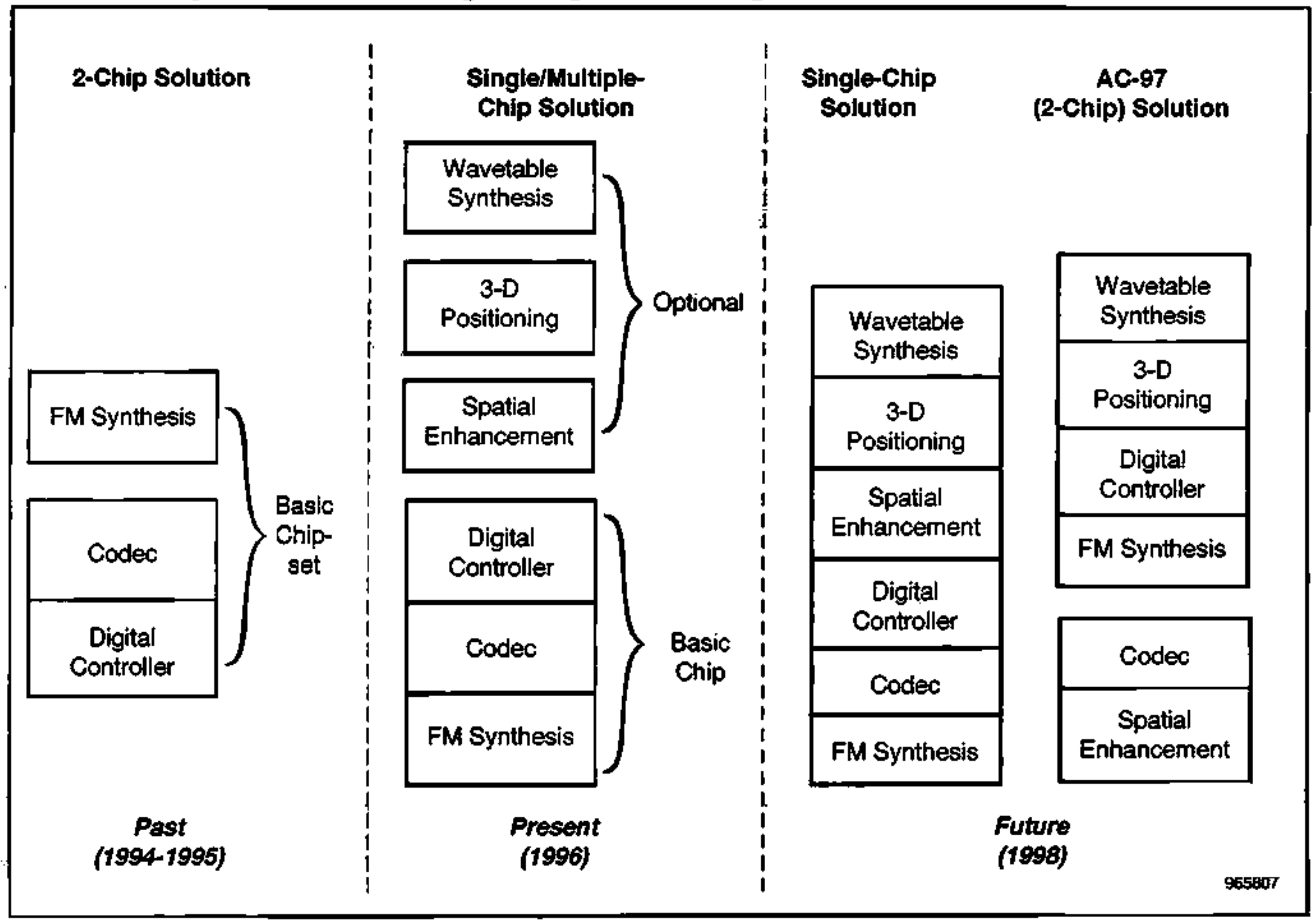
The techniques used for 3-D sound rely on pyschoacoustic models of how the human mind perceives sounds in a 3-D space. These techniques effectively trick the mind and are most powerful when used in concert with visual images. An airplane that flies across the computer screen is more believable as a real object if the sound of that airplane seems to come from the object rather than from the speakers. In certain circumstances, the mind will perceive a sound as coming from behind if the listener can hear the object but not see it. As a result, a fighter aircraft or race car might be heard by the game player, get louder, and then roar past the game player, complete with Doppler effect. The result is an engaging, immersive experience that is a little bit closer to virtual reality.

Techniques for 3-D positioning are being developed and brought to market by many of the companies noted for spatial enhancement techniques. This list includes QSound, SRS Laboratories, Spatializer, and others.

Feature Integration for Single-Chip Audio and the Impact of AC-97

Many PC audio chip suppliers have worked to differentiate themselves by reducing the chip count of an audio subsystem rather than just adding new features to a multichip solution. Now that several vendors have single-chip solutions, the race has changed to competition based on lowering cost and increasing the number of features while maintaining the single-chip design. Low chip count combined with a growing list of new features will continue the trend toward motherboard and daughterboard audio implementations for PCs. The popularity of single-chip designs will fade in favor of Intel's AC-97 initiative that advocates dividing the audio functions into two chips, one with the digital elements and the other with the mixed-signal elements. Figure 4-2 shows a diagram of feature integration, including the rise of AC-97 in late 1997 to 1998.

Figure 4-2
Feature Integration for the Single-Chip Audio Chipset



Source: Dataquest (August 1996)

Telephony Integration

The integration of telephony and audio functions in PCs becomes increasingly important as PCs continue to grow as communication tools. Board-level integration of modem chipsets and audio chipsets is common today, but chip-level integration is a further opportunity to reduce costs. Reasons for integration involve minimizing cost by sharing resources for signal processing as well as sharing I/O peripherals such as speakers and microphones. A user playing a game or a music CD does not want to "miss" a phone call because the PC speakers are being used when the telephone rings.

Integrating these functions is challenging for two reasons. First of all, few companies excel in both areas. Analog Devices is one exception and is in a good position to bring a compelling, integrated chipset to market. Cirrus Logic faces geographical challenges because its autio products are designed by its subsidiary Crystal Semiconductor in Austin, Texas, while its modems are designed in Fremont, California.

The second reason that audio and telephony integration is challenging is the pace of development. Modem speeds have more than doubled recently from 14.4 Kbps to 33.6 Kbps and many vendors had difficulty bringing their 28.8 Kbps and 33.6 Kbps modems to market on schedule. Adding audio functions to those modem chipsets would have made them even later than they were otherwise. This issue may change as modem speeds stagnate at their current levels. Dataquest believes that analog modem speeds are near their upper limit for use on standard telephone lines. Greater stability in the modem market will make integration with audio chips more viable.

Other solutions may obviate the need to integrate audio and telephony functions into a standard chipset. Several semiconductor companies are promoting programmable multimedia chips that range from DSP-based solutions to more powerful media processors. DSP-based solutions such as IBM's MWave DSP provide the signal processing and control functions required for audio and telephony functions, while media processors such as the MPact media processor from Chromatic Research provide those functions, as well as video and graphics processing. These programmable solutions generally require a separate codec and will benefit from Intel's efforts to separate the codec functions from the digital controller functions with its AC-97 initiative. AC-97 does include provisions for telephony codec functions.

Several semiconductor companies are promoting programmable multimedia chips that range from solutions based on digital signal processing (DSP) to more powerful media processors. DSP-based solutions such as IBM's Mwave DSP provide the signal-processing and control functions required for audio and telephony functions, while media processors such as the Mpact media processor from Chromatic Research provide those functions as well as video and graphics processing. Intel has provided for the integration of a telephony codec with the audio codec specified in the AC-97 initiative.

Chapter 5
Implementation Trends

PC audio is maturing as a checklist item for many segments of the PC market. The trends for implementation are dictated by the requirements of those markets. Higher degrees of chip-level integration have driven PC audio onto the motherboard, first in the mobile PC market and subsequently in the desktop market, as well. The rapid growth of chip shipments compared to add-in board shipments has changed the dynamics of the PC audio market, creating new opportunities for semiconductor vendors. Two key trends to watch are the continued shift toward motherboard implementations and Intel's ability to reverse the trend toward single-chip audio solutions in favor of its two-chip AC-97 solution.

Shift from ISA Card to Motherboard and Daughterboard Implementations

Implementation trends for PC audio have shifted from add-in cards to motherboard and daughterboard designs. This trend has been fueled by higher levels of integration for audio chips as well as PC audio's movement from luxury feature to standard feature for multimedia PCs. Dataquest expects unit shipments of sound cards to remain at about 15 million units annually through the year 2000. Motherboard and daughterboard implementations are absorbing virtually all the growth as audio subsystems ship in a higher percentage of PCs each year.

Higher levels of integration for audio chips have dramatically reduced the number of ICs as well as the number of passive components required for a typical PC audio subsystem. Fewer components means less board space and simpler designs. Several audio chip companies have integrated essentially all of the audio functions into a single IC and, at the same time, have reduced the need for as many additional resistors, capacitors, and other components as previous designs required. The result is greater flexibility for PC OEMs because audio subsystems have become compact enough to put on the motherboard. PC OEMs can choose to save money by integrating the audio subsystem onto the motherboard or continue to outsource the design and manufacturing of their audio subsystems by purchasing add-in cards. Indeed, PC OEMs put audio chips on the motherboard for many consumer PC models in 1995 and have continued this trend into 1996.

Highly integrated audio chips have also fueled the growth of audio features in mobile PCs. Until the chip count was reduced, it was not cost-effective for OEMs to add audio subsystems to mobile PCs. Audio subsystems are now common on mobile PCs and are forecast to grow to nearly 100 percent penetration by the year 2000.

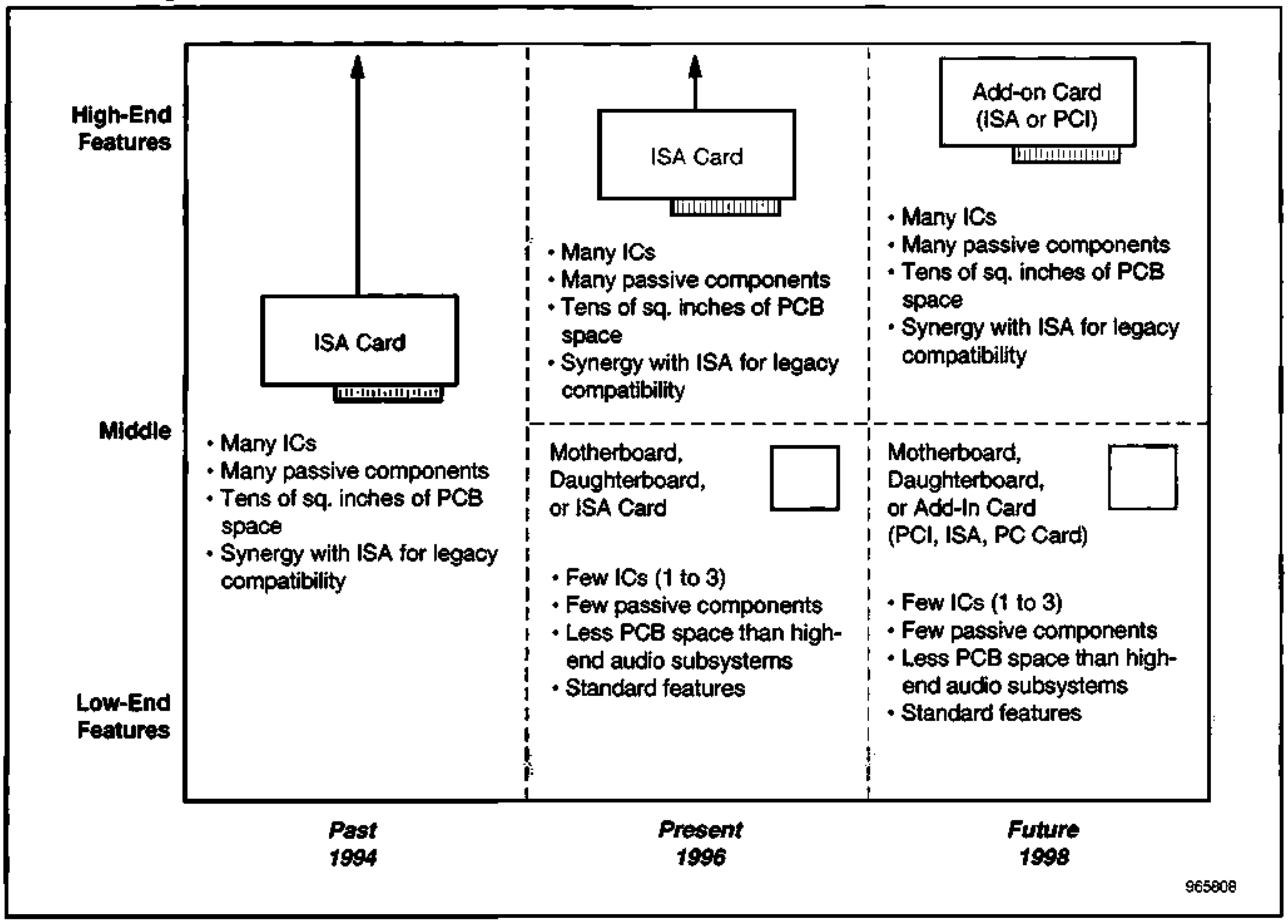
The trend toward motherboard implementations has tremendous impact on the market for standard PC audio chips. Sound cards have a mixture of custom products and standard products, but motherboard implementations essentially require standard products rather than custom ASICs. Custom audio solutions are not cost-effective for most PC OEMs. As audio subsystems ship in more PCs each year, the increased demand for audio ICs will necessarily be served by standard products.

Figure 5-1 shows these implementation trends. Add-in boards will continue to be used to add audio subsystems to PCs but will mostly serve the middle-to-high end of the market. Almost all the growth in the number of audio subsystems installed each year will come from motherboard and daughterboard implementations. Many of those PCs with motherboard audio will be limited to basic feature sets, but some will include advanced features.

The ISA Bus and Legacy Compatibility

The Sound Blaster standard is closely tied to the ISA bus architecture. This link between specific hardware features and legacy software compatibility has prevented PC audio from migrating to the PCI bus. Moving audio chips to the PCI bus is important for system performance reasons as well as configuration flexibility and true plug-and-play. Two features of the ISA architecture that are unavailable in the PCI architecture are the direct memory access (DMA) and interrupt request (IRQ). Two standards for handling DMA and IRQ over a PCI bus have been proposed. Intel supports a standard called PC/PCI, but distributed DMA (DDMA) also has broad industry support. Each standard has advantages and disadvantages, and it is too early to pick which will be more widely accepted.

Figure 5-1
Overall Implementation Trends for PC Audio



Source: Dataquest (August 1996)

Chapter 6
Companies

These five companies are the leading suppliers of audio chips for the PC market. Each one shipped several million audio codecs or integrated codec/controllers into the PC market last year, and each is positioned to participate actively as this market continues to grow. Many other companies are selling PC audio chips, and the competition ranges in size from relatively small companies, such as OnChip Systems and AdMOS, to large, established semiconductor suppliers like Advanced Micro Devices.

Creative Technology Ltd.

Creative Technology is a leading supplier of audio chips and has dominated the market for sound board shipments. In the 1980s, Creative built a strong brand name by selling PC sound boards through retail outlets. Creative's Sound Blaster family of sound boards is the de facto standard for PC audio feature sets and software compatibility because of its strength in the retail market. Software developers have largely depended on Sound Blaster standards to ensure software compatibility, and this mountain of legacy applications gives Creative additional market momentum. Through the early 1990s, Creative successfully managed the transition from a retail board supplier to a retail and OEM board supplier as PC OEMs began adding multimedia features to their product lines. The company managed another transition from 1994 to 1995 as it began selling PC audio chips in addition to its board-level offerings. Creative is the largest sound board supplier, with 67 percent unit market share for 1995, and is the third-largest supplier of PC audio chips, with 15 percent unit market share for the same year.

Creative faces increasing competition in the PC audio market as the demand for audio chips heats up and PC OEMs increasingly favor buying chips rather than boards. Two of Creative's strengths are its brand name and its ability to deliver software compatibility at the chip or board level. The positive impact of these will gradually erode as technology shifts to wavetable synthesis (see Chapter 4) and implementation trends shift to greater use of motherboards and daughterboards rather than ISA cards (see Chapter 5).

ViBRA is the name Creative chose for its family of integrated codec/controller chips. Three versions of the ViBRA chip are available today, the ViBRA 16S, ViBRA 16C, and ViBRA 16CL. Both the 16C and 16CL have integrated FM synthesis, but the 16S does not. Dataquest expects Creative to bring another version to market this fall that includes integrated spatial enhancement.

ESS Technology

ESS Technology took the PC audio chip market by storm in late 1994 by integrating the controller and codec functions onto a single chip. Other companies introduced similar products at about the same time, but ESS was ready for volume production months before those competitors. In 1995, ESS beat its competition to the punch again by integrating the FM synthesis functions. Almost all other vendors were using Yamaha's OPL-3 FM synthesis chips because of Yamaha's patent protection for that technology. ESS took the bold step of creating its own FM synthesis technology, named ESFM, instead of using Yamaha's patented technology. This led to a lawsuit for alleged patent infringement, but the suit was settled this year. Details of the settlement were sealed, but company announcements indicate that the settlement did not have a significant impact on the financial results of either company. The rapid rise of audio features in mobile PCs was fueled by ESS's ability to deliver volume quantities of highly integrated audio chips.

ESS Technology's success over the past two years can be attributed to its ability to deliver highly integrated products in volume ahead of competitors. The company needs to continue adding features faster than competitors to maintain a competitive edge, especially since all major vendors now have single-chip products.

Several single-chip audio solutions are available from ESS, including the ES1688, ES1788, ES1868, and the ES1878. All these chips include the codec, digital controller, and FM synthesis functions. The ES1868 and ES1878 are ESS's flagship products, targeted at the desktop PC and mobile PC markets, respectively. ESS has introduced the ES1869, which adds spatial enhancement to the ES1868 and will begin volume production this fall.

Crystal Semiconductor

Crystal Semiconductor, a division of Cirrus Logic, is the leading supplier of PC audio codecs and has a reputation for high-quality mixed-signal products. Crystal's mixed-signal expertise gives it a competitive edge in the audio market because its codecs meet very high standards for audio quality. This is a distinct advantage because codecs are arguably the most difficult part of a PC audio chipset to design and manufacture. Crystal has leveraged its leadership by adding the digital controller functions to its codecs while continuing to differentiate itself from other vendors on the basis of audio quality.

Crystal introduced a single-chip audio solution with FM synthesis, the CS4236, at the end of last year and started volume production last spring. The CS4237, the next version of the chip, includes spatial enhancement technology licensed from SRS Laboratories and began sampling last spring.

OPTi

PC audio products are a ray of sunshine on a cloudy day for OPTi. Audio products are producing a growing revenue stream for OPTi and have partially offset the large decline in revenue from some of the company's other product lines, such as desktop PC core logic. OPTi was several months behind ESS in terms of integrating all the audio functions into a single chip, but did come through with a complete, single-chip product early this year.

The OptiSound 931 integrates the codec, digital controller, and FM synthesis functions onto a single chip. OPTi began shipping the 931 in spring 1996, and this product kept OPTi in the race this year for PC audio design-wins. The 82C930 is a similar product but did not include FM synthesis.

Analog Devices Inc.

Analog Devices Inc. is well-known for its analog, mixed-signal, and DSP technologies and has been a leading supplier of codecs to the PC audio market. The company has leveraged its mixed-signal expertise by integrating other PC audio components with its audio codecs, just as Crystal Semiconductor did, but has been slower than other companies to bring these products to market.

ADI is closing the gap between itself and its competitors with a host of new products this fall. The SoundPort 1812 is a single-chip audio solution that includes the codec, digital controller, and FM synthesis. It is comparable to products that competitors have introduced over the past 12 months. Two other versions of that chip are scheduled for volume production as well, the SoundPort 1816 and the SoundPort 1815. The SoundPort 1816 adds spatial enhancement to the 1812 and is only a few months, rather than a full year, behind competitive products. The SoundPort 1815 integrates a V.34 modem codec with the 1812.

As a leading provider of audio chips and modem chips, ADI is well positioned to benefit from the integration of PC audio and PC telephony. The SoundPort 1815 is one step in this direction, and Dataquest expects that ADI will leverage its audio and telephony expertise in future products as well.

Chapter 7
Market Share

Crystal Semiconductor is the largest supplier of PC audio chips on a revenue basis, with almost $20 million more revenue than the second-largest supplier, ESS Technology. Crystal dominates the market for audio codecs, and over half its unit shipments were separate codecs rather than integrated codec/controller chips. In contrast, all of ESS's shipments were integrated codec/controller chips. Table 7-1 shows the 1995 PC audio chip revenue and unit shipments by company.

Table 7-1
PC Audio Chip Revenue and Unit Shipments by Company, 1995

	Revenue ($M)	% of Total	Units (K)	% of Total	Rank
Crystal	123.0	32.3	12,000	33.2	1
ESS	105.5	27.7	8,500	23.5	2
Creative	54.0	14.2	5,500	15.2	3
Analog Devices	47.6	12.5	5,030	13.9	4
OPTi	35.5	9.3	4,500	12.5	5
Others	15.6	4.1	610	1.7	
Total	381.2	100.0	36,140	100.0	

Note: Measuring PC audio chip shipments requires clear definitions of what constitutes a unit. For this document, a unit is a PC audio chip that is a codec, a digital controller, or an integrated chip with codec and controller functions. This number is larger than the total number of complete audio subsystems because some PCs have a codec from one vendor and a digital controller from another.
Source: Dataquest (August 1996)

These rankings could change significantly for 1996. The market for separate codecs is forecast to decline from 1995 to 1996 as PC OEMs favor the integrated codec/controller chips over less-integrated solutions. Table 7-2 shows the unit shipments and revenue for integrated codec/controller chips. Note that ESS Technology was the largest supplier of these integrated chips. ESS differentiated its products by packing more features into single-chip products than its competitors. That advantage has been reduced by single-chip offerings from Crystal, OPTi, and Creative that offer comparable lists of features. Market share battles for 1996 will depend more heavily on price and quality than they did in 1995. Integration is less of a differentiator because so many vendors have complete, single-chip solutions.

Looking forward to 1997, changes in vendor rankings could be dramatic once again if Intel's AC-97 initiative is successful. AC-97, discussed in Chapter 4, will reopen doors for suppliers to provide the digital controller separately from the mixed-signal codec. The companies with the strongest mixed-signal capabilities, like Crystal Semiconductor and Analog Devices, could have an advantage in supplying the AC-97 codec. Many vendors will compete for the digital controller business, but that segment of the market may shrink in favor of using the host CPU, a DSP, or a media processor instead of a dedicated controller.

Table 7-2
Revenue and Unit Shipments of Integrated PC Audio Codec/Controller Chips by Company, 1995

	Integrated Codec/Controller Revenue ($M)	% of Total	Integrated Codec/Controller Units (K)	% of Total
ESS	105.5	38.7	8,500	40.7
Crystal	60.0	22.0	5,000	23.9
Creative	54.0	19.8	4,500	21.5
OPTi	32.5	11.9	2,500	12.0
Others	20.9	7.7	390	1.9
Total	272.9	100.0	20,890	100.0

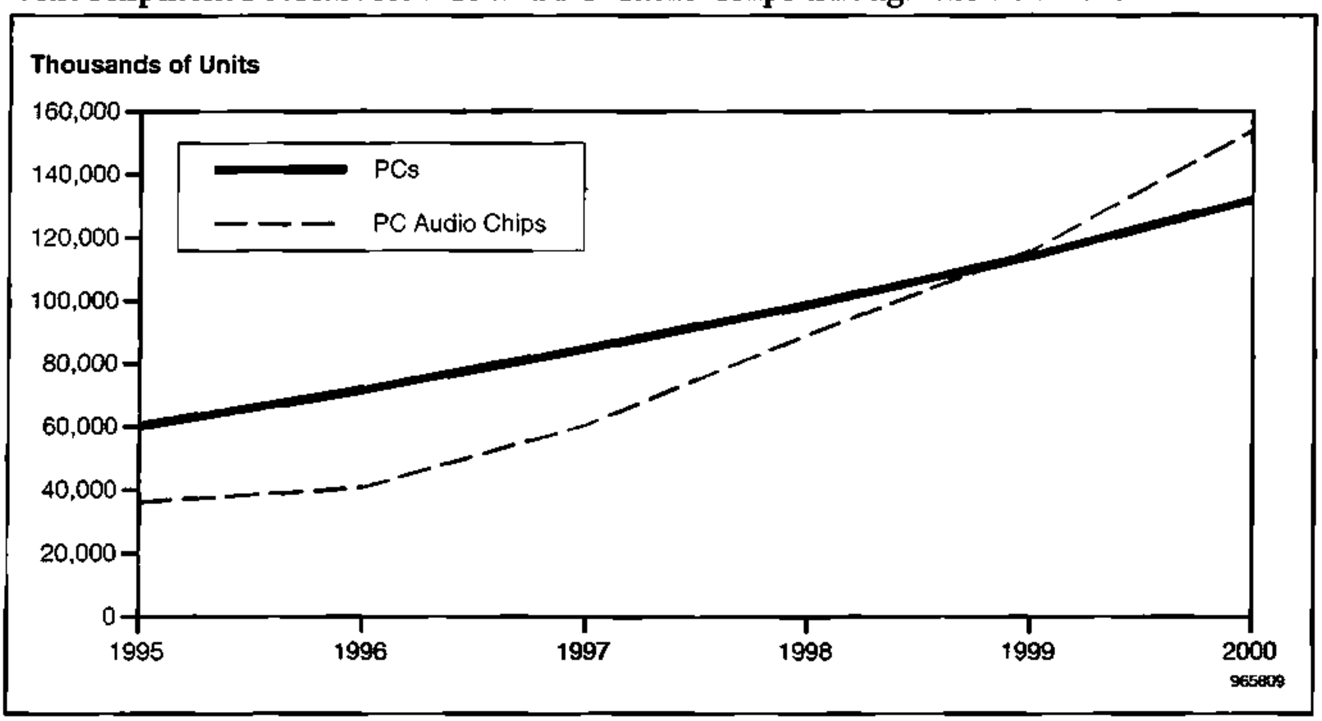
Source: Dataquest (August 1996)

Chapter 8
Market Forecast

The forecast for PC audio chip unit shipments calls for a 33.6 percent CAGR through the year 2000. Revenue is forecast to grow at a more moderate 20.8 percent because declining prices will partially offset the greater unit shipments. The percentage of PCs shipping with audio subsystems will increase through the forecast period, causing demand for audio chips to grow much faster than the overall PC market. Dataquest expects half of all desktop PCs and nearly all mobile PCs in the year 2000 to have audio subsystems. Figure 8-1 shows the unit shipment forecast for PC audio chips through the year 2000. Table 8-1 presents the unit shipment forecast from Figure 8-1 and also includes the revenue forecast for PC audio chips.

Several trends are expected to significantly impact the unit shipments of PC audio chips over the next five years. Companies will continue to enhance their single-chip designs with features such as spatial enhancement, 3-D positioning, telephony integration, and wavetable synthesis. This will reduce the average number of chips per audio subsystem through the latter half of 1997, when chips based upon AC-97 are expected to ramp in volume. AC-97 is expected to grow rapidly, representing over half of the audio installations in 1998.

Figure 8-1
Unit Shipment Forecast for PCs and PC Audio Chips through the Year 2000



Source: Dataquest (August 1996)

Table 8-1
Unit Shipment and Revenue Forecast for PC Audio Chips (Thousands of Units)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
PCs	60,171	71,651	84,694	98,693	114,178	131,700	17.0
PC Audio Chips	36,140	40,669	60,600	89,210	115,793	153,809	33.6
Growth Year-to-Year (%)		12.5	49.0	47.2	29.8	32.8	
PC Audio Chip Revenue ($M)	441.6	546.1	696.7	808.8	907.8	1,136.3	20.8
Growth Year-to-Year (%)		23.7	27.6	16.1	12.2	25.2	

Source: Dataquest (August 1996)

Although AC-97 does not require a dedicated digital controller, the forecast is based on a high initial attach rate for the AC-97 controller, trending down over the following two years. The unit growth for PC audio chips peaks at 49 percent in 1997 for this reason. The long-term expectation is that two-thirds of AC-97 implementations will require a chip other than the CPU to act as the digital controller. That other chip could be a dedicated controller or programmable device, such as a media processor or DSP. The remaining one-third of AC-97 installations will be low-end solutions that use a software controller running on the CPU.

If AC-97 is unsuccessful, overall unit growth for PC audio chips will be much lower, as highly integrated, single-chip implementations will be favored over multichip implementations. Table 8-2 provides additional information about how the total chip forecast is divided between codecs, controllers, and integrated codec/controller chips.

Table 8-2
Unit Forecast for Audio Chips by General Category through the Year 2000 (Thousands of Units)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Separate Codecs	13,250	9,000	19,000	44,000	69,000	94,000	48.0
Separate Hardware Controllers	2,000	0	9,000	26,250	40,000	56,667	95.2
Integrated Codec/Controllers	20,890	31,669	32,600	18,960	6,793	3,142	-31.5
Total	36,140	40,669	60,600	89,210	115,793	153,809	33.6

Source: Dataquest (August 1996)

Chip suppliers in the PC audio market will need to support multiple product strategies as single-chip products compete with AC-97 products. Single-chip products will be important for suppliers to maintain market share for the next few years, even though they are forecast to decline. The dual-chip strategies such as AC-97 are critical because chip-level integration in the PC market is moving across subsystems. The audio subsystem will not stand alone in future PCs. Audio chips will be implemented with graphics, video, and communications chips to minimize the total cost of the system. This trend has already started with combination audio/modem boards and will gain momentum in 1997 with media processors and Intel's MMX technology. Successful chip suppliers will embrace these changes and produce chips that support these integration trends.

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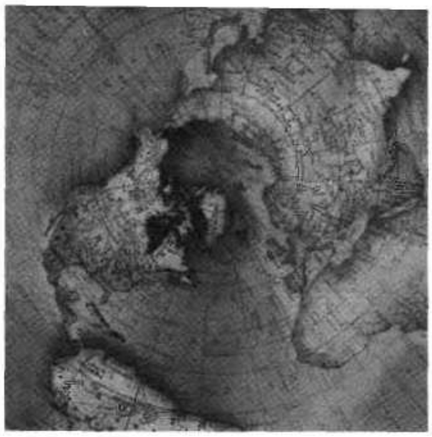

Dataquest

Audio Chips Let PCs Be Heard and Not Just Seen

Focus Report

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-FR-9602
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Table of Contents

List of Figures

List of Tables

Chapter 1
Executive Summary

The market for PC audio chips is driven by high levels of competition and PC buyers' lust for the latest features at the lowest prices. Those same PC buyers demand backward compatibility with their favorite applications from yesteryear, which has an impact on how quickly the market shifts to new standards for generating sound in the PC. Wavetable synthesis promises higher fidelity but must be implemented with legacy hardware functions for backward compatibility with a huge installed base of entertainment software. Spatial enhancement promises to improve music playback as well as sound effects and is a stepping stone to immersive, 3-D positional audio. Intel's AC-97 will most likely end the trend toward single-chip audio in favor of dividing digital and analog functions between two chips and could help to speed up the integration of PC audio and PC telephony.

Implementation trends include a rising tide of motherboard and daughterboard designs as OEMs strive to minimize costs. This trend fuels demand for audio chips rather than the ISA-based cards that have dominated the audio market in the past. Legacy compatibility issues rear their ugly heads again as vendors look to move audio subsystems from the ISA bus to the PCI bus. The move is compelling for performance and flexibility issues, but requires additional standards for dealing with ISA's direct memory access (DMA) and interrupt request (IRQ) requirements.

The battle for market share in the PC audio chip market is led by Crystal Semiconductor because it dominates the market for audio codecs. As the codec is integrated with other audio components, Crystal faces pressure from ESS Technology and Creative Technologies. Creative dominates the add-in card segment of the PC audio market and has leveraged its strong brand name and expertise into the market for PC audio chips, as well, to become the third-largest PC audio chip vendor. The success of Intel's AC-97 initiative could dramatically affect the market share rankings as the codec once again becomes a separate chip and dedicated hardware controllers compete with software controllers running on the CPU for low-end systems. This market change back toward separate codecs will favor those companies with high-quality mixed-signal products.

The market forecast for PC audio chip unit shipments is robust, calling for a compound annual growth rate (CAGR) of 34 percent for 1995 to 2000. Revenue will grow a little more slowly at just under 21 percent owing to moderate ASP erosion over the forecast period. Unit growth will be more modest if Intel's AC-97 initiative is unsuccessful because single-chip audio solutions will lower the chip count per PC compared with Intel's two-chip solution. Either way, demand for audio subsystems will increase as audio features increase their penetration of the growing PC market.

Chapter 2
Introduction

Audio features in PCs have come a long way since the early beeping and buzzing noises in the first PCs. In the late 1980s, sound cards became popular for game enthusiasts to add audio features to their PCs. The rise of the multimedia PC through the early 1990s brought PC audio into the mainstream as "edutainment," and some business applications validated the need for PC audio beyond just playing games. Now, in 1996, audio subsystems are standard equipment for most PCs targeted at the consumer or small office/home office (SOHO) markets. The corporate desktop is the last major PC category that does not generally have sound capability, but that will slowly change. Future applications such as desktop videoconferencing and greater computer/telephony integration create demand for audio features in corporate markets.

The market growth for PC audio chips is driven by lower costs and compelling new features. High levels of integration have shrunk costs and reduced the chip count as well as the board space required for an audio subsystem. These trends have given PC OEMs greater flexibility and have made motherboard implementations feasible. Audio chip vendors must also compete on features and are adding spatial enhancement, wavetable synthesis, and 3-D positioning to their products.

This document provides an overview of the market for PC audio chips. Chapter 3 shows a generic block diagram for an audio subsystem. Chapter 4 identifies major trends for new features in these chips. Chapter 5 highlights the changing ways that PC OEMs are adding audio chips to their systems. Chapter 6 provides an overview of the five largest PC audio chip vendors. Chapter 7 holds the market share statistics and analysis. Chapter 8 presents the forecast for PC audio chips through the year 2000.

Chapter 3

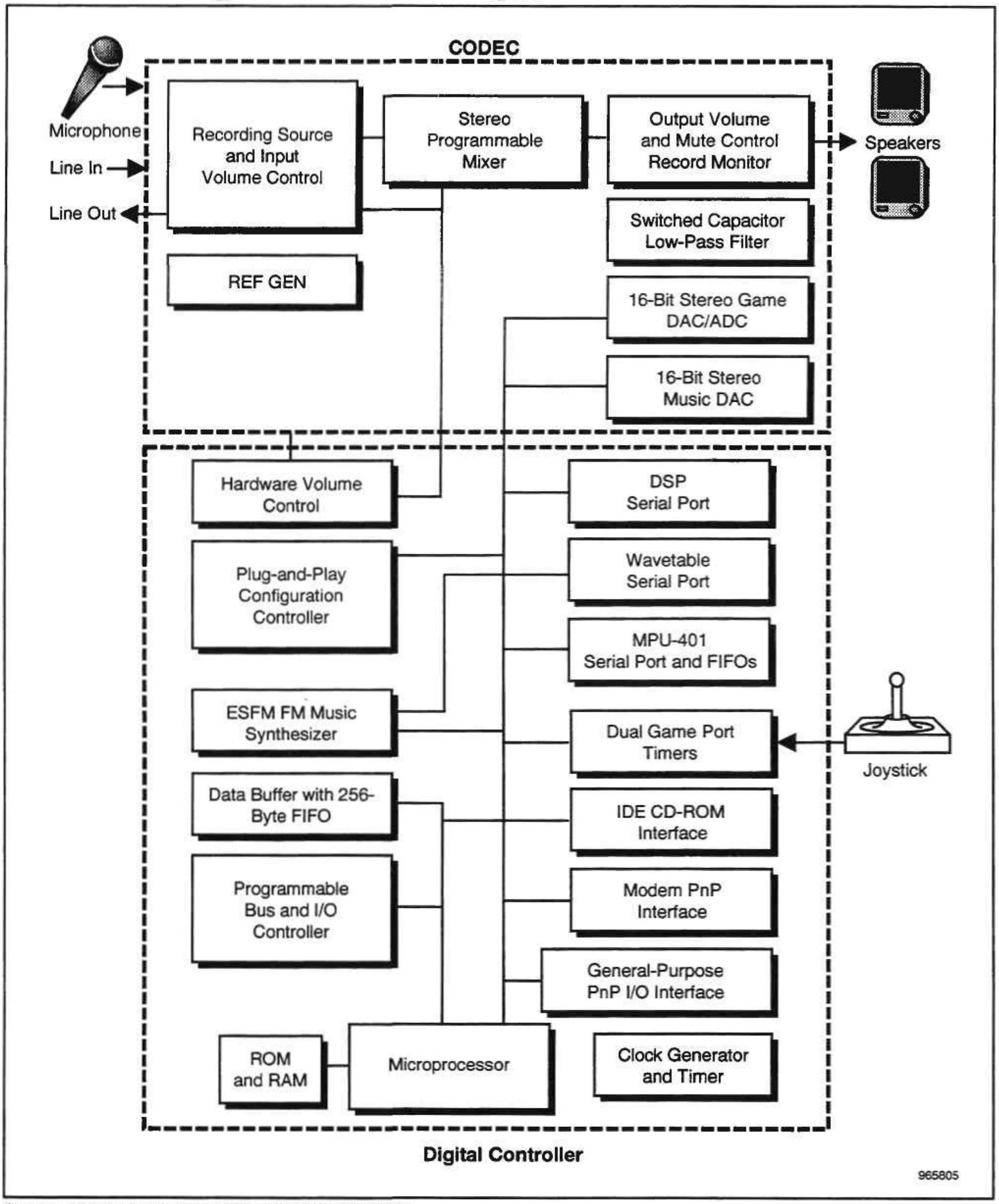
What Is in a PC Audio Subsystem?

The major functional elements of a PC audio subsystem can be lumped into two general categories: digital functions and analog functions. The digital functions are typically integrated into a chip called a digital controller. The digital controller includes all the peripheral control and interface functions, at a minimum, but can also include synthesis functions. FM synthesis is a digital function that was not integrated until recently because of intellectual property issues. All the analog functions, such as digital-to-analog conversion, are typically integrated into a mixed-signal chip called a codec, short for coder/decoder. The terms digital controller and codec will be used throughout this document to represent groups of functions within the audio subsystem. The digital controller and codec may be separate chips or may be integrated onto a single chip. Figure 3-1 shows the specific functions that are commonly included in codecs and digital controllers for the PC audio market.

The core functions of the digital controller are the interface to the ISA bus and the general control functions of moving data between the various parts of the audio subsystem as well as into and out of the PC. The list of functions has grown over time to include a wide variety of interfaces to peripherals such as CD-ROM drives, joysticks, or game pads through the game port, musical instrument digital interface (MIDI) devices, and modems.

