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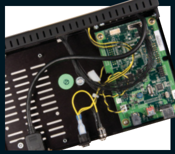

# HACKING THE BRAIN:

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## COMPENSATE FOR WIRING LOSSES WITH **REMOTE SENSING**

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## SELECTING THE BEST BATTERY FOR **EMBEDDED-SYSTEM APPLICATIONS**

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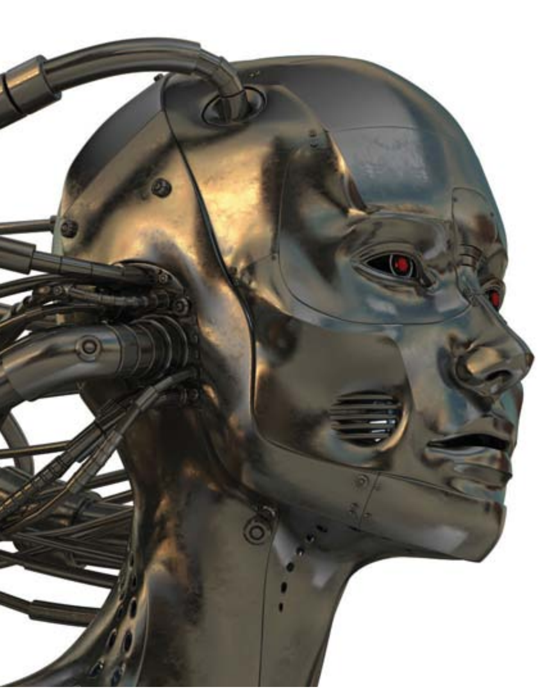

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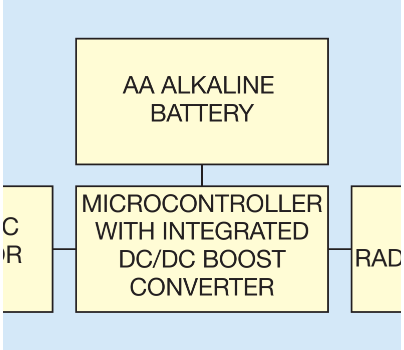


## Hacking the brain: Brain-to-computer-interface hardware moves from the realm of research

30 Advances in both hardware and software are making an accurate and economical brain-to-computer interface feasible.

*by Margery Conner,*
*Technical Editor*

## Compensate for wiring losses with remote sensing

24 By multiplexing a small ac signal on the power wires, you can infer wiring losses.

*by Jim Williams, Jesus Rosales,*
*Kurk Mathews, and Tom Hack,*
*Linear Technology Corp*

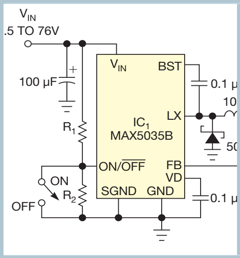
## Selecting the best battery for embedded-system applications

36 As systems and their corresponding power-management strategies become more sophisticated, so, too, does the task of selecting a battery that suits both static and dynamic requirements. Appropriate battery selection involves chemistry, temperature, peak demand, energy transfer, and environmental concerns.

*by Keith Odland,*
*Silicon Laboratories Inc*

## pulse

## DESIGNIDEAS



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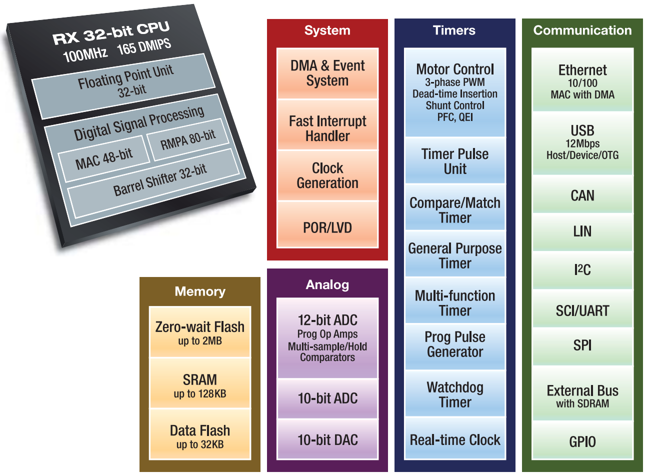

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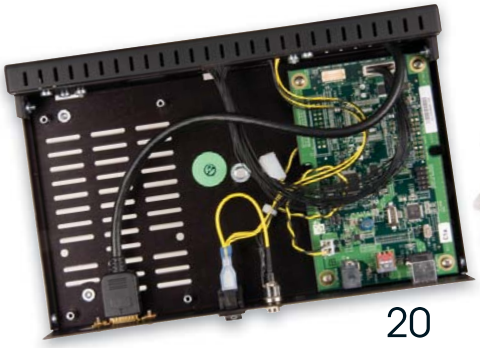
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BY RICK NELSON, EDITOR-IN-CHIEF

# Social networks and innovation

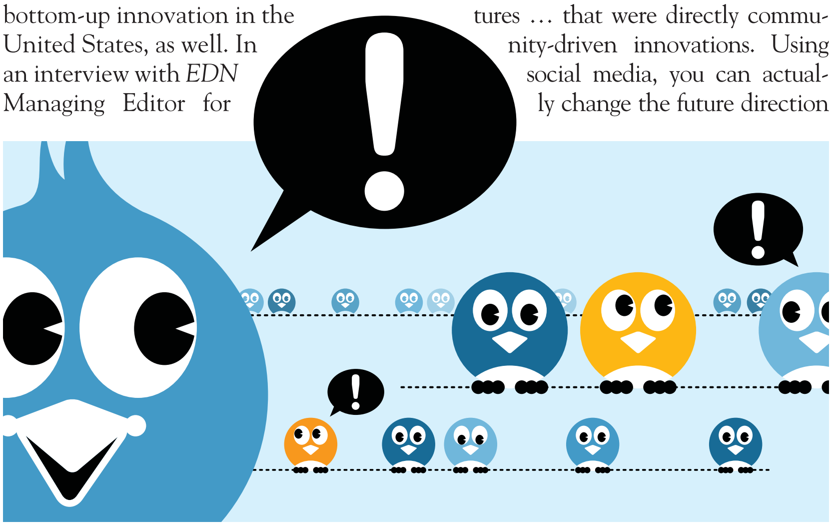
Are social networks a key to innovation? Thomas Friedman thinks so. Writing in *The New York Times* (**Reference 1**), he says, "Today's knowledge industries are all being built on social networks that enable open collaboration, the free sharing of ideas, and the formation of productive relationships—both within companies and around the globe. The logic is that all of us are smarter than one of us, and the unique feature of today's flat world is that you can actually tap the brains and skills of all of us, or at least more people in more places. Companies and countries that enable that [capability] will thrive more than those that don't."

Friedman goes on to quote SRI International Chief Executive Officer Curtis Carlson: "In a world where so many people now have access to education and cheap tools of innovation, innovation that happens from the bottom up tends to be chaotic but smart. Innovation that happens from the top down tends to be orderly but dumb."

Friedman is commenting in the context of the prospects for bottom-up innovation in China given the government's propensity to regulate or prohibit social networks. But skepticism about social networking could hinder bottom-up innovation in the United States, as well. In an interview with *EDN* Managing Editor for News Suzanne Deffree (**Reference 2**), Deirdre Walsh, social-media and community manager at National Instruments, said she is frequently asked, "Why should I care about Twitter?" or "Is Facebook really for business?"

Indeed it is, Walsh says, citing five reasons you should use social networks: get help with support and technical problems, advance your career, be heard—that is, tell your vendors what you want and need—stay connected with peers, and become famous.

Walsh elaborates on that third point—be heard: "LabView 2010 has 14 new features … that were directly community-driven innovations. Using social media, you can actually change the future direction of the product." And, like Carlson of SRI International, she suggests that in social networks innovation—or at least problem-solving—happens from the bottom up: "On our NI discussion forum community, engineers answer 50% of all support questions asked by other engineers. It's not NI coming in to solve their problems; it's a peer-to-peer support network."



Other companies are also taking advantage of social networking. Jeff Hamilton, director of marketing at Newark Electronics and element14, applies social networking to his distribution business, commenting that the element14 Web site, aimed in part at low-volume purchasers that don't command the attention of traditional distribution companies, provides a community as well as commerce. In addition to providing the ability to make purchases, he says, element14 facilitates communications among community members through blogs and other formats while providing access to industry experts.

Walsh of NI notes a paradox in engineers' attitudes to social networking: "People have a stereotype that engineers aren't social, but I find that, when you give them opportunities to share content and have the conversations that they care about, they are some of the best community participants out there. Engineers are the ones who created all of these technologies that they now cringe at. They need to better embrace them and realize there are a lot of opportunities for them to be successful in their career in using them."

Walsh says she presents her fifth reason for using social networking—fame—at least partly in jest. Maybe fame isn't your goal, but you ignore the other four reasons at your peril. **EDN**

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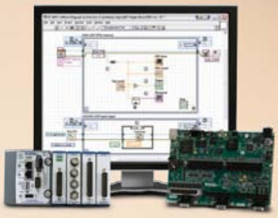
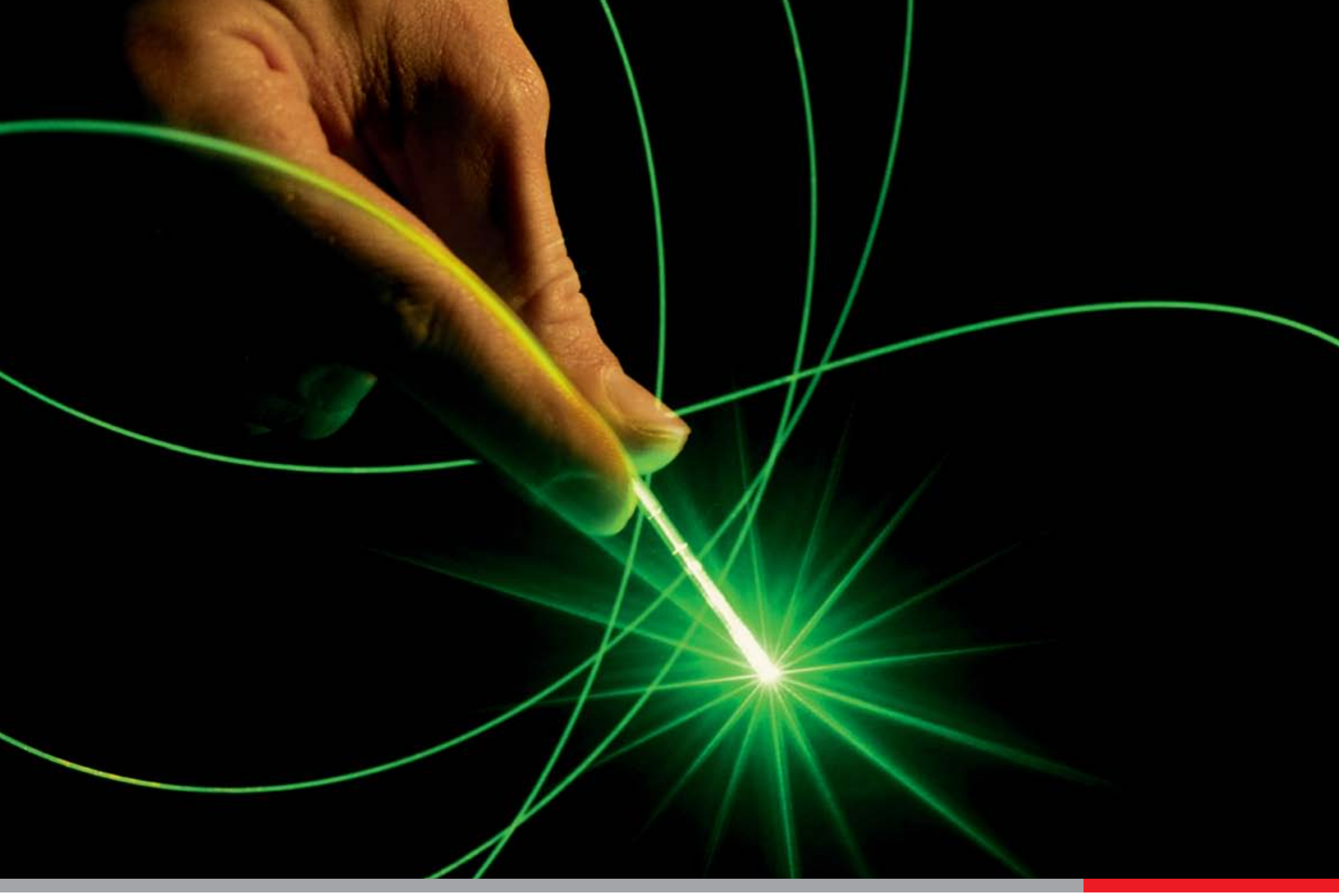
1. Friedman, Thomas L, "Going Long Liberty in China," *The New York Times*, Oct 16, 2010, http://nyti.ms/d3P6gr.
2. Deffree, Suzanne, "Deirdre Walsh: success with social media," *EDN*, Sept 23, 2010, pg 16, http://bit.ly/b3E032.

*Contact me at richard.nelson@cancom.com.*





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EDITED BY FRAN GRANVILLE

# pulse

## INNOVATIONS & INNOVATORS

## Lattice MachXO2 family reduces power and cost for low-density PLD designs

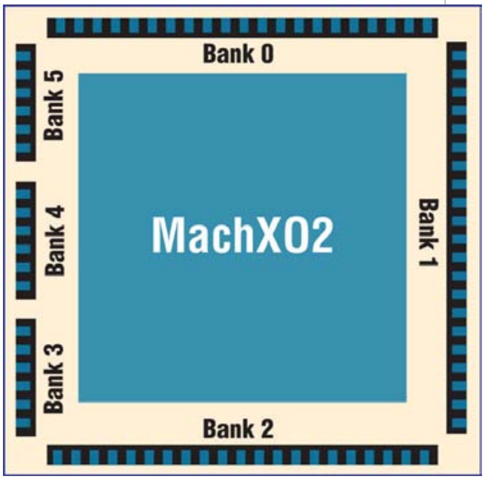
Lattice Semiconductor's new MachXO2 line of low-density PLDs (programmable-logic devices), offers three times the logic density and 100 times lower static-power dissipation than the previous-generation MachXO family. A combination of layout-optimization techniques and manufacturing in a low-power, 65-nm embedded-flash process provides cost savings in small-footprint, 0.8-mm BGA packages. An asymmetrical-banking scheme with triple-staggered I/O pads maximizes the number of usable inputs and outputs.

The family comes in a range of configurations, from the XO2-256, with as many as 256 look-up tables, to the XO2-7000, which has a maximum of 6864 look-up tables. All members of the XO2 line integrate hardened I$^2$C (inter-integrated-circuit), SPI (serial-peripheral-interface), and timer/counter blocks. The line also has options for power performance. The ZE option targets low power, with as much as 60-MHz system performance from a 1.2V supply. The HC option achieves higher performance with a choice of 2.5 or 3.3V, boosting system performance to 150 MHz. All variations integrate an on-chip voltage regulator for 1.2V internal operation. The HE option, which will be available in the XO-2000, -4000, and -7000 configurations, offers 2000, 4000, and 7000-look-up tables, respectively. The option offers a combination of 2- to 5-mW power and 150-MHz operation from a 1.2V supply.

The company is shipping alpha samples of the MachXO2-1200, which integrates 64 kbytes of embedded RAM, 64 kbytes of user flash memory, and an embedded PLL (phase-locked loop). Production quantities should become available in March 2011. Other members of the XO2 family will become available for sampling in the second and third quarters of next year. Prices for the MachXO2 range from 75 cents for the LCMXO2-256ZE/HC TQFP100 to $2 (500,000) for the LCMXO2-1200ZE/HC TQFP100.

To get designers up and running quickly, Lattice offers free PLD-design tools and a variety of free reference designs. Engineers have a choice of designing MachXO2 devices by using the Lattice Diamond Version 1.1 software or ispLever Version 8.1 SP1 starter software, both of which you can download free from the Lattice Web site. Two design kits are also available. The $38 Pico development kit offers a low-cost, battery-operated evaluation platform, and the $149 Control development kit targets system designs.—**by Mike Demler**

▷**Lattice Semiconductor**, www.latticesemi.com.



The MachXO2 line of low-density PLDs offers three times the logic density and 100 times lower static-power dissipation than the previous-generation MachXO family.

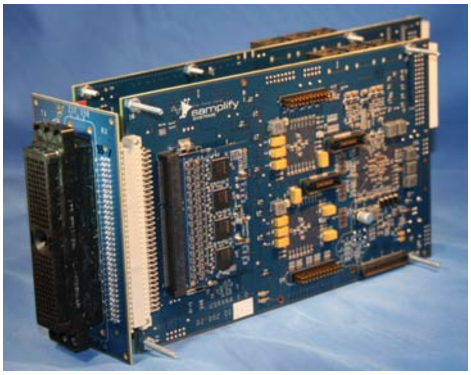
### TALKBACK

**"I saved most of my father-in-law's large collection of valves/tubes for posterity or good use. … There is something of beauty about these devices that a lump of black plastic can never match."**

—Engineer Tony Gore, in *EDN*'s Talkback section, at http://bit.ly/aAokFX. Add your comments.

