The Linley Group

MICROPROCESSOR REPORT

www.MPRonline.com

THE INSIDER'S GUIDE TO MICROPROCESSOR HARDWARE

Two-Headed Snapdragon Takes Flight

Qualcomm Samples Dual-CPU Mobile Processor at 1.2GHz

By Linley Gwennap {7/19/10-01}

Qualcomm is sampling several new versions of its second-generation Snapdragon, broadening the family beyond the initial QSD8650A that sampled early this year. Like that product, the new mobile processors are built in 45nm technology and combine the company's Scorpion CPU with a cellular baseband. The newest model, the MSM8660, sports two CPUs running at 1.2GHz. Later this year, the company plans to sample an even faster product intended for tablets and netbooks.

Scorpion is an ARM-compatible CPU of Qualcomm's own design. The superscalar CPU uses a 13-stage pipeline to generate faster clock speeds than competing products can achieve using ARM's Cortex-A8 or Cortex-A9. For its new products, the company has enhanced the CPU to support multiprocessor implementations and has revamped the circuit design. These changes, along with the shift from 65nm to 45nm manufacturing, provide a 30% power reduction at the same clock speed. Alternatively, the 45nm processors can operate as fast as 1.3GHz in a smartphone and 1.5GHz in larger devices, compared with 1.0GHz for the 65nm devices.

When combined with Qualcomm's new QTR8610 chip, the Snapdragon processors offer a highly integrated solution for mobile devices that combines an application CPU, cellular baseband, Bluetooth, FM, and GPS functions along with the radio-frequency (RF) components required to support all four radios. No other mobile-chip vendor matches this level of integration, nor is any likely to soon.

Although Qualcomm has long supplied cellular basebands for smartphones, the company began shipping the main (application) CPU into smartphones in 2006. By offering processors that combine these two functions, the company has gained many wins with HTC and other second-tier smartphone makers; its processors are often coupled with Microsoft operating systems or, more recently, Android. As Figure 1 shows, these wins have helped Qualcomm gain ground on its two main rivals: Texas Instruments (TI), which supplies smartphone leader Nokia, and Marvell, which supplies the number-two smartphone vendor, BlackBerry maker RIM.

Snapdragon Family Portrait

Table 1 shows the members of the 45nm Snapdragon family. Because these products include a cellular baseband, Qualcomm typically produces two versions of each. Products with a "2" as the second digit support UMTS, the most popular 3G cellular standard in the world. Products with a "6" have a dual-mode baseband that adds support for CDMA protocols, which are used by U.S. carriers Verizon and Sprint and by other carriers in Asia and South America.

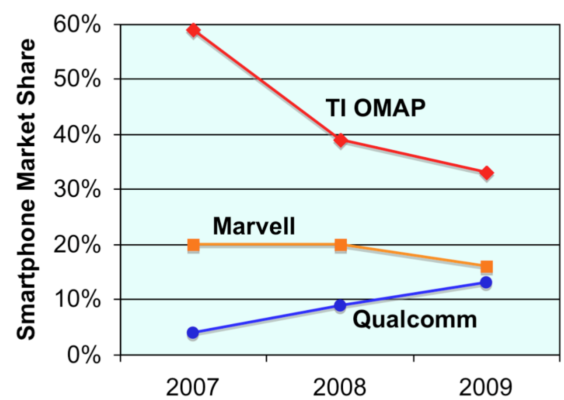

Figure 1. Smartphone market share by application-CPU supplier, 2007–2009. The application CPU can be supplied as a standalone processor, or it can be integrated with the cellular-baseband processor. Other smartphone processor suppliers, including Renesas, Samsung, and ST-Ericsson, have been omitted for clarity. (Source: The Linley Group)

For the 45nm products, the cellular baseband supports all UMTS standards up to HSPA+ with a maximum speed of 14.4Mbps on the downlink and 5.76Mbps on the uplink. The 45nm CDMA products support protocols up to EV-DO Rev B at 14.7Mbps down and 5.4Mbps up. As the leading supplier of 3G-baseband chips, Qualcomm offers proven cellular technology.

The entry-level product in this family is the MSM8x55, which contains a single Scorpion CPU rated at up to 1.0GHz. This CPU offers performance similar to that of the fastest smartphones available today and will first appear in high-end smartphones late this year; in 2011, however, it will become a midrange smartphone processor. High-end smartphones in 2011 will rely on dual-CPU processors such as the MSM8x60, which operates its pair of Scorpion CPUs at up to 1.2GHz. Both of these smartphone processors rely on low-power (LP) DDR2 SDRAM. To reduce board area, Qualcomm supports stacking the SDRAM on top of the processor package.

