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K6 Is World's Fastest x86 Chip

AMD Ships at 233 MHz, Surpasses Pentium Pro Performance

by Linley Gwennap

After the K5 debacle left AMD wandering in a profitless desert for more than a year, the company has returned with a vengeance. With its new K6 processor shipping at clock speeds of up to 233 MHz, AMD now has a processor faster than Intel's best chips. As Figure 1 shows, the higher clock speed helps the K6/PR2-233 exceed the performance of a 200-MHz Pentium/MMX (P55C) and a 200-MHz Pentium Pro on both Windows 95 and Windows NT benchmarks.

AMD is not likely to hold this lead for long; within the next couple of months, we expect Intel to unleash its Pentium II (Klamath) processor at speeds of 233 and 266 MHz, regaining the performance lead. Still, AMD's announcement marks a milestone for the number-two x86 vendor, which has never before outrun Intel on its own turf. Even if the K6 falls behind the initial Pentium II chips, it is likely to keep pace with Intel's fastest chips for at least the next year, allowing AMD to match Intel's desktop PC product line from essentially the top to the bottom.

AMD's dry period left it thirsty for sales, so the vendor is taking an aggressive pricing stance. The list price of the new parts is at least 25% below Intel's price for comparable performance, and AMD plans to offer even greater discounts to large customers: as much as 40% below Intel's best prices. The resurgent vendor hopes to win business quickly with these low prices, allowing it to finally put the idle capacity of its enormous Fab 25 to good use. AMD plans to add even more capacity over the next three years, ensuring that future market share gains will not be held back by production limits.

The release of the K6 is also a vindication of the company's NexGen purchase *(see* **091502.PDF***)*, which some observers ridiculed as overpriced and unnecessary. The K6, which is based on a NexGen design, could garner more than $2 billion in revenue in the next 18 months alone, easily justifying the $600 million acquisition. The former NexGen team continues to lead AMD's CPU development efforts, auguring well for future devices.

Performance Matches P6 Clock for Clock

AMD found a K6-233 to score 72.7 on the Winstone 97 Business benchmark for Windows NT, a result that we duplicated. This system was armed for bear, with 1M of L2 cache, 64M of SDRAM, a Matrox Millennium 4M graphics adapter in 1024 × 768 × 16 mode, and a Seagate Cheetah hard drive using a SCSI controller with a whopping 8M of cache. With the same peripherals, a 200-MHz Pentium Pro system scored 69.9, about 4% less than the K6-233. This result is significantly better than any previously published Winstone 97 score for Pentium Pro.

AMD tested the K6 and Pentium Pro in a more mainstream system configuration: 32M of EDO DRAM, a Western Digital EIDE Caviar 22100 drive, and the ubiquitous Matrox graphics card. Because the K6 uses a Pentium pinout, it was tested with a Via Apollo VP2 chip set, whereas the PPro system used Intel's top-of-the-line 440FX chip set.

As Figure 1 shows, a K6-200 delivers essentially the same performance as a Pentium Pro-200 under Windows NT; the PPro outscores the K6 by less than 1% at the same clock speed on Winstone 97. The K6-233, however, exceeds the PPro's score by 4%.

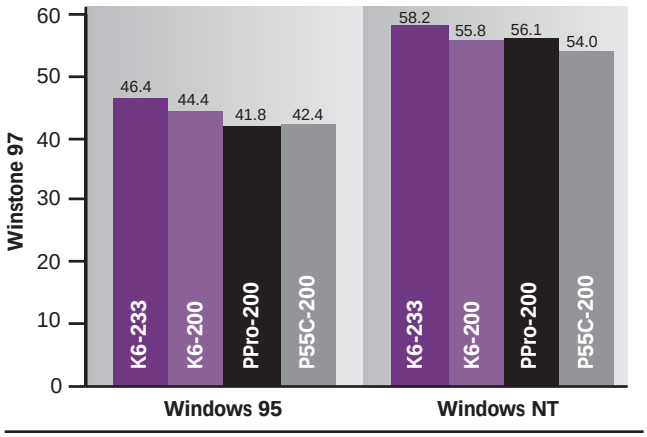

Figure 1. When tested in similar systems, AMD's 233-MHz K6 outscores a 200-MHz Pentium Pro and a 200-MHz Pentium/MMX on the Winstone 97 benchmark under both Windows 95 and Windows NT. See text for configurations. (Source: AMD)

