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Pentium Approaches RISC Performance

486DX2-66 Integer Performance Doubled, Floating-Point More Than Tripled

By Linley Gwennap

Intel has taken the wraps off its eagerly-awaited Pentium design, revealing a high-performance chip that borrows many of the techniques used by recent RISC processors. Superscalar instruction dispatch, a branch prediction buffer, and split on-chip caches propel the 66-MHz Pentium to ratings of 64.5 SPECint92, surpassing some leading RISC chips, and 56.9 SPECfp92 *(see **070402.PDF**)*. These announced performance numbers show that not only has Intel reached its publicly-stated goals for Pentium, but that at least some RISC vendors will be challenged by the new chip.

Although the company revealed much of the inner workings of its new part, it is keeping a few secrets indefinitely, hoping to thwart competitors working on compatible chips. Intel is also delaying its official "product announcement" until May 18, at which time it will reveal price and availability information and allow system vendors to announce their products. The recent technology disclosure provides, for the first time, enough information for a detailed comparison of Pentium to other x86 chips and its RISC competitors.

A Hot Chip in More Ways Than One

The initial Pentium parts will be available at 60 MHz and 66 MHz. The performance difference between the two speed grades is only about 10%, hardly enough to incite customers to move from one to the other. Intel claims that Pentium is yielding well at its 66-MHz target frequency, but the slightly lower speed option indicates that a significant number of chips do not work at that frequency. Early customers will probably be happy to get Pentiums at either speed grade, since even the slower part nearly doubles the performance of Intel's current top of the line, the 486DX2/66, on recompiled code.

The data book confirms rumors that Pentium is a hot chip, quoting a maximum power dissipation of 16 watts at 66 MHz. Typical power is quoted at 13 watts. This is a major jump from the first 486, which used less than 4 watts. Even the 486DX2, which Intel ships with its own 0.35" heat sink, peaks at 6 watts.

Pentium chips will ship without a heat sink, giving the system vendor a choice. Using a heat sink similar to the 486DX2's, the system must provide a gale-force airflow of 650 ft/min to cool the CPU in ambient temperatures up to 40° C. With a 0.65" heat sink, the airflow can be reduced to a merely stormy 300 ft/min.

Designers of large systems are used to such power levels, and Pentium dissipates considerably less heat than the PA7100 or Alpha chips, both of which exceed 20 watts. Since PC fans typically provide only 50–100 ft/min of airflow, however, PC designers will have to rethink their system designs to allow for such a powerful chip.

Pentium Performance Details

Intel expected Pentium to provide twice the integer performance of a 486 at the same frequency, and achieved this goal within a tenth of a SPECmark, as shown in Table 1. The floating-point improvement is much greater at about 3.5 times the 486. These figures demonstrate that superscalar dispatch and an enhanced floating-point unit, techniques first pioneered by RISC workstation chips, also allow CISC chips to perform well on technical programs such as the SPEC suite.

The SPEC ratings and other performance benchmarks quoted by Intel were measured on internal prototype systems using a Pentium processor and an 82496 cache controller *(see **070403.PDF**)*, since no salable systems will be announced until May.

Intel rates the 66-MHz Pentium at 567 iCOMPs *(see **061302.PDF**)*, compared to 297 for the same-frequency 486DX2. This is a bit less than the increase seen in SPECmark, due to the inclusion of 16-bit benchmarks in the iCOMP suite. Table 1 shows that the Pentium performance enhancements are not as effective for the 16-bit programs as for 32-bit tests.

One reason that the 16-bit benchmarks do not show as much improvement is that they tend to stress only the core CPU itself. One of Pentium's improvements is its 66-

MHz, 64-bit bus interface, faster and wider than any 486 chip; the 16-bit programs in Table 1 do not take advantage of the new bus because their inner loops fit in the on-chip cache.

