6 MOS MPU, MCU, AND PERIPHERALS MARKET TRENDS

OVERVIEW

MOS microcomponents include MPUs, MCUs, DSP devices, and microperipheral devices. As defined by the Semiconductor Industry Association (SIA), microprocessors (MPUs) are programmable devices that execute programs stored in external memory. Microcontrollers (MCUs) contain all of a computer's electronic components, including program memory, on a single chip. Digital signal processors (DSPs) are processors that are optimized to process highly math-intensive digitized analog signals. Microperipherals (MPRs) are peripheral chips such as sound and video devices designed to work with MPUs and MCUs.

Quarterly history of the MOS microcomponent market between 1990 and 1996 is shown in Figure 6-1. It is interesting to note the repetitive ASP pattern that occurred in each year since 1990. In the fourth quarter of each year, the microcomponent ASP surged. The growth extended into the first quarter of the following year before declining during the middle two quarters. Beginning in the second half of 1994, the microcomponent market grew rapidly as sales of less costly 486 and hot-selling Pentium MPUs took off. For three years in a row (1993-1995), the microcomponent market experienced excellent growth (40 percent in 1995, 25 percent in 1994, and 37 percent in 1993).

Figure 6-2 shows unit volume and average selling price (ASP) details for the major segments of the microcomponent market. Severe price erosion on 486s and steady price reductions on Pentiums contributed to a seven percent decline in ASPs for the 32-/64-bit MPU segment in 1996. Average selling prices may have declined further, but Intel continued to introduce newer, faster, and more expensive devices throughout the year. Meanwhile, microprocessor unit shipments continued to demonstrate solid growth (16 percent in 1996), led by strong shipments of 32-/64-bit MPUs for PC and embedded applications.

Besides the 32-/64-bit MPU segment, 16-/32-bit MCU and microperipheral unit shipments also grew nicely during 1996 (51 and 21 percent, respectively) in 1996. Growth in the form of communications, graphics, voice, and other support functions for PCs exploded in 1995. In 1996, that growth continued but many of the peripheral functions that were "add-on" features in 1995 were incorporated onto the MPU chip in 1996. This contributed to a slower unit growth rate for microperipherals. Overall, the ASP in the MOS microcomponent segment decreased two percent in 1996 and unit volume increased 14 percent.

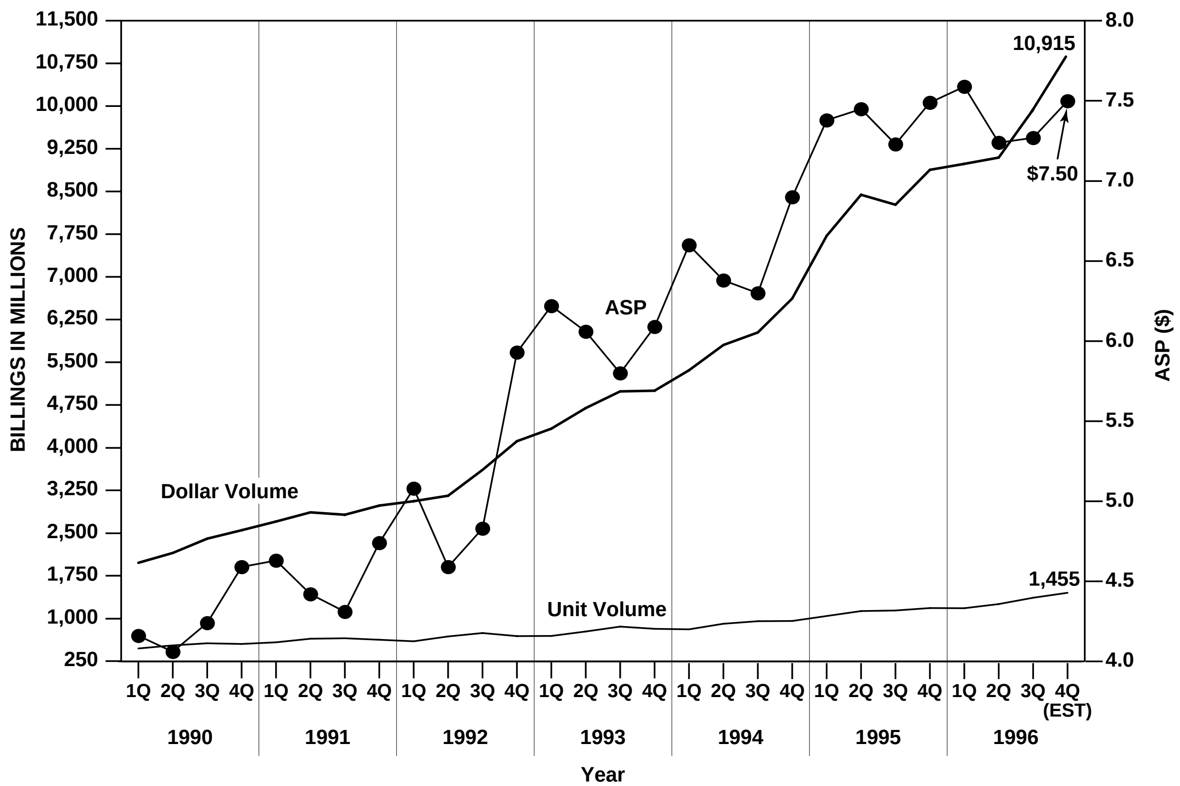


Figure 6-1. MOS MPU, MCU, and MPR Market Trends (Dollars and Units in Millions)

Product	1993 ASP ($)	1994 ASP ($)	1994/1993 Percent Change In ASP	1994/1993 Unit Volume Percent Change	1995 ASP ($)	1995/1994 Percent Change In ASP	1995/1994 Unit Volume Percent Change	1996 ASP (EST, $)	1996/1995 Percent Change In ASP	1996/1995 Unit Volume Percent Change
MPUs										
8-bit	3.10	3.52	14	–11	3.80	8	–14	3.63	–4	–17
16-bit	10.29	9.88	–4	–12	7.92	–20	34	6.08	–23	2
32-bit/64-bit	150.19	150.51	—	31	131.03	–13	51	121.43	–7	35
Total MPU	51.50	64.60	25	2	67.36	4	25	71.47	6	16
MCUs										
4-bit	1.64	1.62	–1	5	1.59	–2	–2	1.33	–12	1
8-bit	3.45	3.33	–3	28	3.39	2	21	2.98	–12	13
16-bit/32-bit	8.13	7.86	–3	100	8.26	5	66	7.05	–15	51
Total MCU*	2.71	2.82	–4	19	3.07	9	14	2.81	–8	11
MPRs	5.04	5.61	11	4	6.55	17	57	6.34	–3	21
Total Micro	6.02	6.54	9	15	7.33	12	25	7.22	–2	14

*Not including DSP

Source: ICE, "Status 1997"

16888L

Figure 6-2. Microcomponent ASPs and Unit Volume Change

Figure 6-3 shows the microcomponent market growth rates from 1993-1996. Growth figures for the MPU and MPR categories remained solid in 1996 while the MCU category grew only eight percent. Despite the single-digit growth of the total MCU market, two segments within the MCU category enjoyed the highest percentage increases for market size. DSPs (42 percent) and 16-/32-bit MCUs (29 percent) experienced the best growth within the microcomponent market. Also performing well was the 32-/64-bit MPU market with 25 percent growth. As a whole, the MOS microcomponent market increased 17 percent in 1996. For 1997, ICE forecasts the microcomponent market to increase another 17 percent.

PRODUCT	1993 ($M)	1994 ($M)	1994/1993 Percent Change	1995 ($M)	1995/1994 Percent Change	1996 (EST, $M)	1996/1995 Percent Change
MPUs							
8-bit	200	200	—	185	–8	145	–22
16-bit	520	440	–15	465	6	365	–22
32-/64-bit	7,870	10,355	32	13,630	32	17,000	25
Total MPU	8,590	10,995	28	14,280	30	17,510	23
MCUs							
4-bit	1,700	1,770	4	1,700	–4	1,440	–15
8-bit	3,700	4,565	23	5,665	24	5,600	–1
16-/32-bit	485	940	94	1,640	74	2,115	29
DSPs	675	1,000	48	1,730	73	2,460	42
Total MCU	6,560	8,275	26	10,735	30	11,615	8
MPRs	3,920	4,550	16	8,385	84	9,825	17
Total Microcomponent	19,070	23,820	25	33,400	40	38,950	17

Source: ICE, "Status 1997" 17204K

Figure 6-3. 1993-1996 Microcomponent Market

Another perspective of the MOS MPU, MCU, and peripherals market is shown in Figure 6-4. Clearly leading the way in terms of market size is the MPU category, specifically 32-/64-bit MPUs. High-performing and high-priced MPU devices targeted for the PC and workstation/server environments kept this the largest segment of the microcomponent market again in 1996.

Figure 6-5 provides a forecast of MOS microcomponent consumption by geographic region for 1996. In 1991, Japan and North America consumed about the same percentage of microcomponents. However, in 1996, ICE estimates that North America was the microcomponent consumption leader with 36 percent of the market. Japan, Europe, and the ROW each had about equal shares of the microcomponent market in 1996.

Figure 6-6 lists the quarterly microcomponent market by region. Clearly, Europe and Asia Pacific were the fastest-growing regions in 1996. Accelerated PC growth in both regions was the driving force that led to the increases. Meanwhile, after having surged in 1995, market growth in North America and in Japan cooled in 1996.

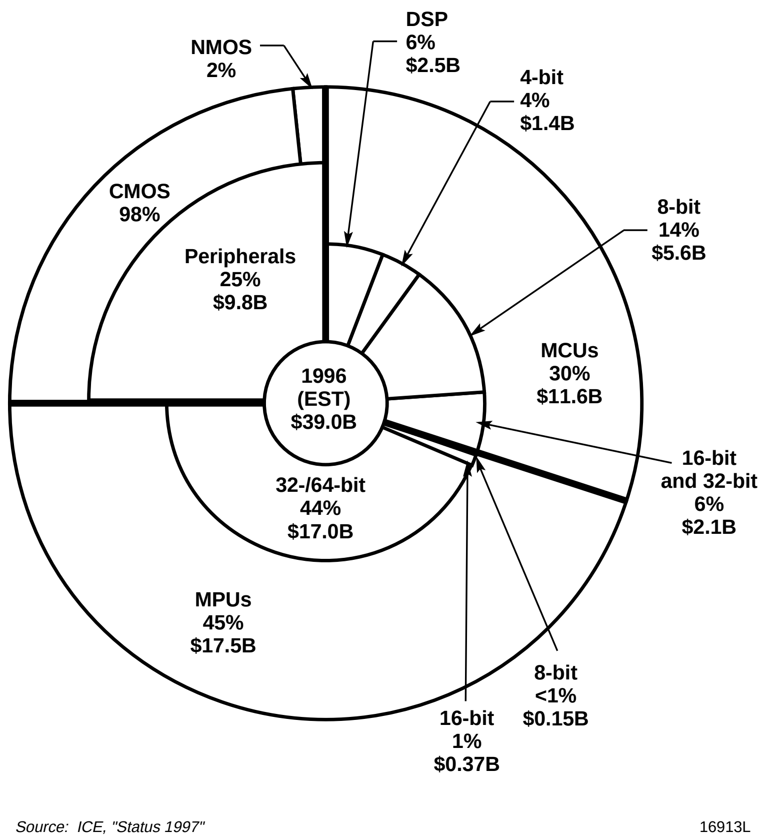


Figure 6-4. 1996 MOS MPU, MCU, and Peripherals Markets

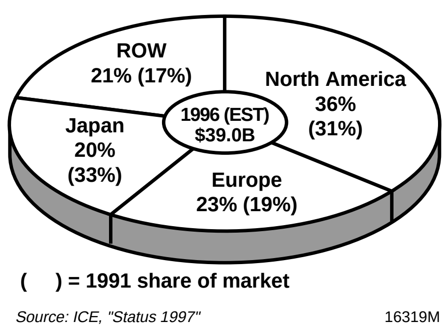


Figure 6-5. 1996 MOS Microcomponent Consumption

Regional microcomponent production is displayed in Figure 6-7. North American companies were the leading suppliers to the microcomponent market again in 1996, with Intel accounting for over 40 percent of the world's microcomponent supply. On the other hand, ROW and European companies had fairly insignificant microcomponent marketshare.

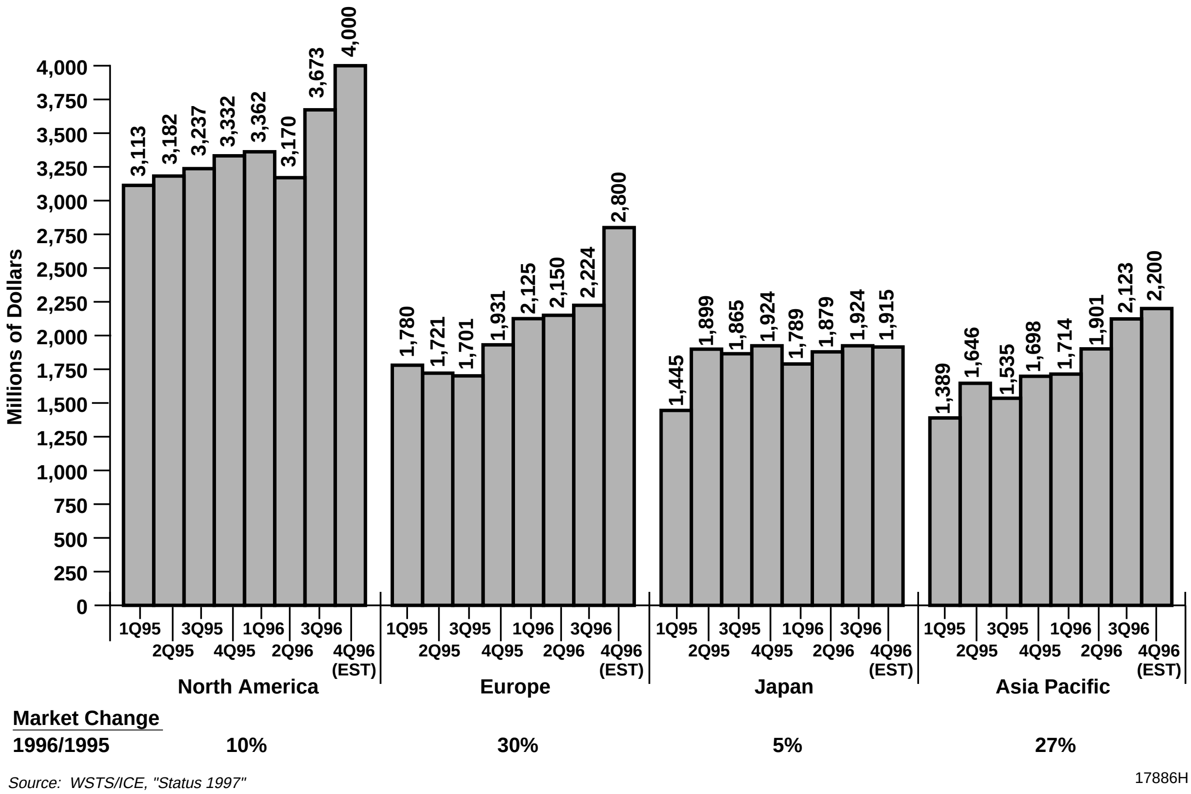


Figure 6-6. Quarterly Microcomponent Geographic Market Trends

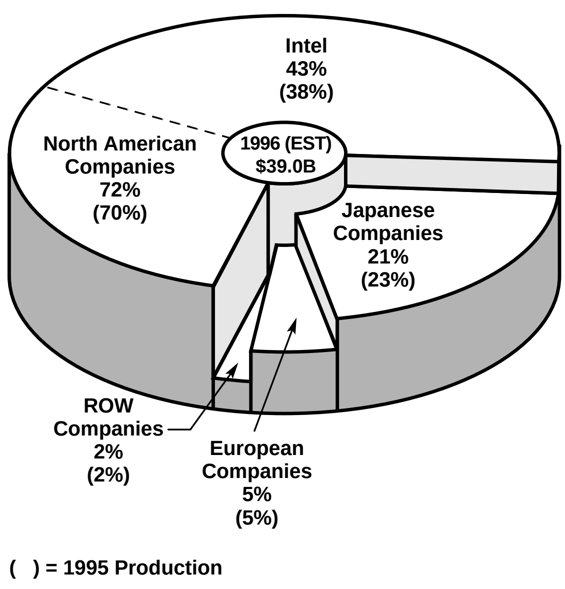


Figure 6-7. 1996 MOS MPU, MCU, and Peripherals Production

Figure 6-8 provides a look at end-use applications for each of the microcomponent segments. It should come as no surprise that computers were the driving force in all three segments, but especially for MPUs. With wide-spread applications such as communications and consumer devices (stereos, appliances, cell phones, etc.), the percentage of end-use applications in the MCU and MPR categories is much more balanced.

