6 MOS MICROCOMPONENT MARKET TRENDS

OVERVIEW

The metal-oxide-semiconductor (MOS) microcomponent segment of the integrated circuit (IC) market includes microprocessors, microcontrollers, microperipherals, and digital signal processors. As defined by the Semiconductor Industry Association, microprocessors are programmable ICs that execute programs stored in external memory. Microcontrollers contain all of a computer's electronic components on a single IC, including program memory. Microperipherals work peripherally to microprocessors, processing sound, video and other signals. Digital signal processors perform real-time processing of a digitized analog signal using arithmetic algorithms; the process is very math intensive and quite complicated. In fact, finding competent digital signal processor designers and programmers can be a challenge for many IC manufacturers.

The quarterly history of the MOS microcomponent segment of the total IC market from 1990 through the estimate for 1997 is shown in Figure 6-1. It is interesting to note the repetitive average selling price (ASP) pattern that has occurred since 1990. In the fourth quarter of each year, the microcomponent ASP increases; this increase extends into the first quarter of the following year before declining during the middle two quarters. Beginning in the second half of 1994, MOS microcomponent market growth accelerated slightly because of the sale of less costly Intel 486 and Pentium microprocessors.

Figure 6-2 shows unit volume and ASP details for the major product application categories in the MOS microcomponent IC market segment, based on final 1996 data. (Note: In the graphics of all subsequent figures, microprocessor is abbreviated MPU, microcontroller MCU, microperipheral MPR, and digital signal processor DSP.) In 1996, severe price erosion on 486 microprocessors and steady price reductions on Pentiums contributed to a -7 percent decline in ASPs in the 32-bit and 64-bit microprocessor category. Based on estimated data for 1997, this track away from the trend of previous years continued through the first half of 1997. However, the anticipated introduction of newer, faster, and more costly Pentium II microprocessors beginning in second half of 1997, will likely prevent continued decline. Microprocessor unit shipments continued to demonstrate solid growth, specifically 18 percent in 1996, led by strong shipments of 32-bit and 64-bit microprocessors for personal computers (PCs) and embedded applications.

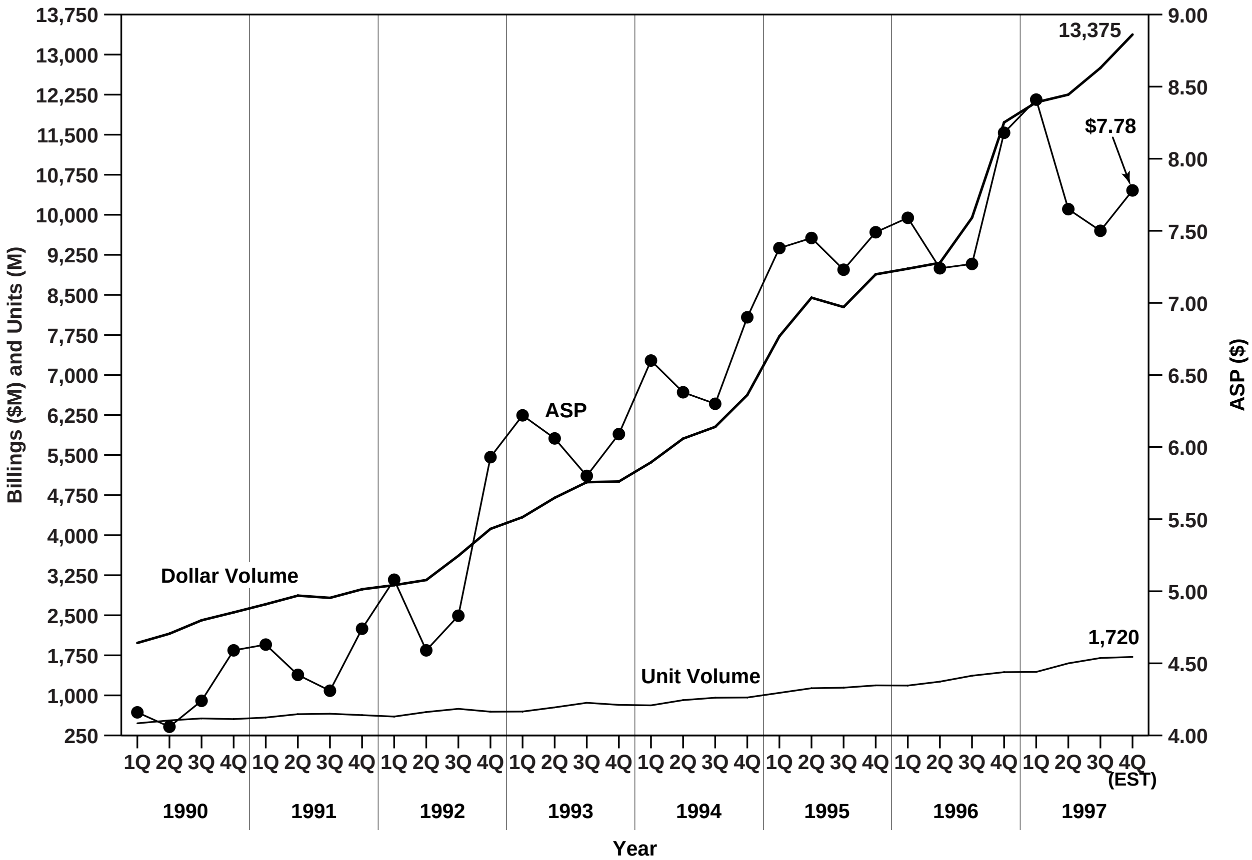


Figure 6-1. MOS Microcomponent Segment of IC Market

Product	1993 ASP ($)	1994 ASP ($)	1994/1993 Percent Change In ASP	1994/1993 Unit Volume Percent Change	1995 ASP ($)	1995/1994 Percent Change In ASP	1995/1994 Unit Volume Percent Change	1996 ASP ($)	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	3.40	–11	–16
16-bit	10.29	9.88	–4	–12	7.92	–20	34	6.16	–22	3
32-bit/64-bit	150.19	150.51	—	31	131.03	–13	51	121.66	–7	42
Total MPU	51.50	64.60	25	2	67.36	4	25	74.35	10	18
MCUs										
4-bit	1.64	1.62	–1	5	1.59	–2	–2	1.30	–18	2
8-bit	3.45	3.33	–3	28	3.39	2	21	2.99	–12	12
16-bit/32-bit	8.13	7.86	–3	100	8.26	5	66	6.99	–15	48
Total MCU*	2.71	2.82	–4	19	3.07	9	14	2.79	–9	11
MPRs	5.04	5.61	11	4	6.55	17	57	6.38	–3	21
Total Micro	6.02	6.54	9	15	7.33	12	25	7.59	4	15

*Not including DSP

Source: ICE

16888M

Figure 6-2. Microcomponent ASPs and Unit Volume Change

Growth of peripheral functions in the form of communications, graphics, voice, and other support for PCs exploded in 1995; this growth continued in 1996 and 1997. However, many of the peripheral functions that were add-on features in 1995 were incorporated onto microprocessors in 1996, resulting in a slower unit growth rate for microperipherals.

Figure 6-3 shows the MOS microcomponent market growth rates from 1993 through the final data for 1996. Growth for microprocessor and microperipheral categories remained at double-digit levels in 1996 while the microcontroller category grew only 7 percent. Despite the single-digit growth of the total microcontroller market, two segments within this category—DSPs at 39 percent and 16-bit and 32-bit microcontrollers at 26 percent—were among the fastest growing categories in the IC industry. As a whole, the MOS microcomponent market increased 19 percent in 1996. When final data are tabulated for 1997, ICE anticipates that the MOS microcomponent market will have increased 27 percent.

PRODUCT	1993 ($M)	1994 ($M)	1994/1993 Percent Change	1995 ($M)	1995/1994 Percent Change	1996 ($M)	1996/1995 Percent Change
MPUs							
8-bit	200	200	—	185	–8	140	–24
16-bit	520	440	–15	465	6	375	–19
32-/64-bit	7,870	10,355	32	13,630	32	18,015	32
Total MPU	8,590	10,995	28	14,280	30	18,530	30
MCUs							
4-bit	1,700	1,770	4	1,700	–4	1,410	–17
8-bit	3,700	4,565	23	5,665	24	5,560	–2
16-/32-bit	485	940	94	1,640	74	2,060	26
DSPs	675	1,000	48	1,730	73	2,405	39
Total MCU	6,560	8,275	26	10,735	30	11,435	7
MPRs	3,920	4,550	16	8,385	84	9,860	18
Total Microcomponent	19,070	23,820	25	33,400	40	39,825	19

Source: ICE 17204L

Figure 6-3. 1993-1997 Microcomponent Market

Another perspective of the MOS microcomponent segment of the IC market is shown in Figure 6-4. Clearly the microprocessor category leads the way in market size, specifically 32-bit and 64-bit microprocessors. High-performing and high-priced microprocessor ICs targeted for PC, server and workstation applications keep this category the largest segment of the microcomponent market.

Figure 6-5 shows MOS microcomponent IC consumption by geographic region for 1996, annotated with the 1991 market share, and the estimated market for 1997. In 1997, North America was the microcomponent-IC consumption leader with 39 percent of the market. Japan, Europe, and the rest of the world (ROW) followed with 17 percent, 23 percent, and 21 percent shares of MOS microcomponent consumption respectively.

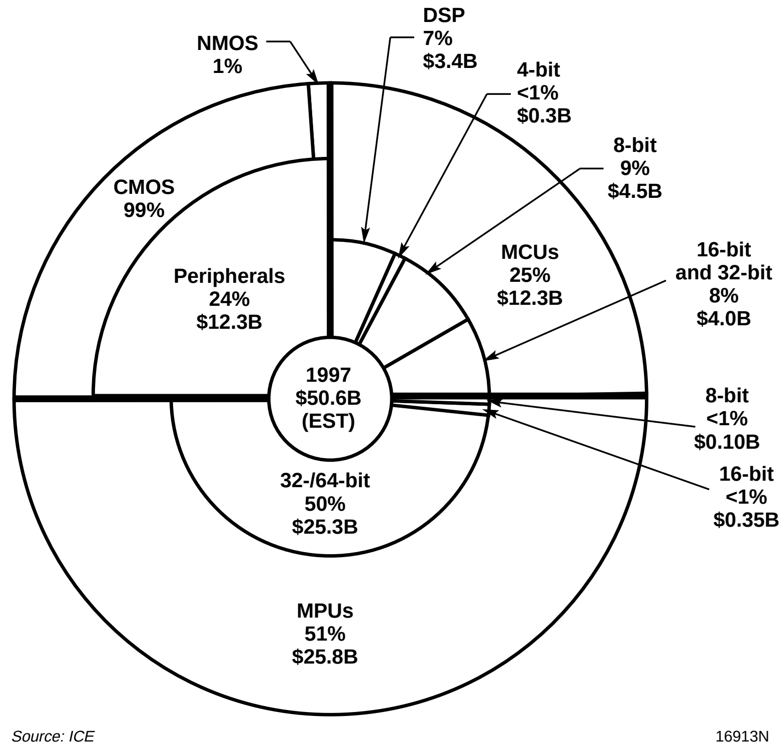


Figure 6-4. 1997 MOS Microcomponent IC Markets

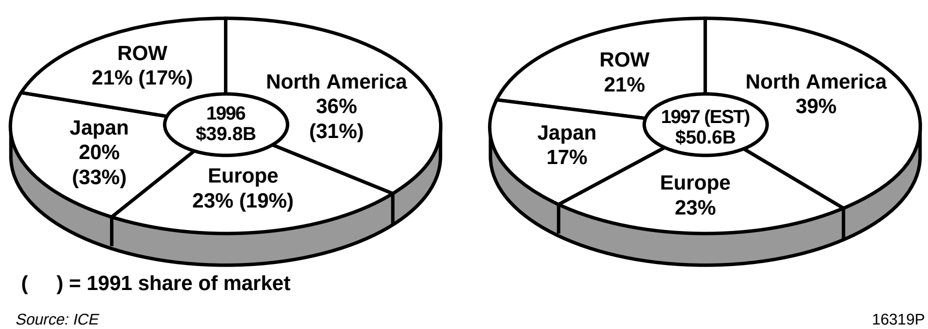


Figure 6-5. 1996 and 1997 MOS Microcomponent Consumption

Figure 6-6 lists the regional markets for MOS microcomponent ICs by quarter. Clearly, the North America and Asia Pacific regions were the fastest-growing throughout 1997, both with significant gains compared with the same period in 1996. Continued growth in the PC and related markets was the driving force that led to these increases.

Regional MOS microcomponent production is shown in Figure 6-7, based on final 1996 data. North American companies were the leading suppliers to the microcomponent market 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 market shares.

