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PC Market Centers On Growing 486 Family

Pentium Captures Headlines, But 486 Dominates Shipments

YEAR IN REVIEW 1993

by Michael Slater

Despite the enormous amount of attention garnered by Pentium and a host of RISC microprocessors in 1993, 1994 was clearly the year of the 486 in terms of volume. The previous champion, the 386, began a steep decline in 1993 and now plays a relatively minor role. In fact, Intel has shifted its 386 efforts to its embedded-control division, marking the formal end of the company's efforts to serve the PC market with this family. Through its joint venture with VLSI Technology, Intel will promote the 386 in an integrated form for PDAs. AMD has taken over as the primary supplier of 386 chips to the low-end PC business.

Intel has accelerated its plans for ramping up Pentium production and has promised steep price cuts to spur demand. In 1994, Pentium will rise from an insignificant blip on the sales charts to occupy a rapidly growing niche, but at least six times as many 486 chips will be shipped. Intel expects that Pentium shipments will account for 15% of the PC market in 1994, which would imply about six million units.

By the end of 1995, Intel expects its Pentium shipments to exceed its 486 shipments. By this time, however, AMD and others will be shipping significant numbers of 486 chips, so total 486 shipments probably will continue to exceed Pentium shipments until 1997. Figure 1 (see below) shows the PC shipments forecast from analyst Dean McCarron at Mercury Research (Scottsdale, Ariz.), which predicts that Pentium volumes will exceed 486 shipments by the end of 1996.

Intel says that it will have five factories producing Pentium chips in 1994. Pushing Pentium aggressively is one way to limit the opportunities left for AMD, Cyrix, Texas Instruments, and others. Intel hopes to position the 486DX2 as a midrange product, raising the bar for 486 competitors, with Pentium taking the high-end role that the DX2 held this year. In the past 18 months, system prices fell dramatically, but mainstream performance levels didn't change as significantly; in 1994, the price points will remain relatively constant while performance gets a major boost.

With its Pentium offensive, Intel also is seeking to counter the threat from RISC architectures. This is more of a long-term than a short-term threat, however; RISC processors will ship significant quantities in PCs this year only in Apple's Macintosh systems. The one million PowerPC Macs that Apple expects to ship constitute an enormous volume within the scale of the desktop RISC market but represent less than 3% of the PC business.

In a year in which Intel was, in many respects, under siege, it managed to produce record sales and profits—a remarkable demonstration of the company's ability to fight back and to benefit from a burgeoning PC business. For the third quarter of 1993, Intel's revenue was up 57% from the year-earlier quarter, and profits jumped an astonishing 143%.

The battle is only just beginning, though, and Intel's market share and profit margins are likely to decline in the coming years. In the long term, RISC processors running Windows NT (or its successors), Workplace OS, or Apple's Macintosh OS could present a significant threat, but in the short term Intel's key competitors are the other suppliers of x86-compatible microprocessors.

In either case, for Intel to continue its growth and profit levels will require significant growth in the PC market. This is a key reason that Intel is investing heavily in technologies such as plug-and-play, PCI, and desktop video. By advancing the PC platform, Intel hopes to keep it competitive with the Macintosh and other RISC-based alternatives, expand the market by appealing to new users, and keep existing users buying ever-faster systems.

486 Variants to Proliferate in 1994

In terms of new products, 1993 was a surprisingly thin year for the 486. Intel rolled out its SL-enhanced (aka S-series) 486 line, adding system management mode and 3.3-V operation to all members of the family,

but offered no new clock speeds, cache sizes, or other performance-related features. Intel had promised 30 new 486 varieties, and while this may have been literally true, the variations—package types, supply voltages, SMM, and clocking schemes—weren't especially interesting, especially for desktop systems. This is in contrast to the previous year, which saw the introduction of the 486SX-33, the 486DX2-50, the 486DX2-66, and the 486SL. Indeed, the most significant change in Intel's product line was the abandonment of the SL integration path, leaving the 486SL as a dead-end product.

The coming year should see much more activity, however. Intel is moving the 486 to its 0.6-micron process, which will enable higher clock rates and reduce production cost. A new version of the 486, code-named P24C and widely rumored as the 486DX3, will be introduced in March as the IntelDX4. In a move designed to provide a protectable name that will be harder for competitors to leverage, Intel has dropped the "486" part of the designation. While Intel has not revealed the product's details, sources indicate that the DX4 will support a range of clock multipliers, including half-steps such as 2.5. These chips are likely to include larger caches, possibly with a write-back protocol. These enhancements would help reduce the performance drag of the main memory system as the mismatch between on-chip and off-chip speeds increases.

The 0.6-micron process is designed for 3.3-V operation, and the DX4 devices probably will be offered at this supply voltage only (but with 5-V I/O). The lower voltage will allow the clock rate to be doubled without increasing the power consumption.

The DX4 will fill the gap between the current 486 line and Pentium. These chips were expected to debut last fall, and there are several possible reasons for the delay. Production problems with the 0.6-micron process could be one reason, but there are clear business reasons as well: the existing 486 line has been selling very well, and there was no compelling need to add another chip to the lineup. Furthermore, a 100-MHz DX4 should come very close to a 60-MHz Pentium in integer performance, especially on code that has not been recompiled with a Pentium-optimized compiler. Intel may want to wait until Pentium has moved up to 80 or 100 MHz to keep its position clear as the performance leader.