The QSD8x50A, as the name suggests, is derived from the QSD8x50, one of the first-generation Snapdragons. Because it is a simple shrink, it is the first of the 45nm family to reach the market. Like its predecessor, the QSD8x50A targets larger devices such as netbooks (which Qualcomm calls smartbooks) and tablet computers. It can also be used in high-end personal navigation devices (PNDs) and portable media players (PMPs). Because these devices provide larger batteries than smartphones do and can tolerate more heat, the QSD8x50A can operate at up to 1.3GHz. It supports standard (PC-style) DDR2 SDRAM, which is faster and less expensive than LP SDRAM. Some smartphone makers will use the QSD8x50A to take advantage of its high performance and early availability.

	QSD8250A, QSD8650A	MSM8255, MSM8655	MSM8260, MSM8660	QSD8272, QSD8672
Typical Applications	Netbook, tablet, smartphone	Midrange smartphone	High-end smartphone	High-end netbook, tablet
Application CPU	Scorpion	Scorpion	2× Scorpion	2× Scorpion
Max CPU Speed	1.3GHz	1.0GHz	1.2GHz	1.5GHz
L2 Cache	256KB	256KB	512KB	512KB
3D Graphics*	41 million	41 million	88 million	88 million
Video Decode	30fps 720p	30fps 720p	30fps 1080p	30fps 1080p
External SDRAM	PC DDR2 or LP DDR2	LP DDR2	LP DDR2	PC DDR3 or LP DDR2
Cellular BB	HSPA+, optional CDMA EV-DO Rev B			
Power (typ) at max CPU load†	700mW‡	500mW‡	850mW@1GHz‡, 1.2W@1.2GHz‡	1.0W@1.2GHz‡, 1.4W@1.5GHz‡
IC Process	45nm LP	45nm LP	45nm LP	45nm LP/G
Samples	1Q10	1Q10	2Q10	4Q10 (est)
Production	3Q10 (est)	3Q10 (est)	1Q11 (est)‡	3Q11 (est)‡

Table 1. Key parameters for Qualcomm's second-generation Snapdragon products. These 45nm processors combine a high-performance application CPU and a 3G cellular baseband in a single chip. They target smartphones, netbooks, and tablet computers. *Peak performance in triangles per second; †all CPUs running Dhrystone at maximum clock speed. (Source: Qualcomm, except ‡The Linley Group estimate)

Late this year, Qualcomm plans to sample a more powerful product for netbooks and tablets: the QSD8x72. Originally scheduled for an earlier release, this complex device extends the capabilities of the QSD8x50A by way of dual Scorpion CPUs, a 1080p video engine, and a new graphics engine that quadruples the performance of the current design. This fire-breathing dragon is built in a 45nm process that uses an amped-up circuit design to boost the maximum CPU speed to 1.5GHz and potentially beyond. This processor will deliver about three times the performance of the 1.0GHz Apple A4 chip found in the iPad, but it probably won't appear in systems until late 2011.

The single-CPU processors have a new 3D-graphics engine that offers nearly twice the performance of the graphics engine in the original QSD8x50. These chips also include a video engine capable of encoding or decoding high-definition (720p) video at 30 frames per second. Video codecs such as H.264 (Main Profile), MPEG4, VC-1, and DivX operate at this resolution and speed. Befitting their greater CPU performance, the dual-CPU models have a graphics engine that redoubles 3D performance to 88 million triangles per second, one of the highest ratings reported for a mobile processor. These chips also support full HD (1080p) video encoding and decoding for the aforementioned codecs, but not for the H.264 High Profile used for Blu-Ray encoding.

All of the 45nm chips retain the same basic architecture as the first-generation Snapdragons; our recent article (see *MPR 3/22/10-01,* "Snapdragon Success") provides an extensive description of this design. To summarize, each processor comprises one or two Scorpion CPUs with level-two cache; hard-wired accelerators for video, imaging, and graphics; a DSP for audio processing; a 2G/3G cellular baseband; and various system interfaces that connect to the other components in a handset. To simplify system design, the processor integrates several analog interfaces such as audio inputs and outputs, component and S-Video, and a touchscreen controller.