# Ultrasound-development kit simplifies software and system design

Samplify Systems Inc has given a boost to medical-electronics-domain experts with the introduction of the SMK9130 ultrasound-beam-forming-development kit. The company based the kit on the Samplify AutoFocus beam-forming technology. The SMK9130 hardware-development tool targets use in ultrasound front ends from probe connectors to PCIe (Peripheral Component Interconnect Express) connectors.


The SMK9130 hardware-development tool targets use in ultrasound front ends from probe connectors to PCIe connectors.

SMK9130's AutoFocus calculation engine automatically refocuses a receiver to capture reflections at different scan depths. It alleviates the real-time requirement of calculating and downloading the delay and weighting coefficients in a back-end computer, thus simplifying software and system design. Programmable tables drive transducer geometry definitions and scan-line parameters, further removing the real-time nature of back-end computer updates. The silicon implementation uses up to 90% less power than does an FPGA.

Samplify's SMK9130 allows ultrasound OEMs to start developing their image-processing algorithms with known-good hardware before the availability of their production systems to reduce software-development and system-integration time.

"The ultrasound market continues to fragment into many specialty applications outside traditional radiology and obstetrics/gynecology," says Allan Evans, vice president of marketing for Samplify. "Samplify is enabling ultrasound manufacturers to focus their R&D resources on their core image-processing algorithms without designing hardware."

The 64-channel SMK9130 includes one 32-channel SMM9132 analog-front-end-receiver module and one 32-channel SMM9133 analog-front-end-receiver module for full continuous-wave-Doppler capability. AutoFocus and QuadBeam phased-array processing combine the received signals from each channel to provide four scan-line outputs per transmission. Trilevel pulsers and a transmitter beam former support transmission for all black-and-white and color modes. The platform also includes a continuously variable power supply for the high-voltage path and supports postprocessing with an interface to a PC host through USB (Universal Serial Bus ) 2.0 or four-lane PCIe 1.1. A Windows software driver controls all the hardware and an image-processing stack. The software is forward-compatible with future ASIC and module products from the company. The SMK9130 will be available in the first quarter of 2011 for $60,000; additional pricing options support volumes for clinical trials and production.

**—by Rick Nelson**

▷**Samplify**, www.samplify.com/ultrasound.

DILBERT By Scott Adams

11.18.10

## EMBEDDED PROCESSORS EMPLOY 40-nm LITHOGRAPHY

**Texas Instruments' latest ARM-based Sitara embedded processors and Integra ARM-plus-DSP multicore hybrid devices feature a lithography reduction to 40 nm. Both the AM3892 and the AM3894 Sitara SOCs (systems on chips) support as many as two tethered displays at output resolutions as detailed as 1920×1280 pixels. The AM3894 also embeds an Imagination Technologies (www.imaginationtechnologies.com) SGX530 GPU (graphics-processing-unit) core operating as fast as 333 MHz to accelerate 3-D graphics. The AM3894 sells for $43.10 (1000). TI has not announced the price of the AM3892.**

**TI's new Integra processors embed a TMS320C674x floating- and fixed-point DSP core operating as fast as 1.5 GHz alongside the ARM system-processor core. The remainder of the peripheral mix matches that of the devices' pin-compatible Sitara siblings. The C6A8167 SOC is a basic $46 (1000) version without a GPU, and the C6A8168, a GPU-inclusive version, sells for $49 (1000). A DDR2 version of the evaluation module is now available for $1895. For more, go to http://bit.ly/cKVtDR.—by Brian Dipert**

**▸Texas Instruments, www.ti.com.**


ULTRA-LOW POWER BATTERY
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# VOICES

## Reaching for ROHS recast

Gary Nevison, legislation expert for element14 (www.element-14.com), the design-information portal of distributor Premier Farnell and its US arm, Newark, discusses the "ROHS recast." He explains the review and reworking of the EU (European Union) ROHS (restriction-of-hazardous-substances) environmental-compliance directive that is currently under way and that will affect electronics designed for sale in the European Union. For more of this interview, see www.edn.com/101118pa.

**Why is the European Union reworking this directive?**

**A** It's ROHS law that it had to be reworked after four years. The initial recommendations came in December 2008, and, since then, it's been discussed at some length. The kind of proposed scope has changed many times in the last year. Taking place behind the scenes are meetings with the European Commission, the European Parliament, and the European Council of Ministers, who have to agree on a final draft. The intention is to reach an agreement so that the proposal can get a "first-reading approval." If we can get the first-reading approval, then the implementation of the new ROHS directive could be as early as 2013.

It's possible that they won't reach agreement, and discussions will go on into 2011.

**What are the main points of the ROHS recast?**

**A** The changes to the scope are significant. One of the proposals is that there will be a Category 11; there are now 10 categories, although categories 8 and 9 [medical and monitoring-and-control instruments, respectively] are yet to be implemented in the original ROHS. Category 11 would be defined as all electrical and electronic equipment, unless specifically excluded. Not all member states agree—certainly, the United Kingdom is one that does not agree—because they feel that this [step] should not go ahead without a full risk assessment. This [development] will happen whether they like it or not, so the United Kingdom, for example, is now lobbying for more exclusions. ROHS will become an open-scope directive, including all equipment unless otherwise excluded.

The next key thing is the number of excluded substances. The proposal that was on the table [in October] was that there would be two more substances [nanosilver and carbon nanotubes] restricted on top of the original six in the ROHS directive. Then there's a further list of 37 substances that will be proposed for priority assessment with a ban possibility. Many of these substances would be the substances of very high concern, currently that REACH [registration, evaluation, authorization, and restriction of chemical substances directive] regulates. … The other proposal is one restricted substance [nanosilver] and to drop the list of 37 substances.

Member states are looking for exclusions in the usual areas: military and national security, large-scale industrial tools, and transportation—those kinds of things. There will be a considerable number of exclusions from this open scope.

**Some industry and trade organizations are petitioning for ROHS to become a more REACH-like directive. Do you see that scenario's happening?**

**A** As an overview, the ROHS directive bans substances based on hazards. If a substance is hazardous and there are alternatives, then it can be banned. REACH restrictions are introduced only if risk to human health or the environment can be proven after complete risk assessment. There is a movement to move the ROHS process toward the REACH approach to adopting restrictions. That [movement] is not part of the vote, but I do think that [change] will happen. … What it probably will mean is that substances may get restricted much quicker, and that [change] is going to have a big impact on the designer. We've already seen REACH with 38 substances of very high concern, whereas ROHS has had six substances since July 2006.

**Will ROHS at some point become a CE (Conformité Européenne)-mark directive?**

**A** ROHS will become a CE-mark directive, which means that for every piece of equipment that has a CE mark there will have to be an awful lot more information provided to the user than what is today. There will have to be technical documents and declarations of conformity that will have to be kept on file for 10 years.

**ROHS is well-known, but what other key legislation should designers be aware of?**

**A** At the minute, ROHS recast is dominating the space. The other one would be REACH, of course. REACH is bringing the industry to its knees in Europe because of the information and safety-data requirements. The one around the corner that, if it finally takes off, will take over is China ROHS, but that [initiative] is still dragging a bit. Beyond that is India ROHS, but that is in the very early stages. Things such as the energy-efficient directives are still moving along at a steady pace; the battery directive is in; the waste directives are moving incredibly slow, so the WEEE [waste-electrical-and-electronic-equipment] recast won't be done at the same time as the ROHS recast. There are lots of little bits coming through. I don't think there are going to be many biggies in the near future. I now spend more than half my time firefighting these small, local bits of legislation. There's a lot going on.

**—interview conducted and edited by Suzanne Deffree**

# Rarely Asked Questions

Strange stories from the call logs of Analog Devices

## Considerations on High-Speed Converter PCB Design, Part 1: Power and Ground Planes.

**Q.** What are some important PCB layout rules when using a high-speed converter?

**A.** To ensure that the design meets datasheet specifications, you should follow a few guidelines. First, an age old question: "Should the AGND and DGND ground planes be split?" The short answer is: it depends.

The long answer is: not usually. Why? In most situations a split ground plane can cause more harm than good, as splitting the ground plane only serves to increase the inductance for the return current. Remember the equation $V = L(di/dt)$? As the inductance increases, so does the voltage noise. As the switching current increases—and it will as converter sampling rates increase—the voltage noise will also increase. Therefore, keep the grounds connected unless you have a reason to split them.

One example is when a form factor restriction prohibits good layout partitioning. This could be because the dirty bus supplies or digital circuits must be located in certain areas to conform with legacy designs. In that case, splitting the ground plane may make the difference in achieving good performance. However, to make the overall design work, a *bridge* or tie point is required to connect the grounds together somewhere on the board. With that being the case, spread the tie points evenly across the ground plane split. One tie point on the PCB often ends up being the optimum place for the return current to pass without reducing performance. This tie point is usually near or under the converter.

When designing the power planes, use all of the copper available for these designated layers. If possible, don't share traces on the same layers, as additional traces and vias can quickly compromise the power plane by breaking it into smaller pieces. The resultant sparse plane can squeeze current paths down where they are needed most: at the converter's supply pins. Squeezing currents between vias and traces increases resistance and can cause slight drops in voltage at the converter's supply pins.

Finally, placement of power planes is critical—don't overlay the noisy digital plane over the analog plane, as they can still couple even if they are on different layers. To reduce the risk of degrading system performance, keep these types of planes separated and non-overlapping throughout each layer in the design if possible.

Stay tuned for Part 2, where power delivery and decoupling high-speed converters will be discussed.

**To Learn More About High-Speed Layout**
http://dn.hotims.com/27761-101

**Contributing Writer Rob Reeder is a senior converter applications engineer working in Analog Devices high-speed converter group in Greensboro, NC since 1998. Rob received his MSEE and BSEE from Northern Illinois University in DeKalb, IL in 1998 and 1996 respectively. In his spare time he enjoys mixing music, art, and playing basketball with his two boys.**

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# Go for the gold with voltage-reference circuits

High-resolution mixed-signal devices present an interesting challenge as you try to find the right voltage-reference design. Although no universal approach exists for these voltage-reference designs, the circuit in **Figure 1** presents an interesting approach for greater-than-15-bit converters.

Some design issues of concern with high-resolution converters are voltage-reference noise, stability, and the reference circuit's ability to drive the voltage-reference pin of your converter. The passive filter comprising $R_1$, $C_2$, and $C_3$ dramatically reduces the voltage-reference noise. The corner frequency of this lowpass filter is 1.59 Hz. This filter reduces both broadband and extremely low-frequency noise. The additional RC filter brings the noise level under control enough for a 20-bit ADC. This situation is encouraging. However, if current is pulled through $R_1$ from the ADC's reference pin, the voltage drop will corrupt the conversion by introducing a voltage drop with each bit decision (**Reference 1**).

The circuit diagram in **Figure 1** has an operational amplifier to isolate the lowpass filter comprising $R_1$, $C_2$, and $C_3$ and to provide adequate drive to the ADC's reference pin. The input bias current of the OPA350 CMOS op amp is 10 pA at 25°C. This current combines with $R_1$'s resistance of 10 kΩ to generate a constant 100-nV dc drop. This level of voltage drop does not change a 23-bit ADC's final bit decision. The input bias current of the op amp changes over temperature, but you can expect a maximum current that is no more than 10 nA at 125°C, generating a change of 100 µV over a 100°C temperature range.

It is useful to put this voltage drop across $R_1$ into perspective. This voltage drop adds to the errors of the voltage-reference device. Suppose that the initial error of the voltage-reference circuit is ±0.05% with an error over temperature of 3 ppm/°C. With a reference of 4.096V, the initial voltage-reference error is equal to 2.05 mV at room temperature plus 1.23 mV at 125°C. In the circuit in **Figure 1**, the voltage-reference device dominates over the op amp's offset and input bias-current errors. An ADC that connects to the circuit in **Figure 1** sees the summation of the errors from the voltage reference, $R_1$, and OPA350 as a gain error.

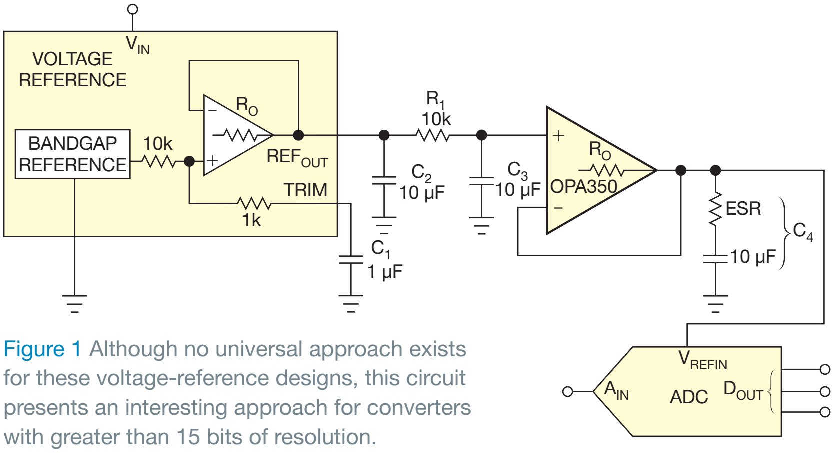

Figure 1 Although no universal approach exists for these voltage-reference designs, this circuit presents an interesting approach for converters with greater than 15 bits of resolution.

The op amp drives a 10-µF capacitor, $C_4$, and the ADC's voltage-reference input pin. The charge residing on $C_4$ provides the needed charge during the ADC's conversion. During the ADC's acquisition and conversion, the size of $C_4$ provides a stiff voltage reference for the ADC's reference pin, which usually has an input capacitance of approximately 2 to 50 pF.

You can compromise the amplifier's stability because $C_4$ and the op amp's open-loop output resistance, $R_O$, modify the amplifier's open-loop-gain curve. Basically, a circuit with good stability is one in which the modified op amp's open-loop-gain curve and the closed-loop voltage-gain curve's rate of closure is 20 dB (see **Figure 2** in the Web version of this article at www.edn.com/101118bb). In this stable circuit, the following **equations** calculate the frequency locations of the pole and zero:

$$f_P=\frac{1}{2\times\pi\times(R_O+R_{ESR-C4})\times C_4}=318\text{ Hz};$$

$$f_Z=\frac{1}{2\times\pi\times R_{ESR-C4}\times C_4}=78\text{ kHz}.$$

The open-loop output resistance of the OPA350 is 50Ω, and the ESR (equivalent series resistance) of $C_4$ is 2 mΩ.

## REFERENCES

1. Baker, Bonnie, "Taking the mixed-signal voltage reference to a higher level," *EDN*, Sept 23, 2010, pg 18, http://bit.ly/9p9lnn.

*Bonnie Baker is a senior applications engineer at Texas Instruments. You can reach her at bonnie@ti.com.*

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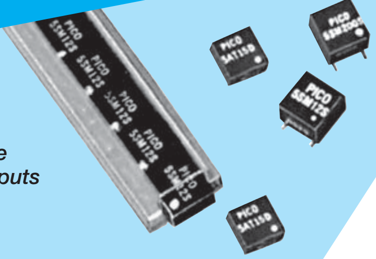

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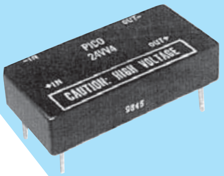

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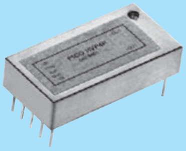

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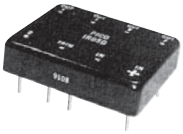

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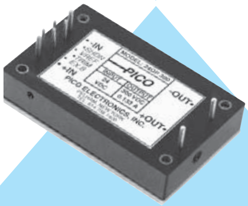

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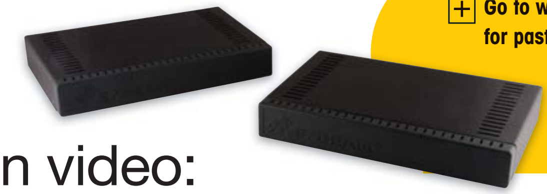
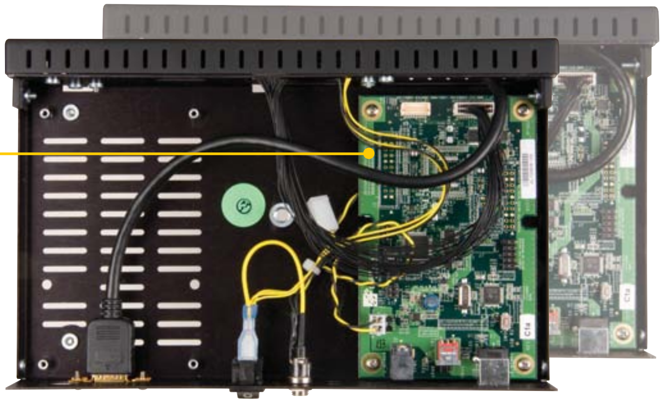


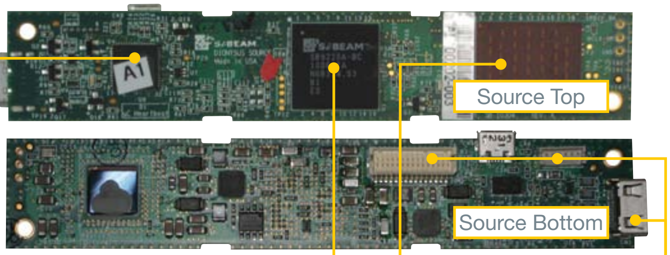
# Wireless high-definition video: silicon consolidation that's maximal

The Wireless Gigabit Alliance's 60-GHz-based high-definition wireless-video-transport scheme may be on the way, but SiBeam's pioneering approach and multiple product generations are already on the scene (see "The quest for robust wireless high-def video connections," *EDN*, Sept 23, 2010, pg 32, http://bit.ly/92oZnS). Peer inside a SiBeam-developed reference design to see how the company accomplishes this hefty bit-rate trick, complete with support for 3-D video presentations and for equipment control and networking augmentations.

