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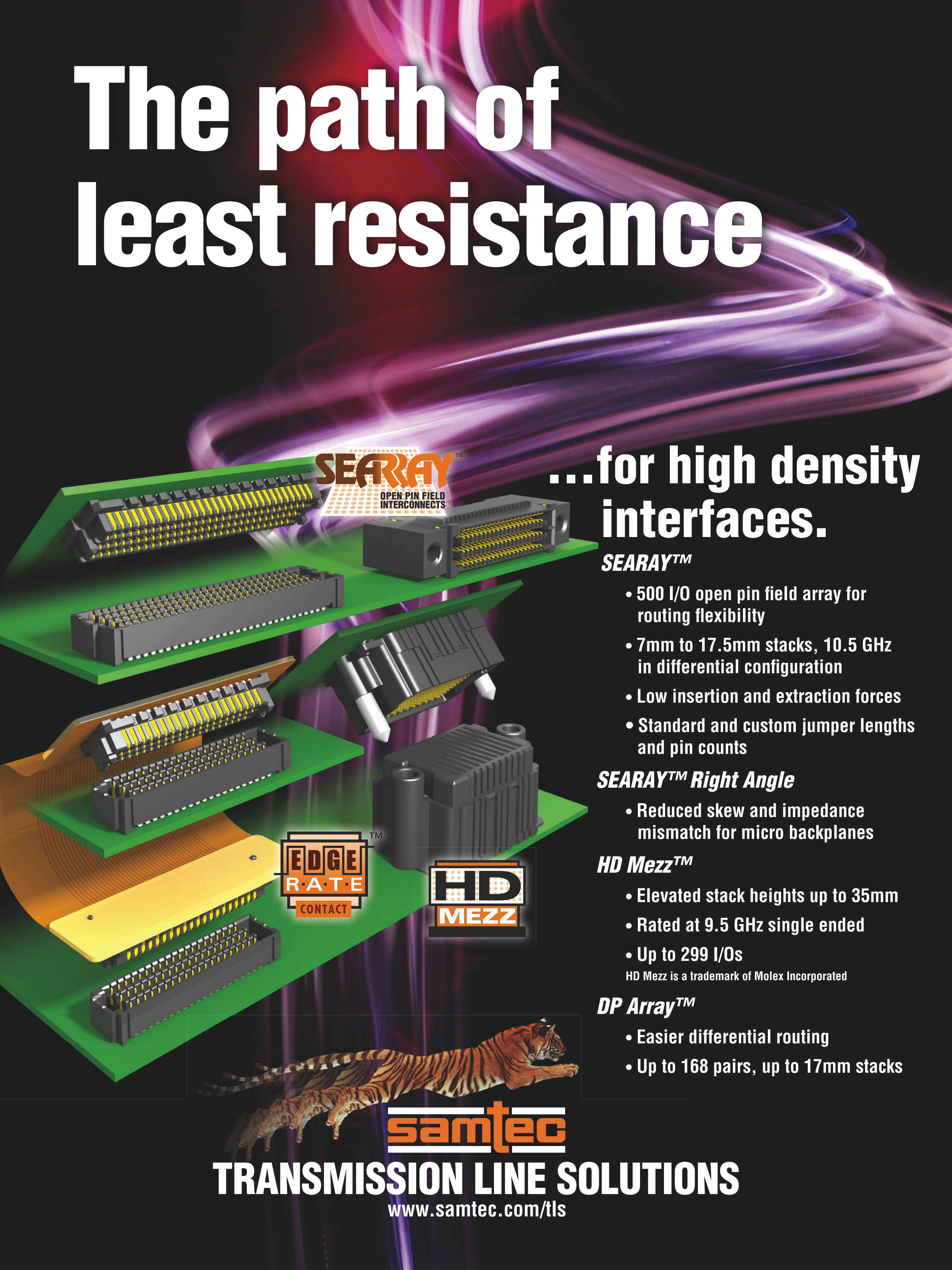
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