MICROPROCESSOR REPORT

THE INSIDERS' GUIDE TO MICROPROCESSOR HARDWARE

VOLUME 7 NUMBER 1 JANUARY 25, 1993

Multivendor 386/486 Market Burgeoning

Steep Price Cuts Follow Proliferation of Vendors and Varieties

By Michael Slater

The past year has been a pivotal one in the 386/486 microprocessor market. Intel's first 386 competitor, AMD, not only established itself as a viable supplier but managed to take the majority of the 386 business away from Intel. Chips and Technologies came and went as a 386 supplier, unable to face the rigors of the intensely competitive marketplace. Cyrix burst on the scene with its 486SLC, gaining several second-tier design wins, and quickly broadened its product line. Texas Instruments began marketing Cyrix-designed processors under its own name, and even IBM jumped into the processor business in an indirect way.

This is a remarkably different landscape than that of two years ago, when Intel was the only supplier of 386/486 processors. Systems designers have more choices than ever before, filling every conceivable price/performance niche, and competition has forced prices down rapidly. Prices for mid-range 386 and 486SX chips dropped more than 50%, helping to fuel sharp drops in system prices.

Through all the bedlam, Intel has done a superb job of keeping its profits up. While Intel has been hit by huge 386 market-share losses and steep price cuts in its low-end and mid-range processors, it has succeeded in moving a large part of the market to its high-end, high-profit 486DX and 486DX2 chips.

386 Market Redistributed

The total 386 market (in units) stayed nearly flat through all of 1991 and 1992, as shown in Figure 1 (see below). Over a two-year period, AMD captured the majority of the 386 business by offering higher clock rates, a static design, and other parametric advantages. Today, the 386DX market has converted almost entirely to AMD's 40-MHz version. AMD has led the 386SX market to 25- and 33-MHz rates; although Intel eventually matched these speeds, it was months behind AMD, which enabled AMD to make major market-share gains. Today, AMD is offering a 40-MHz 386SX, and Intel has followed as far as 33 MHz. Because of Intel's focus on promoting the 486 line, it did not continue to advance the 386, leaving AMD with a clear opportunity.

Cyrix established its role as the third supplier in 1992 with its 486SLC and DLC, which we classify as part of the 386 market because they are pin-compatible and in that price range. Late in the year, Texas Instruments began marketing the Cyrix-designed processors under its own name. Getting TI's endorsement was a major coup for Cyrix when the deal was announced in the spring, but now Cyrix has to compete with TI in the marketplace. It remains to be seen how the market for Cyrix-designed chips will divide between the two companies.

Intel Benefits from 486 Shift

While the basically flat 386 market was redistributed among the suppliers, the growth came from the 486. With PC prices collapsing roughly 50% in 1992, PC buyers were able to afford much more compute power than ever before. Lower prices were one factor behind the shift of the mainstream market from the 386 to the 486; the price premium for 486 systems was small enough so as not to be a significant barrier.

As a result of the 486's strength, Intel turned in its best financial results ever in 1991 in spite of losing most of the 386 market to AMD. While AMD took over the 386 sales, with an average selling price (ASP) of well under $100, Intel's 486 sales skyrocketed. With an ASP of several hundred dollars for most 486 versions, profit from the 486 dwarfed the lost 386 sales. This is a familiar Intel strategy: when prices on older chips drop, Intel leaves that market to a competitor, while Intel allocates its fab capacity to newer, higher-profit chips. Remarkably, the PC microprocessor market was so active in 1992 that AMD was able to generate record profits as well, despite its lack of a 486 product.

In 1993, the 386 market will begin to decline as Intel's 486 sales continue to ramp up and multiple competitors join the 486 market. The 386 won't disappear as

quickly as the 286 did because unlike the 286, the 386 can run essentially all the same software as its successor. The 386 will also live on for a long time as a CPU core in integrated processor/system-logic chips, which could become dominant in low-end portable systems.

Intel proudly announced last fall that its 486 unit shipments exceeded 386 shipments for the first time in the third quarter of 1992. This was true, however, only because Intel had lost most of the 386 market to AMD. According to our estimates, shipments of 486 processors are just now exceeding total 386 shipments.

Moving Into OverDrive

Other than price cuts and the usual clock-rate increases, the big news in Intel's product line was the clock-doubler version of the 486, known as the 486DX2 in the OEM market and as the OverDrive chip in the retail market. These chips match higher on-chip clock rates with slower motherboard designs for a happy compromise between system cost and performance. While the 486DX2-50 isn't quite as fast as the 486DX-50, it provides 85–90% of full 50-MHz performance (based on SYSmark92 and SPECint89) with a lower system cost. The clock doubler also makes a 66-MHz processor more practical; building 66-MHz external buses is tough.

The 486DX2 has been very successful, giving the x86 line a mid-generation speed boost while the industry waits for Pentium. Despite tremendous price reductions in low-end 386 and 486 processors, Intel's top-of-the-line 486DX2-66 still lists for a whopping $570. Chips like this have produced Intel's record earnings in spite of its collapsing 386 sales.

Others have begun playing the clock-doubling game as well. IBM's 486SLC2 has a 16K on-chip cache and a clock-doubler in a 386SX pinout. IBM's latest chip, codenamed "Blue Lightning" (not officially named, but perhaps the 486SLC3?), has a clock tripler to match its 100-MHz internal rate to a 33-MHz system design. Cyrix has clock-doubler designs as well, and AMD is sure to offer them once it gets the basic 486 design into production.