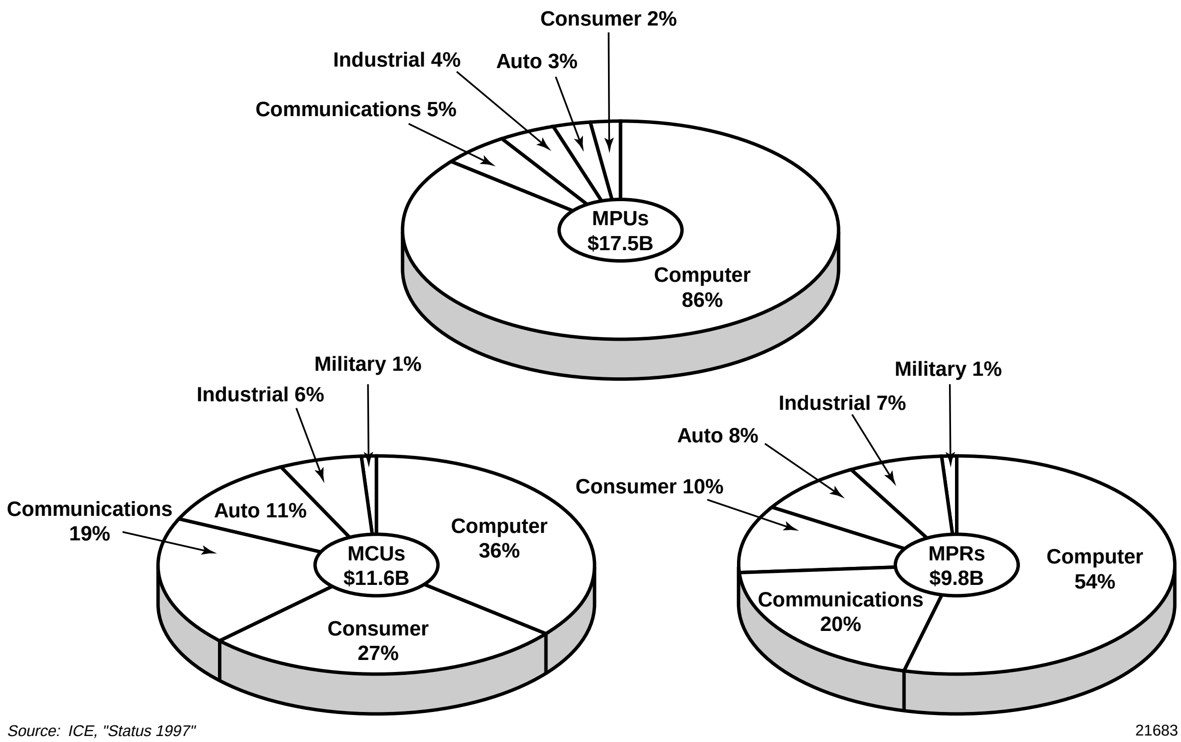


Figure 6-8. 1996 Microcomponent Usage By System Type

TOP TEN MANUFACTURERS

ICE's estimate of the leading MOS microcomponent suppliers for 1995 and 1996 is shown in Figure 6-9. Combined, these top suppliers accounted for approximately three-fourths of the microcomponent market in each year.

It comes as no surprise that Intel was again the leading microcomponent supplier in 1996. Its microcomponent sales far exceeded those of its nearest competitors. Even during a so-called down year for most of the IC industry, strong demand for Intel MPUs (specifically, its Pentium MPU) continued to the point where it now supplies a full 85 percent of the world's PC MPUs. Further, Intel has a good selling RISC processor (i960) and strengthened its peripheral product line-up as well.

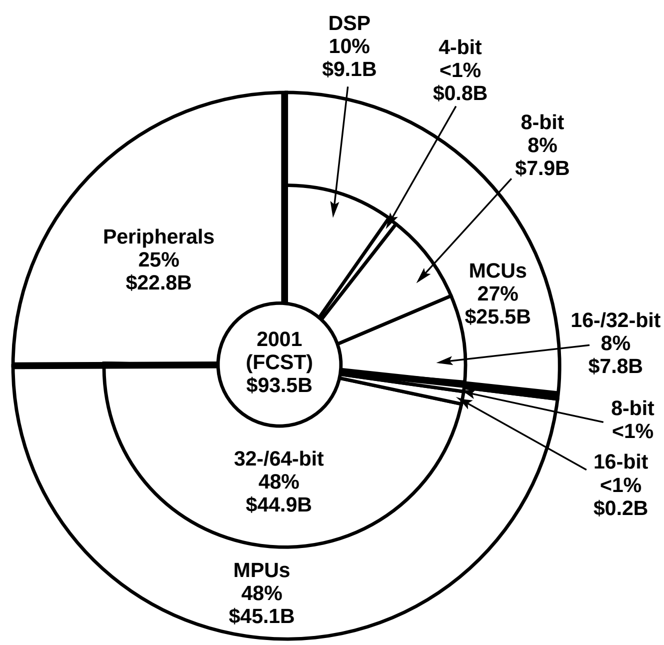
1996 Rank	Company	1995 Sales ($M)	1996 Sales (EST, $M)	1996/1995 Percent Change
1	Intel	12,730	16,600	30
2	Motorola	2,995	2,545	–15
3	NEC	2,235	2,460	10
4	Hitachi	1,515	1,745	15
5	TI	1,290	1,380	7
6	Toshiba	1,148	1,250	9
7	Mitsubishi	1,012	1,135	12
8	Philips	665	1,088	64
9	Cirrus Logic	1,187	975	–18
10	AMD	755	850	13
10	IBM	640	850	33
	Total	26,172	30,878	18

Source: ICE, "Status 1997" 16316N

Figure 6-9. 1996 Top Ten MOS Microcomponent Sales Leaders

MICROCOMPONENT FORECAST

ICE's forecast of the microcomponent market in the year 2001 is shown in Figure 6-10. By that year, there will be a noticeable shift toward more complex MPUs. Nearly all MPU sales will be 32- and 64-bit devices. Higher ASPs associated with these complex products will account for their increased share (to 48 percent in 2001, up from 44 percent in 1996) of the microcomponent market.



Source: ICE, "Status 1997" 13364S

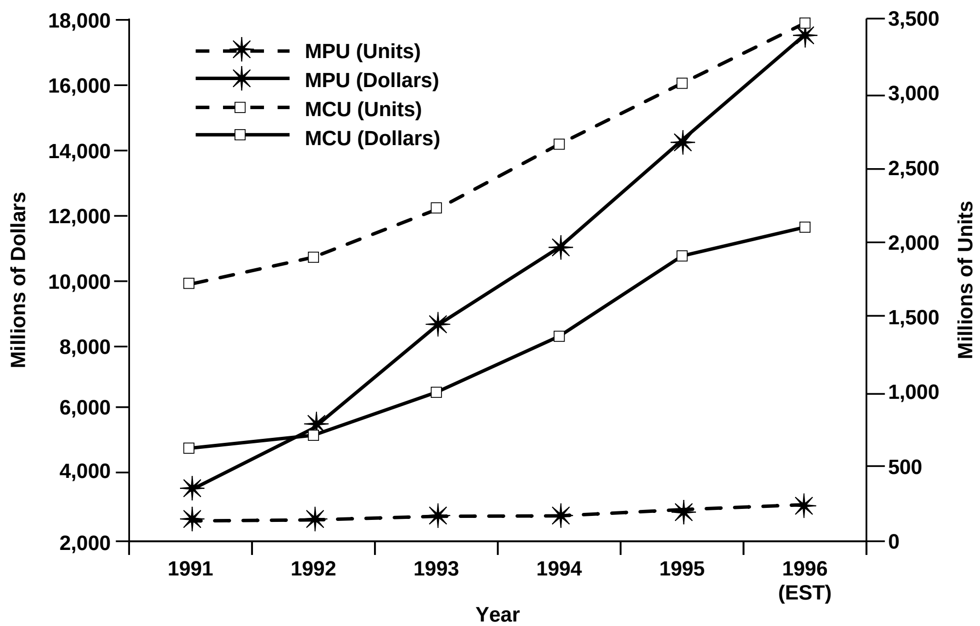
Figure 6-10. MOS MPU, MCU, and Peripherals Market Forecast

Meanwhile, MCU sales will still be led by the ubiquitous 8-bit device, but 16- and 32-bit devices are forecast to show strong gains. Microcontroller replacement is often cited as one of the most promising markets for DSPs—especially at the 16-bit and 32-bit levels. By the year 2001, DSPs are forecast to represent 10 percent of the microcomponent market.

THE MCU MARKET

As defined by WSTS, a microcontroller is a stand alone device that performs dedicated or embedded computer functions within an electronic system without the need of other support circuits. Unlike MPUs, a microcontroller contains almost all of its memory on-chip usually in the form of ROM, EPROM, or EEPROM. The memory is programmed to store customer-supplied instructions.

In 1996, the MCU market was about two-thirds the size of the MPU market. In terms of unit shipments, however, MCUs outshipped MPUs by roughly a 14:1 margin in 1996 (Figure 6-11). Despite ongoing performance improvements, activities in the MCU market are often overshadowed by microprocessors.



Units (M)						
MCU	1,722	1,902	2,221	2,659	3,067	3,470
MPU	136	143	167	170	212	245
Dollars ($M)						
MCU	4,850	5,245	6,560	8,275	10,735	11,615
MPU	3,565	5,460	8,590	10,995	14,280	17,510

Source: WSTS/ICE, "Status 1997" 20318C

Figure 6-11. Comparison of the MCU and MPU Markets

MCU growth is being driven by three key sectors: automobiles, office electronics, and consumer electronics. Inexpensive cars from Korea have from five to ten MCUs each, while many luxury cars use 30 to 40. 1996 S-class cars from Mercedes-Benz used 50 MCUs throughout the vehicle.

Meanwhile, the average office has about 20 MCUs, and the typical home has as many as 100 microcontrollers! In recent years, these areas have contributed significantly to the rise in the MCU market and unit growth.

Figure 6-12 projects the number of MCU devices expected to make their way into new cars, homes, and offices through the end of the decade. There is great potential in these three applications. The figure shows that MCUs in the home are forecast to grow to an average of 226 in the year 2000!

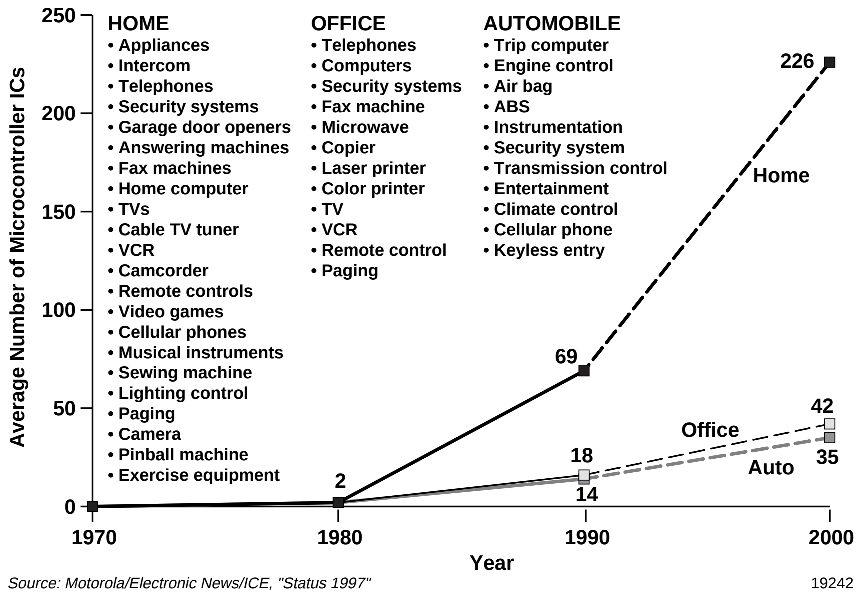
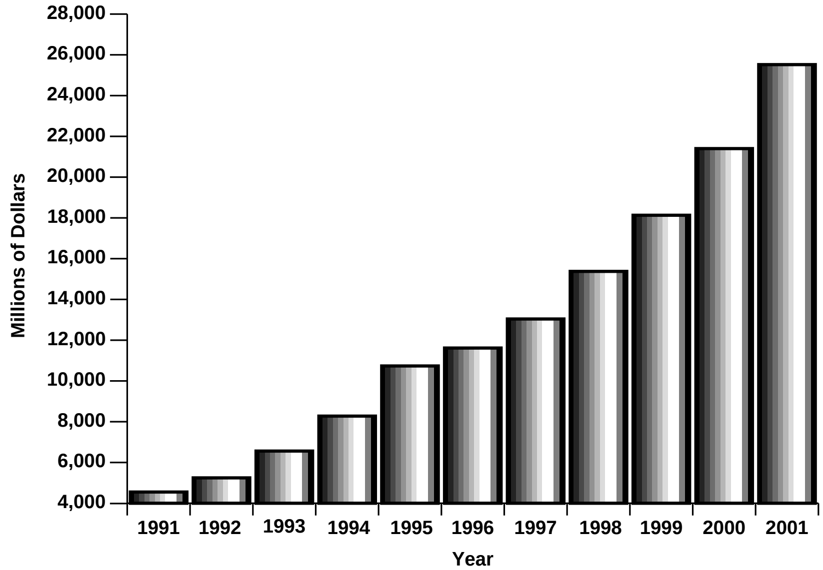


Figure 6-12. Numerous Applications Spur MCU Growth

Numerous applications will allow the MCU market to grow nicely through the early part of the next decade. ICE projects the MCU market to average 17 percent annual growth through the year 2001, when the MCU market is forecast to be $25.5 billion (Figure 6-13). This compares with 19 percent average annual growth of the MCU market during the 1991-1996 time period.

MCUs are typically available in 4-, 8-, and 16-bit configurations. In the past few years, 32-bit devices have started to ship as well. Figure 6-14 shows the percentage of dollars that each density contributed to the MCU market. In this chart, DSPs are included as part of the microcontroller market.

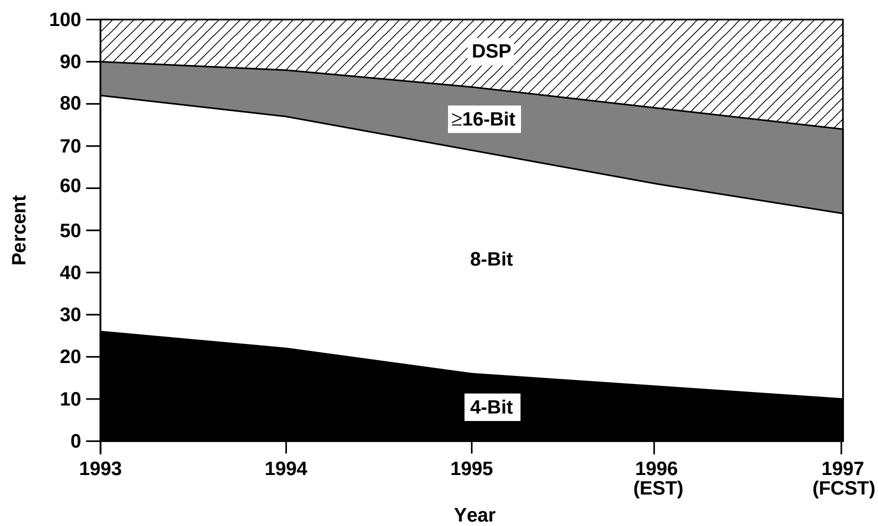
OEMs are turning more often to sophisticated, high-density MCU devices to incorporate into complex, embedded-system applications where there is a drive for computing muscle. As a result, market growth will continue in the 16-/32-bit MCU and DSP markets. Meanwhile, erosion of the 8-bit MCU market caused this segment to drop below 50 percent of the total MCU market in 1996.