The K6 system had 512K of cache, whereas the Pentium Pro relied on its internal 256K cache, a difference that gave AMD a small boost. Although PPro is available with a 512K cache, such parts are virtually unseen in desktop PCs. We expect the K6 will have clock-for-clock performance similar to Pentium II's when both chips use 512K caches.

When running Windows 95, Pentium Pro is hampered by its weaknesses on 16-bit code, falling 6% behind the K6-200 and 10% behind the K6-233 on Winstone 97. Because Pentium II includes features to improve 16-bit performance *(see* **110201.PDF***)*, we expect it to do nearly as well on Windows 95 as on Windows NT, bringing it to clock-for-clock parity with the K6. Of course, until actual benchmarks are available for Pentium II, an exact performance comparison is impossible.

Since the K6 is pin-compatible with Pentium/MMX, it will also compete with that processor. AMD tested the K6 system described above against a similar Pentium/MMX system with a Triton HX chip set and 512K of cache. In this case, the K6 outperformed the Pentium/MMX system by 3% under WinNT and 5% under Win95 when both processors operated at 200 MHz. The K6-233 was 8–9% faster than the 200-MHz Pentium/MMX and should be comfortably faster than a 233-MHz version of that chip.

When the Nx686 was announced *(see* **091401.PDF***)*, NexGen believed it would deliver 10–20% better performance than the P6 core at the same clock speed, but the K6 doesn't achieve this goal. Most of the loss is due to the elimination of the Nx686's direct L2 cache bus, a feature the P6 takes advantage of. On the other hand, the K6 came in well ahead of the Nx686's 180-MHz clock-speed goal, making up for the difference in clock-for-clock performance.

K6 Falls Short on Floating-Point, MMX

Because of the lack of PC-oriented benchmarks that use floating-point or MMX instructions, initial test results in these areas are not conclusive. We believe the K6 will deliver somewhat lower performance than Pentium II in these two areas but could come closer to the performance of Pentium/MMX, particularly on FP code.

The K6 is hampered because its floating-point unit, unlike the P6's, is not fully pipelined; the AMD chip can issue only one FP operation every two cycles. Similarly, the K6's integer multiply unit has half the throughput of the P6's. AMD's latencies are shorter than Intel's, but in an out-of-order CPU, latencies are easily hidden.

Although the K6 implements Intel's MMX instruction extensions, the chip can issue only one MMX instruction per cycle; both Pentium/MMX and Pentium II can issue two. With twice the peak throughput on most operations, the Intel chips should have an advantage on MMX code.

Because of these limitations, the K6 is not the fastest processor for PC buyers who are heavy users of 3D graphics, Photoshop, and other floating-point and MMX applications. But the K6 performs respectably well on these types of programs, so buyers who occasionally use them should not be overly concerned.

AMD has selected a new nomenclature to describe the performance of the K6. The PR2 rating is a second version of the original PR rating; whereas PR compares performance to a non-MMX (P54C) Pentium, PR2 positions the new chip against Intel's P6 family. Because Winstone 97 shows roughly clock-for-clock parity between the K6 and Pentium Pro, AMD has chosen PR2 ratings exactly the same as the clock speed: for example, the 233-MHz K6 is designated PR2-233.

The PR2 rating does not allow direct comparisons against Pentium or Pentium/MMX, but the performance data given earlier shows the K6 delivers about the same performance as a Pentium/MMX that is one clock speed faster. For example, the K6-166 should match up against a P55C-200 on most integer-intensive PC applications.