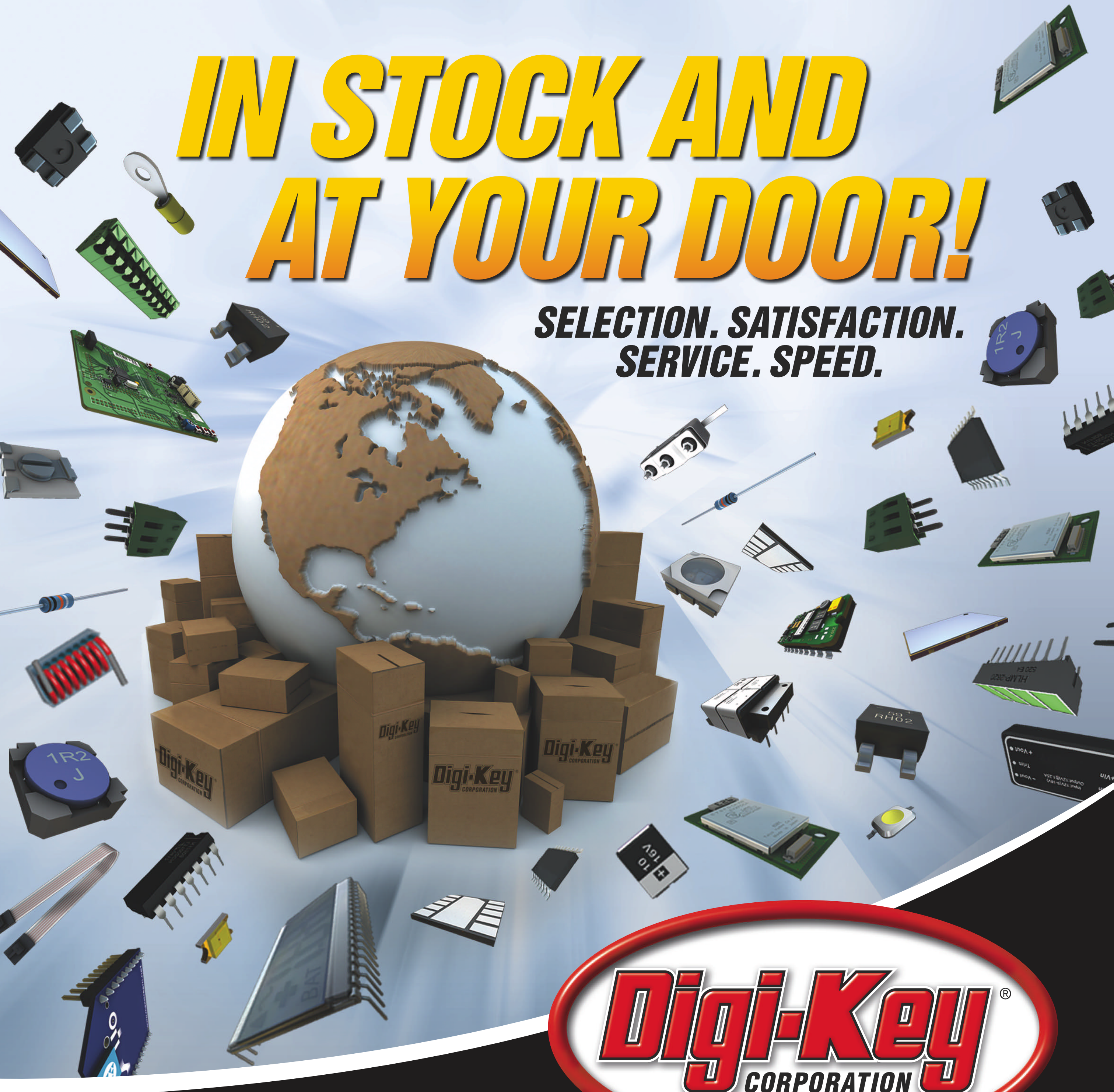
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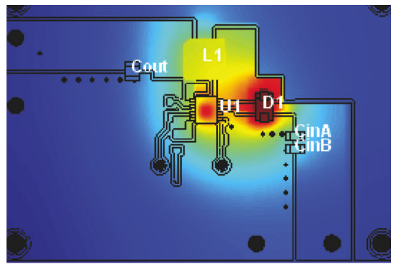

