Intel Redesigns 386 For Embedded Market

New Chips Extend 80186 Line With 32-Bit Performance

by Linley Gwennap

Intel has announced three new chips intended to increase sales of its 386 chips into embedded applications. The first to roll out are a static version of the standard 386SX and the new 386CX, which includes low-voltage operation, SMM for power management, and an expanded address range. The more interesting 386EX, due to sample next spring, combines the 386CX with on-chip peripherals that are popular in the embedded market.

The new Intel chips are fully compatible with DOS, Windows, and their derivatives. For example, the chips support Microsoft's forthcoming At Work operating system, which is designed for printers, fax machines, and other office equipment. Microsoft is also developing a derivative of Windows for the interactive digital TV market as part of its deal with General Instrument *(see **0709MSB.PDF**)*. The new chips could appear in GI's future set-top boxes.

The new 386CX is comparable to AMD's 386SX and SXLV, which have offered SMM and static, low-voltage operation for years. AMD also offers the highly integrated 386SC, which is expected to go into production at about the same time as Intel's new 386EX. Intel hopes that its new chips will prevent the company from losing additional 386 market share to its arch-rival.

Intel's Embedded Strategy

The x86 architecture has long been a player in the embedded market, primarily with the 16-bit 80186. This chip was first announced in 1982 and combines an 8086 processor core with a DMA controller, timer/counters, interrupt controller, serial ports, and other peripherals. Its system logic is not quite compatible with DOS, but the 186 quickly became popular as an embedded processor.

By 1991, Intel estimates that the 186 had gained more than 10,000 design wins and was selling more than 10 million units per year. In that year, the family was expanded with EA, EB, and EC versions, which feature varying levels of integration. All offer static operation at voltages down to 3 V. These parts continue to sell well today, with 1K pricing starting at less than $20. Common applications include modems, disk controllers, and cellular phones.

	3.0 V	3.3 V	5.0 V
Maximum Clock Rate	16 MHz	20 MHz	25 MHz
Dhrystone MIPS (approx)	3.0 MIPS	3.6 MIPS	4.3 MIPS
386CX Power	300 mW	530 mW	1.4 W
386EX Power (estimated)	420 mW	660 mW	2.0 W

Table 1. Intel's new 386CX and 386EX operate at a variety of frequencies, depending on the supply voltage.

At its top speed of 20 MHz, the performance of the 16-bit processor is inadequate for many embedded applications. Some customers began using standard 386 chips as a performance upgrade; Intel estimates that about 30% of its current 386 sales now go into embedded products. Even customers willing to pay more for the higher performance, however, could not replace the 186 in many designs because the 386 lacked static, low-voltage operation and on-chip peripherals.

Intel first tried to upgrade its 186 customers with the 80376 (see MPR 4/1/88, p. 9). The 376 was basically a 386SX crippled to make it impossible to run DOS. A second chip provided the peripherals that are on the 186 chip. Few customers were willing to pony up $150 for the two-chip set, however, and the 376 never got going. Intel then tried, with some success, to move performance-hungry customers to its 32-bit i960 family, but these chips were also expensive and lacked many of the low-power and on-chip peripheral features of the 186.

In 1991, AMD launched its 386 family and, by the end of that year, was shipping static, low-voltage parts with SMM. Intel shifted its emphasis to its 486 line and refused to enhance its own 386 chips to match AMD's. While this proved to be a successful strategy for moving PC makers to the higher-performance processor, it left embedded customers, who could barely afford a 386, in a lurch—or in AMD's hands.

After stamping out desktop demand for its 386, Intel has turned that product line over to its embedded business. The company is now trying to boost its 386 embedded sales above the current level of about 1 million per year. The new chips are Intel's first 386s specifically designed for the embedded market, and they address the limitations noted above. The 386EX, in particular, is a worthy successor to the 80186, albeit a few years late. While the 16-bit chips will continue to be sold for price-sensitive applications, the new 386s will deliver 32-bit performance for applications that require it.

New Embedded Chips Do DOS, Too

A major factor in Intel's new embedded strategy is compatibility with DOS. The 80186 has been successful despite its inability to run DOS, but Intel does not want to continue this strategy. The new chips, including the 386EX, run DOS and other Microsoft software, but are not meant for use in standard PC systems.

Intel now claims that many designers are embedding DOS into their products to reduce design time, a lesson the company may have learned from the chilly reception given to the DOS-less 376. By building applications around DOS, developers can build their software quickly and prototype it on a common PC, taking advantage of a wide array of programs and debugging tools. The final software can then be placed in ROM along with DOS and any necessary support programs. Embedded designers have been using these techniques for years with AMD's and Intel's 386 chips.