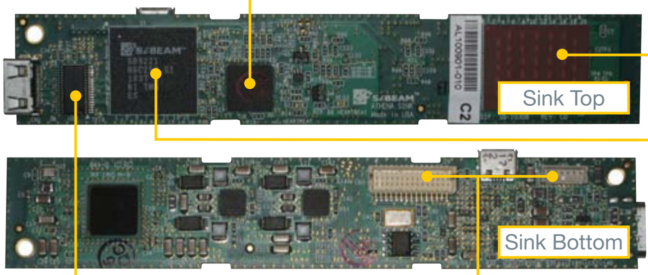
The transmitter and receiver, each measuring 9×6×1.5 in., are identical except for back-panel labels that identify them as "source" and "sink," respectively. An external ac adapter with 12V and 1.7A maximum output specifications powers each of them.



Take off the top covers of the transmitter's and receiver's enclosures, and you'll find that a USB-interface PCB takes up most of the internal space. This debugging and control board mates with PC-side software, and production-system designs won't need it. Such designs can be substantially smaller, less costly, and more power-thrifty as a result.



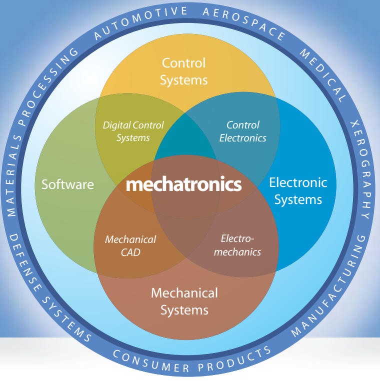
Behind the units' plastic front panels and underneath intermediary metal shields that block all but the transmitting and receiving antenna arrays are 22×125×6-mm PCBs containing the core circuitry for each device. In this case, too, however, some of the silicon content is exclusive to the evaluation task and won't appear in a production design. To wit, the top sides of both the transmitter and the receiver modules include Atmel AT91SAM256 microcontrollers to implement stand-alone operation. In an end-customer design, such as a Blu-ray player, a set-top box, a television, or an integrated home-theater setup, the system processor will typically manage the module, making the dedicated microcontroller unnecessary.



SiBeam's SB9220 HRTX WirelessHD network processor sits on the transmitter module's top side. The SB9210 HRTX RF transceiver is alongside it and underneath a ceramic microantenna-array lid. Corresponding ICs on the receiver module's top side are the SB9221 HRRX WirelessHD network processor and SB9211 HRRX RF transceiver. These latest-generation chip sets handle 1080p-resolution video at 60-Hz frame rates, with color depth as high as 4:4:4. They also comprehend HDMI's CEC feature, as well as WVAN. WVAN support provides the ability for a video source, such as a PC or a game console, to automatically be aware of (and for its user to subsequently select among) various available destination display devices and for a user (at a destination display) to select among available video sources.

A California Micro Devices ESD-protection chip clamps transients originating from the HDMI connector on the receiver module. The transmitter implements ESD protection for its TMDS lines using discrete components. In this case, the HDMI connector mounts on the module back. SiBeam also makes evaluation modules for LVDS and LVCMOS video interfaces. Also visible on both modules' backs are the power- and system-processor-control interfaces.


Figure 1: Robot Visualization
File Edit View Insert Tools Desktop Window Help
Real-Time xPC Target Spy
T41



# Trajectory planning with electronic cams

Is the mechanical engineer or the electrical engineer most responsible for understanding motion?

The cam—an irregularly shaped member on a rotating shaft that transfers motion—has been around since Leonardo da Vinci invented the cam hammer around 1497. Modern uses of the cam include the Nautilus exercise machine, which the late Arthur Jones invented around 1970. The machine uses a cam to modulate resistance. Until recently, the study of cam design and application was a foundation in mechanical-engineering curricula. Today, it seems that you can't find its study anywhere.

In mechatronics design, integration is the key as complexity moves from the mechanical domain to the electronic and computer-software domains. Cams are primary examples of that mechatronics principle as electronic cams gradually replace mechanical cams (**Figure 1**). Transfer implies that you first understand the fundamental principles in the mechanical domain, however. Mechanical engineers are no longer learning cam fundamentals, and they were never part of an electrical engineer's training, so motion systems today most often use crude motion trajectories that stress the machine and motor, produce unwanted vibrations, and result in poor performance.

Aderiano da Silva, an expert in motion control and automation-machine design for Rockwell Automation in Mequon, WI, believes that engineers don't typically understand—and therefore neglect—trajectory planning and its real-time implementation. It typically becomes a crude afterthought.

Trajectory planning is the computation of motion profiles for the actuation system of automatic machines—packaging machines, machine tools, assembly machines, and industrial robots, for example. Direct and inverse kinematic and dynamic models of the machine and its actuation system are necessary. Engineers typically specify desired motion in the operational realm, whereas motion occurs in the actuation space; these realms often differ. You usually express the trajectory as a parametric function of the time, which provides at each instant the corresponding desired position. Once you define the trajectory, implementation issues include time discretization, saturation of the actuation system, and vibrations on the load.

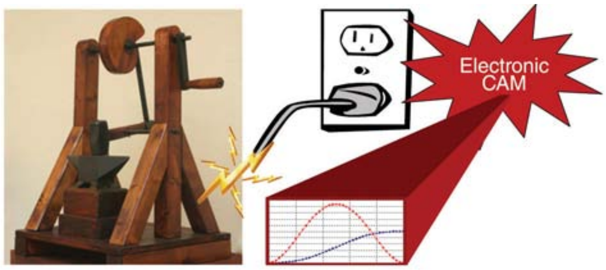


Figure 1 Electronic cams use simpler mechanisms with electric actuators, properly programmed and controlled to generate the desired motion profiles.

Kevin C Craig, PhD, is the Robert C Greenheck chair in engineering design and a professor of mechanical engineering, College of Engineering, Marquette University.

For more mechatronics news, visit mechatronics zone.com.

In past decades, mechanical cams found wide use in transferring, coordinating, and changing the type of motion from a master device to one or more slave systems. Electronic cams are replacing them, with the goal of obtaining more flexible machines, with improved performances, ease of reprogramming, and lower costs. Electronic cams directly obtain motion by means of simpler mechanisms with properly programmed and controlled electric actuators to generate the desired motion profiles, which also allows synchronization of actuators on a position or a time basis.

Once you have defined the displacement and its duration, the choice of the manner of motion from the initial to the final point has important implications with respect to the sizing of the actuators, the efforts on the structure, and the tracking error. Engineers must carefully consider the types of point-to-point trajectories that a system can employ. They must perform both time- and frequency-domain analyses on the complete system—that is, actuator, mechanism, and load, along with the motion profile—to achieve optimal performance. Input shaping and feedforward control are among the techniques engineers use to improve tracking performance.

A key reference is *Trajectory Planning for Automatic Machines and Robots* by Luigi Biagiotti and Claudio Melchiorri. Knowledge from the past combines with new technologies, resulting in innovation. Engineers must never forget this fact. **EDN**

BY MULTIPLEXING A SMALL AC SIGNAL ON THE POWER WIRES, YOU CAN INFER WIRING LOSSES.

# COMPENSATE FOR WIRING LOSSES WITH REMOTE SENSING

BY JIM WILLIAMS, JESUS ROSALES, KURK MATHEWS, AND TOM HACK • LINEAR TECHNOLOGY CORP

Wires and connectors have resistance. This simple, unavoidable truth dictates that a power source's remote load voltage is less than the source's output voltage (**Figure 1**). You could maintain the intended load voltage by raising the regulator output. Unfortunately, line resistance and load variations introduce uncertainties, thus limiting the correction accuracy. You could add a locally positioned regulator, but this approach is inefficient due to regulator losses (**Figure 2**). A classic approach uses "four-wire" remote sensing to eliminate line-drop effects (**Figure 3**). In this case, load-referred sense wires feed the power supply's sense inputs. The sense inputs' high impedance negates the sense-line-resistance effects. This scheme works well but requires dedicated sense wires, a significant disadvantage in many applications.

## "VIRTUAL" REMOTE SENSING

You can eliminate the sense loads and still retain the advantages of classic four-wire remote sensing (**Figure 4**). In this case, a Linear Technology (www.linear.com) VRS (Virtual Remote Sense) IC alternates output current between 95 and 105% of the nominal required output current (**Reference 1**). The IC forces the power supply to provide a dc current plus a small square-wave current with peak-to-peak amplitude equal to 10% of the dc current. Typical systems generally require decoupling capacitor $C_{LOAD}$ for low impedance under transient conditions. In this case, it takes on an additional role by filtering out the VRS square-wave excursions.

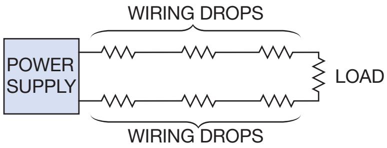


Figure 1 Wiring resistance causes output voltage to drop at the load.

### AT A GLANCE

- Wiring losses reduce the voltage at a load.
- You can add a local regulator to compensate for wiring loss, but efficiency suffers.
- By measuring the current of a small ac signal multiplexed on the output, an IC can correct for voltage drop without using sense wires.
- The technique is applicable to linear, switching, isolated, offline, and power-brick voltage regulators.

You size $C_{LOAD}$ to produce an ac short at the square-wave frequency. Thus, $V_{OUTAC}$, the square-wave voltage at the power supply, is equal to $0.1\times I_{DC}\times R_W$ p-p, where $I_{DC}$ is the square-wave current and $R_W$ is the wire's resistance. Thus, the square-wave voltage at the power supply has a peak-to-peak amplitude equal to one-tenth the dc wiring drop. This figure represents a direct measurement—not an estimate—of wiring drop and is accurate over all load currents. The IC provides signal processing that produces a dc voltage from this ac signal. The IC introduces it into the power-supply feedback loop to provide accurate load regulation (see **sidebar** "A primer on VRS operation").

The power supply can be a linear or switching regulator, a module, or any other power source capable of variable output. You can also synchronize the power supply to the sense IC's operating frequency, which is adjustable over three decades. The sense IC has optional spread-spectrum operation to improve EMI (electromagnetic interference). The IC's 3 to 50V input range allows you to use it in many designs.

This technique employs an estimate—not a direct measurement—of load voltage, so the resultant correction is only an approximation—but a good one (**Figure 5**). In this example, load current increases from 0A until it produces a 2.5V wiring drop. Load voltage drops only 73 mV at maximum current. A voltage drop equivalent to 50% of load voltage results in only a 1.5% shift in load-voltage value. Smaller wiring drops produce even better results.

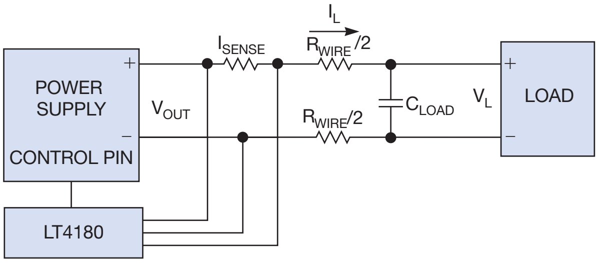
## LINEAR REGULATORS

You can use VRS with a linear regulator. The IC senses current through a 0.2Ω shunt resistor (**Figure 6**). Feedback controls $Q_1$ with $Q_2$, completing a control loop. You design $Q_2$ in cascode to the IC's open-drain output to control a high voltage at $Q_1$'s gate. Components at the IC's compensation pin furnish loop stability and provide good transient response. The design shows good response to load-step waveforms (**Figure 7**). Loop compensation, load capacitance, and the remote-sense IC's sampling rate determine the transient response (**Figure 8**).

You can also apply this technique to a monolithic regulator (see related **figure** in the Web version of this article at www.edn.com/101118df). This approach allows you to add current limiting and simplifies the loop compensation. The transient response is similar to that of the circuit in **Figure 6**. As before, the sense IC's low-voltage drain pin requires you to place a transistor in cascode to control the high voltage at the regulator's set pin.

## SWITCHING REGULATORS

You can also design VRS into switching regulators. A flyback volt-



**NOTES:** THE OUTPUT VOLTAGE EQUALS DC PLUS THE SQUARE WAVE FROM THE WIRING-VOLTAGE DROP.
THE LOAD CAPACITANCE REMOVES THE SQUARE WAVE, SO THE LOAD VOLTAGE CONTAINS ONLY DC.
THE LOAD CURRENT EQUALS DC PLUS THE SQUARE WAVE.

Figure 4 A novel VRS IC compensates for the wiring-voltage drops. It multiplexes a small ac signal over the power wires so that it can calculate the wiring impedance.

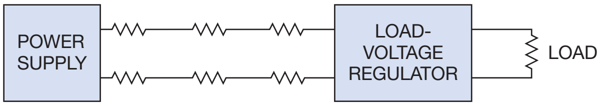


Figure 2 A local regulator solves the problem but is expensive and inefficient.

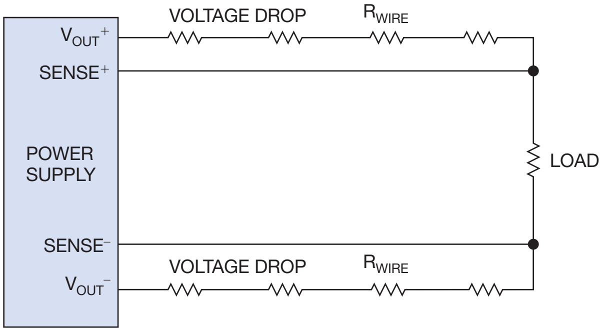


Figure 3 Sense wires can correct for the voltage drop but are complicated. Long sense wires may cause supply instability.

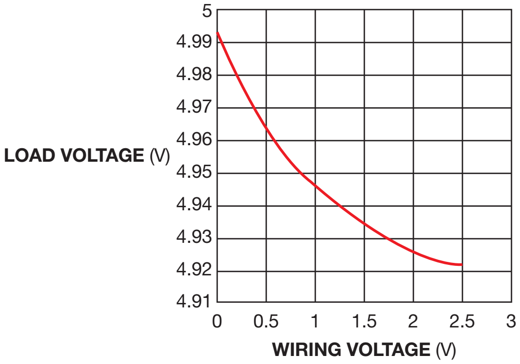


Figure 5 The IC can provide for 1.5% regulation at the load despite a 2.5V drop in the wires.

age-boost configuration has similar architecture to that of the linear examples, although the output voltage is higher than the input voltage (see related **figure** in the Web version of this article at www.edn.com/101118df). In this case, the sense IC's open-drain output is directly compatible with the boost regulator's low-voltage VC pin, so no cascode stage is necessary.

You can also design VRS into switching step-down, or buck, regulators (see related **figure** in the Web version of this article at www.edn.com/101118df). As before, you can control the VC pin of the regulator directly from the sense IC's open-drain output. You design a single-pole roll-off to stabilize the loop. The design maintains a 12V, 1.5A output from a 22 to 36V input despite a 0 to 2.5Ω wiring-drop loss.

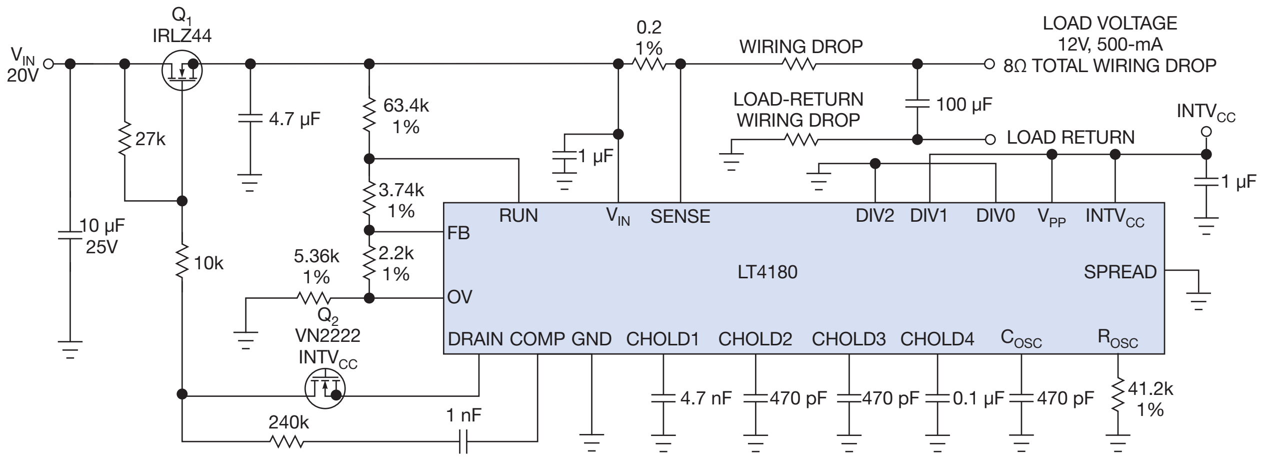
## ISOLATED SUPPLIES

You can adapt the VRS approach to isolated output supplies (see related **figure** in the Web version of this article at www.edn.com/101118df). You use an approach similar to that in the previous examples to supply a fully isolated 24V output. The VRS feature accommodates a 10Ω wire resistance. The flyback-regulator IC and $T_1$ form a transformer-coupled power stage. You use optocoupled feedback to maintain output isolation.

