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U.S. LINEAR INTEGRATED CIRCUIT MARKET

Prepared for

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CHAPTER 1--EXECUTIVE SUMMARY

Semiconductor monolithic components are conveniently classified into three main categories: integrated circuits, discrete components, and opto-electronic components. Linear or analog circuits belong in the category of integrated circuits. These circuits are further classified by function into seven classes: operational amplifiers, comparators, power-management circuits, data conversion and acquisition circuits, special consumer circuits, special communications circuits, and special-function circuits.

LINEAR PROCESSES

Although linear processes share many features in common with digital VLSI processes, linear processes emphasize the optimization of such device parameters as offset voltage, bias current, noise, slew rate, and input impedance rather than parameters such as feature size and functional density that are all-important for digital very large scale circuits.

The most widely used linear fabrication process is the bipolar process. Modifications of the basic bipolar fabrication process create analog components that have characteristics suitable for optimized linear circuit performance. The other two linear fabrication processes that are widely used are the BiMOS and the BiFET processes. BiMOS processes include not only CMOS components, n-channel and p-channel devices, but also npn bipolar transistors. The key advantages of BiMOS fabrication processes are:

- High-density digital control features may be included with analog circuits, which allows for the realization of complex and intelligent monolithic analog subsystems that interface easily with digital systems.

- The silicon die area required for the typical BiMOS analog circuit is normally one-third to one-fifth of an all-bipolar analog design. The BiMOS circuit also dissipates significantly less power.

- CMOS is particularly well suited for special environments such as automotive and telecommunications that require low-power drain and high-noise immunity.

DATAQUEST estimates that 3 to 5 percent by dollar value of all linear products implemented in 1983 used BiMOS and BiFET processes. Approximately 80 percent of all A/D converters shipped to the automotive market are implemented in CMOS. By 1988, DATAQUEST estimates that the percentage of all linear BiFET and BiMOS products shipped will reach 25 percent of the total linear market.

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IMPACT OF CAD/CAM ON LINEAR IC DESIGN

The significant new trends in the implementation of analog systems are:

- The emergence of the standard cell approach to the design of analog ICs
- The increased use of CAD/CAM tools for designing semicustom and custom analog ICs
- The increased availability of new VLSI processes that offer mixed bipolar and CMOS capabilities

In addition to these three factors, the availability of transistor arrays with breakdown voltages above 60 volts and as high as 300 volts has increased the attractiveness of linear semicustom ICs as a part of the offering of the silicon IC foundries.

Although there are more than 100 semicustom and custom IC manufacturers worldwide, there are only a few that offer semicustom and custom linear capabilities. These include:

- Interdesign/Ferranti, Scotts Valley, California--Offers 1-GHz bipolar collector diffused isolation (CDI) together with metal-gate and silicon-gate processes
- Micro Linear, San Jose, California--Offers FP900 and FP300 arrays with f_T's of 1 GHz. In addition, the company offers extensive linear CAD tools using the IBM PC/XT and PC compatibles linked to a DEC VAX. Daisy Logician and Chipmaster workstations are also being used.
- Electronic Technology, Cedar Rapids, Iowa--Offers 3- and 4-micron single-layer CMOS gate arrays. The actual device fabrication is contracted out to AMI, Cupertino, California.
- ZyMOS, Sunnyvale, California--Offers analog functional building blocks such as op amps, power transistors, drivers, capacitors, ion-implanted R-2R ladders, automatic gain-control circuits, and voltage references

TECHNOLOGY PROJECTIONS

The technology projections for the period 1984 through 1988 for op amp linear processes are:

- High-precision and very low-bias current BiFETs
- Combination of BiFETs and CMOS circuits for low-bias currents, low-power precision, and high-speed analog circuits

- The continued evolution of the present 3- to 4-GHz dielectric-isolated bipolar processes that will boost the slew rates to well over 1,000 V/microsecond and achieve settling times of 50 nanoseconds

- Application of dielectric-isolated processing to BiFET technology that will match the specification of the best hybrids: low-bias currents and very low offset voltage drifts

Beyond 1984, the trends to be expected in A/D converters are:

- General-purpose A/D converters will achieve 12-bit resolutions and 25-microsecond conversion times.

- Flash A/D converters will be designed for use at lower frequencies, such as 1 MHz. In addition, a trend is expected toward obtaining higher speeds (600 MHz at reduced resolutions--6 to 8 bits).

- There will be a tendency to use half-flash design techniques to implement high-performance general-purpose A/D conversion products.

- There will be a greater use of 1- to 2-micron high-speed bipolar processes in order to push the high sampling speeds required of flash converters.

- There will be an increase in the use of CMOS for general-purpose A/D converters, especially for the low-cost automotive markets.

The specific D/A trends are for:

- Higher-speed, 14-bit current output bipolar devices

- 12-bit voltage outputs that are double buffered and fully microprocessor compatible. At least one product with 12-bit resolution and 1-microsecond settling time will appear by 1985.

Switched-capacitor techniques that evolved out of the all-MOS charge-redistribution A/D techniques of the mid-1970s will open up new product designs in the areas of telecommunications circuits, speech processing circuits, and adaptive filters. DATAQUEST projects that, between 1984 and 1988, there will be switched-capacitor designs for radio and video systems as these techniques are extended to higher frequencies. However, switched-capacitor designs rely on capacitors having highly stable characteristics, thus dictating linear circuit wafer fabrication lines that are separate from the high-density digital processes.

MARKET ESTIMATES

The worldwide consumption of semiconductors between 1974 and 1983 reflects a compound annual growth rate (CAGR) of 15.5 percent. While total semiconductor shipments grew from $2,264 million in 1974 to $8,286 million in 1983, the integrated circuit segment--that is, bipolar digital, MOS digital, and linear--grew from $1,259 million in 1974 to $6,909 million in 1983 to achieve a CAGR of 20.8 percent for the 1974 to 1983 period.

The consumption of linear integrated circuits grew from $244 million in 1974 to $1,108 million in 1983. This represents a CAGR of 18.3 percent, compared to 13 percent for bipolar digital and 28 percent for MOS. Linear ICs are expected to grow from $1,108 million in 1983 to $2,617 million in 1988.

Regional Market Share Estimates

Of the total 1982 worldwide IC market, which had grown from $600 million in 1975 to more than $2,700 million in 1982, the U.S. manufacturers' share was 47.9 percent, Japanese manufacturers' share was 38.9 percent, European manufacturers' share was 12.9 percent, and Rest of World manufacturers' share was approximately 0.23 percent.

Market Share Estimates by Company

Texas Instruments continues to be the largest U.S.-based manufacturer of linear integrated circuits. In 1982, the value of TI's production was $235 million, increasing to $277 million in 1983. This represents a change of 18 percent for the 1982 to 1983 period. For the 1984 production year, as well as throughout the 1984 to 1986 period, Texas Instruments is expected to maintain its top position as the linear leader, although it has been challenged aggressively by National Semiconductor. All three top linear manufacturing firms, Motorola, National Semiconductor, and Texas Instruments, are suppliers to the large and growing automotive market. TI continues to forge ahead in technology with its offering in new products implemented in linCMOS technology.

National Semiconductor also has an aggressive CMOS program. Most of its A/D conversion products shipped to the automotive market are fabricated in CMOS. Motorola is lagging in linear CMOS, although some fallout from the effort in digital CMOS will appear in linear products during the 1984 to 1986 period. Signetics, which has started to ship linear products fabricated in 2- to 3-micron CMOS, will benefit from a recent technology exchange with Linear Technology, Inc. Analog Devices is a leader in the production of high-performance data conversion products that are implemented in linear-specific CMOS processes.

Market Analysis by Function

In 1983, total op amp and comparator sales were $336 million or 22 percent of total linear sales. The largest producers were National Semiconductor, Texas Instruments, and Motorola, in that order.

Data conversion circuits represent the fastest-growing segment of the IC market, accounting for more than $248 million in 1983. Analog Devices holds the premier position in sales in that segment, followed by National Semiconductor and Motorola.

Special communications circuits will be one of the fastest-growing segments of the linear circuit business, due, in part, to the deregulation of the U.S. telephone industry and the subsequent emergence of many small telecommunications companies and, in part, to the continued conversion of analog equipment to digital replacements. In 1983, sales in this category accounted for $94 million but are expected to grow at a rate faster than 25 percent over the next five years.

Special-function circuits account for approximately the same amount of sales as power-management circuits. In 1983, this total was approximately $200 million.

Company Analysis

There are a total of 20 U.S.-based linear IC manufacturers. The top 8 U.S. based firms accounted for $981 million or 75 percent of all U.S.-based production in 1982. By 1988, the production by the top 8 linear firms is expected to rise to $253 million, or 77 percent of all the U.S.-based production.

The smaller linear IC companies have been established primarily to offer products that cater to niche applications. A sampling of the technologies available from these smaller linear firms is as follows:

- Interdesign/Ferranti, Scotts Valley, California--CDI bipolar technology and semicustom and custom analog circuits
- Precision Monolithics, Santa Clara, California--High-performance bipolar analog circuits
- Silicon General, Garden Grove, California--Power-management circuits
- Comlinear, Loveland, Colorado--High-output (voltage and current) transistor arrays

The strategy of the larger companies is mirrored in the activities of Texas Instruments, National Semiconductor, and Motorola. The emphasis is on high-volume production of commodity linear chips such as operational amplifiers and voltage regulators as well as the more sophisticated functions such as CMOS A/D and D/A conversion products. The emergence of the high growth in the automotive and telecommunications sectors is allowing for growth rates of 18 to 30 percent in the top four linear companies.

An exception to the general rule of high-volume manufacturing of commodity linear ICs has been Analog Devices. This firm is dedicated to the development and manufacturing of precision linear circuits and its growth rate is higher than the linear industry average. The high quality and performance of ICs from Analog Devices results in one of the highest revenues per wafer of all semiconductor firms.

CHAPTER 2--INTRODUCTION

2.1 OVERVIEW AND EVOLUTION OF LINEAR/ANALOG CIRCUITS

Linear or analog circuits belong to one of the three main categories of semiconductor monolithic components. It is convenient to classify semiconductor components into the following three groups:

- Integrated circuits
    - Bipolar digital
    - MOS digital
    - Linear
- Discretes
    - Transistors
    - Diodes
    - Thyristors
    - Other
- Optoelectronics
    - LEDs
    - LED displays
    - Optocouplers
    - Other

Subdivisions are usually based either on application or on the technology used to implement the circuit representation (schematic model), or on the process sequence used in the actual device fabrication. For example, an operational amplifier may be a bipolar or BiFET op amp if it uses a bipolar or a combination of a bipolar and JFET process to integrate its active components.

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Linear Circuit Classification by Circuit Function

Linear circuits are, in general, classified according to the functions for which they are optimized. For example, an operational amplifier is a linear circuit that exhibits certain specifications and is used in those circuit applications that exploit its high-input impedance, low-offset voltage, and large bandwidth, among other parameters. Timers, another class of linear circuits, are specifically designed to provide voltage outputs that are active after a precise, programmable time has elapsed. Linear circuits are classified by function as follows:

- Operational amplifiers
- Comparators
- Power-management circuits
  - Linear voltage regulators
  - Switched-mode voltage regulators
  - Voltage references
- Data conversion
  - A/D converters
  - D/A converters
- Special consumer circuits
- Special communications circuits
- Special-function circuits

An analysis of the products from each supplier of these types of linear circuits will be examined in detail in Section 5.0.

Linear Processes

Linear circuit processes have many features that are common to the VLSI processes used in the manufacture of digital circuits. In fact, many of the advances in design tools, microlithography, and wafer fabrication made in digital integrated circuits often are extended to the domain of linear integrated circuits. Whereas the emphasis in digital circuit design is on feature size and the resulting device and functional density, linear circuit design, to a large extent, emphasizes such analog performance parameters as offset voltage, bias current, noise, slew rate, and input impedance. Other parameters such as V_{be} matching, offset drift with temperature, and resistor matching, though important in digital circuit design and performance, are even more important in linear circuit performance.

The most widely used linear process is the bipolar process. Many modifications of the basic bipolar process are used for linear circuits. Such modifications are for creating components that have characteristics suitable for optimized linear performance. These characteristics include low-noise, low-offset, and low-temperature drift, for example. The basic linear process modifications that are presently used include:

- Dielectric isolation
- Deep n^+ diffusion
- Up-down-diffused isolation
- Two-step emitter diffusion
- Ion implantation
- Double-layer metallization
- Thin-film resistance

The various processes that are employed in linear integrated circuit design provide a variety of components. The resulting linear circuits that are manufactured are designed with components that are common to the particular process employed. At present, the linear integrated circuit processes employed and the active components available are:

- Bipolar--NPN and PNP devices, including super-beta transistors
- BiMOS--NPN and PNP devices and n- or p-channel MOSFETs
- BiFET--NPN and PNP devices and n- or p-channel JFETs

2.2 BIPOLAR, BIMOS, AND BIFET LINEAR DESIGNS--PERFORMANCE COMPARISONS

For this discussion, the design example will be the operational amplifier. The performance of this linear building block when it is implemented using bipolar, BiMOS or BiFET designs is shown in Table 2.1.

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Bipolar

The two significant active devices in bipolar analog circuits are the npn transistor and the pnp transistor. In most linear processes, the NPN device is the most heavily favored in that the specifications for the NPN device become the core specifications around which all other compatible components such as resistors, capacitors, and JFETs are specified. There are three analog bipolar processes:

- Low voltage (LV_{ceo} = 20 volts)--0.8- to 1.0-ohm-per-centimeter epitaxial layer with thicknesses of 8 to 10 microns

- Medium voltage (LV_{ceo} = 30 volts)--2.0- to 2.5-ohm-per-centimeter epitaxial layer with 15-micron thickness and a breakdown voltage of approximately 30 volts

- High voltage (LV_{ceo} = 45 volts)--4- to 5-ohm-per-centimeter, 17- to 19-micron epitaxial layer

All three processes are used for specific circuit designs--low-, medium-, and high-voltage power supplies. In some instances, for interface into gas discharge tubes, for example, higher voltage ratings are necessary; in driving low-impedance loads, high-current drivers are needed. In such cases, modifications are made to specific transistors to meet particular specifications. For such special applications, the typical components desired are:

- A high-current transistor

- A higher-voltage transistor--50 to 300 volts

- Higher-input impedance transistors--superbeta transistors

The pnp transistor is the other component central to the bipolar analog process. There are three types of pnp transistors in use at present: the lateral pnp, the substrate pnp, and the high-performance pnp. Both the lateral pnp and the substrate pnp use the lightly doped n-type epitaxial region of the npn transistor as the base region. Though they have lower performance characteristics than the corresponding npn device, they are extremely useful for biasing, level shifting, and serving as load devices. The forward current gain for either the lateral or substrate pnp is typically 20 to 50, compared to 100 to 300 for the npn device. pnp devices that have current gains that approach 200 can be obtained using a dielectric-isolation process, but the greater number of layers increases the cost of wafer processing.

BiFET

In addition to pnp active devices in a bipolar process, junctions can be implemented using ion implantation. Junction field-effect transistors (JFETs) are highly desirable as linear components because they can be used to implement very high input impedance stages with low bias currents. JFETs are implemented either by double diffusion or by ion implantation. Ion-implanted JFETs are preferred because not only are their parasitic capacitances lower than the double-diffused versions, but the control of the pinch-off voltage, V_p, is better and the gate-to-drain breakdown voltage is much higher for the ion-implanted JFET. The typical parameter values for ion-implanted and diffused JFETs are shown in Table 2.2.

A BiFET linear circuit contains both types of bipolar active devices--npn/pnp and JFET devices. A typical BiFET differential gain stage has a transconductance of 0.7 millimhos. This is 15 times lower than the g_m of a comparable bipolar stage. As a consequence, both the differential gain and the common-mode rejection ratio are a factor of 10 to 20 lower than those of a similar bipolar configuration. The offset voltage of the JFET differential pair is primarily determined by the V_p and I_{dss} mismatch. While the pinch-off voltage match between the two JFETs is highly dependent on the respective match between the channel thickness, the I_{dss} mismatch can be minimized by the choice of I_d.

In summary, the key advantages of the JFET input stage are the very low-input-bias current and the low-stage transconductance. The low-stage transconductance favors high-slew-rate designs using the JFET device. Slew rates of 10 to 30 volts per microsecond are readily achievable with JFET inputs.

The trade-off, as mentioned before, is the high offset associated with the JFET, typically 2 to 10 millivolts, which is 3 to 5 times higher than a corresponding bipolar device. Another disadvantage of the JFET is the temperature dependence of the bias current. Typically, JFET input currents double for every $10^{o}C$ change in temperature, whereas bipolar input currents decrease with increase in temperature.

BiMOS

In addition to the linear bipolar and the linear BiFET technologies, MOS technology is increasingly being applied to the design of linear circuits. Although the performance characteristics of simple MOS linear circuits--NMOS or CMOS op amps, for example--are relatively poor compared to bipolar counterparts, the advantages of CMOS VLSI circuits are significant. The key advantages are:

- The inclusion of high-density control features with analog circuits allows the monolithic realization of complex and intelligent analog subsystems that interface easily with digital systems.

- The area required is usually one-third to one-fifth of a bipolar design at significantly lower power levels.

- CMOS is particularly well suited for automotive applications and telecommunications.

Table 2.1 compares the performance characteristics of CMOS, bipolar, and BiFET op amp circuits.

2.3 LINEAR IC TECHNOLOGY PROJECTIONS

The progress and technology trends in linear integrated circuits are mirrored in the specific trends in two key analog IC products: these two products are operational amplifiers and data conversion products.

Operational amplifiers are the design building blocks not only for analog subsystems but also for chips such as comparators, sampling holes, telecommunications circuits, and filters. The key electrical parameters for op amps that are market-driven are high speed: high slew rate and low settling time, low noise, and large-gain bandwidth product.

Data conversion products, on the other hand, have such key specifications as resolution, accuracy, number of bits, and conversion time. Specific technologies such as MOS charge-redistribution techniques for data conversion products have evolved because of market needs and the inability of the then-current technologies to satisfy the desired specifications.

Another example of the evolution of linear integrated circuits has been the development of switched-capacitor technology. This technology has emerged as a viable design technology because it provides benefits not offered by charge-coupled device filter technology or RC-type integrated filter technology.

Operational Amplifiers

Before 1982, the dominant technology for operational amplifiers was based on dielectric-isolated bipolar processing. Typical offset voltages and drifts were 4 mV and 15 microvolts/^{o}C, respectively. Slew rates were typically 30 to 50 volts/microsecond. The scaling of feature sizes in dielectric processes and the resulting reduced capacitances have allowed bipolar operational amplifiers to achieve gain-bandwidth products of 100 MHz with slew rates of 600 volts/microsecond without a large deterioration in the offset voltage and the offset voltage drift.

BiFET and BiMOS op amps, which originally appeared in the late 1970s, now offer low-bias currents and very high input impedance levels at low cost. Since then, these op amps, especially the BiFETs, have improved in virtually every specification. Variations in fabrication technologies, such as the application of dielectric isolation to BiFET processes and chopper-stabilized CMOS techniques, have allowed the maximum bias currents to be as low 1 picoampere.

