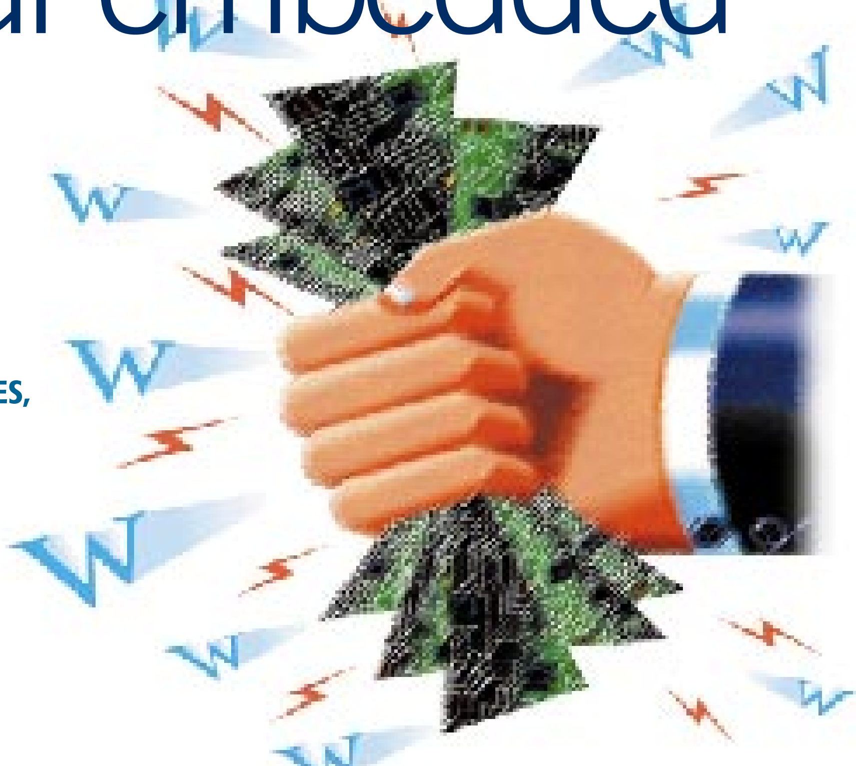
Green Electronics

designfeature By Warren Webb, Technical Editor

SQUEEZE watts from your embedded design



AN EFFICIENT, LOW-POWER DESIGN NOT ONLY SLASHES THE ENERGY YOUR EMBEDDED SYSTEM CONSUMES, BUT ALSO REDUCES THE ENERGY DRAIN ON THE ENVIRONMENT. AS A BONUS, YOU GET A SUPERIOR PRODUCT AT A LOWER COST.

It may seem like a stretch to relate embedded-system design to holes in the ozone or global warming, yet your next design will affect the environment. A single embedded design may cut the world's energy consumption by only a few watts, but millions of embedded systems like yours will make a tremendous impact.

Although embedded products span the spectrum from tiny im-plantable pacemakers to giant radar systems, every product reaps the benefits of reduced power requirements. An efficient, low-power design not only helps the environment, but improves the product qualities that you need to beat the competition. (For more on protecting the environment, see **sidebar** "ISO 14001 measures environmental impact"). A low-power product is smaller, easier to

Illustration Daniel Guidera

cool, and less costly to produce. Customers also are happier with a lower purchase price and operating costs.

However, embedded-system users' expectations are changing, and the path to designing a low-power product has become more difficult. For example, portable-system users now want products that are instantly available and that can provide information without a boot-up sequence. Many networked systems must now be always available to respond to data requests. To meet these needs, designers must construct clever product power-management strategies and maintain a low power budget.

Squeezing the maximum performance from a product with the least power is a goal of every embedded design. Efficient processors, variable-speed clocks, circuit shutdowns, low-voltage logic, software-design aids, and advanced power-management software are just a few of the techniques designers use to shave watts from tomorrow's high-tech systems.

One of the primary power-saving techniques to investigate is a lower supply voltage. Halving the supply voltage reduces static-power dissipation to one-fourth ($P=E^2/R$). However, a reduced supply voltage along with today's fast clocks produce noise-immunity problems. Luckily, logic designers have worked out various fixes to eliminate the ringing in high-speed signals. As an example, Texas Instruments recently introduced the advanced very-low-voltage CMOS (AVC) logic family, which operates on supplies of 3.3, 2.5, or 1.8V and features propagation delays of approximately 2 nsec. Another possible problem with a lower supply voltage is the limited availability of logic functions. Although a quick look at the *EDN* new-products section shows that a flood of new low-voltage-logic functions are on the way, your design may still need a missing element.

