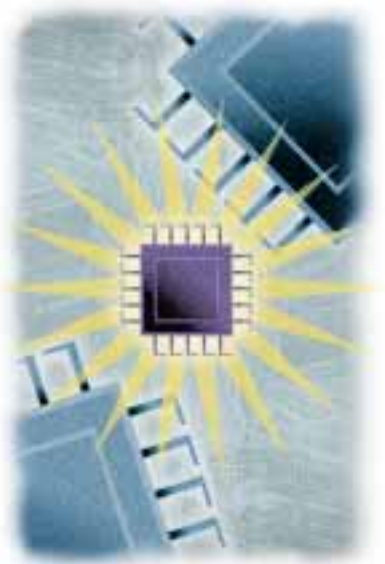


**ALTHOUGH MARKETING EFFORTS FOCUS ON HIGH-END, 32- AND 64-BIT MICROPROCESSORS, DSPs, AND VERY-LONG-INSTRUCTION-WORD PROCESSORS, LOWLY 8-BIT PROCESSORS CONTINUE TO DOMINATE PRODUCTS SHIPPED. FIND OUT WHAT NEW FEATURES, HIGHER PERFORMANCE, BETTER MEMORY INTEGRATION, AND TECHNOLOGY HAVE HELPED TO KEEP THESE DEVICES THE POPULAR AND PRACTICAL CHOICE AMONG DESIGNERS.**



# Microcontrollers wrap many features in small packages

**F**ORGET THE MARKETING HYPE about 32- and 64-bit processors; 8-bit microcontrollers rule. According to Cahners' In-Stat Group ([www.instat.com](http://www.instat.com)), the revenue generated by sales of 8-bit microcontrollers will hit \$4.8 billion this year, far greater than the predicted \$3.6 billion and \$452 million from sales of 16- and 32-

bit processors, respectively. When you translate those dollars into units shipped, the numbers become even more exaggerated due to the lower average selling price of 8-bit devices. (The In-Stat report also indicates that, by 2001, the 16-bit devices will outstrip the 8-bit devices in shipments.) But it's not just the lower device cost that makes 8-bit micros popular; their associated development tools are also less expensive, and 8-bit devices are easier to use. Semiconductor vendors are working to breathe new life into their 8-bit products. This step provides headroom performance and allows design engineers to discover new ways to use 8-bit microcontrollers.

I started working on this article by presenting each microcontroller vendor with a survey. The object of this survey was to provide you with some ammunition as you plan the design of your next embedded application with an 8-bit microcontroller. After receiving the results of the survey, I weeded out the marketing hype to present you with useful information and helpful hints.

The first, and maybe the most important, question in the survey deals with price. I asked 15 microcontroller vendors for information on their lowest cost 8-bit device (Table 1). The first thing to note is that, when you talk price, especially prices of units selling in

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high volumes, it becomes a game.

As one vendor says, "Why would I want to publish my best pricing to drive my lower volume customers crazy trying to get it? This would give buyers who weren't looking a reason to hard bargain with us the next time we're in." This statement explains why the unit volumes in Table 1 range from 10,000 to 1 million.

Another interesting point to note is that you get what you pay for. The features of Zilog's Z8E000, the lowest cost device in the table, don't compare with the peripheral-packed Philips' P87LPC-762BN or Motorola's MC68HC908GP32 (Figure 1). Although the Philips' device costs three times the cost of Zilog's, remember that the price changes when you sit down at the negotiation table.

**FLASH DOESN'T HAPPEN IN A FLASH**

Memory is one of the most important aspects of any embedded-system design. Many embedded systems using 8-bit microcontrollers rely on continually improved process technologies to boost the amount of on-chip memory at lower costs.

For semiconductor manufacturers, the ROM process has the least complexity and lowest silicon-processing cost. Although ROM is useful for stable applications in high volumes, one-time-programmable (OTP) memory benefits lower volume applications because the system manufacturer can buy these memories as standard products. OTP allows you to perform a minimal amount of field upgrades by employing unused memory locations. Except for the more costly EEPROM, flash memory offers the most flexibility, but it has its limitations, such as cost and slow programming. The flexibility of flash memory also poses challenges because of the increased system complexity required for in-system reprogramming. For example, you must design the system to accommodate anomalies, such as losing a modem connection or power during field upgrades.