The period 1984 to 1988 will see the following trends in op amp linear IC processes:

- Higher-precision and very low bias current BiFETs
- Combinations of BiFETs and CMOS circuits for low-bias currents, low power precision, and high speed
- The continued evolution of the present 2 to 3 GHz dielectric-isolated bipolar processes, which will boost the slew rates to well over 1,000 volts/microsecond and achieve settling times of 50 nanoseconds
- Application of dielectric processing to BiFET technology which will match the specifications of the best hybrids: low-bias currents and very low offset drifts

A summary of the progress in op amps by technology is shown in Table 2.2.

A/D Converters

Before 1981, the high-performance A/D products existed as modules or hybrids. Such products had resolutions of 12 bits with conversion times of 400 nanoseconds at one end and resolutions of 16 bits and conversion times of 200 microseconds at the other end. Since 1981, there has been a gradual emergence of high-performance monolithic A/D chips. These chips have evolved from the successful modules and hybrids of the previous generation and have invariably been implemented using CMOS VLSI fabrication processes. The typical specifications of A/D converters are 8-bit resolutions at 400 nanoseconds at one end and 14-bit resolution at 200 nanoseconds at the other end of the spectrum.

Beyond 1984, the trends expected in A/D converters are:

- General-purpose A/D converters will achieve 12-bit resolutions and 25-microsecond conversion times.
- Flash A/D converters will definitely be used at lower frequencies, such as 1 MHz. In addition, a trend is expected toward attaining higher speeds: 600 MHz at reduced resolution, 6 to 8 bits.

- There will be a tendency to use half-flash design approaches to achieve high-performance, general-purpose A/D products.

- There will be a greater use of 1- to 2-micron, high-speed bipolar processes in order to push the high sampling speeds of flash converters.

- The increasing use of CMOS for general-purpose A/D converters, especially for the low-cost automotive markets.

D/A Converters

The linear IC process trends applicable to A/D converters will also apply to D/A converters. Specific D/A trends are for:

- Higher-speed 14-bit, current-output bipolar devices

- More products will have 12-bit voltage outputs that are double-buffered and fully microprocessor compatible. At least one product with 12-bit resolution and 1-microsecond settling time is expected by 1985.

The progress in monolithic D/A converters from 1981 to 1984 is noted in Table 2.3.

Switched-Capacitor Technology

During the mid-1970s, the all-MOS charge-redistribution A/D techniques pointed the way for the use of the MOS capacitor as a useful linear device element. The MOS capacitor possesses very stable temperature and voltage-coefficient characteristics, typically 20 to 50 ppm/^{o}C and 10 ppm/^{o}C, respectively. Although the accuracy of the absolute value of the capacitance is poor, it was demonstrated that designs that exploit the superb accuracy in the ratios of two MOS capacitors are well suited for high-precision filters. The development of the internally compensated op amp was also a key factor at the time. Since then, switched-capacitor techniques using simulated resistors constructed from MOS capacitors and MOS switches have appeared in many product designs. These switched-capacitor techniques will open up new product designs in the areas of telecommunication circuits, speech-processing circuits, and adaptive filters. Between 1984 and 1988, there will be switched-capacitor designs for radio and video systems as these techniques are extended to higher frequencies. Other potential product areas are in music synthesis, speech analysis, data transmission systems, and sonar signal processing systems.

The VLSI processes that are contemplated for switched-capacitor network designs must be analog-specific. Put another way, the processes must be tailored for capacitors that have high quality characteristics. Capacitors fabricated in many of the new mainstream digital processes using silicides employ low-temperature oxides that are not thermally grown. These oxides do not exhibit the stable temperature and voltage-coefficient characteristics desirable for high-performance, switched-capacitor designs. It is expected, therefore, that high-performance, switched-capacitor designs will dictate that analog circuit wafer fabrication lines be kept separate from the high-density digital processes of the 1984 to 1988 period.

2.4 IMPACT OF CMOS AND BIFET TECHNOLOGIES ON LINEAR IC MARKET ESTIMATES

As mentioned in the two previous sections, there was a definite trend toward the emergence of CMOS and BiFET technologies as alternate linear fabrication technologies in the 1982 to 1984 period. These two technologies will become more firmly entrenched as viable options for linear IC technology fabrication and design.

CMOS designs will proliferate in low-cost as well as in high-performance data conversion products. This is especially true for A/D converters such as those that are designed for automotive applications. The unique CMOS advantages of high noise immunity and low power are ideal for this particular market.

BiFET designs which offer low-input bias currents will adopt dielectric isolation techniques to meet high-slew rate and large-bandwidth specifications.

DATAQUEST estimates that between 3 and 5 percent of the dollar value of all linear products implemented in the 1983 to 1984 period used or will use BiMOS and BiFET processes. Approximately 80 percent of all A/D converters shipped to the automotive market are implemented in CMOS.

By 1988, DATAQUEST estimates that the percentage of all linear BiFET and BiMOS products shipped will reach 25 percent of the total linear market.

2.5 IMPACT OF DESIGN AUTOMATION ON LINEAR IC DESIGN ACTIVITIES

The significant new trends in the implementation of analog systems are:

- The emergence of the standard cell approach to the design of analog ICs
- The increased use of CAD/CAM for designing custom analog ICs
- The increased availability of new VLSI fabrication processes that offer not only analog and digital capabilities but mixed CMOS and bipolar

The availability of sophisticated design tools that were previously reserved for complex digital circuits are now being offered to analog system designers. Using such tools, precharacterized analog building blocks such as op amps, multiplexers, and medium-resolution data converters will be increasingly employed in analog designs having much higher levels of integration.

Although such building blocks are not as high performers as the handcrafted general-purpose products, they allow quick realization of market-driven products whose cost-effectiveness depends on monolithic analog and digital solutions.

Specifically, a number of silicon foundries like Zymos, of Sunnyvale, California, are offering analog functional building blocks. Such building blocks include op amps, power transistors and drivers, capacitors and ion-implanted R-2R ladders, automatic gain-control circuits, voltage references, and a choice of I/O configurations. Such standard cells are accompanied by performance characteristics documentation and macromodels that can be merged with digital simulation programs.

Table 2.1

OPERATIONAL AMPLIFIER TECHNOLOGY COMPARISON

Specification	Bipolar	BiFET	CMOS
Input voltage offset, V_{os}	100 microvolt-10mV	5mV	5-10mV
Input bias current, I_{bias}	100	1	5-10
Unity-gain bandwidth (MHz)	1-2	5	2
Slew-rate (Volts/microsecond)	0.1 to 600	12	0.04 to 4.5
Output voltage (Volt)	±10 to ±14	±10	Rail to rail
Output current	40mA	40mA	10mA
Noise (at 1 KHz)	2.5-10	8	25 microvolt p.p
Gain, A_{VO} (V/mV)	100-200	100-200	100

Table 2.2

TECHNOLOGY TRENDS IN OP AMPS, 1980-1984

Year	Technology	Offset Voltage (mVoC)	Offset Drift (mV/ C)	Bias Current	Open-Loop Gain (dB)	Small-Signal Band Width (MHz)	Slew Rate (10^6V/sec)	Settling Time (10^{-6}sec)	Quiescent Current (mA)	Input Noise (mV/Hz1/2)
Pre 1981	Bipolar Dielectric-Isolation	4	15	15nA	100	100	35	1	6	35
1982		5	20	20×10^{-6}A	84	600	600	0.35	25	15
Pre-1982	BiFET	0.5	5	50pA	94	3	15	1.5	[illegible]	12
1982	Laser-Trimmed BiFET	0.25	1	25pA	118	1	3	3.5	1.5	30
	Dielectric-Isolated BiFET	0.5	30	5pA	100	5	8	1	2.1	12
	BiMOS	2	4	4pA	86	0.5	0.5	N/A	1	62
	CMOS Chopper-Stabilized	0.005	0.05	30pA	150	0.45	0.5	15	3.5	5×10^{-6}V P-P
Pre-1982	Super-Beta	0.3	3	50pA	100	1	0.1	3	0.6	150
	Bipolar	0.025	0.6	40nA	120	8	2.8	5	3	4.5
1984	Dielectric-Isolated BiFET	3	5	1pA	106	2	7	2	1	70
	CMOS	2	5	1pA	90-100	0.1 to 2.3	0.04 to 4.4		0.01 to 1	33 to 57

Table 2.3

TECHNOLOGY TRENDS IN D/A CONVERTERS, 1980-1984

Year	Resolution (Bits)	Accuracy (Bits)	Type of Output	Process	Resistors	Trimming	Input Logic	Power Supplies
1982							N	
			Voltage	Bipolar			No latches	
				Bipolar Dielectric Isolation		Laser		±
	16	14	Current	CMOS	Thin-film		Single latches	
						PROM	Single latches	±
						None	No latches	
14	14							
		Voltage or Current				Laser	No latches	
			Bipolar	Diffused		None	No latches	±
1983								
12	12	Voltage		Thin-film			Double offsets	
		Current			Laser			
		Voltage or Current						
		Voltage	CMOS	Thin film	Laser			+
8	8		Bipolar		None			+

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CHAPTER 3--MARKET ESTIMATES BY PRODUCT HIERARCHY

3.1 HIERARCHY OF PRODUCTS

In this chapter, estimates for the linear integrated circuit market in North America are considered. The focus is on estimates of the consumption of linear circuits and the market shares for U.S. linear circuit manufacturers.

Linear integrated circuits comprise the following types of circuits:

- Operational amplifiers
- Comparators
- Power-management circuits
- Data conversion and acquisition circuits
- Special consumer circuits
- Special communications circuits
- Special-function circuits

Definitions and Conventions

DATAQUEST uses a common manufacturer data base for all tables. This base includes all merchant suppliers to the semiconductor market. It excludes captive suppliers that manufacture solely for the benefit of the parent company such as Burroughs, IBM, and AT&T Technologies. Companies that actively market to both the merchant market and their own divisions are included in the data presented. Although there are no specific examples for linear circuit manufacturers, NCR is an example of a digital captive supplier that, since 1982, is offering digital products to the merchant market.

Consumption--DATAQUEST defines consumption as the purchase of a semiconductor device or devices. This definition must be differentiated from the actual use of the device in a final product. Devices that are inventoried at the user level are considered consumption according to our definition.

Hybrids--Hybrid devices (device packages that are a conglomeration of several integrated circuits) are not considered to be part of linear integrated circuit estimates, even though hybrids are manufactured by some linear integrated circuit merchant suppliers such as National Semiconductor and Analog Devices.

Regions--North America is defined to be both the United States and Canada. Latin America, including Mexico, is considered to be part of the Rest of World (ROW) category. Western Europe includes Austria, Belgium, the Federal Republic of Germany (FDR), France, Greece, Italy, Luxembourg, the Scandinavian countries (Denmark, Finland, Norway, and Sweden), Spain, and the United Kingdom.

Data Sources

The information presented in this report is a consolidation from a variety of sources, including:

- The Semiconductor Industry Service's Products and Markets binder
- Estimates presented by marketing personnel from each of the leading eight linear integrated circuit merchant manufacturers as well as some of the other, smaller firms
- Interviews with distributors and purchasers of linear integrated circuits
- Published product data literature
- Trade association data such as those from the Semiconductor Industry Association (SIA) and the Electronic Industry Association (EIA)

Consistency and Accuracy

One of the key objectives in the preparation of the estimates for this report was to achieve consistency among the various estimates that are published by DATAQUEST.

The historical consumption data presented here, for example, are consistent with those presented by DATAQUEST in the Products and Markets binder. However, the projections for the 1984 to 1988 period may differ from the consumption forecast presented in the binder. These forecast data have been derived from analyses performed on data obtained from knowledgeable individuals who were interviewed during the course of this research.

3.2 MARKET ESTIMATES

North American Semiconductor Consumption

The key trends in the North American linear integrated circuit industry, production and consumption, are tightly coupled to the key trends in the worldwide semiconductor industry. The worldwide consumption of semiconductors between 1974 and 1983 reflects a compound annual growth rate (CAGR) of 15.5 percent. While total semiconductor shipments grew from $2,264 million in 1974 to $8,286 million in 1983, the integrated circuit segment (that is, bipolar digital, MOS digital, and linear) grew from $1,259 million in 1974 to $6,909 million in 1983 to achieve a CAGR of 20.8 percent for the 1974 to 1983 period.

The consumption of linear integrated circuits grew from $244 million in 1974 to $1,108 million in 1983. This represents a CAGR of 18.3 percent, compared to 13 percent for bipolar digital and 28 percent for MOS. These statistics are tabulated in Table 3.1. The projections for North American semiconductor consumption for the period 1984 through 1988 are shown in Table 3.2. Linear ICs are expected to grow from $1,108 million in 1983 to $2,617 million in 1988.

Regional Market Share Estimates

Of the total 1982 worldwide linear IC market, which had grown from more than $600 million in 1975 to more than $2,700 million in 1982, the U.S. manufacturers' share was 47.9 percent, the Japanese share was 38.9 percent, the European share was 12.9 percent, and Rest of World manufacturers accounted for approximately 0.293 percent. These market shares are shown in dollars in Table 3.3.

Market Share Estimates by Company

Texas Instruments continues to be the largest U.S.-based manfacturer of linear integrated circuits. In 1982, the value of TI's production was $235 million, increasing to $277 million in 1983. This represents a change of 18 percent from 1982 to 1983. Texas Instruments is expected to maintain its top position as the linear leader throughout the 1984 to 1986 period, although it is being challenged aggressively by National Semiconductor. All three top linear manufacturing firms, Motorola, National Semiconductor, and Texas Instruments, are suppliers to the large and growing automotive market. Texas Instruments continues to forge ahead in technology with its offerings of new products implemented in linCMOS technology, a linear-specific process. These linCMOS products could guarantee TI's domination, although many firms, large and small, are adopting CMOS for the production of linear circuits. National Semiconductor also has an aggressive CMOS program. Most of National's A/D products shipped to the automotive market are fabricated in CMOS.

Motorola is lagging in linear CMOS, although some fallout from the effort in digital CMOS effort will appear during the 1984 to 1986 period. Signetics, which has started to ship linear products fabricated in 2- to 3-micron CMOS, will benefit from a recent technology exchange with Linear Technology, Inc. Analog Devices is a leader in the production of high-performance data conversion products used in CMOS.

DATAQUEST anticipates that TI will maintain its worldwide linear market share of 18 percent for the period up to 1986. After 1986, we expect the smaller innovative linear companies to make significant inroads using technology advances in CMOS and the transformation of hybrid technology to monolithic subsystems, causing TI's market share to decrease slightly.

Market Analysis by Function

The segmentation of linear circuits that will be used for estimating the market size by function is similar to the grouping used in the hierarchy of products except that comparators are grouped with op amps.

In 1983, total op amp and comparator sales were $336 million, or 22 percent of total linear sales. The largest producers were National Semiconductor, Texas Instruments, and Motorola, in that order.

Data conversion circuits represent the fastest-growing segment of the linear IC market, accounting for more than $248 million in 1983. Analog Devices holds the premier position in sales in that segment, followed by National Semiconductor and Motorola.

Special communications circuits will be one of the fastest-growing segments of the linear circuit business, due, in part, to the deregulation of the U.S. telephone industry and the subsequent emergence of the many small telecommunication companies and, in part, to the continued conversion of analog equipment to digital replacements. In 1983, sales in this category accounted for $94 million, but this is expected to grow more than 25 percent over the next five years.

Special-function circuits account for approximately the same amount of sales as power-management circuits. In 1983, this total was approximately $200 million.

Table 3.1

HISTORICAL NORTH AMERICAN SEMICONDUCTOR CONSUMPTION
(Millions of Dollars)

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	CAGR%
Total Semiconductor	$2,264	$1,810	$2,351	$2,742	$3,429	$4,619	$6,067	$6,085	$6,551	$8,286	15.5%
Total IC	$1,259	$1,018	$1,418	$1,795	$2,357	$3,311	$4,744	$4,666	$5,268	$6,909	20.0%
Bipolar Digital	573	362	488	593	721	922	1,443	1,322	1,342	1,716	13.0%
MOS	442	432	660	845	1,151	1,825	2,593	2,532	3,078	4,085	28.%0
Linear	244	224	270	357	485	564	708	812	848	1,108	18.3%
Total Discrete	$ 884	$ 664	$ 789	$ 832	$ 916	$1,067	$1,073	$1,141	$ 998	$1,049	1.9%
Total Opto-electronic	$ 121	$ 128	$ 144	$ 115	$ 156	$ 241	$ 250	$ 278	$ 285	$ 328	11.7%

Table 3.2

NORTH AMERICAN SEMICONDUCTOR CONSUMPTION FORECAST
(Millions of Dollars)

	1982	1983	1984	1985	1986	1987	1988
Total Semiconductor	$6,551	$8,286	$12,008	$15,562	$17,731	$19,038	$22,805
Total IC	$5,268	$6,909	$10,278	$13,542	$15,513	$16,710	$20,205
Bipolar Digital	1,342	1,716	2,385	2,826	3,021	2,909	3,346
MOS	3,078	4,085	6,520	8,923	10,364	11,321	14,242
Linear	848	1,108	1,373	1,793	2,128	2,480	2,617
Total Discrete	$ 998	$1,049	$1,353	$1,578	$1,703	$1,755	$1,895
Total Opto-electronic	$ 285	$ 328	$ 377	$ 442	$ 545	$ 573	$ 705

Table 3.3

ESTIMATED REGIONAL LINEAR MARKET SHARES
(Millions of Dollars)

	1975	1976	1977	1978	1979	1980	1981	1982
US Companies	$389	$443	$579	$781	$998	$1,171	$1,256	$1,308
Japanese Companies	120	249	320	514	602	808	1,111	1,061
European Companies	101	145	181	220	312	351	315	351
ROW Companies	0	0	2	0	0	3	7	8
Total	$610	$837	$1,082	$1,515	$1,912	$2,333	$2,689	$2,728

CHAPTER 4—MARKET ESTIMATES BY APPLICATION

The following major application end markets are analyzed in this chapter:

- Consumer
  - TVs
  - Radios
  - Automobiles
- Computer
  - Personal computers
  - Other computers
  - Disk drives
  - Displays
  - Printers
  - Plotters
  - Modems
- Telecommunications
  - Facsimile
  - PBX
  - Other exchange
  - Telephone
- Industrial equipment
  - Controls
  - Instrumentation
- Government/military

Linear integrated circuit content will not be analyzed for products sold in U.S. end markets that are manufactured outside the United States. The end-market sectors and products that fall into this category are:

- Consumer--TV and radio

- Telecommunications--Facsimile

These products, although consumed in large quantities in the United States, are to a large extent (about 98 percent) manufactured in Far Eastern countries.

4.1 CONSUMER--AUTOMOBILES

The U.S. automobile market is made up of local production and foreign imports. Table 4.1 lists the market percentages for the U.S. automobile market in 1983.