MCU Market($M)	4,850	5,245	6,560	8,275	10,735	11,615	13,040	15,375	18,130	21,400	25,520

Source: ICE, "Status 1997" 20438B

Figure 6-13. MCU Market Trends

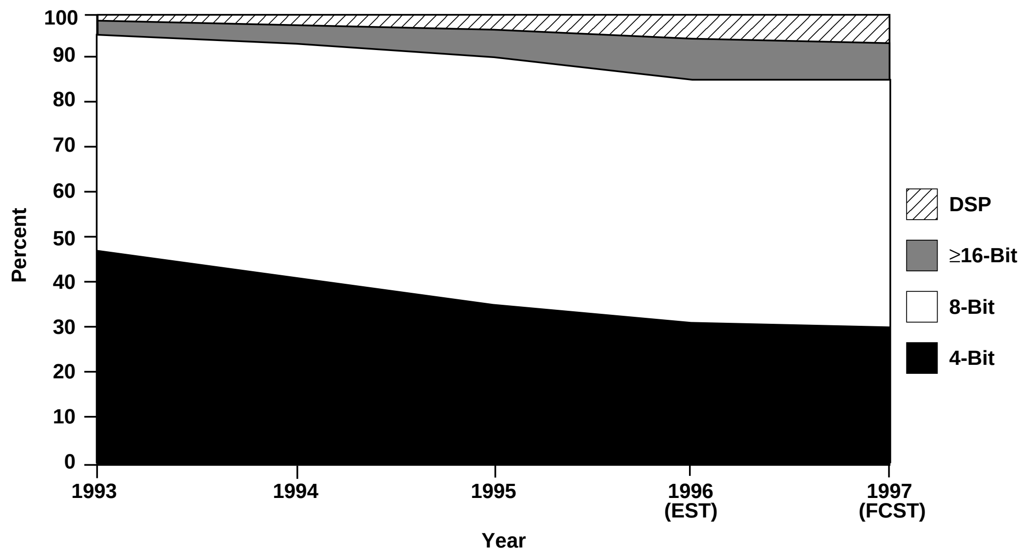


MCU Market (%)	1993	1994	1995	1996 (EST)	1997 (FCST)
4-Bit	26	22	16	13	10
8-Bit	56	55	53	48	44
≥16-Bit	8	11	15	18	20
DSPs	10	12	16	21	26
Total ($M)	6,560	8,275	10,735	11,615	13,040
Percent Change	25	26	30	8	12

Source: ICE, "Status 1997" 20319C

Figure 6-14. The MCU Market by Configuration

In terms of units, low density (4-bit and 8-bit) MCUs dominate. ICE estimates that in 1996, these devices accounted for 85 percent of the total MCU unit shipment volume (Figure 6-15). Though their growth rate is slowing, ICE believes that 4-bit and 8-bit MCUs unit shipments will continue to account for the majority of MCU shipments through the end of the century.



MCU Market (%)	1993	1994	1995	1996 (EST)	1997 (FCST)
4-Bit	47	41	35	31	30
8-Bit	48	52	55	54	55
≥16-Bit	3	4	6	9	8
DSPs	2	3	4	6	7
Total (M)	2,220	2,660	3,065	3,470	3,800
Percent Change	17	20	15	13	10

Source: ICE, "Status 1997" 20320C

Figure 6-15. MCU Unit Shipments by Configuration

Figure 6-16 points out several reasons why 8-bit MCUs remain a favorite among designers. Success in the 8-bit market boils down to the fact that these devices generate formidable computing power, almost always have a smaller footprint than higher-density devices, and are low-cost. Many older 8-bit designs perform exactly as needed—no more, no less—especially in inexpensive system designs (Figure 6-17).

Further, 8-bit devices, like all MCUs, have become more specialized. That is, they provide more performance and are more versatile than ever before. At the same time, 8-bit MCUs are being built using submicron process technologies, which helps lower operating voltages and greatly shrinks the die size of the device. With these characteristics, many 8-bit designs compete with older 16-bit MCUs for new applications (Figure 6-18).

- **Rapid integration of MCU-related functions**
- **Easier-to-operate user interfaces**
- **Move from electromechanical to more reliable electronic systems**
- **Portability in equipment such as cordless/cellular phones and pagers**
- **Need for low-cost solutions**

Source: ICE, "Status 1997" 19234A

Figure 6-16. Elements of the 8-bit MCU's Success

Vendor	Comments
Microchip Technology's PIC	Microchip expanded its PIC line to the mid-range, but still sells a number of low-end PICs. These are minimal controllers with as little as 512 words of ROM/OTP and 25 bytes of RAM. Maximum frequency is 20MHz. Parts are supplied in 18-pin and 28-pin SOIC/SSOS/PDIP packages.
Motorola's 68HC05	The leading 8-bit MCU with 100 to 2,000 chip variations. In large volumes, some chips are competitive with 4-bit pricing. It's supplied with as little as 0.5Kbytes of ROM, 32 bytes of RAM, and a range of packages, including die and 16-/20-/28-pin SOIC, PDIP.
Philips Semiconductor's skinny 8051	You can get an 8051 for under a buck. Philips has a cost-reduced version of its famous "skinny DIP" 8051, the 80C751. It's an 8051 with 2Kbytes of ROM, 64 bytes of RAM, one timer, and I_2C. It's supplied in a 24-pin SSOP/SDIP.
National Semiconductor's COP8	National has revitalized its COP8 family, including low-cost, under-$1 models. National is aggressively pushing prices down. It's supplied with as little as 768 bytes of ROM and 64 bytes of RAM in a 16-/20-/28-pin SOIC, DIP.
Zilog's Z8	Zilog pushed its register-based Z8 down into the under-$1 markets. The Z8 is a register-based machine with up to 256 bytes of register RAM. It's supplied with as little as 0.5Kbytes of ROM and 64 bytes of RAM in a 18-/28-pin SOIC, DIP.

Source: Computer Design/ICE, "Status 1997" 21097A

Figure 6-17. Older Architectures Benefit Inexpensive Designs

One relatively new feature of 8-bit MCUs is the integration of EPROM, EEPROM, or flash on the same chip. Among the companies equipping their MCUs with non-volatile memory are Atmel, Hitachi, Mitsubishi, Motorola, Intel, and Siemens. As Figure 6-19 shows, the amount of memory used with 8-bit microcontrollers is expanding at all levels. Siemens expects flash to be widely used in microcontroller applications, with as much as 80 percent of all embedded controllers using it in five years.

Applications	8-bit MCU Features and Peripherals
Battery charging and management	Measuring temperature – on-chip temperature sensor High-precision A-D converter Charge control D-A converters Pulse-width modulation – current source Low-power sleep for in-battery pack On-chip clock oscillator A-D converter
Motor control	Computational throughput 8x8 hardware – single-cycle multiply Precise pulse-width modulation 160ns resolution Precise capture input
Remote keyless entry	On-board EEPROM data Wide operating voltage range Low standby current High drive outputs
Security/rolling code	EEPROM data memory Computation speed (RISC core) SSOP package
Sensor applications	High-precision A-D converter Programmable A-D resolution Temperature sensor on-chip

Source: Microchip Technology/ICE, "Status 1997" 21098

Figure 6-18. Applications Link With 8-bit MCUs

In the past, each particular MCU sub-category (i.e., 4-bit, 8-bit, 16-bit, etc.) served certain applications and markets according to their respective price and performance points. However, as depicted in Figure 6-20, the microcontroller business has become intertwined during the 1990's. Some high-performance 8-bit MCUs offer comparable performance to 16-bit designs, low-end 16-bit devices have become cost-competitive with high-end 8-bit devices, 32-bit MCUs have encroached on 16-bit territory, and some DSP prices have dropped to MCU levels.

Despite the size of the market, the variety of available options, and the solid base of customers, 8-bit MCU suppliers are increasingly faced with a dilemma—how to give their customers a clear performance upgrade path (to 16-bit MCUs and beyond) while sparing them the associated costs of new code development and expensive new components.

A designer's decision to upgrade or not to upgrade is especially critical in the embedded-control market. Considerations such as architectural and performance issues must be weighed along with silicon costs and the cost of software and training. Figure 6-21 shows a few of the advantages and disadvantages of migrating upward within a chosen MCU family.

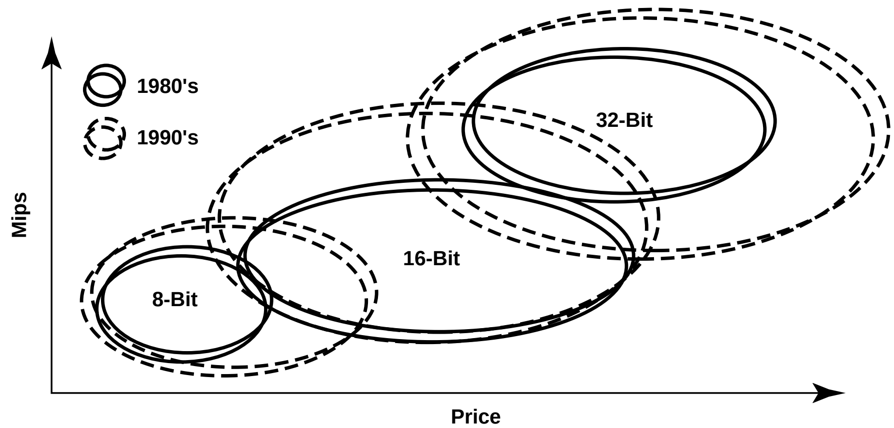
Vendor	Controller	Memory (kbytes)	Clock (MHz)	Comments
Hitachi	H8/300(L)	16, 24, 32, 48, 60	To 16	Mid-to-high-level controller, with low-power (L) versions. Large peripheral set.
Intel	8051	16, 32	12 to 33	Classic 8051 mid-level controller; some dedicated high-end controllers.
Mitsubishi	M380xx	16, 24, 32	8	Mid-level controller with high integration. Larger memory sizes to come. Dual clock.
Motorola	68HC05	12, 16, 24	4	Low-level controller, accumulator-based. Leading 8-bit controller.
	68HC11	20, 32	2	Cadillac of U.S. 8-bitters, accumulator-based. Mid-range controller.
	68HC08	36	8	Upgrade of 05; faster clock; optimized ISA.
National	COP8	16, 32	12	Low-to-mid-level controller, accumulator-based architecture. Packaged with OTP memory die.
NEC	K0	16, 24, 32, 40, 48, 60	5, 6, 10	Mid-to-high-level controller; runs down to 1.8V, low power.
	K2	16, 24, 32	12	Mid-to-high-level controller. Four register banks, eight registers each. 1 Mbyte address space.
Oki	65K	16, 32	10	Redesign of 8051; faster implementation. Four-clock basic instruction cycle.
Philips	8051	16, 32, 64	12 to 40	Classic 8051 mid-level controller. Wide proliferation of parts with some high-end parts. Add MPY/DIV engine.
SGS	ST9	16, 24, 32	12	Mid-to-high-range 8-bitter. Has 256-byte general-register file as RAM. Up to 512 bytes of EEPROM.
Siemens	8051	32	12 to 40	Line of 8051s. Added math unit. 1 kbyte of RAM. DPTRs to up speed.
TI	TMS370	16, 32, 48	To 5	TI has revamped and is pushing x5x, its 8-bit microcontroller; x5xs are the top-of-the-line controller. Register architecture.
Toshiba	TLCS-870	16, 24, 32	8	Low-to-mid-range controller, register-based. Multiple banks in RAM. Supports MPY, DIV, 16-bit arithmetic operations. 32-kHz subclock. LED, LCD, VFT drivers. Up to 32 kbytes of ROM, to 1 kbyte of RAM. 8MHz clock.
	TLCS90	16, 24, 32	To 16	Mid-to-high-range controller with complex peripherals. Includes I/O-DMA controller. Can address up to 1 Mbyte of external memory. Multiple banks in RAM. 32-kHz, LED, LCD, VFT drivers. Has 16-bit extension, the TLCS900. Large register set. Clock up to 16MHz, to 32 kbytes of ROM. 1 kbyte of RAM.

Source: Computer Design/ICE, "Status 1997" 21099

Figure 6-19. 8-bit MCUs Push Memory Limits

Fortunately, for many 8-bit MCU designers, learning a new architecture is not a necessity to reach 16-bit performance. For instance, Philips sells the XA, a 16-bit expansion of the venerable 8051, that is fully compatible with the 8051. Other designers can migrate to the 68HC12, Motorola's successor to the popular 68HC11.

Toshiba has addressed its product line-up to respond to interest in the 8-bit and 16-bit MCU markets. It developed several new products based on existing platforms. Part of its 16-bit MCU strategy is to develop derivative products based on its TLCS-900 family (Figure 6-22).



Source: SGS-Thomson/ICE, "Status 1997" 20322

Figure 6-20. Relative MCU Performance

Advantages

- Little loss of time or money.
- No need to learn new development tools, software packages, or peripheral functionality.
- No reinvestment in support structure.
- Code development and software preservation.

Disadvantages

- Future migration of silicon does not always match migration path of system design.
- Sometimes not "backward compatible." Low-cost version of initial product is easier when migrating within a product family. Backward compatibility of hardware and software is important.

Source: ICE, "Status 1997" 20323

Figure 6-21. Factors Influence Migrating Within an MCU Family

The leading MCU suppliers of 1995 and 1996 are shown in Figure 6-23. Note that the figure includes DSP sales. As a result, DSP suppliers Texas Instruments and Lucent Technologies are ranked among the top MCU suppliers. The success of Motorola and Intel in remaining the two largest MCU suppliers (excluding DSPs) seems remarkable given that most of the world's demand for MCUs has been and continues to be in Japan where vertically integrated companies typically make the devices for use in their own products.

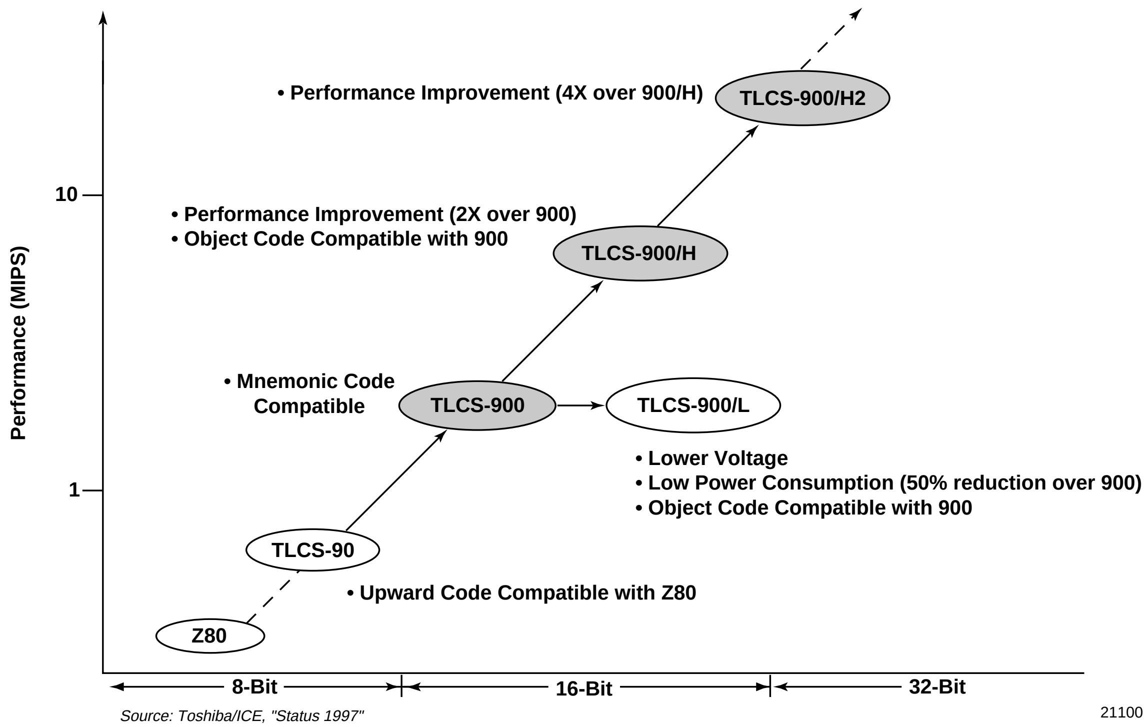


Figure 6-22. TLC-900 Core Roadmap

1996 Rank	MCU* Leaders	1995 Percent Marketshare	1996 (EST) Percent Marketshare
1	Motorola	19	18
2	TI	8	10
3	NEC	11	10
4	Hitachi	8	9
5	Intel	8	9
6	Mitsubishi	9	8
7	Lucent	5	6
8	Matsushita	6	5
9	Toshiba	5	5
10	Philips	5	5
	Others	16	15
	Total	$10.7B	$11.6B

*Includes DSP sales

Source: ICE, "Status 1997" 19233F

Figure 6-23. Leading MCU Suppliers*

Selected highlights from microcontroller vendors are listed below.