The second question in the survey asked the microcontroller vendors about their memory options and strategy. It is clear from

**AT A GLANCE**

- ▷ By 2001, 16-bit devices will start outstripping 8-bit devices in shipments.
- ▷ Semiconductor vendors continue to beef up the peripherals and memory that they integrate on chip.
- ▷ On-chip flash memory has become a focus for most microcontroller vendors.
- ▷ Performance is an important characteristic of the new 8-bit microcontroller architectures, whereas architectures such as the 8051 and 68HC05 are better known for their wide variety of tool support.

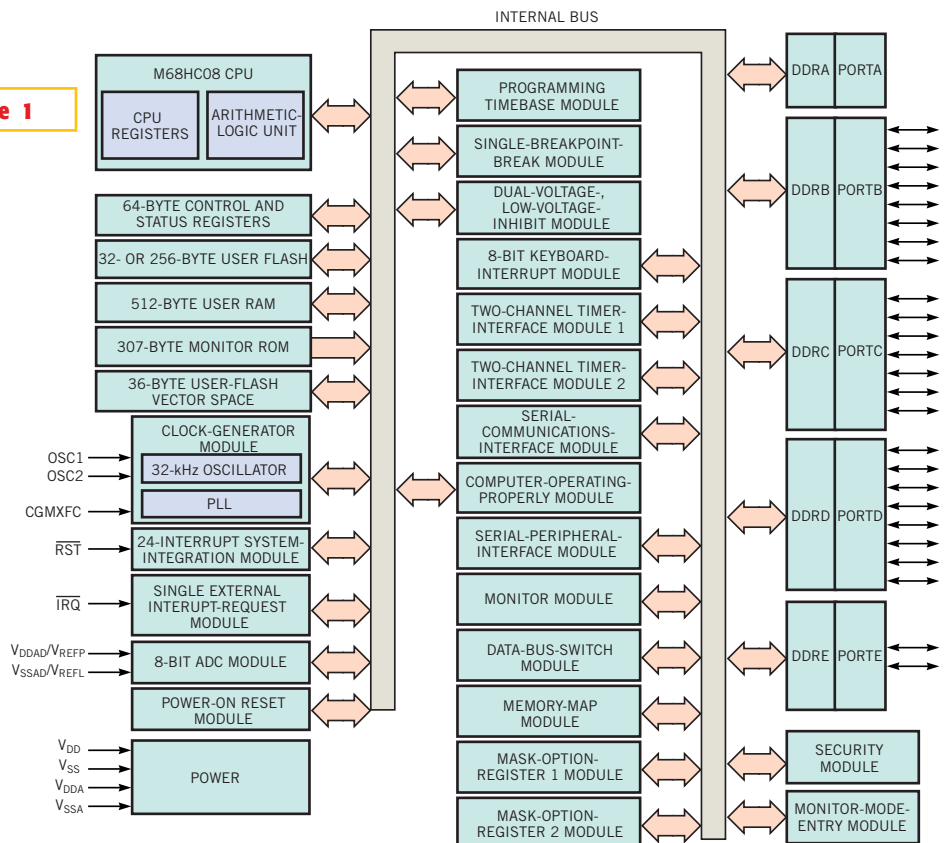
the survey results that flash memory has become the focal point for most vendors as they determine how to decrease costs and increase densities.

Hitachi claims that its flash technology has matured to catch up with its embedded-EPROM prices. As a result, the company is replacing its older EPROM-

based microcontrollers with flash-based devices, offering 8-bit microcontrollers with as much as 60 kbytes of flash memory. Furthermore, Hitachi has already replaced OTP controllers with flash. NEC has taken the same step, although it states that mask ROM will be the most cost-effective option for several years. The company also provides as much as 60 kbytes of ROM in its 8-bit devices. Atmel, another staunch supporter of flash, claims that its flash-based 8051s and AVR microcontrollers are available at mask-ROM prices.