The new 386SX and CX parts are also compatible with existing system-logic chip sets designed for PCs; these chip sets provide similar functions in an embedded design. A variety of peripherals can be easily and inexpensively implemented by taking advantage of existing chips. Many engineers are already familiar with the 386 in PC designs and can use this experience when designing the 386 into an embedded system.

Static 386SX and 386CX

The static 386SX (which has no unique designation) is identical to the standard 386SX in pinout and feature set. The static design allows the CPU clock to be stopped, reducing power consumption almost to zero, without losing any state. The initial version of the static 386SX is rated at 25 MHz; Intel says that by 4Q94 it will offer a faster version that reaches 33 MHz. While Intel will continue selling the dynamic version of the 386SX for at least the next several months, the static 386SX will eventually displace it from the product line.

The new 386CX uses the same die and same 100-pin PQFP as the static 386SX but redefines two pins to extend the physical address range to 64M (26 bits). Not coincidentally, this address range matches the PCMCIA standard, making the CX suitable for controlling an add-in card. The CX also adds system-management mode, which is now available on nearly every Intel x86 CPU. Other features of the CX are identical to the new static 386SX. In addition to the PQFP, the CX will also be sold in a smaller 100-pin SQFP and as unpackaged die for chip-on-board applications *(see **071304.PDF**)*.

Unlike the static SX, the CX is rated for operation at 3.3 V and 3 V, although as shown in Table 1, the clock must be slowed at these lower voltages. Lower-speed, lower-voltage operation greatly decreases power consumption, as the table also shows.

The 386CX is comparable to AMD's 386SXLV. If Intel had introduced the low-power 386CX a year ago, some notebook PC makers might have been interested, but most have now moved to higher-performance processors.

The 386CX could be attractive to vendors of so-called pocket PCs, although Intel is not pursuing these applications. One chip that is, AMD's 386SC *(see **071404.PDF**)*, costs about twice as much as the 386CX but includes a complete set of PC system logic and peripheral interfaces on a single chip. It also operates at 33 MHz even at 3.3 V. For the PDA market, Intel is counting on the recently announced Polar processor *(see **071302.PDF**)*, which also outperforms the 386CX and integrates a variety of PDA functions.

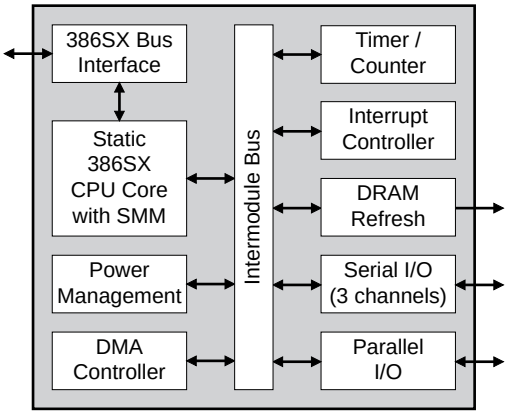

Figure 1. The forthcoming 386EX combines a static 386 core with a set of on-chip peripherals tuned for embedded designs.

Both the static SX and the CX will be built in both 1.0-micron and 0.8-micron CMOS. This strategy allows Intel to take advantage of excess 1.0-micron capacity. The die size of the 0.8-micron version is 31 mm^2, compared to 43 mm^2 for the 1.0-micron dynamic 386SX. The MPR Cost Model *(see **071004.PDF**)* estimates that the 0.8-micron 386SX will cost about $8 to manufacture, compared with $9 for the 1.0-micron version and $10 for the 1.0-micron 386DX.

386EX Integrates Peripherals

The EX starts with the same CPU core as the CX and has the same voltage and speed ratings. It also supports static operation and SMM. The EX adds a variety of system logic and peripherals, as shown in Figure 1.

Although the EX is DOS-compatible, it is not designed for the PC market. Thus, its feature set is quite different from the 386SL, Intel's other highly integrated 386 chip. The 386EX does not include a cache controller or an ISA bus interface, for example.

The EX does not have a complete DRAM controller but provides some simple refresh circuitry. Intel integrated only those functions that are needed by most embedded applications, and the company believes that many of these designs do not require a DRAM controller with page-mode and other fancy features; some even use SRAM instead of DRAM. Designs with simple memory systems can use a PAL to generate the required RAS and CAS signals.