- AMD added two additional parts to its E86 family of embedded devices: the Am186ES and Am188ES microcontrollers. Based on industry-standard x86 architecture, the ES series is 80C186- and 80C188-compatible and suited for applications such as disk drives, hand-held and desktop terminals, set-top controllers, and a variety of telecommunication applications.

- Atmel broadened its flash-based MCU line with a second-generation of devices that offer in-system-programmable flash memory. The first of the new S series features a 24MHz device with 8Kbytes of on-chip flash memory.

- Microchip Technology unveiled its first 8-pin one-time-programmable (OTP) microcontroller family. The series packs the company's RISC-based architecture into 8-pin PDIP and SOIC packages, creating very small 8-bit MCUs. In addition, Microchip launched its first family of 8-bit flash microcontrollers in 3Q96.

- Mitsubishi unveiled its ultra-low power 16-bit MCU core in 3Q96. The device, which saves power by dissipating only 18mW of power at 2.7V, is targeted for low-power designs including wireless handsets, and automotive air bag and suspension systems.

- Motorola updated its 8-bit 68HC11 MCU architecture with the creation of a source-code-compatible 16-bit family, the 68HC12. The new family will provide a performance growth path for the company's current 8-bit customers. The HC12 is Motorola's second microcontroller architecture. It will continue to support the 68HC16 family, which is a higher performance part, but is not software-compatible with the HC11 family.

- Motorola announced it would split its Advanced Microcontroller Division (AMCU) into two divisions because of continued growth. The Custom Microcontroller Solutions Division will focus on the 68HC11 and 68HC12 families, and the AMCU division will focus on the MPC500, 68300, and 68HC16 products.

- NEC sampled a 16-bit MCU with 128Kbytes of on-chip flash memory in 4Q96. Designed primarily for multi-feature cellular phones, the device integrates high-capacity flash memory and RAM and eliminates the need for external memory, thereby reducing the system size, cost, and extending battery life. Sample pricing was set at approximately $45.

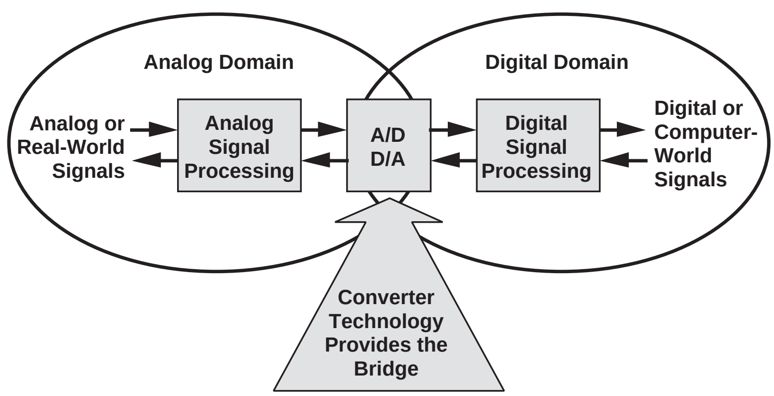
- Sharp introduced its LH77790 embedded microcontroller, a low-cost, low-power, high-performance solution for portable electronic devices including point-of-sales terminals, 2-D barcode scanners, GPS systems, and communications devices.

- Toshiba introduced its MCU with on-board flash memory in 4Q96. The company claims its low-power 16-bit flash MCU (64Kbyte of flash memory) will provide high reliability, low power dissipation, high security, high system speed, and quick time to market all at a low cost. Initial pricing was set at $18.20 in volume quantities.

- Set to enter its 20th year of production, Zilog introduced a family of OTP microntrollers built on the company's Z80 architecture. The new devices include low-voltage versions and are used in applications such as smoke detectors, electronic games, IR remote controls, appliances, and motor controls.

THE DIGITAL SIGNAL PROCESSOR MARKET

Digital signal processing (DSP) is a segment of the IC industry where advanced digital and analog technologies merge (Figure 6-24). The typical function of the DSP device is to perform real-time processing of a digitized analog signal, changing that signal using arithmetic algorithms, and then passing the signal on. The process is very math intensive and quite complicated. In fact, finding competent DSP designers and programmers is often a challenge for many DSP manufacturers.



Source: Analog Devices/ICE, "Status 1997" 16918

Figure 6-24. Real-World Signal Processing

DSP consumption soared in 1995 and again in 1996 mainly because applications emerged that were not envisioned even a few years ago. From a high-end workstation-only environment, DSPs have moved into many common consumer applications. This is particularly true in the communications markets. Lower pricing—accomplished through die shrinks, low-cost packages, and streamlined testing techniques—sparked demand. Displayed in Figure 6-25 is a relative time line showing how DSP devices have emerged in widespread applications as unit prices have declined.

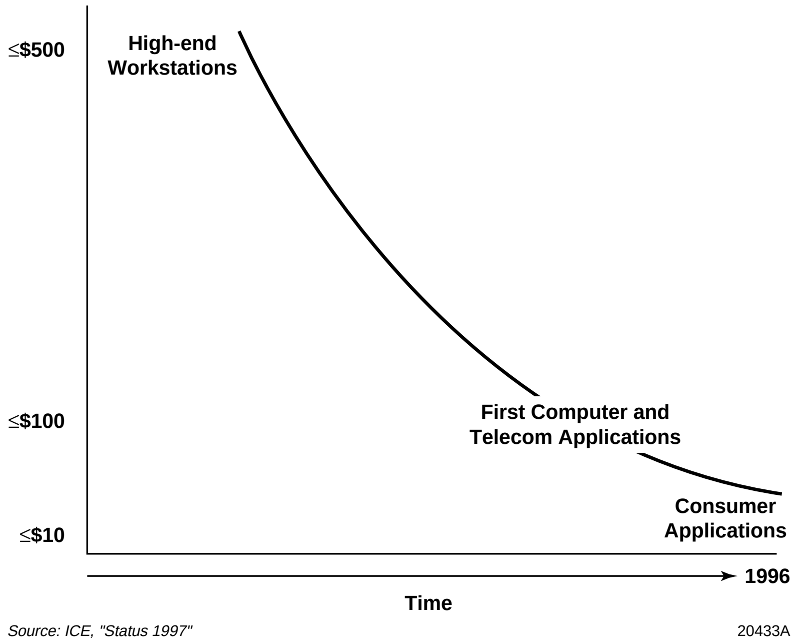


Figure 6-25. As Price Drops, DSP Applications Increase

In 1996, DSP prices ranged from approximately $3 for simple low-end, high-volume devices to several hundred dollars for the most complex, highly integrated devices. Shown in Figure 6-26 are a few examples of how leading DSP vendors are reducing DSP prices.

Company	Product	Type	How Cost is Being Cut
Analog Devices	ADSP-2105 ADSP-2115	16-bit, fixed-point 16-bit, fixed-point	0.6-micron process, optimized chip layout, high yields, packaging
AT&T	DSP1605	16-bit, fixed-point	0.6-micron process, optimized architecture
Motorola	56002	24-bit, fixed-point	0.8-micron process, packaging, test flow
Philips	TriMedia	32-bit, floating-point	Stable mfg. process, 0.35-micron process, packaging
Texas Instruments	TMS320C32	32-bit, floating-point	Reduced on-chip RAM 512 words, 0.7-micron process, three-level metal, plastic packaging
	TMS320C44	32-bit, floating-point	0.7-micron process, plastic packaging, reduced die size for low power consumption

Source: Electronic Business Buyer/ICE, "Status 1997" 20338

Figure 6-26. Selected DSPs are Driving Cost Down

Communication uses represent the dominant DSP application and will likely do so for the next several years (Figure 6-27). Computers represent a significant end use as well and PC suppliers are branching into emerging applications in this arena. For instance, DSP devices are used for image compression in computers, for special effects such as surround sound in audio applications, and for speech recognition and text-to-speech conversion applications. As PCs continue to advance and consumer expectations increase for multimedia capabilities, specialized processors with DSP functionality will become commonplace to enhance the performance of even the most powerful processors. Whether in the home, office, at school, or in mobile applications, DSPs are certain to play a vital role in an increasing number of systems (Figure 6-28).

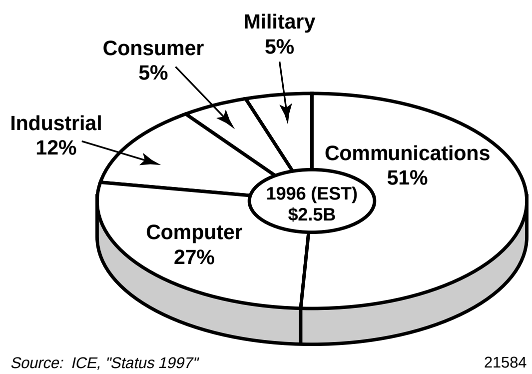


Figure 6-27. DSP Market by Application

Several trends within the industry indicate that DSP devices will become more prevalent in the coming years (Figure 6-29). One trend indicates that DSP devices will make a rapid transition from general-purpose devices to ASIC core-based solutions. For instance, Atmel will license DSP Group's Pine- and OakDSPCores for integration into Atmel's cell and gate array library. This trend toward cored-based application-specific standard products (ASSPs) is putting pressure on DSP vendors to bolster their ASIC capabilities. Figure 6-30 shows that ASSP-based DSPs are the fastest growing segment within the single-chip programmable DSP market.

Additionally, many suppliers including TI, VLSI Technology, LSI Logic, National, and Samsung plan to integrate features of DSP onto MCU devices to further develop their system-on-a-chip technology. Whether through a growing range of applications, die shrinks, low-cost packages, or streamlined testing techniques, many factors are working together to increase the consumption of DSP chips.

The tremendous growth of DSPs—both as stand alone devices and as part of mixed-signal ASICs and multimedia processing engines—placed them near the top of the list of growth areas in the semiconductor industry in 1995 and 1996. Overall, the DSP market grew 73 percent in 1995 and ICE estimates it continued on its strong growth curve (up 42 percent) in 1996 (Figure 6-31).

At Home
- Movies on demand
- Direct satellite television
- Virtual reality games
- Hundreds of cable channels
- Reference book with full-motion pictures
- Dishwashers that sense when dishes are clean then turn off automatically

At the Office
- Hard disk drives that store hundreds of gigabytes
- Voice and data communications simultaneously over the same telephone line
- Desktop videoconferencing with displays from multiple locations
- Intelligent copiers - Copy, then route to appropriate file
- Fast networks - Instant access to information around the world

At School
- Interactive video classrooms that allow teachers to work with students individually
- Learning systems that remember each student's strengths and weaknesses and tailor lesson plans accordingly
- Desktop video clips to explain subjects in detail
- Instant access to library materials

On the Road
- Cellular phones that obey voice commands
- Airport phones that recognize your voice
- Portable wireless fax/modems
- Auto shock absorbers that sense road bumps and cancel them
- Video maps that display your location and the best route to your destination

Source: Texas Instruments/ICE, "Status 1997" 20341

Figure 6-28. DSP Application Explosion

Texas Instruments was the leading producer of DSP devices in 1995 and ICE estimates that it certainly held that lead once again in 1996 (Figure 6-32). TI recognized the impact DSP sales had on its bottom line in 1995 and adjusted product output at different wafer fabs in 1996 to increase the shipment of its DSPs. In addition, the other DSP leaders—Lucent Technologies, Motorola, Analog Devices, and NEC—enjoyed healthy gains in DSP revenues.

A review of DSP highlights from leading vendors during 1996 is provided below.

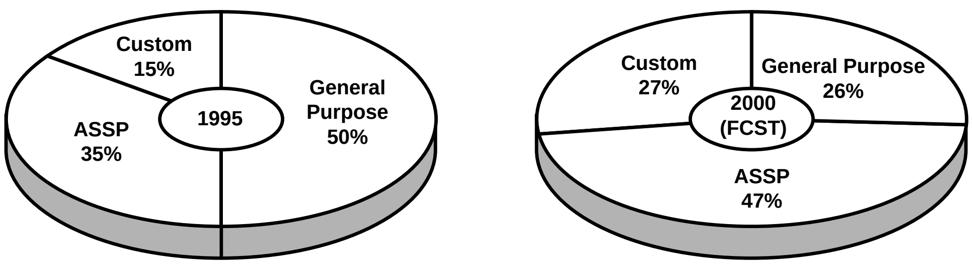
Texas Instruments

As the DSP market and technology leader, Texas Instruments has worked hard to have the complex technology of digital signal processing accepted and understood by the engineering and education communities. In recent years, DSPs have become the biggest contributor to TI's growth. In 1995, approximately 10 percent of TI's sales were from DSPs. In 1996, the DSP portion of TI's semiconductor sales were estimated to be at least 15 percent.

Pricing	Heading lower in U.S., Taiwan, and Europe as makers put more functions on single silicon chip.
Technology	More application-specific devices. Trend is to mix more circuitry – such as MCU – on board with the DSP.
Manufacturing	High-performance is preference. Half-micron (and smaller) processes used to manufacture wide range of fixed-point and floating point models.
Other	Manufacturers offering mixed-signal DSPs that combine digital functions with application-specific analog functions.

Source: ICE, "Status 1997" 20432

Figure 6-29. DSP Trends



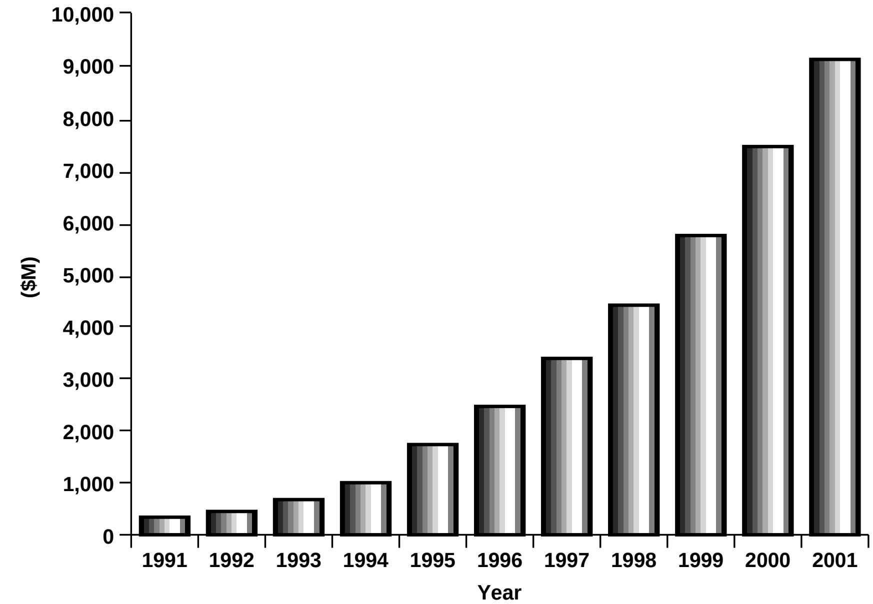
Source: Forward Concepts/ICE, "Status 1997" 21610

Figure 6-30. ASSPs to Dominate Single-Chip DSP Market in Future

TI offered 100 MIPS performance from it 16-bit fixed-point programmable DSP that it introduced in 2H96. Based on the company's 0.25μm, four-layer-metal CMOS process, the 3.3V device combines the company's 320LC54X DSP core and a large amount of SRAM (Figure 6-33). At 100 MIPS, it becomes possible for systems to perform a variety of processing functions on a single chip, which, until now, required several DSPs.

TI also unveiled the first two of a planned series of DSP products that are aimed specifically at the set-top box market. The devices integrate a 16M SDRAM as well as a 32-bit ARM RISC processor, an MPEG-2 video decoder, an advanced graphics accelerator, and decryption modules on a single chip. The AV7100 is specifically designed for the digital satellite system (DSS) while the AV7110 is designed with algorithms for the digital video broadcast (DVB) standard. Each device will be in volume production in 2Q97 and will initially be priced at under $45 in 100,000-unit quantities.