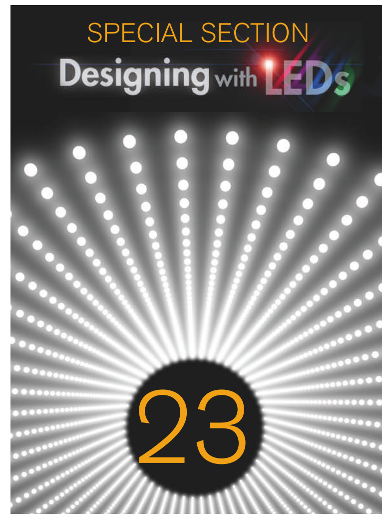

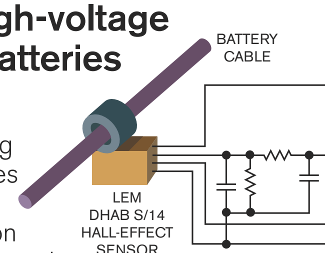

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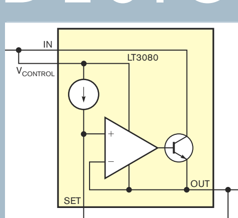

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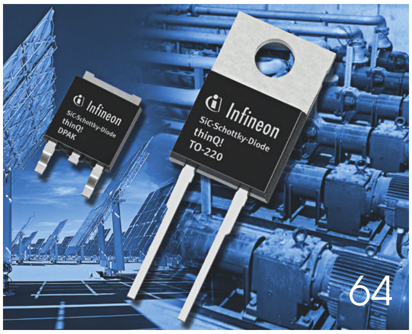

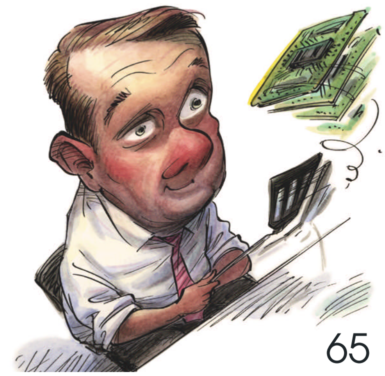

DEPARTMENTS & COLUMNS

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IP: final straw that broke the camel's back or opening Pandora's box?
→www.edn.com/article/CA6643494

FROM *EDN*'S BLOGS

MIT researchers announce lithium-ion-battery breakthrough

From PowerSource, by Margery Conner
A recent article in *Nature* magazine reports on a new lithium-ion-based-battery technology that can perform a complete discharge in less than 10 seconds. What conclusions can we draw from this research?
→www.edn.com/090409toca

Apple's iPhone 3.0: some things I suspect you'd like to know

From Brian's Brain, by Brian Dipert
Only Apple could generate such fervor both leading up to and following its March 17 unveiling of the developer beta for Version 3 of the iPhone and iPod Touch firmware.
→www.edn.com/090409tocb

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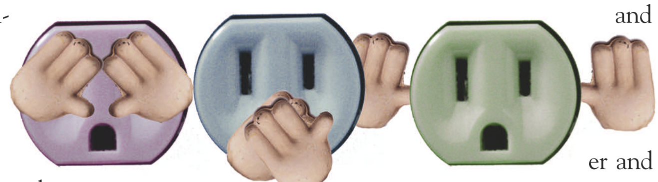
Reed Electronics Group

BY BRIAN DIPERT, SENIOR TECHNICAL EDITOR

Power line: Does market success require resets?

I remain intrigued with power-line-network technology's promise, but the three key technology suppliers for the 200-Mbps PHY (physical) rate—HomePlug AV, UPA (Universal Powerline Association), and HD-PLC (High Definition Power Line Communications)—are unwilling to bury the hatchet and come up with a standard approach.

The disagreements among the competitors, which have the backing of Intellon, DS2, and Panasonic, respectively, mean that an added UPA adapter, for example, will not communicate with HomePlug AV adapters. Even worse, its presence on the power grid will adversely degrade if not squelch the HomePlug AV network. The same undesirable end result will occur in all possible currently available-plus-added power-line-technology scenarios.



The lingering absence of interoperability leads to consumer confusion, and recently claimed compatibility breakthroughs by all three camps turn out to be mostly mirages under close inspection. For example, the IEEE 1901 working group recently wrapped up a draft standard that supposedly merges HomePlug AV and HD-PLC. Read the fine print, though, and you'll find that adapters employing IEEE 1901 can—but are not required to—support dual MAC (media-access-control)/PHY combos to implement both HomePlug AV's OFDM (orthogonal-frequency-division multiplexing) and HD-PLC's Wavelet technologies. Cost-sensitive applications can instead employ a single MAC/PHY—that is, HomePlug AV- or HD-PLC-only—approach, therefore negating any interoperability potential. Admittedly, IEEE 1901 also adds a mechanism that will allow single MAC/PHY adapters—when they come to market—to coexist without degrading each other, although they won't necessarily interoperate with each other.

UPA instead threw its fortunes with the ITU's (International Telecommunication Union's) G.hn effort. Despite its advantages, however, G.hn is a clean-slate approach, thereby adding cost to dual-mode G.hn-plus-UPA devices. I wonder whether DS2's G.hn-inclusive ICs will ever work as advertised and whether, in this fiscally challenged environment of slashed R&D budgets, any phone-line or coaxial-networking suppliers will join the ITU parade. And will anyone care if they do, given that today's dominant networking technologies, Category 5 and Wi-Fi, aren't in the G.hn camp?