Motorola also realizes that flash is a growing requirement for many designers of 8-bit systems and has teamed with AMD's (www.amd.com) research-and-development efforts to reduce the technology's cost. In addition to manufacturing cost, another key flash issue is programming cost. Motorola's flash-based HC08s include Flashwire, a single-wire communication method that allows you to quickly program on the manufacturing line without special modes or high voltages, just  $V_{DD}$ . Motorola's second-gen-

**Figure 1**



**Everything but the kitchen sink: The Motorola MC68HC908GP32 includes a vast array of peripherals and costs \$5.50 (50,000).**

eration flash on the 68HC908GP32 programs 64 bytes in a minimum of 2 msec. Additionally, this process technology supports as many as 10,000 erase cycles.

Although Toshiba believes in the value of flash memory, it is one of the few 8-bit vendors to lack flash-based products. The company plans to offer on-chip flash by 2000 and will use the monolithic, or "bulk-erasable," approach to reducing die size. However, Toshiba believes that its mask-ROM devices will be the predominant memory type supporting 96-kbyte and larger ROM. Infineon also concludes that mask ROM will preside in its 8051-based microcontrollers. The company concedes that the flash process, including yield issues, has considerably higher costs than the same amount of ROM.

Microchip touts its Migratable Memory technology, which provides socket

and software compatibility among its equivalent ROM, OTP, and flash-memory microcontrollers. Migratable Memory technology implies that Microchip uses the same electrical specifications for logic transistors in ROM, OTP, and flash in the company's 0.7- $\mu$ m process.

Microchip complains about the 10-msec flash-memory programming time versus the 10  $\mu$ sec for EPROM for each cell. The manufacturer must have a bulk programming capability much greater than the capability that OTP devices require. Furthermore, in small flash-memory arrays, the design cannot amortize the extra logic that row and column decoding require.

If you need more memory than is available on the microcontroller that you plan to use, you can expand that microcontroller's capability using expansion chips. For example, Waferscale's ([www.waferscale.com](http://www.waferscale.com))

flash-based PSD8XXF ICs provide a variety of external memory and logic combinations. The ICs offer 256 kbytes of flash, an optional second 32-kbyte array of flash or EEPROM, as much as 8 kbytes of SRAM, a 3000-gate CPLD, and extra I/O. The PSD8XXF has a built-in interface that you can configure to work with any 8-bit CISC microcontroller, including those with burst and page architecture. A JTAG port provides first-time programming and subsequent field updates.

#### PERIPHERAL VISION BEEFS UP 8-BIT DEVICES

In the world of 8-bit microcontrollers, the types of integrated peripherals that a vendor offers can make all the difference between a successful design and an unsuccessful design. Although some peripherals, such as timers and basic serial ports, are standard fare on most devices,