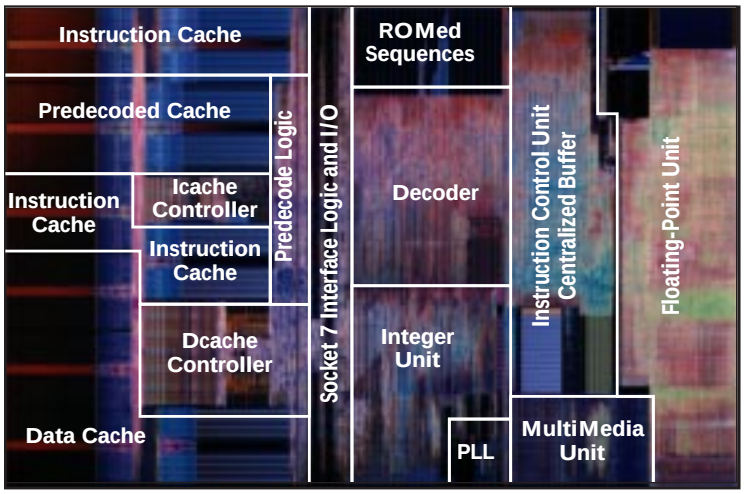

Figure 2. With 8.8 million transistors, the K6 measures 15.7 × 10.3 mm when built in AMD's 0.3-micron five-layer-metal CS-34EX process.

High Power Needed for High Performance

AMD claims it has good yield at 200 MHz, but it had to play some games to get reasonable yield at 233 MHz. While all K6 chips provide 3.3-V I/O for compatibility, the slower parts use a 2.9-V core voltage but the 233-MHz version requires a 3.2-V core, both within the standard for Socket 7 motherboards. Intel, of course, is the master of this game, having shipped Pentium processors at 2.8, 2.9, 3.1, 3.3, and 3.45 V to achieve various speed grades.

The K6-200 dissipates 20 W (maximum) at 2.9 V, while the K6-233 reaches 28 W at 3.2 V. These ratings, particularly the latter, are well above the maximum ratings for Intel's Pentium processors. The K6 requires a fan/heatsink for extra cooling, adding about $2 to the cost of the system.

While these unexpectedly high power ratings are a minor issue for desktop PCs, they will keep the initial K6 chips out of the notebook market. Even at 2.5 V and 166 MHz, the K6 would dissipate 20% more heat

than Intel's hottest notebook parts. In addition, AMD's flip-chip (C4) die attachment is not compatible with the TAB package used in many Pentium notebooks, and AMD has no immediate plans to offer the K6 on daughtercards compatible with Intel's Mobile Modules *(see* **110202.PDF***)*.

0.25-Micron Version Due by Year's End

The initial version of the K6, shown in Figure 2, measures 162 mm^2 in AMD's 0.30-micron five-layer-metal CS-34EX process *(see* **101203.PDF***)*, which is comparable to Intel's 0.28-micron four-layer-metal CMOS process, used for Pentium/MMX and Pentium II. Both AMD and Intel refer to these processes as 0.35-micron CMOS, but we label them by their drawn transistor length, which is smaller.

AMD is already testing K6 prototypes built in its 0.25-micron CS-44 process, which has much tighter metal pitches than the current process. Our analysis of routing density indicates the 0.25-micron K6 could be less than 80 mm^2 in size, reducing our manufacturing cost estimate from $70 for the initial parts to $40 for the smaller version.

By greatly reducing the metal trace lengths and shrinking the transistors, AMD should be able to push the K6 clock speed above 300 MHz. The company plans to ship the first 0.25-micron K6 chips in 4Q97 at 300 MHz. Faster parts should follow early in 1998. Intel plans to deploy its 0.25-micron Pentium II parts (code-named Deschutes) at similar clock speeds around the end of this year, so any performance lead AMD can grab will again be brief.

The 0.25-micron parts will operate at 1.8 V, greatly reducing power dissipation. A 300-MHz part, for example, should dissipate roughly 10 W, about the same as today's hottest Mobile Pentium processors. This change should allow AMD to offer a notebook K6 for the first time, although the vendor must still find a way to offer packaging compatible with Intel's to gain significant share in the mobile market.