There is a potential silver lining to this otherwise-gray cloud: The IEEE 1901 group added a third MAC/PHY option to its draft standard to support G.hn. This option adds even more cost and further increases product-development risk. If everyone ends up supporting G.hn, however, it may be the bridge to interoperability and may even ultimately encourage its adopters to discard their proprietary protocol predecessors.

At times such as these, I wonder whether the power-line-silicon providers need to take one step back to make several steps' forward progress. To use a baseball analogy, they've conceptually built on an X10 power-line-control-protocol foundation by "swinging for the fences" in search of low-probability home runs with local-area and BPL (broadband-over-power-line) networking. However, plenty of opportunities also exist for high-probability singles that cumulatively can also rack up lots of revenue and profit scores.

At January's Consumer Electronics Show, HomePlug, UPA, and HD-PLC all had show-floor presences demonstrating power-line technology's adaptability to an expanded suite of applications. For example, HD-PLC showcased how silicon intelligence at both ends of an electric-vehicle-charging setup, with the help of PLC-data connectivity, can lead to faster charging and longer battery life. Another application is in home- and office-power-usage monitoring for utility companies, along with premises power and temperature control for their customers.

These types of applications have appeal to power-line-IC suppliers beyond their high volume potential. They're protocol-limited, simplifying the implementation and support efforts. They're also data-bandwidth-limited, leading to additional simplification opportunities and easing operating-frequency-spectrum requirements. **EDN**

Contact me at bdipert@reedbusiness.com.

+ An expanded version of this write-up at www.edn.com/090409eda includes related images and video clips.

EDITED BY FRAN GRANVILLE

pulse

INNOVATIONS & INNOVATORS

Prototyping kit shortens embedded-system-development schedules

To cope with constantly shrinking design schedules and to simplify the inevitable product updates, a growing number of embedded-system designers are incorporating reconfigurable-FPGA technology. Lending support to this trend, Altera recently announced the Cyclone III FPGA Edition of its embedded-system-development kit, a platform to simplify the prototyping and development of FPGA-based embedded systems. This three-board development kit features a Cyclone III EP3C120 FPGA device with memories, I/O interfaces, and peripherals. The kit also contains a selection of prebuilt processor systems, IP (intellectual property), operating systems, and software applications. Users create their FPGA-based embedded systems by selecting from a multitude of onboard sample processor systems, demonstration designs, and reference designs.

The Cyclone III FPGA Edition of Altera's embedded-system-development kit simplifies the prototyping and development of FPGA-based embedded systems.

With the recent release of Wind River (www.windriver.com) Linux support for Altera's Nios II soft processor, designers can use this hardware platform as a basis for developing embedded Linux designs. The kit comprises a Cyclone III FPGA-development board with two HSMCs (high-speed mezzanine connectors), an LCD multimedia HSMC board, and a multipurpose HSMC card. The development board features an EP3C120F780 FPGA, 256 Mbytes of dual-channel DDR2 SDRAM with ECC (error-correcting code), 8 Mbytes of pseudo SRAM, 64 Mbytes of flash, and a 10/100/1000-Mbps Ethernet-communication port. The development kit includes Altera's design-suite DVD, featuring the Quartus II Web Edition design software, ModelSim-Altera Starter Edition, the Nios II embedded-design suite, and the MegaCore IP library. The Cyclone III FPGA Edition is available now through Altera's online store and sells for $1995.**—by Warren Webb**

▷**Altera**, www.altera.com.

FEEDBACK LOOP

"We should follow President Obama's suggestion and read instead of watch TV."

—Reader "Martin," in *EDN*'s Feedback Loop, at www.edn.com/article/CA6636515. Add your comments.

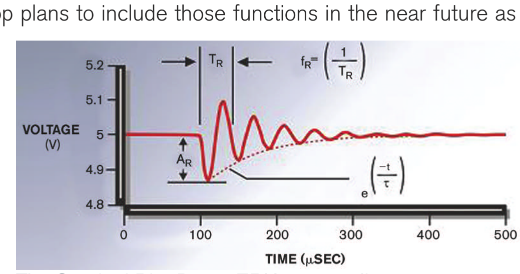
Power systems get transient-load analysis

The Sentinel RingDown EPU (electronic-prognostic unit) from the Ridgetop Group predicts power-supply-system failures by externally monitoring transient response to source or load changes. Transients on a power supply's voltage rails produce "ringing" waveforms that are characteristic of the power system's health. This approach enables pre-emptive condition-based-maintenance strategies for critical systems and devices. RingDown requires no modification to the power-supply circuit: It uses a power supply's externally available power- and output-load lines. It also works with dc brushless motors and electromechanical actuators.