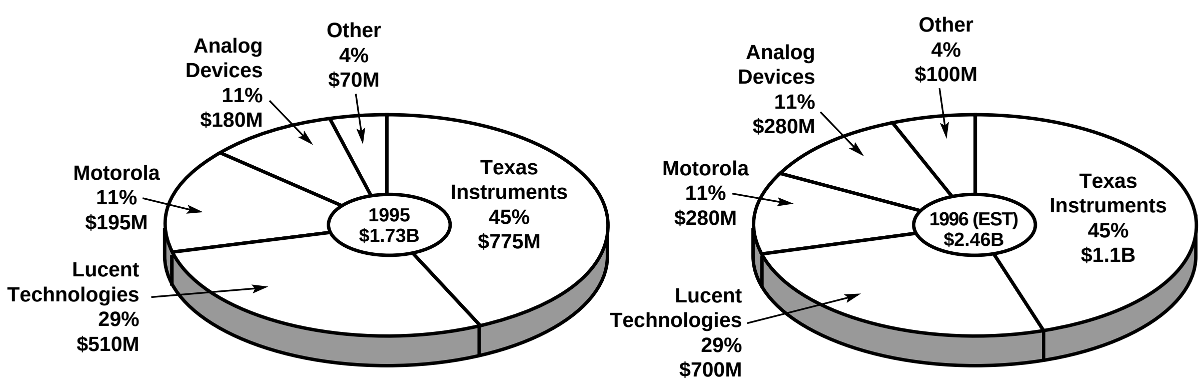
By the year 2001, TI expects ASIC-based solutions to account for 90 percent of its DSP business. TI will differentiate itself in this competitive marketplace by pushing process geometries to deep-submicron (0.18μm) levels for DSP production.



DSP Market ($M)	337	447	674	998	1,729	2,460	3,380	4,400	5,735	7,440	9,110

Source: ICE, "Status 1997" 20435B

Figure 6-31. DSP Market Trends ($M)



Source: Forward Concepts/ICE, "Status 1997" 14503R

Figure 6-32. Worldwide Sales of Single-Chip DSPs

To support its DSP business (and to distance itself from the ailing DRAM market), TI announced that more than 90 percent of the company's $1.8 billion-plus semiconductor capital spending planned for 1996 was for non-DRAM products.

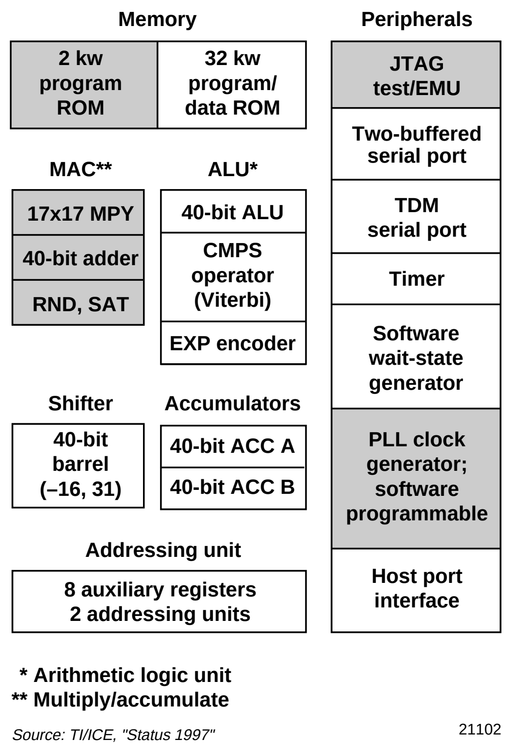


Figure 6-33. TI's TMS320LC548 Fixed-Point DSP (100MIPS, 3.3V, 16-bit)

Lucent Technologies

While Lucent Technologies' DSP devices are highly regarded on the merchant market, a large portion of the DSPs the company produces goes into its own communications products. Lucent produced its first single-chip DSP implementation in 1979 and has since developed its DSP expertise by supplying its internal needs. Lucent's DSP efforts are focused on maintaining its leadership role in telecommunications applications, including cellular phones, modems, and digital answering machines.

In September 1996, Lucent announced its 100-MIPS digital signal processor. Based on a 0.35μm CMOS process, the 16-bit fixed-point DSP1620 crunches 120 million instructions per second. It is scheduled to go into production in 1Q97.

Motorola

Like Lucent Technologies, Motorola developed its expertise in DSP technology by supplying the needs of its own communications systems business. Motorola introduced the DSP566xx core series and the first two offerings in the family, the DSP56602 and DSP56603 that are targeted for cellular phones and other personal communication devices. The family is characterized for lower voltages, ranging from a high of 3.3V to a low of 1.8V. Architecturally, the new family shares the same 24-bit instruction set as the 563xx family (rated for 3.3V and above) introduced in 4Q95, but offers a narrower 16-bit internal data path.

Following the trend of leading DSP suppliers, Motorola expanded its DSP-ASIC efforts. The company is eyeing cores from DSP Group as well as other alternatives.

Analog Devices

Analog Devices Inc. (ADI) continued to aggressively pursue TI's floating-point DSP business with its Sharc line while exploiting its vast experience in codecs and other signal-processing components. In 2Q96, ADI completed testing of its Sharc DSPs for high-grade commercial application conditions and began a manufacturing plan that the company believes will provide a big increase in DSP output for 1997 versus 1996.

ADI introduced a DSP in 4Q96 that it labeled a real-time music engine. The ADSP-2106x is a Sharc DSP-based media accelerator and is among the industry's fastest floating-point DSPs. When combined with powerful music synthesis software, the result is a wide range of musical sounds and effects that today requires numerous, expensive processors and large pieces of equipment.

Meanwhile, ADI opened its AD21xx 16-bit fixed-point DSP architecture to other companies. It licensed Acer Laboratories, AMD, Aspec Technology, and Mentor Graphics to use the DSP core for embedded applications in ASICs.

A sampling of DSP families from several vendors is shown in Figure 6-34. Other highlights from the DSP market segment are provided below.

- DSP Group, the company whose Pine and Oak DSP designs have been licensed by numerous vendors including LSI Logic, VLSI Technology, GEC Plessey, Samsung, and NEC, announced plans for its next-generation core. The Palm DSP core, which debuted in 2H96, is intended to be manufactured using a 0.35μm CMOS process and will offer performance of 100 MIPS, compared with 40 MIPS for the Oak.

- Philips announced its "Big Cats" family of video graphics controller (VGCs) chips. The devices will work along side of (and independent of) the multi-function TriMedia DSP architecture that the company debuted in mid-1996.

Company	Family	Data Width	Program Width	Native MIPS (1)	Notes
3Soft Corporation	M320C25	16 bits	16 bits	15 MIPS	Provided as synthesizable HDL
Adaptive Solutions	CNAPS	16 bits	64 bits	1,280 MIPS	Scalable 2-chip SIMD multiprocessor
Analog Devices	ADSP-21xx	16 bits	24 bits	20 MIPS	No visible pipeline effects
	ADSP-216x	16 bits	24 bits	25 MIPS	Two serial ports, timer, power-down mode
	ADSP-217x	16 bits	24 bits	33 MIPS	Host port, two serial ports, power-down mode
	ADSP-2181	16 bits	24 bits	33 MIPS	Host port, two serial ports, DMA
	ADSP-21msp5x	16 bits	24 bits	26 MIPS	Integrated 16-bit A/D and D/A
	ADSP-21020	32 bits	48 bits	33 MIPS	Two off-chip memory buses
	ADSP-2106x	32 bits	48 bits	40 MIPS	Strong support for multi-processor designs
Lucent Technologies	DSP16xx	16 bits	16 bits	50 MIPS	Flash memory versions available for prototyping
	DSP32xx	32 bits	32 bits	20 MIPS	Intended for PC multimedia applications
Clarkspur Design	CD2400	16 bits	16 bits	30 MIPS	Simple, very compact architecture
	CD2450	16-24 bits	16 bits	50 MIPS	Adjustable data word width
DSP Group	PINE	16 bits	16 bits	30 MIPS	Provided as synthesizable HDL and layout
	OAK	16 bits	16 bits	40 MIPS	Provided as synthesizable HDL and layout
	PALM	N/A	N/A	100 MIPS	—
IBM Microelectronics	MDSPxxxx	16 bits	24 bits	25 MIPS	Intended for PC multimedia applications
Motorola	DSP561xx	16 bits	16 bits	30 MIPS	Integrated 16-bit A/D and D/A
	DSP5600x	24 bits	24 bits	33 MIPS	24-bit data word
	DSP9600x	32 bits	32 bits	20 MIPS	Dual external memory buses
NEC	uPD7701x	16 bits	32 bits	33 MIPS	Two serial ports, one parallel port, 4-bit I/O lines
SGS-Thomson	D950-CORE	16 bits	16 bits	40 MIPS	Coprocessor interface provided
Tensleep Design	A/DSC321	16 bits	16 bits	12.5 MIPS	Similar to TMS320C25
	A/DSC421	16 bits	16 bits	25 MIPS	Similar to TMS320C25
	A/DSC521	16 bits	16 bits	30 MIPS	Similar to TMS320C25
Texas Instruments	TMS320C1x	16 bits	16 bits	8.8 MIPS	First commercially successful DSP
	TMS320C2x	16 bits	16 bits	12.5 MIPS	TI's second-generation fixed-point DSP
	TMS320C3x	32 bits	32 bits	30 MIPS	Low-cost versions compete with fixed-point DSPs
	TMS320C4x	32 bits	32 bits	30 MIPS	Intended for multiprocessor applications
	TMS320C5x	16 bits	16 bits	50 MIPS	TI's latest fixed-point family
	TMS320C80	32/64 bits	8/16/32 bits	250 MIPS	Contains four fixed-point DSPs plus a RISC CPU
Zilog	Z89Cxx	16 bits	16 bits	20 MIPS	Available with a microcontroller on one chip
Zoran	ZR3800x	20 bits	32 bits	33 MIPS	20-bit data word is unique, intended for audio

[1]Native BIOS for fastest member of family

Source: Integrated System Design/ICE, "Status 1997"

21103A

Figure 6-34. Sampling of Digital Signal Processors and Cores

- Pixel Magic, a subsidiary of Oak Technologies, introduced its DSP engine in 4Q96 that is capable of performing a claimed one billion operations per second (1 BOPS or 1,000 MIPS). The PM-44 is the initial member of a planned family of DSPs from Pixel Magic. The device is designed to handle color or monochrome data of any pixel depth, which makes it ideal for imaging applications in digital office equipment such as scanners, fax machines, laser printers, and digital copiers.

- SGS-Thomson and Samsung signed a licensing agreement for DSP core technology. SGS licensed Samsung to use SGS' D950 16-bit fixed-point DSP core, which was introduced in 2Q95. The device, produced using 0.5μm technology, is capable of 40 MIPS performance at 25ns. Both companies can produce stand-alone DSPs based on the core, but Samsung is expected to use the technology to develop new products. SGS will have second-source rights to any products developed by Samsung based on the core.

- VLSI Technology introduced its VVS3010 development chip that combines a DSP Group Pine DSP core with extensive peripherals plus an integrated D/A and A/D codec.

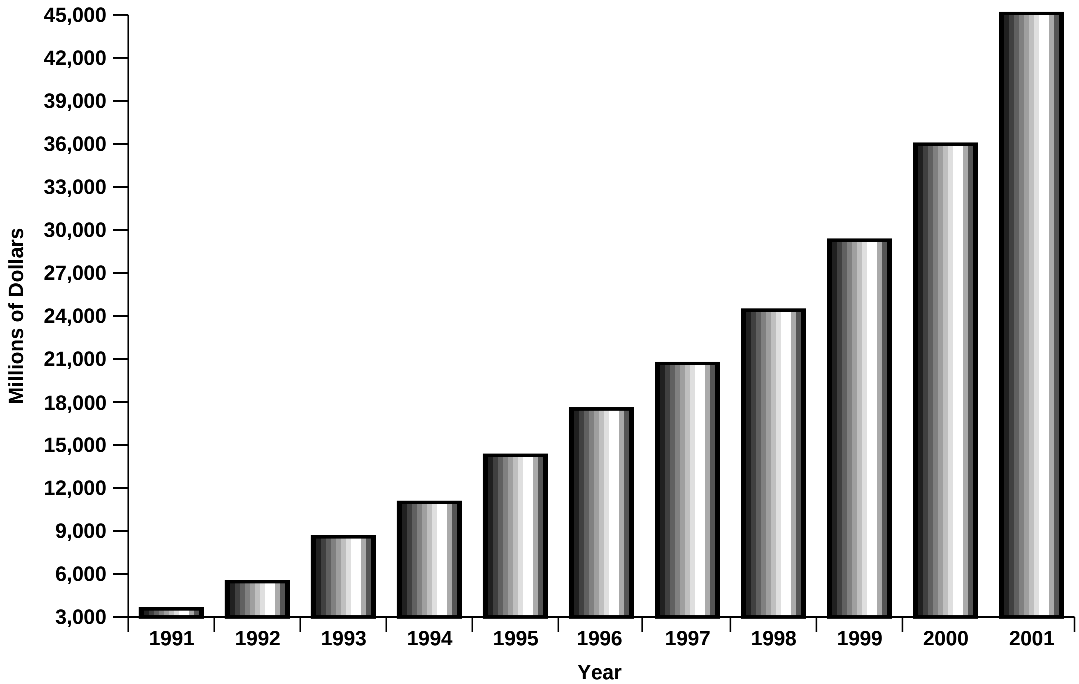
- Zilog unveiled its Z893X3 family of DSPs that targets applications including credit card readers, caller IC, motor control, security systems, and telephony. The series was designed to break down the barriers between DSPs and microcontrollers by including a set of peripherals usually associated with MCUs.

THE MPU MARKET

Microprocessors are the basic arithmetic logic of a computer. According to the Semiconductor Industry Association (SIA) definition, they execute external instructions and perform system control functions. These include the following: instruction decoder, arithmetic logic unit, registers, and additional support logic to support an assembly language. The architecture is optimized for general purpose data processing and the assembly language instructions are retrieved from external memory.

Figure 6-35 shows annual MPU market trends from 1991 through 1996, and ICE's forecast through the year 2001. Revenues increased from $3.6 billion in 1991 to an estimated $17.5 billion in 1996. This represented a cumulative average annual growth rate (CAGR) of 37 percent. Market growth during these years was largely based on sales of 32-bit x86 MPUs.

ICE forecasts the worldwide MPU market will continue on a solid growth curve through the year 2001. The average annual growth rate is forecast to be 21 percent. This translates into market growth from $17.5 billion in 1996 to $45.1 billion in 2001. The demand for more powerful processors in the high-end computer market will continue to drive the MPU market.



MPU Market ($M)	3,565	5,460	8,590	10,995	14,280	17,510	20,685	24,405	29,285	35,980	45,100

Source: ICE, "Status 1997"

18642G

Figure 6-35. Annual MPU Market

MPUs are available in 8-, 16-, 32-, and 64-bit designs. The largest market segment is the 32-/64-bit MPU segment, which will be the focus of this discussion. It accounted for 96 percent of the MPU market in 1995 and 97 percent of the total MPU market in 1996 (Figure 6-36). As will be discussed later in this section, CISC-based architectures continue to dominate the 32-/64-bit MPU market.

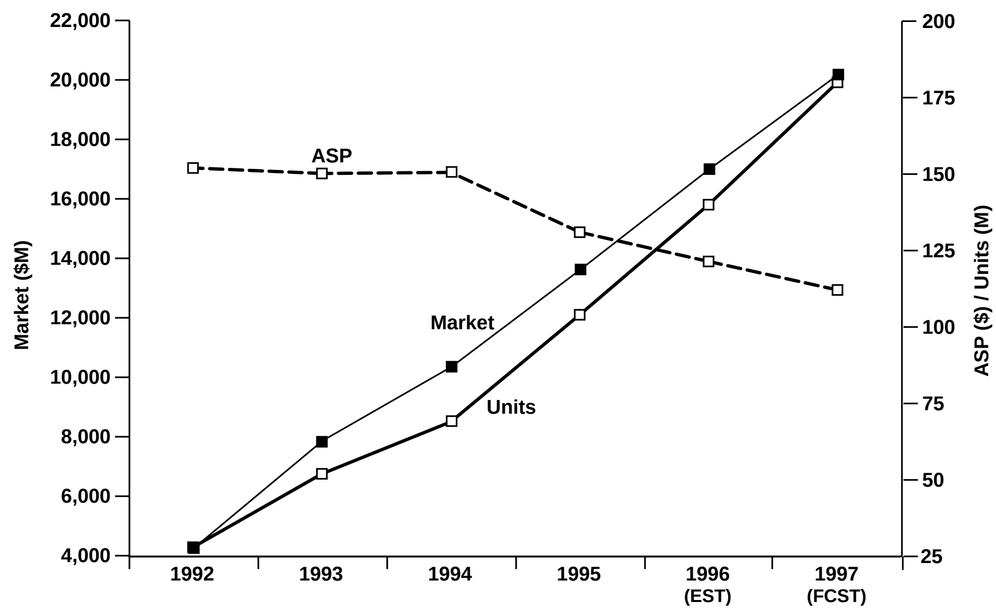
Figure 6-37 shows market growth, unit shipments, and ASPs of the 32-/64-bit market over the past several years and ICE's forecast for 1997. It is interesting to note that from 1992 through 1994, increased competition more than doubled the number of units shipped annually and kept average selling prices essentially flat. In 1996, ICE estimates that 32-/64-bit MPU shipments increased 35 percent to 140 million units, while the ASP slid seven percent to $121.43.

