 By Greg Vrana, Technical Editor

Power down for portables

A BIG BATTERY CAN MEAN SMALL MARKET SHARE. REDUCING POWER CONSUMPTION IN YOUR PORTABLE DIGITAL DEVICE IS THE "GREEN" THING TO DO, AS IN MONEY.

Figure 1 Compaq's iPaq PDA uses a reflective LCD to conserve power.

James Prescott Joule first formulated the relationship between electrical current and dissipated power in the 19th century. Joule's Law states that the power a circuit dissipates is equal to the square of the current times resistance, ($P=I^2R$). The SI (International System) unit of work bears Joule's name in honor of this discovery. What Joule couldn't have known in 1840 was how much useful work engineers would be squeezing out of every joule stored in the batteries of today's portable digital devices (**references 1** and **2**).

The motivation for reducing power consumption in battery-operated devices may seem obvious, but a truly low-power design can change the way we use a product and subtly affect our lives. Two examples are cell phones and PDAs. Part of the reason behind the wide acceptance of these devices is their ability to run on a single charge or set of batteries for a relatively long time. As a consequence, some people claim that they can't live without either. On the other hand, you're lucky if you can use your digital camera for more than a few hours before recharging it or replacing its battery. Early technology adopters may tolerate this inconvenience, but most of us are used to replacing the battery in our film cameras maybe once a year. Before digital cameras are as common as their manufacturers would like them to be, the camera makers will have to improve power consumption.

Other reasons for reducing the power consumption of your design include avoiding thermal problems and reduced reliability. Reducing heat dissipation may eliminate the need for a cooling fan or bulky heat sink and their extra cost. By paying careful attention to power consumption, you can increase the performance and features of your product for the same battery life of your competitors' products. Lower power also means fewer or smaller batteries, which translates into a smaller and lighter form factor for your device. And by decreasing the number of batteries that customers have to replace, they will enjoy a reduced cost of ownership.

OK, WHO LEFT THE (BACK) LIGHT ON?

To reduce power consumption, it helps to know how much power the components of your system use and when they use it. Take a typical laptop PC based on a 600-MHz mobile Intel Pentium III processor as an example. **Table 1** shows the power consumption of the laptop's components running two applications. Most of the power goes to the laptop's LCD screen. Most laptops have transmissive LCDs, which use a CCFL (cold-cathode-fluorescent-lamp) backlight. The CCFL and its drive inverter consume most of the power a backlit LCD uses. Reflective LCDs, on the other hand, don't require a backlight and instead use ambient light for viewing (**Figure 1**). For example, Toshiba's 4-in. color-reflective LTM04-C387S LCD cuts power consumption to 0.4W, and the panel's thickness and weight are half that of a backlit LCD. A device with a reflective LCD may use a light surrounding the display opening to illuminate the front of the screen, which users can turn on in low-light situations.

On the horizon is a 2.1-in. reflective LCD from Toshiba that integrates SRAM into each RGB dot of the LCD's array (**Figure 2**). Once you load an image into the LCD, the display consumes less than 1.4 mW in standby mode with the image visible. Typical power consumption with moving images is about 25 mW. Toshiba is targeting the display for use with cell phones, which spend a lot of time in standby mode.

Figure 3 shows the power consumption of another typical laptop PC during boot-up. By subtracting the power level in **Figure 3b** from the level in **3a**, you can see that the LCD, drivers, CCFL, and inverter consume 12W of power. Subtracting the power level in **Figure 3c** from **3a**, you get the power of just the CCFL and inverter, which is 9W. The backlight and its inverter consume 75% of the power in a transmissive LCD. You can decrease power consumption in a backlit LCD by decreasing the brightness of the CCFL. **Figure 4** shows the power consumption of a laptop with its LCD at maximum and minimum brightness settings.

> **AT A GLANCE**
>
> ▷ Careful low-power design can change the way people use your product and give you an advantage over your competitor.
>
> ▷ Poor low-power design can make your product frustrating to use, if not useless.
>
> ▷ LCDs typically consume the most power in devices that use them. Using a reflective LCD can greatly reduce power consumption.
>
> ▷ The three basics of reducing power are: Turn it off if you're not using it, lower the voltage, and reduce clock frequency.

V^2CF VERSUS PERFORMANCE

Although a low-power microprocessor consumes only around 9% of the power in a full-size notebook PC, that percentage grows as the size of the PC's LCD becomes smaller. A handful of basic principles tell you how to save power in today's low-power processors and almost any other electronic device: Turn it off if you aren't using it, lower the voltage, and throttle back the clock frequency. Most of the techniques you can use to reduce power are based on the fact that power is proportional to V^2Cf, where V, C, and f are voltage, capacitance, and frequency, respectively. Reducing any one of these variables reduces power dissipation.