Electronics in the U.S. Automobile

Semiconductor electronics serve many functions in the typical automobile. The three major U.S. automobile manufacturers (General Motors, Ford Motor, and Chrysler Corporation) are all committed to significant use of electronics in their production models beginning in 1984. The electronics revolution in the automobile is only in its infancy in 1984 models, as evidenced by the low electronic content now compared to the projected use of electronics for not only engine-control systems and entertainment, but also for navigation and anti-skid electronics.

In general, electronics use in U.S. automobiles can be broken down into four main categories:

- Entertainment electronics

  -Digital-tuned AM/FM radios

  -Search scan systems

  -Electronic station memory

  -Power amplifiers

  -Noise-reduction systems

  -FM-blend systems

- Body electronics
  - -Cruise control
  - -Climate/temperature control
  - -Illuminated entry
  - -Automatic headlight dimming
  - -Light reminders
  - -Antitheft systems
  - -Memory seat adjustment
  - -Multiplex wiring
  - -Auto level restraint
  - -Passive restraint systems
  - -Rear window defogger
  - -Auto door locks
- Instrument or in-dash electronics
  - -Digital gauges
  - -Digital clock
  - -Trip computers
  - -Service reminder
  - -Multitone alarms
  - -Audio enunciators
- Engine electronics
  - -Ignition
  - -Spark timing
  - -Field control
  - -Variable displacement
  - -Turbo control
  - -Emission control
  - -Diagnostics

While the three U.S. automobile manufacturers provide similar instrument and entertainment electronic features their electronic control systems differ in the number of functions performed, as, for example, the number of mechanical, pneumatic, and hydraulic analog devices that are combined in the Chrysler system compared to the General Motors system. Table 4.2 lists the functions that are assisted by various digital and analog electronic devices.

The main components of the in-dash instrumentation electronics are fairly similar for all three manufacturers. The main components include:

- Electronic fuel gauges
- Electronic speedometers
- Message center displays
- Selector keyboards
- In-dash computers
- Sensors located around the engine and vehicle

These components are used to provide three basic categories of information:

- On-going driver information
- Warnings
- Process data

<u>On-going Driver Information</u>

The data provided to the driver includes information appearing on the electronic fuel gauge and the electronic speedometer. Both of these instruments are connected to electro-mechanical sensors such as pressure gauges in the case of a fuel gauge and electro-optical light sensors in the case of the electronic speedometer. The analog information is converted to digital form and transmitted serially to minimize wire and cabling logistics.

<u>Warnings</u>

Warning information is usually displayed as printed words on the message-center displays. These messages appear when sensors located around the vehicle and engine detect certain conditions that are on/off or either/or in nature: fuel level below a certain value, door or trunk ajar, oil pressure below a certain value.

Typical warnings include:

- Low fuel
- Alternator out
- Brake fluid/washer fluid/oil low
- Headlight/taillight/brake light out
- Trunk/door ajar
- Engine temperature high

Process Data

A small computer located behind the dashboard displays trip-related information, including:

- Distance traveled
- Time elapsed
- Average speed
- Distance to destination
- Estimated time of arrival
- Distance to empty (fuel)

Market Estimates

Historical estimates for U.S. automobile production for the years 1980 through 1983 and projected estimates for 1984 through 1989 are shown in Table 4.3. DATAQUEST projects that, as a function of time, the total semiconductor content of the average U.S.-made automobile will increase from $40.60 in 1982 to $95.56 in 1988. The semiconductor content of the U.S.-made truck will increase from $26.00 in 1982 to $76.17 in 1988. Significantly, however, the total linear dollar content as a percentage of the total semiconductor dollar content will decrease from 17.2 percent in 1982 to 14.0 percent in 1988 as the dollar value of the more sophisticated digital electronic functions will lower the linear dollar value proportionately.

4.2 COMPUTER

The computer end-market sector is further segmented as follows:

- Personal computers
- Other computers
- Disk drives
- Plotters
- Printers
- Modems
- Displays

The "other computers" segment will not be discussed in detail, but market estimate data will be included in the consolidated table.

Personal Computers and Other Computers

Of all the end-market segments, the computer market is benefitting from the phenominal thechnology advances of VLSI circuits. Specifically, the phenomenal growth of the personal computer since its inception in the late 70's (Apple I introduction) and early 80's (with the introduction of the IBM PC) has and is contributing directly to the growth of many primary and secondary markets. The linear integrated circuit industry is no exception. Although linear IC's do not command the attention of high performance digital microprocessors in large capacity dynamic RAMS, the linear integrated circuit is in itself a very significant component due to its role in power-management circuits --linear and switching power supplies, and communication circuits for data communications.

The U.S. consumption of personal computers for the period 1980 to 1988 is shown in Table 4.4. A personal computer is considered to have the following characteristics:

- 8- or 16-bit microprocessor for CPV electronics
- Minimum configuration consists of 64K RAM, a single 320K byte flexible diskette dome, monochrome or color video monitor, video adapter with pointer attachment keyboard
- End-user price ranges from $1,000 to $5,000.
- The linear content in a typical system varies according to the type of monitor supplied. There is an approximate 2:1 ratio in the dollar value of the linear integrated circuit content in personal computer systems that incorporate color monitors versus monochrome monitors. It is expected that the choice of a color monitor as a preferred display device will be more prevalent in the 1984 to 1988 period.

Disk Drives

Magnetic disk drives are divided into two main classes:

- Flexible disk drives
- Hard or rigid disk drives

Both types of drives are popular storage peripherals for small or personal computers. Flexible disk drives predominate among small systems because it is transportable and inexpensive. Hard disks, are often used for large file storage and memory backup in small systems and have long been the main storage peripheral for many large computers and mainframes.

Flexible disk drives are categorized according to the diameter of the media. There are three main categories:

- 8-inch drives
- 5.25-inch drives
- 3 to 3.5-inch drives

Single-sided and double-sided media are used in each of these diameters. Table 4.5 shows the total North American consumption of all flexible disk drives, both resale and captive quantities, as well as the value of the linear integrated circuits content for the 1980 to 1988 period.

The disk drive controller electronics that are incorporated in the disk drive itself interface the read/write heads with the disk drive/CPU interface electronics, which are mounted external to the drive. The integral disk drive controller performs signal conditioning and read-signal decoding and write-signal encoding. The use of linear integrated circuits in disk drives is confined mainly to minimal amounts of precision op amps, timers, and matched-transistor pairs.

Rigid disks are segmented into four categories, also by diameter:

- 3- to 4-inch drives
- 5.25-inch drives
- 8- to 10.5-inch drives
- 14-inch or greater drives

As in flexible disk drives, the interface electronics that are integral to the hard disk drive function specifically for signal conditioning and processing. Because of the track densities and the accuracies required, the electronics are more sophisticated, resulting in a greater analog electronics content compared to flexible drives. However, like its flexible drive counterpart, the value of digital circuits is by far predominant in value. The North American consumption of hard disk drives, together with the value of the total linear IC content, is shown in Table 4.6.

Plotters

U.S. consumption of all types of plotters is estimated to grow at a 9.5 percent rate for the 1982 to 1988 period. The value of linear circuits in plotters is expected to grow at a higher rate since the trend is for continued addition of functions and features. The value of linear integrated circuits in plotters and U.S. consumption of plotters are shown in Table 4.7.

Printers

Printers are the predominant hard-copy peripheral used with both small and large computer systems. Printers can be segmented into two main classes: impact and non-impact. They are further classified by speed and by the method of character formation: dot matrix or fully formed characters.

This analysis takes into account all types of printers. The estimated values of linear integrated content are based on a typical printer within each group. The typical linear ICs used in low-end printers are voltage regulators, timers, and transistor pairs for the hammer and character drivers.

As an example, a 30-line-per-minute matrix printer consists of three main sections:

- Controller for the printhead
- Dot printer matrix mechanism
- Power supply and filter

The five major classes of printers are:

- Line impact
- Serial impact
- Line non-impact
- Serial non-impact
- Page non-impact

The linear content for each of the above classes along with U.S. consumption of printers are shown in Table 4.8.

Modems

The growth in the consumption of modems has resulted from growing personal computer sales. Personal computer modems, typically microprocessor controlled, accept and execute commands from the personal computer such as automatic dialing and file transfer.

Dataquest estimates that U.S. personal computer modem shipments will rise from 151 thousand units in 1982 to 3.7 million units in 1988. Revenues will rise at a slightly slower rate, from $45.1 million in 1982 to approximately $549 million in 1988.

Estimates for U.S. consumption of modems and linear value is shown in Table 4.9.

Displays

The most common computer display device is a video terminal. The two major subcategories of video terminals are alphanumeric and graphics terminals. Alphanumeric terminals have either monochrome or color interfaces and can range from "dumb" to "intelligent" in capability.

The architecture of a low-end video terminal consists of the following electronic subsystems:

- Keyboard and configuration logic
- Processor electronics
- Master clock and system logic
- Communication interface
- CRT control and display memory
- Video circuits

Table 4.10 shows the projected linear circuit content and U.S. consumption of terminals for the years 1980 to 1988. The linear circuits typically used in low-end video terminals are voltage regulators for the power supplies and timers for the video control circuits. In higher-end terminals, there is an increase in the linear value due to in-card voltage regulation and additional timing circuits.

4.3 TELECOMMUNICATIONS MARKET

Introduction

The U.S. telecommunications market comprises five distinct subsegments:

- Customer premises equipment

  -PBXs

  -PABXs

  -Key telephone systems (KTSs)

  -Residential telephones

  -Facsimile machines

  -Voice/data workstations

- Transmission equipment

  -Multiplexers

  -Carrier

  -Microwave radio equipment

- Data communications equipment

  -Standalone modems

  -Multiplexers

  -T1 multiplexers

  -Data PBXs

  -Local area networks (LANs)

  -Front-end processors

- Cellular radio

  -Base station

  -Radio telephones

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- Telecommunications services
    - Long distance services
    - Local services

The values of production of each of these subsegments for the years 1983 and 1988 are shown in Table 4.11. The largest percentage of the hardware total in 1983 (55 percent of $12,363 million) was customer premises equipment. The next largest subsegment was switching equipment (16 percent) followed by transmission equipment (15 percent) and data communications equipment (13 percent). By 1988, the U.S. telecommunications market (excluding telecommuniations services) is expected to reach $26,193 million. The leading segments then will be customer premises equipment (51 percent or $13,430 million), followed by data communications (19 percent or $1,630 million), switching equipment (12 percent or $3,070 million) and transmission equipment (11 percent or $3,005 million).

Semiconductor linear circuit manufacturers have targeted the customer premises equipment and the central office equipment segments as the key areas of penetration for linear integrated circuits. A detailed discussion of these two market segments follows.

Customer Premises Equipment

Technology Evolution

Customer premises equipment consists of residential telephone systems, key telephone systems, PBXs, PABXs, facsimiles, and voice/data workstations.

Initially, the telephone was designed only to provide person-to-person, real-time verbal communications. As such, it had three major components:

- Transmitter--mouthpiece for transmitting messages
- Receiver--earpiece for receiving messages
- Ringer--indicates incoming calls

The first major development was the addition of a rotary dial for dialing without operator assistance. This dial enhanced outgoing calling efficiency since it avoided the hassles of reaching the operator, especially during peak calling hours.

The next major development was the key telephone set, in 1930, which provided multiline capability. Features included the ability to put one call on hold while answering another incoming call.

The use of LSI electronics in telephones began in the late 1960s with the introduction of push-button or dual-tone multifrequency (DTMF) dialing. The key advantages of the DTMF were increased dialing speed and greater reliability.

In push-button dialing, each key generates a pair of frequencies when pressed. The two frequencies allocated to each key consist of one pair equal to low-group frequencies and another pair for the high-group frequencies. Many of the older DTMF switching systems (both central office and PABXs) are not equipped with touch-tone oscillators to convert DTMF frequencies to dial pulses. Most of the recently introduced telephones, however, can be switched to work either in the DTMF mode or in the pulse mode.

Standard single-line telephone sets are not feature/function programmable. For use with PABX equipment, these line sets are usually station/line card controlled and use one pair of wires. Standard telephone sets offer limited feature/function selections such as call hold, call forward, and message waiting via message-waiting lamps. Such features are generally accessed by dialing a code and are implemented in the PABX rather than in the telephone set.

Microprocessor-controlled, single-line sets were first introduced for use in conjunction with PABX and hybrid KTS/PABX equipment. These sets are now being offered to the residential market and offer such features as:

- Last number redialing
- Memory/speed dialing
- Call forwarding
- Call waiting
- Call holding

<u>Key Telephone Sets (KTS)</u>

Key telephone sets have followed similar developmental patterns as single-line telephone sets. Since the early 1970s, there has been an increasing use of microprocessors in these sets to provide enhanced features. Key telephone sets can be divided into two main categories:

- 1A2-Compatible Sets--These sets have a standard interface and 25- or 50-pair wiring. They usually have 5 to 30 circuit buttons which are normally at the bottom of the dial pad and typically include one hold button. 1A2-compatible sets feature call hold, add-on conference (generally for a maximum of three parties), call waiting, privacy, speakerphones for conferencing and hands-free calling, intercoms for paging, and message-waiting lamps. Such features are generally accessed by dialing a code and are implemented in the KTS or hybrid KTS/PABX rather than in the telephone set.

- Electronic keysets--These sets are mostly enhanced key sets that are vendor specific in that they can only be used with the vendor's own PABX. These electronic keysets are microprocessor-controlled and have multiple features. In addition to being PABX/KTS system specific, these electronic keysets use two-, three-, or four-pair wiring and often provide access by push button to both PABX/KTS features and features incorporated in the telephone set. In general, alphanumeric displays are used to display information like calling number destination and source.

Central Office Equipment--VLSI Electronics in Telephones

The conventional dial telephone set contains no active (an active electronic element is one with gain or switching) circuit components. That is, the ordinary telephone performs no application of the incoming electrical signal. Whatever electrical signal current is produced at the central office is transmitted down the local loop and is heard by the listener. In fact, there is some finite signal reduction due to line loss in the local loop. Any application of the speech signal is done at the central office or in exchanges and repeaters between offices so as to centralize and minimize the cost of expensive and complex equipment. With the advent of very large scale integrated (VLSI) linear and digital electronics, the previously expensive (dumb) telephone is evolving into a smart distributed processing system.

VLSI and LSI analog and digital electronics are used in telephones to accomplish the following functions:

- Electronic speech
- Circuit protection
- Line balancing
- Electronic dialing and ringing
- Enhanced features for intelligent distributed processing

Electronic speech circuits replace the transmitter and receiver. The speech IC is connected to the telephone line via a low-voltage rectifier bridge. Some external components must be added for full functionality. Representative of these ICs are the Texas Instruments TCM1705 and TCM1706, designed for low-impedence electrodynamic microphones and high-impedence electric microphones, respectively. National Semiconductor's TP5700/TP5700-1/ TP5710 are other ICs that function as telephone speech circuits.

The key features of these circuits are that they replace the traditional hybrid transformer, compensation circuit, and side-tone networks to achieve superior audio linearity, distortion, and noise performance. Equally important is that these circuits are typically low-voltage designs allowing them to work over a wide range of operating conditions, including in long-loop extension telephones with operating power derived from the telephone line.

Protection circuits for telephones are necessary because small-signal transistors and linear and digital integrated circuits are easily damaged by high-voltage transience that may appear on the line due to lightening, switch intransience, or power line induction. A typical over-voltage and protection circuit uses the Texas Instruments TCM1703.

Line balancing is necessary because the imbalance of the hybrid e-coupler network results in a fraction of the transmitted signal being fed to the receiver. This balance is normally done by passive networks.

Electronic dialing and ringing circuits have evolved from the commonly used mechanical rotating dials with cams, gears, and contacts. Electronic-pulse dialers must emulate mechanical dialers, that is, they must interrupt the loop current at 10 pulses per second. In addition, they must short out the handset receiver so that no dial pulses are heard by the caller. This function is called muting. There are two ways to connect the dial circuits:

- Dial circuits in parallel with speech network

- Dial circuits in series with speech network

Dialing is also accomplished by sending dial tones over the phone lines. DTMF IC generators typically employ a counter and decoder that count pulses from a 3.58-MHz crystal oscillator and provide output codes that correspond to the required low-frequency and high-frequency tones. Each of the two outputs from the counter feed into separate D/A converters. The sine waves corresponding to the digital codes are summed in an op amp and fed to the speech network as a combined signal. The Texas Instruments TCM5087 is a typical DTMF-generating IC.

Electronic ringing, as with the conventional electro-mechanical bell, must be low cost, efficient, and reliable. However, electronic ringing provides the extra features of variable pitch and variable volume. Single-tone ringers can be built from a few discrete components. The trend, however, is toward multi-tone ringers that can achieve even lower component counts than can single-tone ringers. A typical multi-tone ringer is the PCM 1506.

Market Estimates

The detailed market estimates for the U.S. consumption of customer premises telecommunications equipment and central office telecommunications equipment are shown in Table 4.12. The value of all linear circuits in telecommunications equipment for the period 1983 to 1988 grew from $501 million in 1983 to $1,110 million in 1988.

4.4 INDUSTRIAL EQUIPMENT

The industrial electronic equipment market is segmented as follows:

- Controls--Process controls such as sensors, remote transmitters and receivers, and data acquisition and process computers; nuclear process controls for such activities as fuel handling, instrumentation, waste, and environmental control; motion controls for railroads, automobiles, and pedestrians

- Instrumentation--ATE test equipment, laboratory/scientific equipment, medical instrumentation, automotive instrumentation equipment, telemetry instrumentation, video instrumentation

These are only partial lists of the typical subclasses within the controls and instrumentation classes. Table 4.13 lists the estimated values of linear integrated circuit content in the industrial electronic segments as well as values and quantities for the industrial electronic equipment market.

During 1983, the output of equipment, instruments, and parts is estimated to be 4.7 percent higher than 1982. In 1984, as the recovery of business proceeds, the production of instruments is expected to rise 11.7 percent over 1983.

4.5 GOVERNMENT/MILITARY ELECTRONICS

The semiconductor market for government/military electronics is extremely strong for the 1984 to 1986 period. A 5 percent real growth in defense appropriations is expected for fiscal 1984 as pressure by government and industry for continued military capabilities continues.

The military semiconductor consumption, as shown in Table 4.14, grew almost 10 percent in 1983 over 1982, from $908 million to $1 billion. Since the predominant demand from the government/military community is for more expensive, complex, digital VLSI circuits, DATAQUEST expects that there will be a decrease in the value of linear circuits compared to other types of semiconductors. Linear circuits, which account for 20 percent of all integrated circuits usage in 1980, will drop to 17 percent in 1984 and 15 percent in 1988.

4.6 SUMMARY

The estimates for the North American consumption of linear integrated circuits by end market sector are provided in Table 4.15. These data include both the merchant linear integrated circuit manufacturers' shipments and captive linear integrated circuit consumption by such firms as AT&T Technologies, ITT, Northern Telecom, IBM, Motorola, General Motors, Ford Motor, and Chrysler. The consumption estimates for 1983 are $2,323.3 million, growing to $8,098 in 1988.