Leading 32-bit MPU suppliers and their sales for 1995 and 1996 are shown in Figure 6-38. In terms of market size, Intel, which has dominated the 32-bit market for several years, continued to dwarf its competition. In fact, ICE does not anticipate any company putting a competitive hurt to Intel during the next five years. By introducing new versions of its Pentium and Pentium Pro chips that are both faster and less expensive than competitors' products, Intel continued to tighten its grip on the MPU market.

	1995		1996 (EST)	
	$M	Percent Marketshare	$M	Percent Marketshare
8-bit	185	1%	145	1%
16-bit	470	3%	365	2%
32-/64-bit	13,625	96%	17,000	97%
32-bit CISC	11,995	84%	15,175	87%
32-bit RISC	1,630	12%	1,825	10%
Total MPU	14,280	100%	17,510	100%

Source: ICE, "Status 1997" 19269E

Figure 6-36. The 1995 and 1996 MPU Markets



	1992	1993	1994	1995	1996 (EST)	1997 (FCST)
Market ($M)	4,255	7,870	10,355	13,625	17,000	20,180
Units (M)	28	52	69	104	140	180
ASP ($)	152.00	150.20	150.50	131.00	121.43	112.11

Source: ICE, "Status 1997" 20304B

Figure 6-37. 1992-1997 32-/64-bit MPU Market Trends

Competitors, including AMD, Cyrix, Hewlett-Packard, IBM, Motorola, SGS-Thomson, TI, and a growing group of Asia-Pacific suppliers (Samsung, Winbond, and Macronix among others) have tried to steal marketshare from Intel, but have met with no success. For most of these companies, competing against Intel in 1996 was a very difficult matter (Figure 6-39). Intel, which provided approximately 85 percent of the MPUs for the lucrative desktop PC market in 1996, continued to invest heavily in R&D and new fab capacity for its future processors.

1996 Rank	Company	1995	1996 (EST)
1	Intel	10,370	14,175
2	IBM	740	695
3	AMD	755	450
4	Motorola	466	410
5	TI	295	280
—	Others	999	990
	Total	13,625	17,000

Source: ICE, "Status 1997" 16915L

Figure 6-38. 32-/64-bit MPU Sales Leaders ($M)

- **NexGen absorbed into AMD**
- **Cyrix and IBM Microelectronics had difficulty selling 6x86 processors**
  - **SGS-Thomson not yet in volume production of 6x86**
- **AMD struggled to meet K5's per-clock performance goals**
  - **Now working to get clock speed up**
- **Texas Instruments stuck in 486 market**
- **UMC withdrew from x86 market**

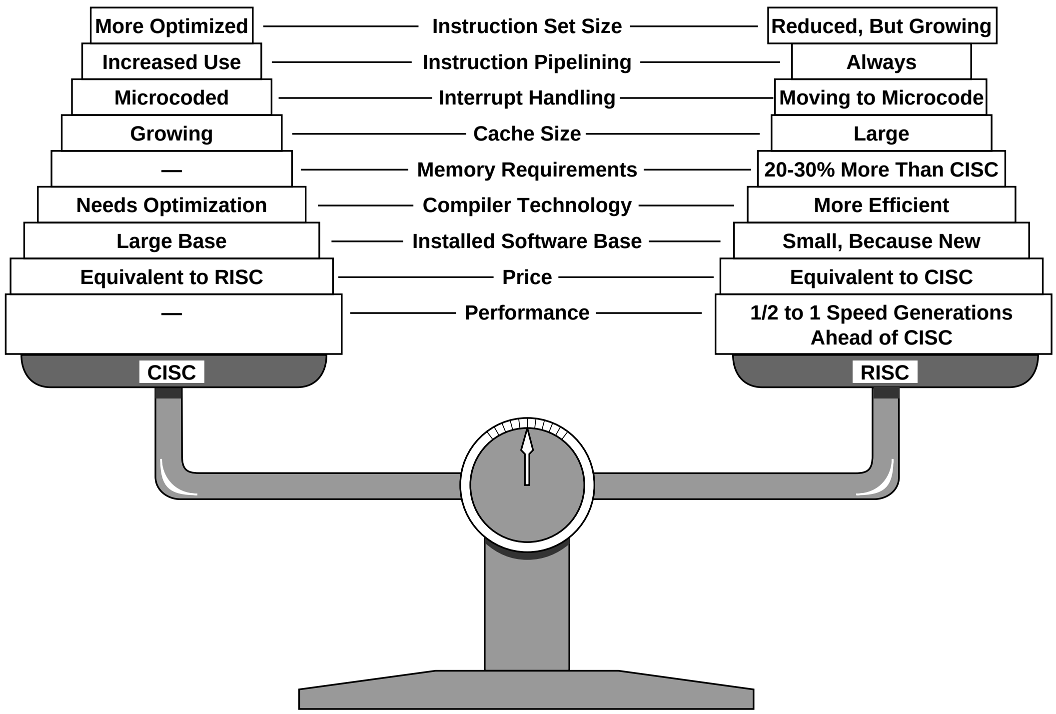
Source: MDR/ICE, "Status 1997" 21625

Figure 6-39. Intel's Competitors Struggle in 1996

CISC versus RISC

The MPU market consists of two main architectures, CISC (complex instruction set computer) and RISC (reduced instruction set computer). The most commonly used, and the greatest number of 8-, 16-, and 32-bit processors are CISC. CISC chips include the complete x86 family (386, 486, Pentium, Pentium Pro) and Motorola's 680x0 line of MPUs. A comparison of the two architectures is shown in Figure 6-40.

Despite the predictions made many years ago that the market for RISC MPUs would surpass the CISC MPU market, ICE believes that will not happen in the foreseeable future. It is true that RISC-based MPUs offer several advantages over CISC devices. In fact, RISC MPUs dominate the performance-minded embedded market. The RISC market will continue to grow through the year 2001. However, that growth will stem from too small of a base for it to become the dominant MPU technology in this decade.



Source: Motorola/ICE, "Status 1997" 21129

Figure 6-40. Characteristics of CISC and RISC MPUs

Figure 6-41 compares the market size and number of unit shipments for CISC and RISC MPUs. As shown, CISC devices dominated both categories in 1995 and 1996.

Figures 6-42 and 6-43 provide an overview of the market size, shipments, and ASP for the leading 32-/64-bit CISC and RISC MPU families in 1995 and 1996, respectively. Anchored by strong growth in the Pentium-class market, the 32-/64-bit market grew 25 percent in 1996. The 486 and Pentium processors shipped nearly equal unit amounts in 1995. However, there was a noticeable and decisive shift to Pentium-class processors in 1996, which led to a 35 percent increase unit shipments. The average selling price of 32-/64-bit MPUs declined seven percent in 1996. The decrease may have been greater had it not been for the Pentium Pro device, which featured an introductory ASP of $750.

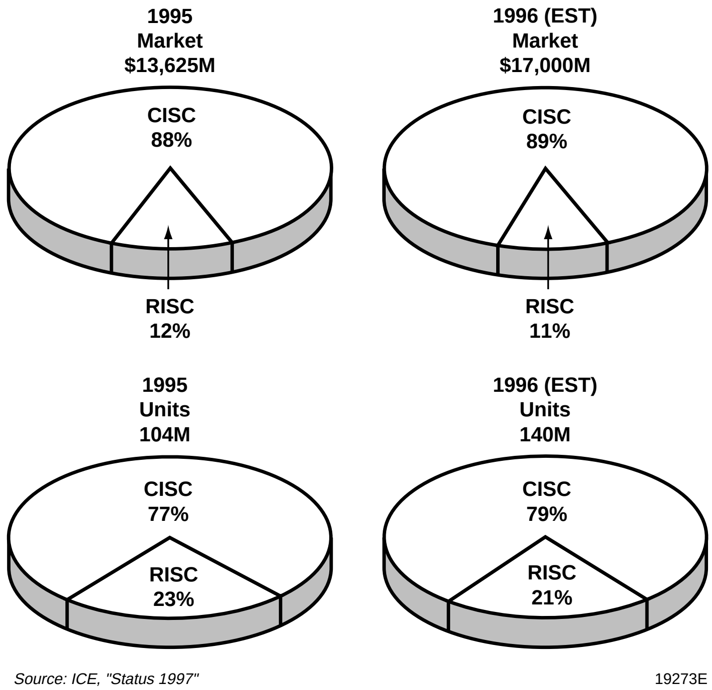


Figure 6-41. 32-/64-bit RISC Versus CISC Comparison

Family	Unit Shipments (M)	ASP ($)	Market ($M)
386	5.6	10.00	56
486	31.8	63.70	2,026
Pentium Class	31.6	298.75	9,440
680X0	11.2	42.23	473
PowerPC	6.5	113.85	740
Other RISC	17.5	50.85	890
Total	104	131.00	13,625

Source: ICE, "Status 1997" 19271D

Figure 6-42. The 1995 32-/64-bit MPU Market

32-bit CISC MICROPROCESSORS

The 1995 and 1996 32-/64-bit CISC market is examined in Figure 6-44. ICE estimates that the CISC segment of the 32-/64-bit MPU market grew 27 percent in 1996 and unit shipments increased 38 percent. In 1995, the majority of CISC MPU shipments were 486 devices. However, that quickly changed during 1996. ICE estimates that Pentium-class devices represented 64 percent of the 110 million CISC MPU shipments. Also, ICE estimates the ASP of 32-/64-bit CISC MPUs declined eight percent in 1996.

Family	Unit Shipments (M)	ASP ($)	Market ($M)
386	4.0	7.00	28
486	27.0	28.00	756
Pentium Class	70.0	180.86	12,660
Pentium Pro	2.0	750.00	1,500
680X0	7.0	33.00	231
RISC	30.0	60.83	1,825
Total	140.0	121.43	17,000

Source: ICE, "Status 1997" 20305B

Figure 6-43. The 1996 32-/64-bit MPU Market (EST)

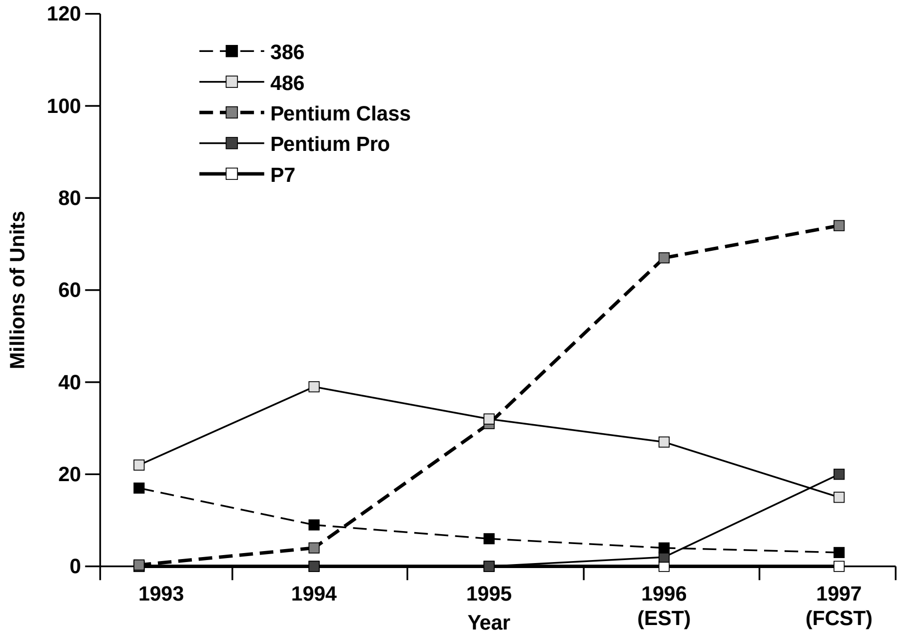
	1995	1996 (EST)
Total Market ($M)	11,995	15,175
Total Units (M)	80	110
ASP ($)	149.95	137.95
CISC Unit Shipments		
386	7%	3%
486	40%	25%
Pentium Class	39%	64%
Pentium Pro	—	2%
680X0	14%	6%

Source: ICE, "Status 1997" 19272E

Figure 6-44. The 32-/64-bit CISC MPU Market

Shown in Figure 6-45 are annual unit shipments of several x86 MPU generations beginning in 1993 and shows ICE's forecast for 1997. It should be noted that MPU devices from Intel's competitors are classified by performance rather than by product name. As an example, the Cyrix/IBM 5x86 and AMD's AM586 device are included in 486 shipments. Meanwhile, the Cyrix 6x86 is included in the Pentium-class category.

ICE believes that 1997 or 1998 will be the year for peak shipments of Pentium-class devices (depending on Intel's strategy at that time). Quick ramp up of the Pentium Pro line will make it the next most widely shipped processor. ICE does not anticipate Pentium Pro (and derivative) processors shipments peaking until after the year 2000.



	1993	1994	1995	1996 (EST)	1997 (FCST)
386	17	9	6	4	3
486	22	39	32	27	15
Pentium Class	0.3	4	31	70	96
Pentium Pro	—	—	—	2	20
Total x86 Units (M)	39	52	69	103	134

Source: WSTS/ICE, "Status 1997" 21533A

Figure 6-45. x86 Unit Shipments by Generation

Activities and highlights of CISC market suppliers during 1996 are summarized in the paragraphs below.

Intel

Intel has long been the world's leading supplier of microprocessors and continues to dominate this market. Intel's first MPU product was introduced in 1971. The 4004 had 2,300 transistors. Since then, Intel increased the number of transistors per processor by nearly 40 percent per year through its Pentium Pro generation (5.5 million transistors, CPU only—21 million transistors including separate level-2 cache). When plotted logrithmically, the number of transistors has increased along a steadily sloping line during the past 25 years (Figure 6-46).

While it has a storied past, Intel's plans for the future are focused on the Pentium Pro, which continues the legacy of the x86 family of processors. A brief review of Intel's x86 MPU development history is shown in Figure 6-47.

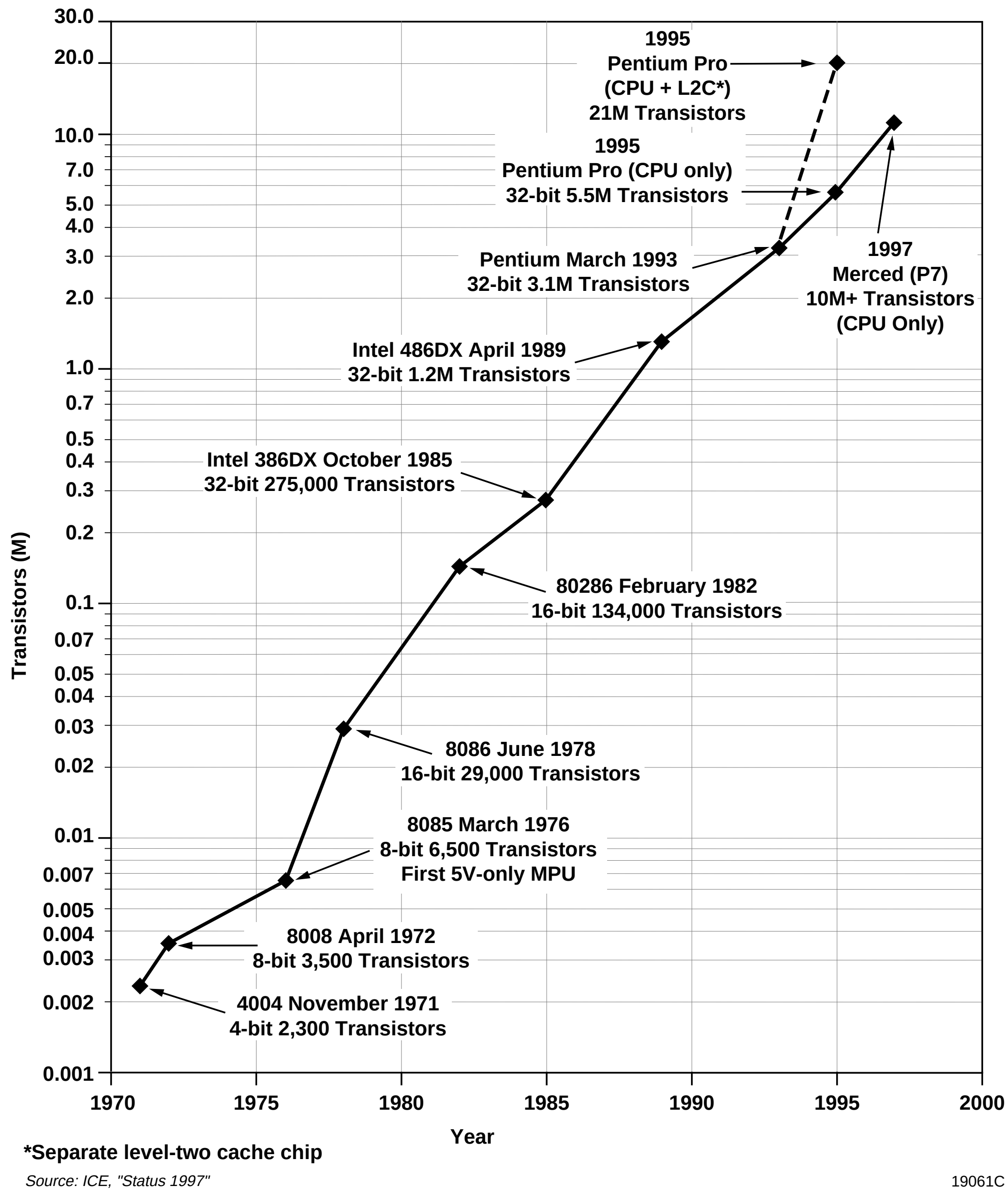


Figure 6-46. Intel MPU Introduction Dates

As shown in Figure 6-48, the transition to Pentium Pro will be well suited for the much heralded Windows NT software environment that is initially targeted for business applications. Figure 6-49 provides a glimpse of how Intel planned to use its Pentium Pro processors in the 1996 market for home-based PCs.