Codecs have also gathered new features as higher levels of integration allowed chip designers to add analog mixing, amplifiers, and compression and decompression to the basic functions of converting between analog and digital formats.

Figure 3-1
Generic Block Diagram of a PC Audio Subsystem



Source: ESS Technology and Dataquest (August 1996)

Chapter 4
Audio Feature Trends

Migration from FM Synthesis to Wavetable Synthesis

FM synthesis has been the de facto standard for producing sound effects on PCs since the early success of Creative Labs with its Sound Blaster series of PC sound cards. Wavetable synthesis is a newer technology that is poised to replace FM synthesis with the promise of higher fidelity. Wavetable synthesis uses brief digital recordings called samples that are modified to create the desired sounds. FM synthesis recreates a sound based on a mathematical formula rather than starting from a recorded sample. The migration to wavetable synthesis is slow because of two major issues: backward compatibility with the popular Sound Blaster standard, which uses FM synthesis, and cost of implementation.

Sound Blaster compatibility is still an important feature for PC audio chipsets. Many PC buyers want to run legacy applications such as DOS-based games and Sound Blaster compatibility is the surest way to do it. Sound Blaster applications need specific hardware features in the audio chips for proper operation and these hardware features are very difficult to emulate with software. As a result, audio chips are burdened with legacy hardware requirements that increase the total cost and effectively slow down the acceptance of new standards.

The cost of implementation is also a barrier to moving from FM synthesis to wavetable synthesis. Wavetable synthesis is more expensive because it requires memory for storing the samples, or digital recordings. Memory requirements vary, but 512KB or 1MB of ROM is considered a minimum, and many add-in cards are sold with 2MB to 4MB of ROM as well as 512KB or more of RAM. Most wavetable implementations can be expanded by the user with additional ROM or RAM for storing more samples, but this increases the total cost. The dramatic declines in memory prices through the early part of 1996 have reduced the cost of adding wavetable audio to PCs and should increase demand for wavetable audio chips.

Waveguide synthesis is a more advanced technique than wavetable synthesis and produces higher quality music. It does require more processing power than wavetable synthesis and therefore will provide a growth path for audio subsystems in the future. Waveguide synthesis will be used in conjunction with wavetable synthesis on high-end PC audio subsystems in 1997 and will migrate into the average PC by the end of the decade.

Software Wavetable Synthesis

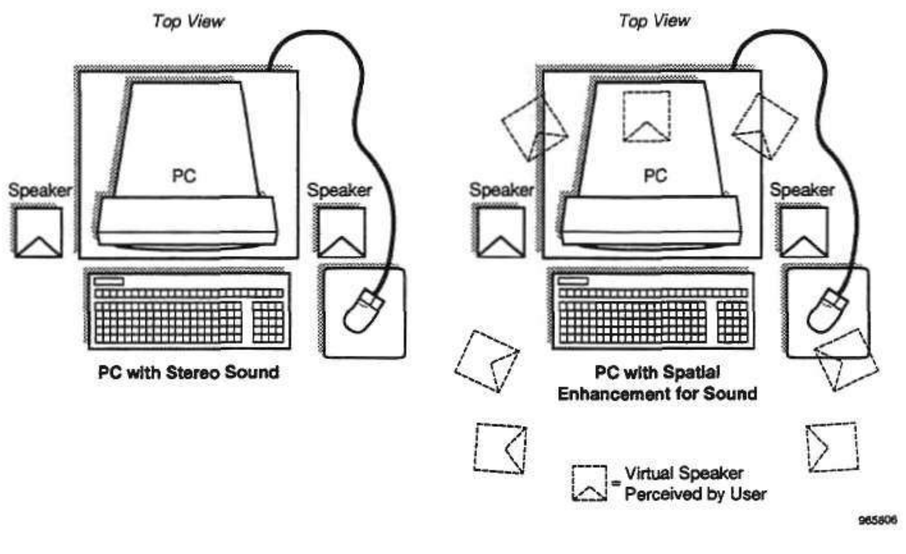
The transition from FM synthesis to wavetable synthesis is being spurred by software wavetable implementations. Software wavetable synthesis costs less than hardware wavetable synthesis because it uses the CPU for the digital signal processing and the PC main memory for storing the samples rather than requiring dedicated hardware. The cost savings do not come without a compromise: software wavetable is lower in quality than hardware solutions. That trade-off is important because PC OEMs cannot substitute wavetable synthesis for FM synthesis without compromising software compatibility. A PC OEM that adds wavetable synthesis to a PC is basically paying for wavetable synthesis in addition to FM synthesis. Software wavetable is compelling because it allows the PC OEM to enhance the audio subsystem at a lower incremental cost than adding dedicated hardware.

Spatial Enhancement Goes Beyond Plain Old Stereo

Spatial enhancement, sometimes called stereo enhancement, is an improvement on stereo sound because it makes the sound appear to come from a 180-degree arc of many speakers rather than just two speakers. In fact, it produces this effect using only two speakers by modifying the audio signals sent to each speaker. A variety of techniques are used. Some involve digital signal processing, while others use analog filters to modify the signals between the digital-to-analog converter (DAC) and the amplifier for the speakers.

Spatial enhancement dramatically improves the quality of music playback on PCs. These features are added to PCs at both the chip level and the board level. The cost of spatial enhancement ranges from under $1 to several dollars or more depending on the level of sophistication. Figure 4-1 shows how spatial enhancement improves the listener's experience by creating the impression that sounds are coming from many speakers rather than just two. Some companies promote spatial enhancement as 3-D sound, but that is misleading because it is really two-dimensional sound.

Figure 4-1
Spatial Enhancement Creates the Impression of Many Speakers Rather than Just Two



Source: Dataquest and Spatializer (August 1996)

Several companies, such as QSound Labs, SRS Laboratories, Spatializer Audio Laboratories, and Binaura, have developed spatial enhancement techniques. These companies are bringing their different technologies to the PC market by licensing specific designs as well as selling chips.

3-D Positioning

3-D positioning of sounds is the newest audio feature for PCs and is the next step beyond spatial enhancement. The ability to position and move sounds in three dimensions using only two speakers enhances the PC user's experience and requires a significant amount of signal-processing capability. 3-D positioning is a major step toward higher levels of realism and creates a more immersive, virtual reality experience. It is available today in both software-only versions and software/hardware combinations and will become mainstream in the second half of 1997 as it becomes integrated with standard audio chips. As PC OEMs design their products for the Christmas 1997 buying season, 3-D positioning will be a major differentiator between audio chip companies.

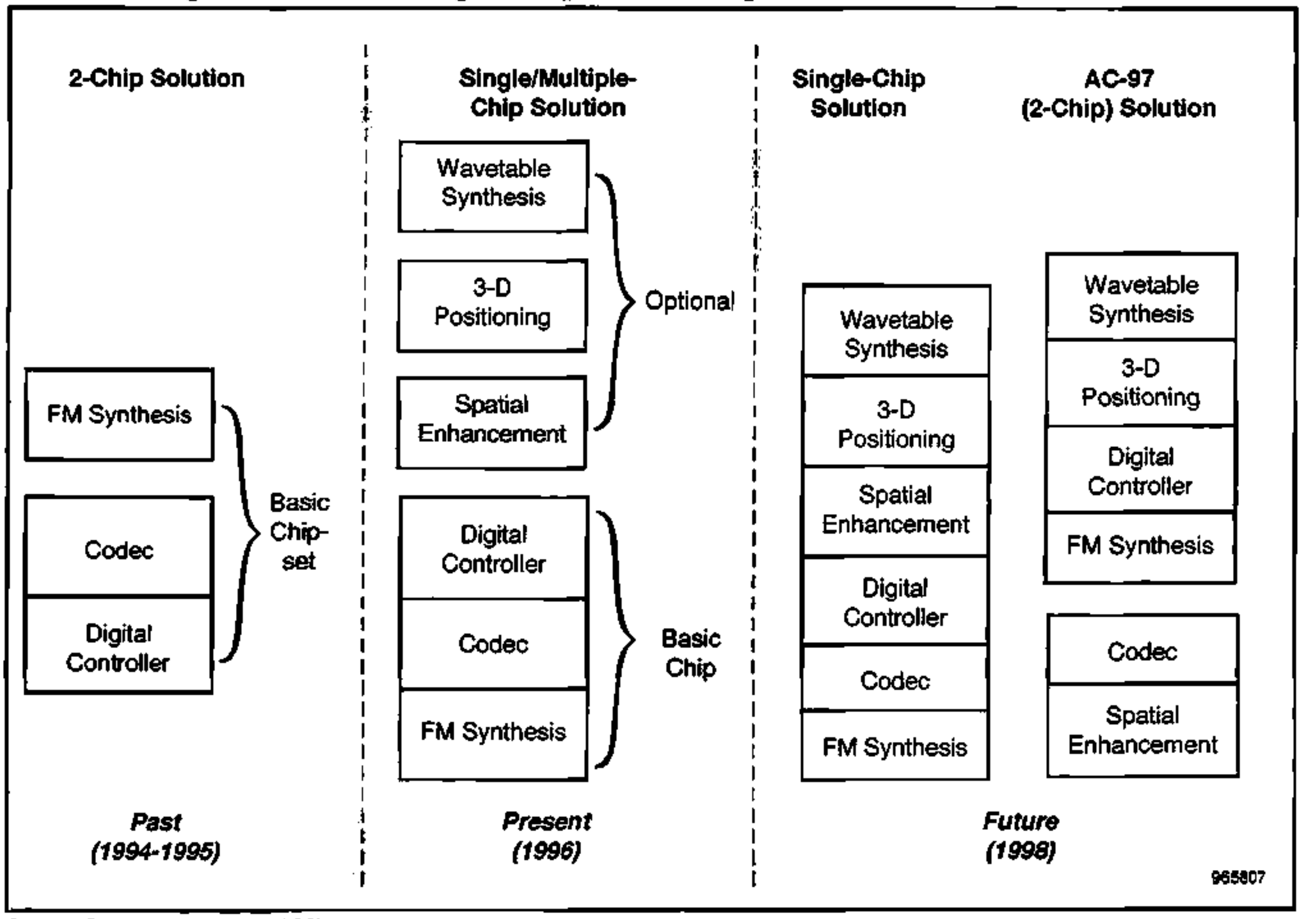
The techniques used for 3-D sound rely on pyschoacoustic models of how the human mind perceives sounds in a 3-D space. These techniques effectively trick the mind and are most powerful when used in concert with visual images. An airplane that flies across the computer screen is more believable as a real object if the sound of that airplane seems to come from the object rather than from the speakers. In certain circumstances, the mind will perceive a sound as coming from behind if the listener can hear the object but not see it. As a result, a fighter aircraft or race car might be heard by the game player, get louder, and then roar past the game player, complete with Doppler effect. The result is an engaging, immersive experience that is a little bit closer to virtual reality.

Techniques for 3-D positioning are being developed and brought to market by many of the companies noted for spatial enhancement techniques. This list includes QSound, SRS Laboratories, Spatializer, and others.

Feature Integration for Single-Chip Audio and the Impact of AC-97

Many PC audio chip suppliers have worked to differentiate themselves by reducing the chip count of an audio subsystem rather than just adding new features to a multichip solution. Now that several vendors have single-chip solutions, the race has changed to competition based on lowering cost and increasing the number of features while maintaining the single-chip design. Low chip count combined with a growing list of new features will continue the trend toward motherboard and daughterboard audio implementations for PCs. The popularity of single-chip designs will fade in favor of Intel's AC-97 initiative that advocates dividing the audio functions into two chips, one with the digital elements and the other with the mixed-signal elements. Figure 4-2 shows a diagram of feature integration, including the rise of AC-97 in late 1997 to 1998.

Figure 4-2
Feature Integration for the Single-Chip Audio Chipset



Source: Dataquest (August 1996)

Telephony Integration

The integration of telephony and audio functions in PCs becomes increasingly important as PCs continue to grow as communication tools. Board-level integration of modem chipsets and audio chipsets is common today, but chip-level integration is a further opportunity to reduce costs. Reasons for integration involve minimizing cost by sharing resources for signal processing as well as sharing I/O peripherals such as speakers and microphones. A user playing a game or a music CD does not want to "miss" a phone call because the PC speakers are being used when the telephone rings.

Integrating these functions is challenging for two reasons. First of all, few companies excel in both areas. Analog Devices is one exception and is in a good position to bring a compelling, integrated chipset to market. Cirrus Logic faces geographical challenges because its autio products are designed by its subsidiary Crystal Semiconductor in Austin, Texas, while its modems are designed in Fremont, California.

The second reason that audio and telephony integration is challenging is the pace of development. Modem speeds have more than doubled recently from 14.4 Kbps to 33.6 Kbps and many vendors had difficulty bringing their 28.8 Kbps and 33.6 Kbps modems to market on schedule. Adding audio functions to those modem chipsets would have made them even later than they were otherwise. This issue may change as modem speeds stagnate at their current levels. Dataquest believes that analog modem speeds are near their upper limit for use on standard telephone lines. Greater stability in the modem market will make integration with audio chips more viable.

Other solutions may obviate the need to integrate audio and telephony functions into a standard chipset. Several semiconductor companies are promoting programmable multimedia chips that range from DSP-based solutions to more powerful media processors. DSP-based solutions such as IBM's MWave DSP provide the signal processing and control functions required for audio and telephony functions, while media processors such as the MPact media processor from Chromatic Research provide those functions, as well as video and graphics processing. These programmable solutions generally require a separate codec and will benefit from Intel's efforts to separate the codec functions from the digital controller functions with its AC-97 initiative. AC-97 does include provisions for telephony codec functions.

Several semiconductor companies are promoting programmable multimedia chips that range from solutions based on digital signal processing (DSP) to more powerful media processors. DSP-based solutions such as IBM's Mwave DSP provide the signal-processing and control functions required for audio and telephony functions, while media processors such as the Mpact media processor from Chromatic Research provide those functions as well as video and graphics processing. Intel has provided for the integration of a telephony codec with the audio codec specified in the AC-97 initiative.

Chapter 5
Implementation Trends

PC audio is maturing as a checklist item for many segments of the PC market. The trends for implementation are dictated by the requirements of those markets. Higher degrees of chip-level integration have driven PC audio onto the motherboard, first in the mobile PC market and subsequently in the desktop market, as well. The rapid growth of chip shipments compared to add-in board shipments has changed the dynamics of the PC audio market, creating new opportunities for semiconductor vendors. Two key trends to watch are the continued shift toward motherboard implementations and Intel's ability to reverse the trend toward single-chip audio solutions in favor of its two-chip AC-97 solution.

Shift from ISA Card to Motherboard and Daughterboard Implementations

Implementation trends for PC audio have shifted from add-in cards to motherboard and daughterboard designs. This trend has been fueled by higher levels of integration for audio chips as well as PC audio's movement from luxury feature to standard feature for multimedia PCs. Dataquest expects unit shipments of sound cards to remain at about 15 million units annually through the year 2000. Motherboard and daughterboard implementations are absorbing virtually all the growth as audio subsystems ship in a higher percentage of PCs each year.

Higher levels of integration for audio chips have dramatically reduced the number of ICs as well as the number of passive components required for a typical PC audio subsystem. Fewer components means less board space and simpler designs. Several audio chip companies have integrated essentially all of the audio functions into a single IC and, at the same time, have reduced the need for as many additional resistors, capacitors, and other components as previous designs required. The result is greater flexibility for PC OEMs because audio subsystems have become compact enough to put on the motherboard. PC OEMs can choose to save money by integrating the audio subsystem onto the motherboard or continue to outsource the design and manufacturing of their audio subsystems by purchasing add-in cards. Indeed, PC OEMs put audio chips on the motherboard for many consumer PC models in 1995 and have continued this trend into 1996.

Highly integrated audio chips have also fueled the growth of audio features in mobile PCs. Until the chip count was reduced, it was not cost-effective for OEMs to add audio subsystems to mobile PCs. Audio subsystems are now common on mobile PCs and are forecast to grow to nearly 100 percent penetration by the year 2000.

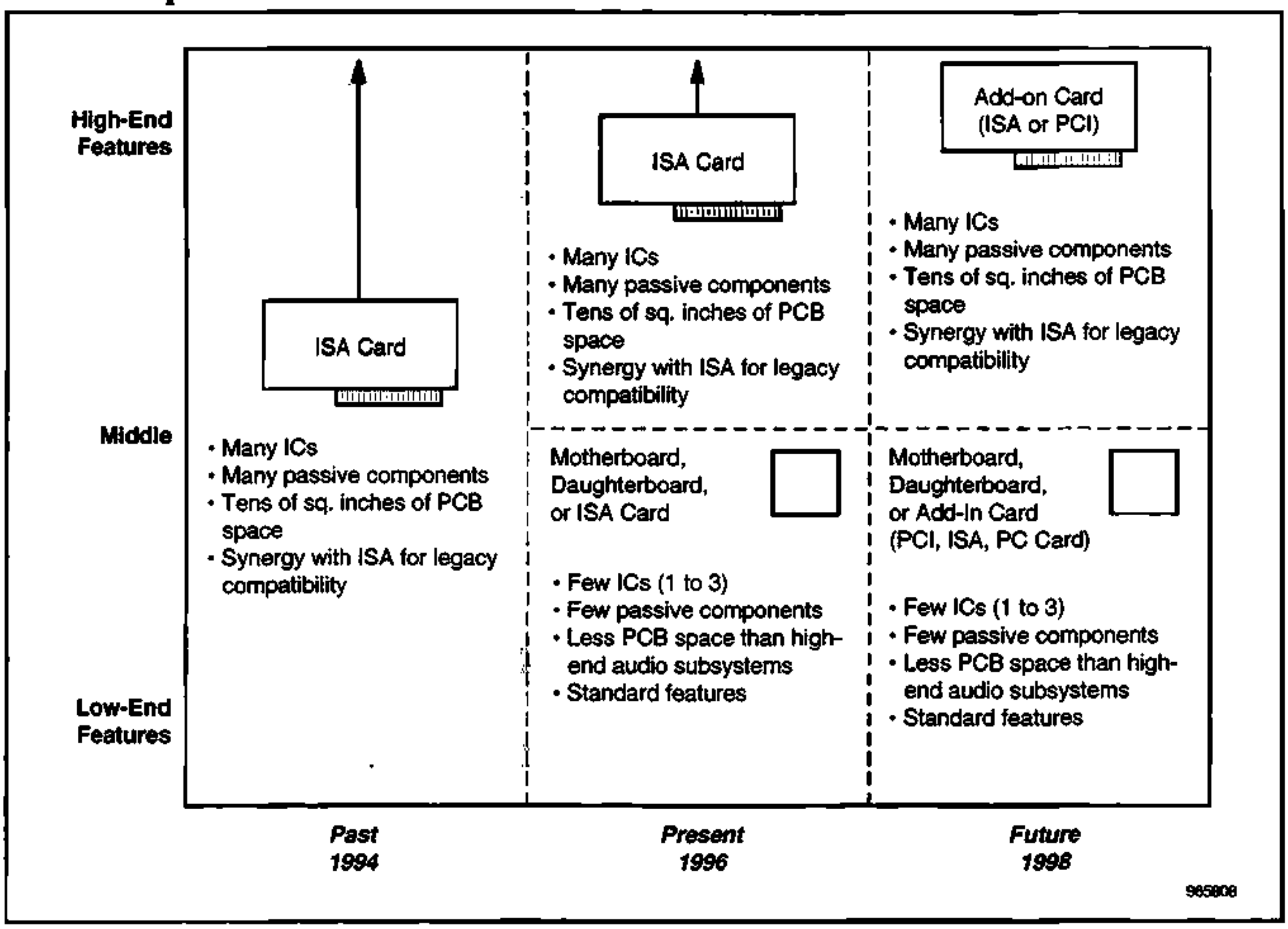
The trend toward motherboard implementations has tremendous impact on the market for standard PC audio chips. Sound cards have a mixture of custom products and standard products, but motherboard implementations essentially require standard products rather than custom ASICs. Custom audio solutions are not cost-effective for most PC OEMs. As audio subsystems ship in more PCs each year, the increased demand for audio ICs will necessarily be served by standard products.

Figure 5-1 shows these implementation trends. Add-in boards will continue to be used to add audio subsystems to PCs but will mostly serve the middle-to-high end of the market. Almost all the growth in the number of audio subsystems installed each year will come from motherboard and daughterboard implementations. Many of those PCs with motherboard audio will be limited to basic feature sets, but some will include advanced features.

The ISA Bus and Legacy Compatibility

The Sound Blaster standard is closely tied to the ISA bus architecture. This link between specific hardware features and legacy software compatibility has prevented PC audio from migrating to the PCI bus. Moving audio chips to the PCI bus is important for system performance reasons as well as configuration flexibility and true plug-and-play. Two features of the ISA architecture that are unavailable in the PCI architecture are the direct memory access (DMA) and interrupt request (IRQ). Two standards for handling DMA and IRQ over a PCI bus have been proposed. Intel supports a standard called PC/PCI, but distributed DMA (DDMA) also has broad industry support. Each standard has advantages and disadvantages, and it is too early to pick which will be more widely accepted.

Figure 5-1
Overall Implementation Trends for PC Audio



Source: Dataquest (August 1996)

Chapter 6
Companies

These five companies are the leading suppliers of audio chips for the PC market. Each one shipped several million audio codecs or integrated codec/controllers into the PC market last year, and each is positioned to participate actively as this market continues to grow. Many other companies are selling PC audio chips, and the competition ranges in size from relatively small companies, such as OnChip Systems and AdMOS, to large, established semiconductor suppliers like Advanced Micro Devices.

Creative Technology Ltd.

Creative Technology is a leading supplier of audio chips and has dominated the market for sound board shipments. In the 1980s, Creative built a strong brand name by selling PC sound boards through retail outlets. Creative's Sound Blaster family of sound boards is the de facto standard for PC audio feature sets and software compatibility because of its strength in the retail market. Software developers have largely depended on Sound Blaster standards to ensure software compatibility, and this mountain of legacy applications gives Creative additional market momentum. Through the early 1990s, Creative successfully managed the transition from a retail board supplier to a retail and OEM board supplier as PC OEMs began adding multimedia features to their product lines. The company managed another transition from 1994 to 1995 as it began selling PC audio chips in addition to its board-level offerings. Creative is the largest sound board supplier, with 67 percent unit market share for 1995, and is the third-largest supplier of PC audio chips, with 15 percent unit market share for the same year.

Creative faces increasing competition in the PC audio market as the demand for audio chips heats up and PC OEMs increasingly favor buying chips rather than boards. Two of Creative's strengths are its brand name and its ability to deliver software compatibility at the chip or board level. The positive impact of these will gradually erode as technology shifts to wavetable synthesis (see Chapter 4) and implementation trends shift to greater use of motherboards and daughterboards rather than ISA cards (see Chapter 5).

ViBRA is the name Creative chose for its family of integrated codec/controller chips. Three versions of the ViBRA chip are available today, the ViBRA 16S, ViBRA 16C, and ViBRA 16CL. Both the 16C and 16CL have integrated FM synthesis, but the 16S does not. Dataquest expects Creative to bring another version to market this fall that includes integrated spatial enhancement.

ESS Technology

ESS Technology took the PC audio chip market by storm in late 1994 by integrating the controller and codec functions onto a single chip. Other companies introduced similar products at about the same time, but ESS was ready for volume production months before those competitors. In 1995, ESS beat its competition to the punch again by integrating the FM synthesis functions. Almost all other vendors were using Yamaha's OPL-3 FM synthesis chips because of Yamaha's patent protection for that technology. ESS took the bold step of creating its own FM synthesis technology, named ESFM, instead of using Yamaha's patented technology. This led to a lawsuit for alleged patent infringement, but the suit was settled this year. Details of the settlement were sealed, but company announcements indicate that the settlement did not have a significant impact on the financial results of either company. The rapid rise of audio features in mobile PCs was fueled by ESS's ability to deliver volume quantities of highly integrated audio chips.

ESS Technology's success over the past two years can be attributed to its ability to deliver highly integrated products in volume ahead of competitors. The company needs to continue adding features faster than competitors to maintain a competitive edge, especially since all major vendors now have single-chip products.

Several single-chip audio solutions are available from ESS, including the ES1688, ES1788, ES1868, and the ES1878. All these chips include the codec, digital controller, and FM synthesis functions. The ES1868 and ES1878 are ESS's flagship products, targeted at the desktop PC and mobile PC markets, respectively. ESS has introduced the ES1869, which adds spatial enhancement to the ES1868 and will begin volume production this fall.

Crystal Semiconductor

Crystal Semiconductor, a division of Cirrus Logic, is the leading supplier of PC audio codecs and has a reputation for high-quality mixed-signal products. Crystal's mixed-signal expertise gives it a competitive edge in the audio market because its codecs meet very high standards for audio quality. This is a distinct advantage because codecs are arguably the most difficult part of a PC audio chipset to design and manufacture. Crystal has leveraged its leadership by adding the digital controller functions to its codecs while continuing to differentiate itself from other vendors on the basis of audio quality.

Crystal introduced a single-chip audio solution with FM synthesis, the CS4236, at the end of last year and started volume production last spring. The CS4237, the next version of the chip, includes spatial enhancement technology licensed from SRS Laboratories and began sampling last spring.

OPTi

PC audio products are a ray of sunshine on a cloudy day for OPTi. Audio products are producing a growing revenue stream for OPTi and have partially offset the large decline in revenue from some of the company's other product lines, such as desktop PC core logic. OPTi was several months behind ESS in terms of integrating all the audio functions into a single chip, but did come through with a complete, single-chip product early this year.

The OptiSound 931 integrates the codec, digital controller, and FM synthesis functions onto a single chip. OPTi began shipping the 931 in spring 1996, and this product kept OPTi in the race this year for PC audio design-wins. The 82C930 is a similar product but did not include FM synthesis.

Analog Devices Inc.

Analog Devices Inc. is well-known for its analog, mixed-signal, and DSP technologies and has been a leading supplier of codecs to the PC audio market. The company has leveraged its mixed-signal expertise by integrating other PC audio components with its audio codecs, just as Crystal Semiconductor did, but has been slower than other companies to bring these products to market.

ADI is closing the gap between itself and its competitors with a host of new products this fall. The SoundPort 1812 is a single-chip audio solution that includes the codec, digital controller, and FM synthesis. It is comparable to products that competitors have introduced over the past 12 months. Two other versions of that chip are scheduled for volume production as well, the SoundPort 1816 and the SoundPort 1815. The SoundPort 1816 adds spatial enhancement to the 1812 and is only a few months, rather than a full year, behind competitive products. The SoundPort 1815 integrates a V.34 modem codec with the 1812.

As a leading provider of audio chips and modem chips, ADI is well positioned to benefit from the integration of PC audio and PC telephony. The SoundPort 1815 is one step in this direction, and Dataquest expects that ADI will leverage its audio and telephony expertise in future products as well.

Chapter 7

Market Share

Crystal Semiconductor is the largest supplier of PC audio chips on a revenue basis, with almost $20 million more revenue than the second-largest supplier, ESS Technology. Crystal dominates the market for audio codecs, and over half its unit shipments were separate codecs rather than integrated codec/controller chips. In contrast, all of ESS's shipments were integrated codec/controller chips. Table 7-1 shows the 1995 PC audio chip revenue and unit shipments by company.

Table 7-1
PC Audio Chip Revenue and Unit Shipments by Company, 1995

	Revenue ($M)	% of Total	Units (K)	% of Total	Rank
Crystal	123.0	32.3	12,000	33.2	1
ESS	105.5	27.7	8,500	23.5	2
Creative	54.0	14.2	5,500	15.2	3
Analog Devices	47.6	12.5	5,030	13.9	4
OPTi	35.5	9.3	4,500	12.5	5
Others	15.6	4.1	610	1.7	
Total	381.2	100.0	36,140	100.0	

Note: Measuring PC audio chip shipments requires clear definitions of what constitutes a unit. For this document, a unit is a PC audio chip that is a codec, a digital controller, or an integrated chip with codec and controller functions. This number is larger than the total number of complete audio subsystems because some PCs have a codec from one vendor and a digital controller from another.
Source: Dataquest (August 1996)

These rankings could change significantly for 1996. The market for separate codecs is forecast to decline from 1995 to 1996 as PC OEMs favor the integrated codec/controller chips over less-integrated solutions. Table 7-2 shows the unit shipments and revenue for integrated codec/controller chips. Note that ESS Technology was the largest supplier of these integrated chips. ESS differentiated its products by packing more features into single-chip products than its competitors. That advantage has been reduced by single-chip offerings from Crystal, OPTi, and Creative that offer comparable lists of features. Market share battles for 1996 will depend more heavily on price and quality than they did in 1995. Integration is less of a differentiator because so many vendors have complete, single-chip solutions.

Looking forward to 1997, changes in vendor rankings could be dramatic once again if Intel's AC-97 initiative is successful. AC-97, discussed in Chapter 4, will reopen doors for suppliers to provide the digital controller separately from the mixed-signal codec. The companies with the strongest mixed-signal capabilities, like Crystal Semiconductor and Analog Devices, could have an advantage in supplying the AC-97 codec. Many vendors will compete for the digital controller business, but that segment of the market may shrink in favor of using the host CPU, a DSP, or a media processor instead of a dedicated controller.

Table 7-2
Revenue and Unit Shipments of Integrated PC Audio Codec/Controller Chips by Company, 1995

	Integrated Codec/Controller Revenue ($M)	% of Total	Integrated Codec/Controller Units (K)	% of Total
ESS	105.5	38.7	8,500	40.7
Crystal	60.0	22.0	5,000	23.9
Creative	54.0	19.8	4,500	21.5
OPTi	32.5	11.9	2,500	12.0
Others	20.9	7.7	390	1.9
Total	272.9	100.0	20,890	100.0

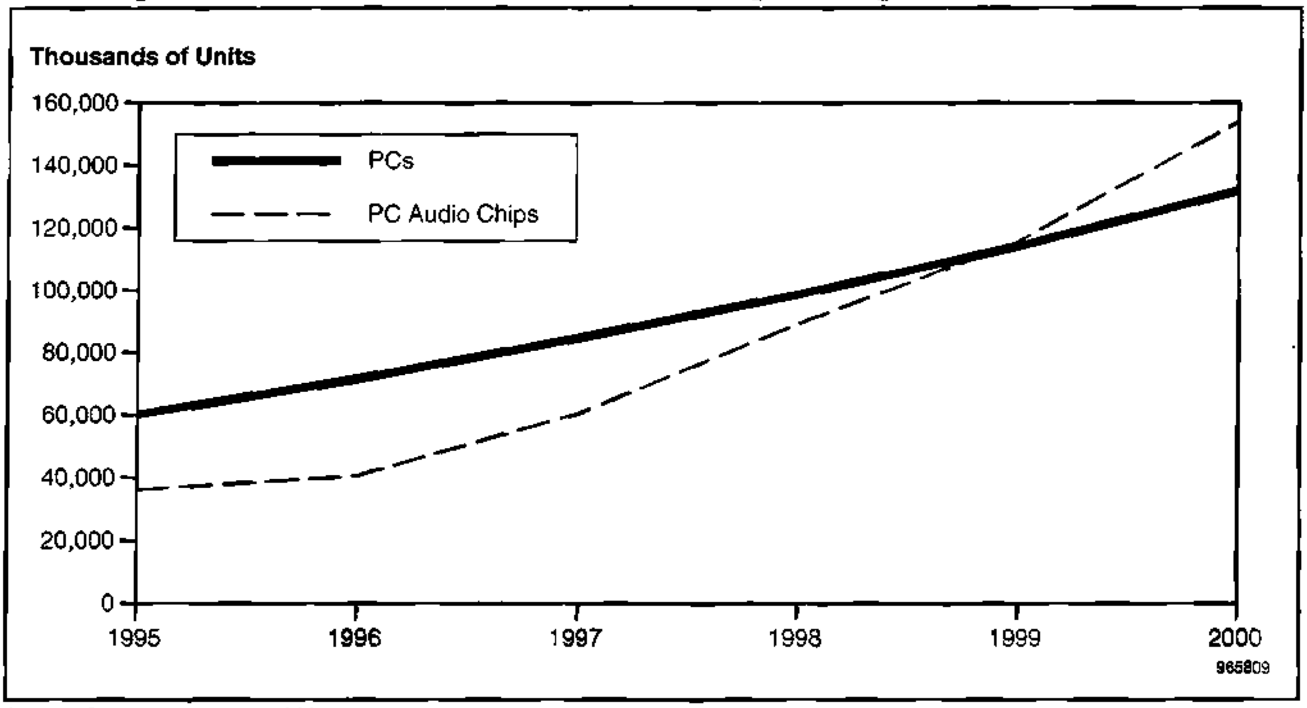
Source: Dataquest (August 1996)

Chapter 8
Market Forecast

The forecast for PC audio chip unit shipments calls for a 33.6 percent CAGR through the year 2000. Revenue is forecast to grow at a more moderate 20.8 percent because declining prices will partially offset the greater unit shipments. The percentage of PCs shipping with audio subsystems will increase through the forecast period, causing demand for audio chips to grow much faster than the overall PC market. Dataquest expects half of all desktop PCs and nearly all mobile PCs in the year 2000 to have audio subsystems. Figure 8-1 shows the unit shipment forecast for PC audio chips through the year 2000. Table 8-1 presents the unit shipment forecast from Figure 8-1 and also includes the revenue forecast for PC audio chips.

Several trends are expected to significantly impact the unit shipments of PC audio chips over the next five years. Companies will continue to enhance their single-chip designs with features such as spatial enhancement, 3-D positioning, telephony integration, and wavetable synthesis. This will reduce the average number of chips per audio subsystem through the latter half of 1997, when chips based upon AC-97 are expected to ramp in volume. AC-97 is expected to grow rapidly, representing over half of the audio installations in 1998.

Figure 8-1
Unit Shipment Forecast for PCs and PC Audio Chips through the Year 2000



Source: Dataquest (August 1996)

Table 8-1
Unit Shipment and Revenue Forecast for PC Audio Chips (Thousands of Units)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
PCs	60,171	71,651	84,694	98,693	114,178	131,700	17.0
PC Audio Chips	36,140	40,669	60,600	89,210	115,793	153,809	33.6
Growth Year-to-Year (%)		12.5	49.0	47.2	29.8	32.8	
PC Audio Chip Revenue ($M)	441.6	546.1	696.7	808.8	907.8	1,136.3	20.8
Growth Year-to-Year (%)		23.7	27.6	16.1	12.2	25.2	

Source: Dataquest (August 1996)

Although AC-97 does not require a dedicated digital controller, the forecast is based on a high initial attach rate for the AC-97 controller, trending down over the following two years. The unit growth for PC audio chips peaks at 49 percent in 1997 for this reason. The long-term expectation is that two-thirds of AC-97 implementations will require a chip other than the CPU to act as the digital controller. That other chip could be a dedicated controller or programmable device, such as a media processor or DSP. The remaining one-third of AC-97 installations will be low-end solutions that use a software controller running on the CPU.

If AC-97 is unsuccessful, overall unit growth for PC audio chips will be much lower, as highly integrated, single-chip implementations will be favored over multichip implementations. Table 8-2 provides additional information about how the total chip forecast is divided between codecs, controllers, and integrated codec/controller chips.

Table 8-2
Unit Forecast for Audio Chips by General Category through the Year 2000 (Thousands of Units)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Separate Codecs	13,250	9,000	19,000	44,000	69,000	94,000	48.0
Separate Hardware Controllers	2,000	0	9,000	26,250	40,000	56,667	95.2
Integrated Codec/Controllers	20,890	31,669	32,600	18,960	6,793	3,142	-31.5
Total	36,140	40,669	60,600	89,210	115,793	153,809	33.6

Source: Dataquest (August 1996)

Chip suppliers in the PC audio market will need to support multiple product strategies as single-chip products compete with AC-97 products. Single-chip products will be important for suppliers to maintain market share for the next few years, even though they are forecast to decline. The dual-chip strategies such as AC-97 are critical because chip-level integration in the PC market is moving across subsystems. The audio subsystem will not stand alone in future PCs. Audio chips will be implemented with graphics, video, and communications chips to minimize the total cost of the system. This trend has already started with combination audio/modem boards and will gain momentum in 1997 with media processors and Intel's MMX technology. Successful chip suppliers will embrace these changes and produce chips that support these integration trends.

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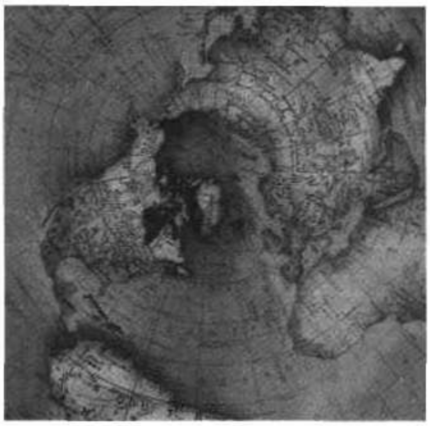

Dataquest

Trends in the Semiconductor Content of PCs and Workstations

Market Trends

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-MT-9603
Publication Date: July 29, 1996
Filing: Reports

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Table of Contents

List of Figures

List of Tables

List of Tables

Chapter 1

Executive Summary

The PC market and semiconductor markets are inherently linked by the simple fact that PCs consume more semiconductors than any other single application. The growth of the semiconductor market depends on a robust PC market just as the PC market depends on new semiconductor devices to differentiate the latest models from older designs. This relationship is symbiotic—profits from the semiconductor industry are funneled back into product and process development, driving more features and more performance into microprocessors, graphics chips, memory devices and all the other semiconductor devices in PCs.

The PC market, including motherboards and handheld PCs, is forecast to grow at a cumulative annual growth rate of 16.3 percent on a revenue basis from 1995 to the year 2000, with Japan and Asia/Pacific exhibiting higher growth than other regions. The semiconductor content of that total PC market, including motherboards and handheld PCs, is forecast to grow at a 16.1 percent cumulative annual growth rate for the same period. So the semiconductor content of the typical PC will remain steady as a percentage of factory selling price.

This document provides market data, market forecasts, and market trend information for both the PC market and the PC semiconductor market. Chapter 2 provides an introduction and discussion of methodology. Chapter 3 provides Dataquest's latest PC forecast with breakouts by form factor, regional demand, and microprocessor type. Chapter 4 provides trend information about the semiconductor market for PCs and workstations. Chapter 5 has market size and forecast information for the PC and workstation semiconductor markets. Chapter 6 provides market forecast and semiconductor content information about several standard input/output (I/O) peripherals.

Chapter 2
Introduction and Methodology

This document is the third in a series of four that provide reference information and analysis about the markets for semiconductor devices in personal computers. The four books cover graphics controllers, core logic chipsets, microprocessors, and an overview that includes a model of total semiconductor content for PCs. Specific areas of information include:

- PC system market size (in production terms) in revenue, units, and average selling price (ASP)
- PC system market and product feature trends
- Hardware architecture trends and semiconductor device opportunities
- Semiconductor content and market forecast
- Listings of key OEMs

The information in this report is gathered from both primary and secondary sources. Primary sources include surveys and interviews of industry vendors and customers, as well as analyst knowledge and opinions. Secondary sources include government and trade sources on sales, production, trade, and public spending. Semiconductor content assumptions are based on both surveys of producing OEMs and physical teardown evaluations by Dataquest analysts of representative personal computers.