**TABLE 1—REPRESENTATIVE LOWEST COST, 8-BIT DEVICES**

Company	Device	Price	Quantity	Memory	Other features
<b>AB Semicon Ltd</b> Circle No. 301	AB180-20	\$3.70	100,000		Two 16-bit timers, UART, fixed-point 32-bit arithmetic unit, DMA controller
<b>Atmel Corp</b> Circle No. 302	ATtiny11	49 cents	500,000	1-kbyte flash	8-bit timer, analog comparator, watchdog, on-chip oscillator, one external interrupt
<b>Dallas Semiconductor</b> Circle No. 304	DS80C310-QCG	\$1.97	50,000	256-byte RAM	Four clocks per machine cycle, UART, three 16-bit timer/counters, dual data pointers, 10 internal/six external interrupts, power-on reset
<b>Hitachi</b> Circle No. 305	H8/3640	\$1	100,000	8-kbyte ROM, 512-byte RAM	Three 8-bit timers, one 16-bit timer, 8 one 14-bit PWM timer, watchdog, two SCI ports, eight 8-bit ADC, 32-kHz subclock generator
<b>Infineon</b> Circle No. 306	C501	70 cents	10,000	8-kbyte ROM, 256-bytes RAM	Serial interface, three 16-bit timers, 32 I/O ports
<b>Microchip</b> Circle No. 307	PIC16CR54C	40 cents	500,000	768-byte ROM, 25-byte RAM	12 I/O pins, 8-bit timer, high current sink/source for direct LED drive, watchdog timer, RC oscillator
	PIC12CR509A	49 cents	100,000	1536-byte ROM, 41-byte RAM	Five I/O pins, on-chip oscillator, 8-bit timer, watchdog, direct LED drive
<b>Mitsubishi</b> Circle No. 308	M37531M4-XXXFP	\$1.69	10,000	8-kbyte ROM, 256-byte RAM	2.2 to 5.5V operation; 16-bit-wide address bus; three 8-bit timers; 16-bit watchdog timer; 10-bit, eight-channel ADC; UART; one clock-synchronized serial port; one external interrupt, seven high-current output ports for LED operation; key-on wake-up function, 29 programmable-I/O ports, built-in clock-generating circuit
<b>Motorola</b> Circle No. 309	68HC705KJ1	49 cents	500,000	1240-byte OTP, 64-byte RAM	15-stage multifunction timer, on-chip oscillator, low-voltage reset, watchdog, keyboard interrupt, high-current I/O port
<b>NEC</b> Circle No. 310	789011	80 cents	100,000	2-kbyte ROM, 128-byte RAM	Two 8-bit timers, UART, 22 programmable I/O ports, two-channel serial interface
<b>Philips</b> Circle No. 311	P87LPC762BN/BD	\$1.05	10,000	2-kbyte OTP, 128-byte RAM	Oscillator, watchdog, 32-byte customer-code EPROM, UART, I <sup>2</sup> C, comparators, timers/counters, brown-out detector, power-on re/set, keypad wake-up, LED drivers
<b>Samsung Semiconductor</b> Circle No. 312	KS86C0004	73 cents	500,000	4-kbyte ROM, 208-byte RAM	RC oscillator, 12-pin key matrix, one 8-bit timer, one 8-bit timer/counter, 14 interrupt sources, 32 I/O ports
<b>Scenix</b> Circle No. 313	SX28AC	\$3	10,000	3-kbyte flash, 136-byte RAM	Analog comparator, programmable I/O, brown-out detector, 8-bit timer, watchdog
<b>STMicroelectronics</b> Circle No. 314	ST6203CB1	58 cents	50,000	1 kbyte ROM or OTP, 64-byte RAM	8-bit timer, watchdog, nine I/O lines with high-current capability, internal backup oscillator system, brown-out detection
<b>Toshiba</b> Circle No. 315	TMP87C405AM	80 cents	1 million	4-kbyte ROM, 256-byte RAM	Nine interrupt sources, programmable watchdog timer, 22 programmable I/O ports
<b>Xemics SA</b> Circle No. 317	XE8301	\$2.10	100,000	22-kbyte ROM, 512-byte RAM	Clock prescaler, watchdog time, power-on reset, supply-level detection, 20-pin programmable I/O, crystal and RC oscillator, UART, four 8-bit timers with PWM
<b>Zilog</b> Circle No. 318	Z8E000	39 cents	500,000	0.5-kbyte OTP, 32-byte RAM	One 16-bit timer, watchdog, four hardware interrupts, 13 I/O pins

each vendor typically offers microcontrollers with special features. Many vendors recommend their analog/digital converters, which many applications require. For example, Atmel, Infineon, Toshiba, and others offer fast 10-bit ADCs. Infineon claims conversion times as low as 6  $\mu$ sec and accuracy within 5 to 10 mV at 0 to 5V operation. Microchip claims to be the only vendor to offer a 12-bit resolution ADC on an 8-bit microcontroller; its PIC16C770 and PIC16C771 devices offer this feature in a 20-pin package.

Another popular peripheral is a controller-area-network (CAN) interface. Dallas Semiconductor offers a dual-CAN interface for its 8051-based microcontrollers. This feature allows the chip to serve as a bridge in large CAN networks. Its interface also supports DeviceNet, a high-level CAN protocol. In-

fineon's CAN interface provides all features of the CAN 2.0B specification. Many other vendors, including Microchip, Motorola, and STMicroelectronics, also provide CAN controllers.