Do-It-Yourself CPU

Qualcomm has taken a different approach than its competitors by developing its own ARM-compatible CPU, known as Scorpion. Most other processor vendors simply license the latest Cortex CPU from ARM, whereas Qualcomm must support its own CPU design team (which is based in North Carolina). The company accepts this expense so as to differentiate its products.

The Scorpion CPU implements the ARMv7-A instruction set, including TrustZone and the Neon extensions, under an architecture license from ARM. The superscalar CPU can issue two instructions per cycle. To improve performance, it can speculatively issue instructions while waiting for the result of a previous instruction. This technique, known as out-of-order execution, is also used in ARM's Cortex-A9 design, as Table 2 shows. Because executing instructions that turn out to be unneeded wastes power, the Qualcomm design uses this technique carefully.

The Scorpion pipeline is 13 stages long for load/store instructions and 10–12 stages for simple integer instructions. To compensate for potential pipeline stalls, the CPU includes a complex branch predictor that maintains both local and global branch history. Although this pipeline design is similar to that of Cortex-A8, Scorpion achieves about 25% better clock speed than Cortex-A8 in the same process technology (e.g., 1.0GHz versus 800MHz in 65nm). Alternatively, Scorpion can achieve the same clock speed at 30% lower power.

Although Cortex-A9 uses a shorter pipeline with only eight stages, it achieves clock speeds similar to those of Cortex-A8. The shorter pipeline enables Cortex-A9 to achieve slightly better instructions per cycle (IPC) than Scorpion, because of the smaller penalties for branch mispredictions and other pipeline hazards. Therefore, Cortex-A9 will have a slight performance advantage at the same clock speed, but Scorpion still has a clock speed advantage at the same power level.

Scorpion includes a floating-point unit compatible with ARM's VFPv3 (vector floating point) extensions. Using these VFP instructions, the chip can perform eight floating-point operations per cycle for a total of 8,000 MFLOPs. The Neon unit implements the full 128-bit data path, enabling up to 16 eight-bit operations per cycle (twice as many as in Cortex-A8 and Cortex-A9). These parallel computations can greatly accelerate 3D graphics, video, and imaging.

The CPU includes 32KB instruction and data caches as well as a complete memory-management unit (MMU) suitable for high-level operating systems. The CPU also has 256KB of SRAM that can be allocated in 64KB increments to level-two (L2) cache or tightly coupled memory (TCM).

Redesigned for Multicore

Although the 45nm Scorpion continues to support the same ARMv7-A instruction set as its predecessor, the new version is fully compatible with Cortex-A9. The changes include some new debugging and system-management instructions designed for multiprocessor configurations. (Cortex-A9 is the first ARM CPU to be commonly deployed in multiprocessor designs.)

After extensive testing and characterization of the 65nm Scorpion design, Qualcomm's CPU design team identified several critical paths that were limiting the CPU clock frequency. The team modified these paths in the 45nm design to increase the speed beyond what would normally be obtained from a simple shrink. Although the Snapdragon chips are all built in a low-leakage LP process, the QSD8x72 adds some faster G transistors to accelerate critical timing paths and further boost the clock rate. The judicious use of these transistors, which have relatively high leakage current, minimizes the reduction in battery life.

Scorpion's CPU subsystem was further modified to support symmetric multiprocessing (SMP) dual-CPU configurations. The dual-CPU models include a shared 512KB level-two (L2) cache—twice the cache size of the single-CPU versions. The L2 cache transfers data at the same clock speed as the CPUs and is directly connected to both CPUs. In a typical Cortex-A9 design, by contrast, the shared L2 cache is connected to the CPUs through the slower AXI bus, and it transfers data at that bus's speed.

At 350mW (typical) for 1.0GHz operation, the 45nm Scorpion CPU is quite miserly, using 30% less power than the 65nm CPU. This reduction is partly because of the smaller transistors, of course. The increase in maximum clock speed also allows the CPU to achieve 1.0GHz at a lower supply voltage, delivering additional power savings. At 1.2GHz, the CPU requires 420mW, indicating an increase in voltage. Qualcomm has not yet determined the power required to achieve 1.5GHz in the QSD8x72, but assuming another small voltage increase, it could rise to 650mW. This chip, however, is intended for devices that are less power sensitive.