The forecast methodology is based on various methods and assumptions, depending on the specific market. To form a solid basis for projecting system demand and capital, government, and consumer spending, assumptions are made for various regions of the world. For specific markets, saturation and displacement dynamics are considered as well. Key exogenous factors such as new software introductions, exchange rate changes and government policies are also considered. Semiconductor content forecasts are based on interviews of system marketers and designers (including makers of enabling semiconductor technology), along with an analysis of historical trends.

Project Analyst: Geoff Ballew

Chapter 3

Personal Computer and Workstation Markets

Market and Production Trends

Personal Computers

Market and production trends in PCs and workstations are as follows:

- Although notebook and subnotebook computers have enjoyed strong growth, desktop systems will continue to dominate the computing platform because of their lower manufacturing costs, their ability to handle robust configurations with large amounts of storage, and their role in offering the fastest and latest computing technologies.
- Notebooks have enjoyed solid unit growth and even higher revenue growth because of their ability to replicate desktop environments. Larger LCDs, bigger hard disks and integrated CD-ROM drives continue to narrow the performance gap between desktop and notebook PCs.
- Ultraportable and notepad shipments continue to grow but may be surpassed by handheld PCs as the second-largest mobile category, behind notebooks.
- Shipments of laptops and transportable units declined again for 1995 but are forecast to remain steady in terms of unit volume through the forecast period.
- In the world of mobile computing, handheld devices continue to promise function and mobility but face size, weight, and cost issues. Dataquest has defined two categories for these handheld devices, but only the handheld computer category is covered in this document.
  - Expandable organizers: These are computers that typically measure 3.0 x 6.0 x 0.75 inches and weigh less than a pound. They are distinguished by their ability to allow the user to add applications and memory and by the fact that expansion is proprietary to a particular device or family. The operating systems typically are proprietary. The market for these devices is expected to peak at more than 0.5 million unit shipments in 1995 and then slowly shrink to fewer than 0.4 million by 1999.
  - Handheld computers: These devices typically measure 4.0 x 7.0 x 1.0 inches and weigh about one pound. They are distinguished from expandable organizers by their adherence to hardware and software compatibility standards. The operating systems are open and licensed, and application development and memory expansion are open to third-party developers and may be distributed in a standard format (such as PCMCIA). Personal digital assistants (PDAs) fall into this category.

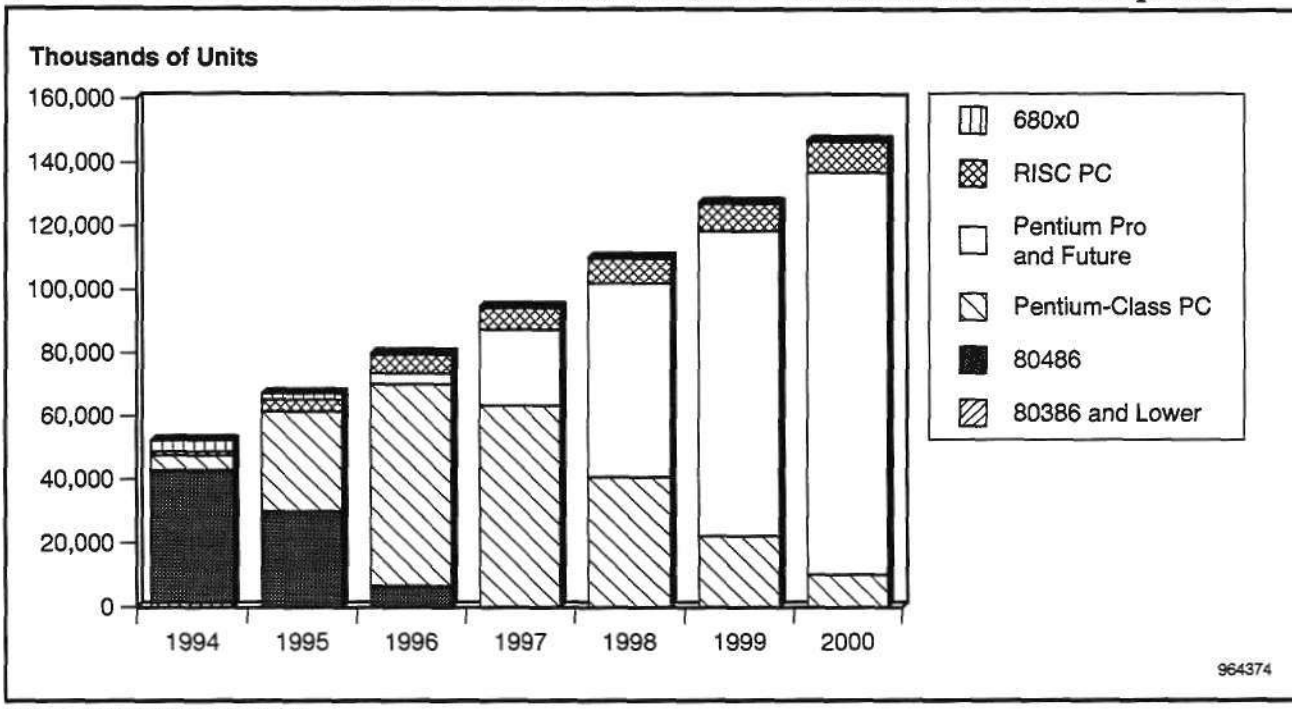
- Strong growth in the worldwide home PC market will continue across all regions of the world except for the U.S. home market, which shows early signs of saturation. Price elasticity is a key issue in reaching lower-income homes in all regions of the world.
- Microsoft's Windows 95 operating system was launched in the second half of 1995 with actual product sales beginning on August 24. Its most significant impact on hardware is the need to upgrade to 16MB of main memory.
- Emerging markets and regions will account for a sharply increased proportion of shipments by 1998.
- The multimedia PC market continued its torrid growth in 1995. Shipments of complete multimedia systems doubled from 1994 to 1995, reaching 20.9 million shipments.
- Major PC manufacturers will continue to place a strong emphasis on the branding of PCs.
- Manufacturing strategies are dictated by economies of scale, with strong influence from free trade zones, the availability of components, and the quality and price of labor. For desktop PCs, the trend is toward assembling units close to the end market or at least having the final configuration (including CPU and main memory installation) executed on demand close to the end market. For mobile PCs, production is largely focused in Japan and other Asian countries. A rising tide of OEM notebooks from Taiwanese vendors will maintain Asia/Pacific's growing influence on the mobile PC market.
- Motherboard production will depend more heavily on the Asia/Pacific region as suppliers regain some of the market share they lost because of Intel's rapid growth in the motherboard business in 1994 and 1995.

Figures 3-1 to 3-3 and Tables 3-1 to 3-7 present Dataquest's worldwide PC market forecasts. Figure 3-4 shows the regional variation in markets from 1994 to 2000.

OEMs

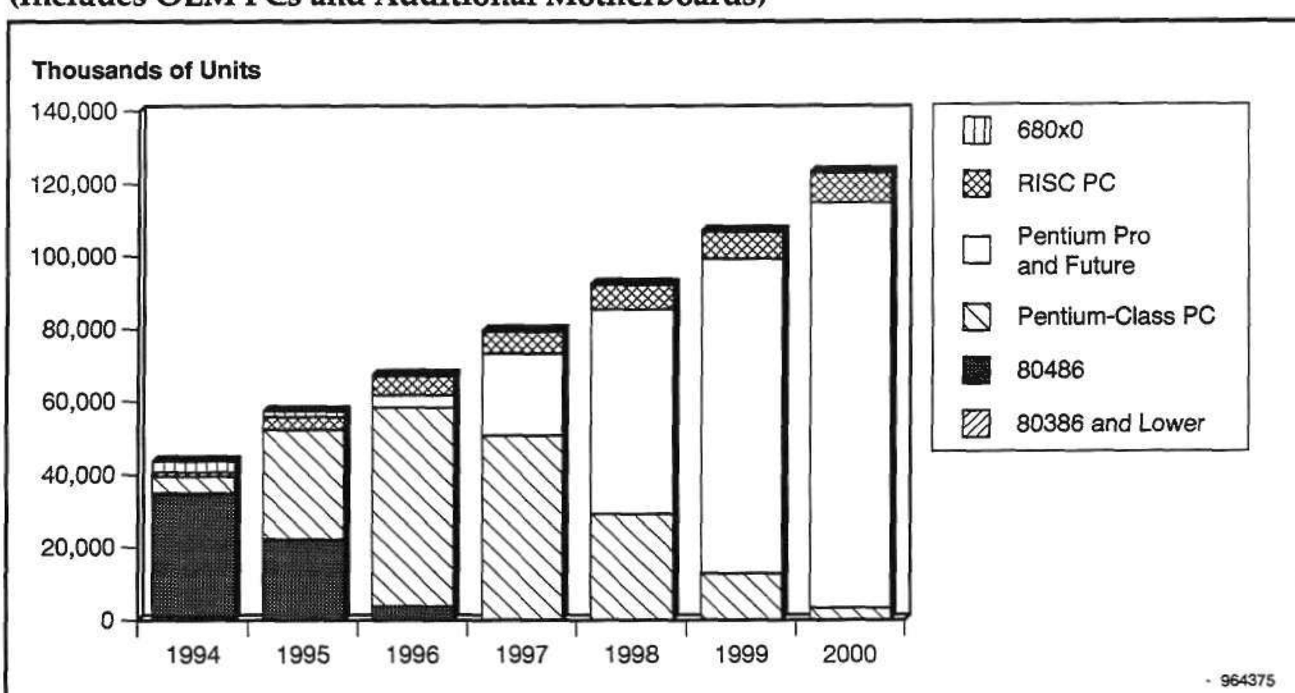
Tables 3-8 and 3-9 list the key OEMs ranked by revenue and unit shipment market share. Compaq retained the No. 1 spot despite fierce competition from the smaller OEMs but lost just a bit of market share on a revenue basis. Compaq faces a challenge in keeping the top spot for 1996 because the merger between NEC and Packard Bell has created a larger competitor. The combined shipments of NEC and Packard Bell make the new company the largest PC company in the world, based on 1995 unit shipments. Hewlett-Packard posted the largest gain in market share of all of the top 10 OEMs with the rapid growth of its Pavilion line of multimedia PCs.

Figure 3-1
Worldwide Personal Computer Shipments by Microprocessor Type (Includes OEM PCs and Additional Motherboards; Excludes Handheld Computers)



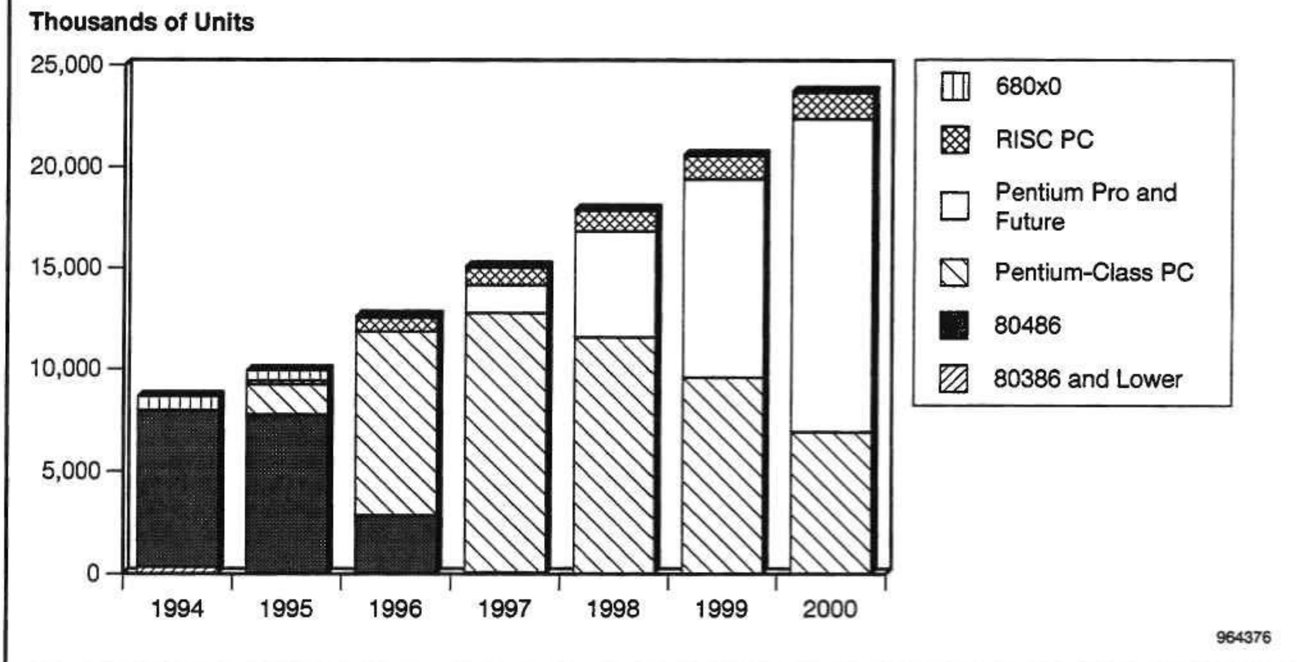
Source: Dataquest (June 1996)

Figure 3-2
Worldwide Desktop/Deskside Personal Shipments by Microprocessor Type (Includes OEM PCs and Additional Motherboards)



Source: Dataquest (June 1996)

Figure 3-3
Worldwide Mobile Personal Computer Shipments by Microprocessor Type (Excludes Handheld Computers)



Source: Dataquest (June 1996)

Table 3-1
Worldwide Personal Computer Market by Product Type*

Product Type	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Desktop/Deskside								
Units (K)	39,252	50,259	59,043	69,651	80,847	93,610	108,012	16.5
ASP ($K)	1.88	1.95	1.99	2.01	2.01	1.99	1.95	0
Factory Revenue ($M)	73,937	98,000	117,575	139,907	162,558	186,484	210,500	16.5
Transportable/Laptop								
Units (K)	166	44	42	45	44	43	43	-0.9
ASP ($K)	6.25	5.41	6.35	5.90	5.52	5.53	5.26	-0.6
Factory Revenue ($M)	1,035	240	269	263	243	240	224	-1.4
Notebook/Tablet								
Units (K)	7,480	8,649	11,116	13,049	14,965	16,709	18,979	17.0
ASP ($K)	2.49	2.71	2.44	2.47	2.37	2.34	2.31	-3.2
Factory Revenue ($M)	18,653	23,464	27,119	32,283	35,531	39,055	43,804	13.3

(Continued)

Table 3-1 (Continued)
Worldwide Personal Computer Market by Product Type*

Product Type	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Ultraportable/Notepad								
Units (K)	997	1,219	1,450	1,950	2,838	3,816	4,667	30.8
ASP ($K)	1.84	2.49	2.24	2.26	2.18	2.12	2.09	-3.4
Factory Revenue ($M)	1,832	3,034	3,246	4,411	6,173	8,085	9,750	26.3
Handheld								
Units (K)	390	481	611	850	1,336	2,352	5,052	60.0
ASP ($K)	0.82	0.60	0.55	0.50	0.45	0.40	0.35	-10.2
Factory Revenue ($M)	318	289	336	425	601	941	1,768	43.7
Additional Motherboards								
Units (K)	4,404	7,036	8,266	9,752	11,318	13,105	15,121	16.5
ASP ($K)	1.18	1.00	0.82	0.69	0.70	0.68	0.76	-5.4
Factory Revenue ($M)	5,178	7,018	6,805	6,776	7,889	8,957	11,422	10.2
Total PC (Including Handheld and Additional Motherboards)								
Units (K)	52,689	67,688	80,528	95,296	111,348	129,635	151,873	17.5
ASP ($K)	1.92	1.95	1.93	1.93	1.91	1.88	1.83	-1.3
Factory Revenue ($M)	100,952	132,044	155,350	184,064	212,996	243,762	277,468	16.0
Workstation								
Units (K)	735	841	937	1,027	1,105	1,204	1,307	9.2
ASP ($)	15.06	15.79	15.08	14.64	14.42	14.16	13.75	-2.7
Factory Revenue ($M)	11,070	13,287	14,133	15,036	15,936	17,050	17,975	6.2

*ASP and factory revenue include standard peripherals and memory upgrades installed by the factory or PC assembler.
Source: Dataquest (April 1996)

Table 3-2
Worldwide Personal Computer Shipments by Microprocessor Type (Thousands of Units) (Includes Additional Motherboards; Excludes Handheld Computers)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	1,491	76	0	0	0	0	0	-100.0
486	41,553	30,007	6,778	295	0	0	0	-100.0
Pentium Class	4,605	31,543	63,496	63,289	40,847	22,453	10,317	-20.0
Pentium Pro and Future	0	4	3,478	23,940	61,433	96,262	126,982	680.0
RISC PC	1,153	3,738	5,862	6,903	7,731	8,567	9,523	20.6
680x0	3,495	1,838	304	20	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	52,298.3	67,206.5	79,917.6	94,445.9	110,011.9	127,282.8	146,821.4	16.9

NA = Not applicable
Source: Dataquest (April 1996)

Table 3-3
Worldwide Desktop/Deskside Personal Computer Shipments by Microprocessor Type (Thousands of Units) (Includes Additional Motherboards)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	1,139	63	0	0	0	0	0	-100.0
486	33,929	22,231	3,913	210	0	0	0	-100.0
Pentium Class	4,583	30,082	54,509	50,589	29,259	12,837	3,361	-35.5
Pentium Pro and Future	0	4	3,478	22,558	56,213	86,476	111,549	660.1
RISC PC	1,153	3,547	5,176	6,025	6,694	7,402	8,223	18.3
680x0	2,851	1,367	234	20	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	43,655.8	57,294.1	67,309.6	79,402.3	92,165.3	106,715.3	123,132.8	16.5

NA = Not applicable
Source: Dataquest (June 1996)

Table 3-4
Worldwide Mobile Personal Computer Shipments by Microprocessor Type (Thousands of Units) (Excludes Handheld Computers)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	352	13	0	0	0	0	0	-100.0
486	7,624	7,776	2,865	85	0	0	0	-100.0
Pentium Class	22	1,461	8,987	12,700	11,588	9,616	6,956	36.6
Pentium Pro and Future	0	0	0	1,381	5,221	9,786	15,432	NM
RISC PC	0	191	685	877	1,038	1,165	1,300	46.7
680x0	644	471	71	0	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	8,642.5	9,912.4	12,608.1	15,043.6	17,846.6	20,567.5	23,688.6	19.0

NM = Not meaningful
NA = Not applicable
Source: Dataquest (June 1996)

Table 3-5
Worldwide Personal Computer Revenue by Microprocessor Type (Millions of Dollars) (Includes Additional Motherboards; Excludes Handheld Computers)*

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	1,480	58	0	0	0	0	0	-100.0
486	76,725	52,457	10,366	351	0	0	0	-100.0
Pentium Class	13,879	68,620	121,653	113,622	69,078	36,608	16,890	-24.5
Pentium Pro and Future	0	19	12,090	56,090	129,249	190,752	241,521	558.7
RISC PC	2,808	7,768	10,487	13,554	14,067	15,461	17,289	17.4
680x0	5,741	2,832	418	22	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	100,634.1	131,755.6	155,013.8	183,639.1	212,394.2	242,820.9	275,699.8	15.9

*Factory revenue includes standard peripherals and memory upgrades installed by the factory or PC assembler.
NA = Not applicable
Source: Dataquest (April 1996)

Table 3-6
Worldwide Desktop/Deskside Personal Computer Revenue by Microprocessor Type* (Millions of Dollars) (Includes Additional Motherboards)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	978	42	0	0	0	0	0	-100.0
486	57,365	33,077	5,250	221	0	0	0	-100.0
Pentium Class	13,691	62,792	97,997	83,565	44,406	17,769	4,223	-41.7
Pentium Pro and Future	0	19	12,090	51,697	114,537	165,051	203,562	536.6
RISC PC	2,808	7,294	8,757	11,178	11,506	12,621	14,136	14.1
680x0	4,273	1,794	286	22	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	79,114.3	105,017.9	124,379.9	146,682.8	170,447.9	195,441.1	221,921.9	16.1

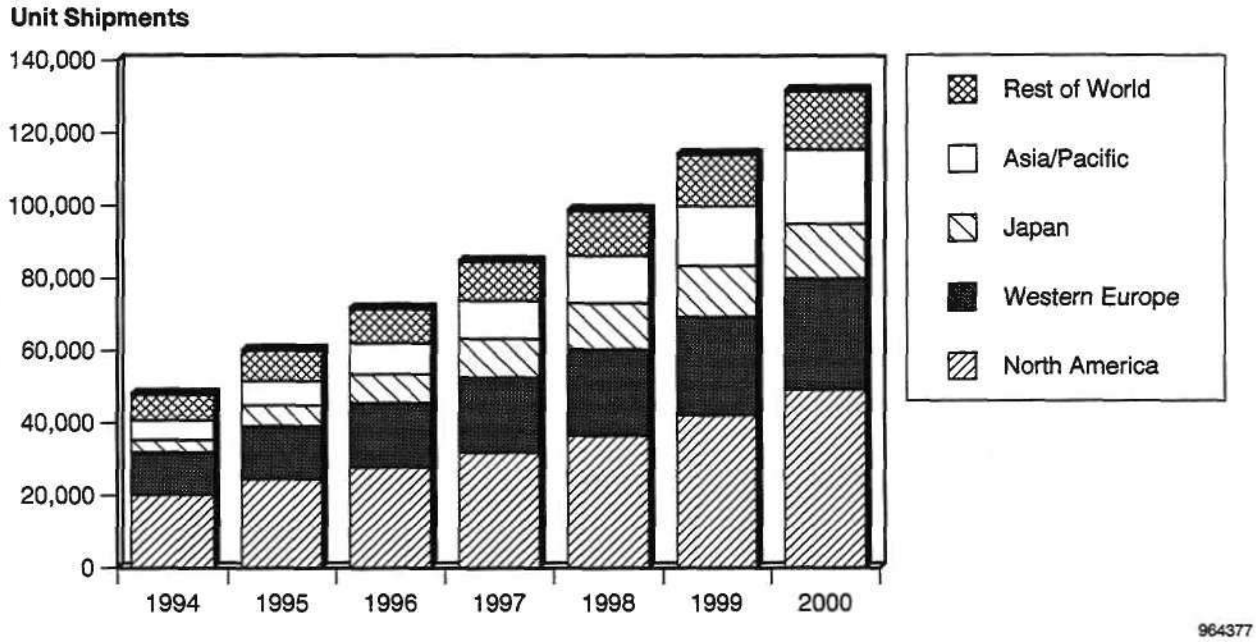
*Factory revenue includes standard peripherals and memory upgrades installed by the factory or PC assembler.
NA = Not applicable
Source: Dataquest (April 1996)

Table 3-7
Worldwide Mobile Personal Computer Revenue by Microprocessor Type* (Millions of Dollars) (Excludes Handheld Computers)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
386 and Lower	502	17	0	0	0	0	0	-100.0
486	19,360	19,381	5,116	130	0	0	0	-100.0
Pentium Class	189	5,828	23,656	30,057	24,673	18,839	12,666	16.8
Pentium Pro and Future	0	0	0	4,394	14,712	25,701	37,959	NA
RISC PC	0	474	1,730	2,376	2,561	2,840	3,153	46.1
680x0	1,469	1,039	132	0	0	0	0	-100.0
Others	0	0	0	0	0	0	0	NA
Total	21,519.8	26,737.7	30,633.9	36,956.3	41,946.3	47,379.9	53,777.9	15.0

NA= Not applicable
*Factory revenue includes standard peripherals and memory upgrades installed by the factory or PC assembler.
Source: Dataquest (April 1996)

Figure 3-4
Regional Personal Computer Markets (Unit Shipments)



Note: This document does not include regional PC production data because that data was not finalized in time for publication. Regional PC production data will be published in a document when finalized later this summer.
Source: Dataquest (June 1996)

Table 3-8
Personal Computers—Worldwide Revenue Market Share (Percent)*

	1994	1995
Compaq Computer Corporation	10.4	10.2
IBM	8.9	8.0
Apple Computer	8.4	7.7
NEC	5.4	5.5
Packard Bell	3.9	4.5
Hewlett-Packard	2.7	3.6
Dell Computer Corporation	3.2	3.6
Toshiba	3.6	3.4
Acer	2.3	2.7
Gateway 2000	2.7	2.7
Others	48.6	48.0
Total	100.0	100.0

*Does not include motherboard upgrade revenue
Source: Dataquest (April 1996)

Table 3-9
Personal Computers—Worldwide Unit Market Share (Percent)*

	1994	1995
Compaq Computer Corporation	10.0	10.0
IBM	8.2	7.9
Apple Computer	8.3	7.8
Packard Bell	5.2	5.3
NEC	4.1	4.8
Hewlett-Packard	2.7	3.7
Acer	2.6	3.1
Dell Computer Corporation	2.7	3.0
Toshiba	2.5	2.5
AST Research	2.7	2.3
Others	51.0	49.5
Total	100.0	100.0

*Does not include motherboard upgrade revenue
Source: Dataquest (April 1996)

Systems Technology and Architecture Trends

The technology road maps of PCs and workstations are principally driven by the twin factors of economy and improved end-user features. PC makers typically try to give the buyer more features with each new product generation while maintaining price points. Workstation makers are known more for emphasizing performance and other features, although the low end of the workstation market is forced to compete directly with the high end of the PC range. Some specific trends are listed in the following sections.

Personal Computers

Trends in PCs are as follows:

- Desktop power demand will come from servicing graphical user interface (GUI) and WYSIWYG-oriented applications, including processing (compressing and decompressing); store, forward, and read multimedia (OLE-enabled); and real-time multimedia such as desktop videoconferencing. Networking support increasingly will require faster servicing as transfer rates climb (for example, toward 100 Mbps over Ethernet) and the size and frequency of transferred files and e-mail increase as well.
- Pentium-class microprocessors will continue to dominate as multimedia features and higher clock frequencies give these processors a midlife boost in performance. Next-generation microprocessors (MPUs) such as Pentium Pro will grow in importance and are expected to match unit shipments of Pentium-class MPUs at the end of 1997 or early 1998.
- The PowerPC alliance will continue to be a major element for Apple and IBM but may suffer from Motorola's decision to pursue process development independently.

- Peripheral Component Interconnect (PCI) and Industry Standard Architecture (ISA) combinations are the overwhelming standard for backplane buses. PCI will be enhanced with Accelerated Graphics Port (AGP) in 1997. ISA will continue to exist for some time to maintain compatibility with the vast bulk of legacy add-in cards.
- Plug-and-play PCs, with support from major players such as Microsoft, Intel, Compaq, Advanced Micro Devices, and others, will be a significant feature in the drive to make PCs more user-friendly. Universal serial bus (USB) and IEEE 1394 will be the standards for external plug-and-play devices, with USB shipments starting in 1996.
- The green PC, stimulated by the Energy Star program and similar requirements coming out of Europe, is being recycled with new emphasis on desktop PC power management. Advanced configuration power interface (ACPI) and Microsoft's OnNow are critical elements of renewed efforts to make desktop PCs more efficient.
- Enhanced Integrated Development Environment (EIDE) will remain the dominant interface to mass storage, with parallel SCSI the choice for connecting external mass-storage devices. Parallel SCSI will face increasing pressure from serial SCSI standards (predominately IEEE 1394, with fiber channel arbitrated loop making inroads in the workstation market).
- Serial and parallel I/O have remained fairly constant, but now new technologies such as 1394/Firewire, Access.bus, and USB are vying to displace those trusted standbys.
- USB ports will appear on PCs this year, with rapid growth in 1997 and 1998. This local bus for the PC will provide a common standard for communicating among PCs, modems, scanners, joysticks, keyboards, mice, monitors, and printers.
- Mobile computers will be enhanced with 32-bit CardBus slots rather than the standard PCMCIA slots, but the average number of slots per mobile PC may decline as modems and network controllers become standard equipment on more notebook designs.
- Other key trends in mobile computing will include commercialized low-power-consuming components, standardization of operating voltage for circuits and components at 3V/3.3V, continued increases in sophistication of battery management, improved battery technology, and effective handwriting/voice recognition capabilities.

Table 3-10 highlights projected trends in PC technology.

Figure 3-5 shows areas that offer opportunities for enhancement.

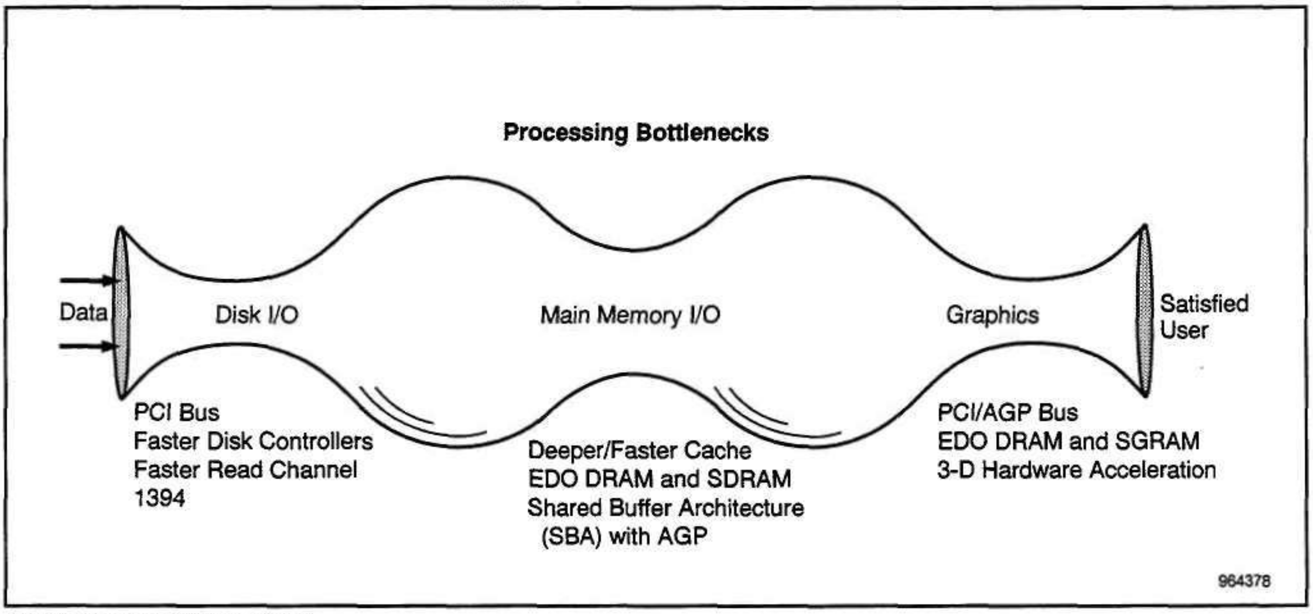
Tables 3-11 through 3-15 provide forecasts for key PC and workstation technologies.

Table 3-10
The Evolving PC

	1994	1996	1998	Trend
Main Memory (Factory-Installed)	8MB to 10MB FPM DRAM	14MB to 16MB EDO DRAM	20MB to 24MB SDRAM	Toward synchronous types of DRAM
CPU	486 DX2/DX4	Pentium 100 MHz to 133 MHz	Pentium 200 MHz/ Pentium Pro; with MMX	Rapid adoption of MMX; shift from Pentium to Pentium Pro
Cache (Factory-Configured)	128KB	0KB/256KB	256KB/512KB	Cacheless Pentium Pro systems are unlikely; minimum increases to 256KB
Peripheral Buses	VL/ISA	PCI/ISA	PCI/AGP	Rise of AGP for graphics; systems will have some support for legacy ISA peripherals
Graphics and Video	32-bit, 2-D acceleration, 1MB buffer	64-bit, 2-D and video acceleration, 2MB buffer	64-bit, 2-D, 3-D and video acceleration, 2.5MB dedicated, sharing of main memory via AGP	Rapid growth of 3-D as graphics vendors strive to continue to add value
Storage	EIDE (5MB/sec)/SCSI	EIDE (13MB/sec)/SCSI-2	EIDE (20MB/sec)/SCSI-2/ 3/1394	EIDE likely to remain in-box interface; rise of 1394
Local I/O	RS-232/422	RS-232/422, beginning of shift to USB	USB, RS-232/422	USB will become primary interface; RS-232/422 for legacy items

Source: Dataquest (April 1996)

Figure 3-5
PC Performance Enhancement Opportunities



Source: Dataquest (June 1996)

Table 3-11
Worldwide PC Bus Requirements (Percentage of Total or Category)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
VL/ISA	66.9	49.2	15.6	0.6	0	0	0	-100.0
PCI/ISA	16.6	44.0	81.4	63.1	24.7	5.0	0	-100.0
PCI/AGP/ISA	0	0	0	35.0	75.0	95.0	100.0	NM
Other	16.5	6.8	3.0	1.3	0.3	0	0	-100.0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 3-12
Worldwide Penetration of PCMCIA/PC Card/CardBus Slot Forecast (Thousands of Slots)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
With One or More Type II Slots	10,389	13,175	14,411	11,529	6,917	2,767	0	-100.0%
With One or More Type III Slots	4,040	4,831	5,139	5,115	4,804	4,408	5,000	0.7%
With One or More CardBus slots	0	0	2,522	3,153	3,783	4,540	5,448	NM
Total	14,429	18,005	22,072	19,796	15,504	11,714	10,448	-10.3%

NM = Not meaningful
Source: Dataquest (June 1996)

Table 3-13
Worldwide PC (Host) Storage Interface Requirement (Percentage of Category)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
All PCs								
EIDE/ATA	85	86	88	85	72	44	15	-29.5
SCSI (I/II/III)	15	14	12	10	8	6	5	-18.6
1394/SSA/FC-AL	0	0	0	5	20	50	80	NM
Pentium Pro and Future								
EIDE/ATA	0	20	50	70	60	50	40	14.9
SCSI (I/II/III)	0	80	49	25	20	20	20	-24.2
1394/SSA/FC-AL	0	0	1	5	20	30	40	NM
RISC PC								
EIDE/ATA	2	10	10	10	10	10	10	0
SCSI (I/II/III)	98	90	90	75	60	30	15	-30.1
1394/SSA/FC-AL	0	0	0	15	30	60	75	NM

NM = Not meaningful
Source: Dataquest (June 1996)

Table 3-14
Worldwide PC Graphics Standard Penetration (Motherboard-Based or Add-In) (Percent)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Std VGA	28.9	9.4	0.8	0	0	0	0	-100.0
2-D Acceleration	68.3	66.2	28.9	4.1	0	0	0	-100.0
2-D Acceleration with Video Acceleration	2.8	24.3	66.9	73.0	44.9	14.9	1.6	-41.7
2-D, 3-D, and Video Acceleration	0	0.1	3.4	22.9	55.1	85.1	98.4	325.6

Source: Dataquest (June 1996)

Table 3-15
Worldwide Embedded Communications and Multimedia in PCs (Percentage of Total)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Overall PC								
Analog Modem	1.5	1.6	1.9	2.3	2.8	3.2	3.6	18.3
LAN	0.9	1.7	8.6	21.3	21.4	21.6	21.8	66.1
USB	0	0	8.7	46.0	91.9	100.0	100.0	NM
Sound I/O	3.5	22.4	28.9	37.2	39.7	40.5	41.3	13.0
Graphics	44.9	57.4	57.9	66.4	66.5	66.5	66.5	3.0
MPEG Decoder	0.0	0.6	1.2	2.0	2.0	2.0	2.0	28.4
General-Purpose DSP	0.1	0.5	1.0	1.7	2.3	3.0	3.7	49.7
Desktop/Deskside PC								
Analog Modem	1.4	1.5	1.7	2.0	2.4	2.7	3.0	14.9
LAN	1.0	2.0	10.0	15.0	20.0	25.0	25.0	65.7
USB	0	0	10.0	50.0	100.0	100.0	100.0	NM
Sound I/O	1.2	21.4	25.0	30.0	35.0	40.0	50.0	18.5
Graphics	34.0	50.0	50.0	60.0	60.0	60.0	60.0	3.7
MPEG Decoder	0	0.5	1.0	2.0	2.0	2.0	2.0	32.0
General-Purpose DSP	0.1	0.4	0.8	1.6	2.3	3.2	4.0	58.5
Mobile PC (Excluding Handhelds)								
Analog Modem	2.0	2.0	4.0	6.0	10.0	12.0	14.0	28.5
LAN	0.1	0.1	1.0	2.0	3.0	4.0	5.0	118.7
USB	0	0	2.0	25.0	50.0	100.0	100.0	NM
Sound I/O	15.0	28.3	50.0	75.0	90.0	95.0	100.0	28.7
Graphics	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0
MPEG Decoder	0	1.0	2.0	2.0	2.0	2.0	2.0	14.9
General-Purpose DSP	0	1.0	2.0	2.0	2.0	2.0	2.0	14.9

Source: Dataquest (June 1996)

Chapter 4

Semiconductor Market Trends for PCs and Workstations

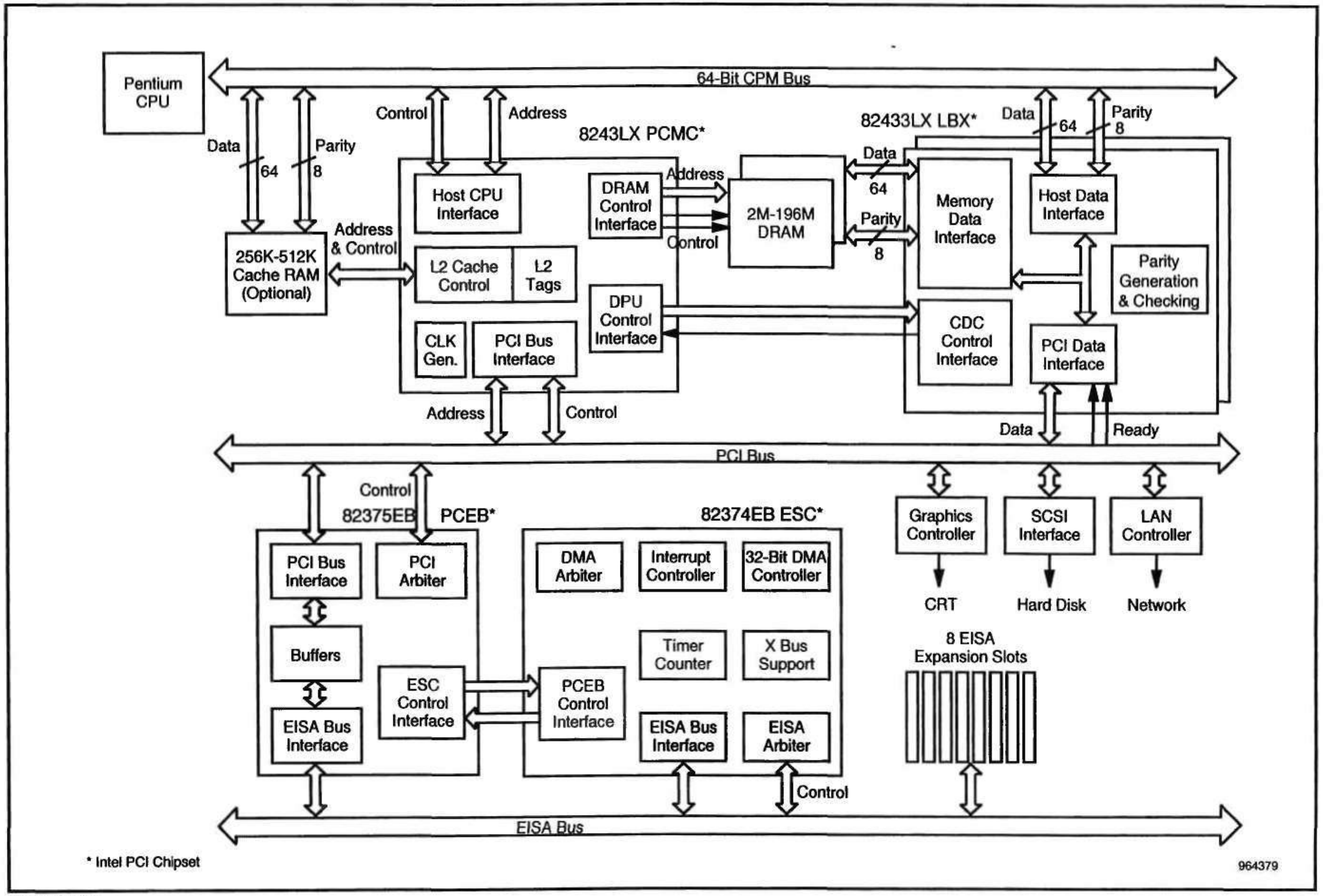
Semiconductor Market Opportunities and Technology Trends

Semiconductor market opportunities and technology trends are as follows:

- New generations of Pentium, Pentium Pro, PowerPC, Alpha, PA-RISC, SPARC, and MIPS processors will drive future PCs, workstations, and servers. Future trends include internal frequencies climbing past the current 200-MHz offerings for PCs and 400-MHz offerings for workstations. Multiprocessing features will also be available in many workstations and high-end PCs using Pentium Pro MPUs.
- Proprietary processors such as Advanced RISC Machines' ARM will continue to be used in palmtop devices and other communications-based applications.
- PCs with an average of 14MB to 16MB DRAM main memory in 1995 will move to 32MB DRAM in 1998.
- Increased opportunities will emerge for synchronous DRAM (SDRAM) as MPU speeds outstrip conventional memory architectures.
- Bursting, MPU-specific SRAM will be used for cache design. Static RAM (SRAM) modules were becoming more popular, but are costly compared to soldered-down designs.
- New chipsets to support MPUs and the new buses (USB and the AGP enhancement to PCI) will continue to emerge.
- Mixed-signal accelerated window graphics on a single chip (with RAMDAC) will be mainstream. High-resolution (1024 x 768, 16-color) 3-D graphics (OpenGL for workstations; Direct3D for consumer PCs) and digital video features will become more prevalent.
- Mixed-signal I/O chips will support high-speed storage and peripherals communications (EIDE, SCSI, IEEE 1394/Firewire). Chips integrating LAN and SCSI control will complement existing super I/O functions.
- Sound and video coder/decoders (codecs) and I/O functions will be used in multimedia systems. Microsoft, IBM, and Apple are continuing to provide multimedia and telephony interfaces to their operating systems.