Another reason for the lower performance is the sensitivity of Pentium to instruction scheduling. Due to the large number of compiler changes (many of which also improve 486 performance), old binaries generally have 15%–30% lower performance than recompiled code on Pentium *(see **061405.PDF**)*. Since the 16-bit benchmarks were not recompiled, they do not show the same performance gain. Thus, PC users upgrading to Pentium may not see a doubling of performance over a 486 system, but they will still get a significant gain, particularly with new software optimized for Pentium.

Ready For RISC Competition

Figure 1 graphically compares Pentium's SPEC performance to that of leading RISC chips, with complete details listed in Table 2. These numbers show that, despite Intel's improvement, top RISC processors such as the Alpha chip, the PA7100, and the R4400 all outperform Pentium by 30% to 60% on SPECint92. These chips will continue to offer a performance advantage over CISC products in high-end systems, such as those listed in Table 2. Many of these systems do, of course, cost much more than is expected for Pentium-based PCs.

On the integer benchmarks, Pentium does surpass the fastest processors from both IBM and Sun. In fact, the 40-MHz SuperSPARC is a full 20% slower than Pentium. IBM's RIOS 2 processor, due a few months after Pentium systems, should boost the RS/6000 product line back among the RISC leaders. Sun, however, will have a harder time regaining its performance advantage over Intel's chips *(see **070404.PDF**)*.

Looking at floating point, Pentium's enhancements begin to close the gap with the RISC chips, but all are still comfortably ahead of the Intel processor with the exception of SuperSPARC, which holds only a 10% advantage over Pentium.

		66-MHz Pentium	66-MHz 486DX2	Pentium Advantage
32-bit	Dhrystone MIPS v2.1	101.2	51.6	96%
	SPECint92	64.5	32.2	100%
	Linpack MFLOPS (SP)	14.7	3.1	374%
	SPECfp92	56.9	16.1	253%
16-bit	Norton SI v6.0	211.4	144.2	47%
	Power Meter v1.7	46.4	29.5	56%
	Landmark v2.00 CPU	385.0	223.1	73%
	Landmark v2.00 FPU	1128.2	545.8	107%

Table 1. Pentium performs better on 32-bit benchmarks than 16-bit tests, relative to the 486DX2. Integer benchmarks are shown in white, floating-point tests in gray. (Source: Intel)

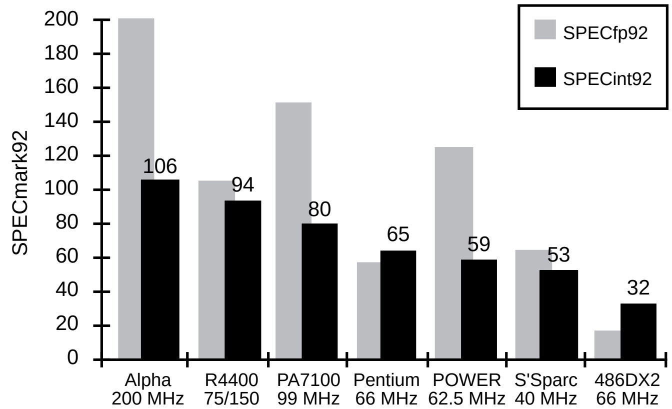

Figure 1. Pentium's integer performance exceeds IBM RIOS and SuperSPARC but floating-point still lags the RISC chips. (Source: vendors' SPEC submissions)

These numbers imply that power users will still look to the hot RISC chips for maximum performance. Particularly in the markets for workstations and compute servers, the superior floating-point performance of the RISC processors will allow them to continue their dominance. SPARC is the only RISC architecture that seems to have a performance problem, but in technical markets, SPARC systems are more likely to lose out to faster RISC systems than to Pentium systems.

Recently, workstations have been replacing PCs on the desktop of some professionals, such as engineering managers and financial analysts, who use a mixture of commercial and technical applications. This market segment, potentially much larger than the pure technical segment, may prove to be fruitful ground for Pentium "workstations" that offer near-RISC performance plus full compatibility with over 50,000 x86 applications.