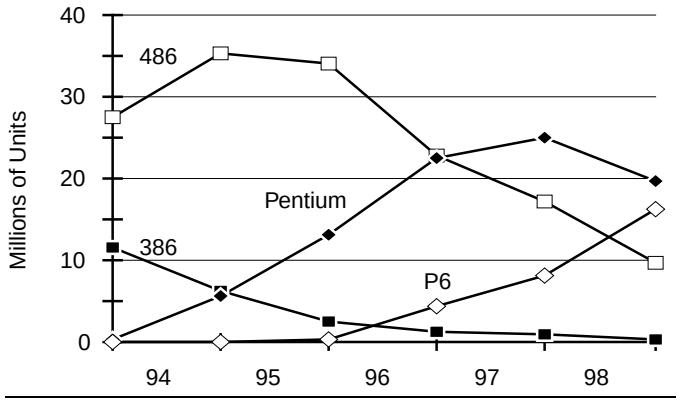

Figure 1. This PC shipments forecast shows that the 486 is still going strong, but it will begin its decline next year. (Source: Mercury Research)

Figure 2 shows Mercury Research's forecast for the division of the 486 market over the next five years. Last year, the market was evenly split between the 486SX and the combination of the 486DX and DX2. This year, the 486DX2 will largely displace the 486DX. The 486DX-33 was the single most popular 486 flavor in 1993; in 1994, the 486SX-33, DX2-50, and DX2-66 will share the limelight. In the coming years, the DX4 will take on increasing importance, and the various SX versions will shrink in significance as DX2 prices drop.

Pentium Moves to 0.6-Micron Process

Other than the DX4, Intel's major thrust in 1994 will be to proliferate the Pentium line. Today's 0.8-micron Pentium will be short lived, and a new design, code-named P54C, will take the lead as the volume Pentium processor. Designed in a 0.6-micron process, this chip will cut the power dissipation by more than 50%, greatly simplifying the thermal considerations for system designers. It will also increase yield at 66 MHz, which has been so poor that Intel had to increase the minimum Vcc specification, and it will enable even higher clock rates—probably 80 MHz at first and 100 MHz or higher by the end of the year. The denser process should decrease production cost as well. Unlike the original Pentium chip, the P54C presumably will support an external bus optionally running at a fraction of the CPU speed, a feature that is needed to make system designs practical as the on-chip speed is increased.

While the P54C will make Pentium a more practical mainstream processor, from both a chip manufacturing and system design perspective, it will also introduce some new problems. While it will accept 5-V inputs, it will operate only from a 3.3-V supply, which will require system designers to tackle new power supply designs. Intel also has integrated the APIC (advanced priority interrupt controller) on the chip, which dictated a change in pinout. As a result, system designers not only will need new power supplies, they also will need new board designs for the P54C.

Including the APIC on the processor is key to Intel's enhanced OverDrive upgrade strategy, which is to allow the second processor to supplement, rather than replace, the original processor. This is an appealing strategy; it always seemed a waste to disable the original CPU when an OverDrive processor was added. Virtually no additional logic will be required to support the two-processor configuration. The two processors will share the second-level cache, so they will not be as effective as a high-end

multiprocessor system in which each CPU has its own second-level cache, but the performance boost still should be significant.

Of course, having two processors won't provide any performance boost at all without software that knows what to do with the second processor. Windows NT is likely to be the most popular operating system that will provide the needed multiprocessor support. This appears to be a small market, however, at least for the next couple of years. Chicago, which will be the mainstream version of Windows in 1995, doesn't have multiprocessor support.

Intel also will move the Pentium CPU core downmarket with the P24T, a version of the processor with an extended 486 pinout that will be marketed as an OverDrive processor for 486DX2 systems. The pinout is similar to the standard OverDrive socket, but with an extra row of pins all the way around. Most of these pins are used for power and ground, but six of them provide additional signals to support the chip's write-back cache.

Heat dissipation issues have plagued this upgrade device. Although Intel says it told system makers how much heat such a chip would dissipate, many vendors put in the P24T socket but did not provide enough cooling. As a result, Intel now plans to offer the chip with an integral "fan-sink" that has a built-in fan. This will allow it to be used in systems that don't provide enough airflow on their own. It will require more vertical clearance than the original design, however, so Intel probably will offer the original version as well for systems that have enough airflow but not the vertical space above the processor socket.

This chip also could be used in new systems, but it is not clear how compelling it would be. On integer applications, it is likely to have similar performance to a DX4, which will be cheaper to manufacture. For users who want maximum performance, the full 64-bit-bus Pentium design makes more sense.

AMD Jumps into 486 Game

For AMD, 1993 marked its much-heralded entry into the 486 market, giving Intel its first direct competition for its highest-volume microprocessor family. The year was also marked by a series of legal upsets (see sidebar) that didn't keep AMD out of the market but kept the legality of AMD's products in question. Early in the summer, AMD began shipping its reverse-engineered 486DX using Intel microcode, and over the course of the summer and fall, AMD added SX and DX2 versions. AMD's 486SX uses clean-room microcode, in the sense that it was developed independently of Intel's 486 code. AMD's designers did, however, use Intel's 386 microcode, to which AMD thought it had a clear right as a result of the arbitration ruling. With the arbitration ruling now in the hands of the California Supreme Court, the legality of this microcode is in question, so AMD is developing yet another version of the 486 microcode that is truly clean. All things considered, AMD has displayed remarkably poor judgment on microcode-related issues.