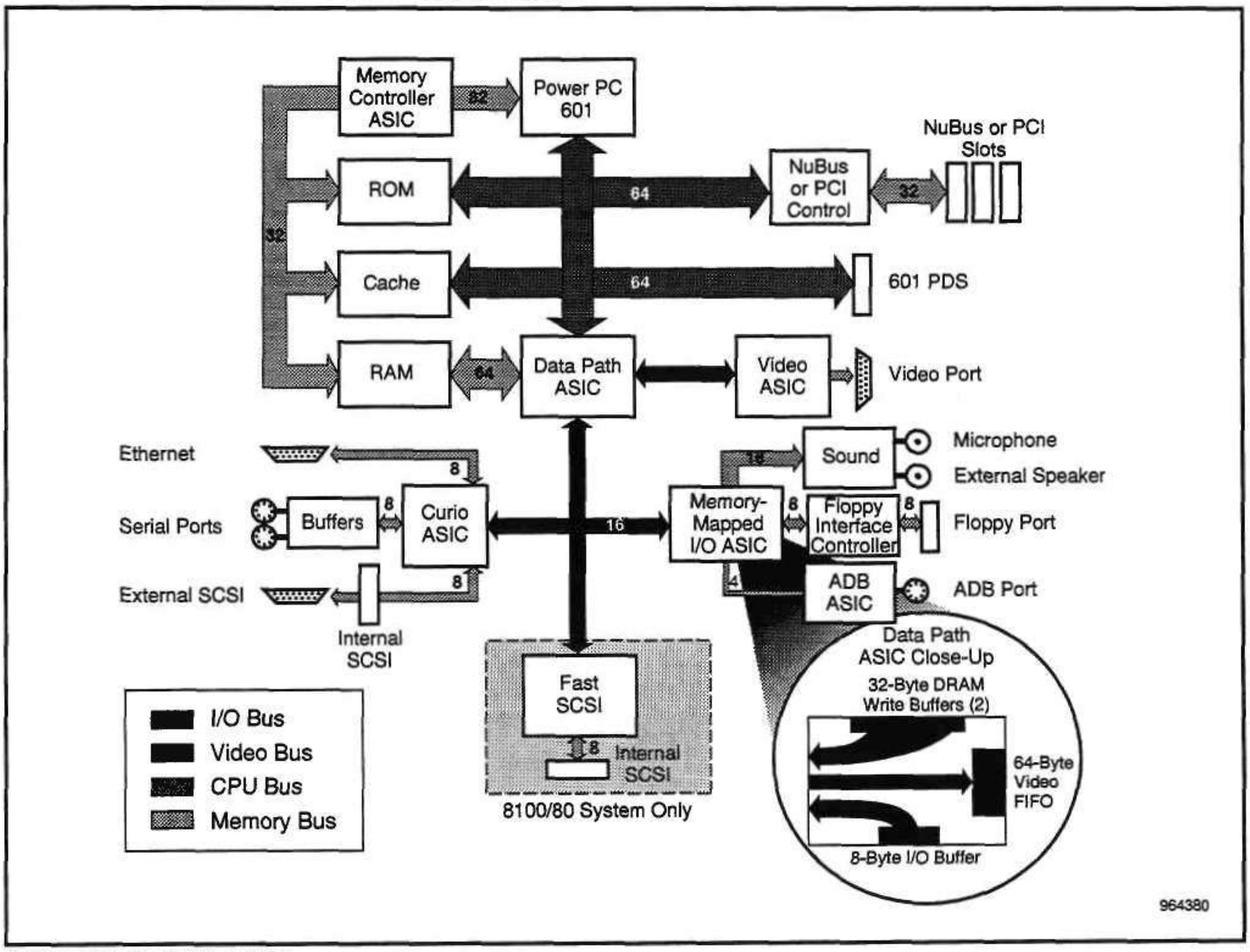
Figures 4-1 to 4-4 provide block diagrams for generic Pentium desktop, Power Macintosh, generic notebook, and Apple Newton systems.

Figure 4-1
Generic Pentium-Based Desktop PC Using PCI Bus



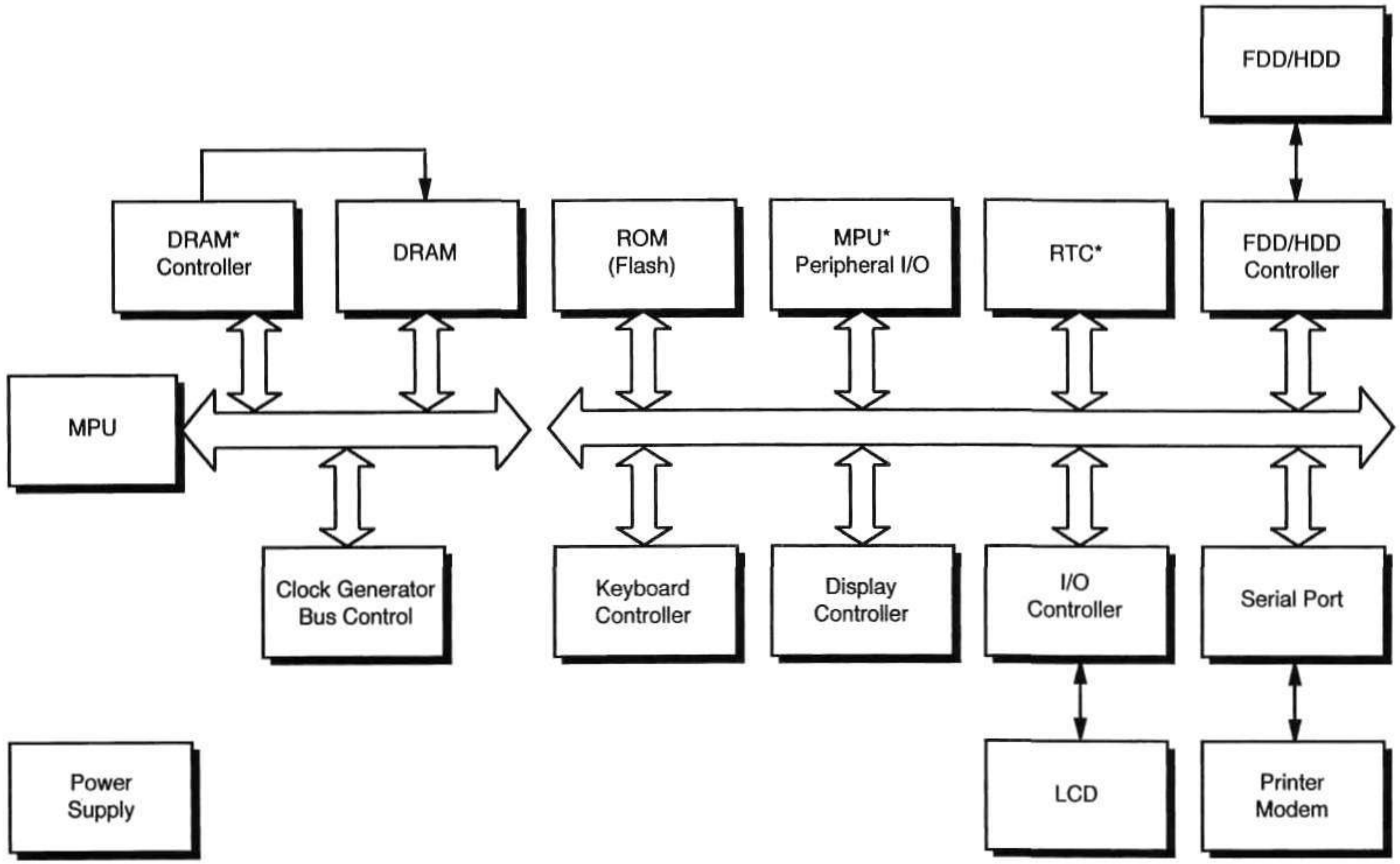
Source: Intel

Figure 4-2
Power Macintosh Hardware Architecture



Source: Dataquest (June 1996)

Figure 4-3
Generic Notebook Block Diagram

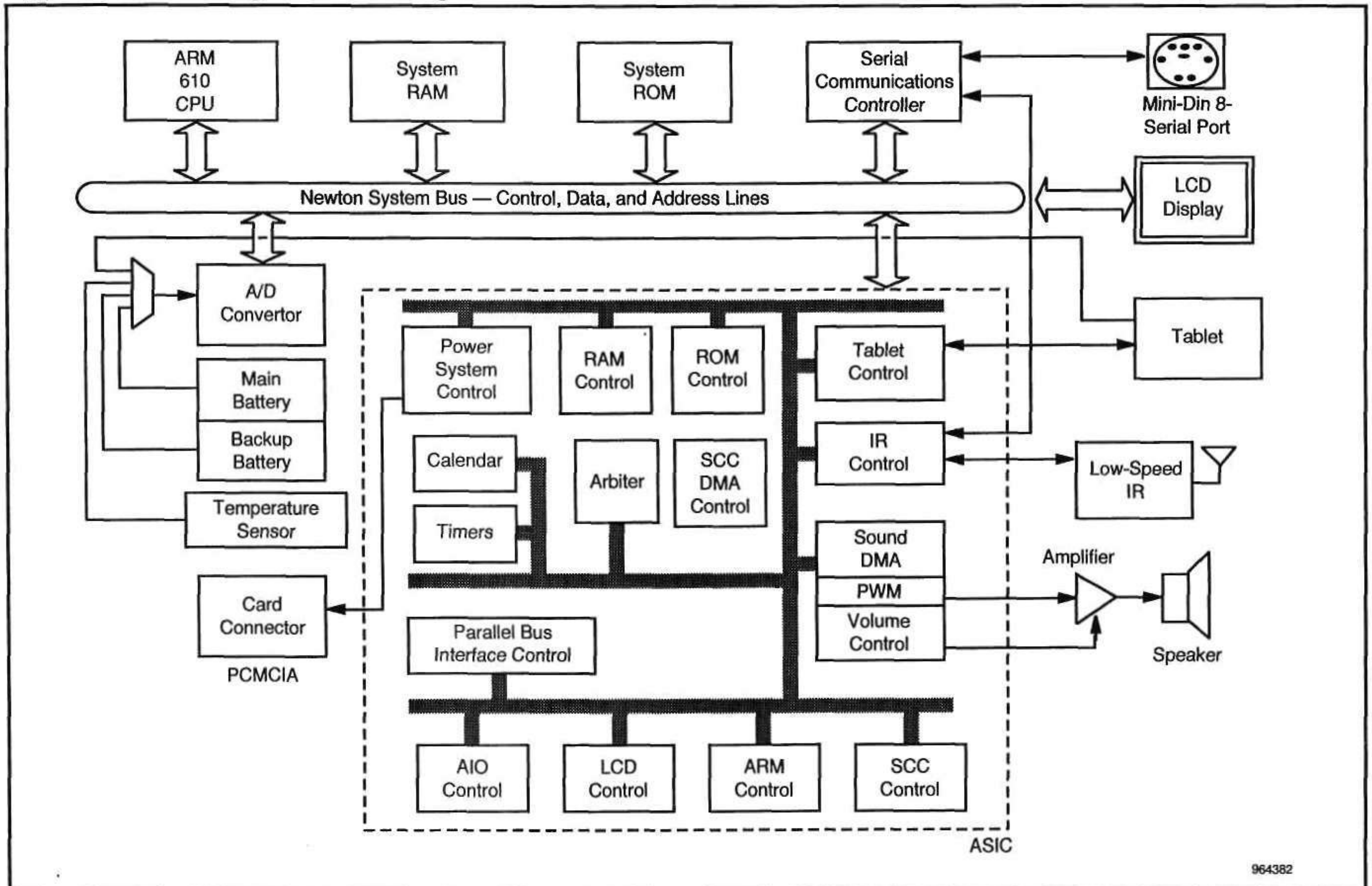


*Can be part of core logic chipset

964381

Source: Dataquest (April 1996)

Figure 4-4
Apple Newton MessagePad Block Diagram

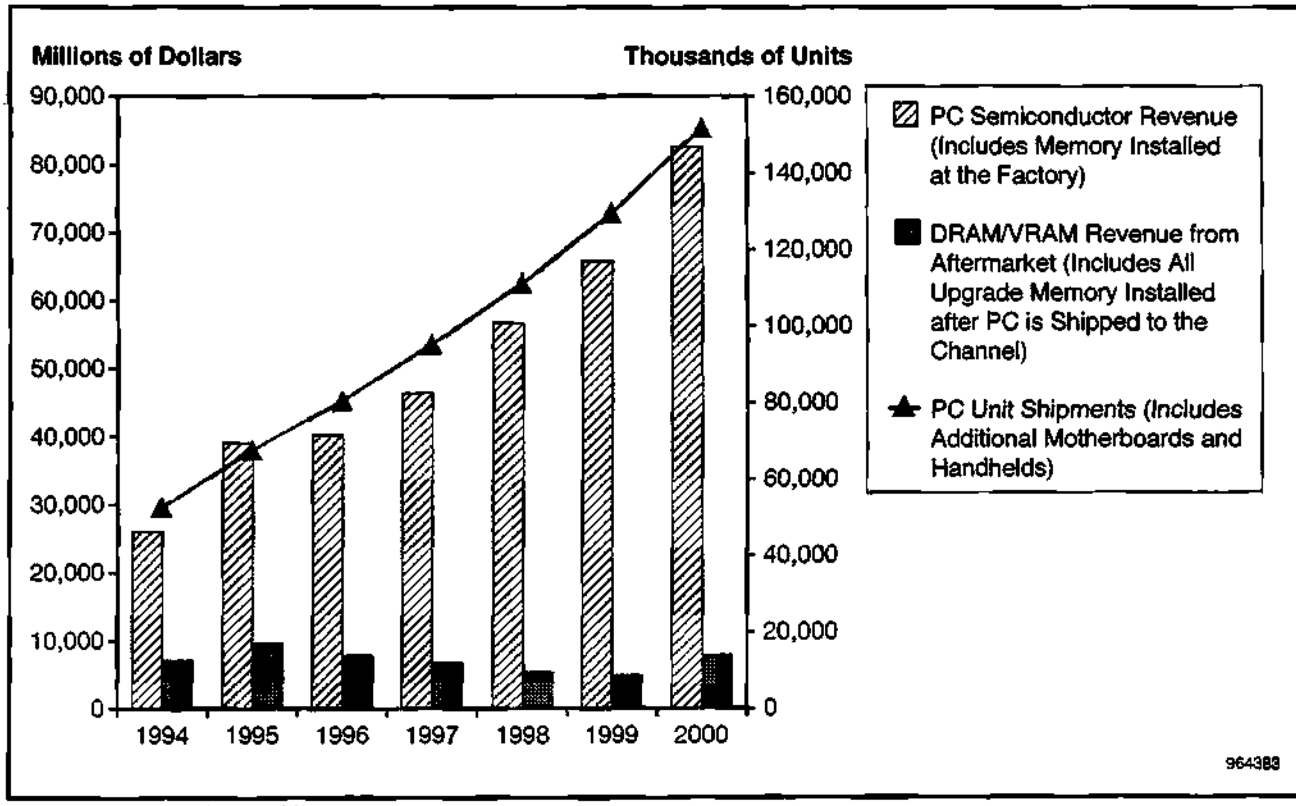


Source: Apple, PC Week

Chapter 5
Market Size and Forecast for PC and Workstation Semiconductors

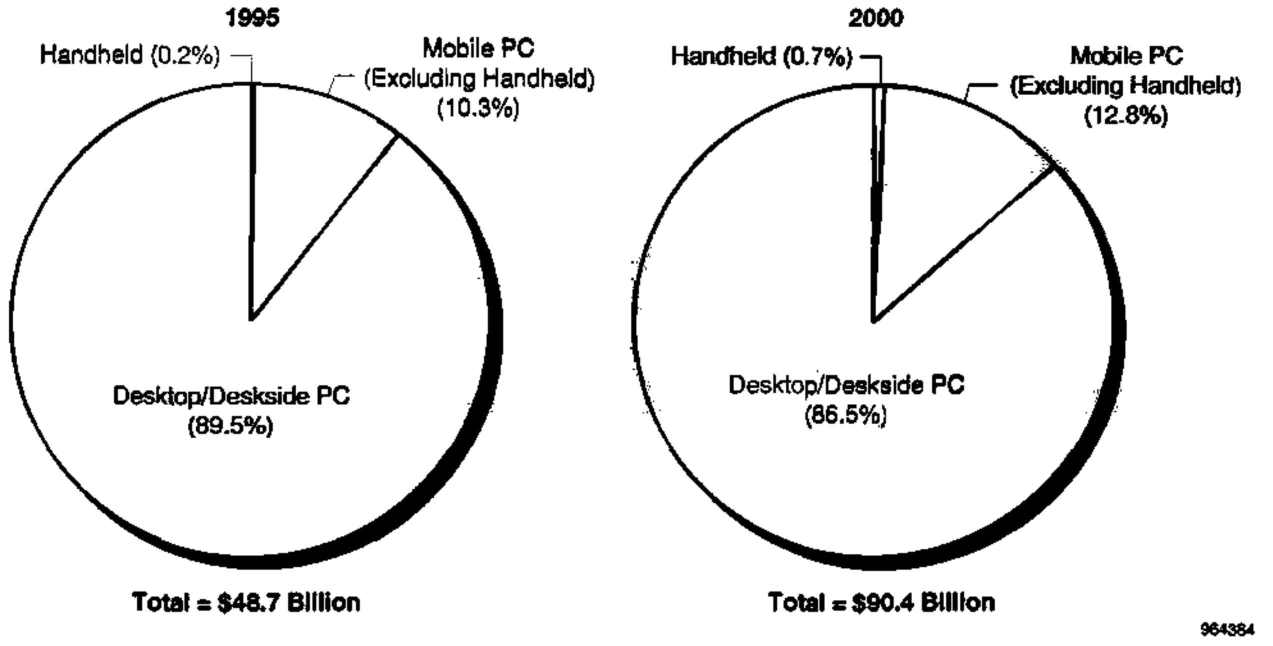
Figures 5-1 and 5-2 and Tables 5-1 and 5-2 provide forecasts and illustrations of semiconductor opportunities in the PC and workstation markets, including a focus on opportunities by region, system type, and semiconductor device type.

Figure 5-1
Worldwide PC Semiconductor Market (Revenue in Millions of Dollars, Shipments in Thousands of Units)



Source: Dataquest (June 1996)

Figure 5-2
Worldwide PC Semiconductor Consumption by Product Type (Percentage)



Source: Dataquest (June 1996)

Table 5-1
Worldwide PC Production and Semiconductor Market (Less Peripherals; Includes Standard Handhelds)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Complete PC Systems								
Units (K)	48,284	60,652	72,262	85,544	100,030	116,530	136,752	17.7
Factory ASP ($K)	4.30	4.55	4.33	4.36	4.23	4.10	3.88	-3.1
Factory Revenue ($M)	95,775	125,027	148,544	177,288	205,106	234,805	266,046	16.3
Semiconductor Content per System ($)	497	586	503	489	510	510	549	-1.3
Semiconductor TAM ($M)	24,016	35,551	36,330	41,812	51,030	59,382	75,138	16.1
Desktop/Deskside PC Systems								
Units (K)	39,252	50,259	59,043	69,651	80,847	93,610	108,012	16.5
Factory ASP ($K)	1.88	1.95	1.99	2.01	2.01	1.99	1.95	0
Factory Revenue ($M)	73,937	98,000	117,575	139,907	162,558	186,484	210,500	16.5

(Continued)

Table 5-1 (Continued)
Worldwide PC Production and Semiconductor Market (Less Peripherals; Includes Standard Handhelds)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Semiconductor Content per System ($)	519	605	519	502	531	536	582	-0.8
Semiconductor TAM ($M)	20,368	30,417	30,667	34,949	42,931	50,213	62,887	15.6
Mobile PC Systems								
Units (K)	9,032	10,394	13,219	15,893	19,183	22,920	28,741	22.6
Factory ASP ($K)	2.42	2.60	2.34	2.35	2.22	2.11	1.93	-5.8
Factory Revenue ($M)	21,838	27,026	30,970	37,381	42,548	48,321	55,546	15.5
Semiconductor Content per System ($)	404	494	428	432	422	400	426	-2.9
Semiconductor TAM ($M)	3,647	5,134	5,663	6,863	8,099	9,169	12,251	19.0
Additional Motherboards								
Units (K)	4,404	7,036	8,266	9,752	11,318	13,105	15,121	16.5
Factory ASP ($K)	1.18	1.00	0.82	0.69	0.70	0.68	0.76	-5.4
Factory Revenue ($M)	5,178	7,018	6,805	6,776	7,889	8,957	11,422	10.2
Semiconductor Content per System ($)	519	605	519	502	531	536	582	-0.8
Semiconductor TAM ($M)	2,285	4,258	4,294	4,893	6,010	7,030	8,804	15.6
Total Production								
Units (K)	52,689	67,688	80,528	95,296	111,348	129,635	151,873	17.5
Factory ASP ($K)	1.92	1.95	1.93	1.93	1.91	1.88	1.83	-1.3
Factory Revenue ($M)	100,952	132,044	155,350	184,064	212,996	243,762	277,468	16.0
Semiconductor Content per System ($)	499	588	504	490	512	512	553	-1.2
Semiconductor TAM ($M)	26,301	39,809	40,624	46,705	57,040	66,412	83,942	16.1

Source: Dataquest (June 1996)

Table 5-2
Worldwide PC Semiconductor Market by System (Millions of Dollars)

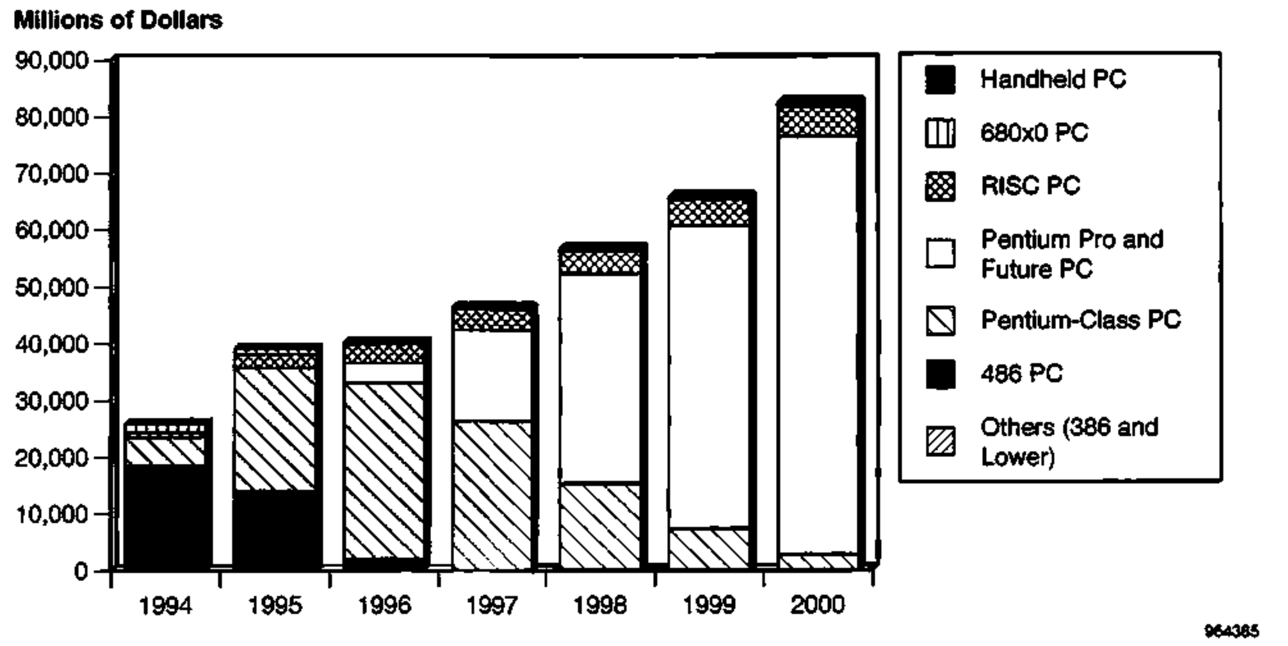
	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Other (386 and Lower)	388	17	0	0	0	0	0	-100.0
486 PC	18,249	14,152	2,201	73	0	0	0	-100.0
Pentium-Class PC	4,955	21,623	31,003	26,379	15,515	7,374	2,791	-33.6
Pentium Pro and Future PC	0	7	3,475	16,072	36,954	53,490	73,855	532.5
RISC PC	901	2,397	3,345	3,693	4,027	4,676	5,256	17.0
680x0 PC	1,396	803	83	8	0	0	0	-100.0
Handheld PC	74	94	128	149	219	344	663	47.8
Total	25,963	39,094	40,235	46,375	56,715	65,885	82,565	16.1
Year-to-Year Growth (%)		50.6	2.9	15.3	22.3	16.2	25.3	

Source: Dataquest (June 1996)

Semiconductor Opportunities by System

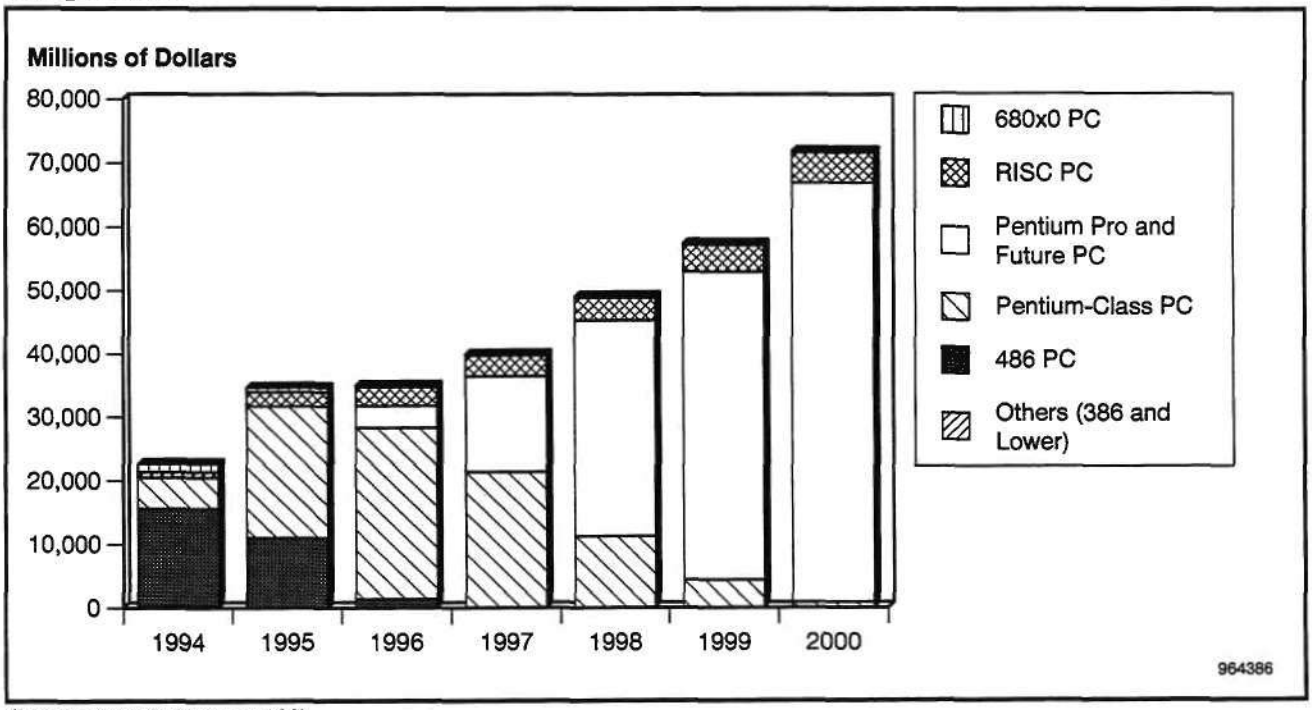
Figures 5-3 through 5-12 and Tables 5-2 through 5-4 detail semiconductor opportunities by system.

Figure 5-3
Worldwide PC Semiconductor Market by Microprocessor Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



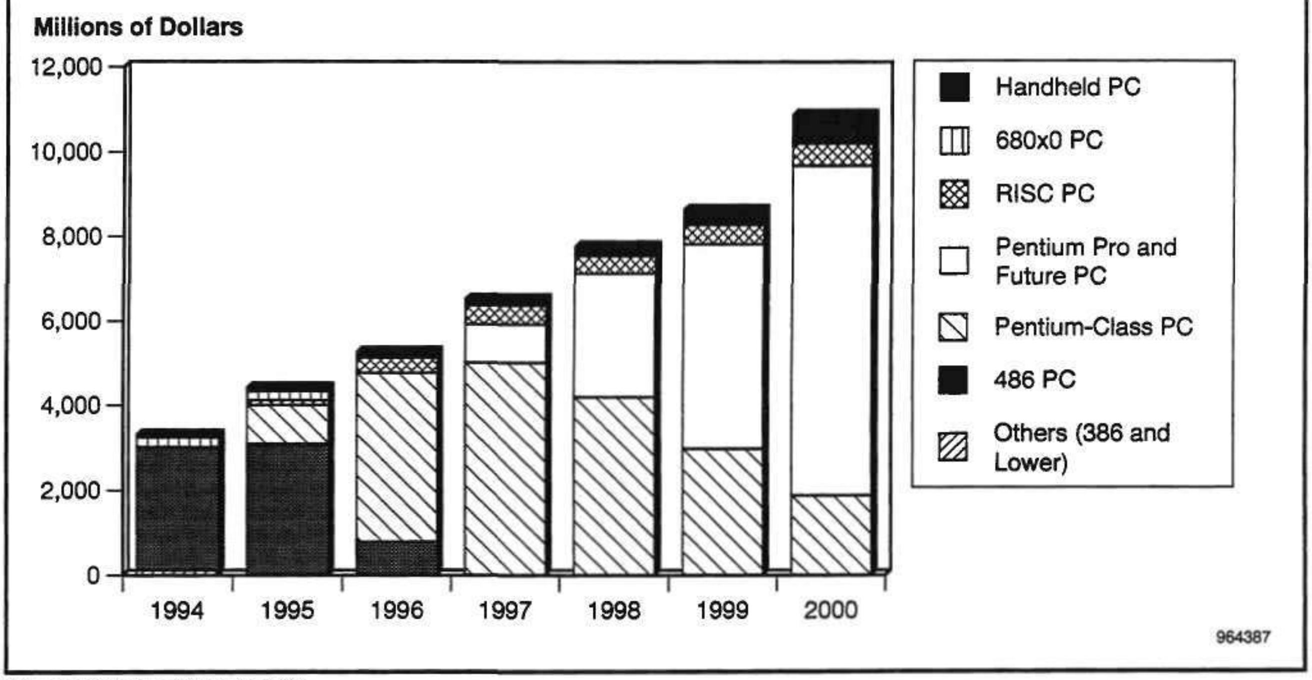
Source: Dataquest (June 1996)

Figure 5-4
Worldwide Desktop/Deskside PC Semiconductor Market by Microprocessor Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



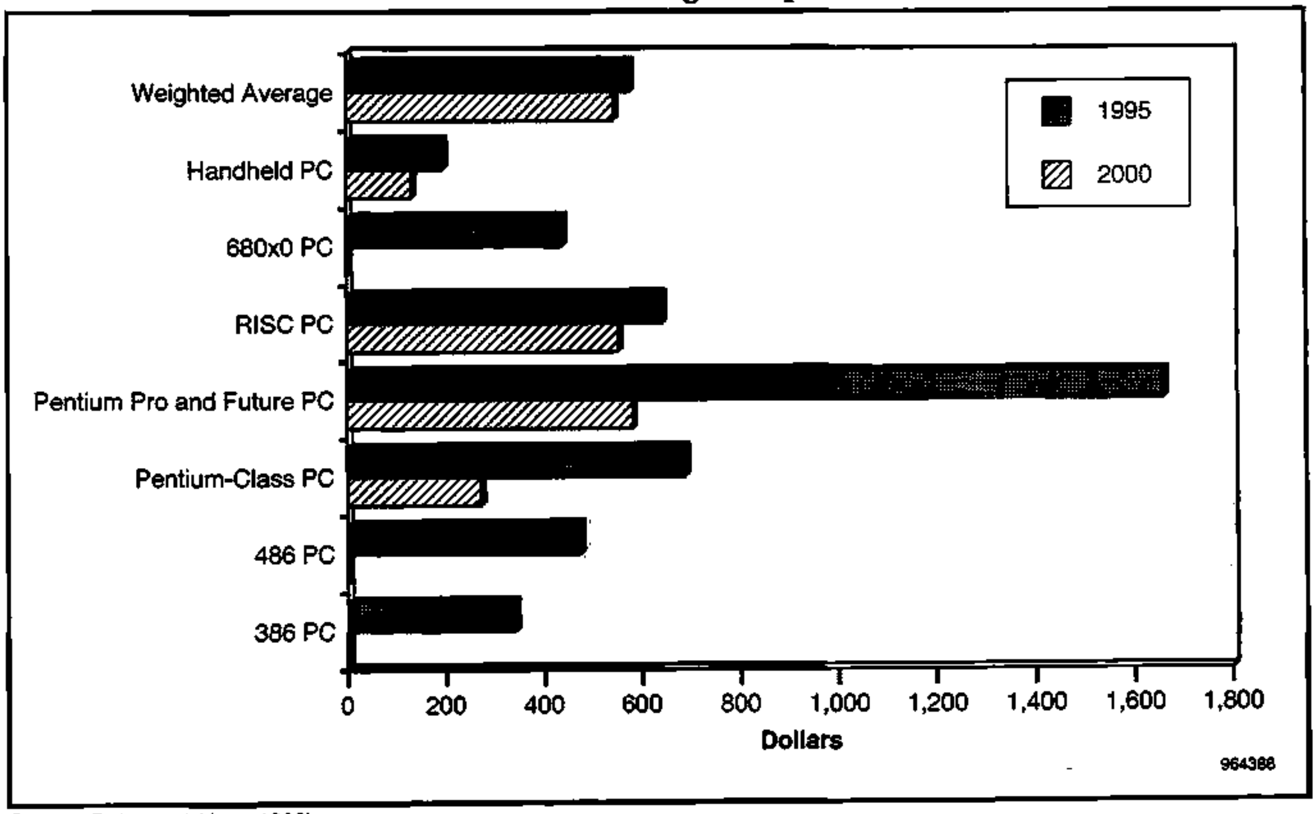
Source: Dataquest (June 1996)

Figure 5-5
Worldwide Mobile PC Semiconductor Market by Microprocessor Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