Table 4.1

U.S. AUTOMOBILE MARKET SHARES

Manufacturer	Percent of U.S. Market
General Motors	47.50%
Ford	22.81
Chrysler	13.71
Subtotal	84.02%
Import	15.98
Total	100.00%

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Table 4.2

COMPARISON OF ELECTRONIC FUNCTIONS USED BY THE TOP LINE U.S. AUTOMOBILE MANUFACTURERS

General Motors	Chrysler	Ford
o Canister/fuel injector	o Electronic panel injector	o Electronic fuel injector
o Spark timing	o Auto-calibration circuit	o High energy ignition
o Idle speed	o Electronic spark advance	o Exhaust gas recirculation
o Exhaust gas recirculation	o Automatic idle speed	o Canister-purge system
o Canister purge		o Feedback carburetor activator
o Cruise control		
o Air management		
o Transmission torque converter clutch		
o Early fuel evaporation		
o Modulated displacement		
o Instrument panel display		
o System self diagnosis		

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Table 4.3

NORTH AMERICAN CONSUMPTION OF SEMICONDUCTORS IN AUTOMOBILES AND TRUCKS

	1982	1983	1984	1985	1986	1987	1988
Vehicle Production							
Automobiles (Millions)	5.1	6.8	8.0	7.9	8.1	7.8	8.2
Trucks (Millions)	1.9	2.4	3.0	2.9	2.95	2.8	2.9
Semiconductor Content/Vehicle							
Automobiles ($)	40.60	51.60	65.50	71.98	79.1	86.94	95.54
Trucks ($)	26.00	36.12	49.13	54.82	67.18	68.26	76.17
Automobile Semiconductor by Functional Category %							
Entertainment Electronics (%)	13.1	14.1	15.3	15.0	14.7	14.4	14.1
Body Electronics (%)	9.1	9.8	10.5	10.6	10.7	10.8	10.89
Driver Information (%)	7.1	6.6	6.4	7.6	8.9	10.7	12.7
Engine Electronics (%)	70.7	69.9	67.8	66.2	64.6	63.1	61.6
Semiconductor Content ($M)	256.4	437.6	671.4	727.6	838.9	869.2	1004.3
Automobiles ($M)	207.0	350.9	524.0	568.6	640.7	678.1	783.4
Trucks ($M)	49.4	86.7	147.4	159.0	198.2	191.1	220.9
Linear Content ($M)	44.2	71.6	106.3	111.9	125.0	125.3	140.9
Automobiles ($M)	33.1	52.5	74.9	79.6	86.4	89.5	101.1
Trucks ($M)	11.1	19.1	31.4	32.3	38.6	35.8	39.8

Table 4.4

WORLDWIDE PRODUCTION OF PERSONAL COMPUTERS BY U.S. MANUFACTURERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988
Shipments ('000's)	367.0	547.3	1111.0	2552.0	5032.0	7196.0	10290.0	12657.0	15568.0
Revenue End-User ($M)	764.1	1469.2	3181.9	7445.4	14196.4	20300.9	29030.3	35707.27	43919.94
Total IC Content ($M)	25.98	49.952	127.28	372.27	709.82	1218.05	1741.8	2320.97	3854.79
Linear Content ($M)				37.0	58.0	91.0	143.0	226.0	356.0

Table 4-5

U.S. CONSUMPTION OF FLEXIBLE DISK DRIVES

	1980	1981	1982	1983	1984	1985	1986	1987	1988
8-inch									
Units (000s)	713.0	822.0	1101.0	962.0	860.0	768.0	688.0	602.0	499.0
Value ($M)	833.6	948.3	1303.5	1079.1	947.1	838.7	747.1	648.9	534.9
Linear ($M)	33.5	38.0	52.0	43.0	33.0	29.4	26.1	23.0	18.7
5.25-inch									
Units ('000s)	508.3	958.2	2565.0	5574.0	8544.0	11330.0	12985.0	14301.0	13713.0
Value ($M)	290.0	524.8	1332.2	2712.1	3830.1	4626.7	4874.7	4872.2	4170.0
Linear ($M)	8.7	15.7	39.9	81.4	95.7	115.7	121.9	121.8	104.0
8-10.5-inch									
Units ('000s)			15.0	107.0	859.0	2140.0	4287.0	7497.0	11807.0
Value ($M)			6.3	43.9	292.7	662.8	1186 3	1895.0	2922.0
Linear ($M)			.1	.9	4.4	9.9	17.8	28.4	43.8

Table 4-6

U.S. CONSUMPTION OF RIGID DISK DRIVES

	1980	1981	1982	1983	1984	1985	1986	1987	1988
3-4-inch									
Units (000s)	-	-	0	23.9	187.6	516.2	1340.8	2681.3	3978.3
Value ($M)	-	-	0	29.4	212.0	537.2	1299.8	2480.7	3461.8
Linear ($M)	-	-	0						
5.25-inch									
Units ('000s)	1.4	33.4	139.4	764.4	1303.6	2602.9	3062.2	3899.2	4747.6
Value ($M)	4.2	92.7	259.0	1342.1	2184.1	4006.3	4773.6	6382.8	7879.7
Linear ($M)									
8-10.5-inch									
Units ('000s)	59.6	130.5	200.9	229.2	349.7	457.1	501.4	519.0	539.3
Value ($M)	440.4	884.5	1360.0	1748.6	2707.5	3610.1	3955.3	4290.2	4635.8
Linear ($M)									
14-inch									
Units ('000s)	303.0	313.4	276.1	282.9	322.5	326.3	313.3	316.1	306.8
Value ($M)	4114.0	4534.0	4600.0	5159.0	6262.0	6737.0	7074.0	7307.0	7304.7
Total Linear Content($M)				42.6	55.5	66.8	73.7	88.2	98.1

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Table 4.7

ESTIMATED U.S. CONSUMPTION OF PLOTTERS

	1980	1981	1982	1983	1984	1985	1986	1987	1988
Units ('000s)	12.5	13.5	13.2	14.5	14.8	15.6	16.3	17.1	17.9
Value ($M)	88.0	96.0	105.5	115.5	126.5	139.0	151.6	166.1	181.9
Linear IC ($M)	2.6	2.9	3.2	5.8	6.4	6.9	7.6	8.3	9.1

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Table 4.8

NORTH AMERICAN CONSUMPTION OF PRINTERS
(Millions of Dollars)

	1980	1981	1982	1983	1984	1985	1986	1987	1988
Serial Impact	2079.8	2921.9	4053.3	4910.5	5505.9	5649.6	5811.2	5484.3	4938.6
Fully Formed	522.8	773.3	1054.8	1338.5	1524.4	1624.0	1878.3	1678.2	1560.3
Dot Matrix	1557.0	2148.6	2998.5	3572.0	3981.5	4025.6	3932.9	3806.1	3378.3
Linear Content	31.2	43.8	56.7	63.8	74.3	79.1	84.3	75.8	61.5
Line Impact	1993.1	1971.4	1733.8	1397.3	1480.0	1410.6	1367.1	1285.4	1195.6
Fully Formed	1867.1	1809.9	1554.6	1213.1	1288.6	1203.6	1122.2	997.0	886.3
Dot Matrix	126.0	161.5	179.2	184.2	191.4	202.0	244.9	288.4	309.3
Linear Content	1.9	2.4	2.7	2.8	2.9	3.5	4.2	4.6	5.3
Serial, Non-Impact	144.3	123.1	160.9	206.9	318.0	703.7	1225.7	2158.9	2588.3
Direct Thermal	113.2	98.6	141.8	179.1	189.1	166.7	169.5	200.7	206.4
Thermal Transfer	--	--	--	--	23.5	121.4	378.8	773.0	1017.0
Ink Jet	31.1	24.5	19.1	27.7	105.4	415.6	677.4	1185.2	1364.1
Linear Content	.5	.4	.3	.4	1.9	6.2	10.2	17.8	20.5
Line, Non-Impact	17.1	19.7	16.0	14.6	86.4	164.6	372.2	641.8	749.9
Direct Thermal	17.1	19.7	16.0	11.6	8.6	6.2	4.0	2.9	2.2
Thermal Transfer	--	--	--	3.0	77.8	158.4	368.2	638.9	747.7
Linear Content	.3	.4	.2	.2	1.5	2.5	5.6	9.6	11.2
Page, Non-Impact, Plain Paper	287.8	333.4	362.3	460.2	741.4	1236.6	2234.7	3327.0	3974.0
Linear Content	8.6	10.0	12.6	18.4	33.4	59.4	107.3	135.0	185.0
Total Printer	4522.1	5369.5	6326.3	6989.4	8131.7	9165.1	11010.9	12897.4	13446.1
Total Linear Content	42.5	57.0	72.5	85.6	114.0	150.7	211.6	242.8	283.5

Table 4.9

ESTIMATED U.S. CONSUMPTION OF PERSONAL COMPUTER MODEMS

	1980	1981	1982	1983	1984	1985	1986	1987	1988
Units ('000s)	55.0	88.0	151.0	208.0	310.0	531.0	1026.0	2191.0	3725.0
Value ($M)	24.0	32.0	45.1	53.6	68.5	104.4	185.3	363.7	549.2
Linear IC Value ($M)	.7	1.0	1.4	1.6	1.1	1.6	2.8	5.5	8.3

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Table 4.10

U.S. CONSUMPTION OF TERMINALS
(Millions of Dollars)

	1981	1982	1983	1984	1985	1986	1987	1988
Teleprinters	600	500	520	520	540	580	600	630
Linear content	12	11	10	10	11	12	12	13
CRT Terminals	3600	4000	4680	5600	6800	7900	7200	10600
Linear content	162	180	210	252	306	360	414	477
Special Purpose Terminals	1900	2150	2600	3300	4200	5100	6200	7500
Linear content	95	108	130	165	210	255	310	375
5% Special Purpose Workstation (Engineering)	200	250	320	420	540	680	770	920
Linear circuit	13	16	21	27	35	44	51	60
6% Special Purpose Workstation (Business office)	1250	1500	2000	2600	3150	3300	3500	3700
Linear content	75	90	120	156	189	198	210	222
Total	7550	8450	10120	12440	15230	17560	20270	23350
Linear content	357	405	491	610	751	869	997	9147

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Table 4.11

U.S. TELECOMMUNICATIONS INDUSTRY VALUE
(Millions of Dollars)

Category	1983	1988
Customer Premises	$ 6,820	$ 13,430
Transmission	1,832	3,005
Data Communications	1,630	4,938
Telecommunications Services	111,100	187,900
Switching Equipment	1,950	3,070
Cellular Radio	131	1,750
Total	$123,463	$214,093

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Table 4.12

NORTH AMERICAN LINEAR SPECIAL TELECOMMUNICATIONS
EQUIPMENT MARKET ESTIMATES

	1983	1984	1985	1986	1987	1988
Customer Premises Equipment						
PBXs						
Lines (000s)	3,567.00	3,880.00	4,222.00	4,594.00	4,998.00	5,439.00
Analog (000s)	1,427.00	1,358.00	1,262.00	1,149.00	1,000.00	564.00
Digital (000s)	2,140.00	2,522.00	2,955.00	3,445.00	3,998.00	4,895.00
Dedicated Telecom Semiconductor Contact ($M)	135.50	153.30	173.10	195.20	219.90	256.00
KTS						
Telephones (000s)	3,600.00	3,751.00	3,909.00	4,073.00	4,244.00	4,422.00
Value ($M)	2,360.00	2,407.00	2,455.00	2,504.00	2,554.00	2,605.00
Dedicated Telecom Semiconductor Content ($M)	142.00	144.00	147.00	150.00	153.00	156.00
Residential Telephone						
Units (000s)	19,300.00	23,681.00	29,056.00	35,652.00	43,745.00	53,675.00
Value ($M)	1,140.00	1,489.00	1,944.00	2,539.00	3,316.00	4,331.00
Dedicated Telecom Semiconductor Content ($M)	57.00	74.00	97.00	127.00	166.00	217.00
Voice Data Workstations						
Units (000s)	30.00	62.00	130.00	240.00	510.00	1,060.00
Value ($M)	40.00	87.00	189.00	400.00	910.00	1,500.00
Dedicated Telecom Semiconductor Content ($M)	3.20	7.00	15.00	32.00	73.00	120.00
Central Office Equipment						
Lines (000s)	8,860.00	9,790.00	10,818.00	1,954.00	13,209.00	14,600.00
Analog (000s)	2,658.00	2,937.00	2,704.00	2,391.00	1,981.00	1,460.00
Digital (000s)	6,202.00	6,853.00	8,113.00	9,563.00	11,888.00	13,140.00A
Dedicated Telecom Semiconductor Content ($M)	163.00	180.14	235.30	267.80	334.80	360.60
Total Dedicated Telecom Semiconductor Content ($M)	500.70	558.40	667.40	772.00	946.70	1,109.60
Adjusted Total Telecom Semiconductor Content ($M)*	651.00	771.00	914.00	1,083.00	1,342.00	1,690.00
Merchant ($M)	135.30	189.80	266.30	373.50	524.00	735.10
Captive ($M)	515.70	583.30	659.80	746.30	844.20	954.90

*An adjustment in the total semiconductor content is made to take into account the exclusion of transmission, data communications equipment, and cellular radio markets for the entire 1983-1988 period.

Table 4.13

ESTIMATED U.S. CONSUMPTION OF SEMICONDUCTORS IN THE INDUSTRIAL MARKET

	1980	1981	1982	1983	1984	1985	1986	1987	1988
Shipments of Equipment	15,478	17,227	19,180	20,085	22,439	24,900	27,390	29,855	33,140
Total Semiconductor Usage	697	855	969	1,125	1,502	1,868	2,192	2,389	2,718
Linear Percent of Semiconductor Shipments	30	39	38	51	76	102	109	125	155

Table 4.14

ESTIMATED U.S. GOVERNMENT/MILITARY SEMICONDUCTOR CONSUMPTION

	1980	1981	1982	1983	1984	1985	1986	1987	1988
Integrated Circuits	583	628	729	810	926	1,080	1,247	1,441	1,664
Digital	463	503	582	665	766	900	1,040	1,211	1,414
Linear	120	125	147	145	160	180	207	230	250

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Table 4.15

NORTH AMERICAN CONSUMPTION OF LINEAR INTEGRATED CIRCUITS
BY END-MARKET SECTOR
(Millions of Dollars)

	1982	1983	1984	1985	1986	1987	1988
Consumer	44.2	71.6	106.3	111.9	125.0	125.3	140.9
Automotive	44.2	71.6	106.3	111.9	125.0	125.3	140.9
Captive	13.3	15.1	17.1	19.4	21.9	24.9	28.2
Merchant	30.9	56.5	89.2	92.5	103.1	100.4	112.7
Computer	na	1,307.9	1,508.1	1,789.0	2,151.5	2,577.0	3,097.5
Personal Computer	na	37.0	58.0	91.0	143.0	226.0	356.0
Other Computer	420.0	519.0	530.0	566.0	678.0	836.0	1,029.0
Printers	72.5	85.6	114.0	150.7	211.6	242.8	283.5
Personal Computer Modems	1.4	1.6	1.1	1.6	2.8	5.5	8.3
Plotters	3.2	5.8	6.4	6.9	7.6	8.3	9.1
Terminals	405.0	491.0	610.0	751.0	869.0	997.0	1,147.0
Disk Drives	na	167.9	188.6	221.8	239.5	261.4	264.6
Telecommunications	550.0*	651.0	771.0	914.0	1,083.0	1,342.0	1,690.0
Captive	430.0	505.7	583.3	659.8	746.3	844.2	954.9
Merchant	120.0	135.3	189.8	266.3	373.5	524.0	735.1
Industrial	39.0	51.0	76.0	102.0	109.0	125.0	155.0
Captive	1.6	1.9	2.3	2.7	3.3	3.9	4.7
Merchant	37.4	49.1	73.7	99.3	105.7	121.1	150.3
Government/Military	145.0	147.0	160.0	180.0	207.0	230.0	250.0
Total	na	2,228.5	2,621.4	3,096.9	3,675.5	4,399.3	5,333.4
Captive	444.9	532.7	602.7	681.9	771.5	837.0	987.8
Merchant	na	1,695.8	2,018.7	2,415.0	2,904.0	3,562.3	4,345.6

*Estimate

CHAPTER 5—COMPETITIVE ANALYSIS

5.1 COMPANY ANALYSIS

The top eight U.S. manufacturers of linear integrated circuits are:

- Analog Devices
- Fairchild Semiconductor
- Harris Corporation
- National Semiconductor
- RCA Corporation
- Texas Instruments
- Motorola
- Signetics

In addition to these leading suppliers, there are a number of smaller companies that supply linear integrated circuits. These smaller companies include:

- AMD
- Comlinear Corporation
- Elantec
- Exar Integrated Circuits
- Interdesign/Ferranti
- Linear Technology
- Maxim Integrated Circuits
- Micro Linear
- Precision Monolithics Incorporated
- Raytheon Semiconductor
- Silicon General
- Thomson-CSF
- Unitrode Corporation

With the exception of Analog Devices, the top eight U.S. suppliers of linear ICs manufacture a broad range of large-scale integrated circuits, which include standard digital logic and microprocessor circuits as well as custom circuits. Because of their broad range of expertise in research and design and manufacturing, these firms are the leaders in the production and marketing of linear ICs.

On the other hand, the smaller firms, such as Silicon General, have been set up primarily to produce circuits or to exploit a given circuit or process technology in order to control particular niches of the marketplace. The following sections analyze each of the leading eight U.S. linear integrated circuit merchant suppliers.

Analog Devices

Analog Devices is a vertically integrated semiconductor and systems manufacturer with headquarters in Norwood, Massachusetts. The company is divided into two major groups: Components and Instruments and Systems. Most of the Components group is located in Wilmington, Massachusetts, and all of the Instruments and Systems group is located in Norwood.

Analog Devices manufactures more than 600 standard products, ranging from simple operational amplifiers and A/D integrated circuits to sophisticated computer-based systems. Analog Devices' integrated circuit components include operational amplifiers, sample-hold amplifiers, instrumentation and isolation amplifiers, and analog-to-digital (A/D), digital-to-analog (D/A), voltage-to-frequency (V/F), frequency-to-voltage (F/V), sample/hold (S/H), and RMS/DC converters. Analog Devices offers both modules or hybrids that perform these functions. A module or hybrid is a sealed, self-contained component inside of which is a group of ICs and/or discrete components.

Financial Highlights

Analog Devices' financial highlights for the years 1981 through 1983 are shown in Table 5.1. Total sales for the company were $214 million in 1983, a rise of 23 percent over 1982 sales. Net income almost doubled from $9.87 million in 1982 to $18.4 million in 1983. This corresponds to a net income equivalent of 9 percent of sales, up from 6 percent in 1982. Typically, 60 percent of all Analog Devices' products are sold domestically. The company's primary overseas customers are in Japan, France, West Germany, and the United Kingdom. By business segment, the analog integrated circuit products segment accounted for 65 percent of total sales in 1983 or $139 million. The analog circuit component business is a growing percentage of the company's total business as evidenced by a change from 55 percent of total sales in 1980 to 65 percent in 1983.