During the first half of 1996, Intel introduced its multimedia extension (MMX) technology for its MPUs. MMX provides all PCs with a baseline for performing multimedia functions such as video conferencing and the capability to display full-motion video with stereo sound. It does this using

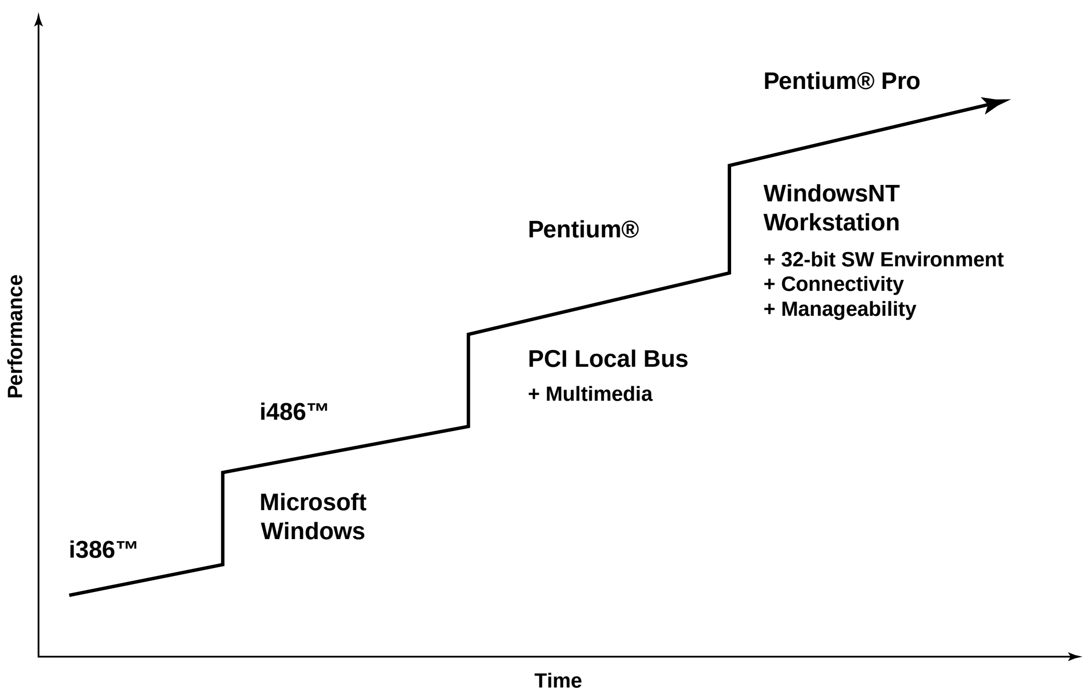
15 percent less processing power than a standard (non-MMX) Pentium (Figure 6-50). The company plans to incorporate MMX across its entire line of Pentium and Pentium Pro microprocessors. The first device to use MMX will be the Pentium P55C.

Intel Code: Other Names:	P2 286	P3 386	P4 486	P5 Pentium	P6 Pentium Pro	P7 Merced
Start of Design Work	1978	1982	1986	1989	1990	1993
Formal Introduction	Feb. 1982	Oct. 1985	Apr. 1989	Mar. 1993	Q3 1995	1997 or 1998*
Volume Shipments	1983	1986	1990	1994	1996	1998 or 1999
Number of Transistors	134,000	275,000	1.2 million	3.1 million	5.5 million	10+ million
Initial MIPS	1	5	20	100	250	500*
Peak Sales Year	1989	1992	1995	1997*	1999*	2002*

* Estimates

Source: Business Week/ICE, "Status 1997" 20309C

Figure 6-47. Intel's MPU Development History



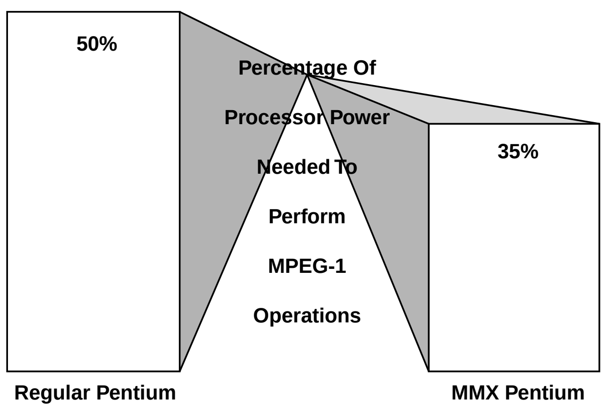
Source: Intel/ICE, "Status 1997" 21105

Figure 6-48. Intel's Next Transition

System Price	1Q96	2Q96	3Q96	4Q96
Performance >$3.0K	PP-166	PP-166	PP-200	P55C PP-200
Segment 4 $2.5-3.0K	PP-166	PP-166	PP-200	PP-200
Segment 3 $2.0-2.5K	PP-150	PP-166 PP-150	PP-166	PP-200 PP-166
Segment 2 $1.5-2.0K	PP-133 PP-120	PP-150 PP-133	PP-150 PP-133	PP-166 PP-150
Segment 1 $1.2-1.5K	PP-100 PP-75	PP-120 PP-100	PP-120	PP-133 PP-120

Source: Intel/ICE, "Status 1997" 21106

Figure 6-49. Intel's Home Processor Roadmap



Source: Intel/ICE, "Status 1997" 21107

Figure 6-50. MMX: Less Power, More Performance (MMX Cuts CPU Overhead)

Beyond Pentium Pro

A look at Intel's near-term processor roadmap (Figure 6-51) reveals that a version of the Pentium Pro (code named "Klamath") will be introduced in 1997 to bring yet a higher level of performance to the mainstream PC market. Klamath will be a CMOS, single-chip device, rather than the BiCMOS, two-chip offering for current Pentium Pros. It will initially operate at speeds of 200MHz with later versions expected to reach clock speeds of 266MHz.

Next in line is the Deschutes, which will be introduced in late 1997. The Deschutes, built using Intel's 0.25μm CMOS process, will be a die-shrink version of the Klamath. Clocks speeds of the Deschutes will likely approach 300MHz. A muscle-bound version of the Deschutes (code named P68) will follow. Its performance could be as much as 50 percent more than the Deschutes, but the trade-off will be a much larger die size.

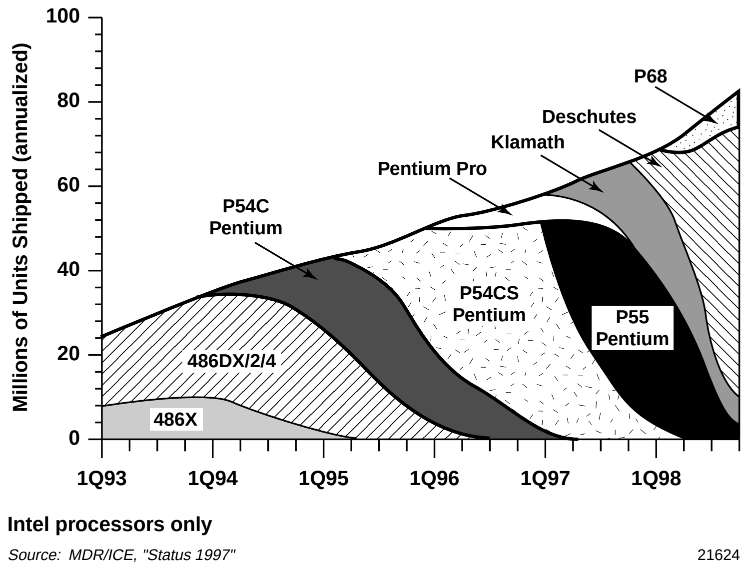


Figure 6-51. Pentium Pro Sets Stage for Klamath, Deschutes

Another chip on Intel's near-term roadmap is the Merced (a.k.a. P7). This device will be the first to use the 64-bit architecture jointly developed by Intel and HP. It is slated to appear in samples in 1998. Whether using its own design teams or combining efforts with HP, Intel is poised to bring many new and powerful MPU devices to market in the next two or three years. Competitors, many whom have only recently brought their Pentium-class chips to the market, will have to work overtime to keep pace with Intel's aggressive strategies.

To reach and maintain its lofty position as world semiconductor leader, Intel has invested billions of dollars on wafer fab capacity and leading-edge processing equipment. It will soon be manufacturing most of its processors using 0.35μm or smaller process technology (Figure 6-52). By reducing the process geometries used to manufacture its MPUs (Figure 6-53), Intel is able to keep its manufacturing costs under control and hamper the efforts of its competitors to gain marketshare.

Advanced Micro Devices

Amid steep price declines in the 486 market and Intel's aggressive moves to transition the microprocessor market to Pentium-class devices, AMD's MPU sales declined substantially in 1996. One indication of the rough battle AMD has endured in the MPU market is given by the percentage of AMD's total company revenue generated from MPU sales (Figure 6-54).

During the first half of 1996, AMD shipped its long-delayed K5 CPU in 75MHz and 90MHz versions. In 2Q96, AMD announced a 100MHz version of the device. AMD delivered 120MHz and 133MHz versions of its devices in 4Q96, and hoped to ship a 150MHz version in 4Q96. In moving to the mid-100MHz speed range, AMD placed itself closer to the "sweet spot" of the industry.

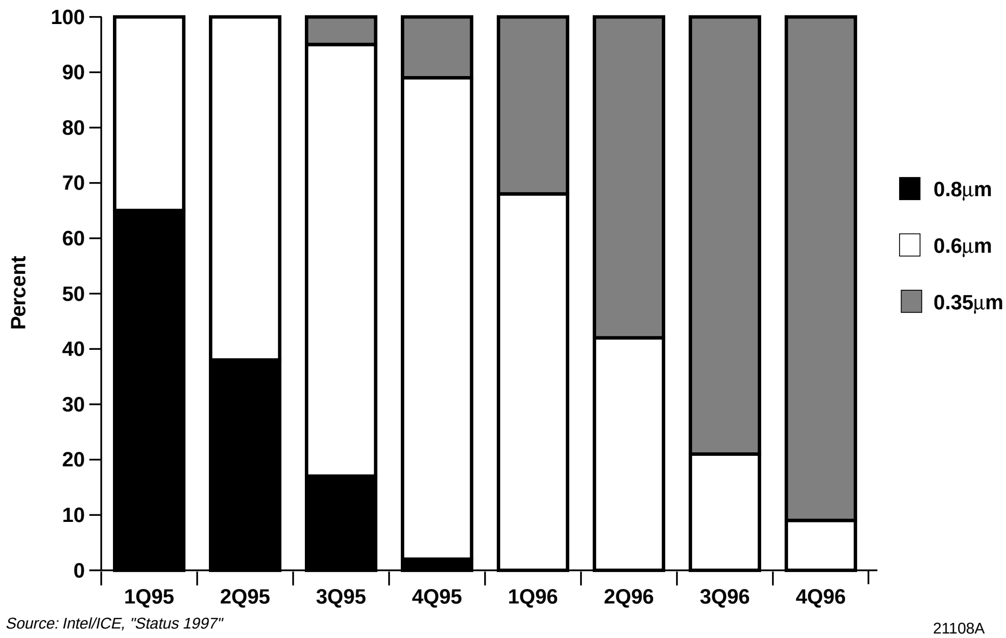


Figure 6-52. Intel's Microprocessor Capacity by Technology

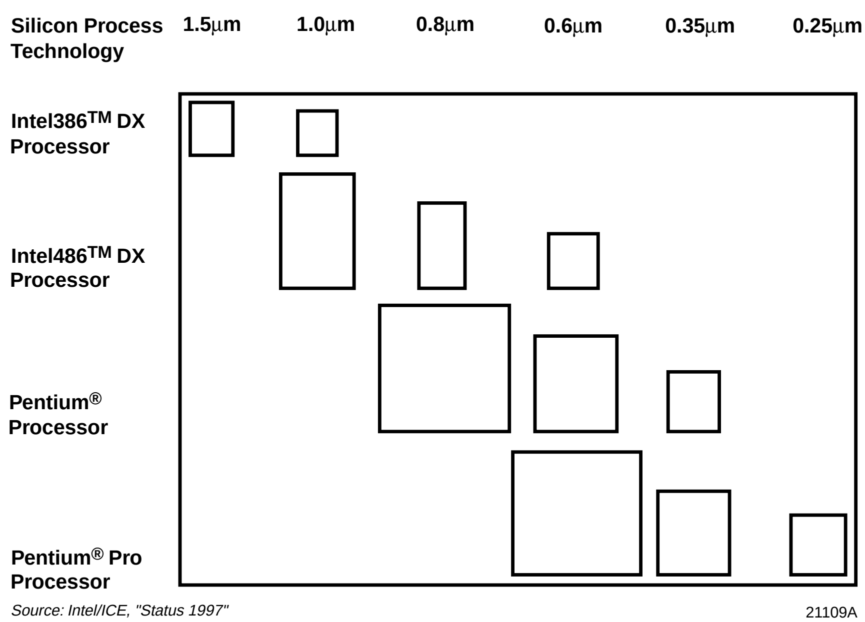


Figure 6-53. Intel's MPU Process Technology Roadmap

However, as noted earlier, AMD struggled to meet the K5's per-clock performance goals it initially scheduled. It hoped to ship three million K5s in 1996. In 3Q96, K5 sales totaled 500,000 units, which provided little relief for AMD's sagging MPU business.

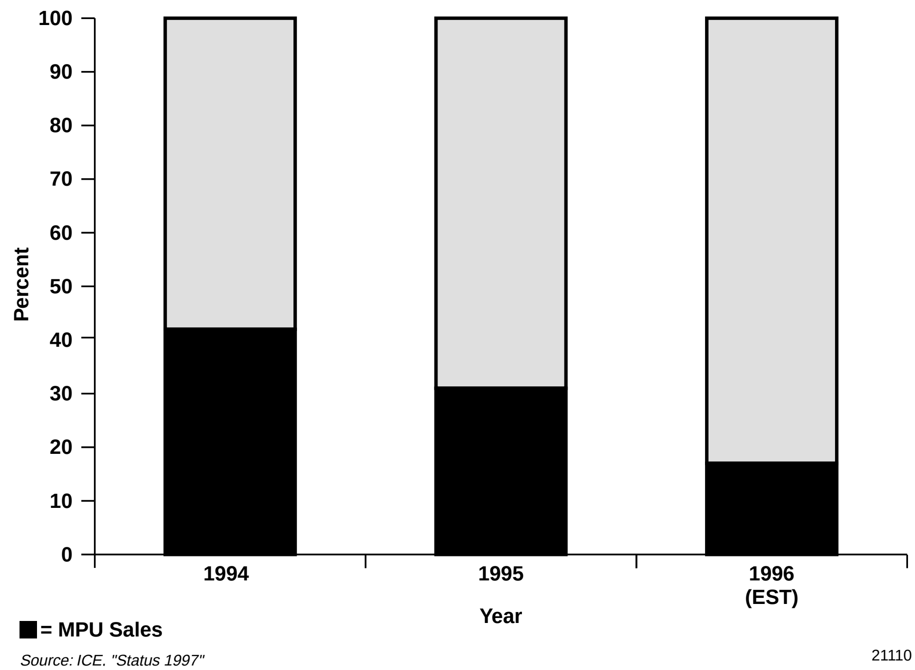


Figure 6-54. AMD's MPU Sales as a Percent of Total Revenue

The biggest key to AMD's return to profitability will be its ability to bring the K6 processor to market in a timely manner. The K6 is based on NexGen's Nx686 design and targets Intel's Klamath performance (Figure 6-55). The K6 will include a Pentium pinout, MMX compatibility, and enlarged caches. K6 samples started to ship in 4Q96 (December) and production is slated for 2Q97 if everything goes as smoothly as planned. If the K6 can perform as promised, AMD may be able to reclaim its position as a solid x86 competitor. The wait, however, may be agonizing.