It isn't yet clear whether the retail version of the DX2—the OverDrive upgrade processors—will be as successful. Cutting the cost of a CPU upgrade sounds great, and Intel's shareholders should like the idea of selling two processors for every system, but it remains to be seen whether large numbers of system owners will bother to upgrade. Even if no one buys the upgrade processors, however, the OverDrive campaign will have benefited Intel because it provides another reason to buy a low-end 486 system instead of a high-end 386 system.

Dramatic Price Cuts

One factor behind the dramatic growth in 486 shipments was the rapidly declining price of the 486SX. Intel brought down the 486SX price to compete with the 386DX. The 486DX, for which Intel did not have any direct competition, fell more slowly in price, following Intel's traditional slope of about 5% per quarter.

Table 1 shows how Intel's and AMD's prices dropped over the course of the year. (This table includes only processors that were on both the 1Q92 and 1Q93 price lists.) While high-end 486DX prices fell only 23%, prices for mid-range chips such as the 386SL, 386DX, and 486SX dropped 40–60%. AMD cut its prices by

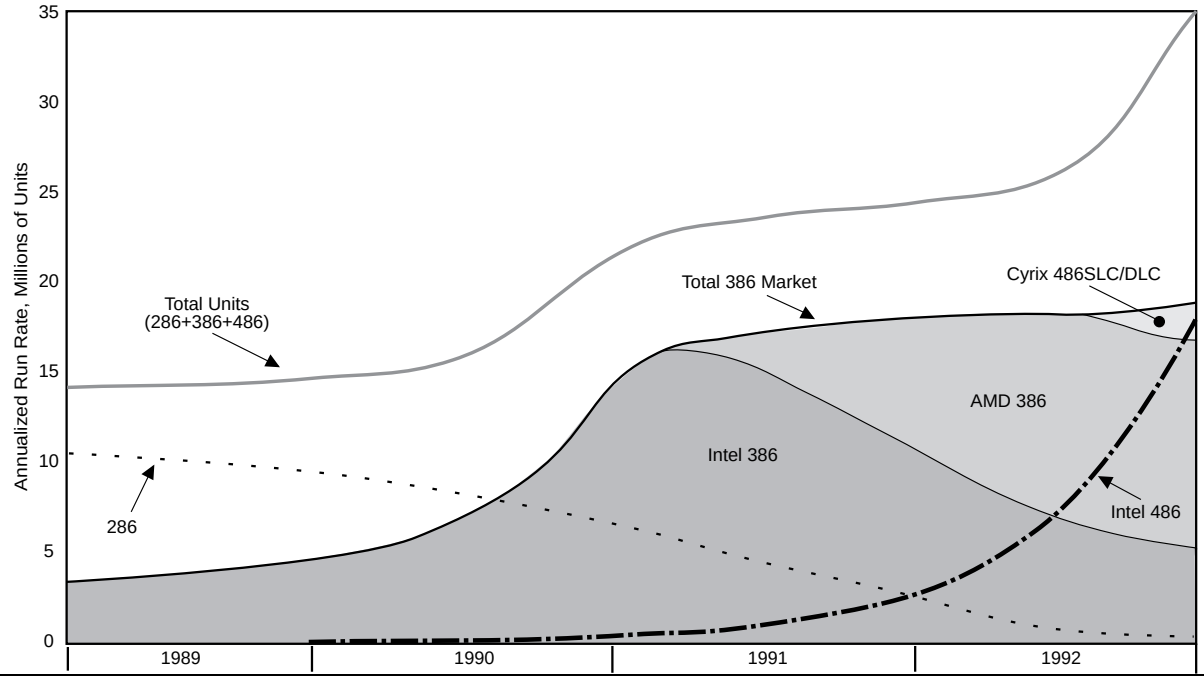

Figure 1. Trends in x86 market share over the past four years. (Source: Microprocessor Report estimates.)

Processor	1Q92 Price	1Q93 Price	1Q92-1Q93 Decrease
Intel			
i386SX-16	$56	$39	30%
i386SX-20	$82	$52	37%
i386SL-20	$126	$55	56%
i386SL-25	$178	$66	63%
i386DX-25	$152	$91	40%
i386DX-33	$190	$97	49%
i486SX-16	$202	$118	42%
i486SX-20	$237	$118	50%
i486SX-25	$319	$123	61%
i486DX-33	$417	$317	24%
i486DX-50	$610	$469	23%
AMD			
Am386SXL-25	$76	$34	55%
Am386DXL-25	$150	$73	51%
Am386DXL-33	$180	$73	59%
Am386DXL-40	$180	$78	57%

Table 1. Intel and AMD price reductions during 1992. (Source: Published 1000-piece prices; PGA packages except 386SX and 386SL.)