The EX brings the standard 386SX bus out to the pins so a standard DRAM controller (or other peripherals) can be added externally. Like the CX, the EX ex-

tends the address range of the external bus to 26 bits. It also provides separate read and write signals (unlike a 386SX) for a glueless interface to common ROM and SRAM chips.

The integrated processor has many system-logic functions that are roughly equivalent to those on the 82360SL "companion" chip. These include two DMA controllers, three timer/counters, two interrupt controllers, two asynchronous serial ports, and up to 24 bits of parallel I/O. The DMA controller is enhanced for extended 26-bit addressing, although this feature can be disabled for strict compatibility. The EX does not include a real-time clock or memory mapper, although it has eight programmable chip selects. Unlike the 360SL, the new chip also has a synchronous serial port.

Unlike the CX, the EX includes several power-management features. Power Save mode allows the CPU clock to be divided by any power of two up to 64; during non-critical code segments, running the clock at a lower speed reduces power usage proportionally. Idle mode stops the CPU clock entirely while the on-chip peripherals to continue to function; this cuts power usage by about 60%. Finally, the entire chip can be halted when no useful work is being done, reducing power consumption to less than 1 mW. The static design maintains all internal state even when the clocks are stopped.

The integrated EX will not be available as soon as the initial SX and CX parts; Intel expects the EX to reach production in 3Q94. Projected pricing for the EX is $39. It will be built in a 0.8-micron, three-layer-metal CMOS process. Since the design is not yet complete, the die size is not known, but Intel expects it to be about 60 mm^2, nearly twice the size of the 0.8-micron CX. This size, however, would be barely a third of the similarly integrated 386SL, which measures 169 mm^2 in a 1.0-micron process.

The MPR Cost Model estimates that the 386EX will cost about $15 to manufacture; compared with the CX, the cost difference is not as large as the area increase because much of the cost of these tiny chips is in the testing and packaging.

Free Real-Time OS Available

Although DOS is a key component of the embedded 386 strategy, many embedded applications require an operating system with a fast interrupt-response time. For these applications, each 386CX and EX processor comes with a binary license for Intel's iRMX real-time operating system. This OS includes a multitasking kernel, peripheral drivers, and a static debugger. It supports a variety of third-party C/C++ compilers.

For an additional fee of about $2300, users can purchase a software developer's kit (SDK) that consists of complete iRMX documentation, a simulator, debugger, low-level monitor, and other utilities.

Price and Availability

Intel plans to sample the static 386SX and 386CX in 4Q93, with production in 1Q94. At 25 MHz, the static 386SX is priced at $26 and the 386CX at $27.30, both in 5K quantities. The company expects to sample the 386EX next April, with production in 3Q94. The 386EX will cost $39 in 5K quantities.

For more information, contact your local Intel sales office or call Intel's Embedded Hotline at 800.468.8118.

386 and 960 Split Embedded Market

The new parts will allow Intel to compete with AMD for embedded 386 designs that require low-power features. The extra address pins on the CX give it an edge in applications that need a larger memory space, such as PCMCIA devices. Designers using DOS, At Work, or similar operating systems should also find the new parts attractive.

The 386EX, with its on-chip peripherals, will reduce the cost of 386-based embedded systems and allow 80186 users to upgrade their designs easily to 32-bit processing power—if they haven't already bolted to another 32-bit architecture in the meantime. AMD's 386SC offers a richer set of peripherals than the EX and delivers 66% more performance at 3.3 V. It does, however, cost about 30% more than the EX. The AMD chip is designed to be customizable; AMD says that it could quickly produce a part that matches the EX in price and feature set, but it has yet to indicate any intention to do so.

For many 32-bit applications, the 386 is underpowered, particularly when compared with many RISC processors. Intel hopes that performance-sensitive designers will choose its 960 family; the low end of the 960 line delivers more performance than the 25-MHz 386SX for a 25% lower cost. Other RISC processors also offer a price/performance advantage over the 386SX; IDT's R3041, for example, delivers much more performance at about the same price.

Thus, potential customers for Intel's new 386 chips must derive significant benefits from x86 compatibility, due either to their choice of operating system or to compatibility with existing 80186 designs or other existing software. If these situations are not applicable, customers may be better off with a RISC chip.

As the sun sets on the life of the 386 as a PC engine, Intel has belatedly tailored the part for the embedded market. In this way, the 386—using fully amortized fabs and with only a little new design work—will continue to thrive for years to come as the controller for copiers, digital televisions and telephones, handheld devices, and other embedded appliances. ♦