You can design step-down isolated converters that incorporate remote virtual sensing (see related **figure** in the Web version of this article at www.edn.com/101118df). This 48V input to the 3.3V, 3A output has a fully isolated output. The regulator IC drives $T_1$ through $Q_1$. $T_1$'s rectified and filtered secondary supplies output power, which the remote-sense IC corrects for line drops. You maintain isolation by transmitting the feedback signal with an optoisolator. The optoisolator's output collector ties back to the regulator IC's VC pin, closing the control loop.

VRS IS ADAPTABLE TO ISOLATED OUTPUT SUPPLIES AND ACCOMMODATES A 10Ω WIRE RESISTANCE.

You can also add VRS to a brick or half-brick isolated input module (**Figure 9**). You don't use the module's sense terminals. Instead, you introduce the sense IC's wiring-drop correction at the module's trim pin. The power-brick-module trim pin's transient response defines the available control bandwidth (**Figure 10a**). The trim pin's dynamics dictate your expectation for the loop response of this module (**Figure 10b**). The load-step response is less than 40 msec with this Vicor module. The module's trim-pin dynamics limit the clean and well-controlled response envelope. Turn-on dynamics into a 2.5A load are equally



**NOTE:** GUARD PINS NOT SHOWN.

Figure 6 The VRS IC can work with linear voltage regulators.

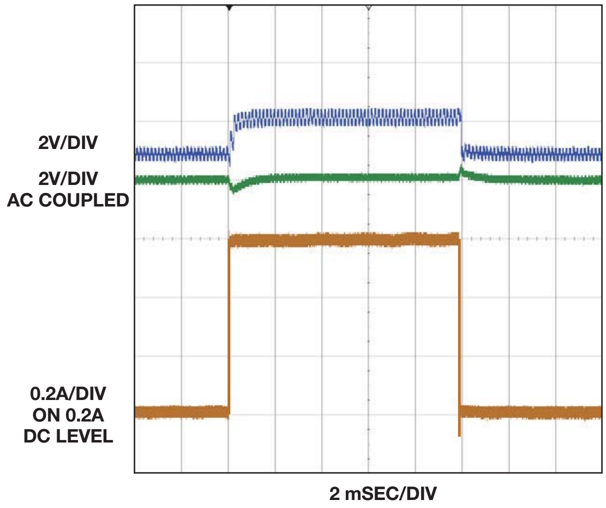


Figure 7 The voltage at the load (center trace) recovers from a load step (bottom trace) on the circuit of Figure 6. The sense-pin waveform shows the small ac excitation voltage (top trace).

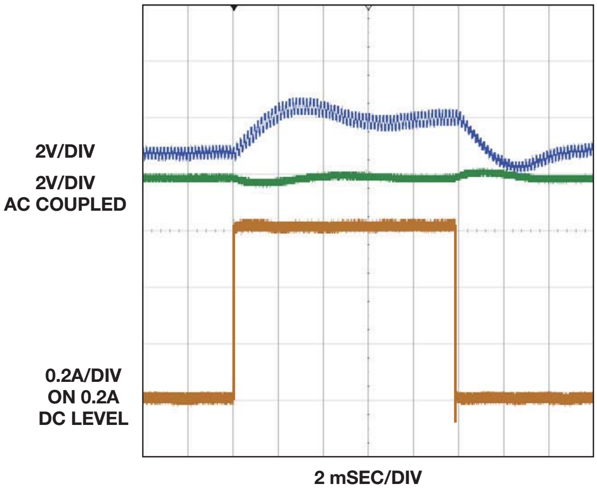
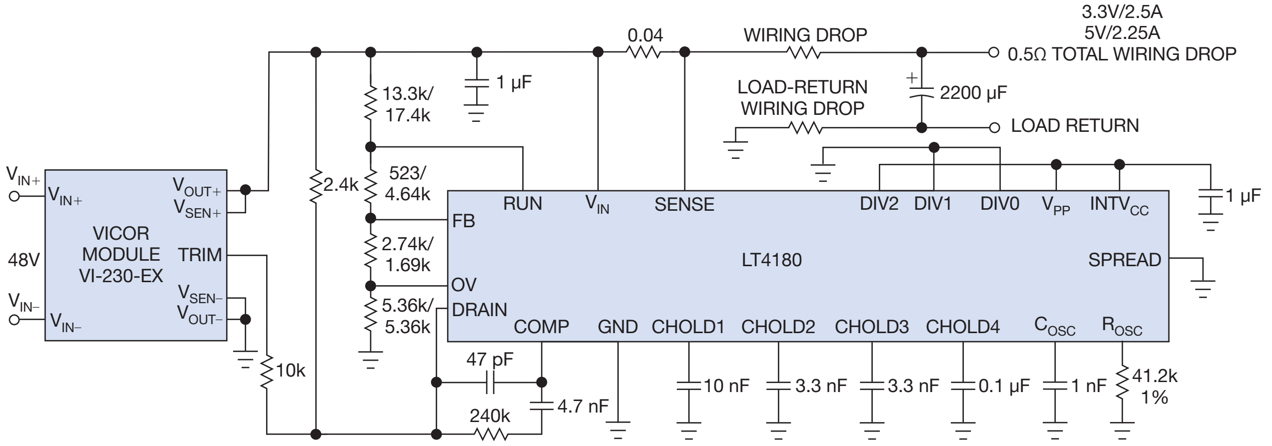


Figure 8 Increasing the load capacitance from 100 to 1000 mF improves transient response.



**NOTE:** GUARD PINS NOT SHOWN.

Figure 9 The sense IC can control the trim pin of a brick-type power module to correct for wiring losses.

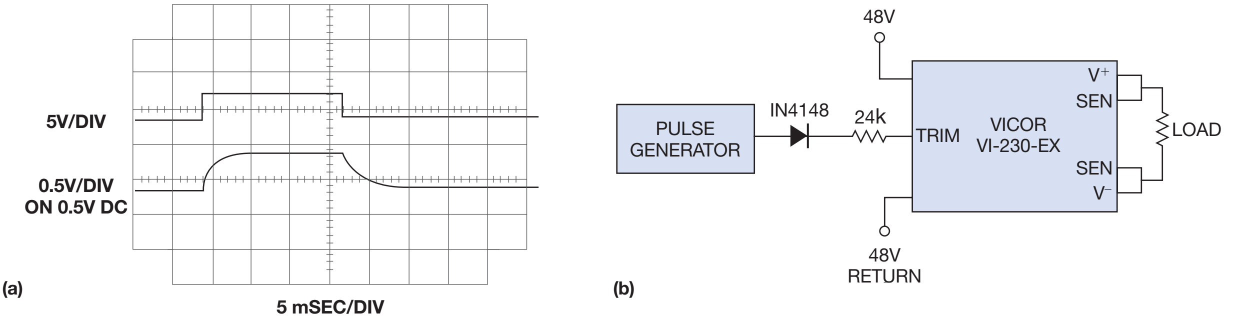


Figure 10 The power-brick-module trim pin's transient response defines the available control bandwidth (a). The trim pin's dynamics dictate your expectation for the loop response of this module (b).

well-behaved (**Figure 11**). The sense IC's operation arrests the initial abrupt rise at the third vertical division (**Figure 12**). The sense IC controls the output ascent's conclusion to the regulation point in a damped fashion. You can barely discern the sense IC's sampling square wave in the output waveform's settled portion.

You can also apply VRS to offline power supplies (see related **figure** in the Web version of this article at www.edn.com/101118df). A typical VRS-aided offline isolated output supply has a 5V output with 2A capacity. The schemat-

## A PRIMER ON VRS OPERATION

**Voltage drops in wiring can produce considerable load-regulation errors in electrical systems (Figure A). As load current, $I_L$, increases, voltage drop in the wiring increases, and the load voltage decreases. The traditional approach to solving this problem, remote sensing, regulates the voltage at the load, increasing the power-supply voltage, $V_{OUT}$, to compensate for voltage drops in the wiring. Although remote sensing works well, it requires an additional pair of wires to measure at the load, which can sometimes be impractical.**

**The LT4180 eliminates the need for a pair of remote-sense wires by creating VRS (virtual remote sensing). The IC achieves VRS by measuring the incremental change in voltage that occurs with an incremental change in current in the wiring (Figure B). You can use this measurement to infer the total dc voltage drop in the wiring, which you can then compensate for. The VRS IC takes over control of the power supply through its feedback pin, $V_{FB}$, maintaining tight regulation of load voltage $V_L$.**

**Figure C shows that a new cycle begins when the power supply and VRS close the loop around the supply voltage. Both the supply voltage and the supply current slew and settle to a new value, and the VRS stores these values. The device opens a new supply-voltage feedback loop and sets up a new feedback loop that commands the power supply to deliver 90% of the previously measured current (0.9A). The supply voltage drops to a new value as the power supply reaches a new steady state, and the VRS IC also stores this information. At this point, the device has measured and stored the change in the output voltage for a –10% change in output current. The next VRS cycle uses this voltage to compensate for voltage drops due to wiring resistance.**

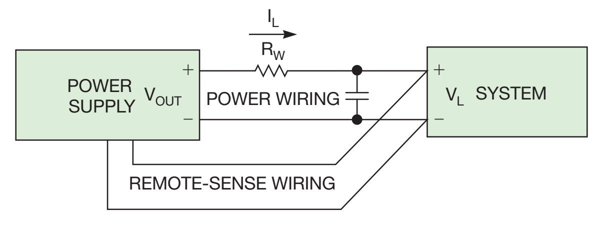


Figure A A four-wire system compensates for voltage drop but is complex.

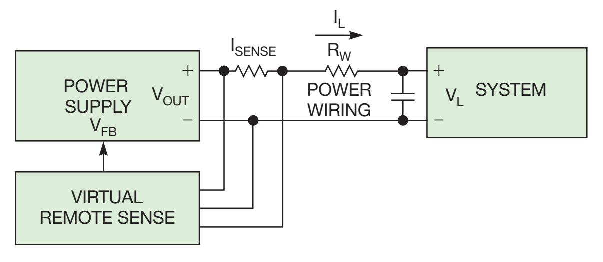


Figure B A virtual-sense scheme can eliminate the need for sensing wires.

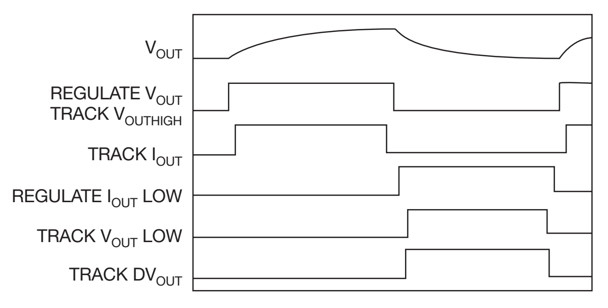


Figure C Remote-sense timing employs a state-machine sequence.

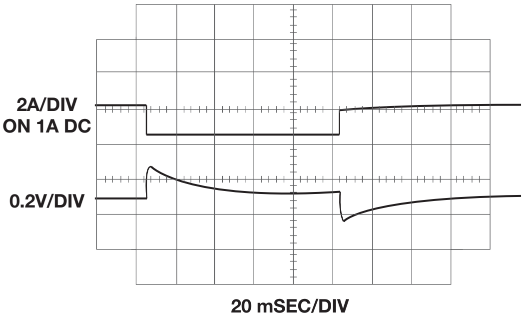


Figure 11 Applying a load step (top trace) to the circuit of Figure 9 yields a well-behaved voltage output (bottom trace).

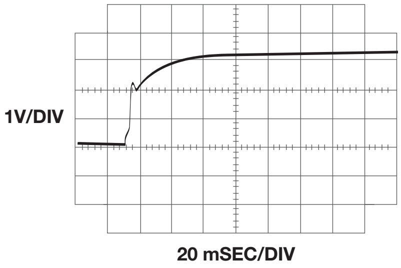


Figure 12 The sense IC also provides a slower turn-on as it begins working at the third vertical division.

ic appears complex, but inspection reveals it to be an ac-line-powered variant of an isolated approach. The sense IC provides remote sensing and closes an isolated feedback loop with optical transmission.

## LAMP CIRCUIT

You can also use a VRS IC to stabilize the drive to a halogen lamp (see related **figure** in the Web version of this article at www.edn.com/101118df). The circuit is a buck-boost SEPIC (single-ended primary-inductance converter, **Reference 2**). This 12V, 30W automotive-lamp output remains constant despite a 9 to 15V input-voltage variation along with any line resistance or connection uncertainties (see related **figure** in the Web version of this article at www.edn.com/101118df). Additional benefits include a constant color output and an extended lamp life due to greatly reduced lamp turn-on current (see related **figure** in the Web version of this article at www.edn.com/101118df). The regulator reduces inrush current to 7A, one-third of the unregulated value. **EDN**

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# HACKING THE BRAIN:

## BRAIN-TO-COMPUTER-INTERFACE HARDWARE MOVES FROM THE REALM OF RESEARCH

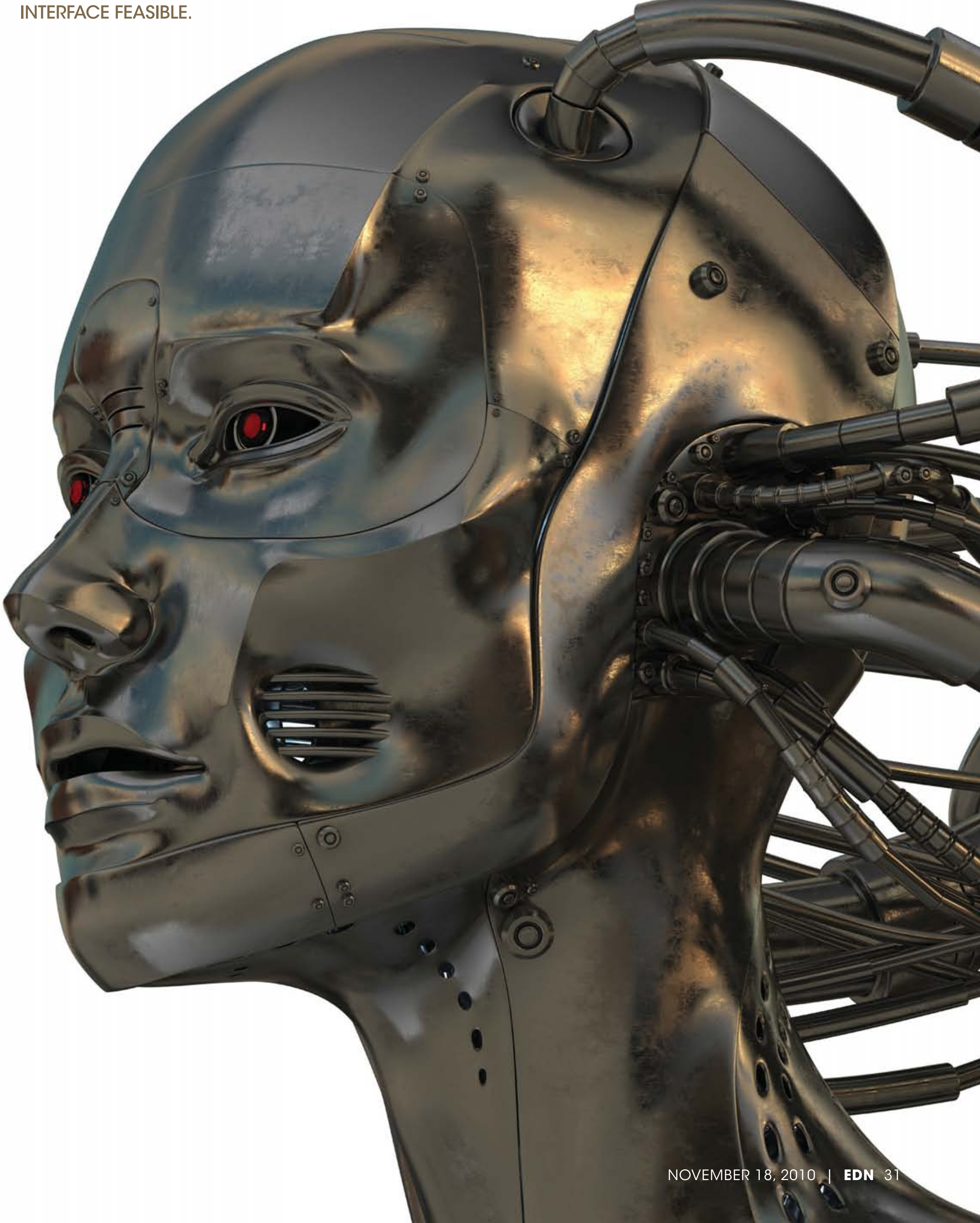
BY MARGERY CONNER • TECHNICAL EDITOR

An accurate, low-cost BCI (brain-to-computer interface) can help realize the science-fiction ideal in which there's no need to speak, gesture, or type into a keyboard to communicate with machinery: You just think—and the machine responds. BCI technology is not just the domain of sci-fi junkies: An obvious use for BCI control is in medical therapeutic equipment for paralyzed patients or for research into brain conditions, such as Parkinson's disease or epilepsy. Other possible applications include game-control interfaces and military equipment. For example, the Defense Advanced Research Projects Agency's bionic-arm project to improve the state of the art for prosthetics partially funded research into BCIs at the University of Utah. Plus, the growing use by the military of remotely piloted aircraft highlights the potential the military sees for BCI.