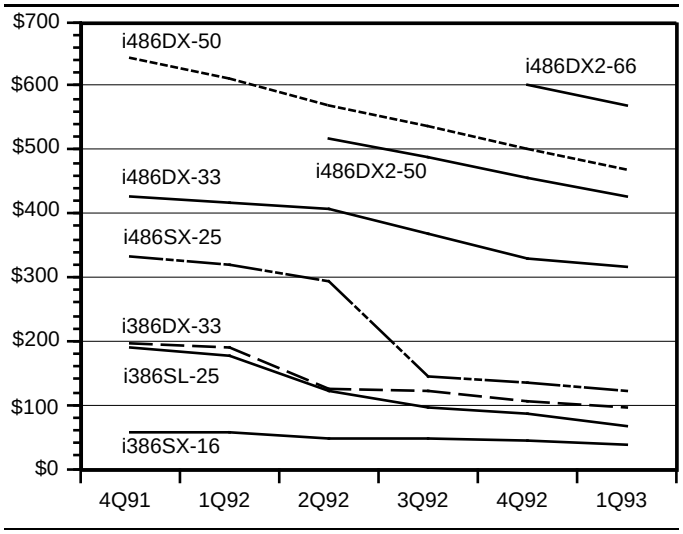

Figure 2. Intel price trends during 1992. (Source: Published 1000-piece prices; PGA packages except 386SX and 386SL.)

roughly 55%.

As Figure 2 illustrates, the collapse of 486SX prices has left a huge gap between the $317 486DX-33 (the least-expensive 486 with on-chip floating-point) and the $123 486SX-25. Since the 486SX die is only slightly smaller than the 486DX, the profit margin on the DX part is much higher. Fortunately for Intel, demand for the high-profit 486DX has remained strong despite its relatively high price.

A minor factor that reduced chip prices further was a trend toward plastic packaging. AMD began offering its 386 in a plastic quad flat pack (PQFP) in 1991, but Intel stuck to the traditional PGA (pin grid array) for its 386 and 486 until the second half of 1992. For Intel's 386DX, the PQFP is $5 less than the PGA version. AMD has been emphasizing plastic packages for its 386DX chips; its PQFP version is $22 cheaper than the PGA. For Intel's 486SX, the PQFP version is about $25 cheaper.

Figure 3 shows how Intel and AMD cut their prices together over the course of the year, but Intel didn't follow all the way. At the start of the year, AMD's 25-MHz 386SX was priced identically to Intel's 20-MHz version. In addition to offering a higher clock rate for the same price, AMD charges no premium for its "SXL" version, which offers static operation and lower power consumption. As prices dropped during the year, AMD stayed just below Intel's price for the next higher clock rate.

Cyrix priced its 486SLC at 386DX levels; it is about $40 more than a 386SX, with which it is pin-compatible, but it is roughly 50% faster. The Cx486DLC carries about a $30 premium over a 386DX. With Intel's steep price cut on the 486SX, Cyrix's 486DLC-40 is now somewhat more expensive than Intel's 486SX-20. Already, 1993's pricing is shaping up to have a very different character than 1992; Cyrix actually raised the price of its 486DLC-40 by $30 in 1Q93, something that was unheard of for most of last year.

While Intel used the 486SX to shift 386DX sales to an Intel-proprietary design, it used the 386SL to pull customers away from the 386SX. As Figure 4 shows, what started out as a 59% premium for the SL shrank to 19% by the end of the year (for the 20-MHz versions). In addition, Intel cut the SL price even further by adding a 16-MHz version and versions with the cache controller disabled, bringing the entry-level price down from $135 at the start of the year to $45 at the end—a mere $2 premium over Intel's 386SX-16.

It is important to note that all of these prices are the manufacturers' quoted 1000-piece prices, and volume buyers pay significantly less. For example, while the 486SX-25 lists for $123, Intel's top customers are reportedly paying between $80 and $100. Cyrix appears to be discounting even more heavily off its list prices; while the 486SLC-25 lists for $88, it is rumored to be selling for about half that amount to major customers.

SL Line to be De-emphasized

Intel rolled out its 486SL in November, but the long-term future of the SL line seems to be in doubt. Intel initially planned a wide range of 486SL products, including versions with and without the floating-point unit, and chips with clock rates as low as 12 MHz to reach low price points. Instead, Intel decided to offer only the 25-MHz version with the floating-point unit, with a 33-MHz chip to follow.

While the 486SL has captured a number of design wins and will play an important role in the portable mar-

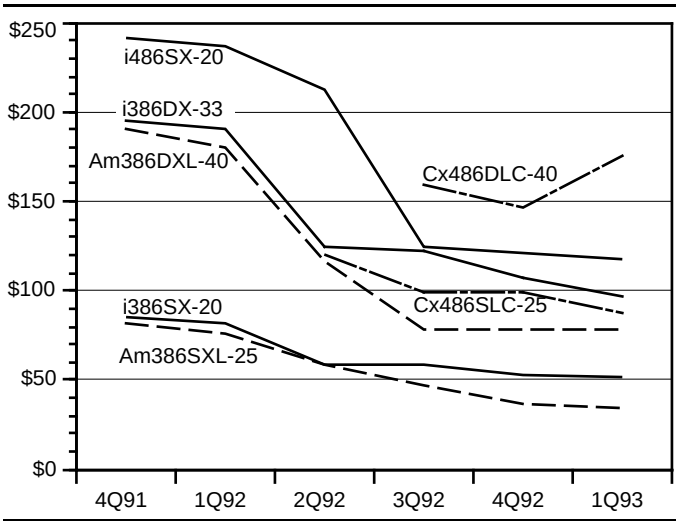

Figure 3. Intel, AMD, and Cyrix pricing trends for low-end and mid-range processors. (Source: Published 1000-piece prices; PGA packages except 386SX and 486SLC.)