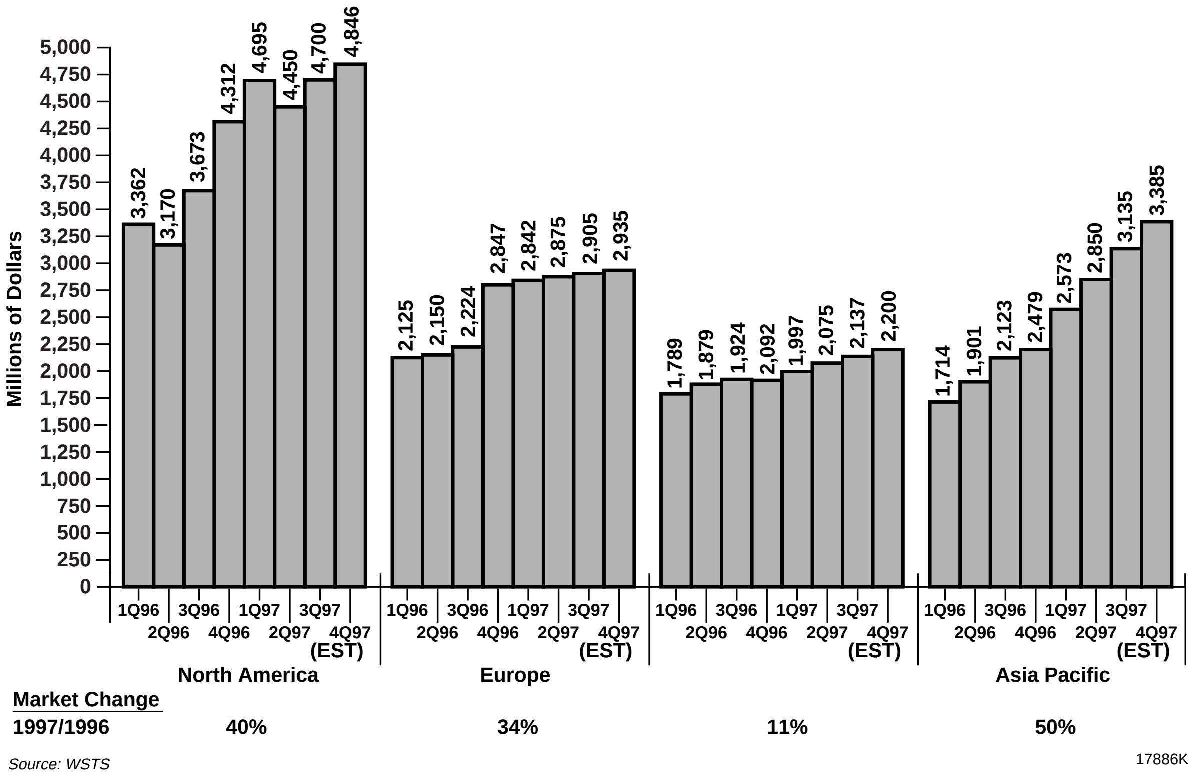


Figure 6-6. Quarterly Microcomponent Geographic Market Trends

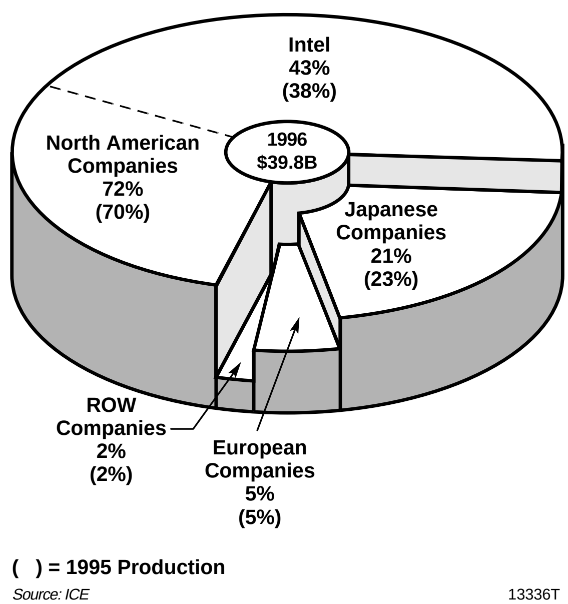


Figure 6-7. 1996 MOS MPU, MCU, and Peripherals Production

Figure 6-8 compares 1996 end-use applications for microprocessors, microcontrollers, and microperipherals; little change is expected when final 1997 MOS microcomponent use is tabulated. Obviously, computers are the largest applications for all three categories, especially microprocessors. The microcontroller and microperipheral categories show a more balanced array of use by system type because these ICs are used in many applications, including communications and consumer devices such as stereos, appliances, cell phones, etc.

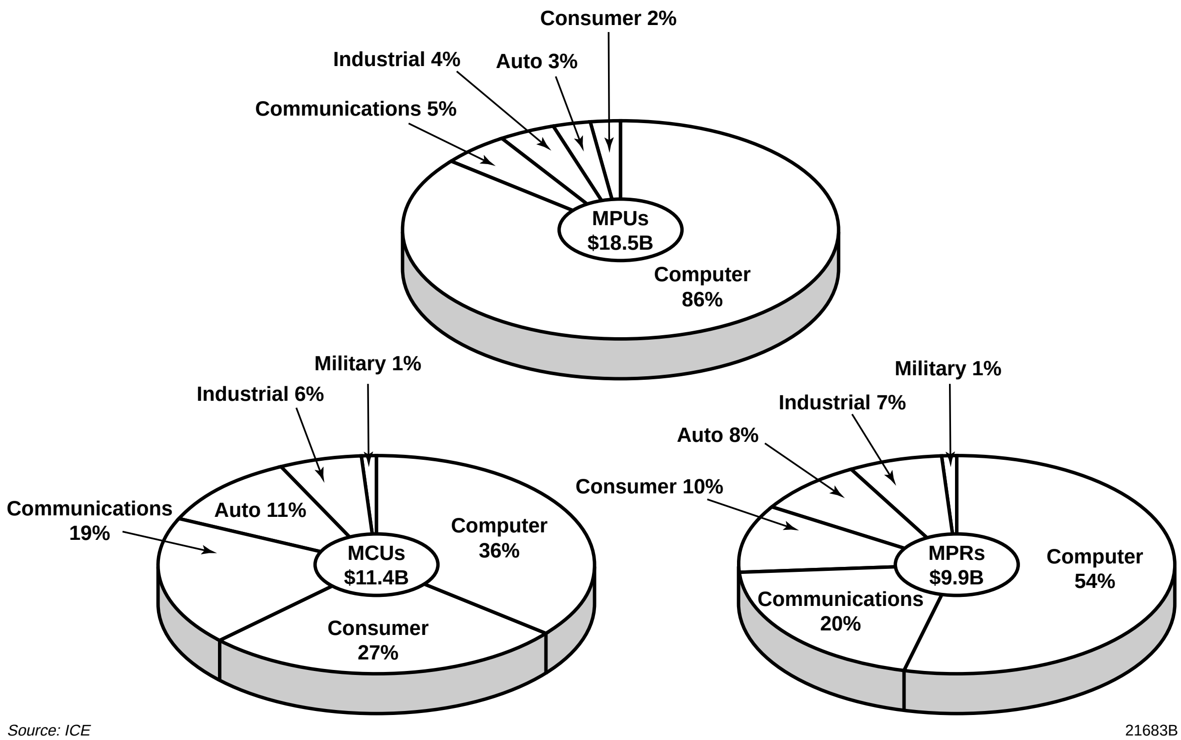


Figure 6-8. 1996 Microcomponent Use by System Type

TOP MICROCOMPONENT MANUFACTURERS

The leading MOS microcomponent IC manufacturers for 1995 and 1996 are shown in Figure 6-9; when the final 1997 sales figures are tabulated, ICE anticipates little change in this list. Combined, these top suppliers accounted for approximately three-fourths of the MOS microcomponent IC market in each year.

Intel continues to lead this group of semiconductor manufacturers, as it has for a number of years. Strong demand for Intel microprocessors, specifically its Pentium, has continued to the point where it now supplies at least 85 percent of the world's microprocessors used in PCs. Further, Intel has a good-selling reduced instruction set computing (RISC) microprocessor, the i960, and a strong peripheral-IC product line.

1996 Rank	Company	1995 Sales ($M)	1996 Sales ($M)	1996/1995 Percent Change
1	Intel	12,730	16,675	31
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	30,953	18

Source: ICE 16316P

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

MOS MICROCOMPONENT FORECAST

Based on ICE's forecast of the MOS microcomponent IC market segment, by 2002 there will be a noticeable shift toward more complex microprocessors (Figure 6-10). In 2002, virtually all microprocessor sales will be 32-bit and 64-bit ICs; 8-bit and 16-bit will account for less than 1 percent of the market. The higher ASPs associated with these complex products will account for their increased share of the MOS microcomponent market, which ICE sees rising to 58 percent of the MOS microcomponent market in 2002.

In the microcontroller category, 16-bit and 32-bit ICs are forecast to show strong gains, but the ubiquitous 8-bit microcontroller will still have a significant share. Microcontroller replacement is often cited as one of the most promising markets for DSPs—especially at the 16-bit and 32-bit levels. Accordingly, by 2002 DSPs are forecast to represent 9 percent of the MOS microcomponent market and 42 percent of the microcontroller category.

THE MICROCONTROLLER MARKET

In 1997, the microcontroller IC category was about half the size of the microprocessor category. However, roughly 15 times more microcontroller ICs were shipped in 1997 compared to microprocessors (Figure 6-11). This statistic clearly shows that microcontrollers are used increasingly in a wide array of smart equipment. The microcontroller market differs from the microprocessor market in that it serves many applications and industries, compared to microprocessors that are used almost exclusively by the computer industry. The microcontroller market is so diverse that no one company can cover it all. This category of ICs is also characterized by low cost, for example IC manufacturer Microchip Technology offers some 8-bit microcontrollers for less than $1.

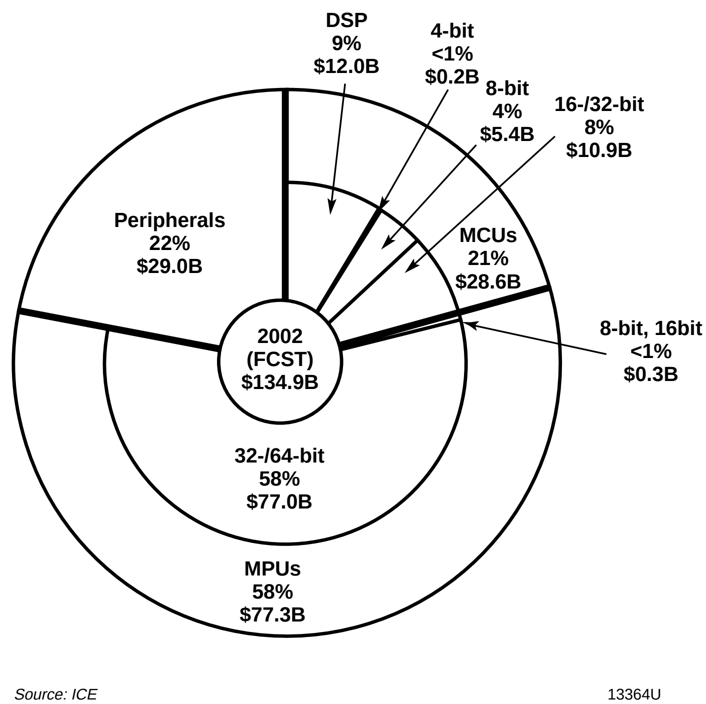
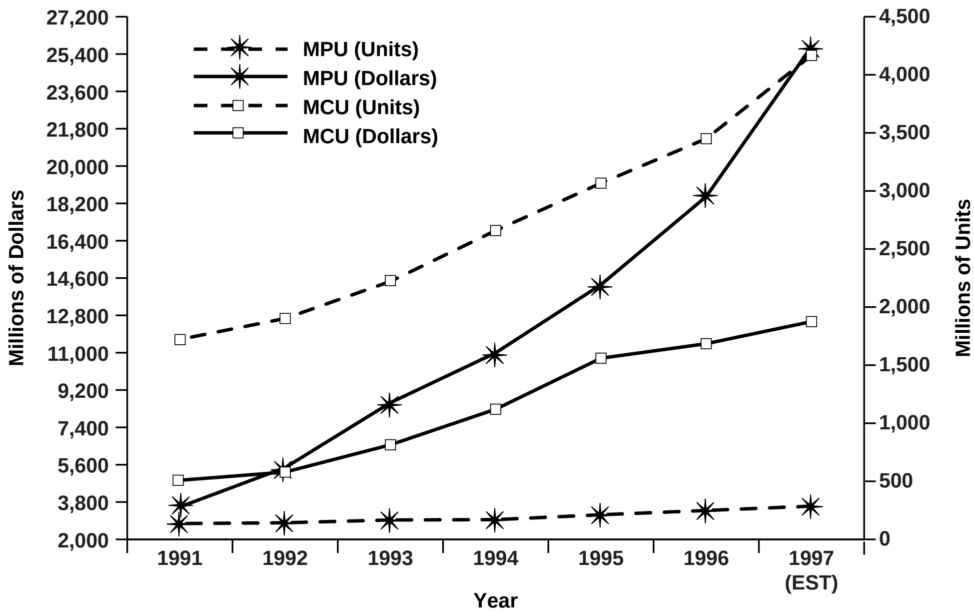


Figure 6-10. MOS Microcomponent Market Forecast

The growth of the microcontroller IC category is driven by three key industry sectors: automobile, office, and consumer electronics. For example, inexpensive cars from Korea have from five to ten microcontrollers each. Luxury cars can contain thirty to forty microcontrollers; the 1996 S-class Mercedes-Benz has fifty microcontrollers throughout the vehicle. To appreciate use of microcontrollers in office and consumer products, consider that the average office has about twenty microcontrollers and the typical home as many as one hundred. Based on the number of microcontroller units shipped, the microcontroller IC market category has more than doubled in the past five years.

Figure 6-12 projects the increasing application of microcontroller ICs for automobile, home, and office applications through 2000. Interestingly, the greatest growth is forecast for home applications, rising to an average of 226 microcontrollers in the home by 2000; almost everything electrically powered will include a microcontroller.

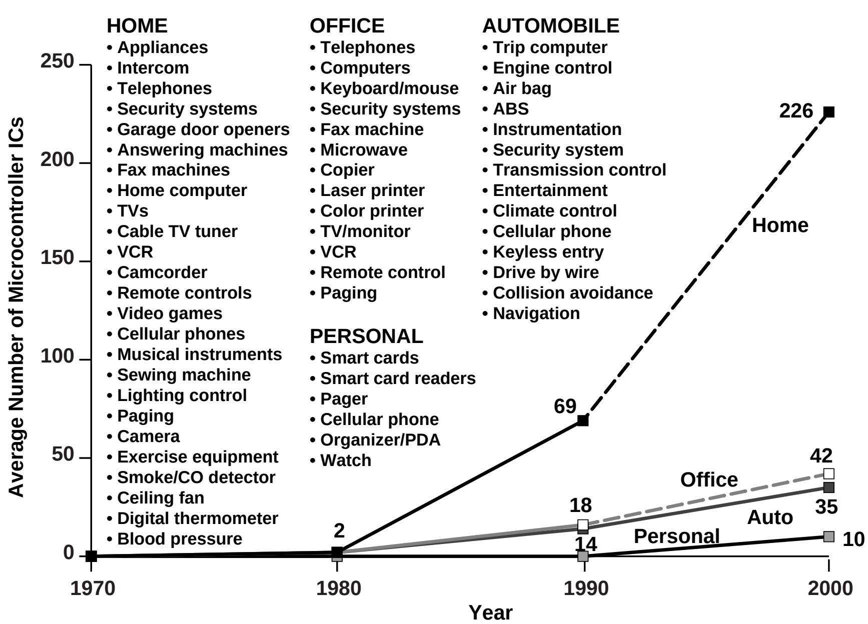
ICE projects the microcontroller IC market category growing an average 18 percent through 2002, when the microcontroller market is forecast to be $28.6 billion (Figure 6-13). This equals the 18 percent average annual growth of the microcontroller market from 1992 through 1997.