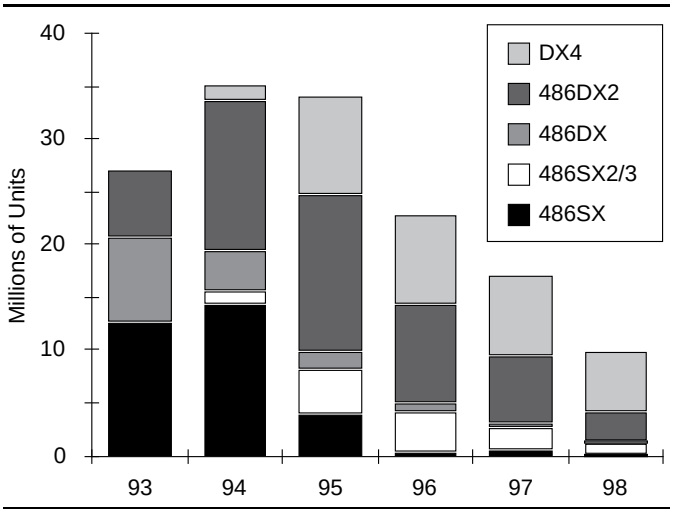

Figure 2. In 1994, the 486DX2 will overtake the 486DX, and in 1995 it and the DX4 will dominate the 486 market. (Source: Mercury Research)

Legal concerns aside, AMD faces some challenges in the 486 market. Two years ago, AMD succeeded in capturing the majority of the 386 market due to a combination of factors. Perhaps the most significant was that Intel's 386 is fabricated in an older, 1.0-micron technology, while AMD, benefiting from its later start, uses a 0.8-micron process. This lowered AMD's costs, decreased the chip's power consumption, and allowed it to run at higher clock rates. These factors made it harder for Intel to remain competitive. AMD moved the 386DX to 40 MHz, a clock speed that Intel never offered, and led Intel in moving the 386SX to 25 and then 33 MHz. AMD also added system management mode (SMM) to its 386 chips, while Intel offers this capability only in its SL and 486 lines. Intel chose to abandon the 386 business to AMD and focus on moving the market to the 486—something that it accomplished very successfully in 1993.

The situation with the 486 is rather different, however. Having abandoned further development of its integrated SL processor family, Intel added SMM to its standard 486 chips, eliminating this as a possible differentiator for AMD. Intel also has aggressively pursued higher clock rates, making it very unlikely that AMD will be able to offer a higher frequency than Intel.

Thus, AMD must compete in the 486 business on a more even footing, and it will not—at least in the next year or two—achieve anything close to the 70% or greater market share that it attained with the 386. AMD is also limited by its production capacity, because its 486 requires a 0.8-micron, three-level-metal process, which the company is running only at its Submicron Development Center (SDC). AMD, which shipped only about

A Brief Guide to the Maze of x86 Litigation

Keeping up with x86-related legal battles has become a nearly full-time occupation. Not only is Intel involved in complex litigation with both AMD and Cyrix, but with the Cyrix/TI battle, the contenders have begun suing each other. Here is a brief rundown on the key cases currently pending.

The result of the long-running Intel/AMD arbitration, through which AMD has sought rights to the 386, remains in question. In 1993, a California appellate court reversed the essential aspects of the arbitrator's ruling, but the California Supreme Court has agreed to hear AMD's appeal of the reversal. This should reach the state's top court this fall, finally ending the eight-year odyssey.

The other critical dispute between the two companies is over AMD's right to use Intel's microcode. In 1992, a jury ruled against AMD in the test case for this issue, based on the 287 math coprocessor. The judge later threw out the jury verdict, however, because of evidence withheld by Intel. The retrial is now under way, and a ruling is likely in late February. Of course, whatever the result, it will be appealed, so the final decision won't be reached soon.

Another court case, in Texas instead of California, focuses on similar issues but in the context of the 386. In this case, Intel also asserts that certain PLA contents are protected by copyright and not licensed to AMD. AMD has sought to delay this trial until after the arbitration issue is settled, but the federal appellate court recently decided that the case can proceed independently. No trial date has been set, but a trial this year is likely.

Intel has also sued AMD over its 486. In addition to the claims in the 386 case, Intel claims that AMD does not have the right to the in-circuit emulator (ICE) microcode that Intel says AMD used to implement SMM; that AMD's "clean-room" microcode violates Intel's copyrights; and that the patent license does not apply to chips produced after 1995. A summary judgment hearing on the ICE microcode aspect of the suit is scheduled for February 23. No trial date has been set.

AMD has sued Intel for allegedly violating antitrust statutes with its sales practices. The trial is set to begin in October, so the decision might not be rendered until 1995.

The key legal issue for Cyrix, and for future fabless x86 vendors as well, is whether a foundry's license protects against claims of patent infringement. So far, several courts have ruled that it does, but the issue is now under appeal. The key test case is Intel v. ULSI. An Oregon court ruled in favor of Intel, but the Court of Appeals for the Federal Circuit reversed the lower court's ruling. The U.S. Supreme Court is due to decide this month whether it will hear Intel's appeal; if it agrees to do so, a trial is likely late this year.