The brain is a 3-lb bag of fluids and neurons that communicate by firing off tiny electrical pulses. There are several ways to track these electrical signals: One requires going beneath the skull and implanting electrodes onto or into the brain itself. This approach is risky business and so far has found use only for therapeutic purposes—for example, for the study and treatment of epilepsy. Another method, ECOG (electrocorticography), dates back to the 1950s. It places electrodes directly on the exposed surface of the brain but still beneath the skull to record electrical activity from the cerebral cortex.

More recent work by researchers at the University of Utah uses silicon electrodes the size of baby aspirin that float above the brain but still under the skull. In microECOG, the device comprises an array of electrodes rather than just one (**Figure 1** and **Reference 1**). The researchers placed arrays of tiny electrodes between the skull and the brain. They found that these electrodes can accurately detect the brain's signals that control arm movements. Surgeons placed two kinds of microECOGs on the brains of severely epileptic patients. Parts of the patients' skulls had been temporarily removed for placement of the larger ECOG electrodes, which locate and treat the brain area responsible for epileptic seizures. These larger, metallic, button-like electrodes are numbered in the **figure**. **Figure 1** (left) also shows two microECOG arrays, each with 16 microelectrodes that connect to microwires

ADVANCES IN BOTH HARDWARE AND SOFTWARE ARE MAKING AN ACCURATE AND ECONOMICAL BRAIN-TO-COMPUTER INTERFACE FEASIBLE.



that pass through the orange and green tubes. Photo-editing software outlined the electrodes in the **figure**. **Figure 1** (right) shows one microECOG array with 32 microelectrodes that connects with microwires entering through a clear tube at the bottom of the **figure**. The green wires connect to the large, conventional ECOG electrodes.

ECOG and microECOG are intermediate steps between electrodes that penetrate the brain and EEG (electroencephalography), which places electrodes outside the skull on the scalp. Compared with the risky, surgical nature of ECOG, EEG is a relatively simple procedure that relies on electrodes anchored through an adhesive to the scalp. However, to reach electrodes on the scalp, the brain's electrical signals must travel through the skull. Bone conductivity is low, and signals attenuate rapidly. By the time the brain's signals make it through the surrounding membrane, skull, skin, and hair, these already-faint signals are vanishingly small. EEGs for medical purposes use electrodes that require a conductive jelly that can be messy to apply and remove. These medical-grade EEG-sensor systems can cost tens of thousands of dollars, keeping research into BCIs within the realm of academia and medical research (**Figure 2**).

However, the lucrative gaming market, in which thought control of games is a novel gimmick, and military applications are driving the interest in BCI devices, which are starting to appear at prices far below the tens of thousands of dollars you can expect to pay for medical-research-quality EEG. Recently, products such as Emotiv's Epoc and NeuroSky's Mindset have become available for approximately $150 to $300.

## AT A GLANCE

- EEG (electroencephalography) technology is the least invasive—and least accurate—of BCIs (brain-to-computer interfaces).
- As prices for EEG technology drop, expect more development of BCI for gaming and military applications.
- Hardware filtering of faint signals around the brain immediately after their capture helps ensure their quality before software filtering.

How likely is it that EEG-based headsets can contribute to robust BCI-hardware approaches? Following a BCI workshop early this year at the Massachusetts Institute of Technology, Rod Furlan, Singularity University founder, summarized his thoughts on invasive versus noninvasive BCIs (**Reference 2**). "As noninvasive interfaces are generally limited to reading brain states, it is unlikely they will be able to evolve into robust input and output solutions," he said. "Consensus among the experts in the room was that EEG is probably a dead end because, while it provides great temporal resolution, its maximum achievable spatial resolution will probably fall short of the requirements of future applications."

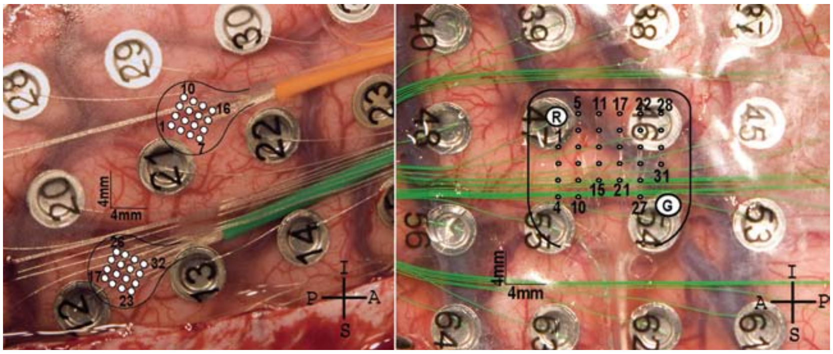


Figure 1 Researchers at the University of Utah use silicon electrodes that float above the brain but under the skull. Two microECOG arrays, each with 16 microelectrodes, connect to microwires that pass through the orange and green tubes (left). One microECOG array has 32 microelectrodes that connect with microwires entering through a clear tube (right). The green wires connect to the large, conventional ECOG electrodes (courtesy Neurosurgical Focus and University of Utah Department of Neurosurgery).

Tan Le, co-founder and president of EEG-headset maker Emotiv, explains the human brain, the limitations of EEG, and Emotiv's approach (**Reference 3**). "Our brain is made up of billions of neurons, around 170,000 km of combined axon length," she says. "When these neurons interact, the chemical reaction emits an electrical impulse, which can be measured. The majority of our functional brain is distributed over the outer surface layer of the brain. To increase the area that's available for mental capacity, the brain surface is highly folded. This folding presents a significant challenge for interpreting surface electrical impulses because everyone's cortex is folded differently. Even though a signal comes from the same functional part of the brain, by the time the structure has been folded, its physical location is very different between individuals, even identical twins.

"[Emotiv created] an algorithm that 'unfolds' the cortex [to] map the signal closer to its source and make it able to work across a mass population. EEG measurements typically involve a hair net with an array of sensors. The Emotiv headset is a 14-channel, high-fidelity EEG-acquisition system and requires no scalp prep [and] no conductive gel. It only takes a few minutes to put on and for the signals to settle. It's wireless and costs only a few hundred dollars."

Pull it out of the box, connect it to your PC, place it on your head, spend a few moments on the canned exercises that let the headset algorithms learn your brain-wave pattern, and you can begin manipulating virtual images on your PC with your brain (**Figure 3**). Pretty neat, huh?

Hacker Cody Brocious thought so, too. New to the world of BCI, Brocious was impressed by the simplicity of the Emotiv device, and he wanted to delve deeper. He asked for donations within the hacker community to buy one and quickly raised the money. He discovered the key to the encrypted data coming over the USB connection and built a decryption routine. So far, his library of code hacks to the device just pulls raw data from the unit; there's no ability to filter the signals or tell which sensor corresponds to each data stream. Brocious created Cody's Emokit project, an open-source library for reading data directly from the headset, and

Figure 2 Medical-grade EEG-sensor systems can cost tens of thousands of dollars, keeping research into BCIs within the realm of academia and medical research.

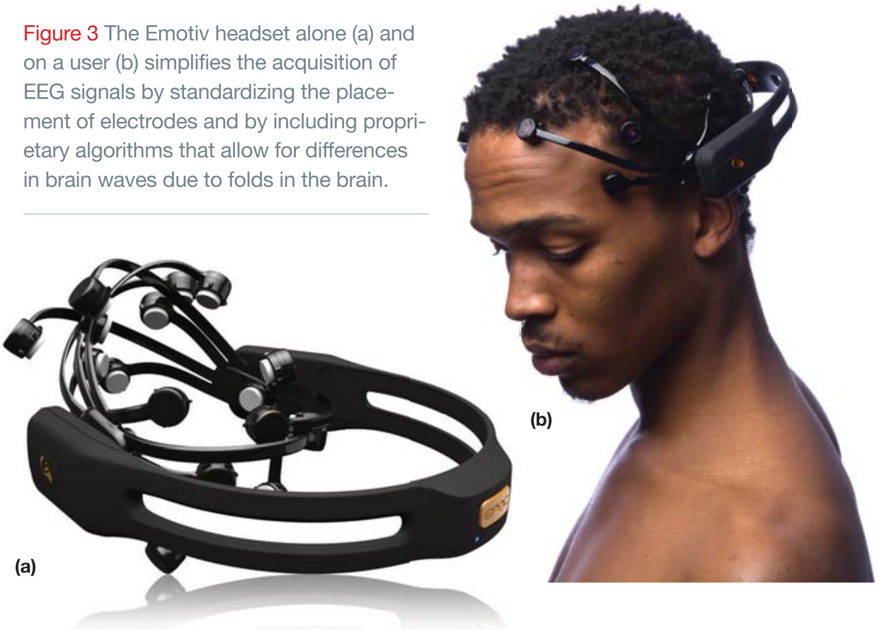


Figure 3 The Emotiv headset alone (a) and on a user (b) simplifies the acquisition of EEG signals by standardizing the placement of electrodes and by including proprietary algorithms that allow for differences in brain waves due to folds in the brain.

posted about his project on the Emotiv user forum, which the company runs (**Reference 4**).

Emotiv officials didn't like the fact that Brocious had cracked the encryption and posted his library. They claimed that doing so could force the company out of business (**Reference 5**). Emotiv sells a $700 developer's version of the headset that allows access to the data, but it is not an open environment; the company controls access. Apparently, Emotiv is working to close the encryption hole and thus end Cody's project.

## OTHER APPROACHES

Alternatives to EEG exist for measuring small signals on the surface of the head. One such technology, EOG (electrooculography), employs eye polarization. The back of the eye is more negative than the front of the eye because of the large populations of neurons on the retina. As the eye moves, the electric field surrounding the eye also moves. Electrodes on the left and right side of the face and above and below the eyes can measure these fields. An electrode behind the ear serves as a reference voltage.

Waterloo Labs comprises a group of engineers at National Instruments that builds and documents electronics projects using the company's components. Its implementation of an EOG-measurement device that controls the *Mario* video game provides a good example of the design challenges of acquiring small differential signals in a noisy environment, such as the head (**Reference 6**). A National Instruments RIO (rapid input/output) single-board computer performs the signal processing for the EOG. A custom daughterboard performs signal acquisition, amplification, filtering, and digitization (**Figure 4**).

The inputs to the EOG are the bipotential signals measured at the electrodes; these signals are smaller than those of background environmental noise, such as RF-communication signals or 60-Hz ac-mains noise. Fortunately, each electrode picks up the same noise, making the interference the common signal. Amplifying the difference between the electrodes and rejecting everything common to them yield the EOG's signal. The Waterloo Labs engineers used an Analog Devices 8221 instrumentation amplifier because of its low noise and high common-mode rejection.

Whenever metal, such as that composing an electrode, touches an electrolytic solution, such as human skin, a po-

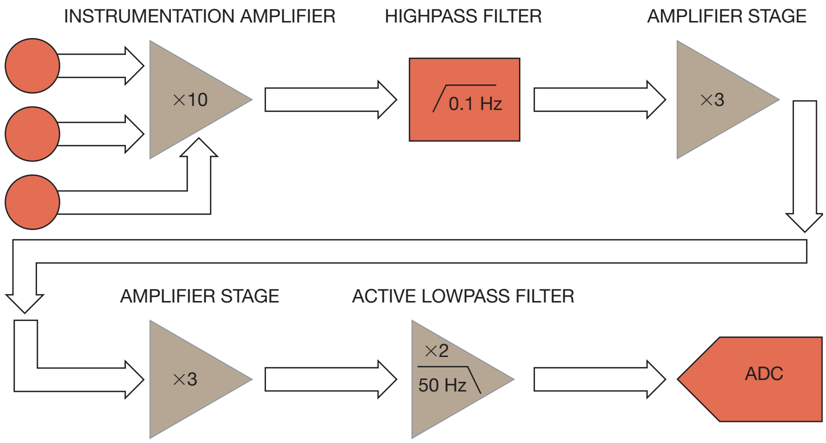


Figure 4 A National Instruments RIO single-board computer performs the signal processing for the EOG. A custom daughterboard performs signal acquisition, amplification, filtering, and digitization.

tential difference—the half-cell potential—results. The 8221 amplifies the half-cell potential along with the EOG signal. If the amplifier's gain is too high, the half-cell potential swamps the EOG's signal. The half-cell potential cannot overpower a gain of 10, which is enough to distinguish it from the noise. The circuit next uses a highpass RC filter set to 0.1 Hz to reject the half-cell voltage. Without the half-cell constant, the circuit can further amplify the signal, carefully adding no noise back in after all that work rejecting it. It uses two low-noise, high-offset amplifiers to keep the signal clean. The final stage uses a lowpass filter set to 50 Hz to remove any high-frequency noise, including 60-Hz ac-mains voltage, and then an ADC.

As for electrical isolation, the EOG receives its power from a 9V battery, so it has no dangerous voltages. However, the video-game controller, the TV display, and the RIO all use 120V wall power, so if there's a short in the transformer, the EOG user will get a 120V jolt of electricity across the face. To avoid this painful scenario, the circuit uses an isolated AD7401 ADC that magnetically couples the signal across a dielectric gap so that there is no electrical connection between the EOG and the RIO. The AD7401 can withstand 120V wall power for an indefinite amount of time and more than 3000V for as long as a minute. **EDN**

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## FOR MORE INFORMATION

**Analog Devices**
www.analog.com

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BY KEITH ODLAND • SILICON LABORATORIES INC

# Selecting the best battery for embedded-system applications

AS SYSTEMS AND THEIR CORRESPONDING POWER-MANAGEMENT STRATEGIES BECOME MORE SOPHISTICATED, SO, TOO, DOES THE TASK OF SELECTING A BATTERY THAT SUITS BOTH STATIC AND DYNAMIC REQUIREMENTS. APPROPRIATE BATTERY SELECTION INVOLVES CHEMISTRY, TEMPERATURE, PEAK DEMAND, ENERGY TRANSFER, AND ENVIRONMENTAL CONCERNS.

Nonrechargeable, or primary, batteries find wide use in mainstream embedded-system applications (**Table 1**). This category of batteries includes alkaline devices, which manufacturers typically fabricate using manganese dioxide and zinc powder with a caustic alkali of potassium hydroxide as an electrolyte. This battery technology is used in many standard applications, such as smoke detectors, personal medical equipment, portable audio devices, and high-energy flashlights. Both OEMs and consumers can easily obtain these batteries. The nominal voltage of an alkaline cell is 1.5V, with a discharge voltage of 0.9V.

Another type of primary battery, zinc-carbon, is a predecessor of and similar in composition to alkaline technology. This low-performance battery addresses cost-sensitive applications that do not require high performance, such as toys, alarm clocks, and radios. These batteries are readily available to OEMs. The nominal voltage of these cells is 1.5V, with a discharge voltage of 0.9V.

A third type of battery is lithium, which most commonly uses the designation BR or CR. BR lithium batteries come in a variety of form factors but are most commonly available as coin-cell batteries. Manufacturers typically fabricate them using a carbon monofluoride gel and a lithium alloy. This composition has good high-temperature characteristics, and the batteries usually have low self-discharge characteristics. As such, they find use in applications that require long service intervals and have relatively low power requirements. Such applications include water and gas meters, heat-cost allocators, electronic toll-collection systems, and tire-pressure-monitoring systems. These batteries are also readily available to OEMs. The cell's nominal voltage is 3V, and its discharge voltage is 2.2V.

Like BR lithium batteries, the CR type uses a lithium alloy for the anode but replaces the cathode with a manganese-dioxide material. This material reduces the internal impedance of the battery. As such, a CR cell generally better suits supplying higher pulse currents than its BR counterpart at the expense of a slightly higher self-discharge rate and lower performance at high temperatures. Applications include remote keyless entry, RFID (radio-frequency identification), and watches. Both OEMs and consumers can easily obtain these batteries. Their nominal voltage is 3V, and discharge voltage is 2.2V.

Lithium-thionyl-chloride batteries are relatively new and have extremely low self-discharge rates, enabling battery life of approximately 20 years. They also benefit from a flat discharge

TABLE 1 COMMON BATTERY TYPES

| Battery | Anode (–) | Cathode (+) | Nominal voltage (V) | Approximate energy density (MJ/kg) | Special characteristics |
|---|---|---|---|---|---|
| Alkaline | Zinc | Manganese dioxide | 1.5 | 0.5 | Long shelf life, supports high- to medium-drain applications |
| Zinc-carbon | Zinc | Manganese dioxide | 1.5 | 0.13 | Economical in cost per hour for low current consumption |
| Lithium (BR) | Lithium | Carbon monofluoride | 3 | 1.3 | Wide temperature operation, high internal impedance, low pulse current |
| Lithium (CR) | Lithium | Manganese dioxide | 3 | 1 | Good pulse capability, stable voltage during discharge |
| Lithium-thionyl chloride | Lithium | Sulfur-oxygen chlorine | 3.6 | 1.04 | Low self-discharge rate, can support 20-year battery |
| Zinc-air | Zinc | Oxygen | 1.4 | 1.69 | High energy density, battery life of weeks to months |

profile over time so that the terminal voltage stays relatively constant over the entire service life. Manufacturers of these batteries typically fabricate them using a solution of lithium tetrachloroaluminate in thionyl chloride as the liquid cathode, with a zinc alloy as the anode. This technology is more costly than other lithium chemistries and finds use in applications demanding extremely long battery life, such as water and gas meters and other industrial- and military-electronic applications. These batteries are uncommon in consumer applications and are available to OEMs through a select set of suppliers. The cells have nominal voltages of 3.6V and discharge voltages of 2.2V.