The EPU is currently a power-supply-specific board that comes with driver and analysis software. Ridgetop plans to include those functions in the near future as a single IC, employing the current software. The baseline price for one RingDown IP (intellectual-property) license is $50,000 plus NRE (nonrecurring-engineering) charges.

—by Margery Conner

▷**Ridgetop Group**, www.ridgetop-group.com.



The Sentinel RingDown EPU can predict power-supply-system failures by externally monitoring transient response to source or load changes.

Simulator speeds eye measurements

Agilent Technologies has introduced a 1 million-bit-per-minute signal-integrity channel simulator for multigigabit chip-to-chip data-link design. The channel simulator allows you to perform an interactive eye-diagram measurement from channel simulations within the ADS (Advanced Design System) signal-integrity design-and-analysis environment. "With a throughput that's a thousand times faster than Spice, it is now practical to make changes to the channel or the transmit-and-receive equalization and see eye-measurement results instantaneously," says Colin Warwick, signal-integrity-product manager with Agilent's EEsof EDA division. "The channel simulator … allows our customers to build the model from regular ADS circuit- and physical-level components," he says. "They can access tuning, optimization, and batch mode—all from an intuitive user interface."

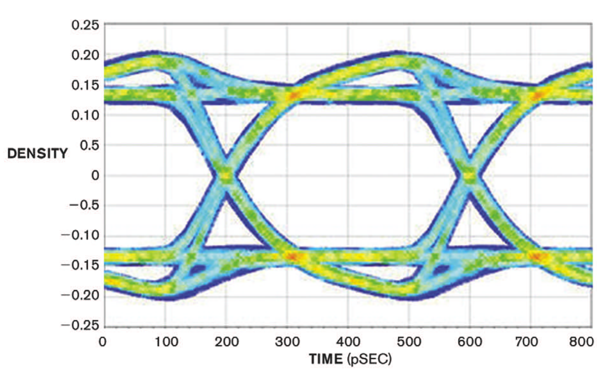
The most common applications for the ADS channel simulator are design and verification of the chip-to-chip multigigabit-per-second serial links that are present in almost all currently available consumer and enterprise digital products—from laptop computers to data-center servers to telecommunication-switching centers to Internet routers. The simulator helps signal-integrity engineers take into account physical phenomena, such as impedance mismatch, reflections, electromagnetic coupling, crosstalk, and microwave-frequency attenuation due to the skin effect and dielectric-loss tangent.

The ADS channel simulator allows signal-integrity engineers to perform what-if design-space exploration. To aid this workflow, the product uses impulse-response analysis to automatically extract a fast, linear FIR (finite-impulse-response) model from any combination of ADS circuit- and physical-level components. This approach results in simulation throughput of more than 1 million bits per minute. Fast eye measurement lets signal-integrity engineers interactively produce the resulting eye measurements—and optimize transmitter and receiver equalization—in serial links such as PCI Express (peripheral-component-interconnect express), USB (universal serial bus) 3.0, and 10-GbE (gigabit Ethernet).

Agilent's channel simulator will be available as part of the ADS 2009 release in both the legacy E8885 convolution simulator and its successor, the new W2302 transient-convolution element. The base price is $26,000.

—by Rick Nelson

▷**Agilent Technologies**, www.agilent.com.



The channel simulator allows you to perform an interactive eye-diagram measurement from channel simulations within the ADS signal-integrity design-and-analysis environment.

DILBERT By Scott Adams

04.09.09

FPGA SERIAL I/O HITS 11.3 GBPS

In the latest additions to its Stratix range of FPGAs, Altera has incorporated serial-data transceivers that support signal rates as high as 11.3 Gbps. The company envisages the Stratix IV GT's parts finding applications in 40- or 100-Gbps systems.

You might use a link at the maximum speed to directly connect an optical receiver or transmitter to the FPGA. At these speeds, signals propagate over a few centimeters at most; nevertheless, Altera says that, with appropriate design, PCB (printed-circuit-board) designs on FR (fire-retardant)-4 material should be viable.

The GT parts will have 24 transceivers that will run at the highest speed, and 24 support 6.5 Gbps. They have 230,000 to 530,000 logic elements, 13.9 to 20.3 Mbits of internal RAM, and as many as 1288 18×18-bit multipliers.

Altera has also added the Arria II GX family of 3.75-Gbps-capable chips with 16,000 to 256,000 logic elements and four to 16 transceivers. A new suite of reference designs and design examples use these new parts. The latest version of the company's Quartus software supports both series.