LOW-POWER PROCESSORS

Processor selection is another major contributor to the power consumption in embedded designs. Your initial tendency might be to select the fastest and most capable processor that you can cram into your design, leaving plenty of computing power in case you encounter software problems. The "power-sensible" solution would be to select a low-speed processor with just barely enough capability to do the job. The practical answer lies somewhere between these two approaches and depends on the power-management flexibility of the chosen processor.

Processor designers offer a host of power-management features that you can use to optimize your embedded system. For example, several types of wait, idle, standby, and sleep modes suspend processor operation during periods of inactivity. The trade-off is how quickly the processor can resume operation when called back to action. *EDN*'s 25th Annual µP/µC Directory describes the power-management features of most of today's popular microprocessors (**Reference 1**).

Designers also incorporate automatic power-saving features into their processors' architectures. According to Gideon Intrater, director of product marketing at MIPS Technologies, these architectures automatically shut down execution units, such as the floating-point processor, when inactive. By gating the clock, CPU designers can reduce the power to even a single register. Automatic power reduction relieves software developers of optimizing the CPU's internal power, says Intrater, and helps fight time-to-market pressures.

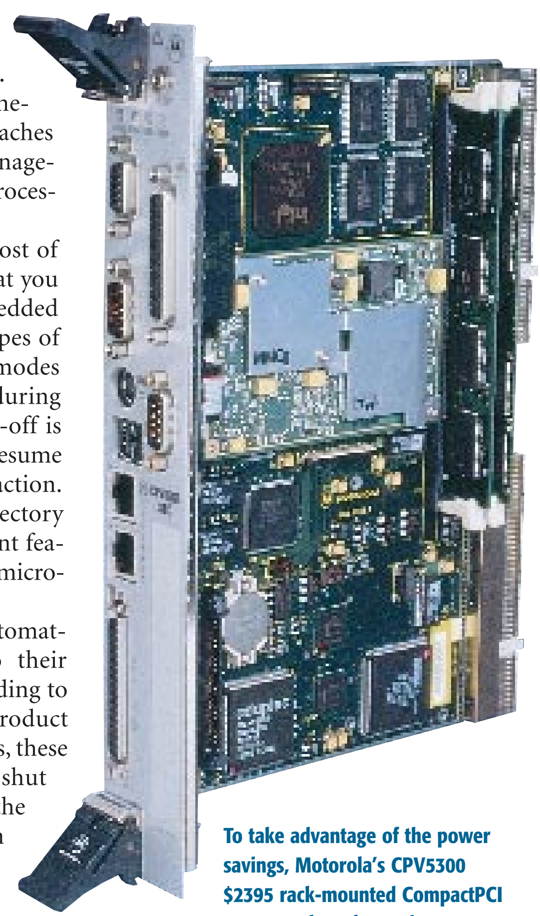
System power consumption also directly relates to CPU clock speed. Many CPUs tolerate a variable-speed clock, allowing designers to adjust the frequency for optimal power savings and to retain the capability for extra speed when an application requires it. Some designers use the variable clock speed to dynamically control the clock rate and, therefore, power consumption from software. The program can increase the CPU clock speed when processing demands are high and then throttle back to a lower speed for noncritical tasks. This type of dynamic control is quite effective in battery-operated systems.

SENSORS SAVE ENERGY

Environmental sensors can also help optimize the power consumption in an embedded system. Strategically placed sensors can measure internal

AT A GLANCE

- ▷Smaller size, longer battery life, lower cost, and increased reliability come with a low-power embedded design.
- ▷User demand for instantly available, portable electronic products urges designers to create effective power-management strategies.
- ▷Processor vendors offer a host of power-management features to attract energy-conscious designers of embedded systems.
- ▷CPU shutdown modes, reduced system voltages, and slower clocks translate into lower power consumption.
- ▷Optimal embedded power savings result from an integrated software-management plan that controls system, CPU, and peripheral devices.