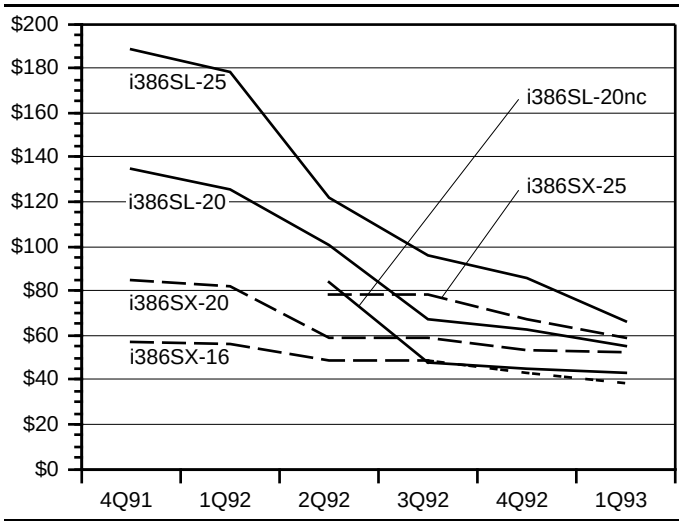

Figure 4. Intel's converging 386SX and 386SL pricing; "nc" indicates no cache support. (Source: Published 1000-piece prices.)

ket this year, it appears that the integration path represented by the 486SL—putting the bus controller, DRAM controller, and system logic on the processor chip—may be a dead-end for now.

Intel's scaling back of its plans for the SL line are no doubt based, in part, on simple economics: the SL chips are expensive to build. The peripheral functions included on the 486SL swell its die size to twice that of the 486DX, making it a much more expensive chip to produce. These functions can be replicated in an external chip set at very low cost, so it is more economical to use a standard 486DX and a third-party chip set. In the long run, SL-style integration will make sense, but not without denser chip geometries and more carefully compacted designs than Intel's 486SL. Adding several blocks of random logic and high-power buffers to a tightly-packed CPU core dramatically decreases the chip's overall transistor density, and the added transistors have relatively low value because of the extremely low-margin pricing prevalent in the chip-set market.

In short, the 486SL appears to be over-integrated for today's economics. Intel is making the chip attractive to system makers by sacrificing its own margins, hiding the 486SL's high production cost. The 486SL has strategic value to Intel because it offers features that its competitor's won't match right away, but there is also a down-side: some system makers are wary of Intel's sole-sourced designs, now that they have multisourced alternatives.

The one key feature that is part of the SL architecture and cannot be replicated in external chip sets is the system management mode (SMM). By adding this feature to its standard processors (without the on-chip system logic included in the SL line), Intel can continue to offer this capability without suffering from the cost burden of the 486SL's die size.

Intel has stated that it will have 25 new 486-family microprocessors for the portable market during 1992, and these will presumably all be members of the rumored "S series" that will add SMM, 3.3V operation, and static design to the standard 486SX, 486DX, and 486DX2 cores. Given these three processor lines, each of which is likely to be offered at several clock rates, in two or three different packages, and in 3.3V and 5V versions, it's easy to see how Intel will come up with 25 new 486 variants.

AMD's Role

In its two years of participation in the 386 market, AMD has become remarkably well established. Its customers include not only dozens of third-tier companies but most of the second tier and some of the first—the only notable holdouts are IBM, Dell, and Compaq. Even IBM is using AMD processors in a low-end machine sold in Europe, and major companies such as DEC and AST are featuring AMD-based products.

Even though AMD's 386 is based on Intel's logic design and microcode, AMD was able to distinguish its product primarily by offering higher clock rates. Static operation, lower power consumption, a 3.3V version, and a system management mode also helped AMD in the portable market.

AMD's entry into the 486 market has been stymied by legal setbacks. Although AMD and Intel agree that AMD has the right to use Intel's patents, the companies disagree on whether AMD has the right to use Intel's copyrighted microcode. Last summer, in a case that originated from AMD's 287-compatible coprocessor, a jury ruled that AMD did not have the right to use Intel's microcode. The judge later refused to review the verdict,

Major x86 Events of '92

Early in 1992, AMD announced its plans to begin 486 production in 4Q92 *(see **0602MSB.PDF**)*, but AMD's loss of the critical microcode copyright case *(see **060901.PDF** and **0612MSB.PDF**)* pushed the anticipated production date out to mid-'93.

After years of proceedings and deliberations regarding the dispute between Intel and AMD over their ill-fated technology exchange pact, the arbitrator awarded AMD $15 million in damages and a license to produce 386 chips *(see **060402.PDF**)*. The ruling was confirmed by the California Superior Court *(see **0608MSB.PDF**)*. Intel's appeal of the confirmation is still pending.

Intel taped-out the P5 in mid-April *(see **0607MSB.PDF**)* and broke the official silence with limited demonstrations two months later *(see **0610MSB.PDF**)*. Intel slipped the introduction date from fall '92 to the first quarter of '93. Some technical details were revealed at the Hot Chips conference *(see **061201.PDF**)* and the Microprocessor Forum *(see **061405.PDF**)*, but many aspects of the chip's design remain shrouded. Intel's only formal announcement regarding the chip was its name—Pentium *(see **0614MSB.PDF**)*.