Cyrix

Cyrix has participated in the x86 MPU market for several years. Its sales, however, have remained relatively small because of its inability to obtain adequate fab capacity until it inked an agreement with IBM in the early 1990's. Since September 1993, IBM has supplied about 60 percent of Cyrix's MPU needs. In 1996, the two companies agreed to extend their relationship, which provides Cyrix with additional wafer processing capacity on a foundry basis through December 1997.

Much like AMD, Cyrix needs healthy MPU sales in order to be a stable company. The firm hoped its 6x86 would reverse its financial struggles. However, the device took a long time to come to market and as a result, Cyrix's 1996 revenues dropped considerably (down 40 percent through the first three quarters of 1996). A review of Cyrix's planned 6x86 ramp schedule is shown in Figure 6-56.

	AMD-K5	AMD-K6	Intel P55C	Pentium Pro
L1 Cache	16K instr 8K data	32K instr 32K data	16K instr 16K data	8K instr 8K data
MMX?	No	Yes	Yes	No*
Out-of Order Execution?	Yes	Yes	No	Yes
Max Clock	100MHz	180+MHz	200MHz	200MHz
Voltage	3.3V	~2.9V	2.5V	3.3V
Transistors	4.3 million	8.8 million	4.5 million	5.5 million
IC Process	0.35µm	0.35µm	0.28µm	0.35µm
Metal Layers	3M	5M	4M	4M
Die Size	181mm^2	180mm^2	140mm^2	196mm^2
Production	Now	1H97	1H97	Now

***Klamath, a single-chip version of the Pentium Pro, will feature MMX technology.**

Source: MDR/Vendors/ICE, "Status 1997" 21738

Figure 6-55. Comparison of AMD and Intel MPUs

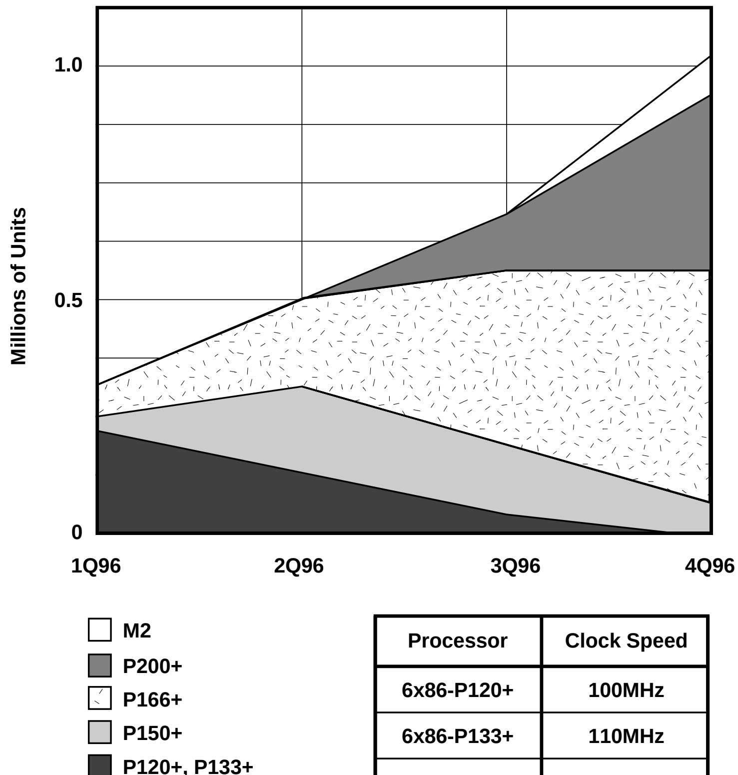
Cyrix's goal was to sell five million of its 6x86 (also called M1) MPUs in 1996. Actual output fell well short of that goal. The processors were targeted at Intel's P55C (Figure 6-57). To jump start sales of these devices, Cyrix signed a five-year deal with Electronic Data Systems (EDS) Corporation to build and market 6x86-based personal computers. Cyrix hopes to use the PCs as a "proving ground" to demonstrate the capabilities of its MPU design.

The company hoped to be sampling its next-generation M2 microprocessor—an x86 device with more multimedia support—in 4Q96. The M2 is slated to be built using IBM's 0.5μm, five-layer metal CMOS process. Further details of the M2 are shown in Figure 6-58.

Looking to the future, Cyrix signed a multi-million-dollar agreement with Cadence Design Systems under which Cadence will assist Cyrix in the development of the company's seventh-generation microprocessor family, code-named M3. The M3 will be built around the Cyrix M1 core and incorporate more than 10 million transistors.

Additional highlights from the 32-bit CISC MPU market are shown below.

- Chromatic Research revealed its second-generation Mpact™ media processor architecture. Delivering up to 6,000 MOPS (millions of operation per second), the Mpact2 solution provides up to twice the overall performance of the first Mpact generation and up to 10 times the 3D graphics performance of motherboard solutions shipped in 1996. Chromatic Research also announced that its media processors will be co-designed, manufactured, and marketed by SGS-Thomson.



Processor	Clock Speed
6x86-P120+	100MHz
6x86-P133+	110MHz
6x86-P150+	120MHz
6x86-P166+	133MHz
6x86-P200+	150MHz

Source: Cyrix/ICE, "Status 1997"

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Figure 6-56. Cyrix Aims for High-End Processors

- Digital Equipment Corporation (DEC) provided its Alpha NT systems the ability to execute standard Win32 application programs written for x86 systems. The new technology, dubbed FX!32, began shipment with all Alpha Windows NT systems in 2Q96. Digital claims translated applications can run as fast on a mid-range Alpha chip as they would on a high-end Pentium system.

- Conceding it has hit the end of the performance road for its 486 microprocessor, Texas Instruments introduced a 100MHz version and announced four notebook customers for the device. The company believes its 100MHz product will find wide acceptance in many developing markets including China, Brazil, India, and Mexico. Meanwhile, TI directed its focus to bringing its 686-level family to the marketplace, although the company released no timetable for its introduction.

- Intel, which previously indicated it would not ship 0.25µm devices in volume until 2H97, now says it expects such production to begin in 1H97, matching the efforts of Texas Instruments, IBM, and a few other select vendors.

	6x86	M2	P55C	Pentium Pro
L1 Cache	16K unified	64K unified	16K instr 16K data	8K instr 8K data
MMX?	No	Yes	Yes	No*
Max Clock	150MHz	255MHz	200MHz	200MHz
Supply Voltage	3.3V	2.5V	2.5V	3.3V
Transistors	3 million	6 million	4.5 million	5.5 million
IC Process	0.44µm	0.35µm	0.28µm	0.35µm
Metal Layers	5M	5M	4M	4M
Die Size	169mm^2	<200mm^2	140mm^2	196mm^2

*Klamath, a single-chip version of the Pentium Pro, will feature MMX technology.

Source: MDR/Vendors/ICE, "Status 1997" 21739

Figure 6-57. Comparison of Cyrix and Intel MPUs

- Superscalar x86 MPU
- Optimized for 16-bit and 32-bit code
  - 2x faster than the 6x86 on 32-bit code
- 180MHz to 225MHz operation
- MMX software compatible
- Utilizes existing board and chip set infrastructure (standard 6x86 socket)
- 2.5V core, 3.3V bus interface
- 6M transistors
- Less than 200 sq. mm, 0.35µm, 5-layer metal CMOS
- Production 1H97

Source: Cyrix/ICE,"Status 1997" 21626

Figure 6-58. Cyrix M2 Key Features

THE RISC MPU MARKET

Leading-edge performance has always been characteristic of the RISC MPU market. RISC's strengths, including high processing rate and memory bandwidth, are well suited for executing and processing data. Moreover, RISC's clean, straightforward architecture helps keep down chip costs.

	1994	1995	1996 (EST)
Market ($M)	721	1,631	1,825
Units (M)	10	24	30
ASP ($)	72.10	67.95	60.83

Source: ICE, "Status 1997" 21118A

Figure 6-59. RISC MPU Market History

The RISC MPU market is still quite small compared to the CISC MPU market. It grew to $1.8 billion in 1996, an increase of 12 percent (Figure 6-59). One reason for the growth is that numerous RISC vendors increased the code density and performance of their chips. Also, suppliers made a strong effort to improve development tools that enable faster time to market.

	1995	1996 (EST)
Total Market ($M)	1,630	1,825
Total Units (M)	24	30
ASP ($)	67.92	60.83
RISC Unit Shipments (%)		
Hitachi SH	36	38
MIPS	18	20
PowerPC	11	17
i960	19	15
ARM	4	4
29000	6	3
Sparc	4	2
Alpha	1	1
PA-RISC	1	<1
Transputer	<1	<1

Source: ICE, "Status 1997" 19274E

Figure 6-60. The 32-/64-bit RISC MPU Market

The 1995 and forecasted 1996 32-/64-bit RISC MPU market and leading RISC processors are displayed in Figure 6-60. ICE estimates that in 1996, the "big four" RISC processors accounted for 90 percent of total RISC unit shipment volume.

Hitachi's SuperH (SH) series of RISC devices, which are part of numerous consumer (i.e., video game) applications outpaced the long-time leader—Intel's i960—in total number of unit shipments in 1995 and 1996. Intel put its i960 marketing and development efforts on the "backburner" in order to focus in on the more lucrative Pentium and Pentium Pro markets. As a result, Intel lost a few key design-ins to companies such as Hitachi and Motorola.

Powerful 32-bit RISC MPUs have been incorporated into many embedded applications (Figure 6-61). RISC architecture stands out in embedded applications because of its favorable price/performance characteristics. For example, IBM's 50MHz 401GF sold for $13 in 4Q96. A 40MHz 386DX and 386SX could be had for around $10. And, a MIPS MPU sold for less. The fastest embedded RISC processor in 4Q96 was AMD's 486DX5 at 133MHz. This remarkable performance was available for around $30! Whether embedded or non-embedded, RISC processors will be used in several new products and technologies targeted for the home and office environments (Figure 7-62).

Category	Typical Application	RISC Processors	Comments
Data flow	Laser printers, X-terminals, communications (routers, bridges, servers), image processing	MIPS (R4600, IDT R30XX), i960, 29K, Motorola ColdFire, PowerPC (403, 505)	Processing stage. Processes data and passes it on. High memory bandwidth, high processing throughput.
Interactive/ Video/Portable (IVP)	Set-top boxes, video games, PDAs, interactive video, portable information appliances	MIPS (Toshiba R3900, NEC R4100/4300/4600, IDT 4600/4650/4700), ARM (6XX/7XX), NEC V851, Hitachi SH1/2/3	Interactive, video processing. Ranges from portables to set-top boxes. Needs low cost, low power, high throughput.
Classic Embedded	Embedded controllers, disk controllers, automotive, industrial control and monitoring	Motorola ColdFire, Hitachi SH, NEC V851, National Piranha, ARM, MIPS cores (LSI Logic)	Classic embedded world. Needs mix of CPU power, low cost, low power dissipation. RISC controllers — CPU with embedded peripherals on-chip.

Source: Computer Design/ICE, "Status 1997" 20441

Figure 6-61. Embedded RISC Application Categories

RISC processors are widely used in the workstation/server market where performance, not price, is the greatest concern. From a desktop standpoint, RISC MPUs have not been warmly embraced. In fact, the PowerPC was the first volume RISC processor used in a PC platform. However, aside from serving traditional Mac customers, PowerPC has failed to convert many x86/Pentium users.

DEC will attempt to compete in the PC market with a system based on its Alpha RISC processor. The company announced that beginning in the first half of 1997, it would supply a low-cost, Alpha-based PC to compete against the Pentium Pro PC market. The announcement came less than a week after DEC and Samsung entered into an agreement that licenses Samsung as an alternate source manufacturer of current and future implementations of Digital's Alpha 64-bit RISC MPU.

Key highlights from the RISC market are outlined below.

Motorola/IBM PowerPC

In August 1996, IBM and Motorola announced a roadmap for the PPC family. It is clear the two companies are investing large amounts of capital in both individual development efforts for the family, as well as the co-development at Somerset, their joint operation. By the year 2001, the two companies hope to have a 300MHz version of their PPC available using 0.25µm technology.

Product	Definition	Chip Suppliers
Video-Game Players	Powerful RISC microprocessors fill the screen with movie-type 3-D realism	Advanced RISC Machines, Hitachi, LSI Logic, Motorola, Silicon Graphics
Digital TVs	Embedded microprocessors add functions such as viewer-controlled instant replay and automatic picture adjustment. Then, watch for high-definition TV.	LSI Logic, Philips, SGS-Thomson, Silicon Graphics, Texas Instruments
Cable-TV Set-Top Boxes	New chips provide interactive TV and video-on-demand movies and flag programs that match your viewing preferences. Some will even double as a PC.	IBM, Intel, Motorola, SGS-Thomson, Silicon Graphics, Sony, MicroUnity
Digital Videodisk	New chips will power DVD systems that can store 18 billion bytes of data – enough for a four-hour movie – on CD-size platters. Later, DVD systems that also record digital video could displace VCRs and make it easier to edit home videos.	Sony, Silicon Graphics, Motorola, IBM
Intelligent Home and Building Systems	Data networks will link scores of microchip brains in "smart" alarm clocks and many other products so they can cooperate on assuring the occupants' comfort and safety.	Hitachi, IBM, Motorola, NEC, Toshiba, Echelon
Wireless Phones and Videophones	Future models will add computing and text-messaging capabilities, then little TV screens – and eventually they'll even translate foreign languages.	Intel, MicroUnity, Motorola, 8x8

Source: Business Week/ICE. "Status 1997" 21122A

Figure 6-62. New Microprocessors Promise More "Smarts"

IBM

In 4Q96, IBM presented its newest processor, the P2SC for its PowerPC family. The P2SC is a very large and complex 64-bit implementation that may only be available in high-end workstations. The chip has 15 million transistors (9.3 million for cache memory). While the P2SC represents leading edge technology for IBM, its PowerPC 6xx chips operating at speeds of 200MHz and faster are available for the "every day" PC user.

Exponential

A new player in the PowerPC camp is Exponential. With the help of the three main players in the PowerPC fold, Exponential developed a BiCMOS version of the PPC604 chip called the X^{704}. Exponential claims its design and process roadmap will keep them two years ahead of CMOS processors. Its processor is targeted for use in high-end graphics workstations, servers, and Macintosh systems running MacOS, Windows NT, and UNIX.

Hewlett-Packard

Hewlett-Packard introduced the latest in its PA-8000 family, the PA-8200. These devices were to be sampling by the end of 1996 with volume production slated for the first half of 1997. One of the critical design goals for the PA-8200 was for end users to achieve at least 50 percent better performance on software applications when using the new processor. HP believes that, depending on the application, its PA-8200 will improve performance 35-75 percent.

Digital Alpha

Digital Semiconductor announced its newest Alpha processor, the 21264. This processor screams "speed!" The Alpha 21264 achieves its performance through the use of a lot of silicon and blazing clock rates. At 500MHz, the 21264 would not normally be considered a desktop machine. However, using applications such as 3D rendering, photoshop, or simulation, it is possible to use the 21264 in the desktop arena.

Sun Microsystems

Taking advantage of its unique knowledge as developer of the Java programming language, Sun Microsystems now offers a line of processors capable of running Java software code "exponentially faster" than competing microprocessors. The Java processor line consists of three products: the picoJava core, the microJava controller, and the UltraJava processor. Four Asian semiconductor companies announced manufacturing support for the new JavaChips processors from Sun. LG Semicon, Mitsubishi, NEC, and Samsung signed on as licensees of the Java parts. All four licensees indicated that they would incorporate the chips into their own OEM products as well as sell them on the merchant market.