To take advantage of the power savings, Motorola's CPV5300 $2395 rack-mounted CompactPCI computer board contains a Pentium II mobile laptop CPU.

temperatures to control mechanical airflow, reduce clock speeds, or signal malfunctioning hardware. Depending on the application, a set of reduced-capability functions can continue partial operation in the face of temperature extremes or certain internal failures.

You should analyze your embedded system from a power-consumption viewpoint before starting the final hardware design. For example, in today's world of networked systems, it may be just as easy to control your system from a PC on the network as it is from the built-in keyboard and display. You can then eliminate this hardware from your design, a decision that also simplifies the application-software task because off-the-shelf network software is widely available.

Another technique for saving power is to incorporate newer technologies. For example, miniature LCDs can produce optical images consuming 1/100 the power of but with the same resolution as notebook-computer monitors. A simple lens system provides an effective full-sized virtual image (**Reference 2**). For example, Kopin offers miniature monochrome and color LCDs designed into prototype pagers (**Figure 1**).

Small, portable embedded systems are

Figure 1

Miniature monochrome and color LCDs integrated into prototype pagers use 1/100 the power of their full-sized counterparts.

not the only beneficiaries of power-saving hardware and software. Large bus-based systems, such as CompactPCI and VME, are fast to incorporate power-saving processors and peripherals. Many CompactPCI CPU vendors have designed CPU boards around Intel's Pentium II mobile module just to take advantage of the reduced cooling requirements (**Reference 3**). Lower power

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For more information on products such as those discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or use *EDN*'s InfoAccess service. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

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requirements translate into wider temperature ranges because of the lower nominal junction temperatures, says Joe Pavlat, director of product marketing at Motorola Computer Group and president of the PCI Industrial Computer Manufacturers Group (PICMG). If you can eliminate a fan or reduce the time that the fan runs, you also increase system reliability, says Pavlat.

SOFTWARE POWER MANAGEMENT

The real energy savings occur when a software power-management system drives the power-reduction features of the hardware. Intel, Microsoft, and Toshiba America Information Systems introduced an Advanced Configuration and Power Interface (ACPI) for desktop and notebook PCs in 1997. ACPI transfers the responsibility for power management from the PC BIOS to the operating system. The operating system is aware as you load new applications, and it has the data to make power-management decisions. Windows 98, CE, and NT include portions of ACPI.

Although ACPI targets desktops and notebooks, it makes a good model to follow when developing a software power-management system for embedded systems. With ACPI, software automatically controls the power to peripherals, and peripherals can also activate the processor. For example, receiving an incoming call with a modem powers the processor from standby mode in time to capture the data. This aggressive power management greatly increases battery life on portable embedded devices.

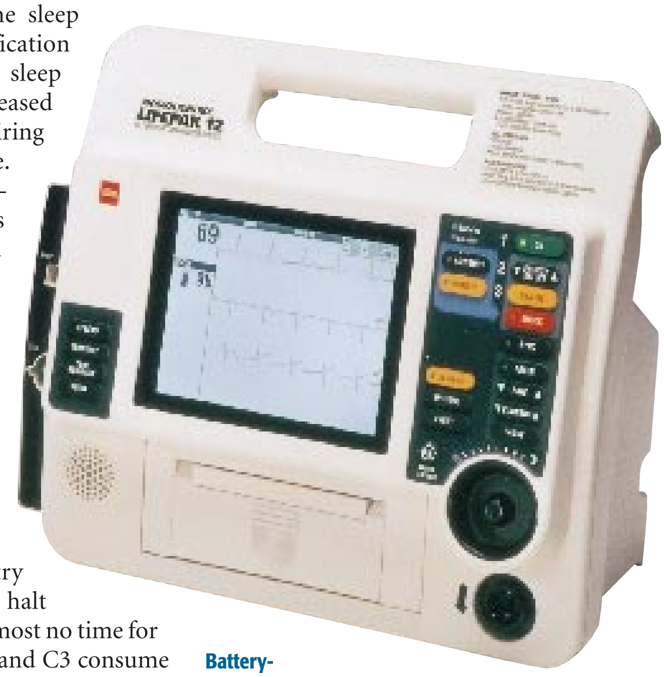
ACPI defines a series of reduced-power states for the system, processor, and peripheral devices. When the system has been idle for a specified amount of time, the software enters system power-management, or sleep, states. The CPU does no work in any of the sleep states. The ACPI specification defines four levels of sleep states, each with increased power savings but requiring more time to resume. For example, if the software saves the contents of memory to disk in a level-four sleep state, the CPU takes several seconds to power up the disk and reload memory before resuming operation.