Zinc-air batteries provide a much higher energy density than the previously noted types. They receive their power by oxidizing zinc with oxygen from the air with the help of a hydroxide-based solution. Consumers are most familiar with this type of battery for hearing aids and camera batteries; however, much larger versions of this type find use in marine- and railroad-navigation applications. These batteries have a shelf life of multiple years. Once they are in service, however, they last on the order of hundreds of hours in consumer applications. Both OEMs and consumers can easily obtain them. These batteries have nominal voltages of 1.4V and discharge voltages of 0.9V.

## BATTERY SUITABILITY

Engineers assess a number of parameters when evaluating the suitability of a battery type for an application. Some of the most common factors they use in this analysis include nominal voltage, energy capacity, energy density, self-discharge capabilities, and dynamic considerations. The nominal voltage is the voltage as measured across the battery's positive and negative terminals. Engineers often partition multiple batteries in series or in parallel to provide a more desirable cell voltage or current supply to the application.

Energy capacity is the stored energetic content of the battery. The SI (Système International d'unités) unit for energy is joules, but most battery manufacturers specify it in milliamp hours. Because the total energy in a battery is a function of both the amount of current that the battery can source and the terminal voltage, using joules is a more consistent way of comparing batteries with different chemistries. You can easily convert a battery capacity from milliamp hours to joules with the following **equation**: $E=C\times V_T\times 3.6$, where E is the energy in joules, C is the capacity in milliamp hours, and $V_T$ is the terminal voltage.

Battery chemistries rely on electrochemical reactions to provide electrical energy. Some of these reactions are more potent than others, which can lead to the development of small batteries with the same energy content as some larger counterparts. This size-to-energy ratio is the energy density. As a general rule, the higher the energy density, the more costly the battery technology is. Designers constantly struggle to find the optimum balance of cost and energy density.

Batteries do not last forever. Even if they sit unused on a shelf, electrochemical reactions are still taking place, slowly diminishing the batteries' energy content. This naturally occurring process is the self-discharge rate. Alkaline batteries generally have a service life of seven to 10 years. Lithium BR and CR batteries have a service life of 10 to 15 years, and lithium-thionyl-chloride cells can last more than 20 years. Self-discharge rates and other deteriorative mechanisms affecting battery life can highly depend on temperature and duty-cycle characteristics. Fluctuating duty-cycle requirements often can have an adverse effect on the ultimate discharge characteristic of a battery.

Dynamic physical parameters also affect battery performance. Variations in temperature, output impedance, duty cycle, and energy delivery affect battery-loading conditions and ultimately shape the battery-selection process. Some of these variations are first-order effects, and you must give them appropriate consideration.

Many systems have high dynamic bandwidth with respect to power demand. For example, a wireless sensing system in an advanced-metering-infrastructure-class gas or water meter can have dormant power consumption on the order of microwatts and an active peak consumption of watts. In other words, dynamic-system-power-demand bandwidth can be microwatts during low-duty-cycle sleep mode and watts

## TABLE 2 GLASS-BREAKAGE-SENSOR OPERATING STATES

| | Frequency | Description |
|---|---|---|
| Measurement | Event-driven | Piezoelectric shock sensor interfaced to system I/O; upon breakage event, the system wakes up |
| Transmit | Once per minute | Transmits sensor and battery status back to the control panel |
| Receive | Once per minute | Receives acknowledgment from panel |
| Sleep | All other times | Maintains low-power sleep mode, real-time clock, and I/O function |

during active and high-duty-cycle radio-transmit mode. This situation creates additional power-delivery requirements that the battery must accommodate alone or with another energy-storage device. To solve this problem, engineers often place a capacitor in parallel with the battery to provide peak energy demand. In these cases, they must also consider the additional design issues of the capacitor's cost, size, charging scheme, and leakage.

In addition to the noted considerations, engineers must pay attention to battery-discharge profiles, which can vary greatly depending on the battery chemistry and the power-demand profile both peak load and duty cycle. Environmental considerations, especially temperature, can affect battery performance. System-level considerations, such as battery-replacement interval and system-voltage requirements, also influence battery selection. Environmental considerations, such as recycling, toxic materials, heavy metals, safety, and shipping regulations, are of concern, as well.

## MEETING REQUIREMENTS

As with most other engineering problems, designers must weigh a set of sometimes-conflicting requirements to develop the best approach to meeting system specifications. To illustrate this point, consider an exaggerated example. Law-enforcement personnel sometimes use stun guns, which are high-voltage, nonlethal electronic-control weapons, to incapacitate combative subjects who pose a risk to a police officer, an innocent citizen, or themselves. These devices deliver thousands of volts to the assailant's body, temporarily disrupting the nervous system and rendering the individual unconscious. The system uses a transformer, among other techniques, to step up the battery voltage thousands of times higher than its original terminal voltage.

Instead of using a transformer, a device designer could choose to achieve the design objective by arranging 30,000 AAA alkaline batteries in series. This design would also be able to deliver a 45,000V shock to the assailant, along with other obvious practical limitations of using an approximately 0.8-mile-long (1.33-km-long), 792-lb (360-kg) stun gun—not to mention the 50-kV thumb switch!

Although an exaggeration, this example highlights the fact that, by using modern electronics, you can overcome some of the natural limitations of the battery's electrical chemistry and use them in different ways. As another example, zinc-air batteries have long found use in hearing aids because of their energy density of 1.69 MJ/kg and ability to deliver high peak currents. The batteries typically have a service life of less than three months due to the time it takes the electrolytic reaction to reach its conclusion. However, this service lifetime is acceptable for the application, and the batteries come in "calendar" packs so that the user has a new replacement battery for each month.

Another aspect of this battery chemistry is that the terminal voltage of a single cell is typically 1.4V. Specialized low-voltage circuits for hearing aids address this limitation, but the battery voltage does not translate easily into mainstream embedded-system electronics. You would need to make additional provisions to make a nominal 1.4V cell useful for standard CMOS embedded electronics.

Fortunately, more devices are integrating advanced power-management units to address these challenges. For example, a chip with an integrated dc/dc boost converter could boost the 1.4V input voltage of a zinc-air battery or the 1.5V input of a common alkaline battery to an appropriate value for the system.

More important, a dynamically programmable boost converter could change the output voltage depending on the needs of the system so that the energy from the battery to the system always operates efficiently. This operation would enable system engineers to optimize the power-supply efficiency for the use case during runtime.

For example, a bidirectional wireless sensor node for a home-security application could be a glass-breakage sensor with a bidirectional communication link comprising a transmitter and a receiver. This sensor monitors the condition of a window and periodically reports the status of the window and the battery to the main control panel. The communication between the sensor and the control panel uses a transmitter/receiver/acknowledgment protocol, which reduces the number of redundant messages the sensor sends to the panel. Most of the time, the sensor is in a low-power mode to maximize battery life. **Table 2** defines the states the glass-breakage sensor can occupy.

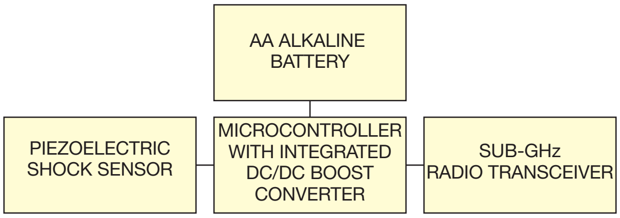

Figure 1 A glass-breakage-detection system comprises a microcontroller with an integrated dc/dc converter, a sub-1-GHz radio transceiver, a piezoelectric shock sensor, and an alkaline battery.

The system comprises a microcontroller with an integrated dc/dc converter, a sub-1-GHz radio transceiver, a piezoelectric shock sensor, and an alkaline battery (**Figure 1**). You can make four assumptions about the system: First, the piezoelectric sensor is self-powered

### TABLE 3 ENERGY REQUIREMENTS USING LITHIUM BATTERY, FIXED VOLTAGE REGULATION

| Mode | Frequency | Duration | Current (I) | Voltage (V) | Switching loss (%) | Energy (J) |
|---|---|---|---|---|---|---|
| Sleep | 60 | $954.9\times10^{-3}$ | $600\times10^{-9}$ | 3 | 0 | $103.1\times10^{-6}$ |
| Processing | 1 | $100\times10^{-6}$ | $4\times10^{-3}$ | 3 | 0 | $1.2\times10^{-6}$ |
| Transmit | 1 | $15\times10^{-3}$ | $27\times10^{-3}$ | 3 | 0 | $1.2\times10^{-3}$ |
| Receive | 1 | $30\times10^{-3}$ | $18\times10^{-3}$ | 3 | 0 | $1.6\times10^{-3}$ |

### TABLE 4 ENERGY REQUIREMENTS USING ALKALINE BATTERY, DYNAMIC VOLTAGE REGULATION

| Mode | Frequency | Duration | Current (I) | Voltage (V) | Switching loss (%) | Energy (J) |
|---|---|---|---|---|---|---|
| Sleep | 60 | $954.9\times10^{-3}$ | $600\times10^{-9}$ | 1.5 | 0 | $51.6\times10^{-6}$ |
| Processing | 1 | $100\times10^{-6}$ | $4\times10^{-3}$ | 1.8 | 10 | $800\times10^{-9}$ |
| Transmit | 1 | $15\times10^{-3}$ | $27\times10^{-3}$ | 3 | 10 | $1.4\times10^{-3}$ |
| Receive | 1 | $30\times10^{-3}$ | $18\times10^{-3}$ | 1.8 | 10 | $1.1\times10^{-3}$ |

and generates a 3V pulse if the glass breaks. This signal triggers an external interrupt that "wakes up" the microcontroller. Second, the microcontroller core is regulated to 1.8V by an internal regulator. The RAM, power-management unit, and real-time clock can operate at voltages as low as 0.9V so that the microcontroller can operate from one AAA alkaline battery. Third, the power amplifier in the transceiver's transmitter block provides higher output power and higher efficiency when its voltage rail approaches the maximum-rated power rail. Finally, an internal 1.8V regulator regulates the low-noise amplifier, receiver chain, PLL (phase-locked loop), and synthesizer in the radio. The minimum operating voltage is 1.8V.

If you look carefully at the system assumptions, it becomes clear that dynamically adjusting the battery voltage optimizes power efficiency and performance. For example, you can obtain maximum transmitting-power efficiency when the transceiver is operating at 3V. The alkaline battery has only a 1.5V nominal terminal voltage, so you can achieve 3V operation with the integrated dc/dc boost converter, yielding approximately 90% efficiency. However, internal regulation limits the receiver chain to 1.8V. Supplying 3V during the receiver transaction would cause the internal low-dropout regulator to reduce efficiency to 60%. It would be better to dynamically adjust the output of the dc/dc converter from 3 to 1.8V and increase the efficiency during the sensor's receiving transaction.

Compare the system using a lithium coin-cell battery with a fixed-voltage rail with an alkaline battery using the dynamic-switching technique. The switching loss is 0% using the coin cell because the switch-mode supply is not in use and the terminal voltage is 3V. You also may not need to increase the size of the coin cell to meet the peak current demand because this resizing would require the use of a large, expensive coin cell. In the alkaline-battery case, you can assume a 10% switching loss.

**Tables 3** and **4** detail the energy each element of the wireless-sensor application requires. The sleep duration is 1 second minus the sum of all of the other transactions. The processing, receiving, and transmitting functions occur once per minute. **Table 3** shows the requirements for a 3V, 620-mAhr-rated, approximately 62-cent CR2450 lithium battery, and **Table 4** shows the requirements for a 1.5V, 1125-mAhr-rated, approximately 25-cent AAA alkaline battery.

With this usage profile, the CR2450 battery would last approximately 4.33 years. With the same usage profile, the AAA alkaline battery would last approximately 4.65 years. This duration represents 16% higher efficiency, resulting in a 7% increase in service life with a 60% decrease in battery cost. This comparison demonstrates the gains you can make by using more modern dynamic techniques of energy conversion. These gains highly depend on the duty cycle of the functions that derive the greatest benefit from the high-efficiency power supply. As the receiver-mode duration or duty cycle increases, so do the benefits of using the alkaline-battery approach with the switched-mode supply. The dc/dc converter's output could be 3.3V—that is, 0.3V higher than that of the lithium battery—and could provide greater output power and enhanced range.

Given the growing sophistication of battery technologies and chip-level power-management techniques, the industry has come a long way since Alessandro Volta discovered the voltaic pile in 1800 (**Reference 1**). More than 200 years' worth of technological evolution and innovations in the fields of chemistry, electrical engineering, and manufacturing have resulted in batteries thousands of times more sophisticated in design and function than when Volta invented the original versions. Today's system designers now have many more options when selecting the appropriate battery to support their next embedded-system designs. **EDN**

## REFERENCE

1 "Voltaic pile," Wikipedia, http://en.wikipedia.org/wiki/Voltaic_pile.

## AUTHOR'S BIOGRAPHY

*Keith Odland is a product manager for Silicon Laboratories' microcontroller products. Before joining Silicon Labs, he was a technical-solutions manager for Future Electronics, where he developed and deployed marketing and business-development programs for 8- and 16-bit microcontrollers. He also co-founded Technology Kitchen, where he developed a specialty instrument for the general aviation industry, which an established aircraft-instrumentation maker adopted. Odland has a bachelor's degree in electrical engineering from the University of Texas—Austin.*

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# designideas

READERS SOLVE DESIGN PROBLEMS

## CMOS circuit latches relays

JC Maillet, Gabriola Island, BC, Canada

Control applications often require that you set a relay latch in position until you need it to change state. Latching relays accomplish that task. When you send them a pulse, they either remain in the current state or change states, depending on the polarity of the pulse and the current state of the relay. The circuit in **Figure 1** switches the state of a DPDT (double-pole/double-throw) latching relay based on a pulse. It comprises a momentary-switch-to-step-voltage-signal generator, a differential-pulse converter, a relay driver, and a relay coil.

A momentary switch produces a step-voltage signal that drives the circuit. The circuit uses a simple pulldown switching action (push-on/release-off), such as the one comprising $R_S$, $C_S$, and $S_2$, or a flip-flop latching action (push-on/push-off), such as the one comprising $IC_{1A}$, $IC_{1B}$, $R_1$, $R_2$, $C_1$, and $S_1$. In the simple pulldown case, you can also add a debounce circuit. The pushbutton switches let you test the circuit before connecting it to another input source.

The differential-pulse converter comprises $IC_{1C}$, $IC_{1D}$, $IC_{1E}$, and $IC_{1F}$. The last two stages of the CD4069 hex inverter are self-biased in linear mode around $V_{DD}/2$, where $V_{DD}$ is the drain-to-drain voltage and corresponds to Pin 14 of $IC_1$. The circuit takes a rise or a fall at $IC_{1C}$ and converts it to opposing pulses of equal length at the outputs of $IC_{1E}$ and $IC_{1F}$. The order of the pulses is synchronous with the edge direction at the input of $IC_{1C}$.

The output-driver stage buffers the voltage outputs of $IC_{1E}$ and $IC_{1F}$ to drive the relay coil. The op amps provide differential current dumping through the load without incurring substantial waste in idle mode. An LED-indicator circuit comprising $R_4$ and $D_1$ shows the orientation of the relay switch.

Assuming that the circuit powers up with $C_1$ uncharged, $IC_{1A}$ and $IC_{1B}$ always start off in a state in which $R_1$ sees $V_{DD}$ on both sides. All inverter stages operate in digital mode except for $IC_{1E}$ and $IC_{1F}$.

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When you apply power to the circuit, these two stages self-bias around $V_{DD}/2$ and operate in linear mode. The op amps, wired as followers, also bias their outputs near $V_{DD}/2$. That action leaves the relay coil with a negligible offset/error voltage thanks to the matching of the devices in the hex-inverter IC and the op amps' high open-loop gain.

Stages $IC_{1E}$ and $IC_{1F}$ ac-couple through capacitors $C_5$ and $C_3$, respectively. The capacitors produce an impulse at the in-

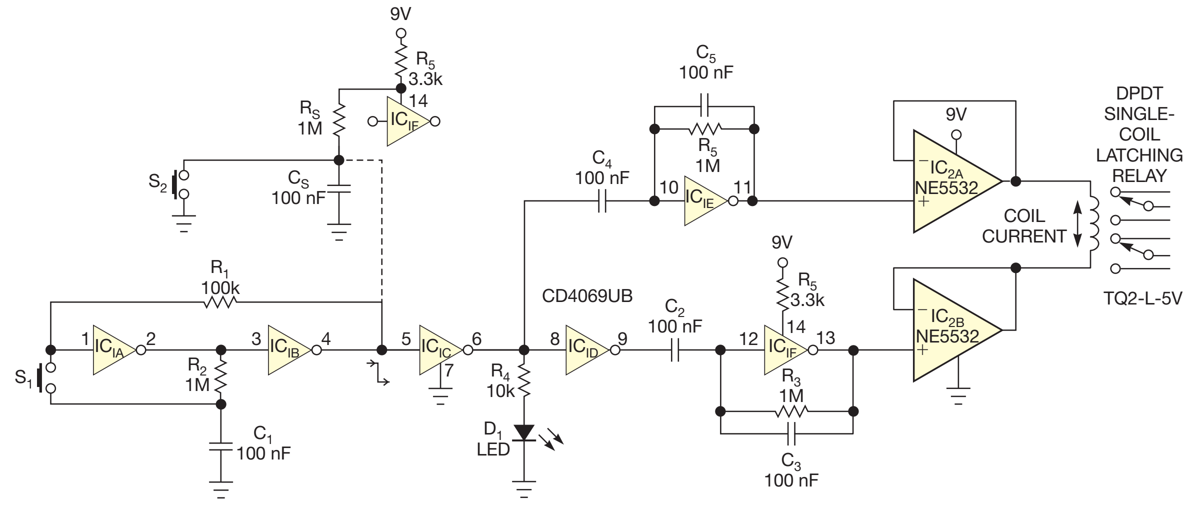

Figure 1 A change in state at the input of inverter $IC_{1C}$ can drive a latching relay to change state.