Units (M)							
MCU	1,722	1,902	2,221	2,659	3,067	3,450	4,167
MPU	136	143	167	170	212	249	286
Dollars ($M)							
MCU	4,850	5,245	6,560	8,275	10,735	11,435	12,500
MPU	3,565	5,460	8,590	10,995	14,280	18,530	25,760

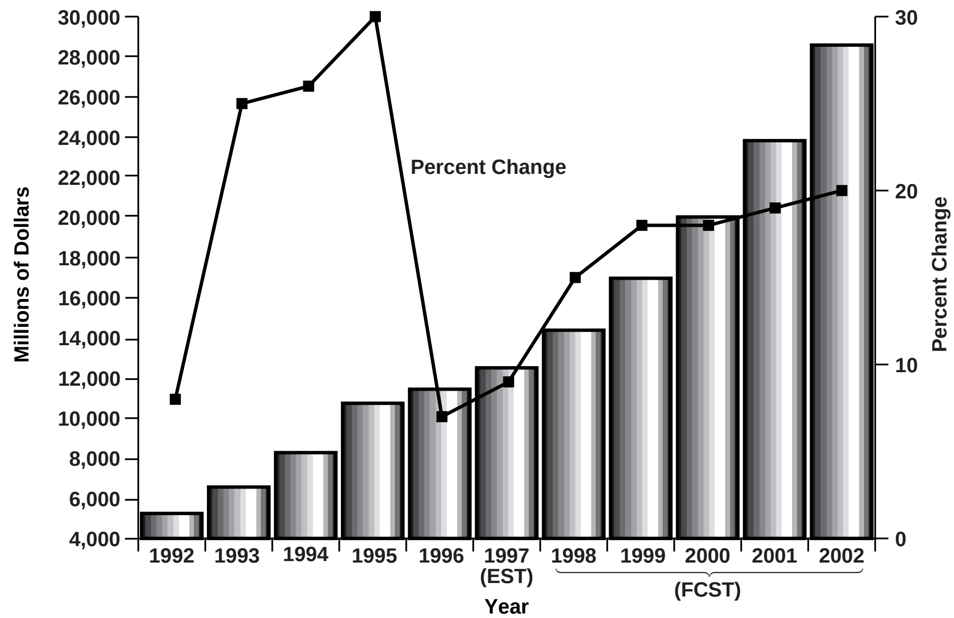
Source: WSTS 20318E

Figure 6-11. Comparison of the Microcontroller and Microprocessor Markets



Source: Motorola/Electronic News 19242B

Figure 6-12. Numerous Applications Drive Microcontroller Growth



MCU Market($M)	5,245	6,560	8,275	10,735	11,435	12,500	14,375	16,963	20,016	23,819	28,582
Percent Change	8	25	26	30	7	9	15	18	18	19	20

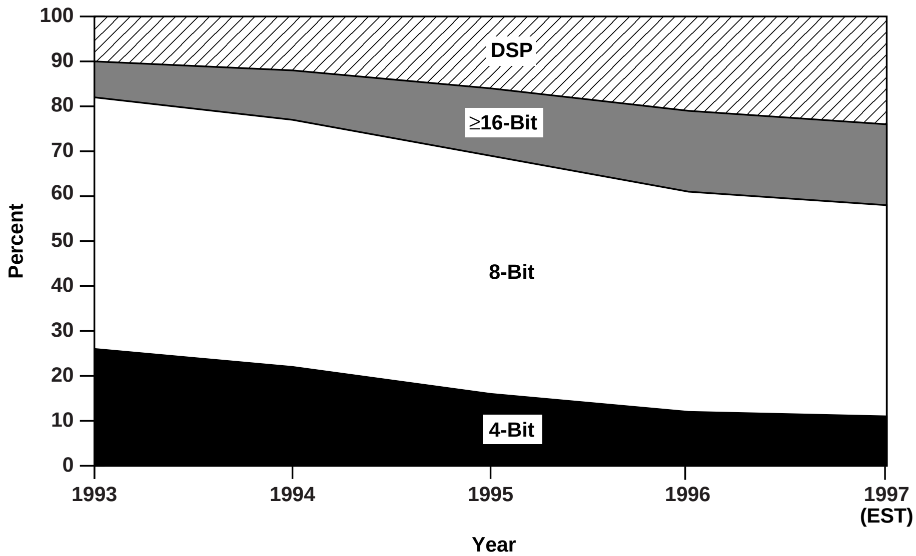
Source: ICE 20438D

Figure 6-13. Microcontroller Market Growth and Forecast

The microcontroller market category is subdivided into 4-bit, 8-bit, and 16-bit configurations; in addition, DSPs are lumped into this category. In the past few years, 32-bit microcontroller configurations have been available. Figure 6-14 shows the percentage of dollars that each of these subcategories contributed to the microcontroller IC application category. This data shows that DSPs are capturing a significantly growing share of the microcontroller market.

Original equipment manufacturers (OEMs) are turning more often to sophisticated, high-density microcontroller ICs to incorporate into complex, embedded systems where there is a need for computing power. As a result, ICE sees a steady market in the 16-bit and 32-bit microcontroller market subcategories.

While the 8-bit microcontroller market will slightly erode through 2002, manufacturers have increased the functionality of these ICs such that they remain extremely competitive with high-end microcontrollers. In fact, while some conventional users of 8-bit microcontrollers have migrated to 16-bit ICs to take advantage of increased memory and power, other applications that have traditionally tapped the 4-bit category for inexpensive ICs are now using 8-bit microcontrollers that cost less than $1.



MCU Market (%)	1993	1994	1995	1996	1997 (EST)
4-Bit	26	22	16	12	11
8-Bit	56	55	53	49	47
≥16-Bit	8	11	15	18	18
DSPs	10	12	16	21	24
Total ($M)	6,560	8,275	10,735	11,435	12,500
Percent Change	25	26	30	7	9

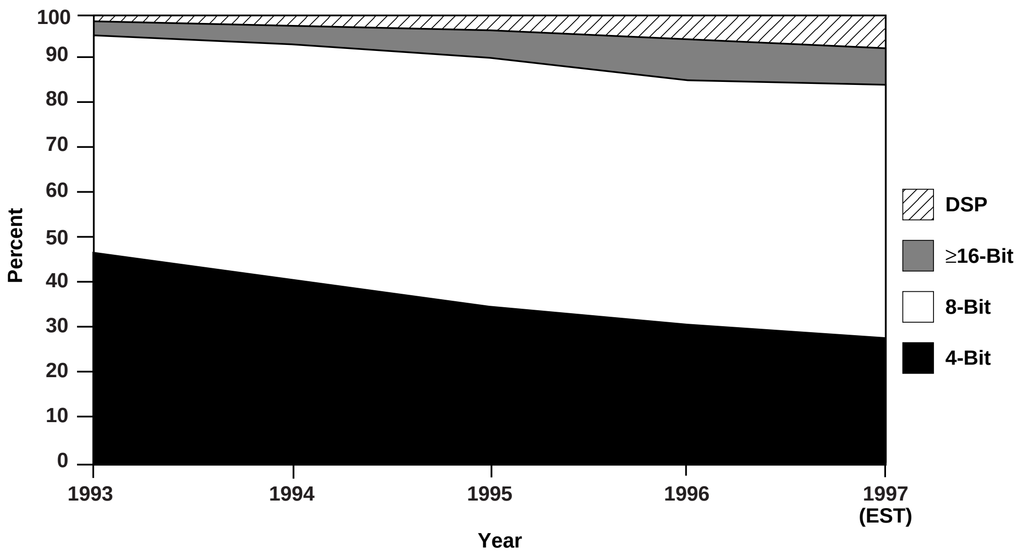
Source: ICE 20319E

Figure 6-14. The Microcontroller Market by Configuration

In terms of unit shipments, low density 4-bit and 8-bit microcontrollers dominate. ICE shows that in 1996, these ICs accounted for 85 percent of the total microcontroller unit shipment volume (Figure 6-15). Although growth rates in these categories may slow, ICE believes that 4-bit and 8-bit microcontroller unit shipments will continue to account for the majority of microcontroller shipments through 2002.

Figure 6-16 outlines several reasons why 8-bit microcontrollers are still favored among system designers. The success comes down to the fact that these ICs generate formidable computing power, almost always have a smaller IC footprint than higher-density ICs, and are low-cost. Many older 8-bit designs perform exactly as needed, especially in inexpensive system designs (Figure 6-17).

Further, 8-bit ICs, like all microcontrollers, have become more specialized. That is, they provide more performance, including more memory, timer functions, and multiple channels, and are more versatile than ever before. Some manufacturers have introduced microcontrollers that integrate liquid crystal display capabilities aimed at 8-bit consumer applications requiring an inexpensive display.



MCU Units (%)	1993	1994	1995	1996	1997 (EST)
4-Bit	47	41	35	31	28
8-Bit	48	52	55	54	56
≥16-Bit	3	4	6	9	8
DSPs	2	3	4	6	8
Total (M)	2,220	2,660	3,065	3,450	4,167
Percent Change	17	20	15	13	10

Source: ICE 20320E

Figure 6-15. Microcontroller Unit Shipments by Configuration

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

Source: ICE 19234B

Figure 6-16. Elements of the 8-Bit Microcontroller's Success

At the same time, 8-bit microcontrollers are being built using submicron process technologies; this helps designers lower operating voltages and shrink die size. With these characteristics, many 8-bit designs compete with older 16-bit microcontrollers for new applications (Figure 6-18).

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 one dollar. 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 21097B

Figure 6-17. Older Microcontroller Architectures Benefit: Inexpensive Designs

One relatively new feature on some 8-bit microcontrollers is the integration of read only or flash memory on the same IC. Among the companies equipping their microcontrollers with nonvolatile 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 memory to be widely used in microcontroller applications, with as much as 80 percent of all embedded controllers using it in five years.

On-board memory has increased on higher-density microcontrollers as well. This and other activities in the ≥16-bit microcontroller market are briefly reviewed in Figure 6-20.

In the past, each particular microcontroller subcategory (i.e., 4-bit, 8-bit, 16-bit, etc.) served certain applications and markets according to their respective price and performance characteristics. However, as depicted in Figure 6-21, the microcontroller business is now intertwined: Some high-performance 8-bit microcontrollers offer comparable performance to 16-bit designs, low-end 16-bit microcontrollers have become cost-competitive with high-end 8-bit microcontrollers, and 32-bit microcontrollers have encroached on 16-bit territory. In addition, some DSP prices have dropped to microcontroller levels.

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 21098A

Figure 6-18. Applications Link with 8-Bit Microcontrollers

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

A designer's decision to upgrade or not is especially critical in the embedded-control market. Considerations such as architectural and performance issues must be weighed along with IC cost and the costs of software and training. Figure 6-22 shows a few of the advantages and disadvantages of migrating upward within a chosen microcontroller family.

Fortunately, for many 8-bit microcontroller 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 its venerable 8051 IC, that is fully compatible with the 8051. Other designers can migrate to the 68HC12 IC, Motorola's successor to the popular 68HC11.

Toshiba addressed its product line-up to respond to interest in the 8-bit and 16-bit microcontroller markets. It developed several new products based on existing platforms. Part of its 16-bit microcontroller strategy is to develop derivative products based on its TLCS-900 IC family (Figure 6-23).

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 21099A

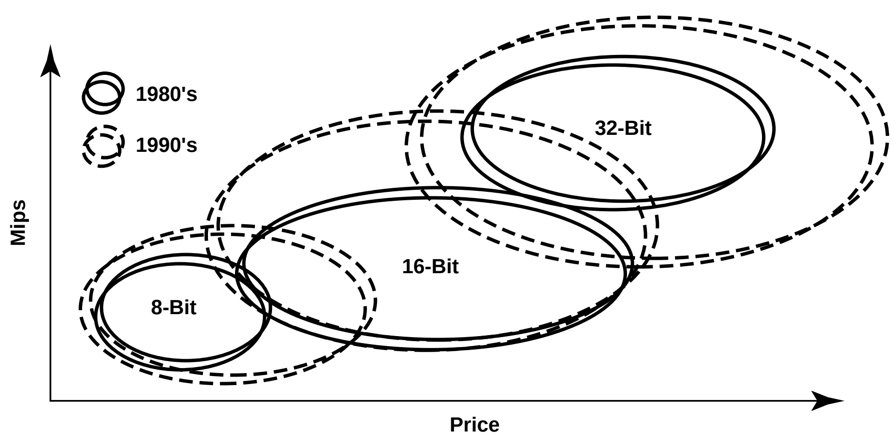
Figure 6-19. 8-Bit Microcontrollers Push Memory Limits

Both Samsung and Integrated Silicon Solutions (ISSI) leveraged their high-speed memory design expertise to enter the microcontroller market with a family of products integrating nonvolatile memory. Samsung introduced an 8-bit OTP microcontroller with embedded EPROM, while ISSI delivered its IS80C51 and IS80C31 ICs. The ISSI chips incorporate industry-standard 8051/31 8-bit microcontroller cores with speeds of 40MHz. Figure 6-24 shows ISSI's 1997 roadmap for more memory-intensive and flash-based microcontrollers.

- AMD announced the availability of its 16-bit AM186ED that features an on-board DRAM controller. The device delivers zero-wait-state performance at 40MHz with 50ns DRAM, 70ns SRAM, or flash memory. The device reduces system cost by enabling embedded designers to specify low-cost, glueless interface to DRAM.
- Motorola continued the trend of adding flash memory onto its MCUs when it introduced its 16-bit 68HC916YC MCU with 100Kbytes of flash memory.
- Targeting advanced consumer electronics, IBM introduced its 32-bit 403GCX PowerPC for embedded control. The device is ideally suited for the next generation of set-top boxes, imaging systems, communications products, and network computers.
- NEC introduced its V831 MCU that features an enhanced multimedia instruction set. It was developed to handle the digital processing of graphics, audio, and data requirements for multimedia, internet, and networking applications.
- Philips unveiled its first 8-bit 80C51 flash MCU and announced plans to launch a superset of new flash controllers set for delivery in 4Q97.
- Citing the fact that demand for microcontrollers with embedded flash is soaring, Toshiba unveiled a 16-bit MCU (TLCS-900/H) with 128Kbytes of on-board flash.

Source: ICE 22739A

Figure 6-20. Activities in Higher-Density Microcontroller Market



Source: SGS-Thomson 20322A

Figure 6-21. Relative Microcontroller Performance

The leading microcontroller suppliers in 1995 and 1996 are shown in Figure 6-25, which is based on final market data. This data includes DSP sales; as a result, DSP suppliers Texas Instruments and Lucent Technologies are ranked among the top microcontroller suppliers. The success of Motorola and Intel in remaining near the top of this list, even excluding DSPs, seems remarkable given that most of the world's demand for microcontrollers has been and continues to be in Japan where vertically integrated companies typically make the ICs for use in their own products.