The price for the smallest Arria II GX device is $15 (100,000). For more details on all of these products, go to www.edn.com/090409pa.

—by Graham Prophet

▶**Altera, www.altera.com.**

400-MHz to 2-GHz DSOs offer high-end features for lower prices

LeCroy has announced the Xi-A series of 400-MHz- to 2-GHz-bandwidth WaveRunner digital oscilloscopes. The series includes the MXi-A family, whose members perform advanced signal analysis and capture a maximum of 10G samples/sec in 12.5 million points/channel of acquisition memory. You can interleave pairs of channels to capture 25 million-point records. The company also announced the Xi-A VBA vehicle-bus-analyzer family, which it has tailored for debugging new motor-vehicle subsystems' serial-communication capabilities. A spectrum-analyzer option for all Xi-A models allows debugging in both the frequency and the time domains. All Xi-A units can also accept the company's plug-in, 36-channel mixed-signal adapter.

The new series incorporates the X-Stream II hardware architecture with advanced computing and memory resources, which increases acquisition and display speed, especially when manipulating long waveform records; TriggerScan rare-event-capture technology, which facilitates debugging and analysis; and new LXI (local-area-network-extensions-for-instrumentation)-based connectivity and control options for automated-test systems. All Xi-A units feature a large, bright, high-resolution, wide-screen display and a space-efficient footprint.

In addition, all Xi-A models are compatible with the manufacturer's optional low-speed serial-triggering and -decoding packages, which help you to quickly analyze I^2C (inter-integrated-circuit), SPI (serial-peripheral-interface), UART (universal-asynchronous-receiver/transmitter), RS-232, CAN (controller-area-network), LIN (local-interconnect-network), and FlexRay protocols. The comprehensive set of easy-to-use analysis tools, including WaveScan advanced search and analysis, WaveStream fast-viewing mode, and LabNotebook for documentation and report generation, aid in understanding and validating designs.

LeCroy ships all Xi-A VBA models with FlexRay TDP (trigger/decode/physical-layer) testing, LIN-bus testing, and a trigger-and-decode capability that decodes CAN serial data into symbolic, application-layer text directly on the oscilloscope display. Prices for the Xi-A series, the MXi-A units, and the VBA units start at $11,810, $12,925, and $19,095, respectively.

—by Dan Strassberg

▷**LeCroy Corp**, www.lecroy.com.

The WaveRunner Xi-A series of 400-MHz- to 2-GHz-bandwidth digital scopes features a spectrum-analyzer option and other features that enable quick insights into the behavior of units and systems under test. According to the company, the scopes help you to explain and correct anomalous unit-under-test behavior in a fraction of the time that competitive instruments require.

04.09.09

POWER-SUPPLY MODULATION STEPS UP HANDSET-POWER-AMP EFFICIENCY

RF-engineering company Nujira has extended the reach of its efficiency-boosting technology for power amplifiers into the handset. The company has until now focused on the infrastructure side of communications, selling its HAT (high-accuracy-tracking) power-line modulators into applications such as base stations.

The fundamental principle is that RF power amps—especially those for modern digital-modulation schemes, such as 3 and 4G (third- and fourth-generation) LTE (long-term evolution) and WiMax (worldwide interoperability for microwave access)—must be linear; that is, they must operate from a fixed-voltage rail. When modulation levels are low, a great deal of the power in the output stage contributes nothing to the output; therefore, efficiency is low.

HAT modulates the power rail to the power amp in step with the RF-waveform envelope, reducing losses. Nujira has now applied the principles of HAT to an IP (intellectual-property) business model and aims to sell the same concept, which it brands as Coolteq-I, into handsets. Thus equipped, a handset power amplifier could be twice as efficient when transmitting an HSUPA (high-speed-uplink-packet-access) waveform and as much as four times as efficient for WiMax. Licensees will implement Coolteq-I IP in the power regulator for the power amp and in the baseband chip set to derive the envelope signal.

In hardware terms, the implementation should be cost-neutral because it replaces an existing regulator, and the added gate count in the baseband is almost trivial. As well as improving efficiency, the technology will assist the architecture shift necessary for reducing multiple power amps for different bands into—typically—two wideband amplifiers.