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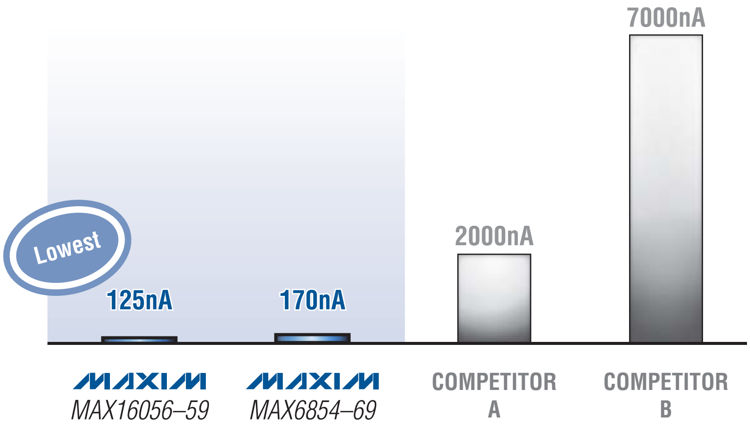

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|---|---|---|---|
| MAX16056 | ✓ | Push-pull | 8-TDFN |
| MAX16057 | — |  | 6-TDFN |
| MAX16058 | ✓ | Open drain | 8-TDFN |
| MAX16059 | — |  | 6-TDFN |

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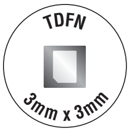

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puts of $IC_{1E}$ and $IC_{1F}$ from the step outputs of $IC_{1C}$ and $IC_{1D}$. Lossy integrators $IC_{1E}$ and $IC_{1F}$ lengthen the inverted pulses at the outputs. Following these events, the outputs of $IC_{1E}$ and $IC_{1F}$ gradually return to their equilibrium state, which helps prevent a bucking field from forming in the relay coil and toggling back. **Figure 2** shows the shape and timing of the pulses.

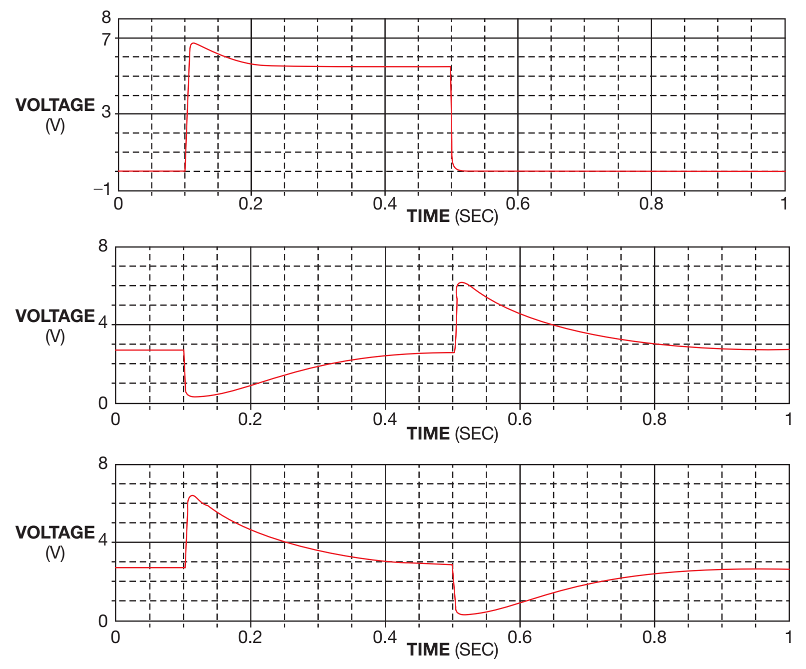

Figure 2 Integrating impulses with capacitors across inverters produces the signals necessary to set the state of the relay.

$R_3/C_3$ and $R_4/C_4$ establish time constants, which roughly set the total length of these pulse tails at 500 msec. This time is more than enough to satisfy the relay coil's hold requirements, which, for the Panasonic TQ2-L-5V, are 3 msec or less. If the relay coil at first finds itself in an asynchronous position, it can reorient itself after a single push of the switch if necessary.

Dropping $IC_1$'s $V_{DD}$ through series-supply resistor $R_5$ limits the idling currents in linear-biased stages $IC_{1E}$ and $IC_{1F}$. This resistor represents a compromise between the power these two stages dissipate and the available voltage swing to toggle the relay through the op amps.

The circuit operates from a 9V source, and, with the component values in **Figure 1**, $IC_1$'s $V_{DD}$ lies at approximately 5.5V. The overall current draw between toggles is approximately 8 mA.**EDN**

# Power USB devices from a vehicle

Fons Janssen, Maxim Integrated Products Inc, Bilthoven, the Netherlands

Automotive accessories such as PNDs (portable navigation devices) usually receive their power or charge using a simple adapter that a user plugs into a cigarette lighter. Sometimes, however, you may want to power or charge two devices at once. The circuit in **Figure 1** can handle that task.

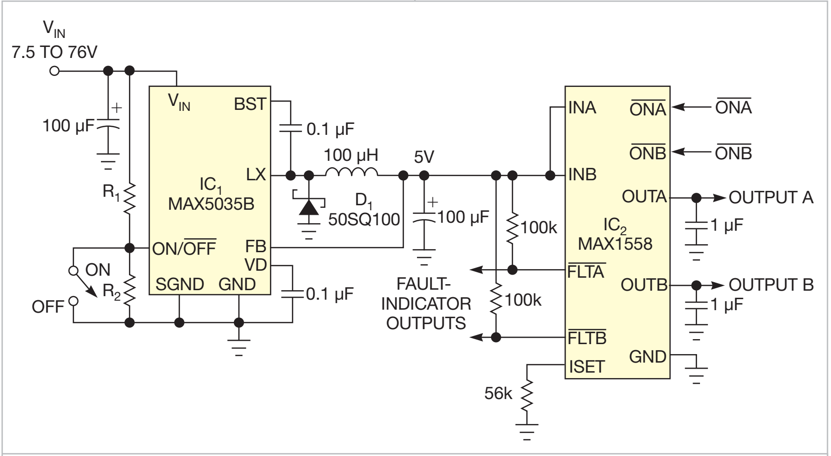

Figure 1 An automotive USB power supply generates two regulated, supply-voltage outputs from an unregulated input.

$IC_1$ generates 5V from any 7.5 to 76V input—a wide enough range to include the complete range of car-battery voltage plus the 40V spike that can occur during a load dump. The IC is simple to use because it has an internal power switch and requires no compensation circuit.

$IC_2$ distributes to two outputs the 5V that $IC_1$ generates. It not only distributes power but also protects against overload conditions. Most portable equipment receives its power or charge through a USB (Universal Serial Bus) interface, whose current limit is 500 mA. Because $IC_2$ targets use in USB applications, it latches off any port that tries to deliver more than 500 mA but does not affect the other port. Automatic-restart capability ensures that the port recovers automatically after the removal of the overload condition.

**Figure 2** shows the protection feature in action. Output B has a constant load of 300 mA, and Output A switches between a 100-mA load and a 600-mA overload. $IC_2$ switches off Output A after an overload but allows a 20-msec delay to avoid responding to brief tran-

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| Part | Features | Maxim Package Area (mm²) | Closest Competition Package Area (mm²) | Maxim Current Consumption (mA) | Closest Competition Current (mA) | Maxim Tx Power (dBm, max) | Closet Competition Tx Power (dBm, max) |
|---|---|---|---|---|---|---|---|
| MAX1472 | ASK | 9 | 32 | 9.1 | 14 | 10 | 10 |
| MAX7044 | ASK, clock output | 9 | 32 | 13.8 | 14 | 13 | 10 |
| MAX7057/ MAX7058 | Frac-N programmable frequency ASK/FSK, dual-frequency ASK | 60 | 50 | 8.5mA ASK,<br>13mA FSK | 17 | 10 | 10 |

## 300MHz to 450MHz Transceivers

| Part | Features | Maxim Package Area (mm²) | Closest Competition Package Area (mm²) | Maxim Current Consumption (mA) | Closest Competition Current (mA) | Maxim Tx Power (dBm, max) | Closest Competition Tx Power (dBm, max) |
|---|---|---|---|---|---|---|---|
| MAX7030/MAX7031/ MAX7032 | 315/345/433.92MHz ASK,<br>308/315/433.92MHz FSK | 25 | 49 | 8.5 to 12.5 | 16 | 10 | 10 |

## 300MHz to 450MHz Receivers

| Part | Features | Maxim Sensitivity (dBm) | Closest Competitor Sensitivity (dBm) | Maxim Current Consumption (mA) | Closest Competitor Current Consumption (mA) |
|---|---|---|---|---|---|
| MAX1473/MAX7033 | ASK, 3.3V/5V, AGC, AGC hold (MAX7033) | -114/-114 | -113 | 5.5 at 3V | 5.0 at 5V |
| MAX1471 | ASK/FSK, polling timer | -114 ASK, -108 FSK | -113 ASK, -105 FSK | 7.0 at 2.4V | 5.7 at 5V |
| MAX7042 | FSK, 3.3V/5V | -110 FSK | -97 FSK | 7.0 at 2.4V | 9.0 at 2.7V |

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sients (**Figure 2a**). The circuit removes the overload 80 msec later; after another 20-msec delay, the automatic-restart feature brings Output A back online. Output B is unaware of the problem in Output A (**Figure 2b**). The fault-indicator output, however, goes low to indicate a problem in Channel A.

This circuit is small because it requires few external components. You can build it into a cigarette-lighter plug or place it in a small space behind the dashboard. **EDN**

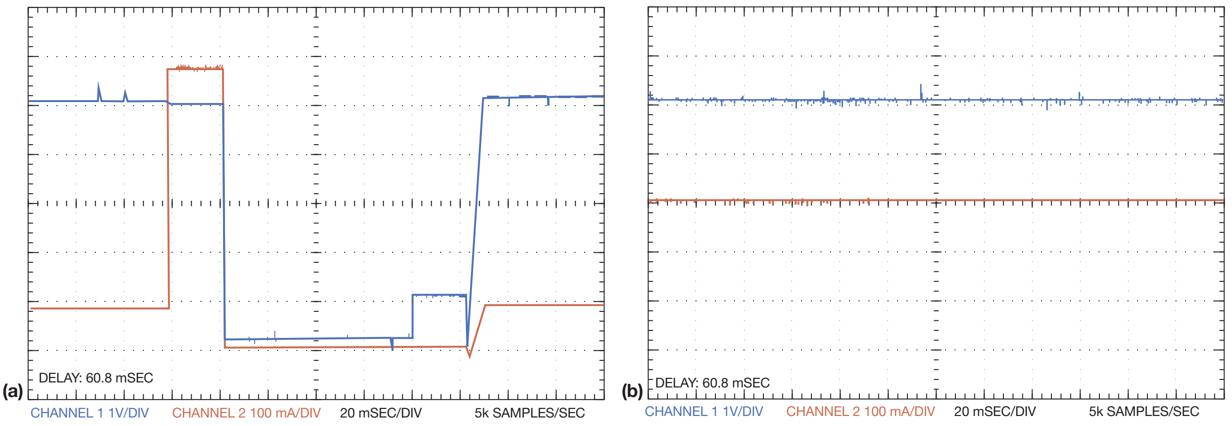

Figure 2 These current/voltage waveforms from Figure 1 show that an overload on Output A (a) has no effect on Output B (b).

# Microcontroller interfaces to 24V

Adolfo Mondragon, Electrolux Products, Juarez, Mexico

Industrial-control applications often use PLCs (programmable-logic controllers) working at logic levels of 24V. That voltage creates a challenge to the safe use of a microcontroller. Such a design requires a physical barrier between the microcontroller and the 24V signals to avoid damage in case of errors or short circuits.

A simple and inexpensive way to switch 24V with a microcontroller is to use the ULN2003 or ULN2803 transistor drivers, which have seven and eight outputs, respectively. These ICs can energize light bulbs or solenoid valves at 500 mA. Damper diodes in these ICs eliminate the need for numerous passive components, especially in designs using coils.

Because of their digital inputs, passive components require numerous parts, complicating assembly, increasing cost, and increasing the need for troubleshooting and maintenance. Few simple ICs can handle more than 24V.

With this voltage in mind, you can use an interface IC, such as the MC1489 or the SN75189 inverter, as an RS-232 line receiver. These ICs can receive digital signals as large as ±30V. As a bonus, they have some hysteresis-level transition, making them able to discriminate some of the electrical noise in signals (**Figure 1**).

You can connect these devices directly to a microcontroller. If you mount them in DIP sockets, you can easily replace

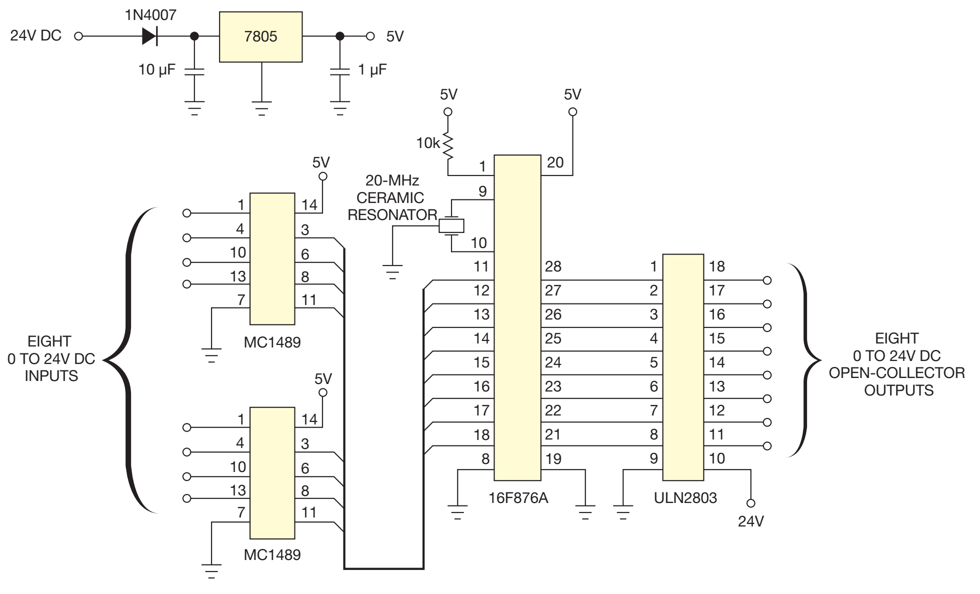

Figure 1 RS-232-interface ICs, such as the MC1489, can adapt 24V inputs to a microcontroller.

them in case of damage. The circuit uses a 78L05 linear regulator to decrease the power-supply voltage to 5V. The 1N4007 between the 24V dc and the 5V LM7805 regulator protects the circuit from possible power-supply wire reversal. You must take that fact into account in programming your microcontroller because the signals complement the input.EDN

# Use LEDs as photodiodes

Raju R Baddi, Raman Research Institute, Bangalore, India

The simple circuit in **Figure 1**, which can be powered with a 3.6V nickel-cadmium rechargeable battery, lets you use an LED to detect light. The circuit consumes practically no quiescent power. Two LEDs act as photodiodes to detect and respond to ambient light. When ambient light is present, the upper LED, a small, red, transparent device covered with a black pipe, has a higher effective resistance than the lower, large, green LED. The voltage drop across the input of the NAND gate is less than its threshold voltage for logic 1, making the output of the NAND gate low. When the ambient light goes off, the voltage drop across the reverse-biased green LED increases, forcing the NAND gate's output high.

This type of light detector is highly power-efficient and is ideal for battery applications. You can use the NAND gate's logic output to drive an LED driver or a relay driver, or you can connect it to a microcontroller.

Place the circuit so that sufficient light falls on the green sensor LED. Doing so avoids any voltage build-up near the junction that could be close to the NAND gate's threshold voltage. The NAND gate's power consumption rises sharply at the threshold voltage. When the gate's input voltage is within the defined limits for the logic state, its power consumption is extremely small.EDN

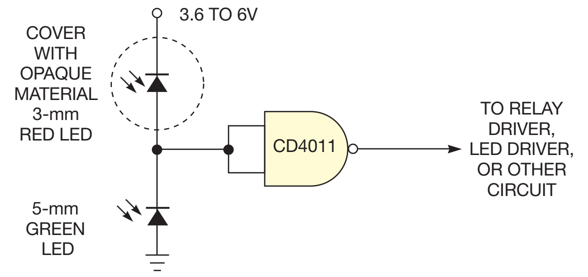

Figure 1 An LED's resistance changes with ambient light, which changes a voltage that drives a logic gate.