After six months of pre-announcement demos, Intel's clock-doubler version of the 486 debuted as the 486DX2 *(see **060304.PDF**)*. A few months later, Intel introduced essentially the same chip as the OverDrive processor for end-user upgrades *(see **060802.PDF** and **0612MSB.PDF**)*. The 66-MHz 486DX2, which is the fastest x86 processor in production, emerged in mid-summer *(see **0611MSB.PDF**)*.

Intel added 3.3V versions of the 486SX *(see **0605MSB.PDF**)* and 386SL *(see **0608MSB.PDF**)*. Intel introduced its 486SL *(see **061501.PDF**)*, following in the footsteps of the 386SL.

Intel invested $50 million in VLSI Technology and entered into a joint project to develop integrated processors for the PDA market based on a 386SL core *(see **0610MSB.PDF**)*.

IBM added to its line of x86-compatible microprocessors with its 486SLC2 *(see **0604MSB.PDF**)*, offering the chip on a daughtercard to other system makers *(see **0611MSB.PDF**)*. Late in the year, IBM previewed a 100-MHz, clock-tripled version called "Blue Lightning" *(see **0616MSB.PDF**)*.

Chips and Technologies announced its Super386 processor line back in the fall of 1991 *(see µPR 10/2/91, p. 1)*. In March, Intel sued C&T for patent infringement *(see **060403PDF**)*. A few months later, C&T cancelled its 386SX and ended promotion of its 386DX just as the chips finally neared production *(see **0611MSB.PDF**)*.

Cyrix joined the x86 fray with its 486SLC *(see **060501.PDF**)*, and then followed up with the 486DLC *(see **060801.PDF**)* and the 486S2/50 *(see **0615MSB.PDF**)*. The company also began beta-testing 386 upgrade modules *(see **0612MSB.PDF**)*. Cyrix won an important legal victory against Intel when the court ruled that Cyrix was protected by its foundry's patent cross-license agreements *(see **061101.PDF**)*.

Shortly after Cyrix launched its 486SLC, Texas Instruments announced its plans to market Cyrix-designed microprocessors *(see **0607MSB.PDF**)*. TI began shipping chips in the fall *(see **0614MSB.PDF**)*.

Vadem joined the market for low-end "PC on a chip" products with the NEC-made VG-230 *(see **0608MSB.PDF**)*.

forcing AMD to switch to clean-room microcode. AMD has said that this will delay its 486 introduction about six months, from late '92 to mid-'93.

When AMD is able to ship its clean-room 486, it will have to work especially hard to convince prospective customers of the chip's compatibility and performance. This hasn't been as much of a challenge for AMD's 386 because it uses Intel's logic design and microcode. AMD's clean-room design won't be state-for-state compatible with Intel's 486, so there may be some small performance differences as well as compatibility issues.

The clean-room approach doesn't give AMD any immunity from lawsuits, either; Intel may well question whether the microcode is completely "clean" and look for ways in which AMD's development process may have used some of Intel's intellectual property. Assuming that AMD has done the job properly, it should prevail in the end, but Intel can keep the legal questions alive well into 1994, if not longer.

AMD executives now say that they recognize the need to break free from duplicating Intel's designs, regardless of the legal situation; the 486 is the last Intel design that AMD plans to duplicate gate for gate. While AMD will start out with a 486 that is as close to Intel's as AMD can legally make it, AMD plans its own proliferation of 486 variants. Two natural opportunities are versions with a larger on-chip cache, or a write-back cache to boost performance. AMD is also likely to extend the clock range of the 486SX, offering it at 50 MHz and possibly in a clock-doubler version.

In addition to these incremental designs, AMD is developing next-generation, superscalar CPU cores that are, like the Cyrix chips, completely independent of Intel's designs. AMD has not released any information on these chips. While the company doesn't yet have any track record in creating truly independent implementations of the 386 architecture, it does have experienced design teams that have been working on variations of Intel's designs and on the 29000 family. Some of the senior 29000 staff—notably Mike Johnson—are now working on next-generation x86 designs.

The coming year will be a pivotal one for AMD. If it completes its clean-room microcode on time, encounters no compatibility

problems, and is able to ramp up production quickly, it could be a major player in the 486 market by the end of the year. Delays in any one of these areas, however, could push volume shipments out into 1994. AMD has built an enormous 386 business in only two years, but 386 sales are now peaking. If AMD is much delayed getting into the 486 business, it could see a significant revenue dip.

C&T Stumbles

The 386 market lost one vendor in 1992 before it even began full production: facing a tough competitive situation and dwindling cash reserves, Chips and Technologies decided to bail out of the 386 market and cancel its 486 development program. (Officially, the company is still offering its 386DX part, but there is no marketing effort associated with it.) C&T went through many iterations of its design before it was adequately debugged, which eroded customer confidence. It also had repeated production delays and a large die size that made it hard to be price competitive, especially for 386SX chips.

C&T is continuing to market its PC/Chip product, which puts an XT-class PC on a chip, but it remains to be seen whether the company will have the resources to aggressively develop next-generation versions. Today, there is a low-end market for highly integrated chips with 8086-class cores. Within a year or two, however, similar products will be available with 386-class cores, and if C&T can't offer such a product, it will find its market shrinking.