Cypress Semiconductor's 8-bit product offerings center on the Universal Serial Bus (USB) interface. The company offers the low-end CY7CXXXX and EZ-USB (a result of the company's acquisition of AnchorChips). For 1.5-Mbps USB applications, the CY7CXXXX uses a Cypress-developed 8-bit architecture and serves the human-interface-device (HID) market that includes mice, keyboards, and joysticks. For USB applications requiring the full 12 Mbps, Cypress combines this interface with a 24-MHz 8051 core, the RAM-based EZ-USB. This family contains an intelligent-USB core that offloads 90% of the USB task from the 8051. The company has devised three ways of loading the 8051 firmware. One interesting and unique way allows you to download the 8051 firmware via the USB port during power-up or numeration. Infineon, STMicroelectronics, and others also have USB peripherals. Similar to Cypress' product, Infineon's USB interface supports both full- and low-speed USB communication.

Another interesting twist relates to 8-bit devices that allow you to dynamically create your own peripherals. One example is the 8051-based FastChip from Triscend ([www.triscend.com](http://www.triscend.com)), which allows you place peripheral modules from its library around the dedicated processor core and install the new design in Triscend's FPGA-like silicon. Scenix Semiconductor also allows you to dynamically create peripherals and offers a virtual-peripheral approach to implement the peripheral functions in software rather than in hardware. Scenix provides virtual-peripheral modules that include UARTs, multimaster I<sup>2</sup>C functions, and dual-tone multiple-frequency detection. Scenix also offers a virtual-peripheral network-connectivity protocol stack that provides direct Internet access.

According to Will Strauss, president of industry-analyst company Forward Concepts ([www.forwardconcepts.com](http://www.forwardconcepts.com)), the Scenix microcontroller "appears to have the horsepower to do all the Net protocol functions, provide a physical interface, and still run an application," although Strauss says he hasn't verified

this fact. The SX stack can communicate with any Web browser and lets you receive and transmit e-mail. The stack includes the physical-interface layer with the Transmission Control Protocol/Internet Protocol, enabling system designers to produce embedded Internet devices without external physical access chips or a gateway PC.

## THE REAL SOCs

Although the "buzz-phrase" of the year is "systems on chips" (SOCs), the semiconductor marketing folks have managed to misconstrue the meaning of the term. To some, throwing a few functions onto the same die as a processor core constitutes an SOC. In the 8-bit world, where cost accounts for almost everything, "system on chip" is a literal term. Besides lower cost, other by-products of SOCs include reduced board real estate, lower power consumption and EMI, and increased reliability. To take advantage of these characteristics, vendors often put the entire system, except for a few resistors and capacitors, the power supply, and connectors, on the chip. Several of the semiconductor vendors gave their viewpoints of what SOCs are and how their products can help you reduce system cost and provide other benefits.

System cost depends on many factors. You can minimize or eliminate external components by placing programmable pullups on I/O pins to help eliminate external resistors, which also eliminates the cost of soldering them onto the board. Motorola, STMicroelectronics, and others offer high current-sink and -source capability on I/O pins, which can help you eliminate the need for external drivers. An 8-bit device should also have adjacent  $V_{DD}$  and  $V_{SS}$  pins to make it easier for you to connect bypass capacitors.

The devices should also integrate programmable low-voltage reset circuits to eliminate the 25-cent-or-more cost of using external supervisory circuits and to prevent system lockup due to line-voltage brown-out conditions. Motorola's HC08s have a dual selectable low-voltage interface that allows you to use them in 3 or 5V systems. STMicroelectronics provides three levels of low-supply-voltage detection. Microchip provides programmable low-voltage detection that allows you to choose the low-voltage-detection range at the system level via software. Dallas Semiconductor

Operating frequency (MHz)	Package
40	100-pin QFP
6	Eight-pin DIP
33	40-pin DIP
	64-pin DIP
40	40-pin DIP
20	14-pin DIP
4	Eight-pin DIP
8	36-pin SOP
4	16-pin DIP
	28+H27-pin SSOP
20	20-pin DIP
4	40-pin DIP
50	Eight-pin DIP
8	16-pin DIP
8	
10	20-pin SOP
10	18-pin DIP

implements a power-fail reset/interrupt feature that allows the microcontroller to perform a controlled shutdown during a power failure; the microcontroller interrupts all processor operations when it detects a power failure and takes appropriate action.