Price/Performance Key in Some Markets

For commercial applications, such as database and file servers, the performance advantage of the RISC chips is smaller, since these applications rely mainly on integer performance. These large servers often use multiple processors, which can further negate the absolute performance advantage of RISC. For these designs, the price/performance of the processor is most important.

Intel has not announced an official list price for Pentium, but most speculation is that the chip will initially cost around $1200, with major customers paying $800–$1000. This is comparable to the prices of the fastest Alpha, R4400, and SuperSPARC chips. (HP and IBM do not release pricing for their processors.)

Other factors influence processor subsystem cost. SuperSPARC, for example, requires a $600 cache control chip for maximum performance. The Alpha system shown in Table 2 has a large, expensive cache; a 150-MHz system with a more reasonable cache has a 30% lower performance rating, making it more comparable to

System	Intel prototype	Compaq Deskpro/66M	DEC 7000 Model 610	HP 9000 Model 735	RS/6000 Model 980	SGI prototype	SparcStation 10 / Mod. 41	SPARC Classic
Processor	Intel Pentium	Intel 486DX2	DECchip 21064	HP PA7100	IBM Power 6264	MIPS R4400	TI SuperSPARC	TI microSPARC
Clock Rate	66 MHz	66 MHz	200 MHz	99 MHz	62.5 MHz	75/150 MHz	40 MHz	50 MHz
Cache (on/off-chip)	16K/256K	8K/256K	16K/4M	none/512K	32K/64K	32K/4M	36K/1M	6K/none
espresso	60.4	30.6	105.3	92.3	55.0	82.5	47.7	26.2
li	88.0	49.0	111.8	86.4	59.7	105.1	49.6	20.7
equtott	54.5	29.7	142.5	90.9	67.1	134.1	90.2	51.9
compress	41.4	20.1	70.2	66.0	51.3	69.6	33.9	18.5
sc	96.0	51.9	178.4	71.7	64.5	101.6	71.1	34.2
gcc	62.8	23.9	69.6	76.7	59.3	84.9	44.3	18.8
SPECint92	64.5	32.2	106.5	80.0	59.2	94.2	53.2	26.4
spice	49.0	19.2	96.6	91.9	73.7	80.0	43.1	17.0
doduc	49.2	15.3	138.3	142.0	88.6	83.8	49.3	17.0
mdljdp2	62.5	16.8	147.2	192.1	124.2	133.8	67.7	24.6
wave5	38.7	5.9	111.6	112.1	69.2	81.1	49.1	13.7
tomcatv	68.3	16.3	307.1	138.0	210.3	160.6	59.3	20.8
ora	64.6	22.7	167.2	276.9	103.1	111.2	118.5	31.2
alvinn	111.9	27.5	502.9	176.8	206.2	116.0	147.3	34.0
ear	129.7	28.8	605.7	258.4	174.2	210.9	78.3	28.9
mdljsp2	30.1	9.0	76.3	92.3	57.3	66.5	32.6	14.5
swm256	40.9	10.3	201.3	79.3	95.8	68.5	39.0	13.3
su2cor	48.2	19.5	290.7	177.2	208.1	115.7	85.7	25.9
hydro2d	55.6	16.3	215.7	166.1	126.7	117.3	64.2	22.3
nasa7	48.2	15.4	261.7	123.3	203.9	124.9	59.2	27.3
fpppp	62.9	18.1	194.1	237.1	172.6	82.4	71.3	16.9
SPECfp92	56.9	16.0	200.4	150.6	124.8	105.2	63.4	21.0

Table 2. SPECmark92 ratings for Pentium, the 486DX2, and various RISC processors at their highest-performance frequencies and configurations. All of these chips are currently sampling or shipping. (Source: vendors' SPEC submissions)

Pentium. With these adjustments, Pentium is competitive but not superior to the RISC chips for server applications. Companies such as Sequent and NCR that currently sell x86-based servers will upgrade to Pentium, while other vendors will probably stick with their current RISC processors.