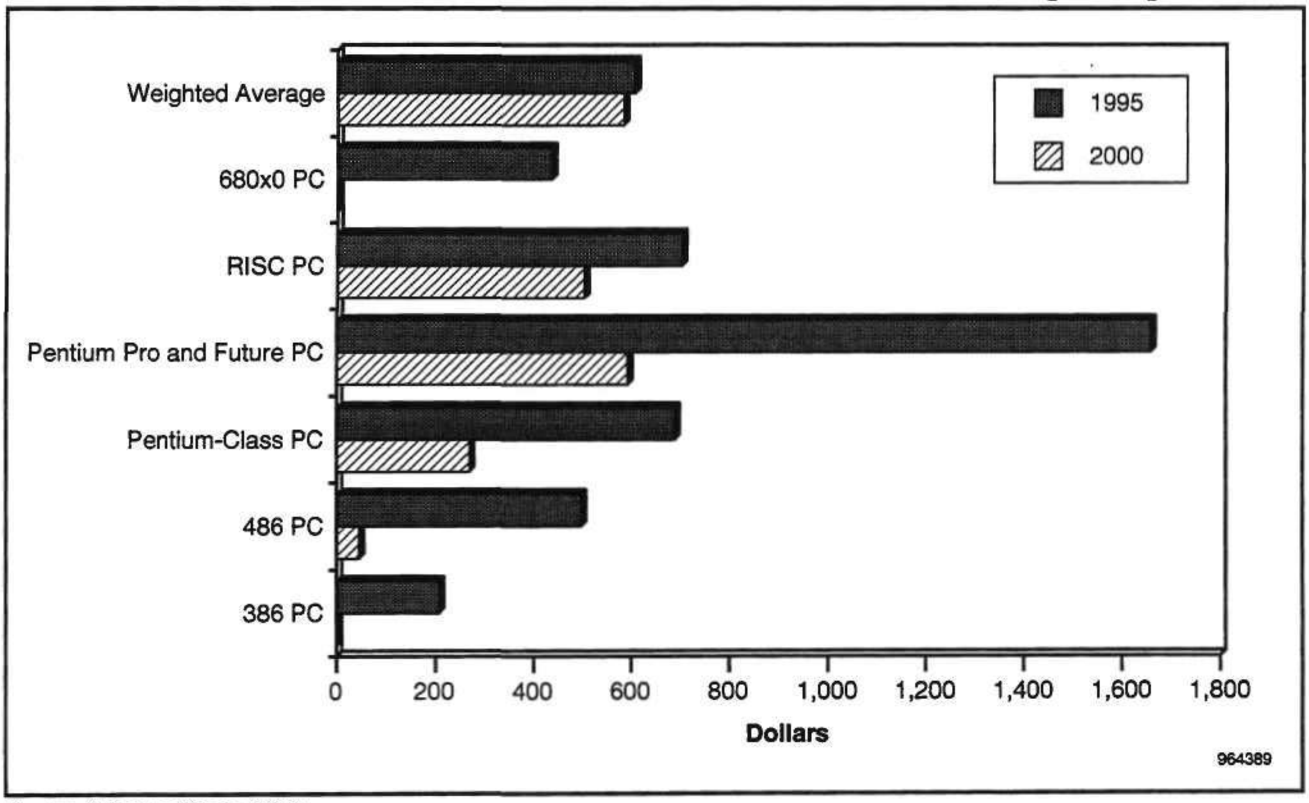
Source: Dataquest (June 1996)

Figure 5-6
Average Overall PC System Semiconductor Content (Includes Semiconductor Value on Motherboard and Card-Based Peripherals Such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



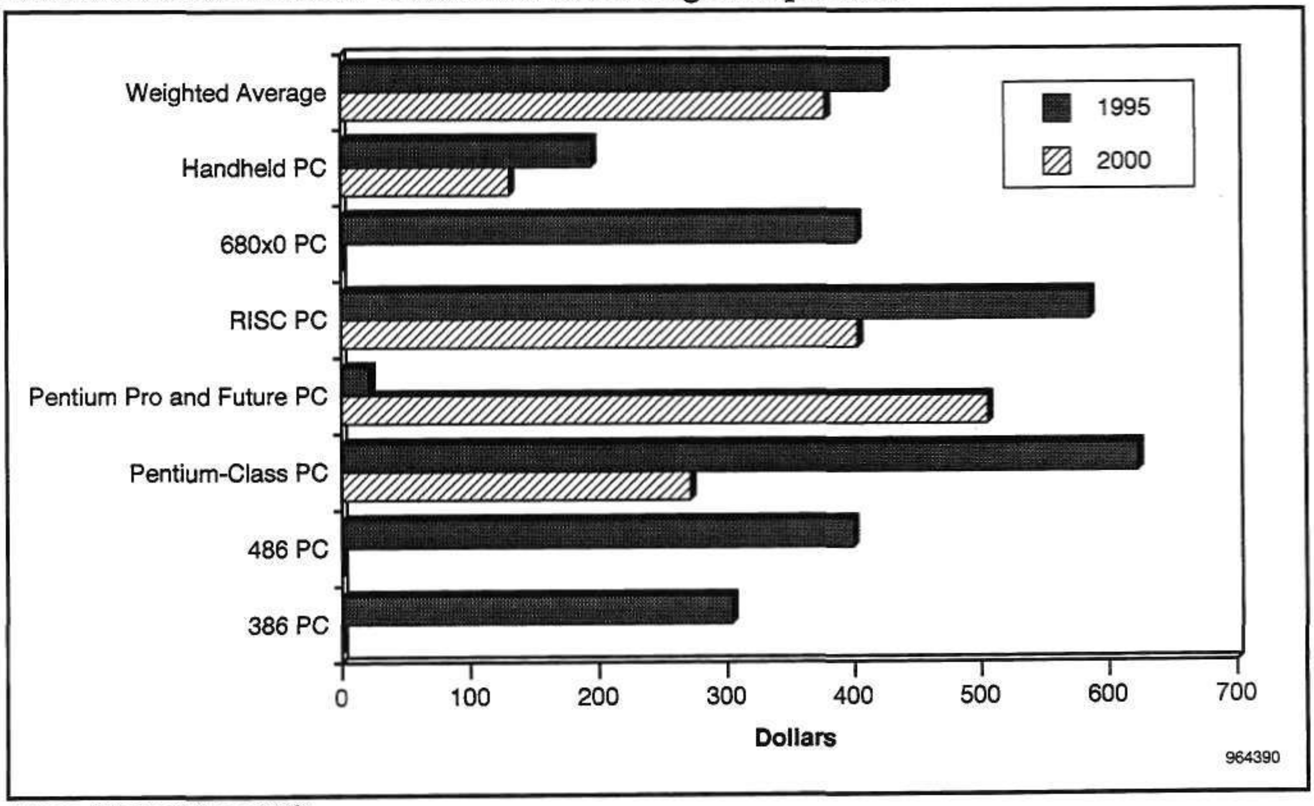
Source: Dataquest (June 1996)

Figure 5-7
Average Desktop/Deskside PC System Semiconductor Content (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



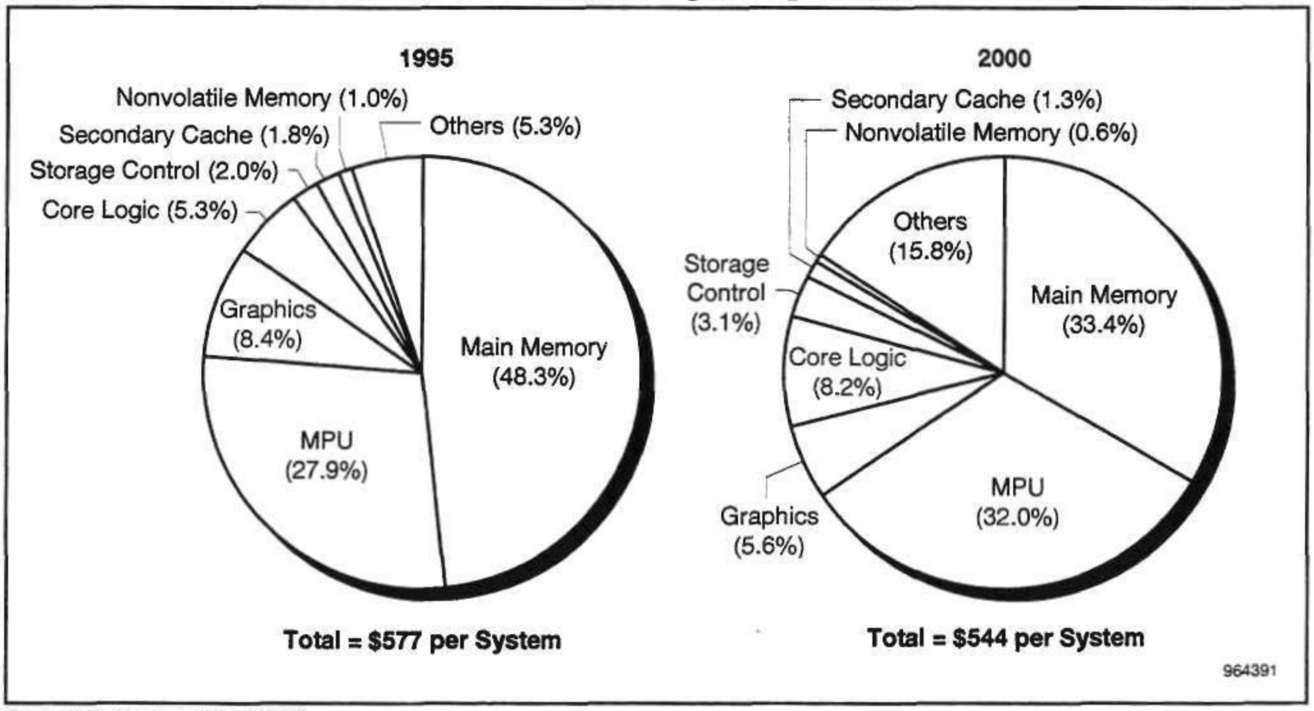
Source: Dataquest (June 1996)

Figure 5-8
Average Mobile PC System Semiconductor Content (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



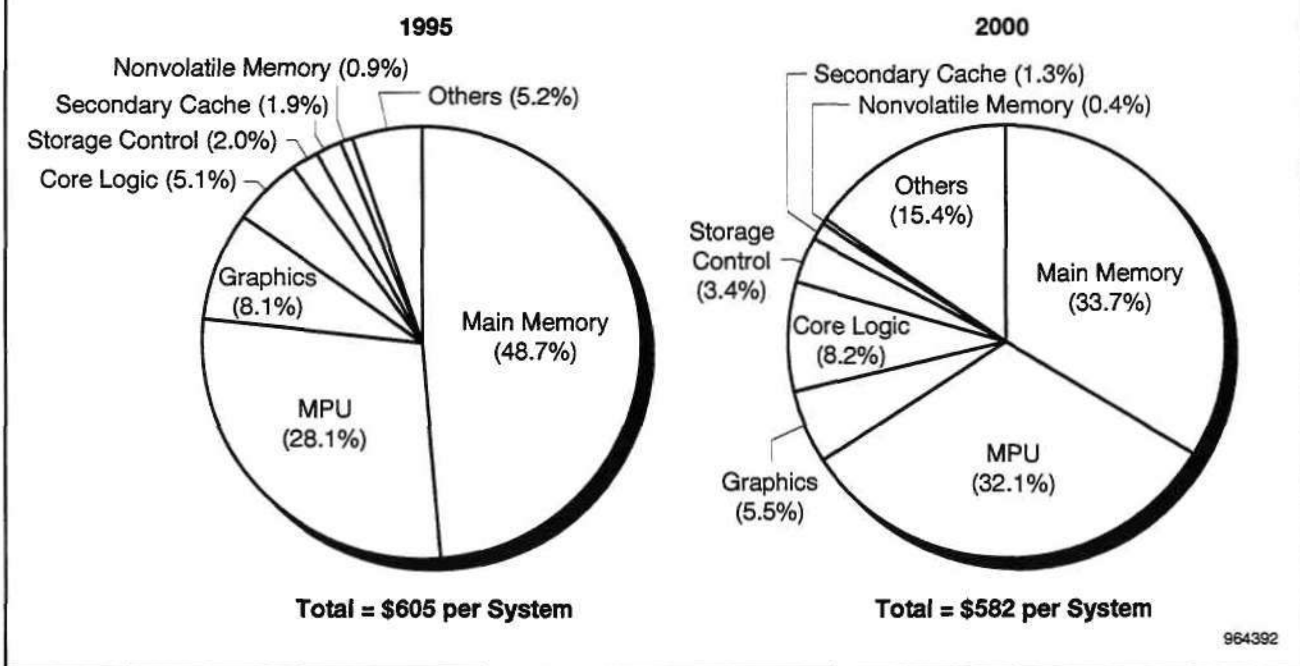
Source: Dataquest (June 1996)

Figure 5-9
Overall PC Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



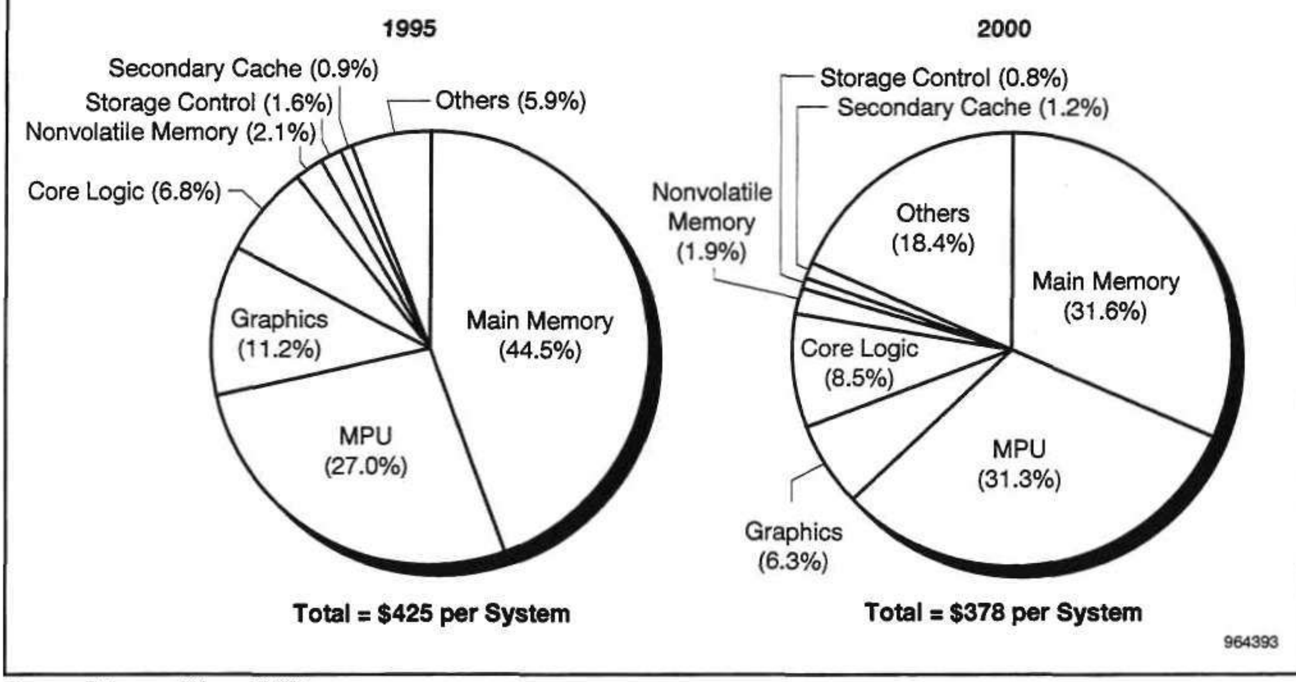
Source: Dataquest (June 1996)

Figure 5-10
Overall Desktop/Deskside PC Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



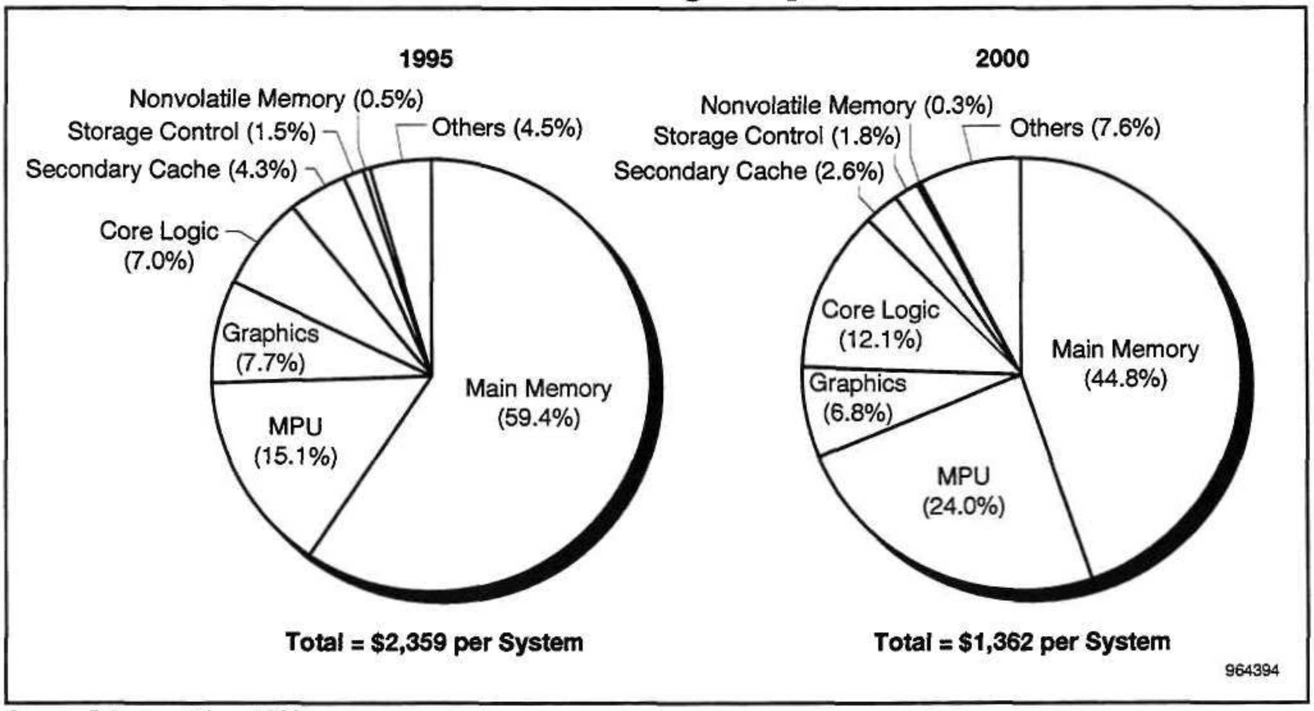
Source: Dataquest (June 1996)

Figure 5-11
Overall Mobile PC Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



Source: Dataquest (June 1996)

Figure 5-12
Overall Workstation Semiconductor Content Trend (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



Source: Dataquest (June 1996)

Table 5-3
Worldwide Desktop/Deskside PC Semiconductor Market by System (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Others (386 and Lower)	259	13	0	0	0	0	0	-100.0
486 PC	15,372	11,051	1,402	54	0	0	0	-100.0
Pentium-Class PC	4,935	20,713	27,023	21,369	11,304	4,386	905	-46.5
Pentium Pro and Future PC	0	7	3,475	15,168	34,028	48,637	66,054	518.6
RISC PC	901	2,285	2,981	3,244	3,609	4,220	4,731	15.7
680x0 PC	1,187	605	79	8	0	0	0	-100.0
Total	22,654	34,674	34,960	39,842	48,941	57,243	71,691	15.6
Year-to-Year Growth (%)		53.1	0.8	14.0	22.8	17.0	25.2	

Source: Dataquest (June 1996)

Table 5-4
Worldwide Mobile PC Semiconductor Market by System (Millions of Dollars)

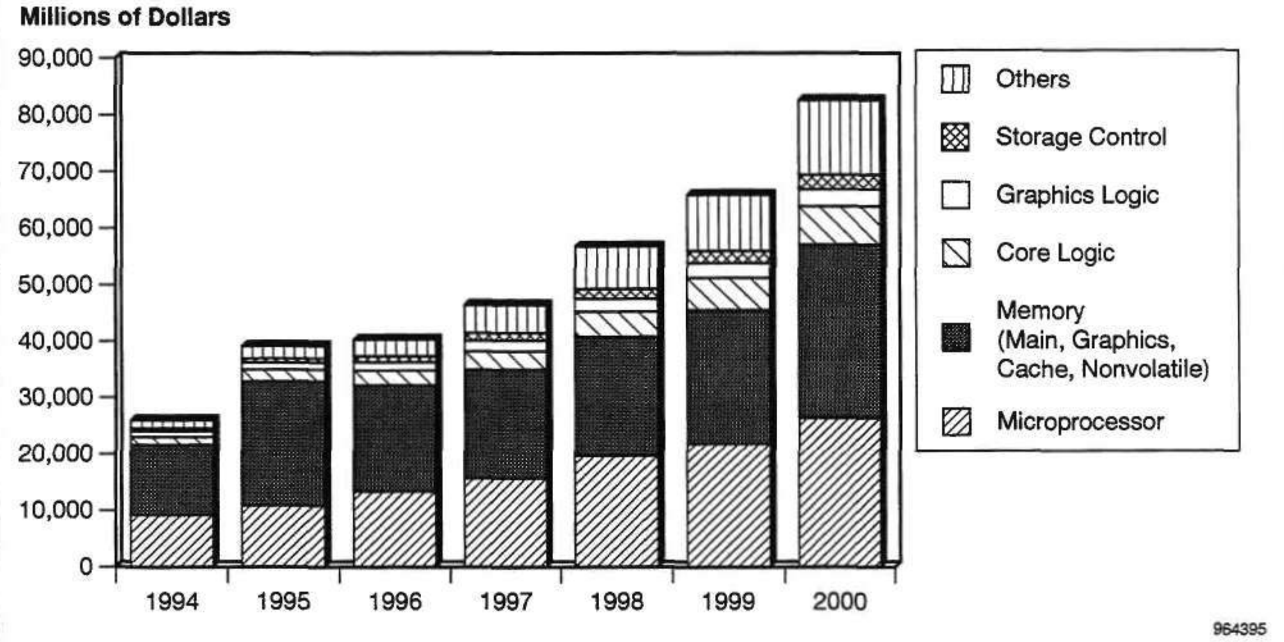
	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Others (386 and Lower)	129	4	0	0	0	0	0	-100.0
486 PC	2,878	3,101	799	19	0	0	0	-100.0
Pentium-Class PC	20	911	3,980	5,011	4,211	2,989	1,886	15.7
Pentium Pro and Future PC	0	0	0	904	2,926	4,853	7,801	NM
RISC PC	0	112	364	448	417	456	525	36.2
680x0 PC	209	198	3	0	0	0	0	-100.0
Handheld PC	74	94	128	149	219	344	663	47.8
Total	3,310	4,420	5,275	6,532	7,774	8,642	10,874	19.7
Year-to-Year Growth (%)		33.5	19.3	23.8	19.0	11.2	25.8	

NM = Not meaningful
Source: Dataquest (June 1996)

Semiconductor Opportunities by Device Type

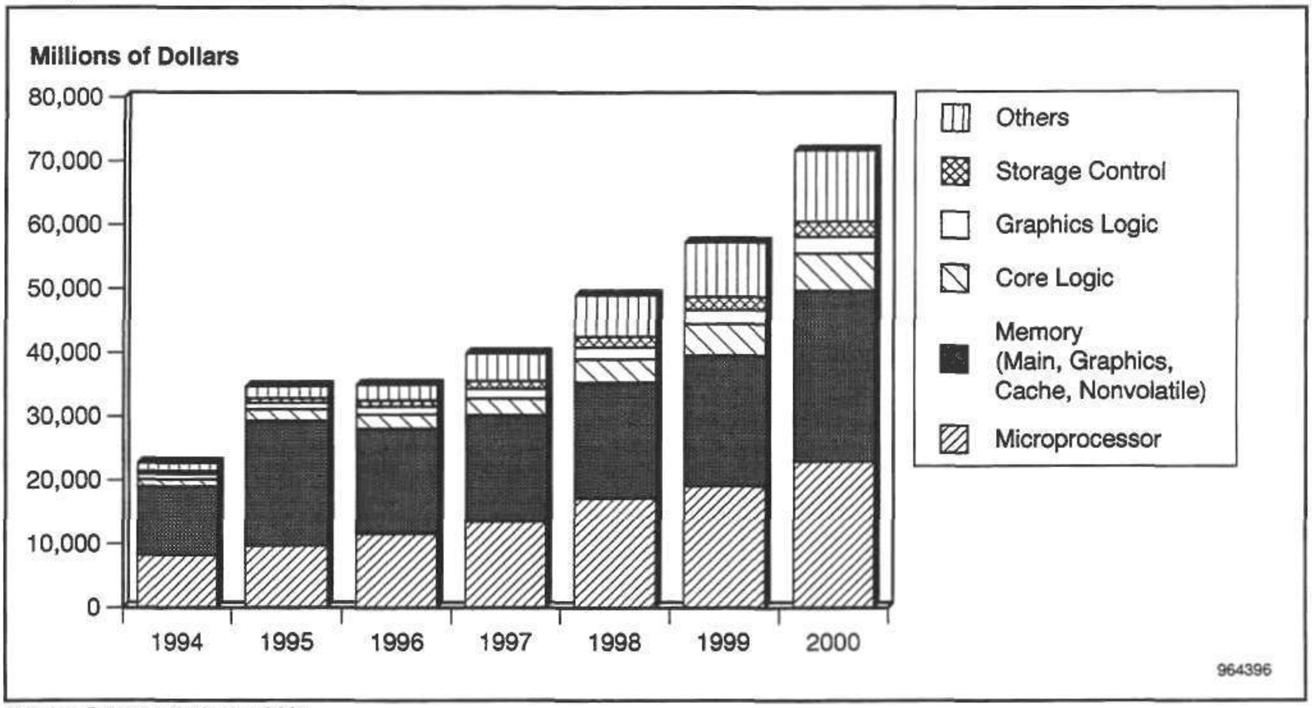
Figures 5-13 through 5-24 and Tables 5-5 through 5-17 detail semiconductor opportunities by device type.

Figure 5-13
Worldwide Total PC Semiconductor Market by Device Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



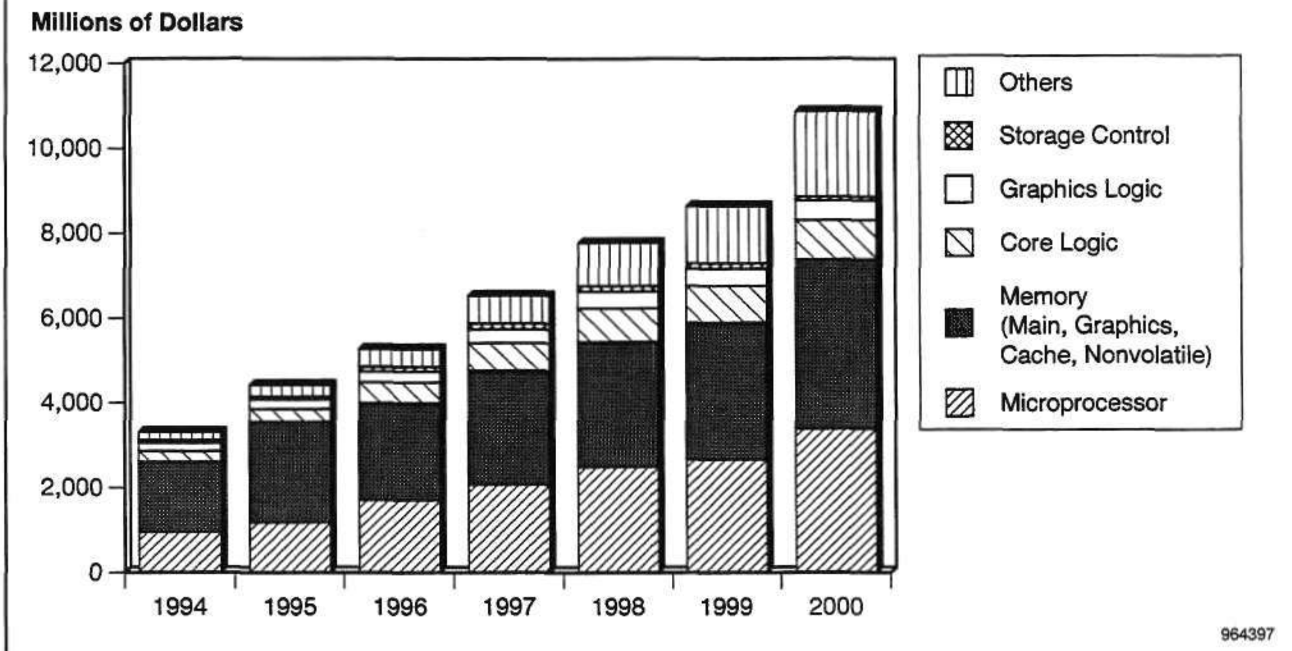
Source: Dataquest (June 1996)

Figure 5-14
Worldwide Desktop/Deskside PC Semiconductor Market by Device Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



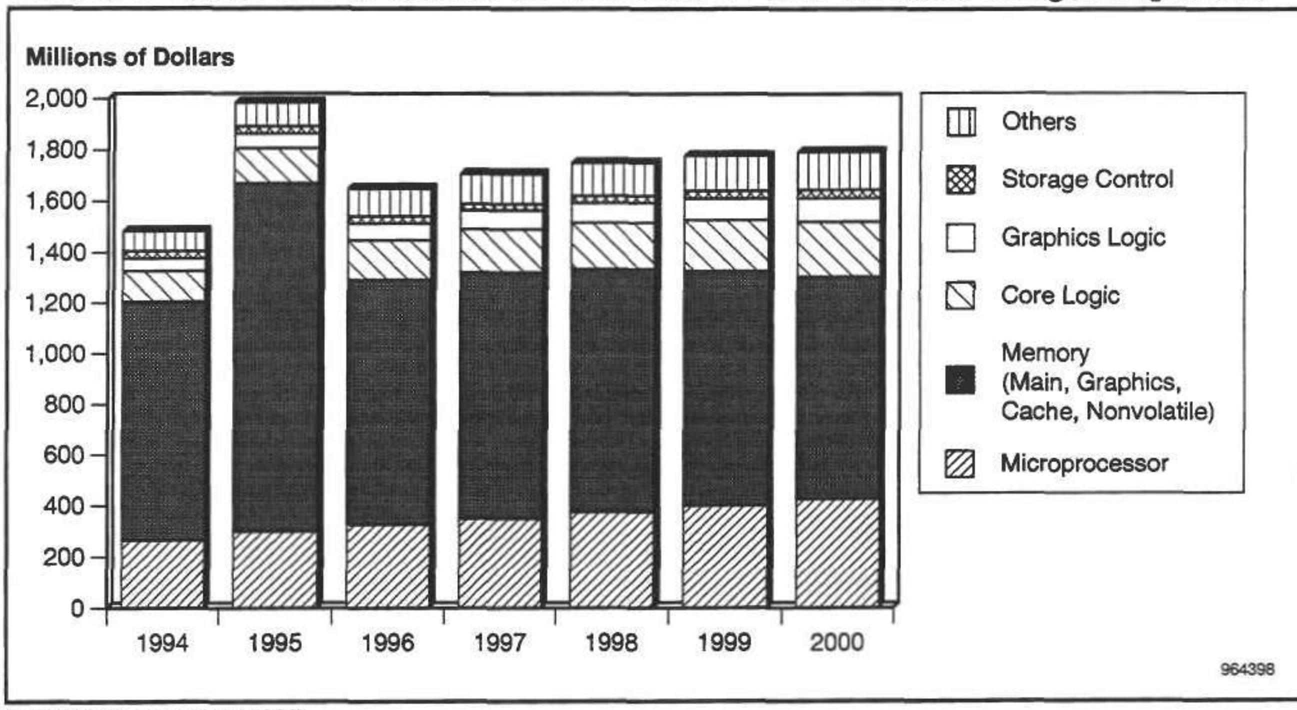
Source: Dataquest (June 1996)

Figure 5-15
Worldwide Mobile PC Semiconductor Market by Device Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



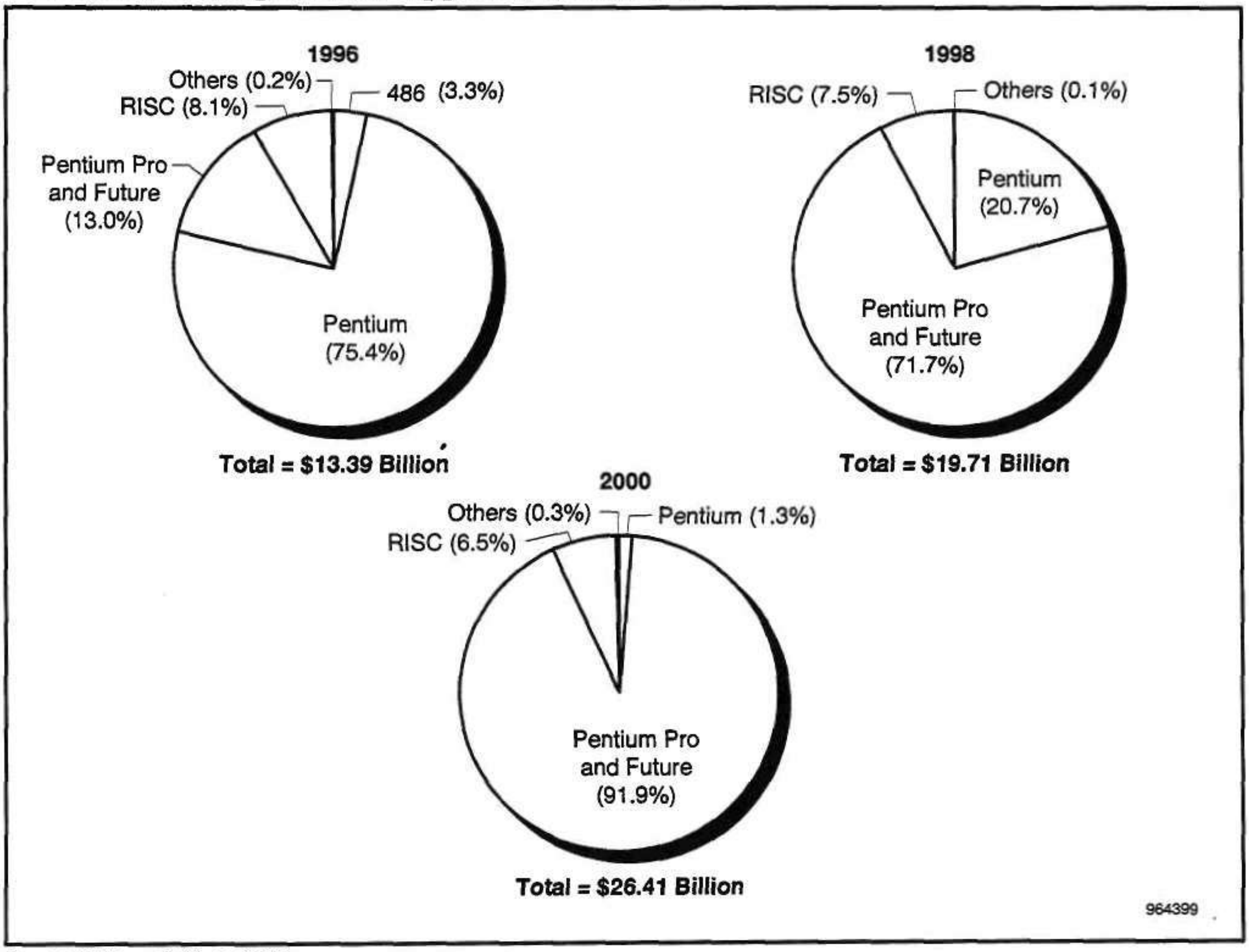
Source: Dataquest (June 1996)

Figure 5-16
Worldwide Workstation Semiconductor Market by Device Type (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)



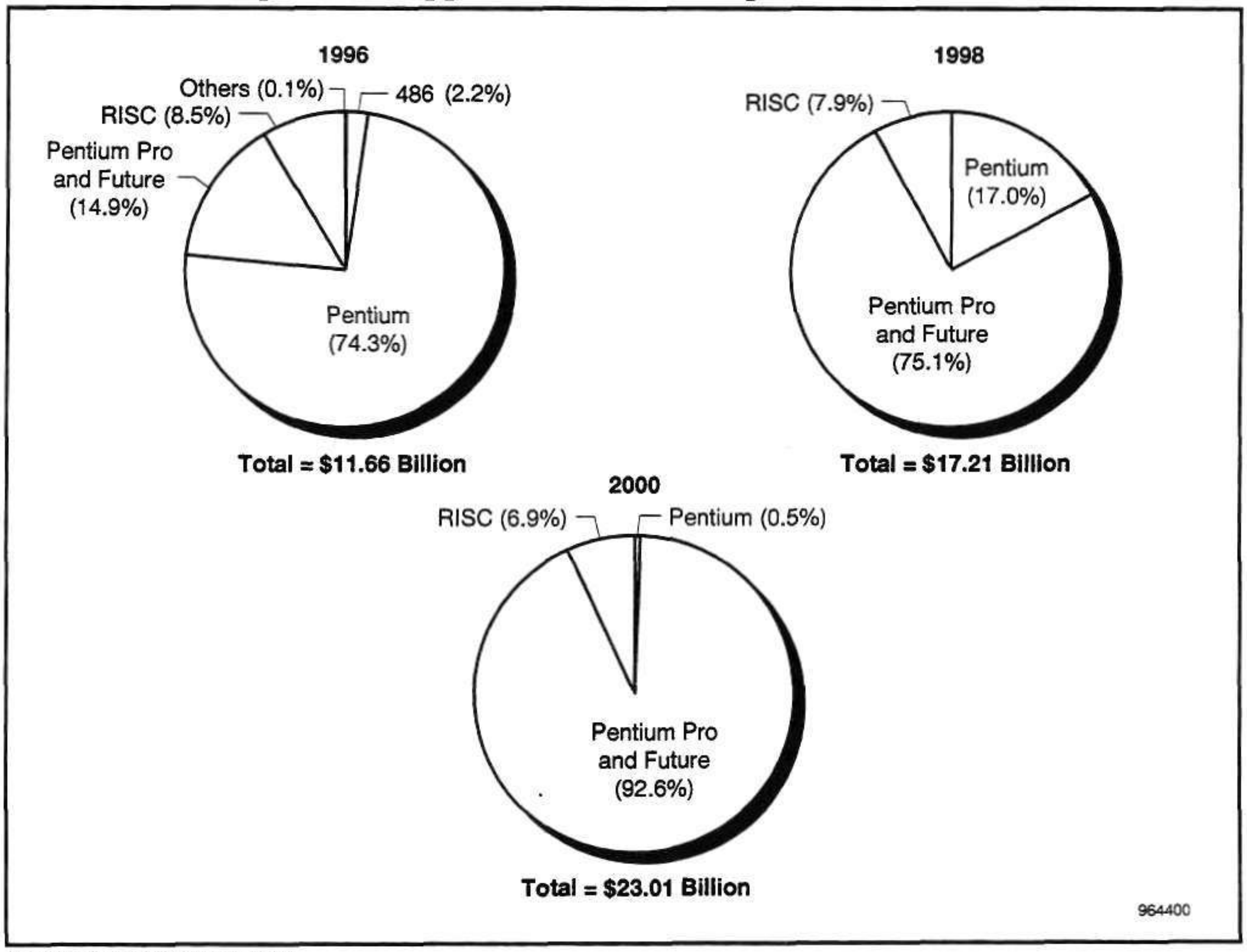
Source: Dataquest (June 1996)