Another critical legal issue for all of Intel's competitors is the so-called '338, or Crawford, patent, which Intel asserts requires system makers to have an Intel patent license if they use a non-Intel x86 processor with paging enabled. Intel brought an International Trade Commission action against Taiwanese PC maker Twinhead, and both AMD and Cyrix have intervened on Twinhead's behalf. The ITC trial is scheduled to begin in May. AMD has separately sued Intel, seeking a determination that its customers are licensed under '338; this suit is on hold pending the outcome of the ITC trial.

Cyrix has sued Intel, seeking to overturn four Intel patents and asserting that, even if the patents are valid, system makers are covered by the chip maker's license. The licensing aspect was tried late last year, and a ruling is expected any day. A trial on patent validity and infringement, as well as antitrust issues, is set to begin this month.

Intel sued Cyrix over its "Ditto" parody of the Intel Inside logo. In a rare out-of-court settlement, Cyrix has agreed to drop the campaign.

Cyrix and TI are suing each other, each claiming breach of their agreement. TI is seeking access to Cyrix's 486S, 486DX, and M1 designs, while Cyrix is asking the court to take the 486SLC core back from TI, which would put that company out of the x86 business, at least temporarily.

350,000 486 chips in 1993, expects to reach a production level of about one million units per quarter by mid-1994—about one-tenth of Intel's plans. This 10% market share should be attainable by AMD even without any real product differentiation, thanks to the relationships it has established as a supplier of 386 processors and the desire of many system makers, especially in the Far East, to be less dependent upon Intel.

AMD does have a few opportunities for differentiation, if it can exploit them before Intel fills the gaps. One is for a higher-speed 486SX processor. Intel does not offer a clock-doubled version of this chip, preferring to push users seeking high performance—even if they don't care about floating-point—to the more profitable 486DX2. A 486SX2 chip could be popular, however, since most users need only integer performance. AMD will add such a chip to its lineup this spring, but should it prove successful, Intel could fight back with its own version. Intel clearly has the ability to offer such a chip today; the decision not to is simply one of maximizing profit. Intel may prefer to counter such a chip with aggressive pricing of its 486DX2.

Another opportunity, which AMD foreshadowed at the Microprocessor Forum last fall, is for a 486 with a 16K on-chip cache (twice that in today's chips), using a write-back cache design rather than the slower write-through approach of the standard 486. Intel's DX4 might offer these features before AMD does, however.

At Comdex last year, AMD showed its first 486 chips fabricated using a 0.6-micron process. The company expects to have this process in production at the SDC in the second half of the year. This process shrinks

the 486 to a smaller die size than AMD's 0.8-micron 386, making it practical to double the cache while still keeping the die size modest. It also will enable higher clock rates and reduce power consumption while cutting AMD's costs.

As long as AMD remains limited to production at the SDC, however, it cannot be more than a niche player in the 486 business. The company has said that it is considering foundry arrangements, but it does not expect to reach any such deals until the second half of the year, if at all. AMD's real boost will come in 1995, when its large new fab in Austin is scheduled to come on line. By late 1995, AMD should be in a position to serve as much of the 486 market as it can reach. In the same timeframe, Intel expects the majority of the marketplace to have moved to the Pentium line, so Intel could follow its time-honored strategy of leaving the fading, low-end business to its competitor while focusing its fabrication resources on the more expensive (and, by that time, more profitable) Pentium and its follow-ons. In 1996, AMD could become the primary supplier of 486 processors.

AMD revealed—but did not ship—its first highly integrated 386 design last fall. The 386SC, also called Elan, comes quite close to the goal of being a single-chip PC, less memory. (Ironically, it was Intel that, back in 1990, promised such a chip by 1993, but never delivered it.) The 386SC should find use in low-end subnotebook systems and possibly in WinPad PDAs *(see **060104.PDF**)*, but it is unlikely to become a high-volume product. Its significance is as a test bed for the system-level integration work, and a version with a 486 core—perhaps to debut by early 1995—is more likely to reach high volume.

AMD hopes by the end of 1994 to unveil its first fully independent x86 design, a superscalar implementation code-named K5. With this chip, AMD expects to achieve complete independence from Intel, eliminating the constant court battles. (Somehow, though, we expect Intel will find reason to sue AMD over this chip as well.) AMD has revealed little about the design, except that the company expects it to be competitive with Pentium. Given that this chip will be AMD's first experience with an independent x86 design, as well as its first superscalar design, schedule slips would not be surprising.

It is unlikely that the K5 will offer the architectural extensions that Intel has implemented in Pentium but documented only in the secret Appendix H, but these probably are not critical. The purposes of the extensions—faster interrupt handling in virtual-86 mode and large MMU pages are probably the most important—are relatively clear, and AMD can learn a lot by tracing Windows NT and other software that uses these features. AMD may implement them in slightly different ways, which would require OS software to provide separate code to take advantage of these features. Fortunately for AMD, Microsoft has demonstrated its desire to encourage alternative microprocessor suppliers and is therefore likely to provide the needed support.

Cyrix Moves Up to 486 Pinout

Meanwhile, particularly in the notebook computer market, a third player has made a significant impact. Cyrix first entered the microprocessor business in 1992 with its 486SLC, which combines a 486-like CPU core with a 1K cache and a 386SX bus interface. This chip has been modestly successful, but a combination of low prices and declining demand for these parts has led Cyrix to focus on its newer chips. Last fall, the company released the clock-doubled 486SLC2-50, which is likely to take over most of the SLC's sales.