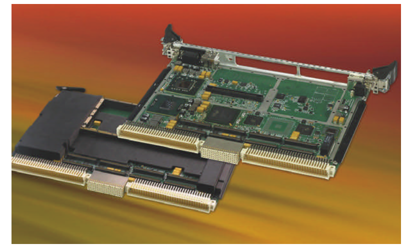
Depending on operating conditions and traffic type—and especially with data traffic exhibiting high peak-average-ratio values—terminal-battery life might improve by as much as 30% due to Coolteq-I alone, Nujira believes. The company will deliver the IP in a conventional fee-plus-royalty model, as a set of design libraries and procedures, with supporting models, an evaluation kit, and a suitable power-amplifier design.

—by Graham Prophet

▶**Nujira, www.nujira.com.**

Rugged computer runs virtual partitions

Aitech Defense Systems recently released a 6U VME single-board computer targeting applications in radar and sonar communications, vehicle-protection subsystems, mission-management computers, and heads-up display controllers. The new C160 computer features the latest Intel (www.intel.com) T7400 Merom Core 2 Duo dual-core processor in either a 2.2-GHz, maximum-performance version or a 1.67-GHz, lowest-power-consumption version.



The C160 computer features the Merom Core 2 Duo dual-core processor in a 2.2-GHz or a 1.67-GHz version.

The rugged, single-slot C160 also uses Intel's VT (virtualization technology), so the board can simultaneously run applications using multiple virtual partitions. The C160 draws only 25W and incorporates a custom metal thermal-management frame and stiffeners for increased resistance against shock and vibration. The board's memory arrays provide volatile and nonvolatile memory resources, including as much as 2 Gbytes of fast DDR2 SDRAM and as much as 8 Gbytes of onboard flash disk.

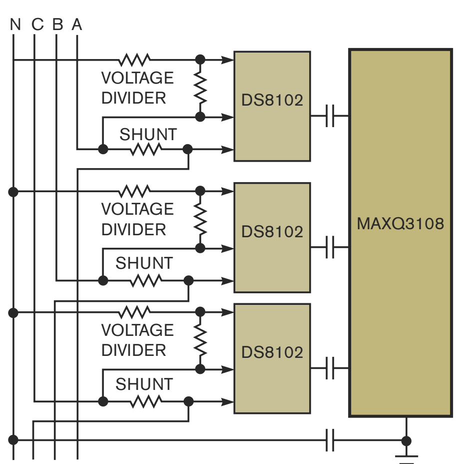
For man-machine-interface applications, the C160 also integrates a GM965 graphics engine with 2- and 3-D graphics outputs in multiple video formats. Operating-system support includes Microsoft (www.microsoft.com) XP Pro, XP Embedded, Linux, and Wind River (www.windriver.com) VxWorks. Prices for the C160 start at $6050. For more, go to www.edn.com/090409pd.

—by Warren Webb

▷**Aitech Defense Systems**, www.rugged.com.

Chip set offers power-meter isolation

The new Maxim MAXQ3108/DS8102 chip set allows multiphase power meters to use inexpensive shunt current sensors on polyphase meters and provide three-phase isolation. Instead of providing isolation at the measurement device, the chip set provides isolation at the interface between the ADC and the MAXQ3108 supervisory microcontroller. Each phase has its own two-channel DS8102 sigma-delta modulator that floats with its respective phase. The output of each DS8102 is a digital bit stream that contains the current-channel measurement, the voltage-channel measurement, and a synchronization signal. The device then Manchester-encodes the composite bit stream so that it can pass over a non-dc continuous medium that serves as the high-voltage isolator.



Maxim's MAXQ3108/DS8102 chip set provides isolation at the interface between the ADC and the MAXQ3108 supervisory microcontroller.

The reference meter uses a PCB (printed-circuit-board)-etch capacitor made of standard FR (flame-retardant)-4 PCB material, withstanding as much as 5 kV and isolating the three phases from one another and from the supervisory microcontroller. Thus, the designer can use any current- and voltage-transducer method.

The MAXQ3108 comes in a 28-pin TSSOP, and the DS8102 comes in a 16-pin TSSOP. Prices are $2.43 and $1.17, respectively. For more information, go to www.edn.com/090409pe.

—by Margery Conner

▷**Maxim Integrated Products**, www.maxim-ic.com.

EDITED BY RON WILSON

Graphene's edge structure affects electronic properties

Engineering-department researchers at the University of Illinois—Urbana say they have experimentally proven that the crystallographic orientation of graphene edges affects the material's electronic properties. The research focused on the effect that the orientation of atoms along the edges of the lattice would have on graphene's electronic properties.