Advantages

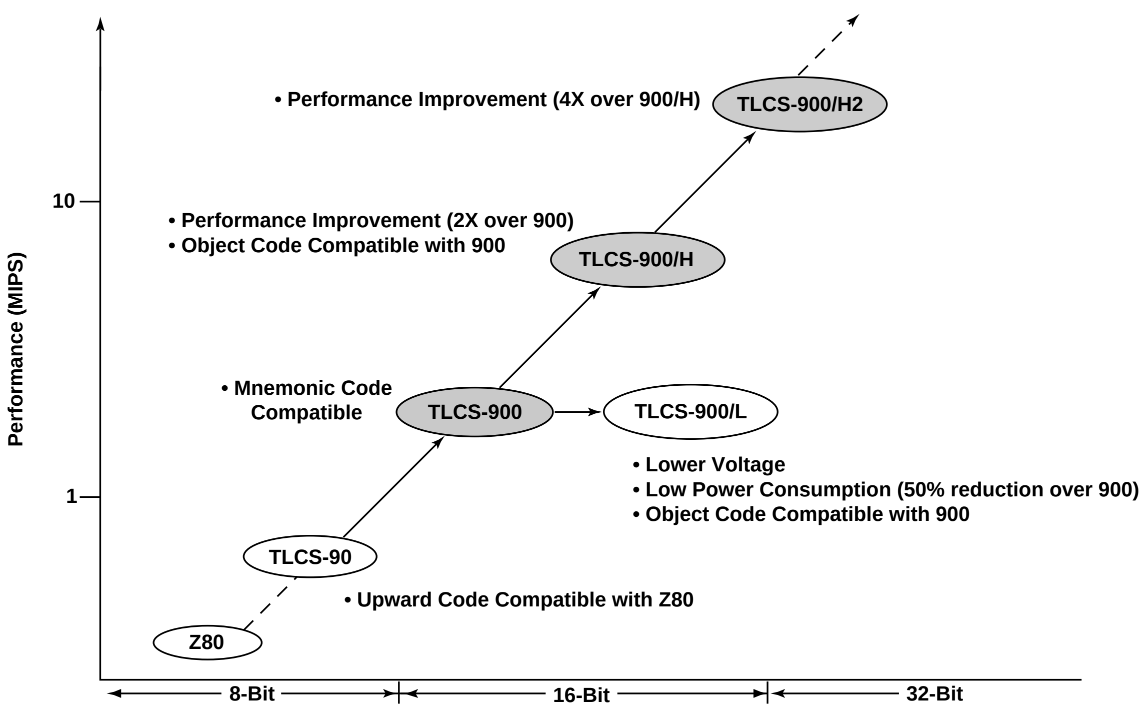
- **Little loss of time or money.**
- **No need to learn new development tools, software packages, or peripheral functionality.**
- **No reinvestment in support structure.**
- **Code development and software preservation.**

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 20323A

Figure 6-22. Factors Influencing Migrating Within a Microcontroller Family



Source: Toshiba 21100B

Figure 6-23. Toshiba's TLCS-900 Core Roadmap

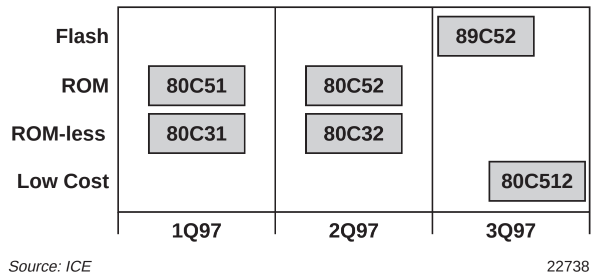


Figure 6-24. ISSI's Microcontroller Roadmap

1996 Rank	MCU* Leaders	1995 Percent Marketshare	1996 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	$11.4B

*Includes DSP sales

Source: ICE 19233H

Figure 6-25. Leading Microcontroller Suppliers*

THE DIGITAL SIGNAL PROCESSOR MARKET

Digital signal processing is a segment of the IC industry where advanced digital and analog technologies merge (Figure 6-26). From a base application in high-end workstations, digital signal processor (DSP) IC consumption began to soar back in 1995 driven by new consumer applications that had not been envisioned just a few years earlier. Application of DSPs has been particularly strong in communications. During this period, lower pricing for DSPs, which IC manufacturers accomplished through design shrinks, low-cost packaging, and streamlined testing techniques, helped to intensify demand (Figure 6-27). Figure 6-28 outlines how some manufacturers have addressed DSP IC issues, driving the cost of these crucial ICs down.

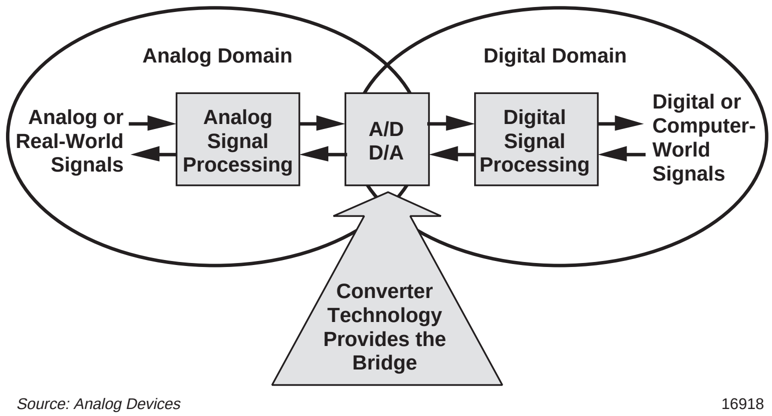


Figure 6-26. Real-World Signal Processing

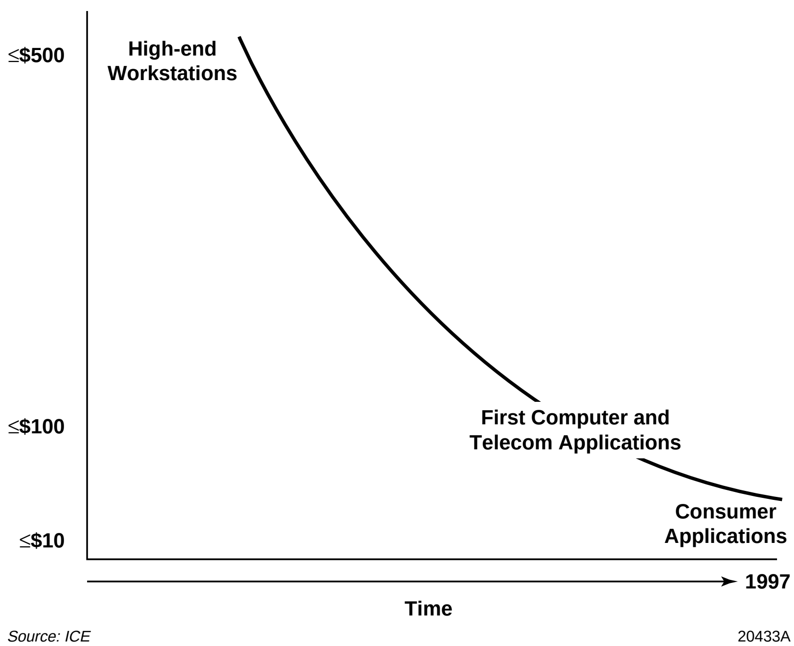


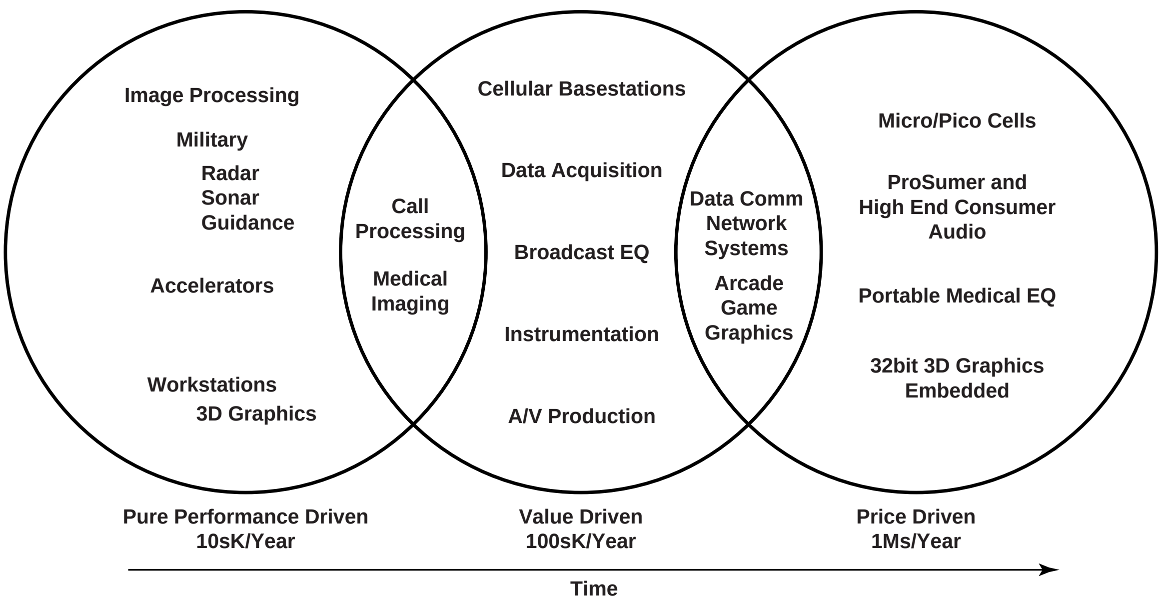
Figure 6-27. As Price Drops, DSP Applications Increase

DSP pricing is largely dependent on processing power. In 1997, DSP prices ranged from less than $3 for simple low-end, high-volume ICs to several hundred dollars for the most complex, highly integrated DSP ICs. Using another metric, at Texas Instruments for example, the cost fell to less than $1 per MIPS (million instructions per second) compared to $200 per MIPS 12 years ago. Similar price declines at Analog Devices allowed this IC manufacturer to offer its low-cost, high-performance ADSP-2104 IC for a recommended retail price of $4.50. Shown in Figure 6-29 are a few examples of how some of the leading DSP IC manufacturers have broadened applications, which, in turn, has helped reduce 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
Lucent	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 20338A

Figure 6-28. Selected DSPs are Driving Costs Down



Source: Analog Devices 22721

Figure 6-29. Analog Devices Helps Broaden DSP Applications

In a general sense, DSP ICs are offered in one of two ways: programmable or nonprogrammable. Nonprogrammable DSPs are usually purchased as drop-in OEM parts for a particular product, for example, modem ICs, speech synthesis ICs, or various other ICs whose names reflect their application. Programmable DSPs are programmed by the customer or the IC supplier to meet customer requirements. Figure 6-30 shows some of the main end-uses for programmable and non-programmable DSP ICs.

PROGRAMMABLE DSPs

- Videoconferencing
- Document Imaging
- Home Video Phones
- Digital Cellular Phones

NON-PROGRAMMABLE DSPs

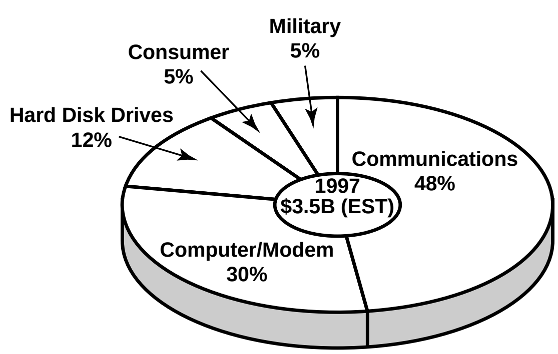
- Dolby Digital
- Motor Speed Regulation*
- Appliance Power Consumption*
- Modems

*** Replacing MCUs**

Source: ICE 22722A

Figure 6-30. Examples of DSP IC Applications

Much of the current market growth for DSP ICs comes from wireless and cellular telephones, modems, and motor-control applications. Communications represent the dominant DSP application and will likely do so for the next several years, as it did in 1997 (Figure 6-31), based on estimated data.



Source: ICE 21584B

Figure 6-31. DSP Market by Application

Computers represent a significant end use for DSPs as well, and PC suppliers are branching into emerging applications. For instance, DSP ICs 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, at the office, at school, or in mobile applications, DSPs are certain to play a vital role in an increasing number of systems (Figure 6-32).

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 20341

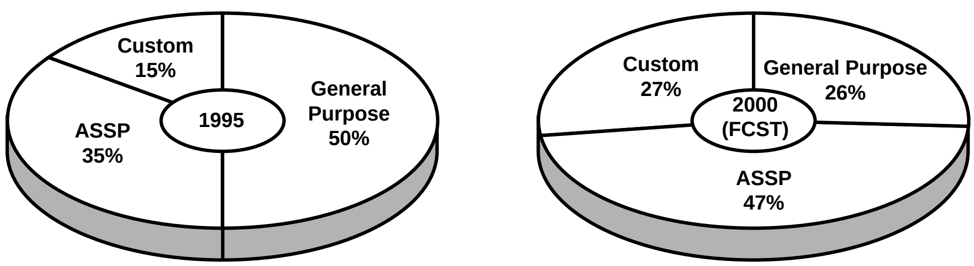
Figure 6-32. DSP Application Explosion

Several trends indicate that DSP ICs will become more prevalent in the coming years (Figure 6-33). One trend suggests that DSPs will make a rapid transition from general-purpose-IC to application-specific-IC (ASIC) core-based solutions. For instance, Atmel will license DSP Group's Pine and Oak cores for integration into Atmel's cell and gate array libraries. This trend toward cored-based application-specific standard products (ASSPs) is putting pressure on DSP vendors to bolster their ASIC capabilities. Figure 6-34 shows that ASSP-based DSPs are the fastest growing segment within the single-chip programmable DSP market.

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 20432A

Figure 6-33. DSP IC Trends



Source: Forward Concepts 21610

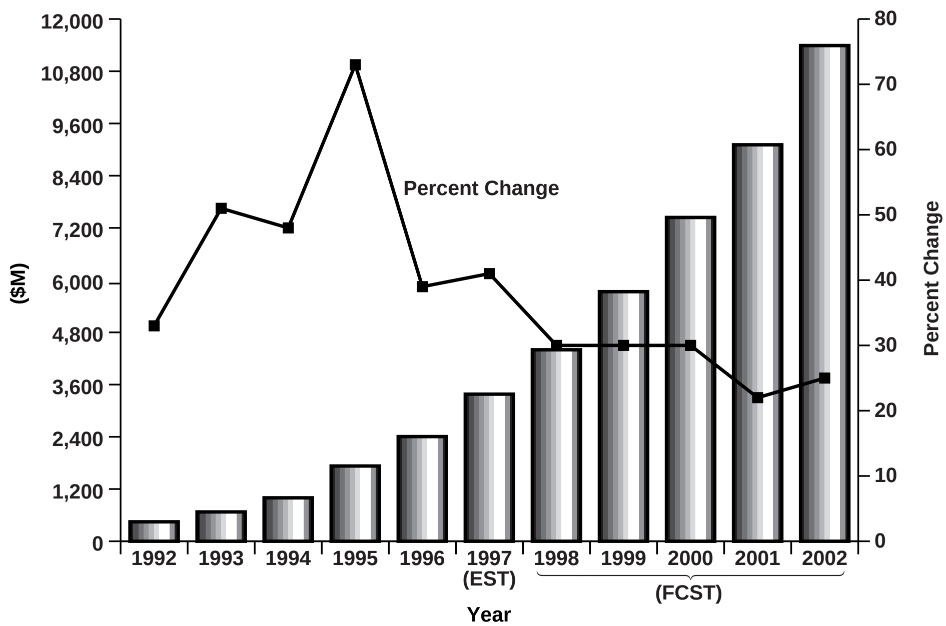
Figure 6-34. ASSPs to Dominate Single-Chip DSP Market in Future

Additionally, many suppliers including Texas Instruments (TI), VLSI Technology, LSI Logic, National Semiconductor, and Samsung plan to integrate features of DSPs onto microcontrollers to further develop their system-on-a-chip technologies. Whether through a growing range of applications, design shrinks, low-cost packaging, or streamlined testing techniques, many factors are working together to increase the consumption of DSPs.