In 1993, Cyrix also added its first 486-pinout parts: the 486S, which has a 2K cache and no FPU, and the Cx486DX, the company's first direct competitor to Intel's 486DX. The Cx486DX has the same 8K cache as Intel's design and an even faster FPU, but it has the same integer core as Cyrix's earlier designs. This core lacks a dedicated address adder and is therefore one clock cycle slower on instructions that perform an address computation. As a result, with the cache in write-through mode, the Cx486DX must run at a higher clock rate than Intel's chip to achieve the same performance. With the cache in write-back mode, it matches or beats Intel's performance at the same clock rate, according to Cyrix.

The 486S has not been very successful, as it has nothing to offer over Intel's 486SX, and Intel's aggressive pricing of that part makes it difficult for Cyrix to compete on price. The Cx486DX has more of an opportunity, since profit margins are much higher in the DX market, but Cyrix has been hampered by yield problems at its primary foundry, SGS-Thomson. Cyrix says that these problems are behind it now, and that it has another unnamed foundry producing chips. The Cx486DX could therefore become a more significant player in 1994, but it lacks the relatively protected niche of Cyrix's 486SLC and could get squeezed between AMD and Intel in the fight for the 486DX market. So far, Cyrix has been unable to ship 66-MHz chips, which Intel is attempting to push into the mainstream. Whatever volumes Cyrix can find are likely to be at low prices.

Cyrix also pioneered the 386 upgrade market last year, offering upgrades for both 386DX and 386SX systems. The 386DX upgrade is straightforward, since that processor is generally socketed. The upgrade for the surface-mounted 386SX required more innovation, using a clip-on attachment that asserts the 386SX's FLOAT pin (intended for board testing) to disable the original processor. Both upgrade devices use a clever scheme, based on comparators that look for key system events, to keep the on-chip cache coherent with main memory with minimal degradation of performance.

Looking toward the future, Cyrix unveiled its M1 superscalar microarchitecture at the Microprocessor Forum last fall, but the company has not described the product specifics and apparently has not yet taped out the design. The company has promised to ship the chip this year, but if other suppliers' experiences with aggressive superscalar designs are any indication, it is likely to be late. Getting the advanced foundry capacity needed to make such a chip could also be a challenge. Sometime in 1995, though, Cyrix could be in a position to compete across the breadth of Intel's product line.

Key x86 Events of '93

Intel repositioned its March Pentium announcement as a "technology disclosure" rather than a product announcement *(see **0702MSB.PDF, 070401.PDF, 070402.PDF,** and **070502.PDF**)*, deferring only the disclosure of price and availability *(see **0707MSB.PDF**)*.

Intel rolled out its S-series processors as the "SL-enhanced" 486 line *(see **070801.PDF**)*.

Intel finally announced a 32-bit follow-on to the ancient 80186 embedded CPU *(see **071405.PDF**)*.

IBM rolled out its 486SLC2 *(see **0705MSB.PDF**)* and formally introduced the clock-tripler version as Blue Lightning *(see **0710MSB.PDF**)*.

AMD jumped into the 486DX market with a part using Intel's microcode *(see **070601.PDF**)* and followed with a 486SX using what was claimed to be clean-room microcode *(see **0709MSB.PDF**)*. Later, AMD revealed that the "clean" microcode actually used some of Intel's 386 microcode *(see **0713MSB.PDF**)*.

AMD gave a presentation at the Microprocessor Forum that hinted at a 486 version with a 16K write-back cache *(see **071505.PDF**)*.

Cyrix added an end-user upgrade processor for 386DX systems *(see **0710MSB.PDF**)* and another for 386SX machines *(see **0717MSB.PDF**)*. Cyrix also introduced a 486DX-compatible chip *(see **071101.PDF**)* and revealed the design of its superscalar Pentium competitor, the M1 *(see **071401.PDF**)*.

Texas Instruments revealed its first derivative chip based on the Cyrix core *(see **071504.PDF**)*.

VLSI Technology and Intel revealed their 386-based Polar chip set for the PDA market *(see **071302.PDF**)*, and AMD countered with its highly integrated 386 tuned for subnotebook PCs *(see **071404.PDF**)*.

NexGen Microsystems began quietly sampling its two-chip Pentium competitor *(see **0714MSB.PDF**)*, but the year ended without any public announcements.

On the legal front, Intel filed an ITC action against Twinhead *(see **0707MSB.PDF**)* in an attempt to use a system patent to block the importation of systems using non-Intel processors. Intel and Cyrix actually settled one aspect of their litigation, that surrounding Cyrix's math coprocessors *(see **0712MSB.PDF**)*.

An appellate court gutted the Intel/AMD arbitration ruling *(see **0708MSB.PDF**)*, but the California Supreme Court agreed to hear AMD's appeal of this decision *(see **0713MSB.PDF**)*.

The long-simmering feud between one-time partners TI and Cyrix broke out into the courts, with each company suing the other *(see **071702.PDF**)*.

TI Takes 486DLC Market, Adds 8K Cache

Texas Instruments became a player in the microprocessor market in 1992 through its partnership with Cyrix, but with that relationship now on the rocks, it is unclear what direction TI's efforts will take.

TI has competed aggressively for 486SLC and 486DLC business. In fact, Cyrix all but abandoned the DLC market in response to TI's low prices. TI has its own fabrication facilities, which gives it more room to negotiate on pricing. It does, however, pay a royalty to Cyrix on each chip sold. TI claims that it is the third-largest x86 supplier, after AMD, having shipped over one million chips under its own label as of last fall.