For high-speed designs, a PLL clock circuit allows you to use more cost-effective oscillators. For example, a low-cost, 32-kHz crystal on the Motorola 68HC908GP32 can generate an internal clock operating as fast as 32 MHz; this feature also greatly reduces EMI. Some of Motorola's devices have simple RC oscillators for even lower cost, and some of its new devices have a programmable internal oscillator with trimming for  $\pm 2\%$  accuracy. The 68HC908GP32's PLL also incorporates a programmable timebase module that allows the part to wake up from Stop mode without using external circuitry. Combining the timebase module with the crystal also allows you to implement a real-time clock with minimal software overhead. One interrupt per second allows the device to update a software clock and calendar. This feature helps eliminate the use of an external clock chip in data-logging and user-interface applications. Meanwhile, Dallas Semiconductor is known for its internal

real-time clock that simplifies software overhead and frees dedicated port pins.

STMicroelectronics provides an internal backup-RC oscillator that automatically takes over if the external oscillator fails. The company, along with Hitachi and NEC, provides multiple oscillator inputs to allow you to switch processor speeds according to an application's need.

Another important ingredient of many designs is an 8-bit microcontroller's internal delays and circuits to support power-up sequencing, eliminating the need for external supervisory circuits. And don't forget the watchdog that many 8-bit microcontrollers support; it is essential for letting the system recover after software malfunctions or spurious noise conditions occur. You can implement high-noise immunity in a variety of ways; for example, STMicroelectronics uses on-chip clamping diodes to protect each pin.

The world of 8-bit system designs leaves little room for sloppiness and extravagance. Every byte of on-chip memory is crucial. The functions and availability of mission-critical peripherals can make all the difference in a successful design. Combine these criteria with the demand to increase performance and de-

crease power consumption, and it's easy to see that the 8-bit processor vendors have their work cut out for them.

#### WHEN SIZE (AND PERFORMANCE) MATTERS

Some vendors will tell you that, in the 8-bit world, the microcontroller core takes a back seat to the peripherals. Others argue that performance is more important because that's one of the factors that keeps designers from jumping to 16- or 32-bit products. (Until the EDN Embedded Microprocessor Benchmark Consortium (EEMBC, [www.eembc.org](http://www.eembc.org)) made benchmarks available, no way existed for you to fairly compare the performance of microcontrollers.) A variety of vendors provided EDN with opinions and facts about the processor cores they use in their 8-bit microcontrollers.

Motorola's perception is that most low-end, 8-bit applications require performance that virtually all 8-bit cores can provide. More demanding applications, however, require higher performance, and Motorola hopes that the EEMBC benchmarks will help analyze the "beefier" 8-bit controllers. A 68HC05 is adequate for simpler functions, such as the generation of a 50-kHz waveform on I/O pins for remote control, but you need the performance of an HC08 or HC11 to hit

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Circle No. 308

#### Motorola

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#### Scenix Semiconductor Inc

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higher frequencies. On the other hand, when you run the HC08 at 1.8V to save power, you must derate the controller's performance. To solve this problem, Motorola designed a remote-control timer as part of its RC microcontroller family.

NEC has a slightly different perspective. Its low-end 8-bit microprocessors feature hardware multiply/divide, bit/nibble manipulation, multiple register sets, and 1-byte Call instructions. Operating at 8 MHz, the core delivers a 256-nsec instruction time that NEC claims meets most performance needs.

Hitachi believes that the CPU core plays an important role in device selection because it can impact the power consumption, code size, performance, and programming capability. Interestingly, performance and architecture efficiency are even more important at lower operating frequencies because every clock matters. In other words, for each cycle, the CPU must accomplish as much work as possible. Hitachi's H8 microcontrollers execute more than 50% of the instructions in two clock cycles.