Linear Strategy

Analog Devices is primarily a market-driven company that has the unusual ability to understand its customers' needs at both the applications and the interface ends. Being vertically integrated, Analog Devices can initially offer products in the form of modules or hybrids that are bigger, more complex, and more expensive than the typical linear integrated circuit. When the demand justifies a monolithic implementation of the module, Analog Devices can then offer such modules as monolithic analog ICs.

Analog Devices' distinct competence is in the field of signal processing. Products and markets are developed internally or through investments in outside companies whose technologies complement those of Analog Devices. Each of Analog Devices' 10,000 different customers fall within one of the following six market segments:

- Laboratory automation
  - CAD/CAM
  - Workstations
- Industrial automation
  - ATE
  - Robotics
  - Process control
- Defense/avionics
  - Navigation
  - Surveillance
  - Fire control
- Energy conservation and development
  - Exploration
  - Energy control
  - Development
- Health care
  - Analysis
  - CAT scanning
  - Digital x-ray
- Telecommunications

All of the six market segments use Analog Devices' products as precision elements for signal processing. Analog Devices' strategy for growth in the late 1980s is dependent on the continued successful development and marketing of linear products that sense and process information as opposed to digital information. In the light of the ever-increasing need to process this data using the precision products that Analog Devices markets, sales goals are $800 million for 1987 and $1 billion by 1989. This translates to company-wide analog integrated circuit sales of $520 million in 1987 and $700 million in 1989.

Fairchild Semiconductor

Fairchild Semiconductor is one of the business units of Schlumberger Limited, a multinational company whose business activities offer oil field services, measurement control, and semiconductor components. Specifically, Schlumberger business sectors are:

- Oil Field Services
  - Wireline services
  - Drilling
  - Production services
- Measurement and Control
  - Electronic management
  - Instruments
  - Fluid metering process control
  - Valves
- Components
  - Fairchild Semiconductor
- Computer Aided Systems
  - Applicon
  - Benson
  - Component test systems
  - Subassembly test systems

The Fairchild Semiconductor facility produces large-scale integrated circuits (LSI) such as logic, memories, microprocessors, gate arrays and imaging devices using MOS, bipolar and CCD technologies. Fairchild's linear circuit offerings include such circuits as voltage regulators, operational amplifiers and telecommunication devices. Discrete components such as transistors and diodes are also manufactured by Fairchild. Fairchild's end-markets incude the computer, communication, telephone, instrumentation, defense and government sectors.

Financial Highlights

1983 was a crucial year for Fairchild. The heavy losses that were sustained in 1982 continued in 1983, though these losses were smaller. New management teams and strategies were put in place and the results of these new directions should be seen beginning in the 1984-1986 period. There has been a large injection of capital into new equipment and plants particularly in such areas as quality control and manufacturing automation.

The first quarter North American revenues and orders for all semiconductors rose 53 percent and 51 percent respectively. The demand was particularly strong for all of Fairchild's major product lines: digital's FAST family, gate arrays, and standard linear commercial production.

In March 1984, the Fairchild Linear Division was recertified by the U.S. Defense Logistics Agency as a supplier of military grade products. DATAQUEST expects the continuing recovery in the U.S. economy and the improvement in the European economies will boost Fairchild's order and backlog rate for all of 1984.

The financial highlights of Schlumberger are provided in Table 5.2.

The revenue estimates for Fairchild Semiconductor are provided in Table 5.3.

Harris Corporation

Harris Semiconductor is one of the four business sectors of Harris Corporation, based in Melbourne, Florida. The other three business sectors are:

- Information systems
- Communications
- Government systems

The semiconductor sector comprises the following units:

- Custom Integrated Circuits Division, Melbourne, Florida
- Semiconductor Products Group, Melbourne, Florida
- Harris Microwave Semiconductor (80 percent owned), Milpitas, California
- Matra-Harris Semiconducteurs, SA (49 percent owned), Nantes, France

The following three divisions make up the Semiconductor Products Group:

- Analog Products Division, Melbourne, Florida, and Kuala Lumpur, Malaysia
- Bipolar Digital Products Division, Melbourne, Florida
- CMOS Digital Products Division, Melbourne, Florida

The semiconductor sector produces standard and custom ICs using bipolar, CMOS, dielectric isolation, gallium arsenide, and NMOS fabrication technologies. The products derived from these technologies for both analog and digital applications include memory, logic, data conversion, telecommunications, and microprocessors. They are sold to the computer, communications, telephone, industrial, and medical equipment instrumentation markets and to defense contractors and government agencies.

Financial Highlights

The performance of the semiconductor sector compared to the other sectors is shown in Table 5.4. In 1983, semiconductor sales were $152 million, a small 1.9 percent increase of $4.3 million over 1982. Losses of $7.7 million were sustained in 1983. Net sales of the semiconductor group were approximately 11 percent of total corporation sales of $1.4 billion.

Harris entered the semiconductor business in general from a military systems base. For the analog segment of the business, Harris positions itself as a horizontally oriented linear IC supplier focusing on the high-performance end of the analog product spectrum.

Harris is hoping that the upturn in the economy and its strength in low-power digital circuits for military markets (low power, increased equipment life, decreased sensitivity to electromagnetic noise, and the ability to work over a wide temperature range), together with emphasis on unique linear applications (high slew rate and wide bandwidth), will enable the analog section of its semiconductor business to do well in the 1984 to 1986 timeframe.

Linear Strategy

Harris provides a broad line of analog integrated circuits that includes bipolar and CMOS switches, multiplexers, amplifiers, and data acquisition and data conversion circuits.

Harris introduced a total of 19 new linear products in 1983, a result of the company's heavy emphasis on research and development during the previous two years. The two significant analog product introductions in 1983 were:

- The HV-1000, a high-voltage AC power-control chip used to control single-phase induction motors, which allows for significant cost-saving benefits by reducing the power consumption of lightly loaded motors
- A 12-bit microprocessor-compatible A/D converter

Harris Semiconductor utilizes a variety of different process technologies in the fabrication of its linear integrated circuits. The processes available and their respective features include:

- Dielectric isolated bipolar
    - High performance
    - High-voltage capability
    - Radiation tolerant
- Combination CMOS/bipolar
    - Multiplexer applications
    - High-voltage CMOS capability
    - Metal gate or silicon gate

- Junction-isolated bipolar
  - Low-cost, proven technology
- Precision resistor technology
  - High-sheet resistance implanted boron
  - Thin-film nickel chromium
  - Laser trimmed
- JFET technology
  - Compatible n- and p-channel JFET devices

The dielectric isolation process technology is the base for most linear designs. The performance advantages of dielectric isolation over junction isolation include:

- High-frequency performance
- High-voltage capability
- Functional flexibility
- Radiation resistance

On the technical side, the dielectric isolation bipolar process offers high-performance NPN and PNP transistors, reduced capacitances, compatible CMOS devices, and minimum parasitic substrate effects such as SCRs, leakage, currents, and device-coupling effects.

For CMOS circuits, in addition to focusing on geometry scaling to achieve higher functional densities and operating speeds for digital circuits (memory and microprocessor), Harris is also optimizing the device characteristics for analog circuit applications in telecommunications. The dielectric isolation process developmental program is oriented primarily toward analog products with particular emphasis on very high voltage circuits for telecommunication and AC power line applications.

National Semiconductor

National Semiconductor is a California-based independent merchant semiconductor manufacturer. The company's primary business segments are components and digital systems. The primary operations of each segment are as follows:

- Components--Development, manufacture, and sale of a broad range of semiconductor products including digital integrated circuits, analog circuits, discrete circuits, hybrids, subsystems, optoelectronic devices, electronic packaging, and miscellaneous services for the semiconductor industry

- Digital systems--Development, manufacture, and sale of microprocessor-based boards and systems, point-of-sale (POS) terminals, and electronic cash registers

National's semiconductor activity is based in Santa Clara, California, with additional development and manufacturing plants in West Jordan, Utah; Grennock, Scotland; Danbury, Connecticut; and Tucson, Arizona.

Financial Highlights

National Semiconductor's net sales in 1983 were $1.21 billion, an increase of $106.4 thousand over 1982. Sales in 1981 amounted to $1.11 billion. The company had a net loss of $14.2 million in 1983, a net loss of $10.7 million in 1982, and net earnings of $52.4 million in 1981.

The major factors contributing to the losses in 1982 and 1983 were the worldwide economic recession, excess semiconductor manufacturing capacity, increased foreign competition, and the strength of the U.S. dollar against many foreign currencies.

Net sales of the components segment were $785 million in 1983, $746.6 million in 1982, and $795.9 million in 1981. The increase in net sales from 1982 to 1983 was due primarily to an increase in volume; average selling prices were essentially unchanged. Although the company sustained net losses in 1982 and 1983, operational profits amounted to $0.4 million in 1982 and $10.4 million in 1983. More detailed financial highlights are shown in Table 5.5.

Linear Strategy

National Semiconductor is a leader in the design and development of linear circuits. In the late 1970s, National began the development of a proprietary CMOS process called poly-squared CMOS. With the use of this new process National has begun to deliver a variety of new linear products using this new process technology. Among the new products are a new active filter family spearheaded by the MF-10. These new circuits will allow National to target new applications in the areas of telecommunications, toys and games, and instrumentation systems.

In addition, National has developed a new proprietary passivation technique called Nitride Plus. This new technique allows for substantial improvement in both the performance and reliability of linear ICs.

National is also placing great emphasis on the data acquisition segment of the linear circuit business. The company's strategy is to offer many of the industry-standard D/A and A/D circuits using the poly-squared CMOS technologies. These circuits will see the merging of more functions such as multiplexing and nonvolatile and volatile storage, as well as intelligent interfacing with the industry-standard microprocessor bus interfaces.

RCA Corporation

RCA's business segments include:

- Electronics
- Broadcasting
- Communications
- Transportation services
- Financial services

RCA's electronics business segments products are classified as follows:

- Components
  - Semiconductor devices
  - Electro-optical devices
  - Circuit boards
  - Tubes
- Subsystems
  - Communications equipment
  - Digital computers
  - Home entertainment
- Systems
  - Communications equipment
  - Digital computers
  - Home entertainment systems
- Funded research
  - Feasibility studies
  - New product design

RCA's linear integrated circuit products fall under the components subsegment within the solid-state division. The two main centers for linear integrated circuit design, development, and production are:

- RCA Solid State Division, Sommerville, New Jersey--Administration, marketing, engineering

- Findlay, Ohio--Wafer processing

The West Palm Beach Gardens, Florida, location is involved mainly in the wafer processing and testing of digital LSI products, which includes microprocessors and peripheral ICs and memories. In addition, RCA has foreign plants located in Taiwan, Malaysia, and Brazil.

Financial Highlights

The financial highlights of the company as a whole are shown in Table 5.6. RCA's total electronics sales increased 11 percent to $4.84 billion in 1983 after a 1 percent decline in sales in 1982. Sales and profits of solid-state devices were higher in 1983 than in 1982.

The sales of the commercial products group fell to $1,139.5 million in 1983 from $1,189 million in 1982, a 4 percent decrease. Linear integrated circuit sales increased from $70 million in 1982 to $75 million in 1983. Sales in 1983, however, were still below the 1981 peak of $76 million.

Linear Strategy

The history of MOS linear circuits, in particular at RCA, can be traced to the early days of integrated circuits. In the early 1970s, RCA was a leading supplier of linear circuits. Though RCA's original products were implemented using bipolar designs, RCA was one of the first IC manufacturers to introduce a MOS-based operational amplifier. Much of the early expertise in MOS design applicable to linear circuits was based on experience gained in the original 4000-CD series of digital circuits. RCA has not followed up the early success of the 4000 digital series and early MOS-based operational amplifiers with more product introductions based on MOS. The sales figures for linear products indicate that between 1981 and 1983, linear sales have not risen by more than $1 million. Between 1983 and 1984, RCA has not made any significant linear product introductions and, at present, most of its products are based on bipolar designs.

DATAQUEST anticipates that RCA will not make any signficant inroads into the linear markets, considering that many of the linear growth areas such as data conversion and telecommunications require innovative products that offer high speed, high resolution, and compatibility with the existing standard microprocessor families.

Texas Instruments

Texas Instruments, based in Dallas, Texas, is engaged in the development, manufacture, and sale of a variety of products in the electrical and electronics industry for equipment markets in the industrial, consumer, and government/military sectors.

The business segments and their representative products that make up Texas Instruments include:

- Components
  - Semiconductor products (linear, discrete, and digital ICs)
  - Electrical and electronic control devices
- Government electronics
  - Radar
  - Infrared surveillance systems
  - Missile guidance and control systems
- Digital products
  - Minicomputers
  - Personal computers
  - Data terminals
  - Printers
  - Industrial controls
  - Electronic calculators
  - Learning aids
- Metallurgical materials
  - Clad metals for use in automotive equipment and appliances
- Services
  - Gas and oil
  - Seismic data processing and consulting

The electronic products can be classified in three subsegments as follows:

- Components
  - Semiconductors
  - Connectors
  - Switches
  - Relays
  - Assemblies
  - Boards
  - Cabinets
- Subsystems
  - Calculators
  - Learning aids
  - Communications equipment
  - Digital computers
  - Test and measurement equipment
- Systems
  - Radar
  - Other communications equipment

A significant amount of sales is due to intersegment traffic between different business segments. TI's semiconductor activity is based in Dallas, Houston, Sherman, and Midland, Texas, with additional development and manufacturing support in Buenos Aires and Campinas, Brazil; Miho, Hatagoya, and Hiji, Japan; Singapore; Kuala Lumpur, Malaysia; Nice, France; Bedford and Plymouth, England; Rieti, Italy; Oporto, Portugal; Tapei, Taiwan; and Friesing, Germany.

Financial Highlights

Texas Instruments' net sales billed in 1983 were $4,580 million, an increase of 6 percent over 1982. Sales increased significantly in all areas except the consumer electronics area, where sales in 1983 were well below the 1982 level. In 1983, excluding consumer activities, net sales billed were up 10 percent and operating profits were up 73 percent from 1982.

The dramatic growth in TI's semiconductor orders during 1983 came primarily from sales to small computer and peripheral equipment manufacturers. In the latter half of the year, there was significant demand from the automotive, telecommunications, mainframe, and minicomputer manufacturers. In general, TI gained more than 50 percent of its business from product areas that were growing faster than the total semiconductor market. This indicates that TI obtained substantially less than 50 percent of its business from the linear circuit business. In 1983, out of a total of $1,885 million for the component business, the linear circuits portion is estimated to have been slightly less than $300 million, 16 percent of the total. Linear circuit revenue as a percentage of TI's total semiconductor revenue was the same in 1982 and represents an increase of 2 percent over 1981 sales. The financial highlights are provided in Table 5.7.

Linear Strategy

Texas Instruments has long been a supplier of linear integrated circuits. Starting out with designs in the early 1970s that were pin-for-pin replacements for National Semiconductor's linear products, the company has rapidly expanded its product line. In a short time, it has become the leader in linear integrated circuit production and sales.

The significant development for Texas Instruments in 1983 was the development of a new analog-specific process called LinCMOS. Initially, this process will be used mainly for developing new families of operational amplifiers and comparators.

The LinCMOS process combines analog and interface applications with bipolar speed by optimizing the use of silicon-gate CMOS for analog designs. The primary benefits of linear circuits implemented with LinCMOS are low power, low voltage, high-input impedance, and low offsets and large swings that are better than those of most bipolar designs and comparable to those of designs that employ BiFET devices. The significant advantages of this process result from the use of a self-aligned, phosphorus-doped silicon gate electrode that reduces the shifts in threshold voltage over time and minimizes shifts due to changes in temperature and voltage. In addition, the integrated circuit bandwidth is increased by a factor of 2 to 3 over that of the metal-gate CMOS because of the built-in overlap of the gate. The resultant gate-to-drain capacitance of the metal gate linear counterpart is seven times that of the LinCMOS.

Texas Instruments will be exploiting the use of this process by continuing to introduce circuits in the following areas (representative products are shown):

- Timers (TLC 551C)
    - LinCMOS timer

- Data acquisition (TLC 7126)
  - Dual-slope A/D converter and LCD driver
  - Successive-approximation A/D converters with a combination of dedicated analog and analog/digital inputs

This strategy of offering products that exploit the best of what linear CMOS can supply will allow TI to remain competitive and to continue its leadership in the area of linear IC design, development, and production.

Motorola

Motorola is one of the world's leading manufacturers of electronic equipment, systems, and components for both the U.S. and international markets. These markets include public safety agencies, utilities, governments, industrial and automotive manufacturers, consumers, service and health care organizations, and the telecommunications and computer industries.

The company's business sectors are:

- Communications
  - Communications equipment distribution
  - Fixed and mobile systems
  - Portable/paging system components
- Semiconductor products
  - Add-in memory systems
  - Bipolar and MOS integrated circuits
  - Bipolar VLSI macrocell arrays
  - Custom design services
  - Custom MOS and bipolar circuits
  - Electronic materials
  - Fiber-optic devices and discrete semiconductors

The company's semiconductor activities are located in Arizona and Texas and in France, Hong Kong, Japan, Malayasia, Mexico, the Philippines, the United Kingdom, and West Germany. Most of the company's research, development, and final test facilities for linear circuits are located in Mesa, Arizona. Assembly of the linear circuits is done offshore at such locations as Hong Kong, Malaysia, and the Philippines.

Financial Highlights

Motorola posted net sales of $4,328 million in 1983, up from $3,786 million in 1982. Net earnings were $244 million in 1983 and $178 million in 1982. Net sales of the semiconductor products sector amounted to $1,601 million in 1983 and $1,297 million in 1982. This sector's operating profit was $213 million in 1983 and $104 million in 1982. The semiconductor product sector continued to show higher sales, orders, and backlog in the first quarter of 1984 than in the corresponding quarter in 1983. New orders from the automotive, computer and peripheral, and military and automatic test equipment markets were especially strong, with lead times for some linear devices at up to 40 weeks. More detailed financial highlights are shown in Table 5.8.

Linear Strategy

Motorola supplies a broad range of linear circuits that include operational amplifiers, voltage regulators, consumer circuits, interface memory, computer and peripheral, numeric display, telephony, and special-function circuits.

Motorola introduced 11 new linear products in the first quarter of 1984. These included new switching voltage regulators, telephone ringer circuits, and a monolithic solenoid driver for automotive fuel-injection systems.

Motorola has a number of process alternatives for linear integrated circuit fabrication. These include the standard linear technologies using NPN and PNP transistors, schottky diodes, thin-film resistors, and two-layer metalization. Integrated injection logic (I^2L) has long been in production and is frequently used for incorporating digital functions onto linear chips. Dielectric-isolation processes have also had a long history at Motorola, providing very high voltage and low cross-talk capabilities. The newer technologies that are being adopted and developed for linear ICs include Mosaic (a high speed bipolar process) and an analog-specific CMOS process.