Taking advantage of the speed-voltage curve, Snapdragon CPUs can shift from a high-speed, high-power mode into a lower-speed, lower-voltage mode to save power. In the dual-CPU models, each CPU has its own voltage plane, allowing software to control the speed (and thus the power consumption) of each individually. The L2 cache uses a third voltage plane, so its speed can be controlled as well. In most applications, one CPU will be adequate for normal operation, and the second CPU can be turned completely off to reduce power. During web browsing, gaming, and other CPU-intensive activities, the second CPU can be enabled for maximum performance. Using both CPUs at full speed can drive the power consumption above 1.0W; to

	Qualcomm Scorpion	ARM Cortex-A8	ARM Cortex-A9
Instruction Set	ARMv7-A	ARMv7-A	ARMv7-A
Superscalar	Dual issue	Dual issue	Dual issue
Instr Reordering?	Yes	No	Yes
Integer Pipeline	13 stages	13 stages	8 stages
Neon (SIMD) Unit	128-bit	64-bit	64-bit
Max Clock Speed*	1.2GHz	1.0GHz	1.0GHz
DMIPS/MHz	2.1DMIPS	2.0DMIPS	2.5DMIPS
Dual CPU?	Yes	No	Yes

Table 2. Comparison of Qualcomm's Scorpion CPU versus ARM's Cortex-A8 and Cortex-A9. Scorpion falls between the two ARM CPUs in instructions per cycle (DMIPS/MHz) but achieves higher clock speeds. *Maximum clock speed in 45nm at typical smartphone power levels. (Source: vendors)

preserve battery life, software should enable this mode sparingly.

Qualcomm is working on a new Scorpion CPU design with significant microarchitecture advances. We expect this version to improve IPC to match or exceed that of Cortex-A9 while maintaining the higher clock rates and greater power efficiency that can be achieved using more-custom circuit design. This CPU could provide a bigger performance advantage for Qualcomm if the company can deliver it into phones in 2012.

Scorpion Stings Competition

As Figure 2 shows, the 65nm Scorpion CPU (in the QSD8250) achieves 1.0GHz operation in smartphones, providing nearly twice the performance of the 600MHz Cortex-A8 in TI's OMAP3430. (TI also offers the 800MHz OMAP3440, but that chip has not been used in a smartphone.) As a result of this advantage, Qualcomm won many high-end smartphone designs that shipped in 2H09 and 1H10, including Google's Nexus One; HTC's HD2, Triumph, Incredible, and Evo 4G; Sony Ericsson's Xperia X10; and Toshiba's TG01, TG02, and TG03. Only recently has TI closed this gap by shipping the 45nm OMAP3630 running at 1.0GHz in the Motorola Droid X.

In the next generation, Qualcomm is taking a phased approach by first offering products with a single CPU (the QSD8x50A and MSM8x55) and then dual-CPU products (the MSM8x60 and QSD8x72). HTC has already announced that it will ship the 1.3GHz QSD8250A in its Mondrian smartphone starting in October. The dual-CPU products will appear about six months later.

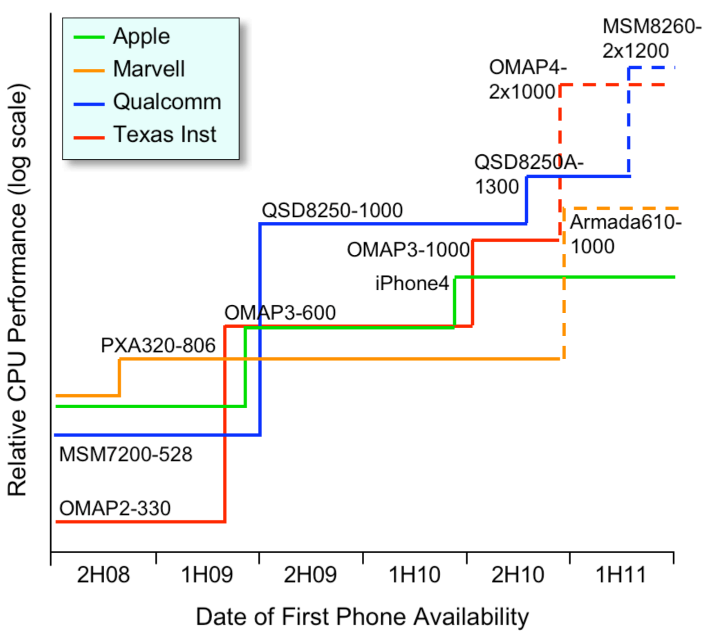

Figure 2. Mobile-processor performance, 2H08–1H11. This chart compares the CPU performance of the fastest processors from leading chip vendors and, for comparison, the processors used in Apple's iPhones. Each processor, labeled with its part number and CPU clock speed, is charted on the date it first appeared in a smartphone; for instance, the QSD8250 first appeared in the Toshiba TG01 in July 2009. (Source: *www.pdadb.net,* The Linley Group)