Microchip concludes that a fast CPU makes peripherals more efficient by providing quicker response to the peripheral. For example, if a serial port operates at 1.2 Mbps, it receives and transmits 8 bits of data in 8.3  $\mu$ sec. To maintain the throughput of the system, the CPU response time must be approximately 8  $\mu$ sec to yield a response time of 25  $\mu$ sec. The register banks of Toshiba's TLCS-870 and TLCS-870/X architecture exemplify microcontrollers that speed CPU response. Alternatively, in control applications, a faster CPU core can more quickly calculate complex equations and enable the peripheral, typically a PWM

output, to respond more quickly to changes in the output. Microchip's PICmicro architecture supports single-cycle execution of instructions, which the company claims outperforms the 68-HC05 by a factor of 2.3. However, this figure does not account for instruction efficiency. It requires more than a Dhrystone benchmark to prove this fact.

#### MORE TO PERFORMANCE THAN POWER

To meet the requirements of real-time applications, the CPU must provide deterministic execution of time-critical tasks, separate stacks for interrupt processing and subroutine operation, and automatic context-saving for interrupts. An efficient instruction set that executes at a constant rate of 20 nsec/instruction, as the Scenix SX28AC100 running at 100 MHz does, helps provide deterministic task execution. In addition, the SX-28AC100's interrupt-response time of 60 nsec helps reduce the time it takes to perform scheduling and context switching. Scenix claims that you need no benchmarks to compare its devices because the company does not address multimarket applications. On the other hand, this stance makes it difficult to verify claims about performance capabilities.

Regarding its 8-bit microcontrollers, STMicroelectronics advises that complex applications also rely on such features as multiple indirect addressing modes, additional index and general-purpose registers, user-remappable interrupt vectors, nested interrupts, and a well-thought-out instruction set.

Atmel says that one of the tricks to achieve a high-performance 8-bit microcontroller is to use a modern—not a 20-year-old—architecture. (So sorry, 8051!)

The company's AVR is a RISC core with single-cycle execution and can address as much as 8 Mbits. Atmel claims that AVR is the fastest 8-bit microcontroller core on the market, but has yet to verify that claim using industry-standard benchmarks.

Atmel and several dozen other vendors sell 8051-based devices into low-end applications. Most of the vendors agree that the value of this architecture results from the fact that designers are familiar with the architecture and with the variety of available tools. Philips Semiconductors, an 8051 vendor, also promotes the reduction of EMC and power consumption. The company's new C51+ core provides a low-power, static core with increased efficiency at six clocks per machine cycle compared with the traditional C51 devices, which operate with a 12-clock core. Dallas Semiconductor also redesigned the "old" 8051 core and offers devices that run three times faster than the original. □

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## REMAIN OPTIMISTIC ABOUT 8-BIT MICROCONTROLLERS

*By Max Baron, Senior Analyst for the Micrologic Information Service, Cahners In-Stat Group*

Results of a recent Cahners In-Stat Group forecast show that 8-bit microcontrollers will continue to grow in volume over the next five years. Calendar year 1998 shipments estimated at 2.5 billion units will increase to approximately 4 billion units by 2003. In-Stat Group bases microcontroller volumes on forecasts of end-user applications, such as

set-top boxes, DVD players/recorders, remote-control devices, digital cameras, automotive sound systems, refrigerators, computer keyboards, mice, and others.

The 8-bit microcontroller compound annual growth rate from last year to 2003 is at an encouraging 9.42%. The group expects the compound annual growth

rate for microcontrollers in general to be 11.50% during the same period. Thus, 8-bit microcontrollers will lose market share, decreasing from 62.36% in 1998 to 56.76% in 2003 as 16- and 32-bit and higher implementations rise. The higher bit devices will double their unit market share from 15.11% in 1998 to 31.56% in 2003 to the

detriment of 4- and 8-bit devices. But, even in 2003, the 8-bit microcontrollers will outnumber the higher bit units by almost 80%.

The 8-bit microcontroller will continue to be an attractive, low-risk, low-cost system-on-chip device wherever its features and performance are sufficient to drive the end application.