Cyrix Joins In

The 386 market gained two new players in 1992: Cyrix, a small company that previously made only Intel-compatible math coprocessors, and Texas Instruments, which licensed the Cyrix design. Cyrix's 486SLC, which combines a near-486-performance CPU core with a 1K cache in a 386SX package, has been quite successful in the notebook market and has even found some desktop sockets. Cyrix also offers its 486DLC, which is 386DX-pin-compatible, and the 486SLC has recently been upgraded to add a system management mode.

Cyrix won an important legal victory in August when a judge ruled that SGS-Thomson's patent cross-license agreement with Intel protected Cyrix's chips from Intel's

What's In a Name?

This year brought an unprecedented level of confusion to the x86 naming game. At the heart of the confusion is the mixing and matching of various processor cores, cache structures, and bus interfaces.

As the saying goes, if it looks like a duck, walks like a duck, and quacks like a duck, it *is* a duck. Things aren't so simple in the microprocessor business, however, where we'd have animals that look like a duck, walk like a duck, but honk like a goose.

Cyrix, Chips and Technologies, and IBM all followed a similar design approach with their 386/486 chips: build a core CPU with 486-like performance, add some on-chip cache memory, and use a 386 bus interface and pinout. The result is a chip that looks like a 386 from a hardware perspective, but it acts like a 486 from a software viewpoint. Just how much it acts like a 486 depends on the speed of the core CPU and the size and organization of the cache.

So, what should we call such a beast? Chips and Technologies took the most straightforward approach, calling its chip the Super386. This is easily the most descriptive name, but it has one key failing: users know that 486 is what's hot and new, and 386 is old and fading. Recognizing this quandary, Cyrix named its chips the 486SLC and 486DLC, even though they are 386 pin-compatible. Intel's marketing machine was quick to condemn the chip as not a "true" 486; computer users, for the most part, are simply confused.

IBM called its first original x86 design the 386SLC, following C&T's approach of thinking of the chip as an enhanced 386. With its next generation chip, however, IBM saw the light: IBM's latest processor is called the 486SLC, even though it has the same CPU core and bus interface as the 386SLC (the main difference is that the on-chip cache is much larger). IBM's choice of the 486SLC name added yet another level to the confusion, since Cyrix has a part with the same name but a completely different design.

The proliferation of options has pushed Intel's naming scheme past the breaking point. In the 386SL line, for example, there are versions without the on-chip cache controller, which are simply called "386SL no cache"; there does not seem to be any real name for the part.

The OverDrive processors are even more confusing. In an attempt to make things simple for computer users, Intel has named the OverDrive chips by the system that they plug into. The "OverDrive for 25-MHz 486DX systems," for example, is otherwise known as the 486DX2-50. The "OverDrive for 25-MHz 486SX systems" has a slightly different pinout, since it is intended to plug into an OverDrive socket, while the OverDrive for 486DX systems replaces the CPU chip. Taking the confusion another step, the OverDrive socket for 486DX2 systems has an additional row of pins not present on conventional OverDrive sockets, and this extended socket will be required for the Pentium-based OverDrive product. When this chip comes out, there are going to be a lot of unhappy users who find that their OverDrive socket isn't the "right" OverDrive socket for the Pentium-based upgrade chip.

Pentium, of course, is today's ultimate in x86 naming. It will be interesting to see how this name evolves to support the inevitable proliferation. Will there be a "Pentium SX"? Given Intel's current tendency toward adopting consumer naming practices, perhaps it will be the "PentiumLite."

claims of patent infringement. While this ruling is, of course, being appealed, for the moment at least it establishes the legality of Cyrix's chips. Texas Instruments' right to make the chips for sale under its own name has not been disputed, so TI will be in the business regardless of any future legal developments.

Cyrix has had no success with first-tier system makers, but it has done reasonably well with second- and third-tier suppliers. In the fourth quarter of 1992, Cyrix shipped about 5% of all 386 and 486 chips—not bad for a tiny company battling Intel and AMD with its first microprocessor products.

One reason for Cyrix's success is that Intel has been unable to keep up with 486 demand, leaving many smaller system vendors with inadequate supplies of this critical chip. Cyrix's chips gave these vendors an available, economical alternative that provides a good fraction of 486 performance and lets these vendors market the systems as 486-based. The 486SLC was particularly attractive for system vendors with aging 386SX-based products; by switching to a Cyrix processor and making a few minor board changes, these vendors were able to upgrade 386SX-based notebook and desktop designs for higher performance with little effort.

Cyrix has exploited the huge gap between Intel's 486SX and 486DX prices by offering its math coprocessors bundled with its 486SLC and 486DLC processors. For a nominal premium—$20 to $40—Cyrix will include a math coprocessor along with the CPU. This gives Cyrix an edge over the 486SX in that adding floating-point to a 486SX system (i.e., using a 486DX) adds hundreds of dollars to the cost. The Cyrix CPU/FPU pair won't match the 486DX's performance, but it is much faster than the 486SX on floating-point code.

Cyrix has also built its 486DLC into a 386 upgrade module that adds clock-doubler and cache-coherency circuits. With tens of millions of existing 386 systems, this is a natural opportunity. One of the challenges is maintaining cache coherency in a system that was not designed for a processor with an on-chip cache. Cyrix has developed a proprietary approach to this problem, based on detecting system-level events—such as the end of a DMA transfer—that indicate that the cache must be flushed. Cyrix has been marketing this module only to corporate sites with hundreds of IBM and Compaq 386 systems, but a fully integrated version that reduces the module to a single chip will be offered on the retail market in 1993.