Motorola has long been a large-volume supplier of commodity linear ICs. The company has also been very strong in linear products required in the consumer market, including FM/IF and audio and television circuits. Particularly strong are the company's automotive offerings, which already constitute a large share of the total market and approximately 26 percent of Motorola's linear sales.

Motorola expects to continue to be a leading supplier in the U.S. automotive market, which is poised for sustained growth in the latter half of the 1980s. The next two strongest markets are the computer and peripherals and communications markets. Motorola will continue to be a leading supplier of specialized circuits to the magnetic peripherals market.

Signetics

Signetics is a business unit under the N.V. Philips Trust. As such, financial details are not available.

The breakout of Signetics products as a percentage of total linear production are as follows:

- Amplifiers (including comparators)--25%
- Voltage regulators--10%
- Data conversion--7%
- Interface--16%
- Special consumer--20%
- Special communications--9%
- Special function--11%

The growth of the corporation, that is, Signetics-Philips for the period 1983 to 1984, was typically 50 to 60 percent. The linear group, however, is limited by wafer fabrication (wafer starts, number of fab lines, resources—engineers, technicians) to between 35 to 40 percent.

Linear Product Analysis

Signetics is shifting from being a producer of commodity linear ICs to being a producer of proprietary products. Signetics sees growth in linear in those areas, such as communications, data conversion, and interface. Signetics is also going to take advantage of the leverage that Philips offers with its high visibility in R&D and production in European centers such as Mullard, England and Valvo, Germany. As an example of the shift in emphasis, Signetics will be relying less on products such as audio circuits (Dolby circuits), and will be relying more on office automation products, such as FSK receivers and transmitters for local area networks used in office automation, and on FM/IF functional blocks for cellular radio.

In addition, Signetics will be stressing its image as a high volume quality producer of linear ICs. Most of its linear products are now used by major corporations without incoming testing—an indication of the quality and assurance that Signetics provides before shipping the product. The culture that Signetics is promoting is one of, "Do it right the first time." Signetics also claims some development first in the area of surface-mounted devices (SMD) as well as switching power supplies.

In summary, Signetics for the 1984-1986 period will seek to exploit its perceived strengths in the following areas:

- Data conversion
- Communications
- Local area networks
- Video and teletex circuits
- Telephone ICs
- Operational amplifiers

In the area of local area networks, the absence of a definitive standard may aid the promotion of Signetics' LAN circuit.

Signetics Growth

The projection for growth for Signetics linear products for the period 1982 to 1986 will be in the range of 13 percent.

Markets

The segments served by Signetics include:

- Government military
- EDP
- Consumer
- Industrial
- Communications

In general, Signetics is moving away from being a second source of other companies' linear ICs, and is encouraging the second-sourcing of its products by other companies. Second-source agreements, like those between Silicon General and Linear Technology Inc. are typical of the second-source agreements that have been set up with Signetics.

Technology

The linear technology is based on:

- Ion implantation
- Zener technology

- Thin film
- Laser trimming
- Double layer metal
- Switched-capacitor networks for filters, A/D's, and D/A's.

The technology ranges from 5-micron bipolar through to 3- to 4-micron NMOS down to 2.5-micron CMOS circuits.

<u>Summary</u>

In summary, Signetics sustained a growth rate of 25 percent for the 1982 to 1983 period. The same for the 1984 to 1985 period is projected. While linear grew at a 35 percent clip in the 1982 to 1983 time frame, a slowing down is in order for the 1984 to 1985 time frame to 20 to 25 percent.

5.2 OVERALL PRODUCT--SUPPLIER ANALYSIS

This section analyzes the linear circuit product classes for each of the eight main U.S. linear integrated circuit suppliers. The linear circuit products are segmented by function as follows:

- Operational amplifiers
- Comparators
- Power-management circuits
- Data conversion and acquisition circuits
- Special consumer circuits
- Special-function circuits
- Special communications circuits

Figure 5.1 is a matrix that contains the product segment offerings of each of the eight leading linear circuit suppliers.

It should be noted that no attempt is made here to detail the degree of product breadth for each of the segments. An analysis of the breadth of products within each segment will be presented on a company-by-company basis in Section 5.3.

It is also important to note that the smaller linear companies (13 in all) offer products that are targeted primarily at segments in the matrix of Figure 5.1. It is important to note that many of the products offered by these companies have become de facto industry standards.

Operational amplifiers

The operational amplifier market can be divided into two broad classes: general-purpose op amps and high-performance op amps. The high-performance subcategory is further divided into five segments: high-speed, high-accuracy, high-output, low-power, and low-input bias current.

General-Purpose Amplifiers

Most operational amplifiers fall into this class. They typically have input voltage offsets of 5 to 7 millivolts and open-loop gains of 20,000 to 100,000. They are typically proven bipolar designs with manufacturing costs that are among the lowest of integrated circuits. Since the cost/performance ratio has been optimized for these devices, they are often used as the building block of most nonsophisticated analog system designs much as the LS00N and gate are the building blocks for most digital system designs.

General-purpose op amps have the following typical specifications:

- Offset voltage, V_{OS}, of 5 mV to 10 mV
- Bias current, I_{OS}, of less than 500 mA
- Power consumption of less than 300 mV
- Slew rate of less than 0.3V/microsecond
- Noise voltage of less than 20 mV/$Hz^{1/2}$ at 1 kHz
- Large-signal voltage gain of greater than 10,000

The LM 741, an industry standard, is a typical general-purpose op amp. The LM 833, NE 5512 dual, NE 5514 quad, LM 324 quad, NE 4558 dual, and MC 3303 quad are popular because they provide cost-effective solutions where more than one general-purpose op amp is needed in a design. In addition, the MC 3303 can operate with a power supply in the range of 3 to 36 volts.

High-Performance Amplifiers

The evolution of the general-purpose op amp into a high-performance building block stemmed from the needs of the marketplace. The different market requirements have created a need not only for amplifiers with greater linearity, or high accuracy, but also with higher speed or low power consumption.

High-speed amplifiers are used primarily in communications and in audio applications. Harmonic distortion and settling times are critical specifications to such applications, and the high-speed amplifier usually meets these specifications. A leading op amp is the NE 5334A. It has a typical input noise voltage of 3.5 nV/$Hz^{1/2}$ at 1 kHz and a typical current noise of 0.4 pA/$Hz^{1/2}$ at 1 kHz.

High-speed op amps are required in data conversion applications. For example, in applications involving complex sonar real-time signal processing, high-speed amplifiers serve as transducer interfaces to other subsystems. Not only are the high-speed parameters (slew rate and settling time) important, but so also are the accuracy of its gain and phase characteristics.

High-bandwidth applications such as video-deflection amplifiers, cable drivers, fiber-optic transceivers, local area networks, and high-speed communication transmitters/receivers require op amps with full-power bandwidths of greater than 40 dB. The Signetics NE 5539 is a widely used part for such applications.

The reading and writing of data in Winchester and floppy disks require read/write and read channel amplifiers. The signal frequencies encountered in these applications can range from 125 kHz for floppy disk drives to 5 MHz for 5.25-inch Winchester drives. The typical products here are the Signetics NE 592 and the NE 5592. Both have differential inputs and 90-MHz bandwidths.

Another high-speed subsegment application and market is the high-slew-rate market, which typically includes buffer circuits and motor drivers where the output must change as rapidly as possible after a step-like change at the input. The typical slew rate specifications in such applications range from 5 volts/microsecond to 600 volts/microsecond. The typical op amps that serve this market include the NE 358, the NE 5539, and the LF 356.

In general, bipolar circuit technology is the preferred fabrication technology for implementing high-speed op amps. The processing generally tends to be complex, as in the case of Motorola's and Harris's dielectric isolation process. The difficulty in designing high-speed op amps is the ability to achieve the high speed and still control the other specs, such as the power dissipation, which in turn affects offset voltage temperature characteristics and input circuit offsets. The bottom line is cost; the product must be made at a low enough cost so that the speed benefits are available to the largest possible base of customers.

High-output amplifiers are used mainly in audio applications and in wide-range current sources and special instrument modules of automatic test equipment. Though the voltage outputs from monolithic high-output op amps are not as high as from hybrids, the situation is changing as more designs become available to replace the traditional expensive hybrids supplied by such firms as Analog Devices and Burr-Brown. A typical product of this group is Precision Monolithics' OP-27. The OP-27's output stage can provide a guaranteed swing of $\pm$10V into 600 ohms with V_S = $\pm$15V. In addition, it provides low noise (18 nV peak to peak--0.1 Hz to 10 Hz--or 3nV/$Hz^{1/2}$), low drift (4.2 mV/^{o}C), and high speed (2.8V/microsecond slew rate).

Low-power op amps find applications in such areas as portable instrumentation, military and satellite systems, and geophysical equipment.

From a linear circuit design point of view, optimum low-power characteristics are usually incompatible with high gain, high speed, and low noise. There is also the overlap in the technologies that are used to implement this type of amplifier. For example, low-power bipolar designs overlap some CMOS designs since such CMOS designs are inherently slow. For very slow applications, however, CMOS is the natural choice. To produce the same voltage gain as a bipolar op amp, the CMOS amplifier usually requires as much current (10 mA); however, its quiescent current can be as low as 10 mA. Such amplifiers are ideal for battery applications. Offsets for these CMOS op amps are typically 2 mV, maximum unity-gain bandwidth is 2 MHz, and the slew rate is 4.5V/microsecond.

Two typical parts are the TLC251 (1 to 16 volts) and the TLC271(3 to 16 volts).

Low-input bias currents in highly accurate op amps are achieved using BiFET processes to implement input devices. These BiFET op amps are used primarily in high-impedance transducer applications, for example: interfacing pH meters, strain gauges, accelerometers, and thermal sensors. The typical products in this market are PMI's OP-15, OP-16, OP-17, and National's LF 155/156/156 series. The PMI OP-15/16/17 series incorporates a unique input bias current translation circuit that reduces the I_B by a factor of 10 over the conventional input design. In addition, the 15-pA spec for the OP-15 is guaranteed over temperature after the device warms up.

Comparators

Differential voltage comparators are high-gain, differential-input, single-ended output amplifiers. The primary function of a voltage comparator is to compare the instantaneous value of the signal voltage at one input with a reference voltage at the other input and to produce a logical 1 or 0 at the output when one input is higher than the other. Although the general-purpose op amp can be designed for use as a comparator, it has the significant disadvantage of slow response time.

Comparators, therefore, are designed primarily to interface digital circuits with peak-to-peak output swings of 3 to 5 volts. A voltage gain of the order of 1,000 is usually sufficient to bring the differential signal amplitude necessary for a full output swing required to drive a digital circuit. The input offset and bias current requirements of a comparator are comparable to those of an op amp.

The most important parameter in most comparator applications is the speed of response or response time. Very fast response times for comparators are desirable, for example, in data conversion applications. In less demanding applications such as zero-crossing detection or in line receivers, lower speed comparators can be tolerated.

The comparator market is categorized by response time. The three significant comparator categories are:

- Low- to medium-speed comparators--These comparators have response times of 100 nanoseconds up to 1 to 2 microseconds. In general, this class of comparators is fabricated using conventional linear bipolar technology with simple circuit designs that operate at low power levels. Most of the designs are extremely low in cost and are available in dual and quad configurations. An example of this category is the LM139.

- High-speed comparators--This category has response times of 25 to 100 nanoseconds and uses only NPN transistors and resistive loads in the signal paths. The swings are usually clamped with diodes to speed up the circuit response time. A typical high-speed comparator is the Fairchild 710 which has a response time of 60 nanoseconds.

- Very high speed comparators--This category has response times in the range of 5 to 10 nanoseconds. Such high speeds are achieved using transistors having f_T's of 1 to 2 GHz (compared to the 500-MHz f_T's for conventional bipolar and low-speed components). The circuit configuration is typically a form of emitter-coupled logic (ECL). A typical circuit of this type is the AM685 which has a response time of 4 nanoseconds. These comparators are used primarily in high-speed data acquisition systems.

Power-Management Circuits

Power-management circuits include all integrated circuits that are incorporated into AC/DC converters, voltage regulators and references, switched-mode power controllers, supervisory circuits, power monitors, voltage sensing and protection circuits, and current-sense latches. These functions provide for improved reliability and better energy conversion efficiency, as, for example, in the case of switched-mode power supplies.

The basic-power management building block is the voltage regulator. The first IC voltage regulator, though produced more than 10 years ago, was the only monolithic voltage regulator building block for a number of years. One of the most popular voltage regulators is the LM723. The 7800 series evolved from the 723 as market requirements dictated the inclusion of peripheral circuitry on the chip, including a high-current-pass transistor. With the rapid acceptance of the 7800 series, the 7900 series of fixed negative voltage regulators was the next family to be introduced. At prices of less than $1 and with good line and load regulation specifications and current capabilities of as much as 1 ampere, these monolithic ICs were well suited for local current regulators.

The next step in the development of the IC voltage regulator was the evolution of the 7800 and 7900 series into the family of dual-polarity tracking regulators. These regulators incorporated positive and negative regulation into a single package with an additional amplifier to allow one output to track the other output. Next came the three-terminal shunt regulator and precision voltage reference sources. Though the popularity of shunt regulators has been declining in recent years due to the competition from more sophisticated and efficient designs, precision voltage reference sources are seeing great market acceptance because these devices fill a special need in data conversion applications.

The analysis of power-management circuits will focus primarily on series regulators and switching regulators.

Series Regulators

There are basically three types of series regulators offered commercially. They are:

- Positive series regulators such as the 7800 series
- Negative voltage regulators such as the 7900 series
- Dual-polarity tracking regulators

Positive Series Regulators- The series- or series-pass-type voltage regulator is usually connected in series between the load and the unregulated supply line. Basically, the series regulator consists of three main subsections: reference voltage generator, error amplifier, and series pass element.

Some designs include overload protection circuitry to protect against burnout.

Negative Voltage Regulators- Negative voltage regulators are much like positive voltage regulators. A Darlington NPN transistor is often used to generate the negative voltage, since high-current monolithic PNP transistors are often not available.

Dual-Polarity Tracking Regulators- Dual-polarity tracking regulators are regulators that supply a symmetrical set of positive and negative supply voltages of equal value but opposite polarity that track each other and stay symmetrical under line voltage and node current changes. These circuits are used in many data conversion applications.

The dual-polarity tracking voltage regulator is a great improvement over the common three-terminal positive 78XX and negative 79XX regulators in the area of line and/or load regulation. The increased complexity of analog systems, that is, the inclusion of many different functions on one board, has led to the need for tracking regulators to supply the power needs of op amps, comparators, sense amplifiers, and signal processors such as gates, multiplexers, switches, D/A and A/D converters, and microprocessors.

For future analog systems, the most significant advantage of dual tracking regulators may not be their superior line and load regulation but the substantial cost savings of the regulator and the associated external circuitry.

Protection circuits are a very important feature of voltage regulators and other power management circuits. These protection circuits, which are integrated monolithically, prevent burnout or permanent damage of the regulators under accidental overload conditions such as short circuits, excessive input/output voltage differentials, and excessive temperature differentials.

Switched-Mode Power Supply (SMPS) Controllers

Switched-mode power supply controllers are basically DC to DC converters in which a DC voltage is applied to a chopper (generally operating above 25 kHz to minimize the size of the inductor elements). The chopped DC voltage is then fed into a transformer, where the voltage may be stepped up or stepped down or inverted as required. The secondary output voltage is then rectified and filtered to provide the desired DC output level. The chief function of the control circuitry is to sense the output and adjust the duty cycle of the chopper's switching transistor to keep the output constant regardless of changes in the input voltage and node conditions.

There are two basic types of converters used in switched-mode power supplies: the forward converter and the flyback converter. In both types, an inductor is used as a storage element. In the forward converter, the inductor is connected in series with the load. The energy is passed to the load and the coil during the uncondition of the chopper. In the flyback converter, the coil is connected in parallel with the load. Energy is stored in the coil during the on period and transferred to the load during the off period.

Each approach has its advantages and disadvantages. In the forward converter, the switching transistor conducts current only during the on condition, and the peak value of the voltage V_{CE} that the device must withstand is only equal to the DC input voltage. The inductor size can be smaller and the capacitor has less ripple to deal with. The disadvantages include difficulty in achieving isolation and the possibility of the full DC input being applied to the load in the event of a shorted chopper transistor. The advantages of the flyback converter are that input/output isolation is easy to achieve and protection against excess voltages in the event of a shorted chopper transistor is not necessary. The V_{CE} peak requirements of the transistor are higher (V_{in} + V_{out}), and the inductor must be larger as well as higher with the current's capability for the capacitor.

The Signetics NE5560 is a monolithic IC that incorporates all the control and protection functions that are required for an SMPS. It can be configured in either a forward or flyback configuration.

Data Conversion and Acquisition Circuits

Digital and analog signals exist as two distinctly different types of information. Analog signals, on one hand, are non-quantized and continuously variable, as, for example, with speech signals. Digital signals, on the other hand, are quantized in binary bits, that is, 0's and 1's. In many electronic systems, it is desirable to have an interface between these two types of signals to convert data from analog to digital or digital to analog. The types of circuits that are used to implement this data conversion are called data conversion circuits. Specifically, analog to digital (A/D) circuits and digital to analog (D/A) circuits convert analog signals to digital codes and digital codes to analog signals, respectively.

A/D Converters

Monolithic A/D converter circuits fall into four basic categories:

- Successive-approximation types produce a digital output which occurs after a succession of trial and error steps.
- Digital ramp or servo-type converters use a binary counter in a feedback loop.
- Integrating (single-, dual-, and quad-slope) and voltage-to-frequency types, which utilize the charging and discharging of a timing capacitor during the conversion cycle.
- Parallel or flash converters perform a complete conversion operation in a single step.

Successive-approximation A/D converters are quite widely used, especially for interfacing with computers, because they are capable of both high resolution (to 10 bits) and high speed (up to 1 megahertz). The two circuit techniques most commonly used in successive-approximation A/D converters are the charge-redistribution and the potentiometric techniques. The former is ideally suited for MOS circuit implementation. The conversion time of successive-approximation A/D converters is fixed and independent of the input voltage.

Digital-ramp or servo-type A/D converters use a D/A converter whose digital input is driven by a counter. The analog input to be converted is compared to the output of the D/A converter. When the D/A output crosses the analog input value, the conversion ceases and the digital representation equals the number of counts that were stored in the output register. Though the concept is simple, this converter has the disadvantage of limited speed for a given resolution, since the conversion time for a full scale change is equal to the maximum number of counts divided by the maximum frequency . For example, at a clock rate of 10 MHz the maximum throughput rate for a 10-bit resolution (1,024 counts) is less than 10 kHz (100 microseconds/conversion). The servo-type is a variation of the digital-ramp type that uses an up-down counter instead of an up counter.