TI's first independent design, created from the Cyrix core, adds an 8K, write-through cache. It is offered in a 386SX-compatible package as the 486SXLC (or SXLC2 with clock doubling) or in a 486SX-compatible package as the 486SXL or SXL2. The SXLC provides more cache than anything Cyrix offers in the 386SX pinout, and it could be an attractive alternative to the 486SLC for notebook systems. The 486SXL doesn't have any obvious appeal, other than price; it is slower than Intel's 486SX, since it has Cyrix's slower CPU core and does not support burst mode on the 486 bus.

TI plans to roll out soon a more highly integrated design, code-named Rio Grande, that will add some system logic to the chip. With Intel de-emphasizing its SL integration strategy, this is a natural place for a company such as TI to step in. Whether it will be able to make the integration more cost-effective than Intel did remains to be seen. One advantage for TI, in a backhanded way, is that it doesn't have the same high-margin alternatives for its wafers that Intel does, so it will be easier to justify making larger chips if they enable the company to gain some market share.

Where TI goes from here may depend on the outcome of its litigation with Cyrix. In a worst-case scenario, if Cyrix were to prevail, TI could be forced out of the x86 market until it developed its own CPU core. It seems most likely that TI will be able to continue using the Cyrix core but won't get access to new Cyrix designs. Should this be the case, TI presumably will continue to pursue various functional integration approaches, adding system logic and peripherals to the Cyrix core, while it develops its own next-generation CPU.

IBM Rolls Out Blue Lightning

IBM, unable to sell its x86 microprocessors on the merchant market because of its contract with Intel, has

nevertheless become a force in the x86 business. In addition to using its microprocessors in many of its own systems, the company has been selling motherboards and CPU modules to several vendors.

In 1993, IBM rolled out the Blue Lightning processor, which—despite its snazzy name—is essentially the same CPU core as its earlier 486SLC2. It also has the same 16K, write-through cache, but with a clock tripler and a 32-bit, 386DX-compatible bus interface. So far, it has been shipped at clock rates up to 75 MHz internal (25 MHz external); a 100-MHz version is planned for this year.

IBM's avoidance of the 486 pinout, with its higher-performance burst bus, is peculiar and may be due to legal restrictions. Although IBM's design is original, its design team started from Intel's 386 design and used Intel's test vectors. As a result, IBM must follow the rules of its contract with Intel. While the details have not been made public, IBM says that it is allowed to build all the 486SLC2 and Blue Lightning chips it wants, as long as it doesn't sell them except as part of a system or subsystem. The 486 contract is separate, and it might not give IBM this same freedom, at least until some later date. It is possible that IBM has avoided the 486 pinout so the chips would be covered under its 386 agreement, rather than its 486 agreement.

Given the massive effort IBM Microelectronics has made to become a force in the semiconductor market, it seems inevitable that there must be next-generation designs under way. IBM has steadfastly declined to comment, but it is widely rumored that the company is developing its next designs using a clean-room method so it won't be bound by the Intel contracts and could sell the chips on the merchant market.

IBM's joint development effort with Intel, the Noyce Design Center, died quietly last year. With the two companies becoming more competitive with each other and Intel moving away from high levels of functional integration, the plans to jointly develop a 486-based, single-chip PC ceased to make sense.

Will NexGen Finally Make It?

The lure of the x86 microprocessor market is almost irresistible, and at least three new companies are likely to join the fray this year.

NexGen Microsystems has been silent for over two years, after repeated schedule slips caused the company to become the target of much skepticism. After such a long delay, many observers have all but written off NexGen, but they could be in for a surprise. Over $100 million has been invested in the company, and samples of a two-chip set have been circulating, especially in Taiwan. NexGen apparently hopes to take advantage of the fact that Intel is widely disliked in Taiwan; Taiwanese system makers have often been at the bottom of the allocation lists, and many believe that they do not get prices that are competitive with what US manufacturers pay. Sources indicate that several Taiwanese PC makers had NexGen processor samples in hand before they saw their first Pentium chips.

Whether NexGen will be able to compete successfully with Pentium remains to be seen. The NexGen microarchitecture is much more aggressive than Pentium's, including features such as out-of-order execution and register renaming. NexGen reportedly has told prospective users that the chip set is 30% faster than Pentium, at the same clock rate, for typical integer code.

The price that they must pay, however, is that the design is more complex: the initial implementation required eight chips. That implementation was used to debug the logic and microcode, and NexGen has shown prospective investors test results confirming its compatibility with at least some PC software. The current design is a two-chip implementation of exactly the same logic, with separate chips for integer and floating-point functions.

One challenge NexGen may face is finding an IC foundry with the required process; the sample chips reportedly were fabricated by HP, which is exiting the foundry business. Other difficulties include keeping up with Pentium's clock rate and Intel's aggressive pricing.

Given its past credibility problems, NexGen has wisely chosen to stay silent until its customers are ready to demonstrate systems. The company has surprised us before, but this time it really seems likely to ship a product this year.

...And More to Come

Another company hoping to take advantage of the Taiwanese system makers' dissatisfaction with Intel is United Microelectronics Corp. (UMC), the largest semiconductor maker in Taiwan. UMC licensed an x86 CPU design from design house Meridian Semiconductor (Irvine, Calif.), and the company had promised to introduce a 486SX-compatible chip by the end of 1993. No such announcement has yet appeared, however.