# Microcontroller drives DSEC motors

Charaf Laissoub, Valeo Interior Controls, Créteil, France

DSEC (digital-satellite-equipment-control) motors find wide use in TV-satellite reception; thus, they are readily available. Eutelsat (www.eutelsat.com) defined the DSEC control protocol, which has been in existence since 1998. DSEC motors offer a resolution angle as high as 0.1°. Thus, you can use them as low-cost alternatives to stepper motors.

The circuit in **Figure 1** is a simple design to drive protocol Version 1.2 of DSEC motors using a PIC10F200 microcontroller from Microchip (www.microchip.com). Version 4.2 fully describes the bus-functional method of data-bit signaling (**Reference 1**; see www.edn.com/101118dia). You derive the 22-kHz-frequency tone from the internal 4-MHz±1% clock. Positioner commands from the protocol specification suit one-way communication. This application requires no receive responses or data messages from the remote motor unit. The long-term recommendation for the dc supply is 12V±1V, and the maximum current is 400 mA.

The circuit uses just one pushbutton switch, $S_1$, and two LEDs to control the state of the motor. At power-on, $LED_1$ remains continuously on. One 1-second-long push on $S_1$ blinks $LED_1$ for 0.25 second and drives the motor one step. A 1- to 2-second push on $S_1$ changes the state of direction. $LED_1$ turns off, and $LED_2$ turns on. Pressing $S_1$ for more than 3 seconds causes one LED to blink during the time necessary to drive the motor back to 0°.

This design uses a motor with a resolution angle of 0.3° and maximum angles of 75° east and 75° west. So this circuit has only 250 pulses for each direction. Once it reaches that value, the active LED continues to blink.

You can download fully commented, three-file assembler source code from the online version of this Design Idea at www.edn.com/101118dia. You can adapt this code to any other baseline family of Microchip microcontrollers that use 12-bit instruction code.EDN

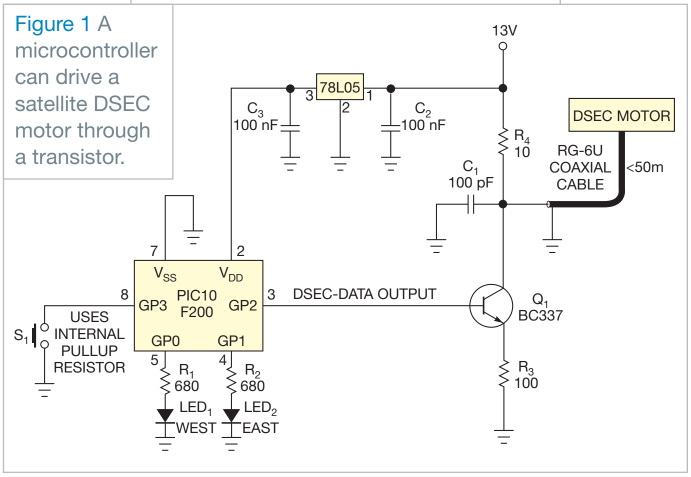

Figure 1 A microcontroller can drive a satellite DSEC motor through a transistor.

# productroundup

## OPTOELECTRONICS AND DISPLAYS

### Low-power LED driver targets coin-cell-power backlighting

The one-channel, quad-mode CAT3661 LED driver targets use in ultra-low-power-LED applications, such as portable handheld medical equipment. The device can drive an LED backlight with a current as high as 5 mA. Soft-start current limiting and short-circuit protection make the device a good fit for coin-cell-battery-powered equipment. The CAT3661 comes in a 16-lead TQFN package measuring 3×3×0.8 mm high. A quad-mode charge pump supports input voltages of 2 to 5.5V and helps the CAT3661 achieve peak efficiency as high as 92%. The device also features a typical quiescent current of 150 μA across all operating modes at full load and a 0A current shutdown. The CAT3661 costs 86 cents (10,000).
**On Semiconductor**, www.onsemi.com

### High-voltage LEDs enable more efficient LED bulbs

The high-voltage XLamp MX-6S and MX-3S LEDs target use in space-constrained LED lamps and bulbs and provide more efficient, smaller power supplies and thermal systems. The MX-6S delivers luminous flux as high as 139 lumens at 60 mA/20V at 6000K and 114 lumens at 3000K. The MX-3S provides luminous flux as high as 122 lumens at 115 mA/10.7V at 6000K and 100 lumens at 3000K. The MX series provides lighting-class performance for high reliability, high efficacy, and color consistency. The devices sell for $1.49 (sample quantities).
**Cree Inc**, www.cree.com

### Free online tools deliver LED-lighting help

Engineers designing with LEDs can access free tools, downloads, and technical information at http://ledlight.osram-os.com/led-ssl-tools. The tools section features LED-lighting resources open to the public, including video slide casts of recent reference designs, LED-product highlights, and solid-state-lighting technical guides. Registration for the tools is free. The tools include PCB-design files, an optic selector that helps users identify the best lens and optics from several of the vendor's partners, and technical papers and reference designs.
**Osram**, http://ledlight.osram-os.com

### Light-pipe system combines brightness, flexibility

The ORCAdapt light-pipe system comprises an adapter with a built-in LED and a flexible light-pipe in a 1- or 2-mm size. The system is available in lengths from 2.5 in. to 238 feet, and it works with single-color, bicolor, or tricolor ORCA LEDs. Prices range from $2 to $5, depending on the LED color and length of the pipe.
**Bivar**, www.bivar.com

## LED driver targets automotive-headlamp-cluster functions

The BD8381EFV-M high-brightness LED driver for automotive-forward-illumination applications provides stable operation over an input voltage of 5 to 30V and removes constraints on the number of LEDs in series connection. The current-mode buck/boost controller integrates voltage, current, and temperature protection. It also provides LED open- and short-circuit protection. The device includes an internal PWM controller so that designers can implement dimming functions with a simple external RC circuit. This circuit can also limit output current in case of LED-overtemperature detection. The BD8381EFV-M sells for $8 (small OEM quantities).

**Rohm Semiconductor, www.rohm.com**

## 10-channel LED driver comes in low-profile package

The 10-channel SC442 white LED driver integrates a 3A boost-power switch. It can drive as many as 120 LEDs at current as high as 30 mA/channel and comes in a low-profile 4×4×0.6-mm, 28-pin MLPQ package. Suiting use in LCD monitors and LCD TVs, the SC442 operates over an input-voltage range of 4.5 to 21V for use with lithium-ion battery packs or regulated 5, 12, or 18V power supplies. It can output 42V and is compatible with boost or SEPIC topologies. Price is $3.20 (3000).

**Semtech, www.semtech.com**

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**TALES FROM THE CUBE** DAVID JEFFREY • MARINE APPLIED RESEARCH AND EXPLORATION

# The devil and the deep blue sea

DANIEL VASCONCELLOS

In the 1970s, I was a research fellow for Edinburgh University, working on a "wave-power" project. We were developing a system that could potentially extract power from ocean waves with high efficiency. This alternative-energy technology was well-suited to Scotland, with its long west-facing coastline.

The nature of gravity-restored waves is such that experiments with models scale up well, so we could evaluate and optimize the system without the expense of full-sized construction. Most of our work was performed at 1/100 scale. We designed and constructed a tank that could reproduce an Atlantic storm at this scale, with wave-energy absorbers to match.

Universities prefer to use ingenuity rather than cash, which meant we had to be creative in selecting the instruments for the project. Luckily, waves are ac—and low-frequency. However, we were able to use an audio engineer's tricks to deal with the instrumentation signals. The wave action excited the wave absorbers—the Salter duck—into a rotary oscillation; applying a pure damping to the motion extracted power. To achieve this damping, we measured the angular velocity and multiplied it by a damping constant. We then applied the product as a torque to counter the duck's movement. Keep in mind that electronics engineers understand the idea of a narrow wave "flume," with a "wave maker" at one end and a "beach" at the other. It is simply the mechanical version of a transmission line.

We measured the angular velocity with a moving-coil meter—used backward. The body was mounted to the test frame so that the needle's pivot aligned with the duck's center of rotation. We used a small extension to glue the needle to the duck body. Any rotary motion of the duck caused the needle to move a corresponding amount. The back EMF (electromotive force) from the meter was therefore proportional to the duck's angular velocity. This technique was inexpensive and robust.

For display purposes, we needed a signal proportional to the duck's angular displacement as well as velocity. Our signals had no dc component, so we integrated the velocity signal using an analog op-amp integrator to get the displacement signal. Analog integrators have a problem with drift, so we put a high-value resistor across the integrator capacitor. This approach halted the drift at the expense of low frequency response but still provided a large dc gain.

During one experiment, I noticed that the displacement signal was drifting. Instead of averaging 0V, it had a nasty dc offset. My first thought was that the moving-coil meter had failed, but it checked out OK with no offset. I then looked at the integrator input. It had a small offset—but enough to cause the displacement drift. Clearly, the problem was occurring between the meter and the integrator. Wait a minute, though: Wasn't the interface between those two components just a piece of wire?

I placed a voltmeter between the output's moving-coil meter and the input to the integrator. Sure enough, I observed a voltage. Perhaps some kind of rogue current was causing it. I then removed power from the system. With nothing to drive it, the voltage was still between one end of the wire and the other. I disconnected the wire at one end and monitored the voltage. It jumped from a few millivolts to about 1V—abnormal behavior for a piece of wire.

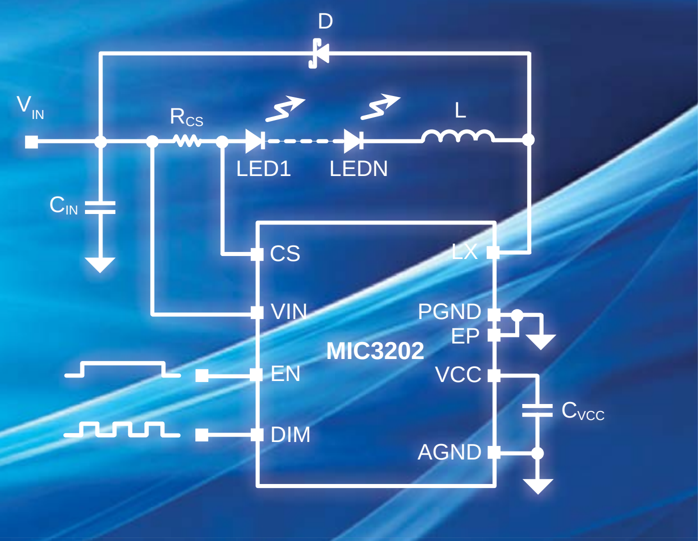
I began to doubt my voltmeter—and sanity—wondering whether I had, in fact, shut off everything. I then remembered that the middle of the wire had a single pin connector. Some moisture had seeped into the connector and transformed it into a battery. Its output resistance was high enough that the voltage was small when the circuit loaded it. As soon as I disconnected one end, however, it reverted to its open circuit.

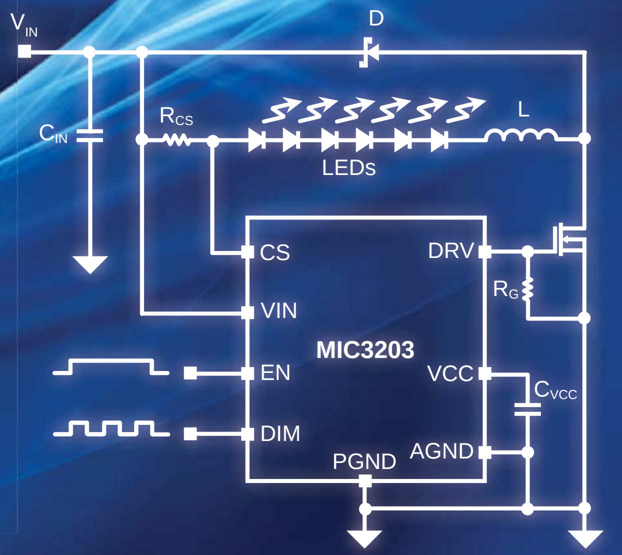
We smeared the connector with silicon grease to keep out moisture—which was rather ironic considering we were dealing with waves in the Atlantic Ocean. Nevertheless, the problem never recurred. **EDN**

***David Jeffrey is an engineer at Marine Applied Research and Exploration (Richmond, CA).***

# Bringing the Power to Light™ with Simple HBLED Drivers

## High Brightness LED Drivers with High-Side Current Sense





### Applications


Landscape Lighting


MR-16 Bulbs


Architectural Lighting

**The** rapid growth of LED lighting applications in commercial, industrial and automotive markets has led to a wide variety of technical challenges for LED Drivers. Micrel is meeting these challenges with simple step-down LED Drivers such as the MIC3202 and MIC3203.

The MIC3202 is a hysteristic step-down LED Driver with integrated MOSFET capable of driving up to 10 HBLEDs with constant currents up to 1A in a thermally enhanced exposed pad SOIC-8L package.

The MIC3203 is a hysteristic step-down LED Driver with an external MOSFET capable of driving up to 10 HBLEDs with power levels up to 40W in a SOIC-8L package.

For more information, contact your local Micrel sales representative or visit Micrel at: www.micrel.com/ad/leddrivers.

### Ideal for use in:

- 12V Lighting Systems (MR-16 Bulb, Under Cabinet Lighting, Garden/Pathway Lighting)
- Architectural, Industrial, and Ambient Lighting
- LED Bulbs
- Indicators and Emergency Lighting
- Street Lighting
- Channel Letters

| Part Number | Input Voltage | Output Current | PWM Dimming | Dithering | Package |
|---|---|---|---|---|---|
| MIC3202 | 6V to 37V | 1A | Yes | Yes | EP SOIC-8L |
| MIC3202-1 | 6V to 37V | 1A | Yes | No | EP SOIC-8L |
| MIC3203 | 4.5V to 42V | Controller | Yes | Yes | SOIC-8L |
| MIC3203-1 | 4.5V to 42V | Controller | Yes | No | SOIC-8L |

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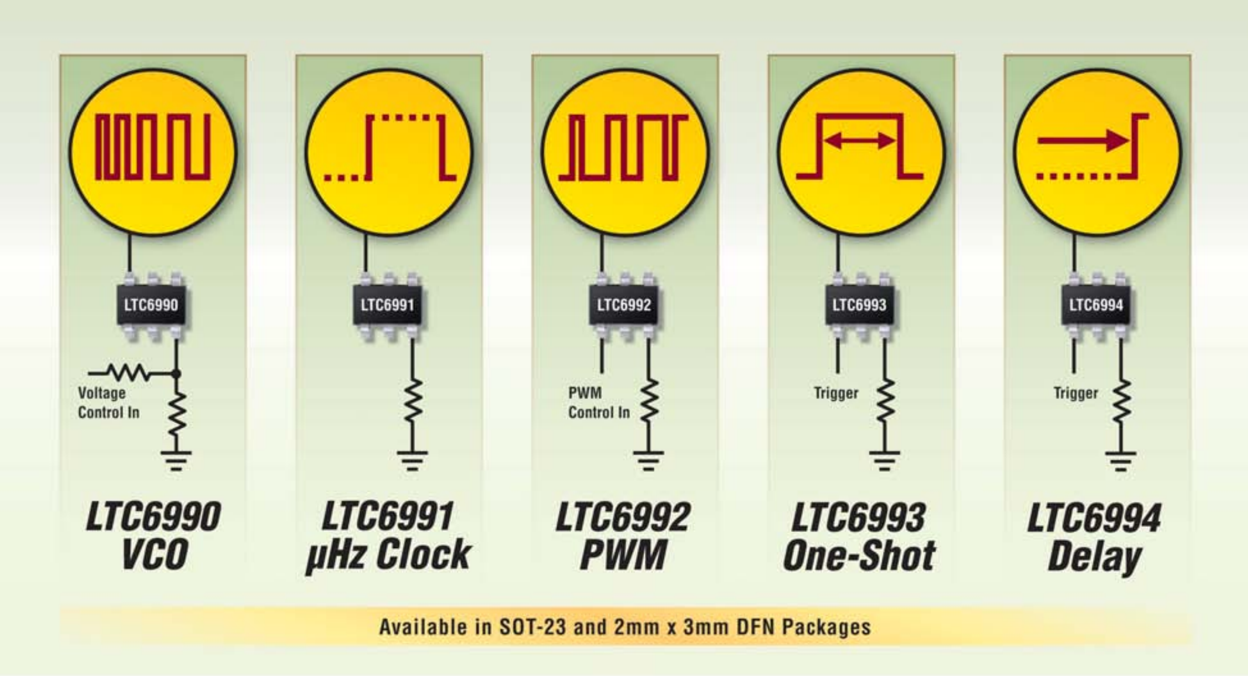
# TimerBlox™



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|---|---|---|---|
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| **LTC6991** | LF Clock | Period from 1ms up to 9.5 hours | 29µHz to 977Hz |
| **LTC6992-1** | PWM | 0% to 100% Pulse Width Control | 3.8Hz to 1MHz |
| **LTC6992-2** | | 5% to 95% Pulse Width Control | 3.8Hz to 1MHz |
| **LTC6992-3** | | 0% to 95% Pulse Width Control | 3.8Hz to 1MHz |
| **LTC6992-4** | | 5% to 100% Pulse Width Control | 3.8Hz to 1MHz |
| **LTC6993-1** | One-Shot | Rising Edge Trigger | 1µs to 34s |
| **LTC6993-2** | | Rising Edge Trigger, Retriggerable | 1µs to 34s |
| **LTC6993-3** | | Falling Edge Trigger | 1µs to 34s |
| **LTC6993-4** | | Falling Edge Trigger, Retriggerable | 1µs to 34s |
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