Figure 2 Toshiba's 2.1-in., 4096-color thin-film-transistor LCD with integrated SRAM uses less than 1.4 mW in standby mode.

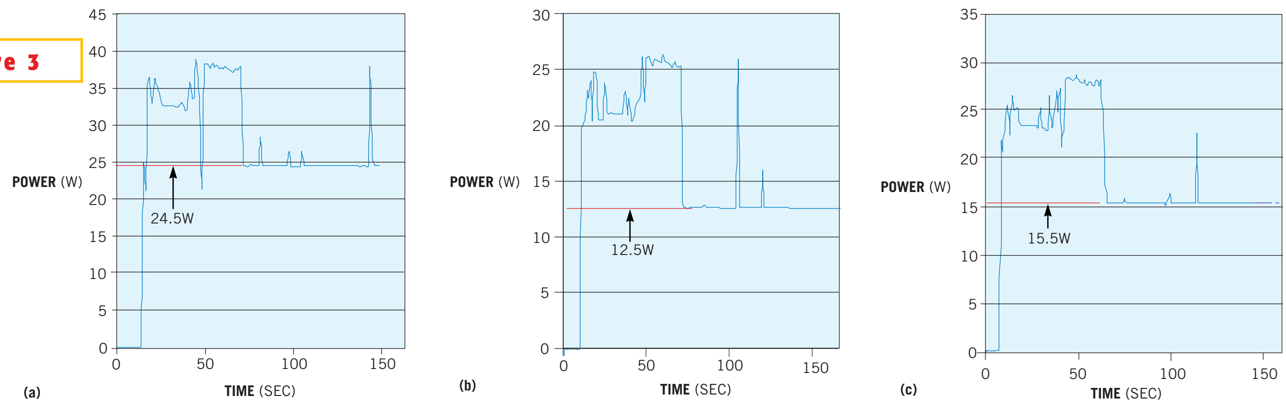
Most microprocessor-based portable devices today selectively power down components of the device to save power. In fact, the power management that subnotebooks use is a good model to base your own design on. By simply turning off unused systems in your device, you can reduce wasted power. The hard part is determining when and how to turn off subsystems. Completely shutting down a component may save the most power, but bringing that same component back online will take longer and increase the response time a user experiences. It may be better to place the component in a sleep or low-power state until you need it. These decisions require thoughtful attention to how a customer will use your product. If a device is constantly going to sleep and taking several seconds to wake up, your customer might find the experience too annoying to use the product.

Chip designers have found that they get the most bang for the buck by operating their silicon at lower voltages to reduce power. From the voltage-capacitance-frequency equation, you can see that power is proportional to the square of the voltage applied to a circuit. Intel, AMD, Transmeta, and other processor vendors use this law of nature to reduce power dissipation. The innovation is to vary the core voltage based on the demand on the processor. Using algorithms developed by their respective companies, the processor determines its computational load and adjusts its core voltage by signaling the voltage converter powering it.

Taking this technique a step further, the processor can also reduce its internal core clocking frequency during periods of low demand. Reducing both voltage and frequency has the effect of cubing power reduction.

Each type of product has a unique power-usage profile. This profile helps you determine the best type of power-reducing techniques to use. PC-processor vendors use dynamic voltage scaling, which makes sense for products that have varying loads. When running a simulation, for example, you want the processor to run at full speed and full power. When doing low-priority tasks or idling, you want the processor to reduce power by

Figure 3



A laptop PC with a 15-in. LCD consumes 24.5W (a). With the display assembly disconnected, the laptop consumes 12.5W (b). With the display assembly connected, but with the CCFL/inverter module disconnected, the laptop consumes 15.5W (c) (courtesy Portelligent).

throttling back its core voltage and clock, because performance is not critical.

For lower cost designs or those for which you can predict the maximum performance you will need, choose the lowest power, single-speed processor that meets your performance objective. This rule of thumb also applies to ASIC design. If your application has a relatively constant throughput, design your ASIC for maximum performance and run it at the minimum voltage that meets your throughput constraints.

One of the advantages of a voltage-scaled processor is that it can perform a given task in a short or long amount of time. In other words, it can do a certain amount of work using a lot of power or a little. This attribute translates directly into battery life. As an example, take a computational task that requires 900 million instructions on an Intel XScale processor. Running at 1.8V and 1200 MIPS, the processor takes 0.75 seconds using 1.8W for a total of 1.35 joules to finish the task. Operating at 0.75V, the same processor uses 40 mW and runs at 185 MIPS. At this lower speed, the processor takes 4.9 seconds to complete 900 million instructions but uses only 0.19 joules. By operating in a low-power mode, the processor can do the same amount of computational work using nearly one-seventh the energy. If you can afford to trade time for performance, you can increase battery life using a voltage-scaled processor.