The tremendous growth of DSPs—both as stand alone ICs 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 1996 and 1997. Overall, the DSP market grew an estimated 41 percent in 1997, and ICE forecasts continued, similar growth through 2002 (Figure 6-35).

TI was the leading producer of DSP ICs in 1995 and 1996 (Figure 6-36); when the final figures are tabulated for 1997, ICE expects that TI will have again increased its market share. TI continues to emphasize the impact of DSP sales on its corporate bottom line. To support its DSP business, in

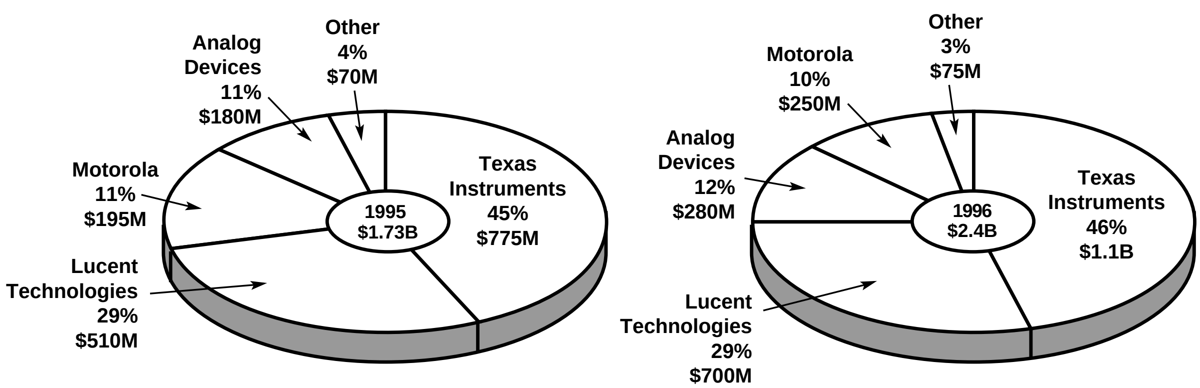
1996 more than 90 percent of TI's $1.8 billion-plus semiconductor capital spending was for non-DRAM products; this trend continued in 1997 and will again for 1998. TI, and several other DSP IC manufacturers, continue to invested in new DSP-dedicated wafer fabrication capacity with new facilities slated to begin by mid-1998 (Figure 6-37).



DSP Market ($M)	447	674	998	1,729	2,405	3,380	4,400	5,735	7,440	9,110	11,390
Percent Change	33	51	48	73	39	41	30	30	30	22	25

Source: ICE 20435D

Figure 6-35. DSP Market Growth and Forecast



Source: Forward Concepts 14503S

Figure 6-36. Worldwide Sales of Single-Chip DSPs

Company	Fab Location	Comments
Analog Devices, TSMC, and other equity partners	Camas, WA	30,000 200mm Wafers/Month in 1999
Cirent Semiconductor (Joint venture with Lucent Technologies and Cirrus Logic)	South Orlando, FL	200mm Wafers, Production Started 1H97
Texas Instruments	Dallas, TX DMOS5 (Ramping) DMOS6 (Under Construction)	Initial Production of 10,000 200mm Wafers/ Month by End of 1997

Source: ICE 22723

Figure 6-37. New DSP Fab Capacity

A few noteworthy items about the DSP market are shown in Figure 6-38, along with the following highlights from leading DSP IC manufacturers:

- **While announcing the first general-purpose very-long-instructional-word (VLIW) DSP, Texas Instruments also announced the end of the road for the C8x DSP family. The company also emphasized the importance of compilers for DSPs with the purchase of DSP-compiler company Tartan.**
- **Motorola's DSP Division became the Wireless Signal Processing Division, although the company still supports many general-purpose DSP and audio applications.**
- **Atmel bought TCSI's Lode architecture.**
- **Most DSP vendors announced support for integrated flash memory.**
- **Intel announced multimedia-extension technology for Pentium to enhance signal processing. Other companies, such as Sun Microelectronics and MIPS Technologies, also announced instruction sets to support signal processing.**

Source: EDN 22725

Figure 6-38. Sampling of DSP Market Activities Through 1H97

Texas Instruments

In the past few years, DSPs have been the fastest-growing product in TI's portfolio and now represent TI's primary product line. In 1995, approximately 10 percent of TI's sales were from DSPs. In 1996, the DSP portion of TI's semiconductor sales were approximately 16 percent. By 2000, TI expects its DSP sales to top $5 billion. Figure 6-39 provides a few milestones in TI's DSP history.

Perhaps the biggest DSP-related news from TI in 1997 came when the company announced its TMS320C6x family of fixed-point DSP ICs. Rarely does a product come along with performance that leapfrogs the competition, yet that also is in tune with leading market trends. At 1,600 MIPS, the TMS320C6201 offers performance 10-times greater than its nearest competition and features TI's very long instruction word (VLIW) architecture that eases software development and will help reduce overall system cost.

1978 – Developed speech-synthesis chip used in "Speak & Spell" game, beginning of TI's drive in DSPs.

1981 – TI established a PC-based DSP University Program designed to support the study of digital signal processing at all levels (undergraduate to Ph.D.) of collegiate study.

1982 – TMS32010 NMOS chip with 5 MIPS performance.

1985 – Introduced first CMOS-based DSP, the TMS320C20. CMOS process resulted in improved performance, and lower power consumption.

1987 – DSP business turns profitable.

1987 – TMS320C17 used in "Julie Doll," demonstrating that DSP devices were inexpensive enough to use in consumer products.

1991 – TI launched customizable DSP (CDSP) effort.

1997 – TMS320C6x introduced. Uses VLIW architecture, 1,600 MIPS, 200MHz, 0.25µm CMOS process. A move to 0.18µm process in 1998 should yield 2,500 MIPS and 250MHz performance.

Source: ICE 22724

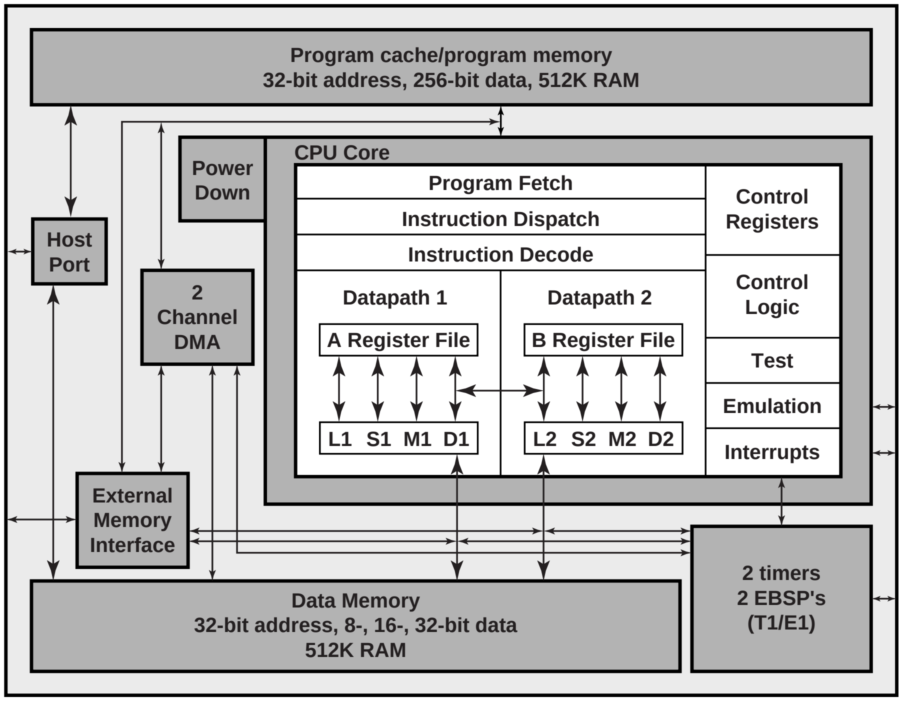
Figure 6-39. Timeline of TI's DSP Business

TI's C6201 DSP architecture also integrated two multipliers and six arithmetic units that provide up to eight instructions per cycle. Further, 1M of on-chip RAM is divided into halves for program and data. A 32-bit external interface supports SDRAM, synchronous-burst SRAM, and asynchronous SRAM (Figure 6-40).

TI's C6201 DSP, while appropriate for a broad range of applications, is expected to have the greatest impact in communications. Already, several OEMs in the data communications, telecommunications, and telephony markets have championed this IC as a system solution for a wide array of applications.

TI also unveiled the first two of a planned series of DSP ICs that are aimed specifically at the TV-set top-box market. These ICs integrate a 16M SDRAM as well as a 32-bit ARM RISC microprocessor, a MPEG-2 video decoder, an advanced graphics accelerator, and decryption modules on a single semiconductor IC. The AV7100 is specifically designed for digital satellite systems while the AV7110 is designed with algorithms for the digital video broadcast standard.

By 2002, TI forecasts that ASIC-based solutions will account for 90 percent of its DSP business. TI will differentiate itself in this competitive market by pushing process geometries to the 0.18µm level for DSP production.



Source: Computer Design 22760

Figure 6-40. TI's C6201 DSP Features VLIW Architecture

Lucent Technologies

Lucent Technologies produced its first single-chip DSP implementation in 1979 and has since developed its DSP expertise by supplying its internal needs. Today, the company's DSP ICs are highly regarded on the merchant market.

The company focuses its DSP efforts squarely on communication applications. Lucent's DSP efforts are centered on maintaining its leadership role in telecommunications, including cellular phones, modems, and digital answering machines. Lucent has put its DSPs in more than 60 percent of the world's digital cellular phones.

Lucent Technologies discontinued new designs that incorporate its 32-bit, floating-point DSP. The company also focused its energy on application-specific rather than general-purpose DSPs. The application-specific products target modems and other communication applications.

Analog Devices

Digital motor control is one area of focus for business at Analog Devices. The company believes that real-time DSP solutions will be used in everyday appliances, such as dishwashers, washing machines, and clothes dryers, that feature some sort of motor; it believes that legislated motor efficiency improvements will become increasingly important.

The Analog Devices Sharc DSPs are the backbone of the company's DSP business. The company was able to break the $100 price barrier with its Sharc DSP as numerous high-grade commercial applications incorporated the device as part of the system. In late 1996, Analog Devices introduced a DSP that was 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 require numerous, expensive processors and large pieces of equipment.

In 1997, Analog Devices also initiated a manufacturing plan to increase its DSP output.

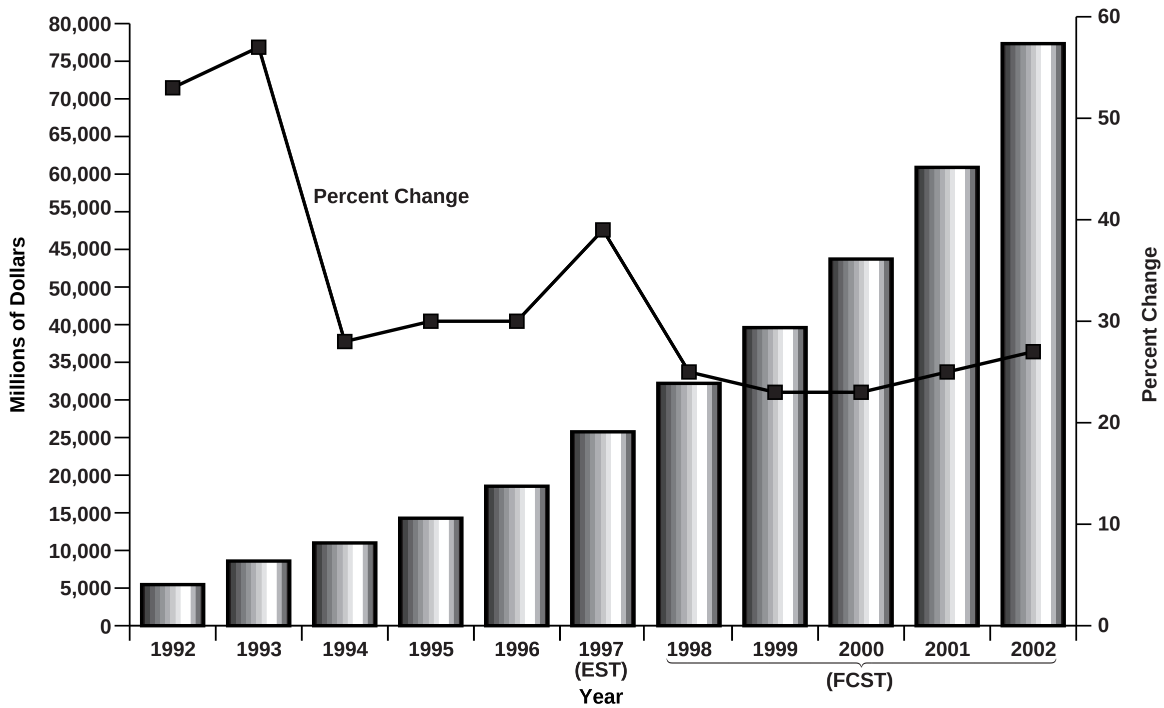
Motorola

Like Lucent Technologies, Motorola developed its expertise in DSP technology by supplying the needs of its own communication 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 applications. This IC 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, which is rated for 3.3V and above, 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.

THE MICROPROCESSOR MARKET

As explained earlier, the microelectronic architecture of a microprocessor is optimized for general purpose data processing where assembly language instructions are retrieved from external memory. Figure 6-41 shows annual microprocessor IC market trends from 1992 through estimated 1997 and ICE's forecast through 2002. This market category has increased from $5.5 billion in 1992 to $25.8 billion in 1997; this is a cumulative average annual growth rate (CAGR) of 40 percent. Market growth during these years was largely based on sales of so-called x86 32-bit microprocessors.