Several competitors, however, are jumping directly to dual-CPU processors using the Cortex-A9 CPU, including TI's OMAP 4, Nvidia's Tegra 2, and ST-Ericsson's U8500. When these processors appear in phones—probably around the end of the year—they will surpass the QSD8250A in performance. Once the dual-Scorpion processors ship, however, Qualcomm should regain the performance lead, albeit by a much narrower margin than in the 65nm generation. This narrower lead reflects the major improvements in both clock speed and IPC that ARM made between the Cortex-A8 and Cortex-A9, whereas the 45nm Scorpion offers only minor enhancements over its predecessor.

Targeting Tablet Computers

Mobile devices need strong CPU performance mainly for web browsing and some games. Both of these applications are well suited to parallel processing, but mobile software that takes advantage of dual-CPU configurations is still under development. No standard performance metric is widely used to measure mobile-CPU performance; EEMBC is developing a new test called BrowsingBench that it hopes will be available by the end of this year. We expect phone makers will release dual-CPU mobile browsers along with their first dual-CPU phones. Other dual-CPU software will take longer to appear.

For larger devices such as tablet computers and netbooks, the QSD8x50A is already sampling at 1.3GHz, and the QSD8x72 aims to reach 1.5GHz when it samples later this year. With two Scorpion CPUs, the QSD8x72 easily outperforms all Cortex-A9 processors, making it ideal for the more demanding software used on these larger devices.

In these systems, Qualcomm's processor will match up against Intel's new Atom (Moorestown) processor, which includes a single CPU running at up to 1.9GHz (see *MPR 5/31/10-01,* "Intel Cuts Atom's Power"). Although the Atom CPU is faster, Qualcomm's dual-CPU configuration should deliver similar or better performance on software that can take advantage of both CPUs. In addition, the QSD8x72 should burn a bit less power than Moorestown, although both chips far exceed 1W at maximum speed. By the time the fastest Snapdragon appears, however, Intel may be offering its next-generation (Medfield) Atom, which will reduce power compared with Moorestown.

The Snapdragon chips also stack up well in multimedia performance. The 3D rating of the single-CPU QSD8x50A is similar to that of OMAP 4; the faster graphics engine in the MSM8x60 and QSD8x72 matches up well against that of 3D-leader Tegra 2. Few smartphone applications can take advantage of this enormous 3D performance, but it may be valuable for a tablet computer's larger screen.

The single-CPU Snapdragons encode and decode HD video at 720p, positioning them to compete with the current crop of Cortex-A8 processors. The dual-CPU products support full 1080p video, like OMAP 4 and other dual-A9 processors, and HDMI output to drive video to an external HDTV. We believe that few users can perceive the difference between 720p and 1080p for the most common use cases (smartphone screens and hotel TVs), but in any case, Qualcomm has done its homework and matched the feature set of its competitors.

Integrating the Smartphone

Qualcomm's strategy is to offer smartphone designers a complete solution encompassing all the major ICs plus low-level software for cellular and multimedia functions. (The company provides a complete software stack, known as Brew, for feature phones.) For nearly a decade, Qualcomm has integrated GPS into its cellular processors, and the company is by far the leading supplier of GPS technology into handsets. A few years ago, the company acquired the Bluetooth operations of RFMD as well as Airgo, a supplier of Wi-Fi chips. These acquisitions have allowed Qualcomm to offer all four connectivity functions required in state-of-the-art smartphones: Bluetooth, FM, GPS, and Wi-Fi.

Taking this approach one step further, the company has combined several of these functions into a single product, the QTR8610, which recently entered production. This product, which works with the new dual-CPU Snapdragons (as well as certain other Qualcomm processors), combines the cellular-RF function with Bluetooth 3.0, GPS RF, and FM receive and transmit. (The FM transmitter can be used to send music to a nearby FM radio.) The sensitivity and accuracy of these functions is competitive with those of third-party connectivity chips. For customers desiring to use third-party connectivity chips, the company provides a standalone cellular-RF chip. Smartphones requiring Wi-Fi can add Qualcomm's WCN1312 chip or a third-party Wi-Fi product.