Price/performance is also a key metric in the midrange desktop market, alternately called either the high-end PC or low-cost workstation segment. As RISC system vendors drop their prices to $5000 and below, these systems compete head-to-head with PCs. In this area, CPU price continues to be critical, along with the price of other system components. The MIPS chips and Pentium both have inexpensive system-logic chip sets available to connect to standard low-cost graphics and peripherals. SuperSPARC has a built-in MBus interface but must give up its expensive cache-control chip and about 10% of its performance to use this interface.

To offer comparable cost, other RISC vendors must move to new CPU designs. IBM will go with its PowerPC 601, while HP will use its PA7100LC. These chips will not be available in systems until 4Q93.

The performance numbers in Figure 2 reflect systems that will sell for about $4000–$5000 around the end of this year. All are estimates, since none of these hypothetical products are yet available. To arrive at these figures, the peak performance of both Pentium and R4400 performance was reduced by 10% to account for the lower-cost system-logic chip sets that are likely to be used in these systems. Performance of the R4400 and SuperSPARC was also adjusted to account for a lack of secondary cache.

These estimates show that all of these processors could end up being very close in integer performance. The MIPS and Alpha processors should have a slight advantage over Pentium, an advantage that could expand if vendors offer R4400 systems with an inexpensive external cache, or if DEC can offer 150-MHz Alpha systems at a low enough price point. Other RISC vendors may have to push their chips harder just to match Pentium.

On the desktop, simply matching Pentium will not make up for the overwhelming software advantage of the x86, leaving the RISC chips with an uphill battle. DEC and MIPS will try to offer superior performance at the same price; MIPS also has the advantage of two very low-cost chips (VRX and Orion) in the works. HP may use the 7100LC's multimedia acceleration as a differentiator. IBM expects the smaller die size of its 601 will provide a much lower cost than Pentium. It remains to be seen whether any of these scenarios will occur, and if they do, whether the market will respond or stick with Intel.

What's Next For Intel?

The impending availability of Pentium creates a

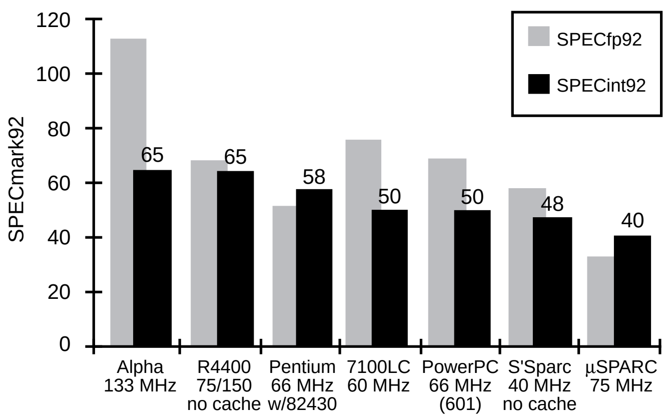

Figure 2. Estimated performance of desktop systems costing about $5000 around the end of 1993 using various processors. (Source: µPR projections)

large gap in Intel's product line, since the 60-MHz Pentium offers a 90% performance gain over the top 486 chips. Intel could fill this gap by offering lower-speed Pentiums, but the company claims that its chip is yielding well at over 60 MHz, so using Pentium to fill the gap would amount to selling perfectly good (and expensive to build) chips at a lower price—not a popular strategy at Intel. Instead, the company is expected to boost the performance of its 486 line.

A new 0.6-micron IC process, becoming available around the end of this year, will give Intel the ability to raise the 486 clock rate to 75 and eventually 100 MHz using clock tripling and 3.3V operation. These "486DX3" chips might also take advantage of the new process to enlarge the on-chip cache to 16K to help make up for the disparity between CPU and memory clock rates. The 486DX3 will fill the performance gap nicely, as shown in Figure 3.