Calculating energy use for simple, theoretical examples isn't hard, but you may not want to base a buying decision on them (**Reference 3**). Thankfully, help is on the way from EEMBC (*EDN* Embedded Microprocessor Benchmarking Consortium), which plans to release benchmark numbers based on power in September. These benchmarks will be valuable to designers trying to find the most power-efficient processor for their applications. In addition to performance scores that vendors submit, you will be able to see how much energy a processor used to run each benchmark. The only drawback is that submitting benchmark scores is voluntary. If one of your vendors is a member of EEMBC and doesn't publish its processors' scores, encourage the company to do so and be curious about why they don't.

If using a voltage-scaling processor makes sense for your design, be aware that you will have to power the processor with a programmable dc/dc voltage converter. Companies such as Analog Devices, Intersil, National Semiconductor, On Semiconductor, and Texas Instruments offer converters for voltage-scaling processors. Look for a converter with the highest efficiency for your application. Converters operating at higher frequencies require smaller or fewer external components, such as capacitors and inductors, but they may be less efficient. PFM (pulse-frequency-modulation) converters are more efficient at light current loads, whereas PWM (pulse-width-modulation) converters are better for higher loads. Some converters, such as TI's TPS6200X family, can operate in either mode for maximum efficiency. Converters may also have different efficiency specifications for different output voltages, so be sure to check their data sheets. And be careful that the operating frequency of your converter does not interfere with other parts of your design.

In some cases, running a task in a short amount of time and therefore at peak performance and power may end up sav-

TABLE 1—POWER CONSUMPTION OF A LAPTOP PC's COMPONENT RUNNING TWO APPLICATIONS

	Power (W)	
Laptop component	**Ziff-Davis BatteryMark 3.0**	**DVD playback**
LCD screen	2.8	2.8
Low-power Pentium III processor	0.8	0.8
440 MX chip set	0.65	0.65
SDRAM (64 Mbytes)	0.1	0.1
Graphics subsystem	0.5	0.5
I/O subsystem	0.1	0.1
Audio subsystem	0.4	0.4
Modem	0.7	0
Hard drive	0.89	0.65
DVD/CD-ROM	0	2.51
Cardbus	0.2	0.2
Fan	0.4	0
Other	1	1
Power supply	0.72	0.72
Total	9.26	10.43

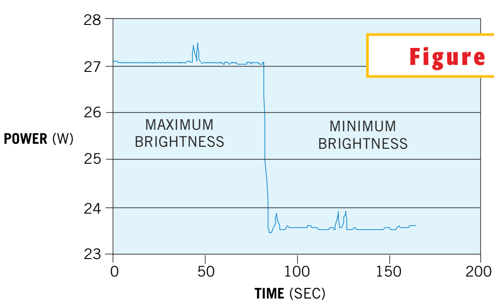
ing energy. If many subsystems must remain active while your task is running, calculate how much power the entire system uses while the task runs. Running the task at peak performance may actually reduce the total amount of energy you use if you can place all the components in a low-power state sooner. Spending some time optimizing your code also contributes to shorter runtimes.

DON'T FORGET MEMORY

SDRAM manufacturers such as Infineon, Micron, and Samsung are making progress in the market for low-power devices (**references 4** to **6**). Historically, SDRAM has been inefficient due to power spent on self-refresh. Because the rate at which a bit cell loses its charge is proportional to temperature, designers typically set refresh frequency to cover worst-case temperature conditions. High temperatures require a high refresh frequency, which means high power. SDRAM rarely operates at worst-case temperature, so a lower refresh frequency is sufficient at typical operating temperatures. Micron's BAT-RAM takes advantage of this relationship by allowing you to set the refresh frequency through an extended register. You have to provide a temperature-feedback circuit to correctly program the register. Another power-saving feature of this SDRAM is the ability to refresh one-quarter, one-half, or all of the memory array. This technique means that you lose data in unrefreshed banks, but you can save power by turning off the unused portion of the memory.

The key to a low-power device is to look at each component in your design *and* how all the components work together as a system. Power-efficient components are a good start, but a truly low-power device is a low-power system. Low-voltage parts are great for reducing power, but they must have compatible interface voltages to work together. Coordinating the power-saving features of your design is important not only to eliminate milliwatts, but also to provide a good user experience. Vertically integrated companies have an advantage in this area over those that must use off-the-shelf parts. Consider designing your own ASIC and spending a few more dollars per part if it means a better product with bigger market share. And look for design ideas in one of the most power-efficient devices you probably already own: a cell phone.□

Figure 4



Adjusting the brightness of the LCD greatly affects a laptop's power consumption (courtesy Portelligent).

You can reach Technical Editor Greg Vrana at 1-512-338-0129 fax 1-512-338-0139, e-mail gvrana@earthlink.net.

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ACKNOWLEDGMENT

I would like to thank David Carey of Portelligent for his insight on this topic.

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