Integrating A/D converters operate by first converting the analog quantity to a function of time and then converting the time function to a digital number using a counter. Dual-slope integrating A/D converters are especially suitable for digital voltmeters and gas chromatograph applications where the relatively long conversion time is traded off against noise reduction advantages. The throughput rate of these dual-slope A/D converters is limited to less than 1/2T conversions per second where T is the sample time as determined by the fundamental frequency. A major shortcoming of conventional dual-slope converters are the errors at the input of the integrating converter or comparator, which show up as errors in the digital word. Such errors can be nullified using, for example, the quad-slope principle, where errors generated and stored in the calibration cycle are subtracted during the count cycle during conversion. The other conversion schemes that fall into this class include single-ramp or V/F converters. The major weakness of these techniques is that the accuracy depends on both the capacitor value and the clock frequency.

Parallel or flash A/D converters offer the fastest and simplest techniques for analog-to-digital conversion. This type of converter uses a separate analog comparator with a fixed reference for every quantization level in the digital word. The outputs of these comparators are then connected by encoded logic to produce a parallel digital output. The speed of this type of converter is limited only by the switching time of the comparator and gates. As the input changes, the output code changes. The serious disadvantage of these converters, however, is that the number of elements increases geometrically with resolution; that is, for N-bit resolution, 2^N-1 separate comparators and reference levels each are needed. The 8-bit high-speed bipolar flash converter from TRW contains 256 latched comparators, a bias string with 255 taps, and associated decoding logic and buffers on a 261 mil X 264-mil chip. The comparators take up approximately 80 to 90 percent of the chip. This converter operates at speeds of up to 35 megasamples per second with 8-bit resolution and $\pm 1/2$ LSB nonlinearity while dissipating 2.5 watts.

__D/A Converters__

Monolithic D/A converters fall into three basic categories:

- Current-scaling converters
- Voltage-scaling converters
- Charge-scaling converters

Most bipolar D/As employ current-scaling techniques using precision resistor arrays and high-speed current switches; voltage and charge-scaling techniques are suitable for MOS designs using MOS capacitors, analog switches, and charge-sensing circuitry. For precision designs (10 bits or over) bipolar data conversion techniques are preferred over MOS circuit approaches.

Commercial D/As vary widely in architecture. At one end of the spectrum are the simple building-block type D/As containing the basic current source or resistor arrays that can be externally interconnected to form a complete converter system. At the other end of the spectrum are D/As that contain all the subsections of a complete D/A converter, including voltage reference and output amplifier. The majority of D/As, however, fall in the middle with the voltage reference and the output amplifier being external to the chip to allow for maximum design flexibility.

Three representative monolithic D/A ICs are PMI's 8-bit DAC-08, Analog Devices 10-bit AD-7520, and AMD's 12-bit Am6012. All are very popular D/As sharing similar overall architectures but having quite different design approaches.

Special Consumer Circuits

This group of analog circuits consists of linear ICs designed specifically for consumer end-market applications. These end-market applications range from AM and FM audio functions and specialized TV chroma processing circuits to fuel-injector ICs for automobiles. Most of the circuits have no second sources and very few have become industrial standards as have the UA709 or the UA741. These circuits are normally monolithic equivalents of standard hybrid subsystems and thus build on the well-understood building blocks of linear circuits such as op amps, comparators, and low-noise amplifiers.

Special consumer circuits are typically grouped by the end markets that they serve:

- Audio--Low noise preamplifiers and amplifiers dynamic noise-reduction circuits, tone and balance circuits, power-amplifiers, and graphic equalizers
- Automotive--Fuel-injector controllers, audio power amplifiers, air-core meter drivers, and ultrasonic transceivers
- Display--LED flashers/oscillators, seven-segment drivers/ decoders, and dot/bar drivers
- Radio--FM stereo demodulators, AM/FM receivers, FM/IF systems, and AM and FM blend demodulators
- Video--Remote control receivers, tuning detectors, video IF amplifiers and PLL detectors, and TV signal processing circuits
- Safety--Ground fault interrupters
- Leisure--Fish-spotting sonar circuits

Special-Function Circuits

This group of linear integrated circuits consists of those circuits that are used in specialized analog applications. These include the following products:

- Voltage references
- Wide-band amplifiers
- Analog multipliers
- Oscillators and function/waveform generators
- Voltage-to-frequency (V/F) Converters
- Frequency-to-voltage (F/V) Converters
- Phase-locked loops (PLLs)
- Timers

Voltage References

Voltage references are used in the design of various analog systems such as data acquisition and conversion systems, power supplies, and low-drift amplifiers to establish a temperature-independent bias reference within the system. In most cases, voltage rather than current is preferred since it is easier to interface with the rest of the circuitry.

The voltage reference (a precision voltage element) differs from a voltage regulator in that the emphasis is on temperature stability rather than on low-output impedance. Temperature stability specifications for voltage references are typically less than or equal to 100 ppm/^{o}C . Whereas voltage regulators are designed to provide large amounts of power, precision voltage references provide nominal amounts of power.

Wide-Band Amplifiers

These circuits provide moderate voltage or current gains, typically in the range of 10 to 100 (10 to 20 dB), over a very wide frequency range, typically DC to 200 MHz. In addition, the typical wide-band amplifier has the following characteristics:

- Accurate gain
- V_{in}/V_{out} transfer characteristics linearity
- Automatic gain control (AGC) and modulation capability (necessary since wide-band circuits are often used in radio and TV receivers where amplitude of the output is maintained by AGC)

- Controlled input and output impedance levels

- Low-noise characteristics

<u>Analog Multipliers</u>

These analog circuits produce an output voltage that is the linear product of two input voltages. The division operation that is the result to being equal to the quotient of two input voltages can also be performed by the analog multiplier. In addition, the analog multiplier is often used for automatic gain control, signal modulation, waveshaping and performing mathematical functions, such as square root, extraction, and n^{th}-power operations.

The analog multipiler is typically implemented in linear circuits, using the variable-transconductance multiplier technique. This method makes use of the dependence of the transmitter transconductance on the emitter current bias. The simple two-quadrant variable-transconductance amplifier can be extended to a four-quadrant multiplier having a dynamic range that is wider and useful for more sophisticated applications.

Most of the analog multiplier products are single-source products. The cost of analog multiplier ICs can vary significantly depending on the linearity, accuracy, and gain stability requirements. To optimize these characteristics, some of the precision analog multipliers available use on-chip, laser-trimmed, thin-film resistors.

<u>Oscillators and Function/Waveform Generators</u>

Monolithic waveform generator ICs are oscillator circuits that produce a dedicated waveform or a variety of output waveforms such as sine, triangle, or square waveforms. Typically, the three design categories of IC oscillators are:

- RC-type relaxation oscillators, which are resistive charge and discharge paths for the timing capacitor

- Constant-current charge and discharge oscillators, which use current sources to charge and discharge the timing capacitor

- Emitter-coupled multivibrators, which use symmetrical charge and discharge path with a timing capacitor connected across the emitters of the differential gain stage

RC-type relaxation oscillators typically have temperature stabilities of ± 100 ppm/^{o}C for f_{o} less than 100 kHz. A representative circuit of this group is the Intersil ICL-8038 (a triangle/square wave oscillator that uses two voltage-controlled current sources connected in parallel).

At high frequencies (greater than 10 MHz), the only practical oscillator circuit that has sufficiently low circuit delays is the all-npn emitter-coupled multivibrator. Without temperature-compensation techniques, this configuration exhibits poor frequency stability. The two representative ICs of this class are:

- Exar-2206/2207/2209, which uses a stable, low-frequency emitter-coupled multivibrator

- AD537, which uses a clamped emitter-coupled multivibrator designed to improve frequency stability. The typical frequency stability of this chip is ±660 ppm/°C for frequencies up to 10 MHz.

Voltage-to-Frequency (V/F) Converters

V/F converters functionally belong to the data conversion class of circuits. However, because of the similarity in circuit design to oscillators and timers, it is appropriate to group V/F converters with the special-function class of circuits..

These circuits encode an analog voltage into a stable frequency that can then be transmitted over long distances or measured or recorded by digital means.

The circuit techniques for V/F converters fall into two categories: ultrawide-sweep multivibrator circuits and charge-balancing oscillators. The ultrawide-sweep multivibrator technique, the basis for the AD537 V/F converter, uses a current-controlled multivibrator in conjunction with a voltage-to-current converter stage. The dynamic range is limited only by the current-handling range of the transistors and diodes in the circuit. The AD537, for example, has a dynamic range of 100 dB with a maximum non linearity error of 0.07 percent and a temperature coefficient of less than 50 ppm/°C.

Charge-balancing V/F converters are capable of higher frequency operation but suffer from slow response times and non linearity due to the finite output conductance of the switched current source.

Frequency-to-Voltage (F/V) Converters

F/V converters are used to decode data from a V/F converter in applications involving remote telemetry and motor speed control. Like V/F converters, there are two basic types of F/V converters: pulse-integrating converters, which integrate a fixed-pulse-width, variable-frequency output signal, and phase-locked loop F/V converters, which lock on to an input frequency and produce an error voltage proportional to frequency deviation of the input signal. In general, the accuracy, linearity, and stability characteristics of F/V converters is essentially the same as those of V/F converters.

Phase-Locked Loops

The phase-locked loop (PLL) is a very versatile system that is composed of a phase detector, a voltage-controlled oscillator (VCO) and a low-pass filter. It is capable of locking on to an incoming frequency signal and either duplicating the frequency of the input signal or extracting the information that may be incorporated into the signal in the form of phase, frequency, or amplitude modulation. Thus, a PLL is used in applications involving frequency synthesisers, bit synchronization, frequency and phase demodulation, coherent amplitude modulation, and tone decoding.

Monolithic PLLs have, in general, much lower maximum oscillator frequencies than PLLs implemented with discrete and SSI or MSI components. Monolithic PLLs such as the popular LM565 have maximum oscillation frequencies of 500 kHz. Recently, newer monolithic PLLs such as the XR215 offer 20 MHz oscillation frequencies.

Timers

The introduction of the NE555 timer by Signetics in 1971 was the basis for the acceptance of the IC monolithic timer circuit as a basic linear circuit building block. Since 1971, the NE555 has been manufactured by a number of IC merchant manufacturers and supplied in a variety of packaging options. In addition to the standard NE555 IC and second sources, there are a number of timer products based on the NE555 that offer unique features such as high-noise immunity and low power consumption.

IC Timers -Monolithic IC timers are used to generate precise time pulses or time delays whose length or repetition rate is programmed by an external RC network. The RC product can be in the range of microseconds to months. Timer ICs can be categorized into two main groups: single-cycle timers and timers/counters. Table 5.9 lists the available timers by timer and manufacturer.

Single-cycle timers operate by a single charging cycle of the external timing capacitor and are simple, low-cost devices that can be used in most sophisticated applications. They offer excellent accuracy and stability characteristics with operation in both the astable and monostable modes. Table 5.10 compares a representative number of single-cycle timers.

Timer/counters, or multiple-cycle timing circuits have the additional capability of providing extremely long delays. They are implemented with circuits that combine a time-base oscillator and a counter. For timing applications requiring time delays in excess of several minutes, these circuits are preferred over the single-cycle timers. The XR-2240 and the MC14536 are representative of this group of timers. Table 5.11 compares a representative number of commercially available counter/timer ICs.

Special Purpose Timers- There are essentially three categories of special purpose timers: precision timers, high noise-immunity timers, and low-power timers.

The LM322 and LM3905 are precision timers offering many improvements over the 555-type timer. These improvements include lower time-delay sensitivity to power supply fluctuations at the beginning and end of the time delay, low power dissipation at higher power supply levels, and extension of the delay times by programming the comparator current levels.

High-Noise Immunity Timers such as the Teledyne 355 is designed expressly for industrial environments where high-noise immunity is an important specification. The operation of the circuit is very similar to that of the 555.

A number of low-power timers are available that perform general-purpose timing functions with a minimum amount of power dissipation. In addition, these low-power timers can operate at down to a few volts, typically 2 volts, compared to 4.5 volts for the regular 555 timer. This feature allows these timers to be used with two 1.5 NiCd batteries. An important market feature of these low-power timers is that they are virtually supply-circuit transient free and offer low threshold, trigger, and reset currents. A comparison of commercially available low-power single-cycle timers is provided in Table 5.12.

5.3 DETAILED PRODUCT--SUPPLIER ANALYSIS

In this section a detailed product-supplier analysis will be presented in tables for each of the product segments and for all of the suppliers that serve that segment. The seven segments (with subsegments) are:

- Operational amplifiers
- Comparators
- Power-management circuits
  - Voltage references
  - Voltage regulators
  - Switched-mode power supply (SMPS) controllers
- Data conversion and acquisition circuits
  - Digital to analog (D/A)
  - Analog to digital (A/D)
- Special consumer circuits
  - Television and audio (sound, chroma, video, deflection)
  - Television games/display
- Special communications circuits
- Special-function circuits
  - Automotive
  - Timers
  - Hall-effect sensors and switches
  - Sonar engine
  - Floppy disk controllers
  - Differential video amplifiers

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5.4 APPLICATION--SUPPLIER ANALYSIS

This section analyzes the applications for which the different segments of linear circuits are used. In addition, an overview of applications and market versus supplier will be presented.

Operational Amplifiers

The operational amplifier is considered to be the basic building block of linear integrated circuits. Using the same classification as in the previous section, the system applications for the different categories of op amps are shown in Table 5.13.

Comparators

Comparator applications fall into three major groupings: very high speed comparators, high-speed comparators, and low- to medium-speed comparators.

Very high-speed comparators, such as the Am685 series, have response times of 10 to 20 nanoseconds. They are used primarily in such applications as high-speed data conversion.

High speed comparators, such as the LM710/LM710C having response times of 40 nanoseconds, find applications in the following areas:

- Pulse height discriminators
- Voltage comparison and high-speed A/D converters
- Go, No-go detectors in automatic test equipment
- Adjustable-threshold front end for line receivers

Low- to medium-speed comparators, such as the LM193 series having a response time of 300 nanoseconds, have applications in the following areas:

- Limit comparators
- Simple A/D converters
- Pulse, square wave, and time delay generators
- Wide-range voltage-controlled oscillators (VCOs)
- MOS clock timers
- Multivibrators
- Switching power amplifiers

Power-Management Circuits

Power-management circuits include the following circuits:

- Conventional voltage regulators
- Voltage references
- Switched mode power supply controllers
- Supervisory circuits
- Voltage-sensing and protection circuits
- Power monitors
- Current-sense latches
- Ground-fault interrupters

Circuits such as the low-priced 3-terminal voltage regulator have found industry-wide acceptance in all electrical designs that require regulated DC power. The latest market thrust, however, is to replace linear power supplies with switching power supplies. These switching power supplies employ switched-mode power supply controllers together with other modem supervisory and voltage-sensing and protection circuits. The efficiency of switching power supplies compared to linear power supplies has stimulated their demand in electrical equipment design.

Data Conversion Circuits

D/A converters, in addition to being categorized by the resolution (the number of bits of digital input), are also divided mainly into two groups: high speed and low cost. Table 5.13 provides representative examples of the two groups.

A/D converters are categorized into three main groups--parallel or flash, successive-approximation, and integrating. Table 5.13 provides representative examples of these main groups. The three key variables that characterize A/D converters are speed (in samples per second), accuracy (in bits), and price (in dollars). There is no overlap in any of the three major groupings of A/D converters, and the price for each group increases sharply at the highest speeds.

Since the capabilities of these three distinct groups of A/D converters do not overlap, the areas of application do not overlap either. The low speed A/D converter market is dominated by integrating converters, the medium performance market uses successive approximation types while the high-speed markets--video processing, TV and radar systems use parla or flash converters almost exclusively. The performance of these three groups of A/D converters and their respective application areas are shown in Table 5.14.

Special Consumer Circuits

Special consumer ICs include low circuits specifically designed for use in the radio, TV, and automotive end markets. As mentioned in Chapter 3, the radio and TV markets are not analyzed in the study. The special linear circuits used in the automotive end markets include:

- Fluid detectors
- Pressure sensors
- Dot/bar display drivers
- Oxygen sensors

Special Communications Circuits

These linear ICs include those circuits used in the telecommunications and market--central office equipment, telephones, key telephones, PBXs and PABXs. The predominant special communication linear ICs are:

- Codecs
- PCM filters
- Filters
- DTMF generators (repetory and non-repetory)
- DTMF decoders
- Pulse dialer circuits
- Ringer circuits

Special-Function Circuits

The major categories include:

- Oscillators
- Timers
- PLLs
- V/F and F/V converters
- Video amplifiers
- Analog multipliers

Linear IC oscillators are essentially monolithic waveform generators that provide a variety of output waveforms such as sine, triangle, and square waveforms. These ICs are extensively applied in laboratory instrumentation, telemetry and test systems, and in telecommunications systems.

The major application areas of timers and the typical end markets include:

- Interval or event timing--all markets
- Pulse generator or shaping--instrumentation
- Oscillator or clock generation--battery and remote instrumentation
- Ramp or sweep generation--instrumentation (oscilloscope, XY recorders)

Phase-Lock Loops (PLLs)

PLLs are suitable for a number of applications. In particular, these ICs are widely used in the communications end market where the specific applications include:

- Frequency synthesizers
- Bit synchronization
- Frequency and phase demodulation
- Amplitutde modulation
- Tone decoding

V/F and F/V Converters

These linear ICs are used in telemetry, remote control, and remote data acquisition applications. Another major application area is the signal isolation area. This application involves the conversion of analog signals to a frequency which is then coupled through an opto isolator and then converted back to voltage through an F/V converter. These chips find applications in the industrial, government/military, telecommunications (test and diagnostic), and consumer end markets.

Wide-Band Amplifiers

These ICs are used in the processing of fast low-level analog signals in video and radio frequency communication systems. The end markets that use these devices include the computer market--especially the high-speed CAD/CAM graphic display subsegments, industrial and government/military.

Analog Multipliers

These ICs find use mainly in the instrumentation subsegment of the industrial end market. Some analog multiplier chips are also used in signal modulation and in automatice gain control applications in the consumer and telecommunication end markets.