MPU Market ($M)	5,460	8,590	10,995	14,280	18,530	25,760	32,200	39,606	48,715	60,894	77,336
Percent Change	53	57	28	30	30	39	25	23	23	25	27

Source: ICE

18642J

Figure 6-41. Annual Microprocessor Market Growth and Forecast

ICE forecasts the worldwide microprocessor IC market will continue on a solid growth curve, with a CAGR of 25 percent through 2002. This translates into market growth from $25.8 billion in 1997 to $77.3 billion in 2002. The demand for more powerful processors in the high-end computer market will continue to drive the microprocessor market.

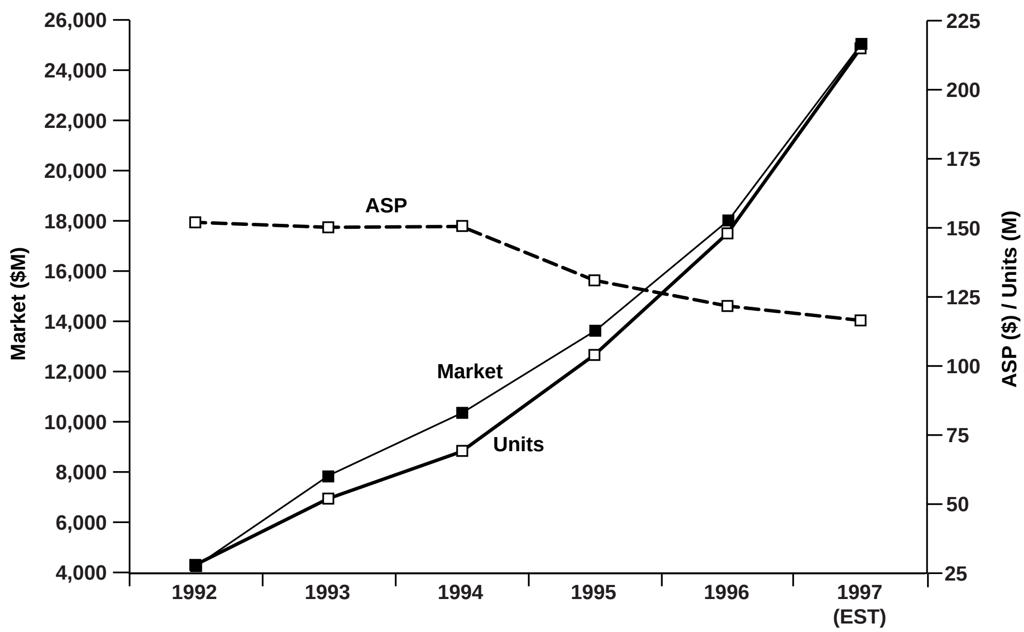
Microprocessors are available in 8-bit, 16-bit, 32-bit, and 64-bit designs. The largest market subcategory combines 32-bit and 64-bit microprocessors, which will be the focus of this discussion. This subcategory accounted for 96 percent of the microprocessor market in 1995 and 97 percent of the total microprocessor market in 1996 (Figure 6-42), based on final market data. As will be discussed later in this section, complex instruction set computing (CISC) ICs continue to dominate the 32-bit, 64-bit microprocessor market.

Figure 6-43 shows market growth, unit shipments, and ASPs of the 32-bit, 64-bit subcategory over the past several years and ICE's estimate 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 ASPs flat. In 1996, 32-bit, 64-bit microprocessor shipments increased 42 percent to 148 million units, while the ASP slid 7 percent to $122.

	1995		1996	
	$M	Percent Marketshare	$M	Percent Marketshare
8-bit	185	1%	140	1%
16-bit	470	3%	375	2%
32-/64-bit	13,625	96%	18,015	97%
32-bit CISC	11,995	84%	16,155	87%
32-bit RISC	1,630	12%	1,860	10%
Total MPU	14,280	100%	18,530	100%

Source: ICE 19269G

Figure 6-42. The 1995 and 1996 Microprocessor Markets



Market ($M)	4,255	7,870	10,355	13,625	18,015	25,045
Units (M)	28	52	69	104	148	215
ASP ($)	152.00	150.20	150.50	131.00	121.72	116.50

Source: ICE 20304D

Figure 6-43. 1992-1997 32-Bit, 64-Bit Microprocessor Market Trends

ICE forecasts the 32-bit, 64-bit subcategory will maintain its 97 percent share of the microprocessor market in 1998, growing 25 percent to approximately $32 billion. Shipments of 32-bit, 64-bit ICs should continue to increase nearly 50 percent while overall ASPs should continue to decline slightly.

1996 Rank	Company	1996
1	Intel	14,525
2	IBM	695
3	AMD	450
4	Motorola	410
5	TI	280
—	Others	1,655
	Total	18,015

Source: ICE 16915N

Figure 6-44. 32-Bit, 64-Bit Microprocessor Sales Leaders ($M)

Leading 32-bit microprocessor suppliers and their sales for 1996 are shown in Figure 6-44; when the final data is tabulated for 1997, the sales for these companies will show growths that parallel the microprocessor market category and little change in company position. Obviously, Intel, which has dominated the 32-bit market for several years, continued to dwarf its competition; Intel continues to monopolize the microprocessor market for personal computers. In fact, ICE does not anticipate any company providing a significant competitive threat to Intel during the next five years. By introducing new versions of its Pentium, Pentium Pro, and Pentium II ICs that are both faster and often less expensive than competitors' products, Intel continues to hold a tight grip on the microprocessor market.

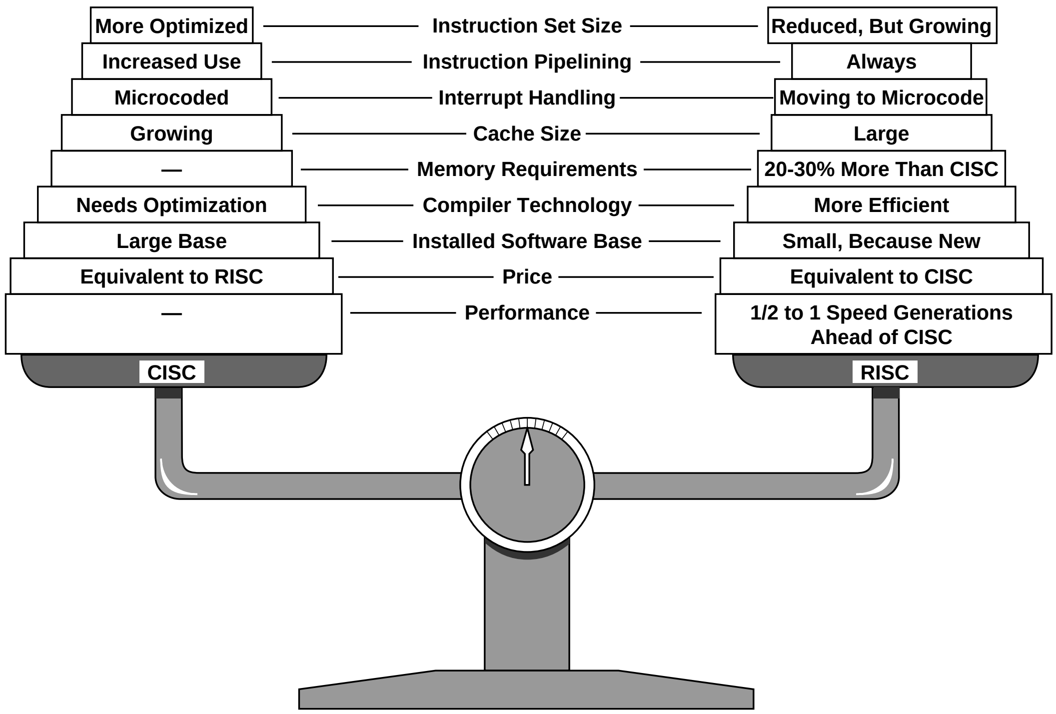
Competitors, including Advanced Micro Devices (AMD), Cyrix, Digital Semiconductor, Hewlett-Packard, IBM, Motorola, SGS-Thomson, TI, and a growing group of Asia-Pacific suppliers including Samsung, Winbond, and Macronix, have tried to steal market share from Intel, but have met with little success.

CISC versus RISC

The microprocessor market consists of two main IC architectures: complex instruction set computing (CISC) and reduced instruction set computing (RISC). A comparison of CISC and RISC architectures is shown in Figure 6-45. The most commonly used, and the greatest number of 8-bit, 16-bit, and 32-bit processors are CISC.

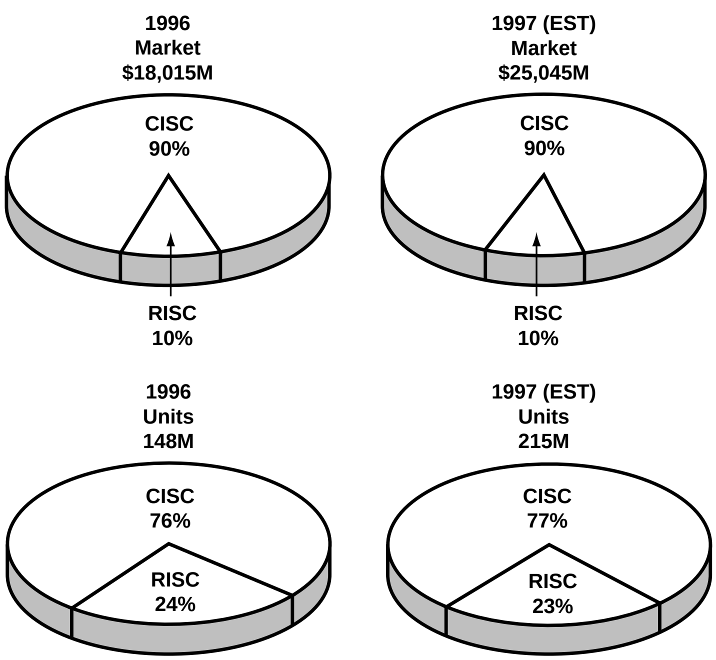
Despite the predictions made several years ago that the market for RISC microprocessors would surpass the CISC microprocessor market, ICE believes this will not happen in the foreseeable future. RISC-based microprocessors do offer several advantages over CISC ICs. In fact, RISC microprocessors dominate the performance-minded embedded microprocessor market. While the RISC market will continue to grow through 2002, the much lower ASPs for RISC ICs will not allow this market to surpass CISC ICs through 2002.

Figure 6-46 compares market shares and number of unit shipments for CISC and RISC microprocessors. CISC ICs dominated both categories in 1997 and are forecast to do the same in 1998.



Source: Motorola 21129A

Figure 6-45. Characteristics of CISC and RISC Microprocessors



Source: ICE 19273G

Figure 6-46. 32-Bit, 64-Bit RISC Versus CISC

32-bit CISC MICROPROCESSORS

Intel is by far the largest of the CISC microprocessor suppliers. Its ICs include the Pentium, Pentium Pro, and Pentium II microprocessors. Other CISC microprocessors include AMD's K5 and K6, the 6x86 from Cyrix, and Motorola's 680x0 family.

Intel

Mention CISC microprocessors and the terms x86, Pentium and Intel should immediately come to mind. The Santa Clara, California-based company has ruled this lucrative market. Together with Windows software supplier Microsoft, the so-called Wintel combination has been at the heart of over 80 percent of all PC shipments for the past several years. With its purchase of graphics peripheral maker Chips and Technologies in 1997, Intel hopes to have an even greater influence on the future direction of the PC market.

Intel's first microprocessor product was introduced in 1971; the 4004 had 2,300 transistors. Since then, Intel increased the number of transistors per microprocessor by nearly 40 percent per year through its Pentium II generation, which has 7.5 million transistors in the central processing unit alone. When plotted logarithmically, the number of transistors has increased along a steadily sloping line during the past 25 years (Figure 6-47).

A brief review of Intel's x86 microprocessor development history is shown in Figure 6-48. From its celebrated history, Intel's plans for the future are focused on the Pentium II that continues the legacy of the P6 family of processors beyond the Pentium Pro. Figure 6-49 provides an excellent look at Intel's microprocessor family and a few performance and technical characteristics.

Since it was introduced in 1993, the Pentium microprocessor has been an outstanding source of revenue and profit for Intel. However, as great as the Pentium has been, Intel will likely phase out all production of this device early in 1998. In the third quarter of 1997, Intel slashed prices on its Pentium and Pentium MMX (multi-media extension) microprocessors by more than 50 percent to move them along on their life cycles and also to put competitive pressure on AMD. The Pentium architecture will move to the embedded microprocessor market. While many embedded 386 and 486 users eagerly await Pentium performance in their systems, they remain cautious about its design challenges. A handful of companies offer Pentium modules in various size and speed options.

Moving from the Pentium, Intel will transition to full production of its Pentium Pro, which is well suited for the Windows NT software environment, and the Pentium II, which was originally code-named Klamath; Intel began producing and promoting it the second quarter of 1997. Figure 6-50 summarizes some of the highlights of the Pentium II microprocessor.