Figure 5-17
Worldwide Microprocessor Opportunities in PCs



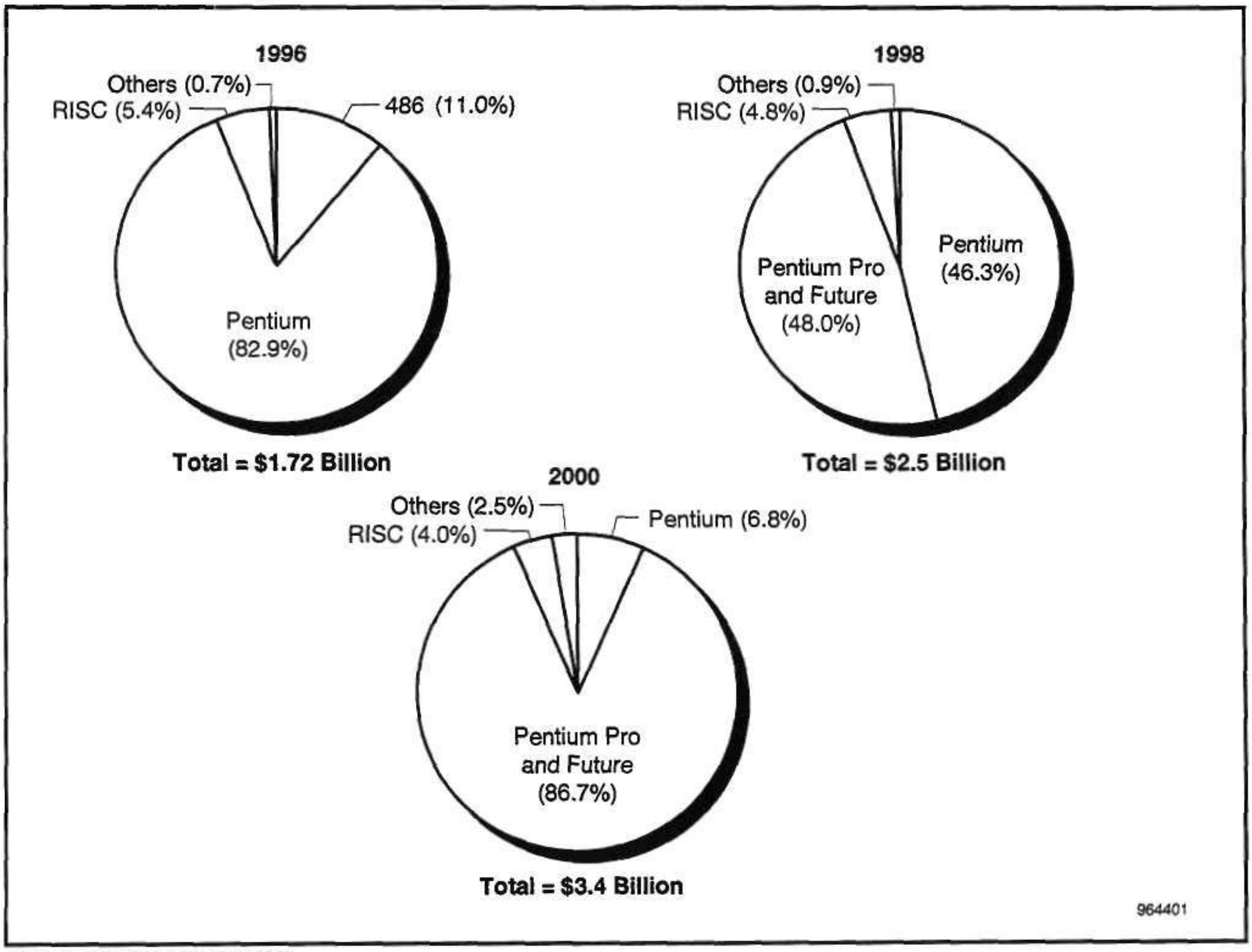
Source: Dataquest (June 1996)

Figure 5-18
Worldwide Microprocessor Opportunities in Desktop/Deskside PCs



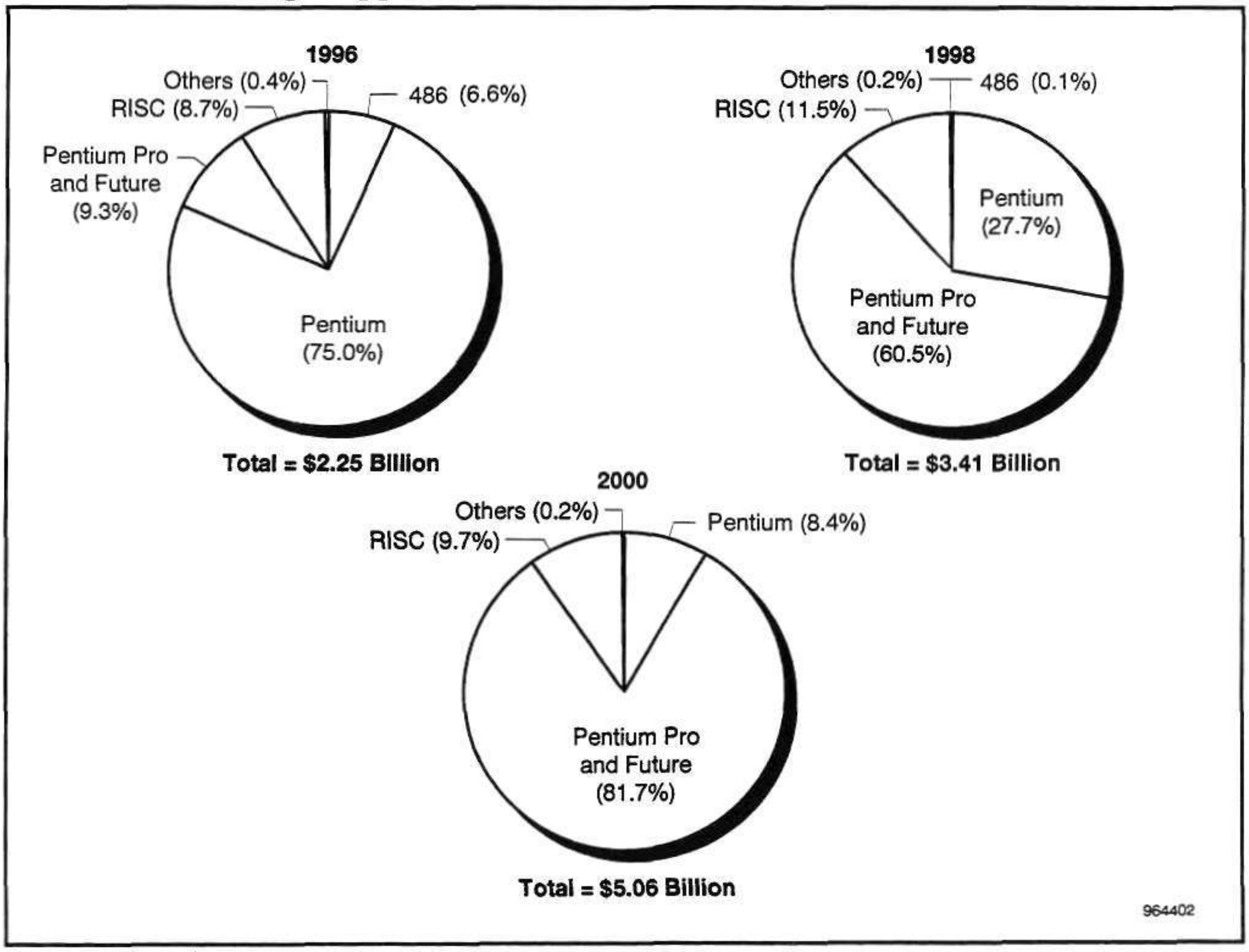
Source: Dataquest (June 1996)

Figure 5-19
Worldwide Microprocessor Opportunities in Mobile PCs



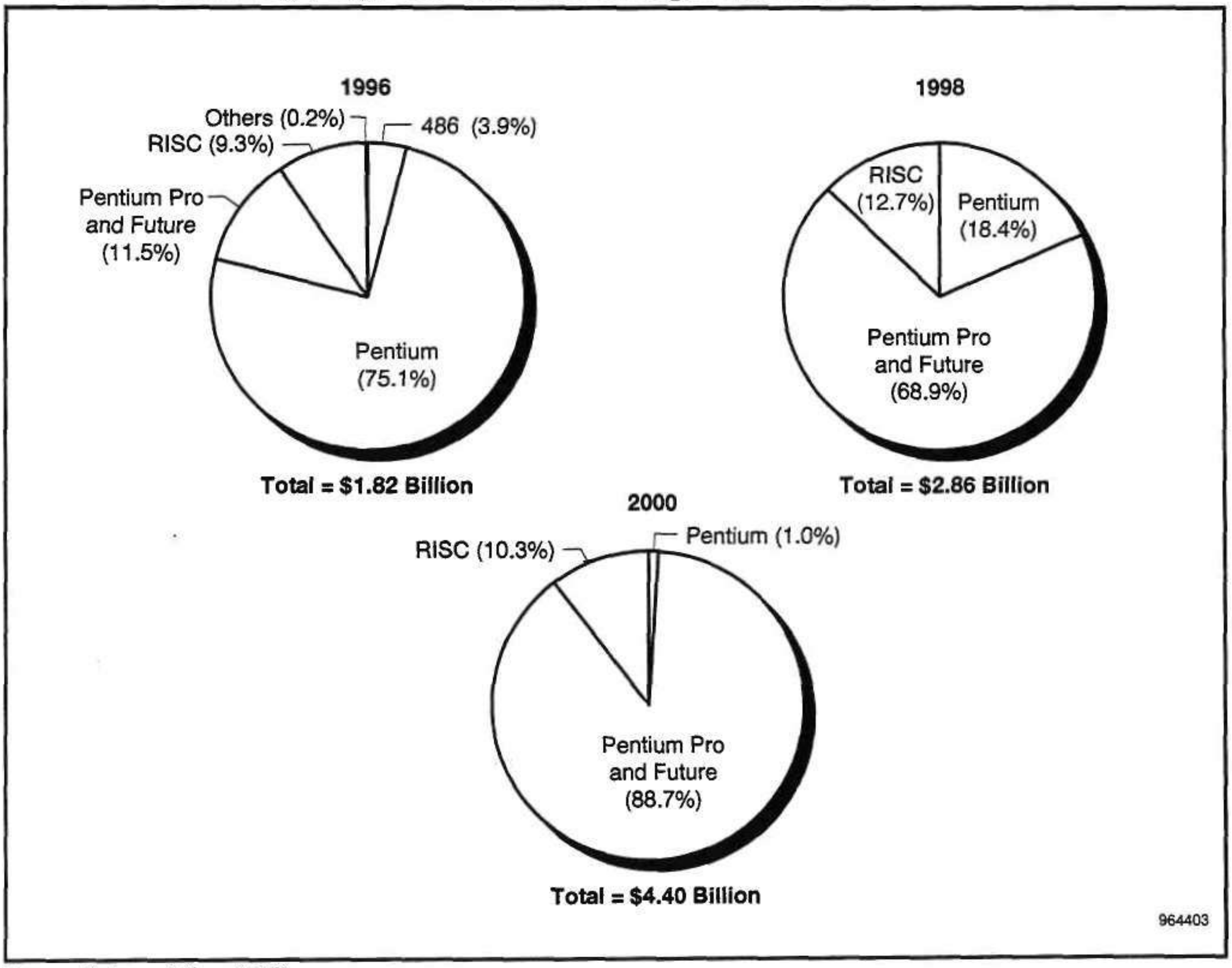
Source: Dataquest (June 1996)

Figure 5-20
Worldwide Core Logic Opportunities in PCs



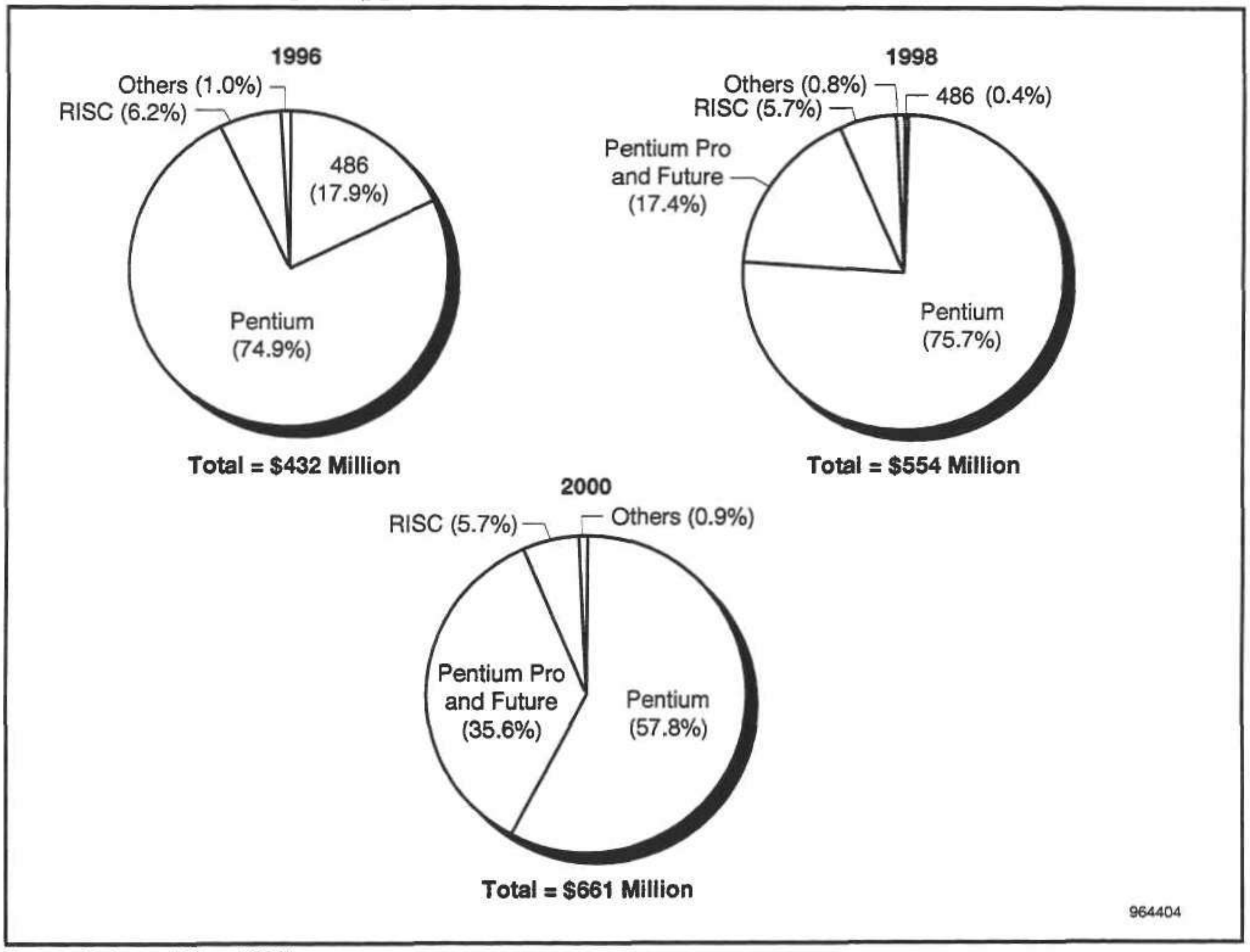
Source: Dataquest (June 1996)

Figure 5-21
Worldwide Core Logic Opportunities in Desktop/Deskside PCs



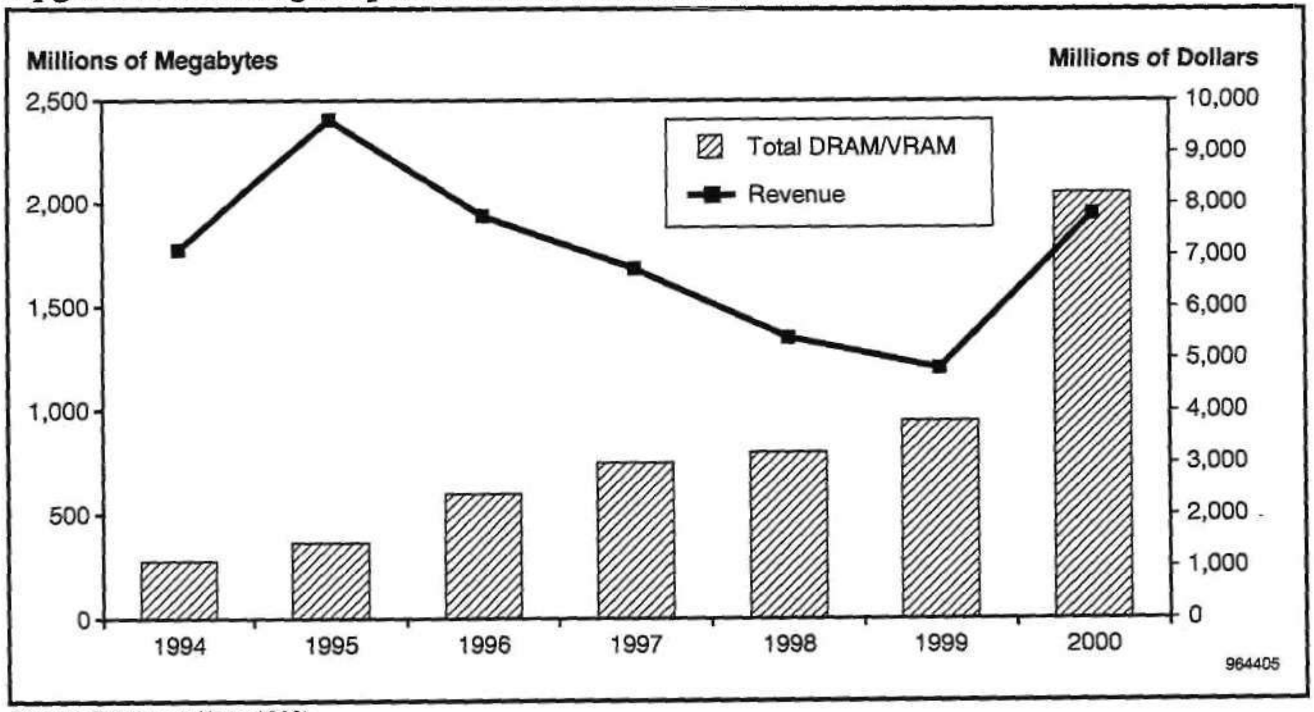
Source: Dataquest (June 1996)

Figure 5-22
Worldwide Core Logic Opportunities in Mobile PCs



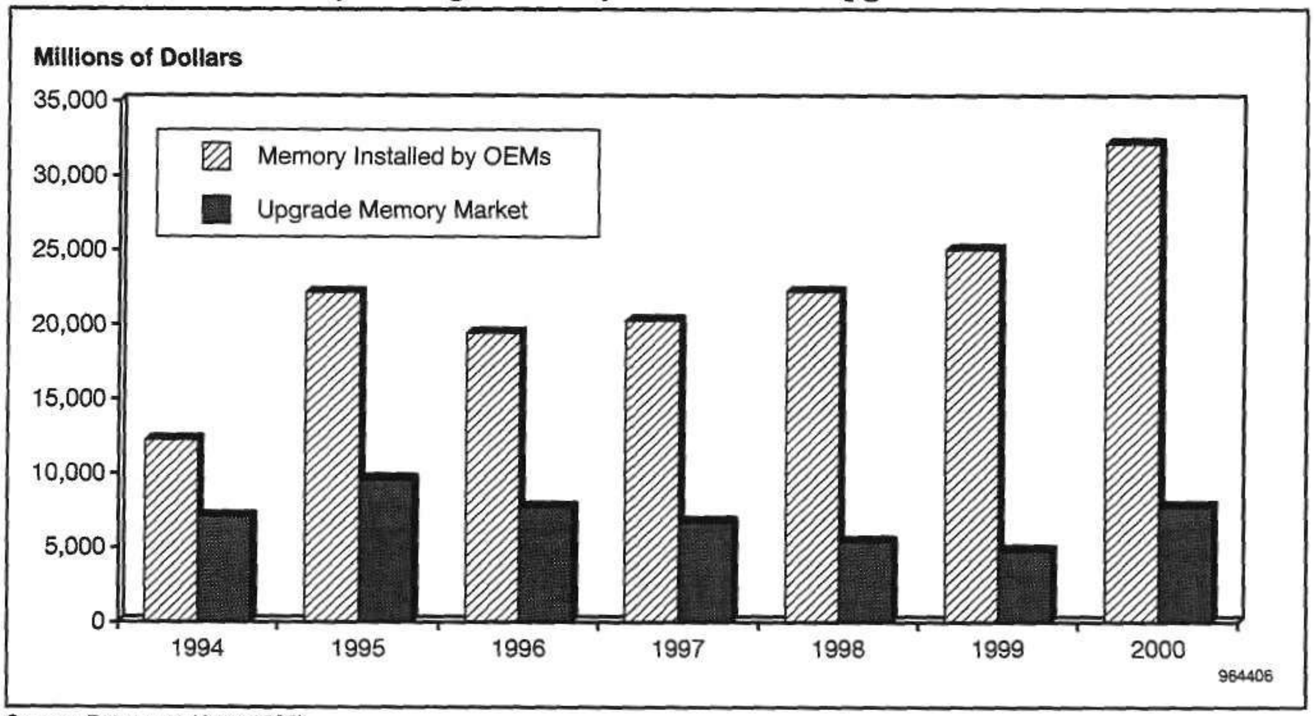
Source: Dataquest (June 1996)

Figure 5-23
Worldwide Aftermarket DRAM/VRAM Memory Demand in PCs (Includes All Memory Upgrades Following Shipment of PC from OEM to Sales Channel)



Source: Dataquest (June 1996)

Figure 5-24
Breakdown of Memory Configuration by OEM versus Upgrades



Source: Dataquest (June 1996)

Table 5-5
Worldwide Total PC Semiconductor Market by Device Type (Millions of Dollars) (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Microprocessor	9,269	10,927	13,386	15,660	19,711	21,789	26,405	19.3%
Memory (Main, Graphics, Cache, Nonvolatile)	12,369	22,017	18,791	19,365	21,079	23,761	30,712	6.9%
Core Logic	1,390	2,059	2,679	3,249	4,512	5,763	6,797	27.0%
Graphics Logic	1,045	1,242	1,464	1,898	2,267	2,583	3,046	19.7%
Storage Control	511	775	1,061	1,349	1,761	2,172	2,541	26.8%
Others	1,380	2,074	2,854	4,854	7,385	9,818	13,064	44.5%
Total Semiconductors	25,963	39,094	40,235	46,375	56,715	65,885	82,565	16.1%
Year-to-Year Growth (%)		50.6	2.9	15.3	22.3	16.2	25.3	

Source: Dataquest (June 1996)

Table 5-6
Worldwide Desktop/Deskside PC Semiconductor Market by Device Type (Millions of Dollars) (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Microprocessor	8,306	9,734	11,663	13,574	17,210	19,113	23,005	18.8
Memory (Main, Graphics, Cache, Nonvolatile)	10,717	19,641	16,514	16,676	18,129	20,530	26,722	6.4
Core Logic	1,137	1,757	2,183	2,590	3,715	4,889	5,867	27.3
Graphics Logic	844	1,022	1,212	1,581	1,873	2,184	2,578	20.3
Storage Control	449	703	943	1,204	1,623	2,046	2,452	28.4
Others	1,201	1,817	2,446	4,218	6,392	8,481	11,066	43.5
Total Semiconductors	22,654	34,674	34,960	39,842	48,941	57,243	71,691	15.6
Year-to-Year Growth (%)		53.1	0.8	14.0	22.8	17.0	25.2	

Source: Dataquest (June 1996)

Table 5-7
Worldwide Mobile PC Semiconductor Market by Device Type (Millions of Dollars) (Includes Semiconductor Value on Motherboard and Card-Based Peripherals such as Graphics, Audio, LAN, and WAN; Excludes Semiconductor Value on Mass Storage Peripherals)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Microprocessor	962	1,192	1,723	2,086	2,502	2,676	3,400	23.3
Memory (Main, Graphics, Cache, Nonvolatile)	1,653	2,376	2,277	2,690	2,950	3,231	3,990	10.9
Core Logic	253	303	497	659	796	874	930	25.2
Graphics Logic	200	220	253	317	394	399	468	16.3
Storage Control	63	72	118	145	138	125	89	4.4
Others	179	257	408	636	994	1,336	1,998	50.7
Total Semiconductors	3,310	4,420	5,275	6,532	7,774	8,642	10,874	19.7
Year-to-Year Growth (%)		33.5	19.3	23.8	19.0	11.2	25.8	

Source: Dataquest (June 1996)

Table 5-8
Worldwide Semiconductor Memory Demand in PCs and Workstations by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	12,094	22,188	18,872	19,294	20,846	23,319	29,939	6.2
SRAM	873	782	571	719	791	912	1,127	7.6
EPROM/OTP/ROM	137	63	16	7	8	9	10	-30.0
Flash	206	355	298	319	395	448	514	7.7
Total	13,311	23,387	19,757	20,338	22,039	24,688	31,590	6.2

Source: Dataquest (June 1996)

Table 5-9
Worldwide Semiconductor Memory Demand in Desktop/Deskside PCs by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	9,677	18,669	15,845	15,866	17,178	19,449	25,460	6.4
SRAM	811	657	461	595	671	769	947	7.6
EPROM/OTP/ROM	92	47	10	4	6	6	6	-33.2
Flash	137	268	198	211	274	305	309	2.9
Total	10,717	19,641	16,514	16,676	18,129	20,530	26,722	6.4

Source: Dataquest (June 1996)

Table 5-10
Worldwide Semiconductor Memory Demand in Mobile PCs by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	1,531	2,243	2,134	2,528	2,774	3,001	3,653	10.2
SRAM	18	39	45	59	59	90	132	27.7
EPROM/OTP/ROM	41	14	5	2	2	3	4	-21.8
Flash	62	80	92	101	115	138	201	20.3
Total	1,653	2,376	2,277	2,690	2,950	3,231	3,990	10.9

Source: Dataquest (June 1996)

Table 5-11
Worldwide Semiconductor Memory Demand in Workstations by Device (Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
DRAM/VRAM	885.5	1,276	893	900	894	868	826	-8.3
SRAM	44	85	65	65	60	53	47	-11.3
EPROM/OTP/ROM	5	1	0	0	0	0	0	-41.6
Flash	7	8	8	7	6	5	5	-10.1
Total	941	1,370	966	973	960	927	878	-8.5

Source: Dataquest (June 1996)

Table 5-12
Worldwide Semiconductor Memory Demand by System for PCs and Workstations (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	6,749	7,323	908	30	0	0	0	-100.0
Upgrade Memory	6,305	3,703	323	10	0	0	0	-100.0
Display Buffer	1,064	936	220	5	0	0	0	-100.0
Cache	630	377	58	0	0	0	0	-100.0
Nonvolatile	194	164	47	2	0	0	0	-100.0
Total	14,942	12,502	1,556	47	0	0	0	-100.0
Pentium-Class PC								
Main OEM	1,769	9,899	12,031	10,024	5,909	2,857	1,306	-33.3
Upgrade Memory	254	5,352	6,257	3,871	1,736	682	157	-50.6
Display Buffer	118	830	2,186	1,503	878	450	132	-30.8
Cache	135	219	369	409	111	7	0	-100.0
Nonvolatile	36	172	181	125	62	29	14	-39.1
Total	2,313	16,473	21,023	15,933	8,696	4,025	1,609	-37.2

(Continued)

Table 5-12 (Continued)
Worldwide Semiconductor Memory Demand by System for PCs and Workstations
(Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Pentium Pro and Future PC								
Main OEM	0	2	904	4,817	10,641	16,165	24,153	564.7
Upgrade Memory	0	2	723	2,536	3,366	3,798	7,107	420.4
Display Buffer	0	0	114	431	1,019	1,218	1,206	439.9
Cache	0	0	0	172	511	761	1,004	NM
Nonvolatile	0	0	15	126	255	318	334	574.1
Total	0	4	1,757	8,081	15,792	22,260	33,805	509.8
RISC PC								
Main OEM	383	1,167	1,219	1,274	1,210	1,427	1,803	9.1
Upgrade Memory	140	479	439	325	299	335	536	2.3
Display Buffer	48	197	295	249	201	188	210	1.3
Cache	35	84	78	73	109	90	75	-2.2
Nonvolatile	9	16	18	15	12	10	9	-9.7
Total	615	1,942	2,049	1,936	1,831	2,050	2,633	6.3
Workstation								
Main OEM	808	1,180	837	853	851	833	797	-7.5
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	77	96	56	47	44	36	29	-21.2
Cache	44	85	65	65	60	53	47	-11.3
Nonvolatile	12	9	8	7	6	5	5	-12.6
Total	941	1,370	966	973	960	927	878	-8.5
Others								
Main OEM	842	471	91	61	93	146	303	-8.5
Upgrade Memory	401	94	13	0	0	0	0	-100.2
Display Buffer	237	87	10	0	0	0	0	-99.9
Cache	29	16	1	0	0	0	0	-100.0
Nonvolatile	92	57	45	51	67	95	162	23.2
Total	1,600	725	161	112	160	241	466	-8.5
Total PC and Workstation								
Main OEM	10,551	20,042	15,991	17,058	18,704	21,427	28,362	7.2
Upgrade Memory	7,100	9,630	7,756	6,742	5,402	4,814	7,800	-4.1
Display Buffer	1,543	2,146	2,881	2,235	2,142	1,892	1,577	-6.0
Cache	873	782	571	719	791	912	1,127	7.6
Nonvolatile	343	417	314	325	403	457	524	4.7
Total	20,411	33,017	27,513	27,080	27,441	29,502	39,390	3.6

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-13
Worldwide Semiconductor Memory Demand for Desktop/Deskside PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	5,596	5,882	610	23	0	0	0	-100.0
Upgrade Memory	5,969	3,177	203	8	0	0	0	-100.0
Display Buffer	869	731	148	4	0	0	0	-100.0
Cache	613	359	54	0	0	0	0	-100.0
Nonvolatile	134	121	34	1	0	0	0	-100.0
Total	13,181	10,270	1,050	36	0	0	0	-100.0
Pentium-Class PC								
Main OEM	1,764	9,552	10,629	8,195	4,345	1,689	460	-45.5
Upgrade Memory	252	5,174	6,023	3,642	1,580	487	51	-60.3
Display Buffer	117	792	2,057	1,366	761	353	92	-34.9
Cache	135	203	341	379	103	7	0	-100.0
Nonvolatile	36	164	142	81	29	8	2	-58.5
Total	2,304	15,884	19,192	13,664	6,818	2,543	605	-48.0
Pentium Pro and Future PC								
Main OEM	0	2	904	4,568	9,865	14,877	22,042	552.6
Upgrade Memory	0	2	723	2,436	3,225	3,501	5,934	402.0
Display Buffer	0	0	114	406	949	1,094	1,060	426.1
Cache	0	0	0	159	474	684	882	NM
Nonvolatile	0	0	15	121	241	297	306	562.6
Total	0	4	1,757	7,690	14,754	20,452	30,225	496.3
RISC PC								
Main OEM	383	1,126	1,077	1,085	1,084	1,273	1,625	7.6
Upgrade Memory	140	469	404	325	271	300	437	-1.4
Display Buffer	48	187	260	217	174	163	181	-0.6
Cache	35	80	65	56	94	78	65	-4.0
Nonvolatile	9	15	15	12	9	7	7	-13.5
Total	615	1,876	1,821	1,695	1,633	1,821	2,315	4.3
Others								
Main OEM	709	332	36	2	0	0	0	-99.9
Upgrade Memory	401	94	13	0	0	0	0	-100.1
Display Buffer	191	65	9	0	0	0	0	-100.0
Cache	28	16	1	0	0	0	0	-100.0
Nonvolatile	50	15	2	0	0	0	0	-100.1
Total	1,379	522	62	3	0	0	0	-99.9

(Continued)

Table 5-13 (Continued)
Worldwide Semiconductor Memory Demand for Desktop/Deskside PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Total Desktop/Deskside PC								
Main OEM	8,452	16,894	13,257	13,873	15,295	17,840	24,127	7.4
Upgrade Memory	6,762	8,915	7,367	6,412	5,076	4,287	6,423	-6.3
Display Buffer	1,225	1,775	2,588	1,993	1,883	1,610	1,333	-5.6
Cache	811	657	461	595	671	769	947	7.6
Nonvolatile	229	315	208	215	279	311	315	0.0
Total	17,479	28,556	23,881	23,088	23,205	24,817	33,145	3.0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-14
Worldwide Semiconductor Memory Demand for Mobile PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	1,153	1,440	298	7	0	0	0	-100.0
Upgrade Memory	335	527	119	2	0	0	0	-100.0
Display Buffer	195	205	72	2	0	0	0	-100.0
Cache	17	18	4	0	0	0	0	-100.0
Nonvolatile	60	42	12	0	0	0	0	-100.0
Total	1,761	2,232	506	11	0	0	0	-100.0
Pentium-Class PC								
Main OEM	5	348	1,402	1,829	1,564	1,168	846	19.4
Upgrade Memory	2	178	234	229	156	195	106	-9.9
Display Buffer	1	39	129	137	117	97	40	0.5
Cache	1	16	28	30	8	0	0	-100.0
Nonvolatile	0	8	39	44	32	21	12	9.3
Total	9	589	1,831	2,269	1,879	1,481	1,004	11.3
Pentium Pro and Future PC								
Main OEM	0	0	0	249	775	1,287	2,111	NM
Upgrade Memory	0	0	0	99	141	297	1,173	NM
Display Buffer	0	0	0	25	70	124	147	NM
Cache	0	0	0	13	37	77	122	NM
Nonvolatile	0	0	0	5	15	22	28	NM
Total	0	0	0	391	1,038	1,808	3,580	NM

(Continue

Table 5-14 (Continued)
Worldwide Semiconductor Memory Demand for Mobile PC Systems (Market Value by Function; Millions of Dollars)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
RISC PC								
Main OEM	0	41	143	190	126	153	178	34.4
Upgrade Memory	0	10	36	0	28	35	99	57.7
Display Buffer	0	10	34	32	27	26	29	23.2
Cache	0	4	13	16	15	12	10	19.0
Nonvolatile	0	1	3	3	3	3	2	17.4
Total	0	66	229	241	199	229	318	36.9
Handhelds								
Main OEM	23	32	55	59	93	146	303	56.4
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	0	0	0	0	0	0	0	NM
Cache	0	0	0	0	0	0	0	NM
Nonvolatile	31	37	43	50	67	95	162	34.6
Total	54	69	98	109	160	241	466	46.5
Others								
Main OEM	110	107	0	0	0	0	0	-99.8
Upgrade Memory	0	0	0	0	0	0	0	-47.0
Display Buffer	46	22	0	0	0	0	0	-99.9
Cache	1	0	0	0	0	0	0	-99.6
Nonvolatile	12	5	0	0	0	0	0	-99.9
Total	167	134	0	0	0	0	0	-99.8
Total Mobile PC								
Main OEM	1,290	1,968	1,897	2,333	2,559	2,755	3,438	11.8
Upgrade Memory	338	715	388	330	325	527	1,377	14.0
Display Buffer	241	275	237	195	215	247	215	-4.8
Cache	18	39	45	59	59	90	132	27.7
Nonvolatile	103	94	97	103	117	140	205	16.9
Total	1,990	3,091	2,665	3,020	3,276	3,759	5,367	11.7

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-15
Worldwide Semiconductor Memory Configuration Assumptions by System for PCs and Workstations (Megabytes per System; Kilobytes per System for Cache)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	5.53	8.16	8.15	9.90	0	0	0	-100.0
Upgrade Memory	5.16	4.13	2.90	3.35	0	0	0	-100.0
Display Buffer	1.00	1.19	1.29	1.00	0	0	0	-100.0
Cache	132.04	142.89	175.90	3.33	0	0	0	-100.0
Nonvolatile	0.15	0.25	0.39	0.43	0	0	0	-100.0
Pentium-Class PC								
Main OEM	13.07	10.50	11.53	15.64	19.05	22.35	29.60	23.0
Upgrade Memory	1.88	5.67	5.99	6.04	5.60	5.33	3.56	-8.9
Display Buffer	1.00	1.00	1.53	1.84	2.22	2.29	1.83	12.8
Cache	256.00	79.17	118.94	176.55	98.95	14.64	0	-100.0
Nonvolatile	0.25	0.25	0.16	0.14	0.14	0.15	0.20	-4.8
Pentium Pro and Future PC								
Main OEM	0	14.16	15.82	19.87	22.81	29.50	44.49	25.7
Upgrade Memory	0	14.16	12.65	10.46	7.22	6.93	13.09	-1.6
Display Buffer	0	2.00	2.00	2.00	2.46	2.50	2.50	4.6
Cache	0	0	0	195.69	302.85	384.00	512.00	NM
Nonvolatile	0	0.25	0.25	0.38	0	0	0	-100.0
RISC PC								
Main OEM	11.30	10.44	12.65	18.23	20.62	29.26	44.28	33.5
Upgrade Memory	4.14	4.29	4.56	4.66	5.09	6.87	13.17	25.2
Display Buffer	1.50	2.00	2.00	2.50	2.50	2.50	2.50	4.6
Cache	262.14	256.00	270.97	288.54	512.00	512.00	512.00	14.9
Nonvolatile	0.25	0.19	0.18	0.15	0.14	0.13	0.14	-6.4
Workstation								
Main OEM	40.00	53.00	68.70	92.30	114.00	136.60	160.50	24.8
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	2.50	3.00	3.00	3.50	4.00	4.00	4.00	5.9
Cache	512.00	752.00	926.00	1,127.00	1,285.00	1,402.00	1,508.00	14.9
Nonvolatile	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-16
Worldwide Semiconductor Memory Configuration Assumptions by System for Desktop/Deskside PCs (Megabytes per System; Kilobytes per System for Cache)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	6.00	10.00	12.00	12.00	12.00	12.00	12.00	3.7
Upgrade Memory	6.40	5.40	4.00	4.00	4.00	4.00	4.00	-5.8
Display Buffer	1.00	1.25	1.50	1.00	1.00	1.00	1.00	-4.4
Cache	157.29	183.50	283.12	0	0	0	0	-100.0
Nonvolatile	0.13	0.25	0.50	0.50	0	0	0	-100.0
Pentium-Class PC								
Main OEM	14.00	12.00	15.00	18.00	22.00	26.00	36.00	24.6
Upgrade Memory	2.00	6.50	8.50	8.00	8.00	7.50	4.00	-9.3
Display Buffer	117.32	791.76	2,057.17	1,365.89	760.74	353.01	92.42	-34.9
Cache	256.00	76.80	128.00	204.80	128.00	25.60	0	-100.0
Nonvolatile	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0
Pentium Pro and Future PC								
Main OEM	0	16.00	20.00	22.50	26.00	34.00	52.00	26.6
Upgrade Memory	0	16.00	16.00	12.00	8.50	8.00	14.00	-2.6
Display Buffer	0	2.00	2.00	2.00	2.50	2.50	2.50	4.6
Cache	0	0	0	192.00	307.20	384.00	512.00	NM
Nonvolatile	0	0.25	0.25	0.38	0.38	0.38	0.38	9.0
RISC PC								
Main OEM	12.00	12.00	16.00	20.00	24.00	34.00	52.00	34.1
Upgrade Memory	4.14	5.00	6.00	6.00	6.00	8.00	14.00	22.9
Display Buffer	1.50	2.00	2.00	2.50	2.50	2.50	2.50	4.6
Cache	256.00	256.00	256.00	256.00	512.00	512.00	512.00	14.9
Nonvolatile	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0

NM = Not meaningful
Source: Dataquest (June 1996)

Table 5-17
Worldwide Semiconductor Memory Configuration Assumptions by System for Mobile PCs (Megabytes per System; Kilobytes per System for Cache)

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
486 PC								
Main OEM	5.50	7.00	8.00	9.00	0	0	0	-100.0
Upgrade Memory	1.60	2.56	3.20	3.20	0	0	0	-100.0
Display Buffer	1.00	1.00	1.00	1.00	0	0	0	-100.0
Cache	19.66	26.76	29.49	11.62	0	0	0	-100.0
Nonvolatile	0.25	0.25	0.25	0.25	0	0	0	-100.0
Pentium-Class PC								
Main OEM	8.00	9.00	12.00	16.00	20.00	24.00	32.00	28.9
Upgrade Memory	4.00	4.60	2.00	2.00	2.00	4.00	4.00	-2.8
Display Buffer	1.00	1.00	1.10	1.20	1.50	2.00	1.50	8.4
Cache	256.00	128.00	64.00	64.00	25.60	0	0	-100.0
Nonvolatile	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0
Pentium Pro and Future PC								
Main OEM	0	0	16.00	20.00	22.00	26.00	36.00	NM
Upgrade Memory	0	0	8.00	8.00	4.00	6.00	20.00	NM
Display Buffer	0	0	2.00	2.00	2.00	2.50	2.50	NM
Cache	0	0	0	256.00	256.00	384.00	512.00	NM
Nonvolatile	0	0	0	0.25	0.25	0.25	0.25	NM
RISC PC								
Main OEM	6.00	8.00	16.00	24.00	18.00	26.00	36.00	35.1
Upgrade Memory	0	2.00	4.00	0	4.00	6.00	20.00	58.5
Display Buffer	1.00	2.00	2.00	2.50	2.50	2.50	2.50	4.6
Cache	256.00	256.00	384.00	512.00	512.00	512.00	512.00	14.9
Nonvolatile	0	0.25	0.25	0.25	0.25	0.25	0.25	0
Handhelds								
Main OEM	1.25	1.60	2.50	3.25	4.00	4.00	4.00	20.1
Upgrade Memory	0	0	0	0	0	0	0	NM
Display Buffer	0	0	0	0	0	0	0	NM
Cache	0	0	0	0	0	0	0	NM
Nonvolatile	2.50	3.50	4.00	4.25	4.50	4.50	4.50	5.2

NM = Not meaningful
Source: Dataquest (June 1996)

Chapter 6
Input/Output and Dedicated Systems

Tables 6-1 through 6-6 detail system and semiconductor market data on selected computer I/O systems.