As for its legal strategy, UMC says that it plans to sell the chips only in the Far East to avoid legal challenges. Intel might try to take action there, but it would be difficult. Unlike AMD, TI, IBM, and Cyrix foundry SGS-Thomson, UMC does not have a patent license agreement with Intel. The only apparent way that UMC could sell the chips (or that its customers could sell systems that include the chips) in countries that enforce US intellectual property laws would be to prove that its chip does not infringe any Intel patents, or that any patents it does infringe are invalid. Either way, it would be a long and expensive legal battle.

Another company that plans to introduce a 486-compatible microprocessor in 1994 is Integrated Infor-

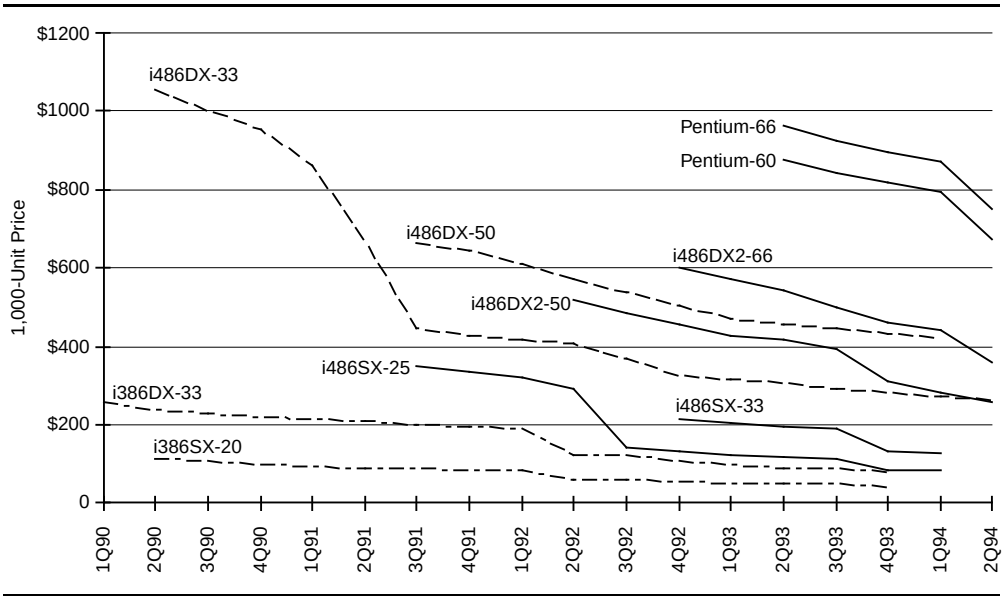

Figure 3. Intel's biggest price reductions will be for the 486DX2 and Pentium. (Source: Intel)

mation Technologies (IIT). The fabless company is currently a supplier of math coprocessors, graphics controllers, and video compression/decompression chips. IIT officials have said that their 486 would offer superior performance but have not provided any other details. IIT presumably would use a foundry that has an Intel patent license to build its chips.

It is surprising that none of the Japanese semiconductor makers has entered the x86 market; it must be hard for them to let a multibillion-dollar market go untouched. Their reluctance is apparently due to a fear of legal repercussions and a desire not to alienate the US any more than they already have. SMOS, a US-based division of Seiko, is rumored to have canceled a 486 project, and no other Japanese 486 efforts have surfaced. (NexGen is heavily funded by Japanese investors, however, and might have a Japanese semiconductor partner.)

DX2 Prices Plummet

While Intel has always reduced its microprocessor prices gradually each quarter, there is little doubt that the intense competition has driven prices down more quickly than they otherwise would have fallen. As Figure 3 shows, the gradual price decreases have been supplemented by occasional sharp drops when Intel had a strategic reason to make major pricing moves.

Four years ago, the 486 was a high-end family, with the 33-MHz version selling for over $1,000. It began to move into the midrange with the introduction of the 486SX the following spring, at $258 for the 16-MHz part—a price that then seemed remarkably cheap. Today, it is down to $79, while the fastest version—the 486DX2-66—costs $440. This broad range has enabled the 486 to span virtually the entire PC market, all the way down to entry-level systems, pushing out the 386.

Last year, Intel's most aggressive price cuts were for the 486DX2. In December, Intel made the unusual move of announcing pricing for the next two quarters for a few key products—among them the 486DX2. As Figure 3 shows, in the second quarter, the 486DX2-66 price will dip below that of the 486DX-50, and the 486DX2-50 price will match that of the 486DX-33, bringing to an end the reign of the non-clock-doubled products.

In part, this move is intended to make room for the DX4, which will offer higher clock rates, and the P24T, which will provide a Pentium core in a 486-like pinout. These products will occupy the now-vacant $500–$600 price range, where Intel often has made much of its profit.

Intel has priced Pentium aggressively from the start, seeking to send a signal that this chip is destined for the mainstream. Even at its introduction, Pentium was priced below what a 486DX-33 cost in its first year. Intel claims that the steep Pentium price cuts promised for the second quarter of this year are justified by additional manufacturing capacity and increased volume.

In reality, Intel's marketing objectives are probably a bigger factor. Intel wants to draw the mainstream market from the 486 to Pentium as quickly as practical to limit the opportunity AMD will have to sell 486 chips. Since AMD won't be able to make more than a few million 486 chips until 1995, Intel has until then to move the market to Pentium, but this will take time. Intel's steep price cut also sends a message to system makers that perhaps they don't need to switch to a RISC processor, such as PowerPC, to get a fast chip at a reasonable price.