Late last year, Cyrix announced its first 486-pin-compatible processor: the Cx486S2/50, which should go into production in the next few months. This chip includes the same core CPU as in the 486SLC and DLC but with twice as much cache (2K) and a clock-doubler circuit. The clock doubler allows the chip to run at 50 MHz internally in a 25-MHz system. Although the on-chip cache is only one-fourth the size of that in Intel's 486 chips, it uses a write-back protocol that is more efficient than Intel's write-through design. While Cyrix has yet to publish benchmarks, it claims that the 486S2/50 is faster than Intel's 486SX-33.

In response to customer feedback, Cyrix has decided to make the clock-doubling feature of the 486S2/50 a pin-selectable option. Thus, the same chip can operate either at 50-MHz internal/25-MHz external or as a pure 50-MHz processor. Cyrix plans to offer a 40-MHz version as well. Eventually, a 66-MHz version will be added.

IBM in OEM Board Market

The surprise player in the 386 market in 1992 was IBM. While IBM is prohibited by its agreements with Intel from selling its own x86-architecture microprocessors on the merchant market, it is allowed to sell them as part of boards and subsystems. IBM has been marketing its 386SLC and 486SLC2 processors, as well as its latest "Blue Lightning" chip, to system motherboard makers as part of a CPU daughtercard.

IBM's chips are impressive; they are conceptually similar to Cyrix's 486SLC/DLC, but with a faster core and much larger caches. They are also remarkably small, thanks to IBM's advanced IC process. Nevertheless, IBM isn't likely to play a major role in the microprocessor business as long as it has to sell the chips as part of subassemblies, even if these can be as little as a chip or two on a small circuit board. IBM has so far announced only one customer for its CPU modules: Reply Corp., which—not coincidentally— is one of the few makers of Micro Channel systems.

IBM's Blue Lightning chip could also serve as the heart of an end-user upgrade product for existing 386 systems. IBM, or one of its OEM customers, could target this market, just as Cyrix has, assuming that they can tackle the cache coherency issues.

Pentium at Last

The big event of 1993, of course, will be the emergence of Pentium as more than a paper tiger. The formal introduction will probably occur in March, with small quantities of systems shipping in the second quarter. Second- and third-tier vendors aren't likely to get production quantities of Pentium processors until the third or fourth quarter. According to some reports, even major OEMs won't be able to get more than a few thousand chips per month. It is likely to be 1995 before Pentium shipments approach current 486 levels.

Pentium chips are likely to be expensive at first—well over $1000—and even at that, Intel will probably make less money from a wafer full of Pentiums than it will from a wafer full of much smaller 486DX2s, which still sell for over $400 each. Intel is currently capacity-limited on its 0.8-micron, three-level-metal production

lines that are required for the 486DX2 and Pentium. As a result, Intel is likely to ramp up Pentium production quite gradually, possibly moving to a 0.6-micron process before high-volume production is begun.

Because of the constrained availability and other factors, Pentium systems are likely to carry premium prices for much of the year. Intel won't have any direct competition at this performance level, and supplies of both chips and systems will be limited. System makers also inevitably charge the highest markup on systems using the latest processor, hoping to recapture a little profit margin while demand for the new technology is high.

As superscalar implementations of the x86 architecture become common, Intel will gain a new advantage over its competitors. Pentium requires a significantly different code-generation strategy (in the compiler) to produce the fastest programs. Pentium-aware compilers are essential to getting the most performance out of that processor. Intel is working closely with compiler vendors to make sure that they produce code that is well-optimized for Pentium. Developers of performance-critical application programs are likely to provide recompiled versions as soon as Pentium systems become available.

Now consider the plight of a company such as Cyrix, which is developing its own superscalar x86 processor that it expects will be faster than Pentium. Cyrix has little chance of getting compiler developers to produce Cyrix-specific code optimizers, and application developers wouldn't be interested in any case.

Intel-compatible processor vendors must therefore design their processors to make do with the compiler optimization strategies dictated by Intel for Pentium. This can be achieved, in part, by using similar design techniques, such as Pentium's ability to simultaneously issue an FXCH (floating-point exchange) instruction along with a floating-point computation instruction *(see **061201.PDF**)*. Another approach is to design the processor hardware so that code-generation strategies are less critical by allowing speculative and out-of-order instruction execution. These techniques allow the processor to effectively reorganize the program as it is being executed, reducing the dependence on compiler optimizations, but they also make the processor design considerably more complex and harder to debug.

More New Chips for 1993

While Intel has, so far, faced direct competition only for the 386, 1993 will bring a raft of 486 competitors. While some will no doubt fight it out in the relatively low-margin 486SX business, much of the activity is likely to be focused on bridging the "floating-point gap": the high premium users must pay today for a 486 with on-chip floating-point.

Cyrix plans to move up the performance curve in 1993, starting with its M-7 processor in March. The M-7 is an enhanced version of the 486S2/50 that is likely to be the industry's first 486DX competitor; it will include an 8K on-chip cache and an on-chip math coprocessor. Cyrix has also revealed its plans for a high-end processor, called Spike or M-1, that is a superscalar design intended to compete against Pentium. Cyrix has claimed that this chip will ship in 1993 and will be faster than Pentium; presumably it will not be pin-compatible. It will be surprising if this chip actually goes into production before sometime in '94, since virtually every superscalar processor design undertaken so far has shipped at least 6 months behind schedule.