Table 6-1
Worldwide Sound Board Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Board Units (M)	13.7	11.5	12.1	12.7	13.4	14.0	14.7	0.1
Board ASP ($)	64.6	66.3	66.3	66.3	66.3	66.3	66.3	0
Board Factory Revenue ($M)	883.1	765.0	803.2	843.4	885.6	929.8	976.3	0
16-Bit and Higher Penetration (%)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0
Semiconductor Content ($)	16.1	17.0	17.5	18.0	18.0	18.0	18.0	0
Semiconductor Market ($M)	220.8	196.3	212.2	229.1	240.6	252.6	265.3	0.1
ASSP/ASIC ($M)	94.9	82.1	86.2	90.6	95.1	99.8	104.8	0.1
Synthesis ($M)	81.7	70.7	74.2	78.0	81.9	85.9	90.2	0.1
Analog/Discrete ($M)	33.1	28.6	30.1	31.6	33.2	34.8	36.6	0.1
Memory/Others ($M)	11.0	14.8	21.6	29.1	30.5	32.0	33.6	0.2

Source: Dataquest (June 1996)

Table 6-2
Worldwide Sound Board OEMs (1995 Unit Share; Percent)

Creative	**61.1**
Aztech	36.5
Diamond	0.5
Turtle Beach	0.3
Others	1.6

Source: Dataquest (June 1996)

Table 6-3
Worldwide Graphics Board Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Board Units (K)	12,634.5	16,677.5	20,013.0	23,815.5	27,673.6	31,741.7	35,836.3	16.5
Board ASP ($)	160.00	152.00	160.00	152.00	148.96	145.98	143.06	-1.2
Board Factory Revenue ($M)	2,021.5	2,535.0	3,202.1	3,620.0	4,122.3	4,633.7	5,126.8	15.1
Semiconductor Content ($)	57.00	55.00	58.00	60.00	59.00	58.00	57.00	0.7
Semiconductor Market ($M)	720.2	917.3	1,160.8	1,428.9	1,632.7	1,841.0	2,042.7	17.4

Source: Dataquest (June 1996)

Table 6-4
Worldwide Digital Video Board Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
Board Units (K)	605.0	1,080.3	1,188.3	1,307.1	1,437.8	1,581.6	1,739.8	10.0
With Hardware Compression and/or Decompression	169.0	351.5	369.0	387.5	406.8	427.2	448.5	5.0
With TV Tuner	100.0	189.0	236.3	295.3	369.1	461.4	576.8	25.0
Board ASP ($)	310.00	227.98	216.58	205.75	195.46	185.69	176.40	-5.0
Board Factory Revenue ($M)	187.6	246.3	257.4	268.9	281.0	293.7	306.9	4.5
Semiconductor Content ($)	87.80	79.79	78.20	76.63	75.10	73.60	72.12	-2.0
Semiconductor Market ($M)	53.1	86.2	92.9	100.2	108.0	116.4	125.5	7.8
TV Signal Processing ($M)	1.5	3.8	4.7	5.9	7.4	9.2	11.5	25.0
Video Scaling/ Processing ($M)	20.0	27.0	28.4	29.8	31.3	32.8	34.5	5.0
Compression/ Decompression ($M)	5.9	17.6	18.5	19.4	20.3	21.4	22.4	5.0
Memory (DRAM/VRAM) ($M)	22.7	27.0	28.4	29.8	31.3	32.8	34.5	5.0
Others ($M)	3.0	10.8	13.0	15.3	17.7	20.2	22.6	15.8

Source: Dataquest (June 1996)

Table 6-5
Worldwide Monitor Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
System Units (K)	41,227.0	54,419.6	65,303.6	77,711.2	90,300.5	103,574.6	116,935.8	16.5
System ASP ($)	352.00	316.80	285.12	256.61	230.95	207.85	187.07	-10.0
System Factory Revenue ($M)	14,494.0	17,240.1	18,619.4	19,941.3	20,854.6	21,528.2	21,874.8	4.9
Semiconductor Content ($)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	0
Semiconductor Market ($M)	188.0	272.1	326.5	388.6	451.5	517.9	584.7	16.5

Source: Dataquest (June 1996

Table 6-6
Worldwide Keyboard Applications Market

	1994	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
System Units (K)	55,961.6	73,869.3	88,643.2	105,485.4	122,574.0	140,592.4	158,728.8	16.5
Semiconductor Content ($)	2.45	2.50	2.50	2.50	2.50	2.50	2.50	0
Semiconductor Market ($M)	137.1	184.7	221.6	263.7	306.4	351.5	396.8	16.5

Source: Dataquest (June 1996)

Key Trends

Sound Boards

Key trends in sound boards are as follows:

- The sound board market faces increasing competition from integrated designs with sound chips on the motherboard or on custom daughter-card modules. Integrated sound chips are primarily used for mobile and consumer PCs, although a few business desktops have integrated sound capability.
- Microsoft has adopted DSP Group's TrueSpeech technology as a compression standard. Several vendors already support ADPCM for compression.
- Movement to 16-bit is nearly complete. Wave-table synthesis is gaining market share.
- Key chip functions include FM and wave-table synthesis (512KB to 4MB ROM-based), ASSP/ASICs (mixed-signal and digital CMOS), audio amplifiers, and mixers. SCSI host adapters have declined in popularity compared to EIDE or proprietary variants of EIDE.

Graphics Boards

Key trends in graphics boards are as follows:

- May receive a boost from the 3-D graphics market until mid-1997 when several new graphics controllers make 3-D hardware more attractive for motherboard implementations.
- Boards are moving to greater than 1000 x 1000-pixel resolutions; accelerated BitBLT-based, 64-bit data paths; and RAMDAC technology moving from 85 MHz to 135 MHz. Also, digital video, 3-D, and sound capability are appearing in the high-end boards.
- Extended data out (EDO) DRAM will be the dominant memory for 1996 but will be replaced with SDRAM/SGRAM in 1997. Minimal buffers start at 1MB and move to 4MB with optional single in-line memory modules (SIMMs). Most high-end add-in boards have a separate RAMDAC, and digital video acceleration functions are being integrated into virtually every design.

Digital Video Boards

Key trends in digital video boards are as follows:

- There will be continued penetration into the multimedia content creator market (software title development, market communications, and training). Playback board growth will be limited to full-screen 15-fps to 30-fps acceleration. Other opportunities exist for TV tuner, capture pass-through, and integrated audio and graphics boards.
- MPEG-1 hardware shifted partly to the motherboard in 1995 but has already reverted to add-in cards, creating greater opportunities for video board OEMs.

- Key semiconductor opportunities include compression decoders for MPEG-1 and JPEG, among others (and encoders for real-time algorithms), decoders and encoders between various video standards such as PAL, NTSC, and CCIR , ASICs (CMOS), digital video processors (scaling, among other functions), and DRAM/VRAM pixel buffers.

Leading digital video board OEMs worldwide are ATI, Creative Technologies, Diamond Multimedia, FutureTel, IBM, Intel, Matrox, Media Vision, Optibase, Optivision, Orchid, Sigma Designs, SuperMac, and Video Logic.

Monitors

Key trends in monitors are as follows:

- Color will grow to 98 percent of the market in 1999.
- 15-inch tubes will be the predominant size in 1996; 17-inches tubes will be predominant in 1997.
- There will be a chip content of about $5 for primarily video amplifier controls (moving to 135 MHz) and CRT controls.

Keyboards

The trend in keyboards is commodity items moving toward ergonomic and wireless versions.

Leading keyboard OEMs worldwide are Keytronic, Silitek, and MaxiSwitch.

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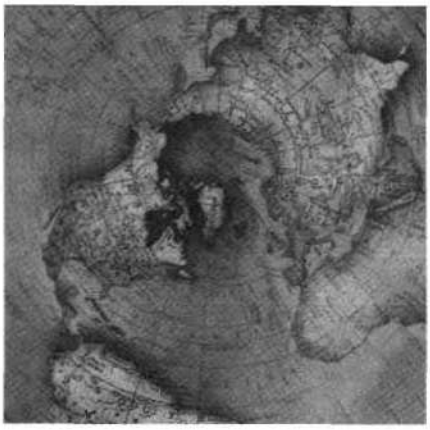

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3-D Graphics Adds Sizzle and Semiconductor Content to Multimedia PCs

Focus Report

Program: Semiconductor Directions in PCs and PC Multimedia Worldwide
Product Code: PSAM-WW-FR-9601
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Table of Contents

List of Figures

List of Tables

Chapter 1
Executive Summary

We all live in a three-dimensional world where depth is just as important as height and width—until we sit down at a PC and stare at a two-dimensional graphical user interface (GUI). The PC world is changing, though, as a new generation of PC graphics controllers is being sold with 3-D graphics acceleration features. The initial 3-D products targeted at the consumer market appeared last year but sold at prices only an early adopter would pay. The year 1996 will bring the transition from niche market to mainstream as competition increases and higher levels of chip integration make motherboard designs with 3-D graphics feasible.

This new market does face some challenges, however. Software and hardware compatibility must improve so that software will run on every 3-D accelerator instead of just one or two. Lower prices for chips as well as board-level products will certainly help fuel this market, but a long list of software titles is also necessary to appeal to a broad market. The bottom line is that 3-D graphics features are the latest reason for a PC user to buy a new graphics card or even a whole new PC. Either way, graphics chip vendors have a new opportunity to add features and differentiate their products from their competitors. This report provides an overview of the market for 3-D graphics chips in multimedia computers, highlighting the issues, trends, features, and market opportunity through the end of the decade.

Chapter 2 contains the market forecast. Chapter 3 explores the impact of 3-D graphics on graphics subsystem design and shows four typical implementations for 3-D graphics features in PCs, ranging from software-only acceleration to three different hardware implementations. Chapter 4 discusses software issues that impact the market potential and hardware standards for 3-D graphics. Chapter 5 describes the features commonly implemented in 3-D graphics hardware and highlights their impact on chipset complexity and market potential. Chapter 6 provides a brief profile of the market players in the 3-D graphics market, and Chapter 7 is the Dataquest perspective on the 3-D graphics chip market for PCs. Appendix A includes a recent Dataquest Alert on a new proposal from Intel for a high-speed graphics port called the Accelerated Graphics Port (AGP).

Chapter 2
Market Forecast

The PC graphics market has an insatiable appetite for new features, and 3-D features are the next item on the menu. 3-D graphics features are not new to the computing world, but a relatively high cost for hardware and lack of compatibility for entertainment software have kept 3-D hardware out of the consumer PC market—until now. Last fall, 3-D graphics products designed for PC gaming rather than workstation applications finally hit the street. Sales volume was relatively low but represented only the early adopters who happily paid $300 to $500 for 3-D graphics with a few bundled games. 3-D accelerators require a critical mass of software development and lower cost to become widespread. Those requirements are being addressed this year as more 3-D games will hit the retail shelves and a variety of new 3-D graphics accelerators will heat up the price competition. Table 2-1 shows the unit shipment forecast for 3-D graphics accelerator chips. Figure 2-1 shows those same numbers as well as the total OEM PC and PC motherboard unit shipments.

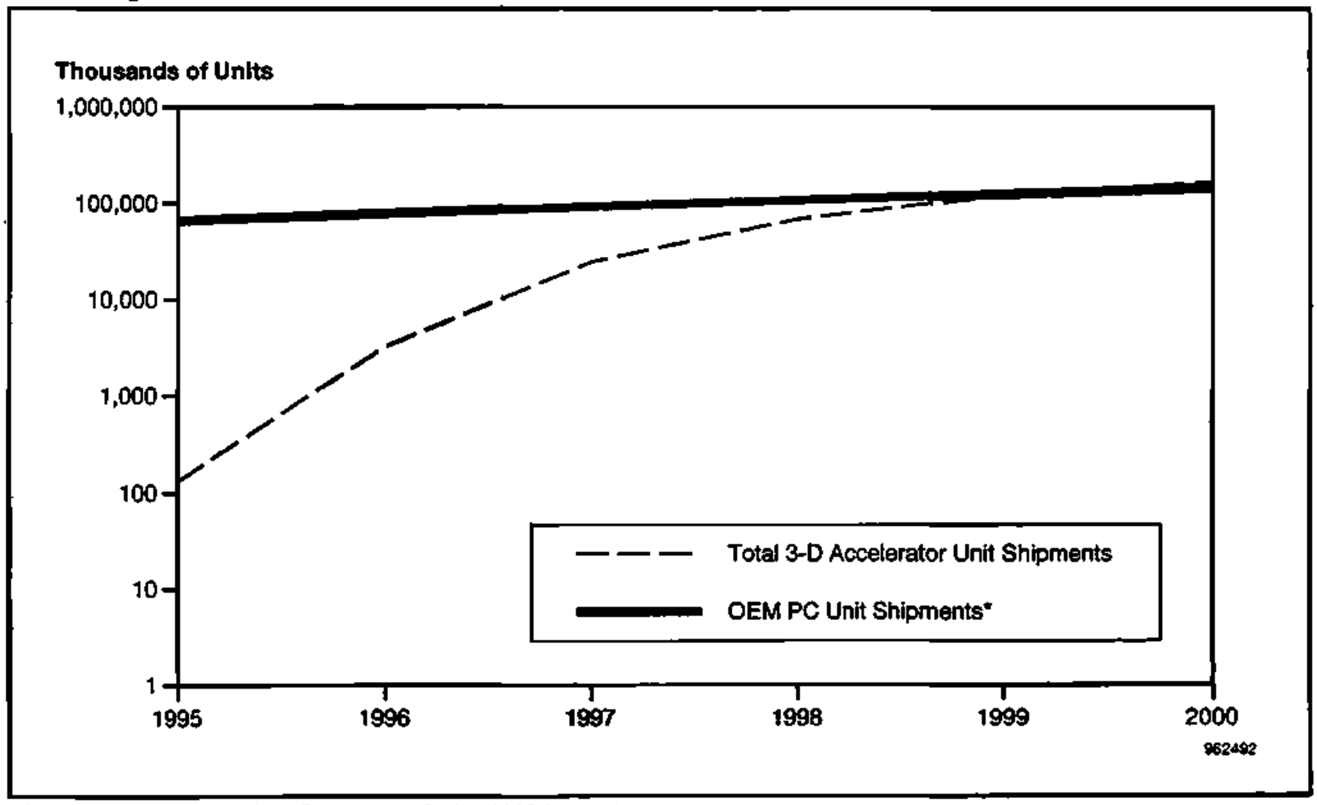
Motherboard implementations could be the biggest factor affecting unit shipments of 3-D accelerators for 1996. The market for 3-D graphics in 1995 was exclusively an add-in card market because single-chip solutions were not available in time for that Christmas. Dataquest believes that 1996 will also be predominantly an add-in card year, with a big transition to motherboard implementations in 1997. A strong commitment from PC OEMs to put 3-D graphics chips on the motherboard could drive higher unit volumes in 1996 by reducing the cost of 3-D to the end user. IBM has already announced that it will use ATI's 3D RAGE chip in a number of Aptiva models this year. This market is elastic, with much greater demand for 3-D accelerators as the cost decreases. Several single-chip 3-D accelerators are pin-compatible with other graphics controllers from the same vendors. These pin-compatible chips give PC OEMs the flexibility to add 3-D graphics to their motherboards without any redesign. The incremental cost of adding 3-D graphics is then simply the additional cost for the controller, which may be as little as $8 to $10 in high volumes, and possibly the cost of a second megabyte of graphics memory, if the OEM had not planned to ship the model with a 2MB buffer.

Table 2-1
3-D Graphics Accelerator Forecast (Units in Thousands)

	1995	1996	1997	1998	1999	2000	CAGR (%) 1995-2000
3-D Accelerator Only	77	250	400	600	800	900	63.5
3-D Accelerator with Other Graphics Functions*	53	3,004	24,203	67,795	121,207	161,649	397.6
Total 3-D Accelerator Shipments	130	3,254	24,603	68,395	122,007	162,549	316.3
OEM PC Unit Shipments**	60,171	71,651	84,694	98,693	114,178	131,700	17.0
Additional Motherboard Shipments	5,528	6,495	7,662	8,893	10,297	11,881	16.5
Total OEM PC and Motherboard Shipments	65,699	78,146	92,356	107,587	124,475	143,581	16.9

*Other functions include a minimum of VGA compatibility, 2-D acceleration, and digital video acceleration.
**OEM PC shipments are from Dataquest's Spring 1996 forecast.
Source: Dataquest (April 1996)

Figure 2-1
3-D Graphics Accelerator Forecast (Thousands of Units)



*OEM PC shipments are from Dataquest's Spring 1996 forecast.
Source: Dataquest (April 1996)

Chapter 3

Impact of 3-D Graphics on PC Design

The addition of 3-D graphics capabilities to today's PCs has a large impact on system design. 3-D graphics functions place high demands on the graphics memory, the peripheral bus (PCI), and the microprocessor. Each of these areas is now a performance bottleneck.

PCI Bus Bandwidth and the New Accelerated Graphics Port (AGP)

3-D graphics subsystems off-load many tasks to the CPU, placing large demands on the PCI bus to carry information back and forth. The PCI bus is actually a performance bottleneck because other devices such as mass storage and I/O peripherals are competing for the bus at the same time. PCI's 130-MB/sec peak bandwidth is not fast enough because of latency (the time lag for granting access to the next peripheral waiting for the bus) and a lack of concurrency (peripherals are not allowed to share the bus even if they both need it at the same time).

Intel has proposed a solution that it calls an Accelerated Graphics Port (AGP). This port is a single high-speed port that is like a PCI slot but uses a faster clock speed and includes a special interface to main memory. The special memory interface is discussed later in this document under the heading Graphics Memory. Of course, PCI was designed to be scalable from its current specification to a higher clock speed (66 MHz instead of 33 MHz) and a wider data path (64 bits instead of 32 bits), but technical and cost issues make those upgrades less attractive than Intel's AGP proposal. The AGP will use a 66-MHz clock, but will effectively double it to 133 MHz by using the rising and the falling edge of the clock signal, making it four times faster than a 33-MHz PCI slot.

Graphics Memory

3-D graphics places high demands on both the size and the speed of the graphics memory. The memory must perform the traditional role of frame buffer as well as provide additional capacity for off-screen information. Two of these demands are storing depth information for each pixel within the 3-D scene (Z-buffering) and holding bit-mapped patterns called textures. An additional need is called double-buffering, which means that two frame buffers are allocated within the graphics memory; one of the frame buffers is used for screen refresh, while the next frame, or screen of graphics, is drawn in the second buffer. This prevents the screen refresh from interfering with drawing the next frame in the memory, but with the cost penalty of doubling the frame buffer size.

The requirements for greater size and speed of graphics memory are driving the adoption of larger graphics buffers and new types of memory. Most 3-D graphics subsystems require a 2MB graphics buffer instead of the 1MB buffer still shipped on many PCs. The needs of 3-D graphics are also driving demand for synchronous graphics RAM (SGRAM) as a replacement for the standard DRAM used for graphics memory on almost all PCs today.

3-D graphics will drive the adoption of a shared buffer architecture (SBA) for memory in PCs as Intel's Accelerated Graphics Port (AGP) becomes available in the second half of 1997. SBA is related to unified memory architecture (UMA), but avoids the performance problems that UMA systems have. SBA involves a dedicated memory for the frame buffer, but allows the graphics controller greater access to main memory. The greatest drawback to UMA remains the main memory bandwidth, which sometimes causes the CPU to wait while the memory is accessed for screen refresh; the benefit of UMA is greater flexibility allocating memory to the graphics subsystem. SBA is an important part of boosting 3-D graphics performance because it provides the benefits of UMA without the drawbacks.

The Microprocessor and Intel's MMX Features

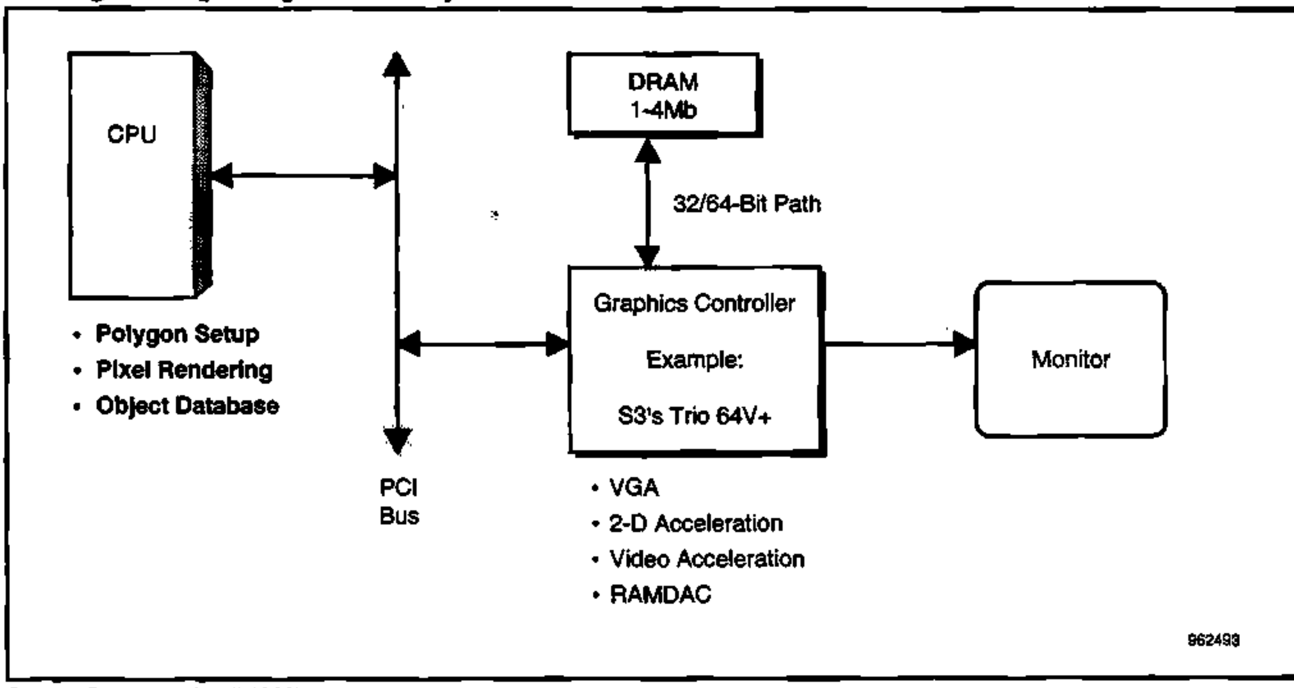
3-D graphics places much greater demands on the CPU than 2-D graphics does. This increases demand for faster microprocessors (MPUs) because 3-D graphics operations are calculation intensive. Consumer expectations for 3-D graphics performance will scale faster than general-purpose microprocessors can deliver, so Intel and other microprocessor companies have added new functions to their designs specifically to accelerate multimedia functions, including graphics operations. Intel has collectively named these new features MMX, short for multimedia extensions. Other MPU vendors have created or will create special acronyms for their own multimedia enhancements, including Sun Microsystems' Visual Instruction Set (VIS).

Intel designed MMX to accelerate many multimedia functions, not just 3-D graphics. The MMX functions are integer-based, while many 3-D graphics setup calculations handled by the microprocessor are floating-point intensive. This could be a performance issue for 3-D graphics if using the MMX functions interferes with access to the floating-point unit. Even though the issue of 3-D graphics performance is unclear, MMX's utility for video decompression and audio or telephony signal processing is not in question. If there is a concurrency issue within the MPU, graphics chip vendors may have a greater opportunity to add value in the graphics area by off-loading the 3-D setup calculations from the CPU, leaving greater capacity for the CPU to process audio, video, and application tasks. As this issue becomes clearer, graphics vendors should align their long-range product plans with MMX, because Intel plans to add MMX to every Pentium and Pentium Pro version. The opportunity for graphics vendors is to complement MMX, because those features are expected to ship in volume as soon as late 1996.

Four Examples of Implementation

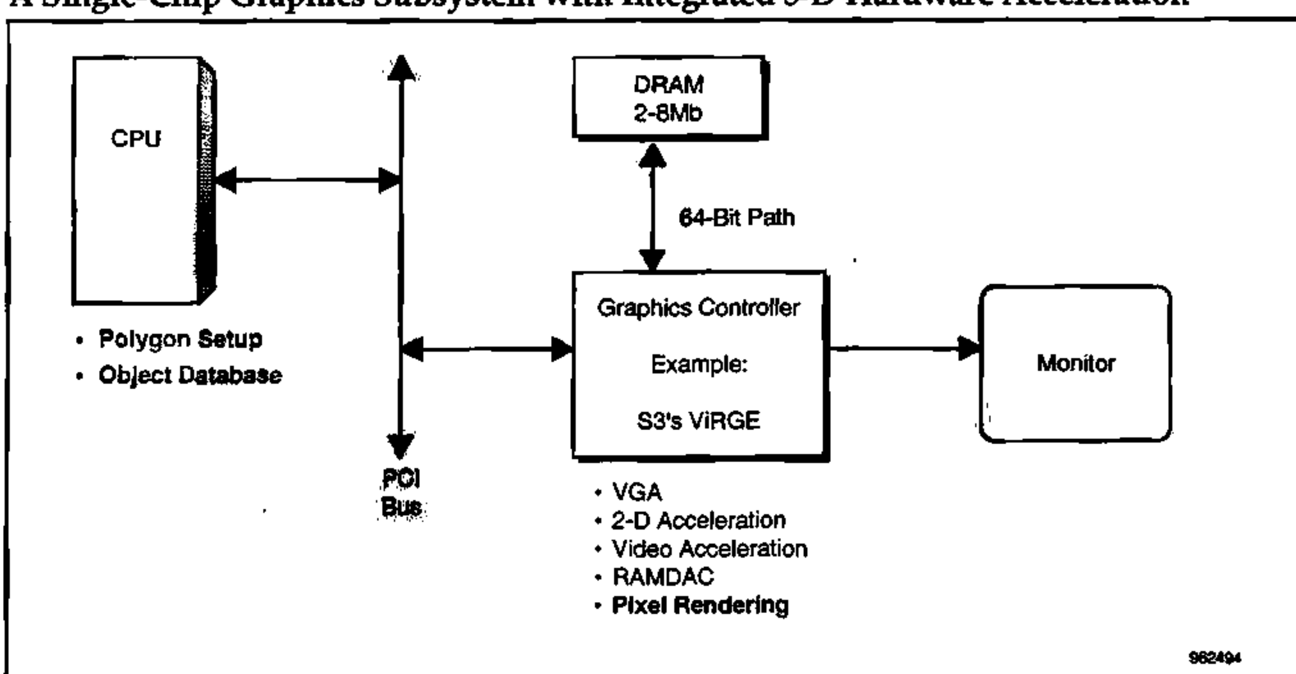
Figures 3-1 through 3-4 show four different graphics subsystem implementations, varying from a typical subsystem today with no hardware acceleration for 3-D graphics to a high-end subsystem that supports only 3-D functions and requires additional hardware for 2-D graphics functions. Each figure is annotated with the size and type of graphics memory that is typical at that performance level. For simplicity, 3-D graphics functions are grouped into three broad categories: object database management, polygon setup functions, and pixel-rendering functions. These are boldfaced in Figures 3-1 to 3-4. Note the shift of these groups of functions from the CPU to dedicated graphics chips as the graphics subsystem becomes progressively more complex.

Figure 3-1
A Single-Chip Graphics Subsystem without 3-D Hardware Acceleration



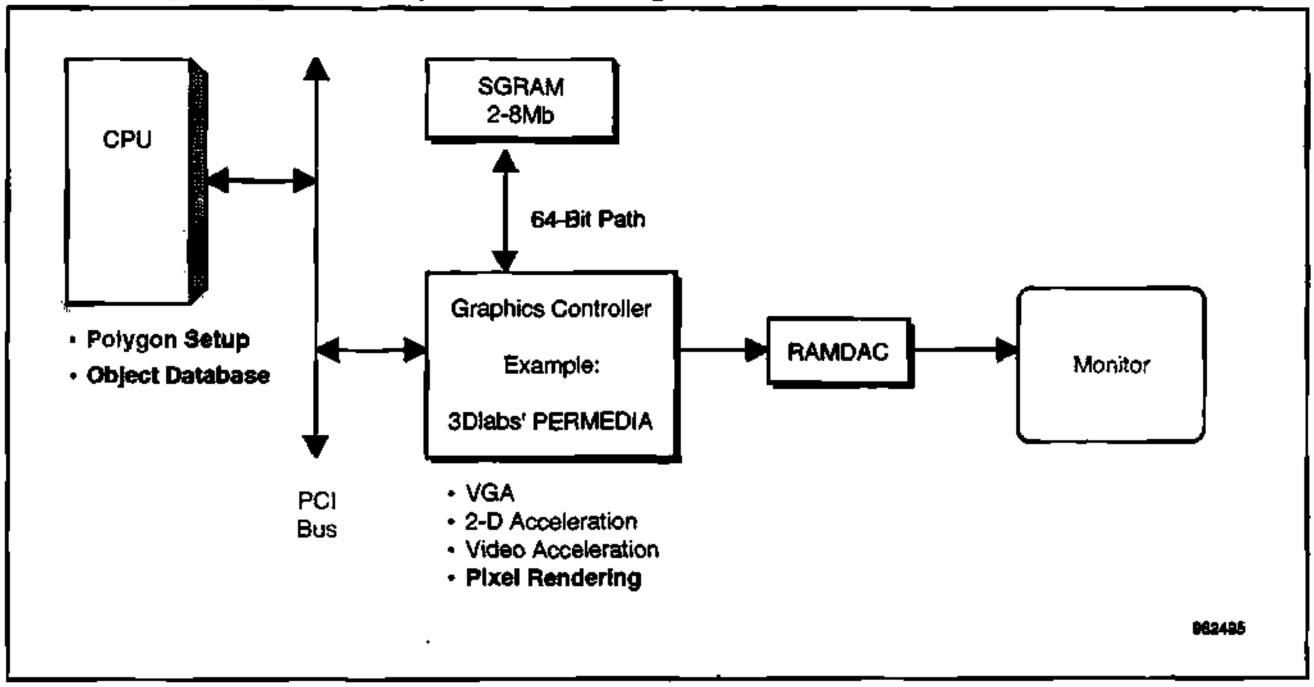
Source: Dataquest (April 1996)

Figure 3-2
A Single-Chip Graphics Subsystem with Integrated 3-D Hardware Acceleration



Source: Dataquest (April 1996)

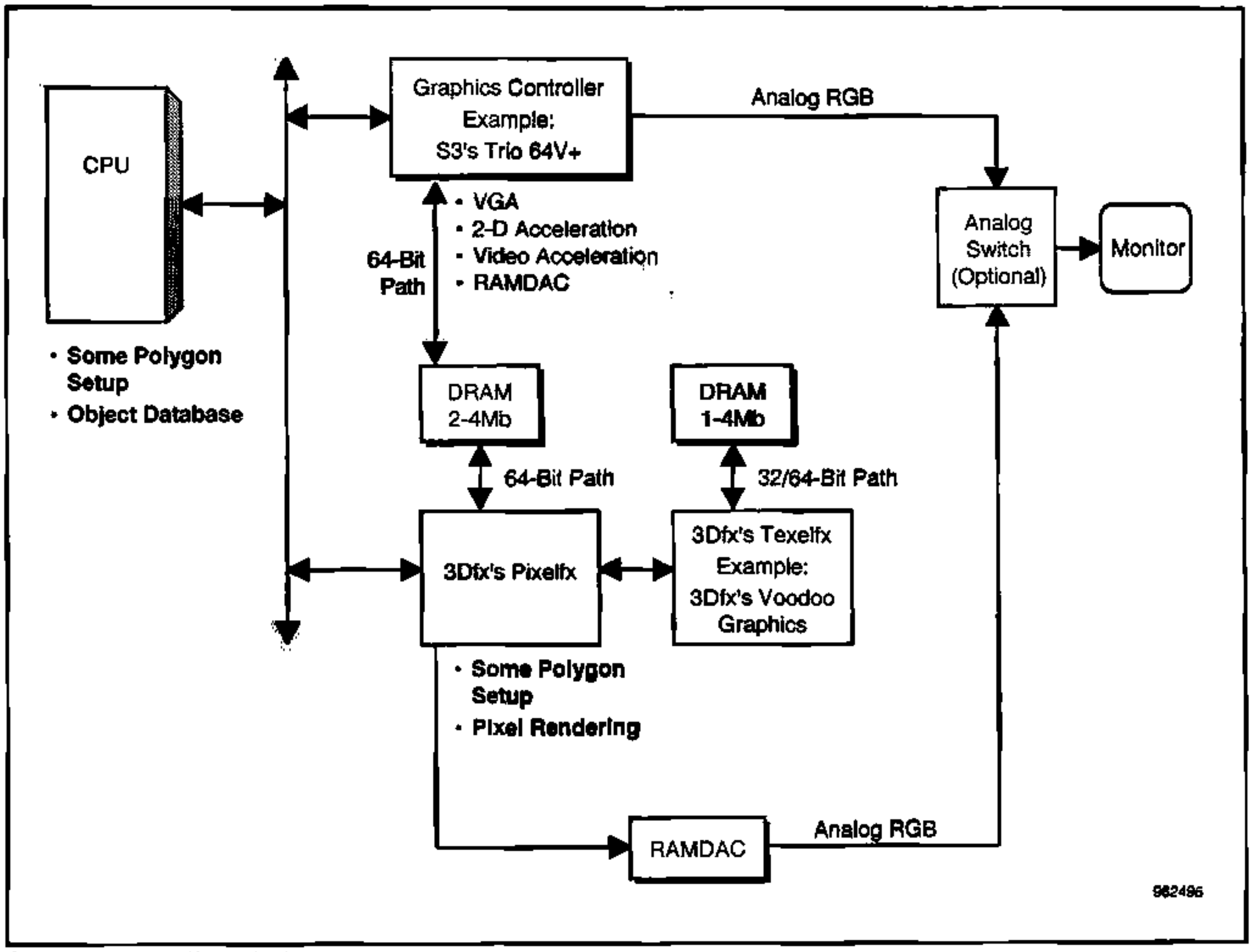
Figure 3-3
A Multichip Graphics Subsystem with Integrated 3-D Hardware Acceleration



Source: Dataquest (April 1996)

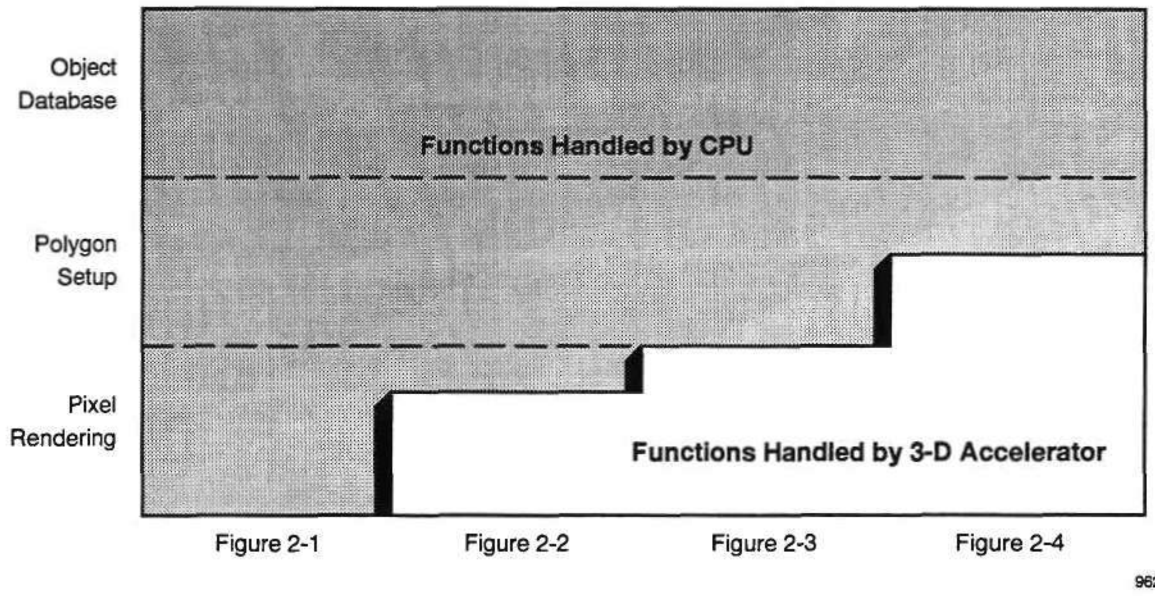
Figure 3-5 summarizes this shift of functions from the CPU to 3-D accelerators shown in Figures 3-1 to 3-4. Pixel rendering (calculating the color of each pixel) is the first task to be off-loaded from the CPU to a 3-D graphics accelerator. The difference between Figures 3-2 and 3-3 in terms of functions is simply the sophistication of pixel rendering and a greater variety of rendering features. The last example, Figure 3-4, shows the shift of some of the polygon setup functions to the 3-D accelerator, which further reduces the workload imposed on the CPU. Polygon setup is basically the translation of the polygon data into the parameters needed by the rendering engine to do its job.