Figure 4 shows the competitive pricing activity at the low end of the market. Cyrix was pushed into cutting its 486SLC prices by Intel's aggressive pricing of the 486SX, and TI's pricing put pressure on Cyrix to drop the 486DLC price. Intel's 386 prices, not shown in this graph, are well above AMD's, a sign of Intel's lack of interest in serving that market. AMD continues to gradually reduce 386 prices, which have now reached a remarkable $20 for the 386SX.

AMD has been aggressive on 386 pricing but, as Table 1 shows, has priced its 486 chips identically to Intel's. Since both companies are capacity-limited, there is no incentive for a price war. Note that these are the manufacturers' official 1,000-piece list prices. Major sys-

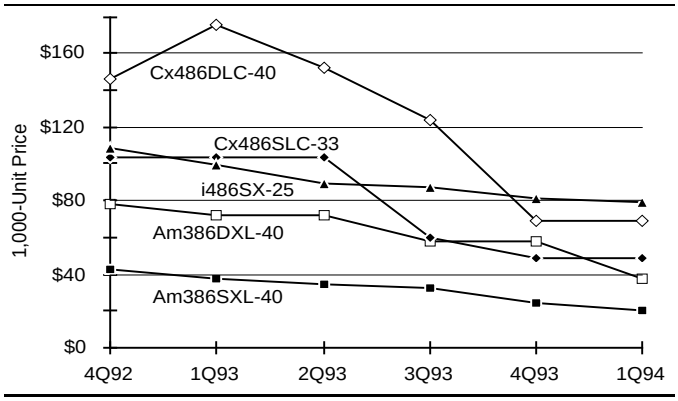

Figure 4. Low-end x86 prices are now in the $20 to $80 range. (Source: vendors)

tem makers pay significantly less; these contract prices are not disclosed.

The Future of the x86

During the course of 1994, Intel is likely to begin beating the drum for the next generation, the P6. Rumors are that this processor will be sold only as a multichip module, combining the CPU chip (or chips) with secondary cache SRAMs, and that it will be aimed primarily at server and mainframe downsizing markets. It is likely to be a four-issue superscalar design that implements speculative and out-of-order execution. While Pentium will be Intel's key weapon against RISC on the desktop, the P6 will become the vehicle that Intel hopes to ride to dominance in larger systems.

While Intel has been mum on details of the P6, rumors are widespread that it implements major extensions to the architecture, including a larger, alternate register set. The P6 could be the start of Intel's evolution of the x86 toward a more RISC-like instruction set architecture. By adding a new programming mode, Intel could begin establishing a new, more modern architecture that eventually would allow it to break free of the x86 baggage.

The furious level of x86 processor development ensures that an ever-broadening range of implementations will be available at competitive prices. Intel continues to have the high end of the product range to itself. In fact, it has little real competition, in terms of volume, even in the mainstream 486 line.

	4Q93	1Q94	2Q94
Intel			
i386SX-25/33	$42/$44	*	
i386DX-33/p	$77/$72	*	
i486SX-25/p/lv	$85/$81/$87	$84/$79/$85	$77 (p)
i486SX-33/p/lv	$133/$121/$133	$129/$117/$129	$113 (p)
i486DX-33/lv	$283/$313	$272/$302	$261
i486DX-50	$432	$420	
i486DX2-40lv	$311	$280	
i486DX2-50/lv	$311/$463	$280/$370	$260
i486DX2-66	$463	$440	$360
i386SL-20nc/lvnc	$36/$43	*	
i386SL-25/nc	$54/$43	*	
i486SL-25/33	$190/$291	$193/$281	
Pentium-60/66	$818/$898	$793/$871	$675/$750
AMD			
Am386SXL-40	$24	$20	
Am386DXL-25p/40	$32/$58	$29/$38	
Am486SX-33/40	$85/$133	$84/$129	
Am486DXL-40	$283	$272	
Am486DX2-50/66	$306/$463	$280/$440	
Cyrix			
Cx486SLC-V25	$58/$58	**	
Cx486SLC-33	$49	**	
Cx486SLC2-50	$86	**	
Cx486DLC-33/40	$69/$69	**	
Cx486S-33/40	$86/$114	**	
Cx486DX-33/40/50	$230/$259/$345	**	
Cx486DX2-50	$288	**	
Texas Instruments			
TI486SLC-33	$59	$59	
TI486DLC-40	$79	$69	
TI486SXLC-33		$79	
TI486SXLC2-40/50		$89/$109	
TI486SXL-33		$119	
TI486SXL2-50		$149	

Table 1. List prices (1,000-piece) for the full spectrum of x86 processors. nc=no cache; lv=low-voltage; p=plastic. *Intel has effectively withdrawn from the 386 market for PCs. **New prices for 1994 not yet announced. Note 2Q94 prices announced only for a few key devices. (Source: vendors)

During 1994, the 486 market will become more competitive, and the first Pentium alternatives may appear, marking the first time Intel will have had competition so early in a product's life cycle. Intel is moving aggressively forward, however, and is in no danger of losing its dominant position—though its profit margins will shrink. The competition benefits the industry because of the options it offers and the pressure it puts on Intel's pricing and policies. And as much as Intel resents its competitors, the competitive x86 market has greatly strengthened the architecture in its fight against the RISCs. ♦