As Figure 3 shows, the primary functions of a leading-edge smartphone can be implemented using four major chips, all supplied by Qualcomm, plus memory. This partitioning is unique in the cellular industry. Several vendors have integrated 2G-cellular RF into the cellular-baseband processor, but none has yet managed this trick with more-complex 3G-RF circuitry. Instead of adding this analog circuitry to the processor, which is built in a leading-edge digital-IC process, Qualcomm combines it with connectivity functions that also comprise mainly analog circuitry. (The digital GPS baseband remains in the Snapdragon processor, as in other Qualcomm designs.) These functions are built in an analog-optimized IC process, reducing manufacturing cost. Vendors such as CSR and Texas Instruments offer combo chips for Bluetooth, FM, and GPS, but these vendors cannot add cellular-RF functions that are customized for a specific cellular baseband.

Price and Availability

The QSD8250A, QSD8650A, MSM8255, MSM8260, MSM8655, and MSM8660 are currently sampling. The QSD8272 and QSD8672 are due to sample by the end of 2010. See Table 1 for production dates and other information. Qualcomm does not disclose pricing for its products; we estimate high-volume pricing ranges from $30 to $40 for each processor and its associated power-management and cellular-RF chips. The QTR8610 connectivity chip is in production; we estimate this product adds about $2 to the price of the chipset. More information on the Snapdragon products is available at *www.qualcomm.com/products_services/chipsets/snapdragon.html*.

Strength in Cellular

Snapdragon's biggest differentiator is its integrated cellular baseband. Tegra 2, OMAP 4, and Atom are all standalone application processors that require a separate cellular-baseband chip. Although some smartphone vendors, such as Apple, prefer this configuration, most are moving toward integrated solutions that eliminate the cost and board area of the second chip.

All major smartphone vendors have adopted Qualcomm's cellular technology for CDMA or UMTS (or both), so they face little downside in adopting Qualcomm's integrated product. Furthermore, Qualcomm offers the highly integrated QTR8610 chip to complete its solution with RF and connectivity functions. This combination allows OEMs to design smaller and thinner smartphones,

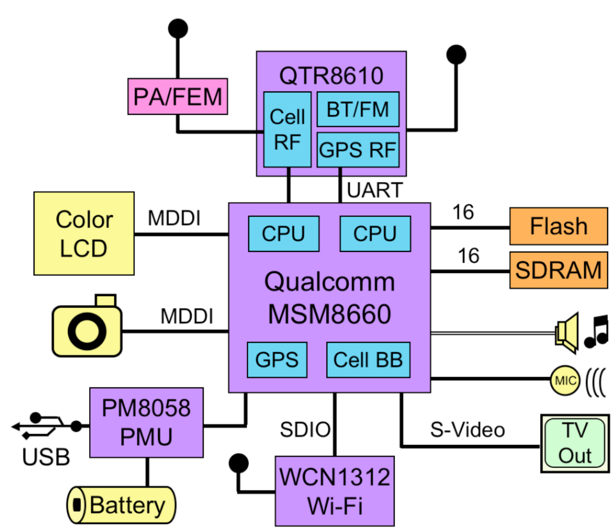

Figure 3. Block diagram of Snapdragon-based smartphone. Four Qualcomm chips, shown in purple, provide all of the core functions of a leading-edge smartphone, including power management (PMU), RF, connectivity, and analog interfaces for audio and video. Memory and an analog front-end module (FEM) complete the system.

and it reduces design time compared with a multivendor solution.

On the flip side, Snapdragon is not appropriate for mobile devices that, like most PNDs and PMPs, do not include cellular connectivity or, like the iPad, offer it only as an option. The cost of the Snapdragon processor incorporates the cost of the cellular baseband, and Qualcomm does not offer less expensive standalone application processors. Thus, for noncellular designs, products such as OMAP 4 and Tegra 2 will win. Qualcomm's expertise and focus is on cellular technology, and with a growing number of tablets, netbooks, and e-readers adding cellular modems, this focus is paying off.

Qualcomm has also invested heavily in CPU development, and this investment appears to be paying off. Even if the company cannot maintain a performance lead at all times, periods of market superiority are better than perpetual me-too status. Qualcomm complements its speedy CPU with competitive multimedia acceleration, proven cellular technology, and industry-leading integration of smartphone functions. These characteristics will help Qualcomm continue gaining share in the smartphone market and beyond. ♦