Texas Instruments recently began production of the Cyrix-designed 486SLC and 486DLC, which TI makes as a foundry for Cyrix and also markets under its own name. (Cyrix uses SGS-Thomson as its primary foundry.) TI has announced plans to introduce derivative parts, based on the Cyrix CPU core but with additional on-chip functions, sometime in '93. It remains to be seen how big a player TI will be in this market.

AMD should finally begin shipping 486 chips in the second half of 1993, assuming that all goes well with the clean-room microcode. AMD will have to fight harder for its 486 market share than it did for its 386 share, however. AMD is unlikely to be able to repeat its 386 strategy of offering higher clock rates (except for the 486SX). By the time AMD ships its first 486 chip, the market will be bursting with dozens of 486 variants from Intel, Cyrix, and TI. It is far too early to count AMD out, however; the 486 market will be very big for several years, and AMD's near-total takeover of the 386 market demonstrates the company's capabilities.

By the latter part of the year, it is possible that Intel's two x86 joint ventures will begin bearing some fruit. Intel's joint venture with IBM, called the Noyce Development Center, is creating integrated processor/system logic chips that will combine Intel's CPU cores and IBM's system logic and display controllers. IBM has advance access to the resulting chips, although Intel will offer the chips later on the open market. It is not yet clear how these chips will be positioned or just when they will emerge. Given the experience with the 486SL, there is also some question about the economic viability of this approach.

VLSI Technology is also building highly-integrated processors as part of a joint venture with Intel, but VLSI's efforts are focused on the handheld market—personal communicators, organizers, and so forth. Intel has translated its 386SL core into VLSI's design tools, and VLSI will work with customers to add custom logic to form single-chip systems. The first—and possibly only—products will be customer-specific; no plans for standard parts have been disclosed.

In addition to these players, several others are

likely to join the 386/486 business in 1993. NexGen, whose products have been delayed so many times that the company has earned the nickname NeverGen, should finally ship a product in 1993. The company is rumored to be near completion of a two-chip set that will replace its current eight-chip design, which probably will not be marketed because of clock-rate limitations. Most observers are skeptical that NexGen will be able to beat Pentium's price or performance. NexGen's plan originally called for it to sell only systems, but it now appears that it may pursue some chip-set sales.

United Microelectronics Corp. (UMC), one of the largest Taiwanese semiconductor makers, licensed a high-speed 386 design in 1991 from Irvine-based Meridian Semiconductor, and the company said at the time that it would market a 486SX-compatible processor in 1993.

In Japan, V.M. Technology (VMT) has been developing a 386-compatible processor, but an expected announcement in 1992 did not materialize. With the market moving quickly to the 486, it is not clear if VMT will ever become a significant player.

Back in the U.S., Integrated Information Technologies (IIT) has acknowledged that it has a 486-compatible development program under way, but no details have been released.

Undoubtedly, numerous other companies have 386/486 processor developments under way; this market is just too big and too profitable to be ignored. It seems that it is only a matter of time before one of the major Japanese semiconductor makers jumps into the business, but legal questions may delay this until 1994 or later.

The Future of the x86

The battle of the RISCs, while obviously critical to RISC vendors, is nearly irrelevant to x86 vendors. In a few years, if Windows NT on RISC platforms is a wild success, RISC processor vendors might sell several million chips per year for the desktop market. For the x86, this might cut annual shipments from, say, 50 million to 45 million—hardly a major factor in the success of the architecture. Note that Cyrix—the youngest and smallest of the x86 vendors—shipped more processors in the fourth quarter of 1992 than all RISC vendors combined shipped in all of 1992 for the desktop market.

The real battle for volume in the desktop microprocessor market will be among the vendors of x86 microprocessors. Intel is clearly in a commanding position. All the high-end x86 processors are still Intel-proprietary, and they have been nearly immune from the price compression that has consolidated the low-end and mid-range processors.

Unless Intel stumbles badly with Pentium, it will retain its performance lead among x86 implementations and have a new core processor from which to spin derivatives—before its competitors are in production with a line of 486DX-class products. Pricing of 486DX chips will surely follow the trend of the 386 and 486SX, eventually heading under $100. The big price cuts probably won't occur until 1994, however, when AMD, Cyrix, TI, and probably others as well have ramped up production. By then, Intel will have once again established the high ground with a range of Pentium-family processors, and Intel may gradually give up the 486 market just as it has with the 386.

The 386/486 market has changed dramatically in the past year, and the coming year should bring even more change. Straight Intel clones, such as AMD's 386, will become a thing of the past, as each vendor develops its own implementation of the architecture. While Intel likes to call the compatible chip vendors "imitators," they are imitating less and less. With Pentium-class designs, no vendor can afford the delay that would be incurred in waiting for Intel's chip to ship and then analyzing it before developing a competitive product. Instead, multiple vendors are creating their own independent implementations of a *de facto* standard instruction-set architecture. The result will be a wider array of offerings than ever before, giving system designers and users more choices and more competitive pricing.

Intel still holds the keys to the kingdom in one important sense: it is the only company with the credibility to evolve the architecture. Perhaps with Pentium, and surely with the P6, new features—and possibly even an entire alternate instruction set—will be added to the architecture. Intel has the leadership role that allows it to add new capabilities and gain broad industry support for them, while other vendors will have to follow Intel's lead. ♦