An ACPI-compliant CPU has three power-management, or "C," states that require little time for entry and exit. State C1, the halt instruction, requires almost no time for the CPU to restart. C2 and C3 consume less power but take longer to resume. Intel reports that a 233-MHz mobile Pentium II processor consumes 0.5W in state C2 and takes 10 μsec to resume. The same processor uses 0.15W in state C3 but needs 65 μsec to restart. The CPU can enter C states during the idle time between operator keystrokes to save considerable power.

The ACPI specification also defines four "D" states that allow the operating system to manage the power consumption in devices and peripheral chips. The D states have different meanings, depending on the type of device. For example, a modem driver may specify D0 for full power, D2 for a 2-sec maximum restore time, and D3 for a 5-sec maximum restore time. Effective use of D states influences hardware design because peripheral power-down occurs at different times.

Effective software power management may also be the difference between life and death in portable, battery-operated medical instruments. A prime example is a defibrillator, which may sit on the shelf in the standby mode for as long as a year before users expect it to produce on command a series of 50A, 2000V pulses. An extensive schedule of daily, weekly, and monthly self-test routines ensures that the defibrillator is ready for action and is also reserving battery power for a possibly lifesaving shock.

Sometimes, the best way to optimize software power management is to measure the energy consumption in real time as the application program executes in the embedded hardware platform. One example of a tool for this type of



Battery-operated medical equipment, such as this defibrillator from Physio-Control, may sit in standby mode for months before delivering a lifesaving jolt.

ISO 14001 MEASURES ENVIRONMENTAL IMPACT

You can do more than reduce the power requirements on your next design to help clean up the environment. ISO, the same organization that gave us ISO 9001, in 1992 developed ISO 14001 to govern the way a company manages its impact on the environment.

ISO 14001 requires that companies implement an environmental-management system to define environmental objectives, outline monitoring rules, and schedule corrective measures. ISO 14001 is currently a voluntary standard that manages emissions, recycling, packaging reuse, conservation, and disposability. ISO 14001 also urges registered companies to demand that suppliers comply with the standard, so you may soon find that big contracts require certification.

Of the more than 6600 ISO 14001-certified companies worldwide, about half are from Japan, Germany, and the United Kingdom. Although the United States is only ninth on the list with about 200 registered companies, those companies are industry leaders, so you can expect the number to grow rapidly.

Figure 2

Power-optimization instruments, such as the $995 PowerAid from SoftAid, allow software designers to measure power consumption at any address in the application program.

firmware optimization is the $995 PowerAid from Softaid. Using a Windows-based program to display results on a standard PC, the PowerAid tracks embedded-system current by address range or software function (**Figure 2**). A software designer can then rewrite or optimize those routines that use the most power.

Even as power consumption in embedded systems falls, researchers are investigating unique energy-saving techniques. Several studies look at harnessing some of the energy expended by normal human activities to reduce or eliminate batteries. For example, a piezoelectric transducer inserted in a user's shoe can extract power from walking. Opening a clamshell case or typing can also provide some of the energy necessary to power a notebook computer. Realistically, however interesting these projects may seem, you are stuck with batteries for the near future.

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Regardless of the techniques you use, the challenge that you face as low-power hardware designers and software engineers is to squeeze the maximum embedded-system performance from the smallest energy expenditure. If you are successful, your efforts will produce a smaller product, longer lived battery, lower project costs, and increased reliability. You can also take pride in the knowledge that your low-power design will slow the ever-increasing energy drain on the world's environment. □

References

1. Levy, Markus, "*EDN*'s 25th Annual µP/µC Directory," *EDN*, Sept 24, 1998, pg 42.
2. Webb, Warren, "Miniature technology fashions wearable computers," *EDN*, Dec 17, 1998, pg 83.
3. Webb, Warren, "60+ flavors of CPU cards accelerate CompactPCI design," *EDN*, Oct 22, 1998, pg 52.

Acknowledgments

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