The die shrink creates an opportunity to add features to the design. In 1998, the company plans to get Fab 25 to its full capacity of 6,200 wafers per week, with two-thirds of those wafers in the 0.25-micron process; we estimate this will increase the fab's capacity to 30–40 million K6 processors per year, even assuming a third of the wafers are used for other products. By 2000, AMD will redouble its capacity by building an equally large fab in Dresden, Germany.

Not even AMD believes it can sell that many x86 chips. With this much capacity, the company can increase the die size of its products with little incremental cost, assuming the fab is treated as a sunk cost. One way to enlarge the die is with a larger, higher-performance CPU core. AMD's K7 will take this approach, but not until 1999.

In the interim, the simplest way to use extra die area is to add cache memory. With five metal layers plus a local interconnect, CS-44 is optimized for dense memory structures; even quadrupling the current 64K of on-chip cache would add only about 40 mm^2 to the die.

AMD Enters Chip-Set Business

To date, AMD's K5 and K6 processors have leveraged the infrastructure built by Intel for its Pentium chips. AMD plans to continue using the Pentium socket, Socket 7, for another three years, whereas Intel has already said it will stop providing feature enhancements to Socket 7. For instance, Intel has no plans to add AGP support to its Pentium chip sets, reserving this feature for its P6 system logic. As a strategic necessity, AMD must ensure Socket 7 has access to leading-edge features over time.

To achieve this goal, the company is working closely with non-Intel chip-set makers such as VIA, Opti, ALI, and SiS. But given the ailing state of these vendors and Intel's dominance of the chip-set market, AMD has little choice but to enter the chip-set business itself, following the footsteps of its rival.

The company announced its first product, consisting of the AMD 640 (north bridge) and 645 (south bridge), which use a 328-pad BGA and 208-pin PQFP, respectively. This chip set provides emerging features such as SDRAM support, UltraDMA, concurrent PCI, USB, and ACPI, making it similar to the new 430TX chip set from Intel *(see* **1102MSB.PDF***)*.

Now sampling, the 640/645 is expected to reach production in 2Q97 at a list price of $30.60 in 1,000-piece lots. By comparison, Intel's 430TX lists for $32.50. AMD's strategy is to keep its chip-set prices below Intel's but above those of third-party vendors, avoiding direct competition with those companies.

In 4Q97, AMD expects to ship an enhanced version of the 640 that adds AGP support, increasing the package size to 444 pads. This version is likely to reach the market too late for most Christmas PCs; Intel hopes to make AGP a key feature this Christmas, but it isn't clear whether the company's first AGP chip set, the 440LX, will ship significantly before AMD's.

The chip-set group, located in Santa Clara (Calif.), grew out of NexGen's chip-set team. With many Silicon Valley chip-set makers shedding staff, building the team was fairly easy.

AMD won't manufacture these chip sets, because they use an older 0.5-micron technology that isn't implemented at Fab 25. We suspect the chips will be built by long-time AMD partner TSMC, although AMD would not confirm this detail.

AMD will provide design documentation for K6/640 motherboards to any manufacturer interested in building them. The company will not, however, emulate Intel's motherboard business, refusing to compete with potential customers. With these chip-set and motherboard efforts, AMD hopes to keep Socket 7 alive even as Intel begins to phase it out of the market.

Price & Availability

The AMD K6 is now shipping in three speed grades: 166, 200, and 233 MHz. In quantities of 1,000, the list prices of the three speed grades are $244, $349, and $469, respectively. Contact your local AMD sales office or access the Web at *www.amd.com/K6.*

Adding on-chip cache would further isolate the 300-MHz CPU core from the pokey 66-MHz external bus. In fact, with 256K of on-chip cache, the external cache could become superfluous, reducing system cost.

AMD is also likely to make some minor architectural enhancements to the K6 core, probably by 2H98. These changes could include increasing the size of the reorder buffer (which AMD calls the ICU), adding a second multimedia unit to enable dual-issue of MMX instructions, and fully pipelining the floating-point unit. These changes will be necessary to boost performance and to position the K6 to compete against future Intel offerings such as Katmai, which is expected around mid-1998 *(see* **1015MSB.PDF***)*.