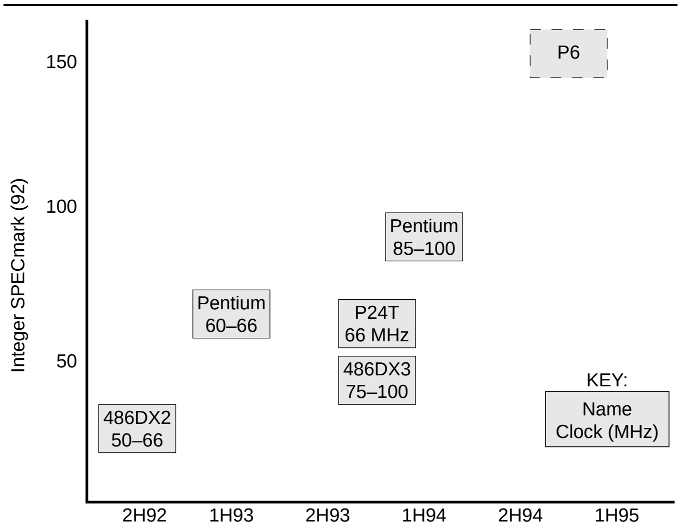

Figure 3. Over the next two years, Intel will continue to extend both the 486 and Pentium families while preparing for P6. (Current chip data: Intel. Future chips: µPR projections)

Pentium will also take advantage of the new process to increase the clock rate and lower both power and manufacturing costs. Likely clock frequencies are 85 and eventually 100 MHz. Larger caches are unlikely in the near term, as Intel needs to reduce the cost of Pentium. Moving to 3.3V will halve the power dissipation of the 66-MHz part and keep the 100-MHz version from needing an even larger heat sink. The 0.6-micron Pentium, with lower fabrication costs and higher performance, will be a potent weapon against both x86 and RISC competitors.

Like the 486, Pentium will spawn many variants, including the oft-discussed P24T, which will fit into the new 486DX2 upgrade socket. An FPU-less version may eventually be deployed to fend off lower-priced competitors. Intel has also hinted at a design that would allow a processor plugged into an upgrade socket to create a true multiprocessor system rather than disabling the original processor. Since Pentium already has MP support in its cache design, adding a bit of support logic to the bus interface would enable inexpensive multiprocessing on the desktop, but is the PC world ready for it?

P6, the eventual successor to Pentium, has been in design for two years. Intel showed a photo of the P6 team with over a hundred people, some spilling out of the edges of the frame. Originally, P6 was due at the end of 1993, but the schedule has now been pushed out to late 1994 or early 1995 to give Pentium a chance to earn its keep. P6 is rumored to be aiming for 2.5× the performance of a 66-MHz Pentium, which would be about 70% more than a 100-MHz Pentium.

Intel refused to discuss the P6 design, but several techniques are available for reaching this performance goal, including implementation of register renaming, wider superscalar dispatch, or out-of-order execution. One persistent rumor is that P6 will implement a new RISC-like instruction set alongside the x86 instructions, easing the implementation of these high-performance features. This line of thinking leads to a P7 that will drop x86 compatibility entirely while adding a 64-bit linear address space.

Conclusion

Pentium will allow Intel to protect its enormous and highly profitable market share from competing RISC and x86-compatible vendors. In 1993, the new chip will be most significant in the server market, where it will maintain the x86 market share against a RISC incursion. By the end of this year, true RISC PCs will be available from a variety of vendors, but Intel should be able to manage the price of its chips so that Pentium systems remain competitive against most of them. If the Orion/VRX or PowerPC chips meet their aggressive price/performance goals, this could upset Intel's apple cart. Initially, Intel need only maintain parity in price/performance, as the overwhelming x86 software base will work to its advantage, but Windows NT may begin to level the playing field as it gains in popularity *(see* ***0704ED.PDF****)*.

In the x86 arena, Pentium establishes a new performance point that is available only from Intel. The market is moving much faster than in the past, however, and Intel's monopoly will not last as long as its four years of 486 dominance; Cyrix plans to bring a competitive part to market by the end of this year. Ultimately, Intel will have to rely on aggressive pricing to maintain its market share, but it has the R&D and manufacturing skills to succeed in this competition as well. ♦