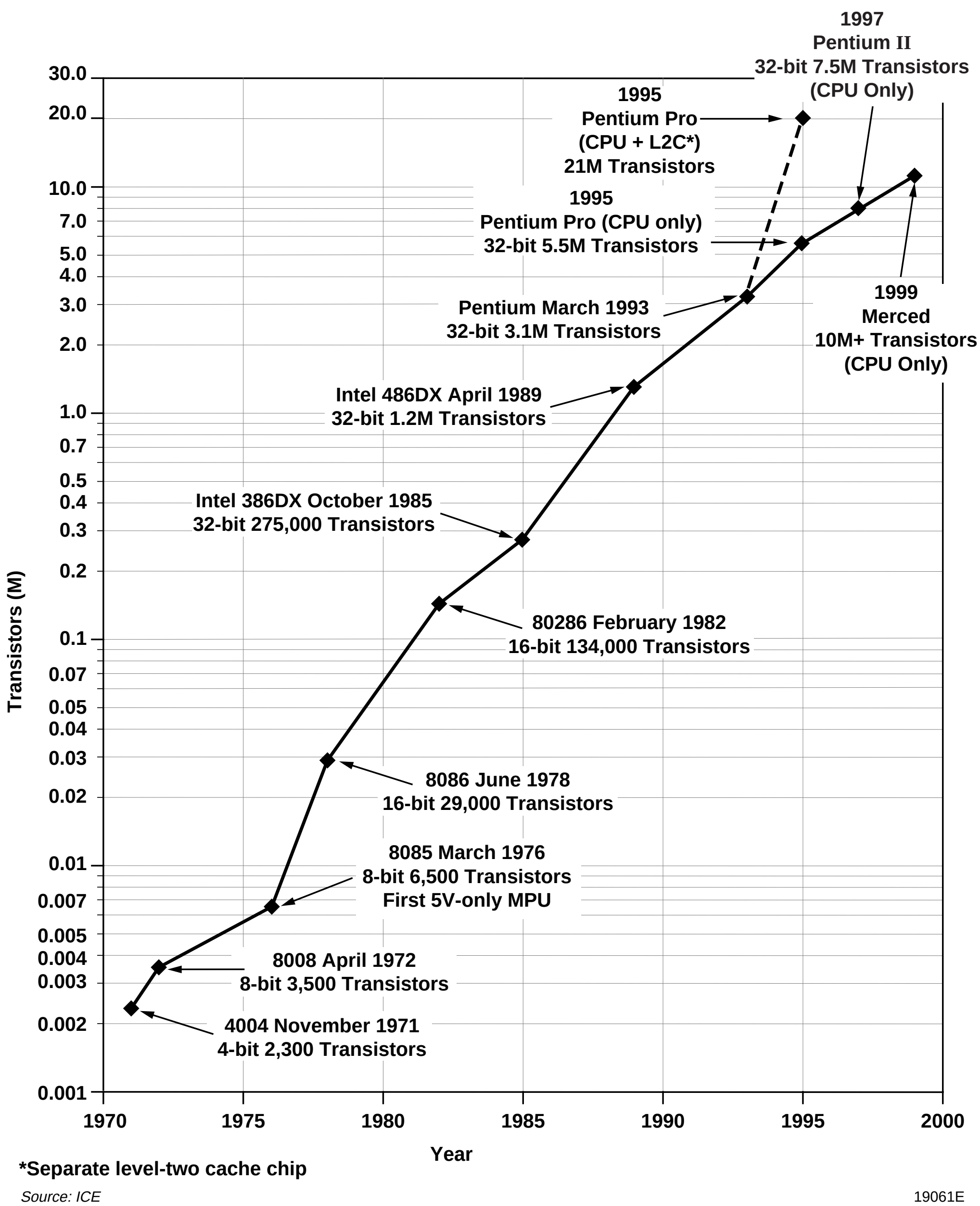


Figure 6-47. Intel Microprocessor Introduction Dates

The Pentium II raised the performance level for PC microprocessors. It is a CMOS, single-chip IC, rather than the BiCMOS, two-chip offering for current Pentium Pros. It will likely cut short the life cycle of the Pentium Pro (Figure 6-51) since it affords all the benefits of Intel's MMX technology while featuring higher clock rates and delivering improved performance on 16-bit code.

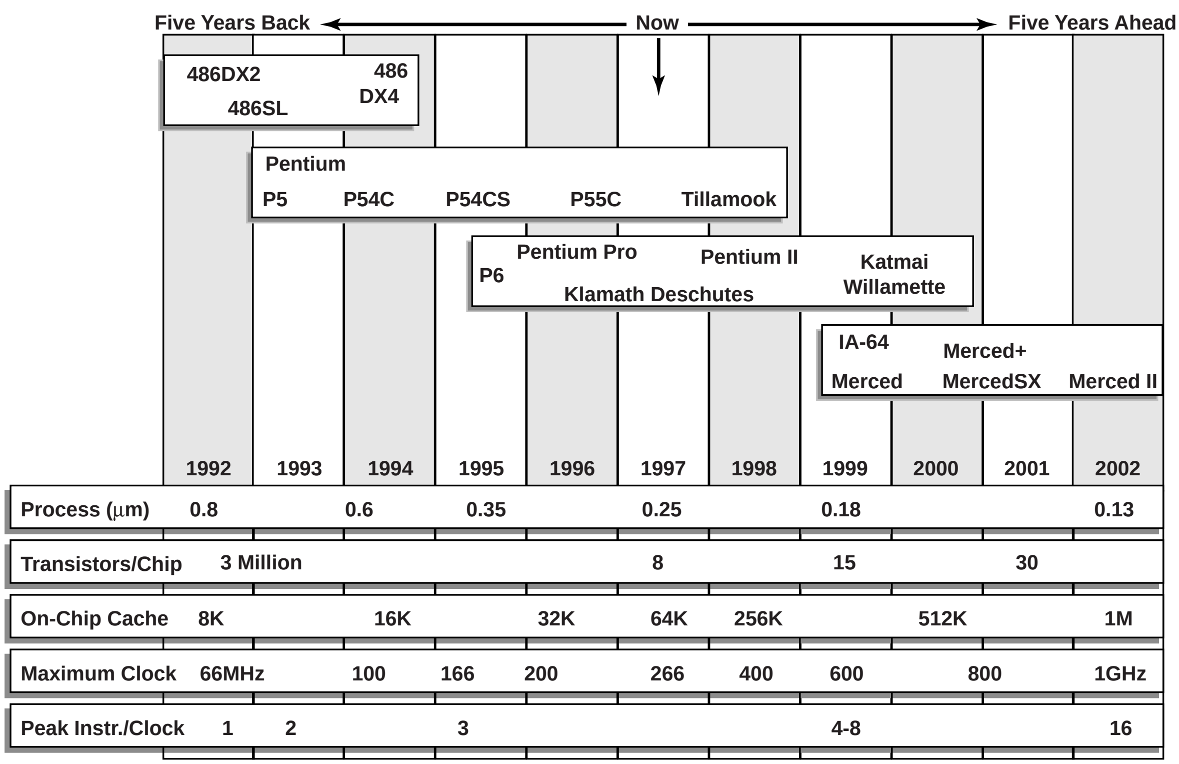
Intel Code: Other Names:	P2 286	P3 386	P4 486	P5 Pentium	P6 Pentium Pro	IA-64 Merced
Start of Design Work	1978	1982	1986	1989	1990	1993
Formal Introduction	Feb. 1982	Oct. 1985	Apr. 1989	Mar. 1993	Q3 1995	1998*
Volume Shipments	1983	1986	1990	1994	1996	1999*
Number of Transistors	134,000	275,000	1.2 million	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

20309E

Figure 6-48. Intel's Microprocessor Development History



Note: Features shown are for highest-performance x86 and IA-64 processors

Source: MicroDesign Resources

22763A

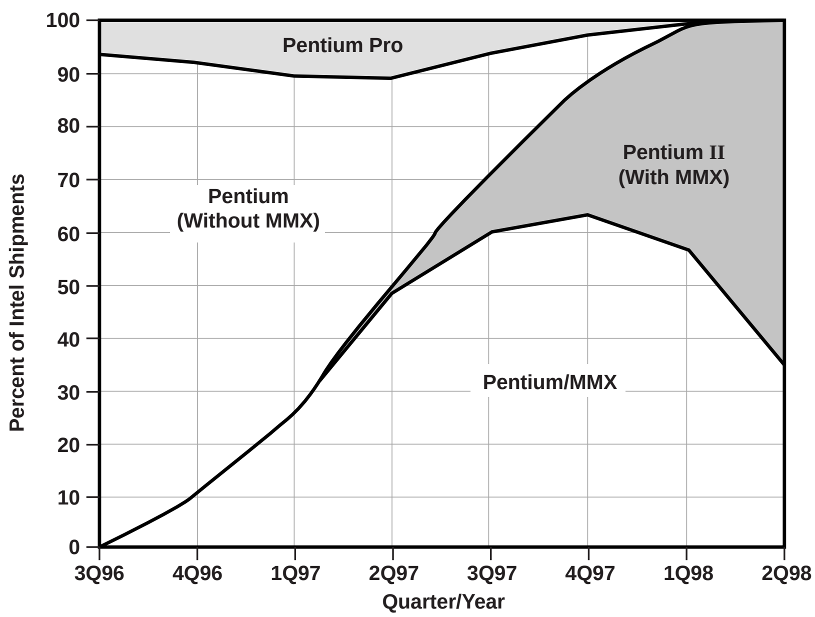
Figure 6-49. Microprocessor Roadmap Shows Greater Performance, Smaller Geometries (Pentium Phased Out as Merced Moves In)

Initial Pricing: PII-266MHz: $775
PII-233MHz: $636

Only sold with 512Kbyte of cache memory.
Only sold as a module, not as a stand-alone chip.
0.28µm, 4-layer metal, CMOS process
7.5 million transistors (CPU only)
Die size: 14.9mm x 13.7mm
Package: 528-pin plastic land grid array (LGA, similar to BGA)
Speedy, 0.25µm version (Deschutes) slated for 3Q97 introduction. First P6 for notebook computers.

Source: ICE 22752

Figure 6-50. Pentium II Highlights



Source: MDR 22753A

Figure 6-51. Intel's Microprocessor Shipment Forecast

Intel will allow the two parts to coexist in its portfolio through 1997. Pentium Pros will be directed mainly at the desktop PC and low-end server markets while the Pentium II is slated mainly for high-end PCs and workstations. By mid-1998, Pentium IIs will become the microprocessor for mainstream PCs.

Pentium IIs were initially available in 233MHz, $636 and 266MHz, $775 versions. A 300MHz version was slated to be released in late 1997. By year's end, prices for the 233MHz and 266MHz Pentium IIs will likely be less than $500. Although Pentium IIs didn't overtake the PC market in 1997, they will generate enthusiasm among those who need a powerful PC. Still, Intel was anticipating a "Pentium II 1997 Christmas season" for the PC market.

A unique feature of the Pentium II is that it is Intel's first microprocessor packaged in the form of a module. The module consists of a daughter card that holds the Pentium II, cache-tag, and external L2 cache chips. This module fits into a connector Intel calls Slot 1. Previous microprocessors plugged into various sockets, the most popular being Socket 7.

Not all OEMs are pleased with the new package, but with no other choice, they will comply. The new package may create additional difficulties for Intel's competitors. Other microprocessor suppliers will want to offer Pentium II-compatible products, but legalities may restrict their efforts to sell modules that plug into Slot 1. AMD's K6 and Cyrix's 6x86 are designed for Socket 7.

To keep the pressure on its competitors, Intel announced that it would make available a die-shrink version of its Pentium II. Using 0.25μm technology, the first of these ICs, code-named Deschutes, where slated to be released in late in 1997. Clock speeds of the Deschutes will initially be 300MHz, but will likely approach 400MHz with a die shrink in the first half of 1998. These microprocessors, which will carry the initial price tag of $1,980, will target the workstation market.

Another IC on Intel's near-term roadmap is the Merced, also know as IA-64; this IC is being jointly developed by Intel and HP. Although details of this 64-bit device are scarce, it is rumored to be the first to use some basic concepts of very long instruction word (VLIW) architecture. Some insiders and early indicators suggest, however, that the device may be more similar to a RISC microprocessor. Samples are slated to appear in 1998, with first production targeted for 1999. Currently, performance speculation abounds for the Merced. Using Intel's P856 CMOS process to manufacture these chips, some have estimated an initial clock speed of 600MHz. Moving to a 0.18μm process could increase the clock speed to 1GHz by 2000. Figure 6-52 summarizes some of the Merced speculation.

We can only wait to see what performance Intel gives its Merced IC. One thing is for sure: competitors, many of whom have only recently brought their Pentium and Pentium Pro class chips to the market, will have to work overtime to keep pace with Intel's aggressive microprocessor development strategies.

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

0.25µm, CMOS P856 Process
VLIW Core
Initial Speed: 600MHz
Initial Die Size: 300mm²
Production (0.25µm): 1H99
(0.18µm): 1H00

Source: ICE 22754

Figure 6-52. Merced (P7) Speculation

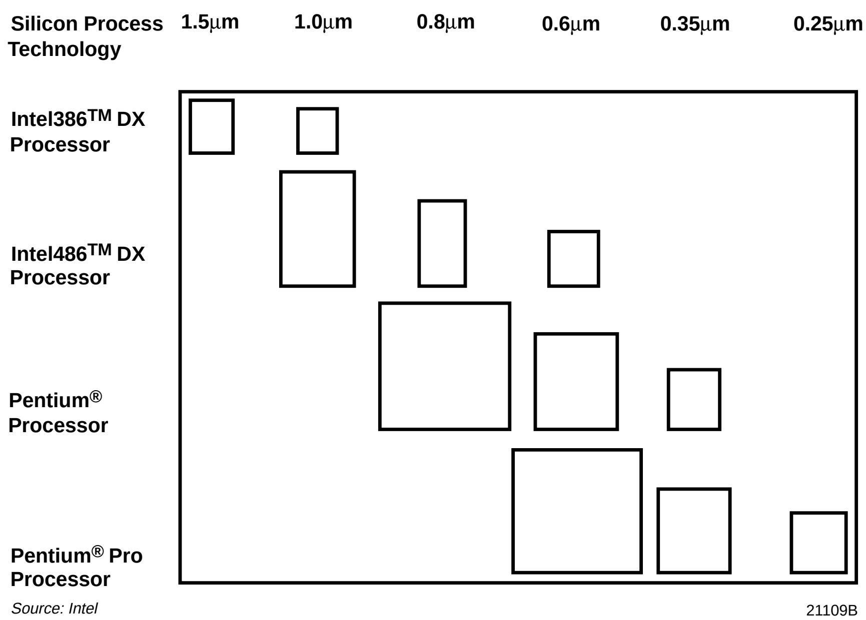


Figure 6-53. Intel's Microprocessor Process Technology Roadmap

Advanced Micro Devices

After a previously unsuccessful attempt at the microprocessor market with so-called K5 technology, Advanced Micro Devices (AMD) aggressively returned to the microprocessor market in 1997 with the introduction of its K6 microprocessor. The K6 will battle the Pentium Pro and Pentium II microprocessors and could quickly help AMD's financial situation, but this depends on how aggressively Intel fights back. It was initially priced at least 25 percent less than comparable Intel ICs. AMD may drive discounts to as much as 50 percent.

With the K6, AMD finally put to use its enormous Fab 25 in Austin, Texas. The facility shipped approximately five million K6 ICs in 1997. For AMD, total microprocessor unit output will not show much difference in 1997 from 1996. However, what is different is the average selling price of its product mix and the profit AMD will likely generate as a result of the higher-performance ICs it supplies.

Through the first half of 1997, AMD announced more than 75 customers that were shipping product or that had announced systems using the K6. Europe was the strongest market followed closely by Asia.

Ultimately, AMD would like to secure between 20 and 30 percent of the x86 microprocessor market (Figure 6-54). Actually, this is about all that Intel is willing to relinquish to all its competitors. If 20 or 30 percent of the x86 market does go to semiconductor manufacturers other than Intel, it will likely be split among a combination of manufacturers, including AMD, Cyrix, and IBM. ICE believes that a more realistic goal for AMD is 15 percent of the total x86 market.