Prices 30–40% Less Than Intel's

The introductory pricing for the K6 is certainly attractive: $349 for the mainstream 200-MHz part and $469 for the high-end 233-MHz version, all in 1,000-unit quantities. Based on AMD's comparisons, the K6 delivers better clock-for-clock performance than a P55C but sells for 30–40% less than Intel's list prices. The K6 sells for 35–40% less than Pentium Pro chips of equivalent clock speeds.

Intel doesn't have a 233-MHz processor, so it is difficult to compare the K6-233 to an Intel chip. We expect a 233-MHz Pentium II to list for about $650, giving AMD a potential 30% price advantage over this processor. Major PC vendors will see an even bigger price gap, as AMD offers big discounts to its largest customers, but Intel's best prices are only about 10% less than its list prices.

We believe this pricing strategy is just about right for gaining market share; Cyrix has been successful in selling out its supply of 6x86 chips by offering prices about 40% lower than Intel's. Although many PC makers are willing to consider alternative x86 suppliers, Intel processors still have a significant intangible value over non-Intel chips, so a smaller discount is not enough to justify switching.

These prices mark a huge change in AMD's financial picture. Throughout 1995 and 1996, the company failed to deliver an x86 product with a three-digit price tag. Only recently did the vendor announce the K5-PR166, which lists at $137. Even the entry-level K6 lists for nearly twice that amount, and AMD has never in its history sold a processor at a price approaching $500. These high prices are enabled by AMD's performance parity with Intel.

Great Market Opportunities

AMD plans to ship hundreds of thousands of K6 chips in 2Q97 and more than five million by the end of 1997. Combined with five million K5s, this would give AMD about 12% of the x86 processor market in 1997. This share is not very different from its 1996 share, but last year most of AMD's shipments were 486 processors at sub-$40 prices, putting its revenue share at less than 3%.

The vendor's ultimate goal is to sell 20–30% of all x86 processors, which we believe is the maximum amount that Intel will tolerate "sharing" *(see* **1104ED.PDF***)*. AMD, however, may have to share this portion with Cyrix, IBM, and other x86 vendors. For that reason, a more likely goal for AMD is a 15–20% unit share.

Several barriers stand in the way of AMD's achieving even this share. Many PC makers, including Dell and Gateway, have close ties to Intel and are not likely to consider an alternative supplier except at the very low end. Businesses, which purchase two-thirds of all PCs, have historically been Intel loyalists, leaving only consumer PCs open to Intel's competitors. Without a strong notebook offering, AMD can't access another significant portion of the market. Finally, AMD must successfully prevent its smaller competitors from gaining ground; as more CPU makers jump into the x86 market, price wars are likely, particularly at the low end of the market.

The biggest barrier to the K6's long-term success is AMD's socket strategy. We project about 55 million Socket 7 desktop PCs will be sold in 1997, giving AMD (and Cyrix) plenty of opportunities, but by 1999 this number will drop to below 20 million. The vast majority of the PC market in 1999 will have switched to Intel's desktop and notebook processor modules *(see* **1103ED.PDF***)*.

To keep Socket 7 competitive, AMD has launched its own chip-set efforts *(see sidebar, previous page)* and will supply free motherboard designs to any vendor willing to build them. The company has also launched the biggest marketing campaign in its history to support the K6 brand. Intel is likely to counter with a megabucks campaign to convince PC buyers and OEMs that sockets are "old" technology with no headroom for the future. We'll put our bets on Intel's marketing engine to firmly establish slots over sockets within two years. With the K7, however, AMD should finally be able to move beyond Socket 7—though to what is not clear.

For the first time, AMD is offering products that match the performance of Intel's line from the bottom to the top. Intel is vulnerable due to its high prices, tight fab capacity, and poor relations with many PC makers, particularly the smaller ones. Over the next year, the K6 will allow AMD to knock the cobwebs out of Fab 25, regain its lost market share, and rebuild its profitability, giving the company a strong base from which to confront its longer-term challenges. M