Figure 5.1

LINEAR CIRCUIT PRODUCT SEGMENT OFFERINGS

Product Segment	Company							
	Texas Instruments	National Semiconductor	Motorola	Analog Devices	Fairchild	RCA	Signetics	Harris
Operational Amplifiers	Full Offering	Full Offering	Full Offering	Full Offering	Full Offering	Full Offering	Full Offering	Full Offering
Comparators	Full Offering	Full Offering	Full Offering	Limited Offering	Full Offering	Limited Offering	Full Offering	None
Power Management	Full Offering	Full Offering	Full Offering	None	Limited Offering	Limited Offering	Limited Offering	None
Data Acquisition	Full Offering	Full Offering	Limited Offering	Full Offering	Limited Offering	Limited Offering	Limited Offering	Limited Offering
Interface	Full Offering	Full Offering	Full Offering	Limited Offering	Full Offering	None	Limited Offering	None
Consumer	Full Offering	Full Offering	Full Offering	None	Limited Offering	Full Offering	Full Offering	None
Special Function	Full Offering	Full Offering	Limited Offering	Full Offering	Limited Offering	Full Offering	Full Offering	None
Special Communication	Limited Offering	Full Offering	Limited Offering	None	Limited Offering	Full Offering	Full Offering	None

Full Offering—Including Second Sources

Limited Offering

None or Small Number of Products

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Table 5.1

ANALOG DEVICES--FINANCIAL SUMMARY, 1980-1983
(Thousands of Dollars)

	1980	1981	1982	1983
Domestic Sales	78,682	92,179	102,652	128,422
International Sales	56,977	64,057	71,334	85,615
Total Sales	135,660	156,236	173,986	214,037
Components	74,613	98,866	111,351	139,124
Assembled-Hybrids & Modules	61,047	59,370	62,635	74,912
Net Income % of Sales	7%	3%	6%	9%
Gross Margin % of Sales	57%	48%	52%	54%

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Table 5.2

SCHLUMBERGER LTD.--FINANCIAL SUMMARY, 1980-1983
(Millions of Dollars)

	1980	1981	1982	1983
Revenue				
Oilfield Services	2,814	3,788	4,054	3,414
Measurement, Control, Components	2,070	1,995	1,971	2,099
Interest & Other Income	153	195	259	284
Other	100	-	-	-
Cost of Goods Sold	2,813	3,244	3,479	3,388
Operating Income				
Oilfield Services	1,184	1,702	1,656	1,187
Measurement, Control, Components	230	131	34	61
Eliminations	(14)	(25)	(18)	(23)
Net Income	994	1,266	1,384	1,084
Per Common Share				
Net Income ($)	3.47	4.57	4.60	3.73
Cash Dividends ($)	0.63	0.77	0.92	1.00
Net Income as % of Revenue	19	21	21	19
Return on equity	36	34	28	20
Capital Spending	748	1,063	1,094	517
Working Capital	1,249	1,637	2,171	3,030
Total Assets	5,242	6,525	7,846	8,353

Table 5.3

FAIRCHILD SEMICONDUCTOR--REVENUE ESTIMATES, 1980-1982
(Millions of Dollars)

	1980	1981	1982
Total Semiconductor	566	462	410
Total IC	461	370	333
BiPOLAR Digital	273	226	206
MOS	103	65	50
Linear	83	79	79
Discrete	81	76	62
Optoelectric	24	16	15

Table 5.4

HARRIS CORPORATION--FINANCIAL HIGHLIGHTS, 1980-1983
(Millions of Dollars)

	1980	1981	1982	1983
Net Sales	928.2	1,120.6	1,301.8	1,423.7
Information Systems	250.5	300.3	324.6	318.6
Communications	266.4	332.7	430.7	425.0
Semiconductors	148.0	180.5	147.2	151.5
Government Systems	263.3	307.1	399.3	528.6
Operating Profit	91.8	125.4	80.8	58.9
Information Systems	23.9	30.1	32.7	27.5
Communications	29.7	33.9	42.1	34.6
Semiconductors	32.1	41.4	(11.4)	(7.7)
Government Systems	25.8	30.1	40.6	44.0

Table 5.5

NATIONAL SEMICONDUCTOR--FINANCIAL SUMMARY, 1980-1983

2900 Semiconductor Drive
Santa Clara, California 95051
Telephone: (408) 721-5033

Operating Performance ($ Millions)	1980	1981	1982	1983
Revenue				
Regional ($ thousands)	910,113	1,110,053	1,104,095	1,210,499
Americas		952,590	1,010,592	1,074,984
Europe		292,990	241,894	295,778
Asia		370,841	382,568	405,338
Corporate		(506,368)	(530,959)	(565,601)
Business Segment ($ thousands)		1,110,053	1,104,095	1,210,499
Components		815,922	753,050	787,983
Digital Systems		321,045	364,744	431,252
Corporate		(26,924)	(13,699)	(8,736)
Profit (Loss) ($ thousands)		106,697	5,024	11,582
Components		99,522	427	10,377
Digital Systems		7,175	4,597	1,205
Capital Expenditures ($ thousands)	116,174	177,084	129,635	131,045
Net Earnings (Loss) ($ thousands)	45,043	52,426	(10,694)	(14,176)
Number of Employees	40,263	35,725	38,267	35,640

Table 5.6

RCA--FINANCIAL SUMMARY, 1980-1983
30 Rockefeller Plaza
New York, N.Y. 10020

Operating Performance ($ Millions)	1980	1981	1982	1983
Sales	7,809.9	7,798.7	8,016.0	8,977.3
Electronics		4,410.3	4,354.0	4,840.3
Consumer Products & Services		2,329.9	2,117.3	2,401.7
Commercial Products & Services		1,184.1	1,189.0	1,139.5
Linear Products	.67	76	70	75
Government Systems & Services		896.3	1,047.7	1,299.1
Broadcasting		1,618.7	1,786.5	2,094.3
Communication		269.8	319.1	377.0
Transportation Services		1,222.3	1,333.8	1,372.0
Financial Services		-	-	-
Other Products		277.6	222.6	293.7
Capital Expenditures		168.9		
Electronics			121.1	162.0
Consumer Products		84.1	45.9	55.6
Commercial Products		62.0	48.9	54.7
Government Systems		22.8	26.3	51.7
Net Income	315.3	54.0	222.6	240.8
Total Assets	7,060.2	7,756.8	7,576.0	7,656.1
Percent return on average shareholder's equity	13.4	(.6)	8.8	9.1
No. of Employees (600s)	133	119	109	110

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Table 5.7

TEXAS INSTRUMENTS--FINANCIAL SUMMARY, 1980-1983

13500 North Central Expressway
P.O. Box 225474
Dallas, Texas 75265

Operating Performance ($ Millions)	1980	1981	1982	1983
Revenue		4,206	4,327	4,580
Regional				
U.S.		3,079	3,231	3,544
Europe		753	722	703
East Asia		810	787	957
Other		(436)	(413)	(624)
Business Segment				
Components (Linear)		1,532	1,503	1,885
Digital Products		1,131	1,173	1,109
Government Electronics		898	1,084	1,236
Metallurgical Materials		200	183	213
Other		445	384	137
Profit (Loss)				
Components		26	34	236
Digital Products		26	23	(705)
Government Electronics		135	161	176
Metallurgical Materials		19	12	23
Services		119	81	22
Other		(150)	(98)	(75)
Capital Expenditures		341	329	454
Components		155	140	232
Digital Products		48	44	27
Government Electronics		45	86	149
Metallurgical Materials		10	4	10
Other		83	55	36
Total Assets		2,310	2,631	2,713
Per Share Earnings ($)	9.22	4.62	6.10	(6.11)
Total Employees	89,895	83,714	80,107	80,696

Table 5.8

MOTOROLA--FINANCIAL SUMMARY, 1980-1983
1303 East Algonquin Road
Schaumburg, Illinois 60196
Telephone: (312) 397-5000

Operation Performance
(Millions of Dollars)

	1980	1981	1982	1983
Revenue				
Regional	3,284	3,570	3,786	4,328
United States		3,381	3,577	4,104
Other Nations		1,223	1,231	1,414
Adjustments		(1,034)	(1,017)	(1,190)
Business Segments				
Communication	1,257	1,443	1,522	1,620
Semiconductor	1,209	1,278	1,297	1,601
Linear	-	-	-	-
Information Systems Products	379	412	485	514
Other	489	518	565	696
Adjustments		(81)	(88)	(103)
Operating R&D Expense	200	251	278	283
Profit (Loss)		354	307	377
Communications Products		165	139	92
Semiconductor Products		131	104	213
Information Systems Products		43	34	(5)
Other		19	37	81
Adjustments		(4)	(7)	(7)
Total Assets	2,292	2,615	2,833	3,236
Net Earnings	192	182	178	244
Per Share Earnings ($)	5.47	5.10	4.64	6.26
Total Employees	75,200	80,800	78,800	88,800

Table 5.9

TIMERS--PRODUCT/MANUFACTURER AVAILABILITY

Generic Timer Type	Manufacturer	Device No.	Package
555	Signetics	NE555V	8-pin plastic MINIDIP
Advanced Micro Devices	NE555V		
Exar	XR-555CP		
Fairchild	UA555TC		
Intersil	NE555V		
Lithic Systems	LS555		
Motorola	MC1455PI		
National	LM555CN		
Raytheon	RC555DN		
RCA	CA555CE		
Silicon General	SG555M		
Teledyne Semiconductor	555P		
Texas Instruments	SN72555P		
556	Signetics	NE556A	14-pin plastic DIP
Advanced Micro Devices	NE556A		
Exar	XR-556CP		
Fairchild	UA556PC		
Intersil	NE556A		
Lithic Systems	LS556		
Motorola	MC3556A		
National	LN556N		
Ratheon	RC556DB		
Silicon General	SG556N		
Teledyne Semiconductor	556J		
322	National	LM322N	14-pin plastic DIP
3905	National	LM3905N	8-pin plastic MINIDIP
2240	Exar	XR-2240-CP	16-pin plastic DIP
Fairchild	UA2240PC		
Intersil	ICL8240CPE		
2250	Exar	XR-2250CP	16-pin plastic DIP
Intersil	ICL-8250CPE		
8260	Intersil	ICL8260CPE	16-pin plastic DIP
L565	Exar	XR-L555	8-pin plastic DIP
Signetics			
L556	Exar	XR-L556	14-pin plastic DIP
355	Teledyne	Teledyne 355	8-pin plastic DIP
7555	Intersil	ICM-7555	8-pin plastic DIP
7556	Intersil	ICM-7556	14-pin plastic DIP
2242	Exar	XR-2242	8-pin plastic DIP

Table 5.10

SINGLE CYCLE TIMERS

Feature	ICM7555	ICM7556	XR-L555	XR-L556
Supply range (V)	2-18	2-18	2.7-15	2.7-15
Supply current (10 mA)	80	160	190	380
Timing accurary (%)	2	2	1	1
Temperature stability (ppm/°C)	50	50	50	50
Supply stability	1	1	1	.5
Output current - sourcing (mA)	-	-	50	50
Output current - sinking (mA)	-	-	2	2
Package (number of pins)	8	14	8	14
Positive trigger	-	-	-	-
Negative trigger	X	X	X	X
Modulation	X	X	X	X
Multiple logic output	-	-	-	-
Astable operation	X	X	X	X
Monstable operation	X	X	X	X
Linear-ramp output	-	-	-	-
Technology	CMOS	CMOS	Bipolar	Bipolar
Original source	Intersil	Intersil	Exar	Exar
Alternate source	-	-	Signetics	Signetics

Table 5.11

TIMER/COUNTERS--COMPARISON OF FEATURES

Feature	ICL-8240	ICL-8250	ICL-8260	MC14536	MC14541	MIC5009	XR-2240	XR-2242
Supply voltage (volts)	4-18	4.5-18	4.5-18	3-18	3-18	4.5-5.5	4-15	4-15
Supply current (mA)	4	4	4	NA	NA	6	4	4
Timing accuracy (%)	.5	.5	.5	2	2	NS	.5	.5
Temperature stability (ppm/°C)	200	200	200	NS	NS	2000	200	200
Supply stability (%/V)	.08	.08	.8	2	NS	.3	.08	.08
Package (number of pins)	16	16	16	16	14	16	16	8
Programming capability	1-255	1-99	1-60	1-255	2^8, 2^{10}, 2^{13}, 2^{16}	1-15	1-255	None
Count code	Binary	BCD	Binary	Binary	Binary	Binary	Binary	Binary
Trigger polarity	+ve	+ve	+ve	+ve	+ve	+ve	+ve	+ve
Modulation	X	X	X	X	X	X	X	X
Technology	Bipolar	Bipolar	Bipolar	CMOS	CMOS	CMOS	Biploar	Bipolar
Original source	Intersil	Intersil	Intersil	Motorola	Motorola	Mosten	Exar	Exar
Second source(s)	None	None	None	None	None	None	None	None

NS = Not specified
X = Yes

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Table 5.12

LOW-POWER SINGLE-CYCLE TIMERS--COMPARISION OF FEATURES

Feature	ICM7555	ICM7556	XR-L555	XR-L556
Supply range (V)	2-18	2-18	2.7-15	2.7-15
Supply current (10 mA)	80	160	190	380
Timing accurary (%)	2	2	1	1
Temperature stability (ppm/°C)	50	50	50	50
Supply stability	1	1	1	.5
Output current - sourcing (mA)	-	-	50	50
Output current - sinking (mA)	-	-	2	2
Package (number of pins)	8	14	8	14
Positive trigger	-	-	-	-
Negative trigger	X	X	X	X
Modulation	X	X	X	X
Multiple logic output	-	-	-	-
Astable operation	X	X	X	X
Monstable operation	X	X	X	X
Linear-ramp output	-	-	-	-
Technology	CMOS	CMOS	Bipolar	Bipolar
Original source	Intersil	Intersil	Exar	Exar
Alternate source	-	-	Signetics	Signetics

Table 5.13

OPERATIONAL AMPLIFIERS--TYPICAL APPLICATIONS

Op Amp Category	Typical Applications	Major Requirement	Typical Device Types
General Purpose	Preamplifiers, buffers, telephone functions, filters, DC amplifiers	Cost Effective	741, NE5512, MC3303
High Accuracy			
High Speed	Broadcast video, CATV, data communications, cable drivers and receivers	10 MHz - 2GHz	NE5539, NE5592, HA-2250, NEJ92
High Slew	Motor drivers, cable drivers	Fast rise and fall times	NE538, LF356, NE5539
Low-Lower	Portable applications	Low voltage and low current	LM-10. TLC251, TLC271
Low Noise	Magnetic data recording, audio and process monitoring	High gain, low rise and wide bandwidth	NE5532, NE553XA, OP-37, NEC5533, NE592, NE5592
Precision	Test instruments, measurements	Low bias current, low voltage offset and drift, low noise, and high gain	OP-07, LF156

Table 5.14

TYPICAL A/D AND D/A CONVERTER PRODUCTS

	8-Bit	10-Bit	12-Bit	14-Bit	16-Bit
A/D Converters					
Flash/ultra high speed	TDC1007J				
Successive approximation					
High speed		AD573	AD572	ICL7115	
Low cost			AD574		
Integrating					
Binary			ICL7109	ICL7104-14	ICL7104-16
Decimal		ICL7136/7	ICL7135		
D/A Converters					
High speed	DAC-08		HA562		
Low cost	ADC7520/30	ADC7521/31	AD7541	ICL7134	

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Table 5.15

PERFORMANCE PARAMETERS AND APPLICATION--AREAS OF A/D CONVERTERS

Type	Relative Speed	6-	8-	10-	12-	14-bit	Technology	Application Areas
			Typical Conversion Times					
Integrating (dual olspe and large-balancing	Low	--	20 ms	30 ms	100 ms	250 ms	MOS	Digital panel meters
	Medium	--	1 ms	5 ms	20 ms	100 ms	MOS	Low-frequency instrumentation
	High	--	0.3 ms	1 ms	5 ms	30 ms	MOS	Radio-control and telemetry
Successive Approximation	Low	60 us	100 us	120 us	150 us	--	MOS, bipolar	General purpose instrumentation
	Medium	30 us	50 us	60 us	80 us	--	MOS, bipolar	EDP and microprocessor interface
	High	5 us	10 us	15 us	20 us	--	MOS, bipolar	Telecommunications (CODECS) and digital controllers
Parallel or Flash	Medium	100 ns	200 ns	--	--	--	MOS, bipolar	Video, radar signal processing
	High	20 ns	50 ns	..--	..--	..--	Bipolar	Image analysis, high speed data files, multiplexing applications

CHAPTER 6—U.S. DISTRIBUTION TRENDS

6.1 OVERVIEW

The growth of U.S. distributors in 1983 was nearly double the combined growth for the previous three years. The top 25 U.S. distributors accounted for more than $4.1 billion of the total of $5.2 billion in 1983.

The 1950s gave transistors to distributors, the 1960s gave them ICs, the 1970s brought microprocessors, and the 1980s are bringing gate arrays, standard cells, and application specific integrated circuits (ASICs). Not to be left out is the growing trend for distributors to get into the computer business. Although it has been a volatile business, it will represent a significant portion in 1984--$1.5 billion.

Revenues of the ten largest U.S. distributors range from Hamilton/Avnet's revenues of more than $1 billion to Future Electronics' revenues of approximately $142 million.

The revenues and earnings for the top 12 distributors for the period 1979 to 1983 are listed in Table 6.1. The total available U.S. market by region is shown in Figure 6.1.

6.2 DISTRIBUTORS' SHARE OF THE SEMICONDUCTOR MARKET

The distributors' share of the U.S. semiconductor market has typically been 20 percent. It is now believed that, between 1984 and 1986, this 20:80 ratio will alter in favor of the distributors. This is believed to be of benefit to both the manufacturers and the distributors as it is generally perceived that distribution is a more cost-effective way to get the product to the customer base in lower volumes than direct sales. The projections are for a share increase by distributors as shown in Table 6.2. Though the 1984 share shows a drop from 1983, it is believed that the 1986 to 1990 period will see a growth in the distribution share of the semiconductor market.

The percentage of semiconductor sales made through distributors varies from manufacturer to manufacturer. Table 6.3 lists the percentage of sales attributable to distribution for the major semiconductor manufacturers. It is generally felt that the distributor's ability to handle ASICs will greatly determine how they will increase their share of the semiconductor component market.

Table 6.1

U.S. DISTRIBUTORS' TOTAL SALES AND EARNINGS
(Thousands of Dollars)

	Sales					Earnings				
	1979	1980	1981	1982	1983	1979	1980	1981	1982	1983
Hamilton/Avnet	512,400	699,500	727,800	781,421	849,600	29,700	47,400	42,000	38,099	34,600
Arrow	177,000	272,000	286,000	347,000	N/A	9,398	21,956	14,536	8,425	N/A
Schweber	N/A	N/A	N/A	N/A	309,000 est.	N/A	N/A	N/A	N/A	N/A
Kierloff	148,889	171,365	189,452	223,488	295,000	6,265	6,704	9,105	3,010	N/A
Pioneer	93,400	120,500	134,000	149,600	290,000	3,300	4,600	4,300	2,900	1,450
Hallmark	106,000	140,000	142,000	154,000	230,000 est.	N/A	N/A	N/A	N/A	N/A
Wyle	157,000	164,000	156,000	142,700	214,000 est.	10,800	11,000	3,600	(3,289)	N/A
Marshall	66,880	83,538	105,663	117,999	130,364	719	1,825	(1,550)	(949)	1,518
Premier	N/A	N/A	N/A	N/A	173,000 est.	N/A	N/A	N/A	N/A	N/A
Future	80,650	87,760	85,600	88,400	142,000 est.	3,900	4,200	3,700	3,900	N/A

Table 6.2

U.S. DISTRIBUTORS' SHARE
OF TOTAL U.S. SEMICONDUCTOR MARKET
(Billions of Dollars)

	1982	1983	1984
Distributor Sales	1.72	1.496	
Percent	20.9	22.8	22.4

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Table 6.3

TYPICAL PERCENTAGE OF SEMICONDUCTOR PRODUCT BY MANUFACTURER SOLD BY DISTRIBUTOR

Manufacturer	1983
National Semiconductor	35%
Advanced Micro Devices	25%
Mostek	24%
Intel	22%
Motorola	17%

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