Figure 3-4
A High-Performance Graphics Subsystem with Nonintegrated 3-D Hardware Acceleration



Source: Dataquest (April 1996)

Figure 3-5
Shift of 3-D Functions from CPU to 3-D Accelerators in Figures 3-1 to 3-4



Source: Dataquest (April 1996)

Chapter 4

Software and Compatibility Issues

The 3-D graphics chip market faces a challenge in terms of software and hardware compatibility. The first 3-D graphics accelerators priced for consumer markets hit the retail shelves with add-in cards last year with a variety of bundled games. These cards had to be bundled with software that had been rewritten specifically to take advantage of those new features because there wasn't any other compatible software. Compatible software in this case is defined as software that can make use of the 3-D features in a given accelerator.

The software market is changing, and there are now a few software titles on the market that support some of the new 3-D accelerators. However, the number of applications is small because a hardware-independent application programming interface (API) for using 3-D graphics accelerators does not exist. Independent software vendors (ISVs) face a trade-off between additional development work for each specific 3-D accelerator and greater compatibility with the installed base of PCs. That trade-off limits the number of games that will run on any single 3-D graphics accelerator.

New APIs will help to solve these compatibility problems. Microsoft will release its Direct3D API this spring, and Apple has already released its QuickDraw 3D RAVE. These new APIs, as well as a more mature API called OpenGL, could make the dream of hardware independence (for 3-D graphics acceleration on PCs) a reality. Hardware independence means that the programmer does not need to know details of the PC hardware for a specific game to be able to use the special features of that PC, such as a 3-D graphics accelerator. This is really made possible by a part of the API called a Hardware Abstraction Layer (HAL). The HAL lets the software make use of hardware capabilities without knowing the details of the hardware. Of course, this also requires the graphics accelerator vendors to make their 3-D graphics accelerators compatible with these APIs from the hardware side. As long as one of these APIs emerges as a universal standard, support from the software community as well as the hardware community will not be a problem because it will simplify product development and increase market opportunity.

Widespread adoption of a single API such as Direct3D or QuickDraw 3D RAVE will fuel demand for 3-D graphics accelerators in two ways. First of all, greater compatibility reduces the buyer's risk of obsolescence. Most consumers will postpone spending $250 or more on a 3-D accelerator if they feel the product may become obsolete quickly. Reducing that fear makes the decision to purchase much easier. Second, if software compatibility is not a distinguishing factor among different 3-D accelerators, then price and performance will be much more important. This will foster competition, resulting in lower prices and greater demand.

Microsoft's Direct3D is the most likely candidate to emerge as the standard API for 3-D games on personal computers because it will be integrated into the Windows 95 operating system, which means that more PCs will have it than any other API. The value of an API increases with the percentage of the installed base that has it, much in the same way that a telephone is more useful if everyone has one. Graphics accelerator vendors should absolutely make sure that their products support Direct3D. Apple's QuickDraw 3D RAVE appears to be strong technically, but would be more likely to become standard if the installed base of PCs included more Macintosh computers. OpenGL is well established in the professional 3-D graphics markets for CAD and scientific applications, but may not be adaptable to the demands of PC game software.

The biggest potential roadblock to Direct3D's becoming the standard API for PC games is performance. Dataquest expects Direct3D to perform well, but if the performance is poor it will not be widely used, regardless of its integration into Windows 95. In that case, Apple's QuickDraw 3D RAVE will have much greater impact. OpenGL is the standard API for the workstation market, with backing from all major workstation vendors, because of its mathematical precision. However, current versions of OpenGL for the PC do not provide the speed required for PC games, so additional development must be done before OpenGL is a realistic candidate for those applications.

An additional benefit of using Direct3D or QuickDraw 3D RAVE is the ability of other APIs to use the hardware abstraction features in those two APIs while providing additional value in terms of feature set or possible speed. Table 4-1 is a more thorough list of popular high-level APIs with a brief comment about each one.

Table 4-1
List of 3-D APIs for the PC Platform

Name	Main Supporter(s)	Comments
BRender	Argonaut	Popular today for PC games; likely to coexist with Direct3D
3DR	Intel	Not likely to be mainstream
Direct3D	Microsoft	Will define universal platform in the future; is expected to include the high-level features of Reality Lab; will be cross-platform, including Windows NT and Mac OS
RenderWare	Criterion	Popular today for PC games; likely to coexist with Direct3D
OpenGL	All major workstation vendors (SGI, IBM, HP, SUN and others)	Widely used for math and scientific applications; may realize broader consumer appeal with 3-D graphics on the World Wide Web; unlikely to have an impact for PC games
QuickDraw 3D RAVE	Apple	Cross-platform; combination of rendering engine and HAL that is similar to Direct3D

Source: Dataquest (April 1996)

Chapter 5

Feature and Product Positioning

Comparing two or more 3-D accelerators fairly is challenging because performance numbers can be misleading and some advanced features compensate for lower performance in other features. This chapter contains a section about the performance numbers currently used for 3-D accelerators, as well as tables showing the relative positioning of these products. For the purposes of this report, 3-D accelerators are lumped into three general categories: low-end, midrange, and high-end products. The features of these products have also been categorized as low-end, midrange, and high-end. Unfortunately, a one-to-one correlation between the product groups and the feature groups is not possible because of the variety of products and features.

Confusion about Performance Numbers

The lack of good benchmarks for 3-D graphics accelerators is a problem because performance numbers are a critical element of selling computers (and therefore graphics products). Excuse me ... what clock speed is your Pentium? ... How many polygons per second does your graphics card render? These performance indicators can be misleading with 3-D graphics, even more so than with other areas of computing, because the metrics (for example, polygons per second) do not map directly to what the user really wants, which is a combination of image quality and interactivity. Image quality is a function of image resolution, number of colors, shading techniques, and the sophistication of the texture mapping as well as the polygon rate. It is difficult to measure because a particular scene might be constructed with fewer polygons if advanced rendering features are used, so a trade-off is possible between rendering feature set and polygon performance. Interactivity is more dependent upon the polygon rate because it affects how many frames per second the graphics controller can draw with a given number of polygons. More frames per second (that is a higher frame rate) is critical for action games like Doom or flight simulators because the game player will be frustrated by small delays between pressing a key and seeing the response.

Positioning of 3-D Accelerator Features

3-D graphics features are much more complex than those for 2-D graphics and can be confusing. Table 5-1 is a list of features that are commonly implemented in 3-D graphics chips; it groups them by level of impact on chip design. More detailed descriptions of the most common features follow the table for those readers who may not be familiar with this terminology.

Polygon Setup

Polygon setup is a high-end feature for 3-D accelerators. It is typically off-loaded to the CPU because it is floating-point calculation intensive and benefits greatly from the floating-point unit (FPU) built into every Pentium microprocessor. The problem with off-loading all the polygon setup to the CPU is simply performance. A typical 3-D accelerator is capable of rendering more polygons per second than the CPU can process. This

Table 5-1
Positioning of 3-D Accelerator Features

Feature	Relative Positioning of Feature*	Comments
Polygon Setup	High-end	Usually completely off-loaded to host CPU
Polygon Rendering Rate		Highly variable depending on number of rendering features and average triangle size
Up to 300,000 Polygons per Second	Low-end	
300,000 to 500,000 Polygons per Second	Midrange	
Over 500,000 Polygons per Second	High-end	
Shading Techniques		
Flat	Low-end	The budget method of shading
Gouraud	Midrange	A nice trade-off between realism and algorithm complexity
Phong	High-end	Calculation intensive
Texture Mapping	Midrange	Impact varies greatly with sophistication of filtering and perspective correction
Perspective Correction	Midrange	Allows scenes to be constructed from fewer polygons
Filtering		
Linear	Low-end	Averages two texels to calculate a pixel
Bilinear	Midrange	Averages four texels to calculate a pixel
Trilinear	High-end	Averages eight texels to calculate a pixel
MIP-Mapping	Midrange	Important for matching detail level to distance of objects
Z-Buffering	Midrange	Stores depth (Z-axis) value for every pixel in the frame buffer
Alpha Blending	Midrange	Holds transparency/translucency information
Antialiasing	High-end	Increases memory accesses, so higher memory bandwidth is required

Note: Midrange products include low-end as well as midrange features. High-end products include low-end and midrange as well as high-end features.
Source: Dataquest (April 1996)

means that the CPU is often a bottleneck for 3-D graphics performance, rather than the 3-D accelerator itself. As a result, some 3-D accelerators share the polygon setup with the CPU to create a more balanced system.

Polygon Rendering Rate

The polygon rendering rate can be misleading because it is typically not the system bottleneck for 3-D graphics in an actual PC. It also varies widely with the average size of the polygons and the number of rendering features (such as texture-mapping, filtering, and perspective correction) that are used. A rough guideline for polygon rates is up to 300,000 polygons per second for a low-end accelerator, 300,000 to 500,000 for a midrange accelerator, and greater than 500,000 for the high-end. Those polygon rates are for textured polygons with an average of 50 visible pixels each.

Shading Techniques

Three shading techniques are popular today: flat shading, Gouraud shading, and Phong shading. These are listed in order of complexity from low to high. Flat shading is the low-end technique. It is fast and simple, but draws attention to polygon edges, making objects look blocky if too few polygons are used. Gouraud shading is a midrange technique and is a nice trade-off between speed and sophistication. Almost all 3-D accelerators use a combination of flat shading for some objects and Gouraud shading for others. Phong shading is an advanced technique that includes effects such a glare and reflection, but it is much slower than Gouraud shading. It is an important differentiator between accelerators and is included on some midrange products, all high-end products, and no low-end ones.

Perspective Correction for Texture Mapping

Perspective correction is a critical texture-mapping feature that is standard for almost all 3-D accelerators. It is important because it reduces the number of polygons in a scene and removes annoying image defects that result from texture mapping without perspective correction. Consider this a required feature for 3-D accelerators.

Filtering

Filtering, like shading, can be done several ways that scale from low to high in terms of performance and image quality. The types of filtering that a 3-D accelerator can use are important differentiators among competing products. Filtering is a part of the texture mapping process and is important to reduce image defects resulting from mapping a 2-D texture onto a 3-D object. The lowest option for filtering is not to do any filtering. If someone talks about point-sampled texture mapping, that person is saying "no filtering is used." The types of filtering, in order of increasing complexity, are linear, bilinear, and trilinear filtering, with each level being twice as demanding as the previous one. Bilinear filtering is the best trade-off between image quality and performance and is a requirement for midrange or higher accelerators.

MIP Mapping

MIP mapping is an important aspect of texture mapping and is included in almost all 3-D accelerators. It allows different versions of a texture map to be used, depending on how much detail is necessary. This improves image quality and speed because the texture can be prescaled with a high-quality scaler, and then stored, rather than being scaled in real time, which increases the processing load on the 3-D accelerator. Any accelerator without MIP mapping will be relegated to the low-end category.

Z-Buffering

The Z-buffer stores the depth or Z-axis value of each pixel in a 3-D graphics scene. 3-D accelerators need to have a Z-buffer to avoid image defects where a background object obscures an object supposed to be in front of it. If a 3-D accelerator renders only visible pixels, then the main memory has effectively been used as a substitute for the Z-buffer. Most 3-D accelerators will render an entire polygon if any part of it is visible. Once a pixel is rendered, it is not written to the frame buffer unless it is "in front of" the pixel currently stored in that location. The basis for determining which pixel is visible is the depth information stored in the Z-buffer. Any 3-D accelerator that does not use a Z-buffer or does not otherwise prevent pixels from being overwritten by background objects should be considered a low-end 3-D accelerator.

Alpha Blending

Alpha blending allows a new pixel to be "blended" with an existing pixel in the frame buffer according to the alpha values of the pixels. This feature is a differentiator among the low-end 3-D accelerators and a required feature for midrange or high-end accelerators.

Antialiasing

Antialiasing is a high-end feature that reduces the "jaggies" or stair-step defects on sloping lines. It is less important for action games than for static images, and it places additional demands on memory bandwidth. For these reasons, it is often omitted from low-end and midrange products.

Product Positioning

Table 5-2 lists the basic details for a variety of 3-D accelerators that have been announced or are expected soon.

Table 5-2
Product Positioning for 3-D Graphics Accelerators

Company	Chip Name	Target Platform	2-D and Motion Video Acceleration?	Integrated RAMDAC?	Number of Chips	Relative Positioning	Availability
3Dfx	Voodoo Graphics	PC, arcade, game console	No	No	Two	High-end	June 1996
3Dlabs	PERMEDIA	PC	Yes	No	One	Midrange	Second quarter 1996
Alliance Semiconductor/3Dfx	Not announced	PC	Yes	TBD	One	Midrange	TBD
ATI	3D RAGE	PC	Yes	Yes	One	Low-end	Now
Chromatic	Mpact	PC; suitable for others	Yes	No	One	Low-end	Third quarter 1996
Cirrus Logic	Unnamed	PC	Yes	Yes	One	Low-end	Fourth quarter 1996
Cirrus Logic/3DO	Unnamed	PC	Yes	TBD	TBD	High-end	Fourth quarter 1996
Creative Labs	Gigi	PC	No	No	One	Low-end	Now
Lockheed Martin	REAL3D	PC	No	No	Two	High-end	Now
LSI Logic	Undefined for PC market; Sony Playstation Graphics Processor	Possible entrant to PC graphics or second-generation chip for game consoles	TBD	TBD	One	TBD	TBD
Matrox	Unnamed	PC	Yes	No	One	Low-end	Now
NEC/VideoLogic	PowerVR	PC, arcade, game console	No	No	Two for current version, one for PCX1	High-end	Two-chips now, PCX1 in third quarter 1996
NVIDIA	NV1	PC	Yes	No	One	Low-end	Now
NVIDIA	NV3	PC	Yes	No	One	Midrange	Fourth quarter 1996
Oak	OTI64311	PC	Yes	Yes	One	Midrange	Second half 1996
OPTi	Unnamed	PC	Yes	Yes	One	Low-end	TBD
Rendition	Verite	PC	Yes	No	One	Midrange	Now
S3 Inc.	ViRGE	PC	Yes	Yes	One	Low-end	Now
SGS-Thomson	STG2000	PC	Yes	No	One	Low-end	Now
S-MOS	PIX (SPC1515)	PC	No	No	One	Low-end	Third quarter 1996
Trident	T3D9692	PC	Yes	Yes	One	Low-end	Now
Yamaha	RPA2	PC	No	No	One	Low-end	Now

TBD = To be determined
Source: Vendors, Dataquest (April 1996)

Chapter 6

Leading Market Players

The market for 3-D graphics accelerators is exciting. Competition includes traditional graphics providers and a number of new companies. Start-ups, as well as established companies new to the PC graphics world, are using 3-D graphics chips as their entree into the PC graphics market. Competition will be fierce as vendors scramble for design-wins at both the motherboard and add-in board levels. This market will see rapid growth as 3-D penetrates the PC market, but that level of growth will be insufficient to support all these players. The companies described below are listed in alphabetical order.

3Dfx

3Dfx refers to its product line as Voodoo Graphics. The implication is that the engineers at 3Dfx have worked magic or voodoo to pack so many features into their products. The company has put a lot of features into their chips, but it plans to charge a premium price for them. The 3Dfx products announced for the PC market so far are positioned at the high end of market. The chips are targeted initially at the PC and arcade game platforms, but could be scaled for home video game units as well. Look for a scaled-down, single-chip solution for the PC market later this year as a joint effort between Alliance Semiconductor and 3Dfx.

3Dfx is a privately funded company founded in March 1994. The first round of venture capital totaled $5.5 million.

3Dlabs

3Dlabs established itself as a 3-D graphics company with accelerators targeted at the commercial desktop and workstation markets. The GLINT 300SX chip from the company has been the highest-volume 3-D graphics accelerator over the past few years. It is an OpenGL accelerator and is most widely used for CAD and other professional applications. The GLINT chip is too expensive for volume consumer applications, so 3Dlabs has leveraged its graphics expertise to create new products tailored for that market. The first chip, called Gigi, was designed for the exclusive use of Creative Labs and powers the 3DBlaster VL-based card from Creative. The follow-on product is called PERMEDIA. The name follows from 3Dlabs' vision of PERvasive MEDIA, where 3-D graphics, 2-D graphics, and digital video features become pervasive. Creative Labs has announced that it will use the PERMEDIA chip in board-level products, as well as the Verite chip from Rendition.

3Dlabs is sampling the PERMEDIA chip now with plans to ramp production quickly. This chip has a good price/performance trade-off, but is not ready for motherboard implementations because it requires an external RAMDAC.

ATI

ATI's chip-level entry in the 3-D graphics market is called 3D RAGE. It is a single-chip design that is pin-compatible with the Mach64 graphics controller. ATI is selling the 3-D Rage chipset at both the chip and the board level. 3D RAGE is a single-chip design and therefore is a motherboard candidate for designs where the Mach64 is already designed in, including the Intel Atlantis motherboard. In fact, ATI has already secured a major PC OEM design-win with IBM's Aptiva line. The name of ATI's board-level product that uses the 3D RAGE chip is 3D XPRESSION.

Chromatic Research

Chromatic is bringing a new business model—the chipless semiconductor company—to the market. The Chromatic chip is named Mpact, but it will not be manufactured or sold by Chromatic. Strategic partners will make and sell the chip while Chromatic will sell the software to use the chip. The company has announced two partners so far, LG Semicon and Toshiba, and expects to announce a third partner soon.

The Mpact chip is not a graphics controller, but it can be used as one. It is actually an embedded processor that, along with some similar products, is defining a new product category called media processors or media engines. Instead of designing fixed-function chipsets, Chromatic and others have designed embedded processors optimized for multimedia-type functions including graphics, digital video, telephony, and audio processing. The Mpact chip is powerful enough to run several functions concurrently and could replace several of the fixed-function chipsets designed into multimedia PCs today.

Chromatic is making rapid progress on the software modules for the Mpact chip and expects to release the final beta versions in March. The hardware design is finalized and appears to be robust and manufacturable. The progress in both hardware and software indicate that technical issues will not be a barrier to Chromatic. Market issues such as design-wins into leading OEMs and sell-through to the end user are the next step. Chromatic expects to announce several key design-wins soon, but this information is not yet public. The Mpact chip offers significant benefits in terms of programmability compared with fixed-function chipsets and could seize market share from the leading graphics suppliers (as well as audio, telephony, and digital video suppliers).

Cirrus Logic

Cirrus Logic does have a 3-D graphics strategy but has been very shy about sharing details publicly. Dataquest expects something like S3's ViRGE chip in terms of price and performance from Cirrus. The similarities will be the following:

- Single-chip
- Pin-compatible with other Cirrus chips (most likely the Laguna series)
- Shipping in time for Christmas 1996

Matrox

Matrox introduced the 3-D Millenium graphics card and ramped up volume in 1995. The company is selling board-level solutions predominantly and appears to be pricing them at the high end of the consumer market. It is likely that it will remain in the premium range of the retail and OEM card market rather than compete for the mainstream 3-D graphics market. This card is not suitable for PC games because it does not include texture-mapping features.

NEC/VideoLogic

NEC and VideoLogic have teamed up to produce a high-end chipset for 3-D graphics on PCs, arcade games, and even home video games. The arcade chipset is the first one out of the gate and consists of two chips: an image synthesis processor (ISP) and a texture and shading processor (TSP). For arcade implementations, multiple ISPs can be used to scale performance. The companies are planning to sample the PC version of this chipset in the second quarter of 1996. The PC version is a single chip, called the PCX1, but offers 3-D graphics only. The PCX1 requires a standard graphics controller to provide the VGA, 2-D, and digital video acceleration features.

A unique feature of these chipsets is the technique for processing 3-D images. Instead of using a standard polygon-based model, the NEC/Videologic products use graphical planes and divide the screen into small chunks that are processed sequentially. This effectively moves the Z-buffer back into the PC's main memory instead of the graphics memory. The reason for doing this is simply graphics memory bandwidth.

NVIDIA

NVIDIA is truly a multimedia company, as proven by its integration of graphics, wave-table audio, and game port features into a single chipset with a single bank of memory. The company started shipping its first product, the NV1, last year and is expected to ship a second-generation product called the NV3 later this year. However, NVIDIA's strengths have also been its Achilles heel. The NVIDIA chips support a nonuniform rational β-splines (NURBS)-based model for 3-D graphics as well as use the more broadly accepted 2-D polygons, but a lack of compatible software made this feature less important. NVIDIA is now emphasizing the polygon performance of its chips instead of evangelizing the NURBS capabilities. NVIDIA's big design-win is Diamond Multimedia's EDGE 3D card. SGS-Thomson Microelectronics makes NVIDIA's chips and has the right to sell the DRAM versions, while NVIDIA sells the VRAM versions of its products.

OPTi

OPTi (like Cirrus Logic) has been very quiet about its 3-D graphics strategy. Dataquest expects a single-chip solution to appear in OPTi's product line. When this product arrives, it will need to compete head-to-head with the other single-chip solutions for motherboard design-wins. In this scenario, S3 and Cirrus have a great advantage because of their current design-wins. OPTi will have to make the product very attractive on a price/performance basis with the ViRGE chip and whatever Cirrus announces.

Rendition

Rendition announced its Verite chipset in 1995 and since then has won an add-in board design with Creative Labs. Creative will produce at least two different PCI boards, one of which will feature Rendition's Verite. This chip is positioned at the high end of the graphics line, so start-up Rendition is playing the price/performance strategy (that is, the product is expensive, but worth it).

Rendition is privately funded by venture capitalists and other investors. Initial funding in April 1994 was $5.2 million. The company secured a second round of financing for an additional $7 million and added Mitsubishi to the list of investors.

S3 Inc.

S3's ViRGE chip is this year's best bet for 3-D graphics on the motherboard. This is one of the lowest-cost 3-D chips announced so far and boasts pin-compatibility with the popular Trio64V+ controller. If an OEM has designed a motherboard for the Trio64V+, then upgrading to 3-D graphics is simply a matter of substituting the ViRGE chip for the Trio64V+ and adding a second megabyte of memory to the frame buffer.

This chip offers lower performance than many of the competing solutions but places well on the price/performance curve. S3 planned the ViRGE chip to be low-cost in order to help the market for 3-D graphics grow, while providing a performance level matched to a Pentium-100 or -120.

S3 is the largest variable in predicting how many 3-D accelerators will ship on PC motherboards. The Trio64V+ chip has a lot of motherboard design-wins, and each one is potentially a win for the ViRGE chip because of the pin-compatibility. If S3 is aggressive on pricing, the company will drive the adoption of 3-D hardware on the motherboard this year. Otherwise, 3-D graphics will remain predominantly an add-in card feature for 1996.

Trident

Trident's 3-D graphics controller is named the T3D9692 and is scheduled to sample in March of this year. The T3D9692 is a single-chip design that includes VGA, 2-D, 3-D, and digital video features like the ViRGE chip from S3. This chip is another good bet for motherboard implementations because of its pin-compatibility with the TGUI9660, TGUI9680, and TGUI9682 graphics products. If it is aggressive on pricing the T3D9692, Trident will help drive 3-D graphics onto the motherboard in 1996.

One unique feature of the Trident chip is support for unified memory architecture. Trident is the first company to announce a UMA, 3-D graphics product. This feature is not critical for 1996, but may become important for 1997. Dataquest expects other vendors to add UMA compatibility to 3-D graphics chips in 1997.

Chapter 7

Dataquest Perspective

3-D graphics is the next big feature for consumer PCs. Christmas 1995 was the first test of board-level 3-D products, and early adopters were willing to pay $300 to $500 for these cards. The year 1996 is the dawn of a new opportunity for 3-D graphics for two reasons. First of all, a number of new 3-D graphics accelerators are available now or will be shortly. These new chipsets will make board-level products less expensive (down into the $200 and higher range) as well as offer greater variety to the buyer. The second reason is motherboard implementations. A few of the new chipsets are suitable for motherboard implementations. Dataquest believes that only single-chip solutions will make it onto the motherboard, and that means VGA, 2-D, 3-D, digital video acceleration, and RAMDAC all in a single chip.

This market is going to grow rapidly, but how rapidly is a matter of great debate. The barriers to rapid growth are the following:

- The retail price of the 3-D cards
- The ability of software to take advantage of these cards
- The lack of a universal API for 3-D applications (corollary to the delays of Direct3D)
- The willingness of PC OEMs to configure their consumer PC models with 3-D graphics as a standard feature

All these are changing in favor of 3-D graphics, but Christmas 1996 is closer than you think. These issues will affect how many retail cards are sold (largely a factor of retail price and number of available games) and in which year, 1996 or 1997, motherboard implementations become the primary driver for this market.

The 3-D graphics hardware market will also be affected by features and market trends for both memory and microprocessors. The price and availability of extended data out (EDO) DRAM and SGRAM can help make or break the market opportunity for specific 3-D graphics chips. Lower memory prices help fuel this market, but sudden changes in the availability of specific memory types or configurations could have significant impact. Intel's new multimedia instruction set, MMX, will also have an effect by accelerating a number of multimedia functions, but the specific impact on 3-D graphics is unclear.

The shift from add-in card to motherboard implementation is a key trend to watch as this market unfolds. Semiconductor vendors that do not currently have a single-chip product (VGA, 2-D, 3-D, digital video acceleration, and RAMDAC) are advised to develop one for no later than spring 1997. The market cannot support the number of 3-D graphics companies now selling or developing products. It is possible for everyone to ship some product at the add-in board level, but the long-term winners will be those delivering motherboard solutions. The Christmas 1997 design-win cycle is crucial for the existence of many of these companies. The battlefield will be littered with the corpses of those companies that do not secure design-wins with either premier board suppliers or (and much better) PC OEMs. Niche markets do exist, but the price elasticity in the consumer graphics market causes sales volumes to shrink quickly as price increases.

Appendix A
Dataquest Alert on Intel's Accelerated Graphics Port

The following Dataquest Alert on Intel's Accelerated Graphics Port (AGP) is included here because of the expected impact of AGP on the 3-D graphics market. This Alert, written by Nathan Brookwood, was sent to all clients of the Semiconductor Directions in PCs and PC Multimedia program on April 5, 1996.

Intel Moves to Close Workstation/PC 3-D Performance Gap

At this year's just-completed Windows Hardware Engineering Conference (WinHEC), Intel unveiled a new aspect of PC system architecture that has the potential to drive a wave of system upgrades and, quite by accident, do major damage to vendors focused on the classic workstation market. Intel calls its new technology the "Accelerated Graphics Port" or AGP. The good news, if you are a workstation vendor, is that this technology will not enter the market until mid-1997 and will be introduced then only on P6-based products.

The driving force behind AGP is the need to increase the available bandwidth between the system's main memory elements and its graphics controller, in order to accelerate the task of creating realistic on-screen 3-D images. Personal computers already have all the performance they need for today's 2-D graphic user interfaces (GUIs). When most 2-D images are dragged around on the screen, they move as fast as the eye can follow. They do not need to move any faster—the eye cannot sense it. But when systems try to create 3-D images, the computational task becomes far more daunting. For every pixel on the screen (there are over 300,000 of them in a 640 x 480 screen, small by today's 2-D standards), the system must figure out which of several objects will be visible, what color it will be, and how that color will be affected by available lighting sources within the image. Then the system must determine where everything will be in the next frame, and repeat all these shading and lighting calculations. It must accomplish all this at a rate of thirty frames per second, or the eye can tell the difference. Developers refer to the process of translating the abstract definition of 3-D objects in the computer's memory into a series of shaded pixels on the computer's screen as rendering, and it is key to 3-D imaging.

Until just a few years ago, computers had no way to accomplish all the calculations needed to render realistic 3-D simulation in real time, so developers cheated. They did all the calculations off line and stored the final result (that is, the completed frames) on the disk for later playback in real time. Even this is not easy, because the system must move lots of data very quickly to the display buffer, but it at least eliminates all the real-time calculations. Of course, it also eliminates any opportunity for interaction; the system is merely replaying a digitally created movie, so this approach is of limited value for games. In order to create the movie *Toy Story,* Pixar needed to render a few billion polygons each second. Arcade-quality games must be capable of rendering one-half million polygons per second in order to achieve a more impressive visual effect than "Donkey Kong" provided a few years ago. Today's fastest PCs can render about 100,000 polygons per second, and midrange technical workstations (from Sun, Hewlett-Packard, Silicon Graphics, and others) achieve rates of 500,000 to 750,000 polygons per second. Table A-1 provides a rough estimate of the graphics performance needed to render scenes of varying complexity in real time. Some really neat games can be played on a $20,000 workstation! Of course, it does not take a sophisticated market research analyst at Dataquest to figure out that the consumer market for $20,000 game consoles is quite small, and thus few game developers have put any effort into this segment.

With its new AGP technology, Intel set out to solve the price/performance problem for 3-D graphics rendering in personal computers. Intel hopes to bring the system cost of rendering 500,000 pixels per second from $20,000 to $2,000, a more workable figure for high-end consumer devices. In order to accomplish this, the system must provide 250 MB/sec to 300 MB/sec of bandwidth between the display controller and the system's main memory. Today, a well-implemented PCI interface between these two points delivers a peak rate of 100 MB/sec, not nearly enough capacity. In order to break this bottleneck, the PCI specification would need to be increased from 32 bits and 33 MHz to 64 bits and 66 MHz. This would take years to implement and would add extra cost to other PCI devices (disk controllers, LAN controllers, and so forth) that really do not need increased performance. Instead, Intel chose a more expedient path, one that enhances a single PCI-like port on the system to 133-MHz operation, and provides over 500 MB/sec of memory bandwidth. Intel ended up calling this port the Accelerated Graphics Port, or AGP. Before this announcement, Intel had referred to it as the Graphics Attachment Point, or GAP.

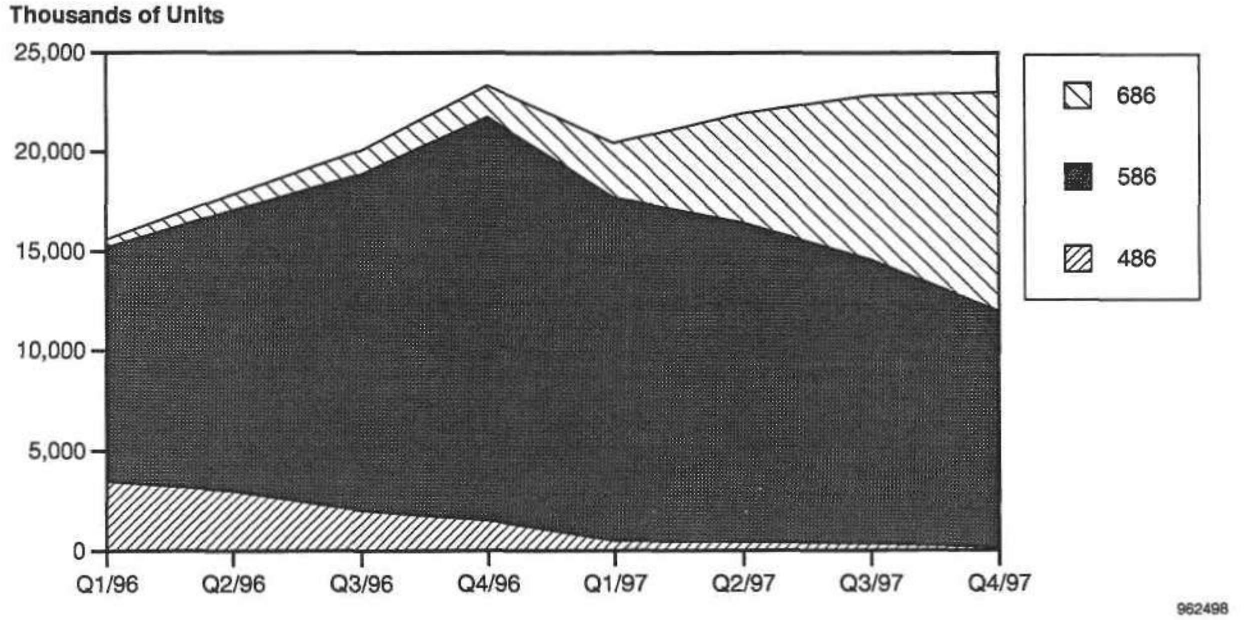
All this memory bandwidth would be useless without a graphics controller that knows how to use it, and Intel is not (yet) in the graphics controller business. So, Intel took its concept to ATI, S3, and Cirrus Logic, and together they worked out the details of the interface between the graphics controller and main memory. This interface will be incorporated into chipsets Intel plans to deliver early next year. Dataquest anticipates that the graphics vendors will target a similar introduction date for their wares. Intel plans to add this feature only to its P6 chipsets; there may be an opportunity for astute Pentium-class chipset vendors to incorporate this technology. Figure A-1 shows Dataquest's latest estimate of 586-class and 686-class unit shipments by quarter through the end of 1997. The majority of units will still comprise 586-class components and 686-type devices with Pentium pinouts, including the Cyrix 6x86 and the AMD 6K86, at the end of 1997.

Table A-1
Graphics Performance Requirements for Image Rendering

Hardware Environment	Today's personal computer	Today's workstation	Today's supercomputer	No real-time solution	No real-time solution	No real-time solution
3-D Graphics Capabilities	Low-resolution games	Complex interiors	Realistic interiors	Realistic faces	Toy Story	Photo-realism
Bandwidth (Polygons per Second)	100,000	1 million	10 million	100 million	1 billion	10 billion

Source: Rendition Inc.

Figure A-1
Quarterly x86 Unit Shipments by Processor Generation in Computational Applications



Source: Dataquest (April 1996)

Historically, the lack of 3-D software standards meant that hardware vendors designing a new 3-D controller had to undertake a major selling effort with software developers to get them to support his device. This took time and limited the market for such devices. This situation is about to change dramatically. For the past year, Microsoft has been getting ready to release Direct3D, a new software component for Windows 95 and Windows NT. Direct3D enters its beta test phase this month. With Direct3D, application software developers design their programs to work with an abstract 3-D device, and then the operating system maps these commands into the specific instructions needed by each individual hardware controller. Microsoft claims that this can be done without adding lots of overhead, which historically has limited customer acceptance of approaches like this. The proof of this pudding will be in the testing, which starts soon. If it delivers acceptable levels of performance, it will unleash a wave of 3-D software applications late this year and early in 1997. Users will be clamoring for increased 3-D performance at the precise moment that AGP hits the market, and its arrival will trigger the onset of a major upgrade cycle to lower-cost ($2,500 to $3,000) Pentium Pro systems equipped with AGP graphics.

Dataquest Perspective

Dataquest sees the AGP technology as a major enhancement to PC architecture that should benefit everyone, with the exception of traditional workstation vendors (Sun, HP, IBM, Digital Equipment, and Silicon Graphics), and dedicated game console vendors (Sega, Sony, and Nintendo). We are particularly encouraged that the DirectX APIs in Windows 95 can permit such radical architectural changes with so little impact on application-level software. If the AGP scenario plays out as smoothly as it was presented at WinHEC, it will signal the start of a new boom in PC hardware innovation, which historically has been held back by the need to be compatible with older hardware interfaces in order to gain software support. Rapid hardware innovation drives industry growth and provides increased value to end customers.

Workstation vendors should pay special attention to this announcement. Three years ago, it was easy to differentiate workstations selling for $10,000 to $50,000 from personal computers selling for $1,500 to $5,000. Workstations had sophisticated multitasking operating systems based on UNIX that were far more capable than the DOS/Windows environment on PCs. A variety of designer RISC CPUs allowed workstations to compute much faster than PCs with mass-market 486 processors or clunky early Pentiums. Workstations could display their results faster, and in more colors, using high-performance 3-D graphics subsystems with lots of dedicated processing power. The introduction of Windows NT in 1993 began the erosion of the workstation's software advantage, a process that continues today. The introduction of the Pentium Pro began to diminish the workstation's computational advantage, which continues to erode today. The introduction of AGP accelerators in 1997 will eradicate the last major competitive advantage that expensive workstations have over mass-market personal computers. It will become increasingly difficult for workstation vendors to justify the premium prices they need to charge to support their relatively low-volume (compared with PC markets) products. It is ironic that Intel does not appear to have targeted workstations with its AGP initiative; workstations are merely innocent bystanders impacted by Intel's desire to expand the PC market through improved 3-D gaming facilities.

PC chipset vendors need to move quickly on this opportunity or they run the risk of being at a substantial performance disadvantage. Intel has proclaimed that the AGP specification, to be released this quarter, will be an open specification, available royalty-free. It has avoided the confusing gobbledygook that surrounded last fall's unveiling of MMX technology.

CPU vendors (both x86 and RISC) must find a way to tap the AGP performance potential and must respond to Intel's MMX extensions, or they will find themselves at a serious competitive disadvantage by the end of 1997.

Graphics controller chip developers have a wide-open field with lots of running room. They will have four times the memory bandwidth they've had up to now, and DirectX puts them squarely in charge of their own software destinies.

Developers of gaming hardware and software also need to take note. Intel has put them on notice that it intends to make the personal computer the ultimate 3-D virtual reality gaming platform. Intel's moves here mesh nicely with Microsoft's gaming initiatives and its DirectX programs.

Content developers for the World Wide Web and for intranets should also study the opportunities created by Intel's 3-D initiative. The combination of Intel's MMX and AGP initiatives means that 3-D capabilities will become a standard feature in personal computers in the 1997 to 1998 period. As the installed base of such systems grows, there will be opportunities for program content to rise above the network clutter via compelling 3-D user interfaces. It hardly matters whether content is authored in VRML, Java, or C++ over DirectX; the hardware will move into place to support a major shift in user interface styles.

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