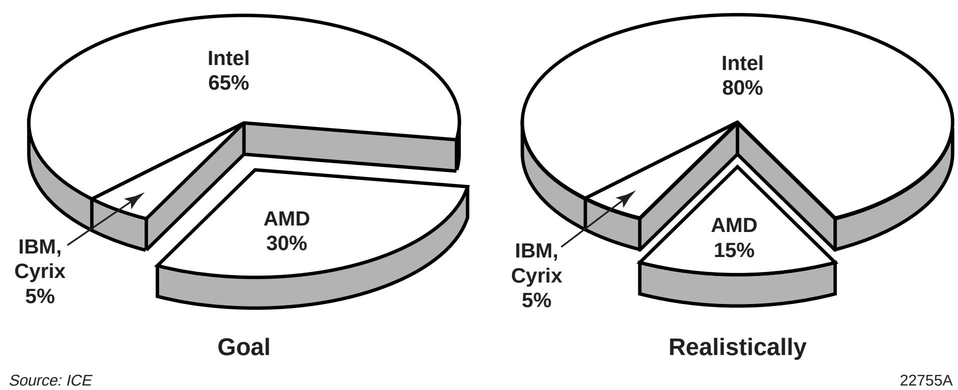


Figure 6-54. AMD's Share of the 1997 x86 Microprocessor Market

Figure 6-55 reviews some of the significant characteristics of the K6 microprocessor. The K6 microprocessor puts out more heat than some of its competitors; the 200MHz version dissipates 20W at 2.9V, and the 233MHz version dissipates 28W at 3.2V, both above the maximum ratings for Pentiums. The higher power ratings are not an issue for desktop manufacturers, where a fan and heatsink for extra cooling only add about $2 to system cost. But this high power rating may dissuade some computer manufacturers from considering the K6 for notebooks, where heatsinking is more difficult.

For a while in the second quarter of 1997, the K6 was the fastest microprocessor on the market. It out-performed the best Pentium Pro IC using several different microprocessor rating tests. The device includes MMX compatibility, enlarged caches, and a Pentium package pinout.

Initial Pricing: K6-233MHz \$469
K6-200MHz \$349

0.35µm, 5-layer metal, CMOS process

8.8 million transistors

Die Size: 162mm^2

Package: 321-pin ceramic Pin Grid Array (CPGA)
Socket 7 Interface

Future: 0.25µm K6 in development, could reduce die size to 80mm^2, increase clock speed to 300MHz, lower operating voltage to 1.8V. First parts due 4Q97.

Source: AMD 22756A

Figure 6-55. Highlights of AMD's K6 Microprocessor

AMD may have benefited from its Pentium-compatible Socket 7 pinout design in 1997, but inevitably, it may prove to be among the biggest threats to the long-term success of the K6. Some forecasts have projected that over 50 million PCs will have been sold in 1997 when the final numbers are in—most with the Socket 7 design. Looking a few years into the future, ICE believes that most computer manufacturers will make the switch to the Slot 1 interface that is compatible with Intel's Pentium II family. This will result in the number of PCs sold with Socket 7 dropping significantly, which could be troublesome for AMD.

ICE believes many PC manufacturers are willing of, perhaps even anticipating, the opportunity to source a company other than Intel for their x86 supplies. Unfortunately, price is not always the best justification for changing microprocessors or suppliers. As the dominant supplier, Intel still wields a substantial intangible value over its competitors' offerings. While AMD may be able to battle Intel on pricing, intangibles may hold the key to the success or failure of the K6, and perhaps, AMD.

Cyrix, National Semiconductor

Cyrix has participated in the x86 microprocessor market for several years. It focuses on the lower end of the PC market, which is believed to be gaining in corporate and consumer sales.

In third quarter 1997, Cyrix agreed to be purchased by National Semiconductor for \$550 million. National plans to cooperate with Cyrix in the development of system-on-a-chip technology for low-cost PC and information appliance markets.

To jump start sales, Cyrix signed a five-year deal with Electronic Data Systems (EDS) to build and market 6x86-based personal computers. Cyrix hopes to use these PCs as a proving ground to demonstrate the capabilities of its microprocessor design.

The company began sampling its next-generation M2 microprocessor—an x86 device with more multimedia support—late in 1996. 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 6-56.

- **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 21626

Figure 6-56. Cyrix M2 Key Features

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.

Centaur Technology

Daring to enter the x86 microprocessor market, Centaur Technology divulged plans for a microprocessor with integer performance of a Pentium MMX, but at a much reduced cost. Centaur, a new company, is a subsidiary of Integrated Device Technology, which will manufacture and market the new microprocessor. Initially scheduled for production late in 1997, the microprocessor will be targeted to the sub-$1,200 PC market, and will be available in speeds of 150MHz, 180MHz, and 200MHz.

THE RISC MICROPROCESSOR MARKET

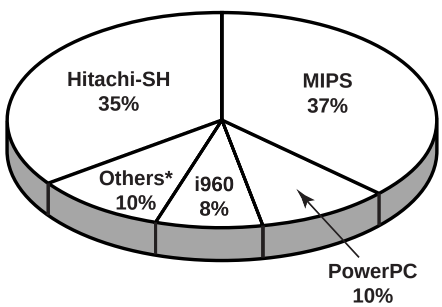
Leading-edge performance has always been characteristic of the RISC microprocessor market. RISC's strengths, including high processing rate and memory bandwidth, are well suited for executing and processing data. Moreover, RISC's clean, straightforward architecture helps keep down IC cost.

	1994	1995	1996
Market ($M)	721	1,631	1,860
Units (M)	10	24	36
ASP ($)	72.10	67.95	51.65

Source: ICE 21118C

Figure 6-57. RISC Microprocessor Market History

But the RISC microprocessor market is still quite small compared to the CISC microprocessor market. It grew to $1.9 billion in 1996, an increase of 14 percent (Figure 6-57). One reason for the growth was that numerous RISC IC manufacturers 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.



*Includes ARM, SPARC, ALPHA, HP-PA

Source: ICE 22757

Figure 6-58. 1996 RISC Unit Shipments by Architecture

Among the leading RISC ICs sold in 1996 was the Silicon Graphics MIPS RISC microprocessor (Figure 6-58). Key to the success of this architecture was its design wins in the Sony PlayStation and Nintendo 64 home video game systems. Further, it was widely used in the Web TV Internet terminal from Philips and Sony, EchoStar's Dish Network satellite receiver, and numerous other communication applications.

From a desktop standpoint, RISC microprocessors have not been warmly embraced. In fact, the Motorola-IBM PowerPC was the first volume RISC microprocessor used in a PC platform. However, aside from serving traditional Mac PC customers, PowerPC has failed to convert many x86 and Pentium users.

Digital Equipment Corporation (Digital Semiconductor) is attempting to compete in the PC market with a system based on its Alpha RISC microprocessor. The company announced that 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 Digital and Samsung entered into an agreement that licensed Samsung as an alternate source manufacturer of current and future implementations of Digital's Alpha 64-bit RISC microprocessor.

Powerful 32-bit RISC microprocessors have been incorporated into many embedded applications (Figure 6-59). RISC architecture stands out in embedded applications because of its favorable price and performance characteristics. For example, IBM's 50MHz 401GF sold for $13 at the end of 1996; a 40MHz 386DX and 386SX could be purchased for around $10. One of the fastest embedded RISC processors is AMD's 486DX5 at 133MHz. This remarkable performance was available for around $30. Whether embedded or non-embedded, RISC microprocessors will be used in several new products and technologies targeted for home and office environments (Figure 6-60).

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 20441

Figure 6-59. Embedded RISC Application Categories

Key highlights from the RISC market are outlined below:

Silicon Graphics MIPS

Figure 6-61 shows the MIPS microprocessor roadmap, which reveals three successive 64-bit designs, the MIPS 12000 followed by the code-named H1 and H2 processors. The R12000 is an extension of the R10000, which is currently available. It maintains the same instruction set and socket compatibility with the R10000. The R12000, however, boosts the central processing unit clock speed to 300MHz. Volume production of the R12000 is slated for early in 1998.

The H1 will be the first implementation of the next-generation MIPS V instruction set and is optimized for image processing, real-time video compression and decompression, and three-dimensional graphics. The H2 takes those characteristics a step further. It is expected to power machines ranging from large scalable servers to desktop systems beginning around 2000.

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 21122A

Figure 6-60. New Microprocessors Promise More "Smarts"

Motorola and IBM PowerPC

The IBM-Motorola roadmap for the PowerPC family is an answer to Intel's Merced microprocessor (Figure 6-62). Their IC, code-named G4, will put two to four central processing units and a shared cache inside a single multichip module. The G4 predecessor, G3 or so-called Arthur, is a 32-bit successor to the PowerPC 6xx series.

Arthur or G3 is expected to pack 6.5 million transistors—1.5 million for the central processing unit and 5 million for on-board cache—onto a die size of 67mm2. The initial version will likely be clocked at 233MHz to 300MHz and be fabricated in a 0.25μm CMOS process.

Motorola and IBM continue their alliance with Apple Computer. However, the two have remained silent regarding the poor performance of Apple, that company's lack of leadership following the 1997 resignation of its chairman and CEO, and the impact it has on the future of the stand-alone PowerPC microprocessor in desktop PCs.

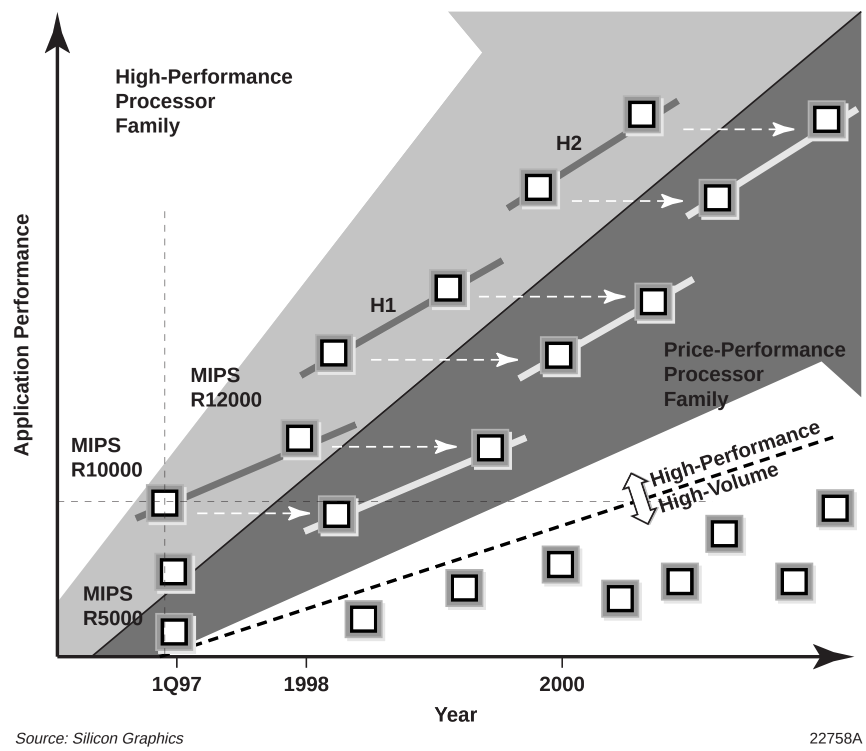


Figure 6-61. MIPS High-Performance Microprocessor Roadmap

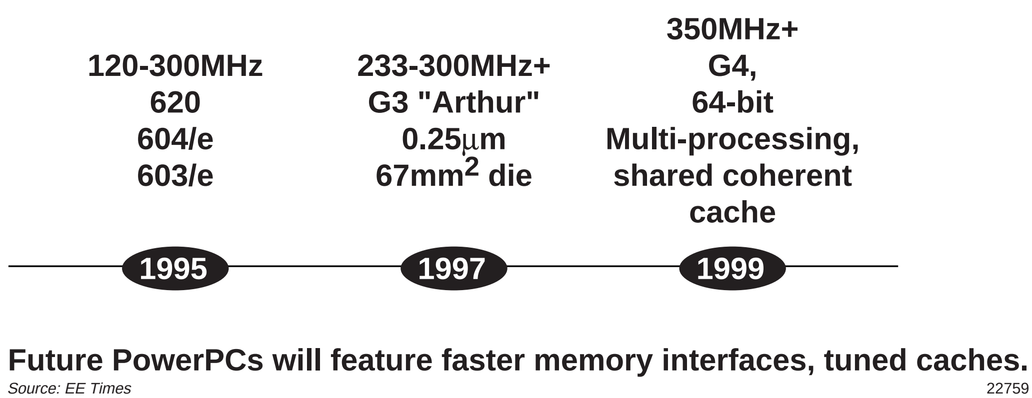


Figure 6-62. PowerPC Roadmap

Motorola and IBM still develop the PowerPC together, but differ on several fronts including manufacturing process and pricing. For the most recent 250MHz PowerPC microprocessor, Motorola set pricing at $395 in quantities, IBM at $720.

IBM

Late in 1996, IBM presented its newest microprocessor, 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 IC 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

Exponential developed a BiCMOS version of the PowerPC604 IC, called the x704. Exponential claimed its design and process roadmap would keep them two years ahead of CMOS microprocessors. However, even as Motorola and IBM deployed PowerPC chips ahead of schedule in 1997, Exponential fell behind. The startup company hoped to launch a 533MHz version of its x704 PowerPC microprocessor by mid-1997, but problems prevented the latest version from reaching its intended clock speed. Instead, the company canceled the x704 program and closed the doors to its main office in San Jose, California, in mid-1997.

Hewlett-Packard

Hewlett-Packard (HP) introduced the latest in its PA-8000 family, the PA-8200. These ICs were sampled at the end of 1996. Volume production was slated for late in 1997. HP believes its PA-8200 will run at a clock speed as fast or faster than Digital's Alpha microprocessors. 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 microprocessor. HP believes that, depending on the application, its PA-8200 will improve performance 35 to 75 percent.

Digital's Alpha

Digital Semiconductor announced its newest Alpha microprocessor, the 21264. 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 PC microprocessor, unless it targets applications such as three-dimensional rendering or simulation.

Digital has also announced that it is producing a 600MHz version of its 21164 Alpha microprocessor. The new IC clocks 20 percent faster than the 21264 IC's 500MHz, while dissipating 30W of power. The improved performance comes from process and yield upgrades.

Early in 1997, Digital filed a lawsuit stating that Intel infringed on Digital's intellectual property patents. Digital has some very good patents; it developed many RISC microprocessor innovations while Intel developed x86 CISC-based processors. With RISC, Digital has the intellectual property. But, Intel's upcoming Merced microprocessor is rumored to be a RISC-like device. Seemingly, the intent of the suit was that Digital wanted to establish its claim to present and future intellectual property, especially knowing the enormous future market size. Curiously, however, this law suit was settled late in 1997, pending government approval, with Intel buying Digital's Alpha IC manufacturing and development operations, in Massachusetts, Israel, and Texas, for just $700 million, the officially reported amount. Digital did keep its Alpha design team, thus becoming a fabless semiconductor manufacturer.

Sun Microsystems

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