The researchers developed a method for cutting and depositing nanometer-sized bits of graphene on atomically clean semiconductor surfaces, such as silicon. They then used a scanning, tunneling microscope to probe the electronic structure of the graphene with atomic-scale resolution. A clear picture emerged, according to Joseph Lyding, a professor in the university's electrical- and computer-engineering department. "Edges with so-called zigzag orientation exhibited a strong edge state, whereas edges with armchair orientation did not," he says. "Pieces of graphene smaller than about 10 nm with predominately zigzag edges exhibited metallic behavior rather than semiconducting behavior. This [finding] has major implications in that semiconducting behavior is mandatory for transistor fabrication."

Controlled engineering of the graphene-edge structure will be necessary for obtaining uniform performance among graphene-based nanoelectronic devices. "Even a tiny section of zigzag orientation on a 5-nm piece of graphene will change the material from a semiconductor into a metal," Lyding says. "And a transistor based on that [material] will not work." Lyding and former graduate student Kyle Ritter recently reported their findings (see "The influence of edge structure on the electronic properties of graphene quantum dots and nanoribbons," *Nature Materials*, March 2009, www.nature.com/nmat/journal/v8/n3/abs/nmat2378.html).

For more details on this research, go to www.edn.com/article/CA6638852.

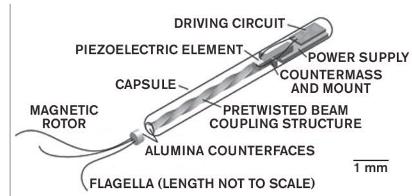
—by Suzanne Deffree

▷**University of Illinois–Urbana**, www.ece.illinois.edu.

Microrobots swim through blood vessels

Just a few years ago, the popular Uncle Kracker song *Follow Me* included the lyrics "I … swim through your veins like a fish in the sea." Though that image was figurative, researchers at Monash University in Australia have now developed a tiny robot that can literally propel itself through veins. Still in the research stage, the 250-micron-wide robot comprises a wiggling piezoelectric resonator motor with spiraling flagella that propel the robot through blood vessels.

The Proteus robot can reach parts of the body, such as a stroke-damaged cranial artery, that catheters have been unable to reach. Attaching the sensor equipment to the microrobot motor enhances the surgeon's view, and the ability to work remotely increases dexterity, according to research-team leader Professor James Friend. "Serious damage during minimally invasive surgery is, however, not always avoidable, and surgeons are often limited by the width of a catheter tube, for example, which, in serious cases, can fatally puncture narrow arteries," he says. Proteus overcomes those limitations because it is small enough for injection into the bloodstream. For more on this robot, along with a video, go to www.edn.com/090409pb.



The Proteus microrobot swims through a patient's veins to treat stroke victims by confronting hardened arteries or addressing blockages.

—by Margery Conner

▷**Monash University**, www.monash.edu.

IMEC SHOWS FLEXIBLE PACKAGED-IC ASSEMBLIES

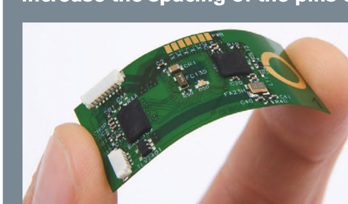
Researchers at IMEC (Interuniversity Microelectronics Consortium) and at Ghent University recently demonstrated results from a 3-D integration process using highly thinned ICs with flexible packaging, materials to create fully flexible circuit assemblies. Researchers thinned an IC die to a thickness of 25 microns. They then mounted the die in an ultrathin, flexible package, which they in turn embedded in a conventional flexible, two-layer PCB (printed-circuit board) using standard flexible-circuit equipment. Such assemblies could have a finished thickness of less than 60 microns.

The approach employs ultrathin interposers in the packaging process. The interposers make the packaged chip fully testable, solving the known-good-die problem, and increase the spacing of the pins on the package, eliminating the need for high-density traces on the flexible PCB.

In the demonstration, IMEC showed a flexible, wearable patient-monitoring board that can measure heart rate and muscle activity and transmit the data wirelessly to a monitoring station. The board includes a microcontroller with an ADC, a biopotential amplifier, and a radio transceiver.—RW

▶**Interuniversity Microelectronics Consortium, www.imec.be.**

▶**Ghent University, www.ugent.be.**



IMEC's flexible, wireless system monitors vital body parameters with an embedded microcontroller chip.

04.09.09

BY HOWARD JOHNSON, PhD

Dangerous games

I hope you fell off your bike when you were a kid. Maybe you broke your arm. I say this not because I'm a mean person, but because that early experience portends one of two things: either a lifetime devoted to the study of physical processes and their limitations or a fear of bicycles. If you are reading this magazine, I'll bet it's the lifetime of study.

You were the kid popping wheelies, probing the limits of unstable equilibrium. On the playground swing set, you swung the highest because you understood resonance. Every time you jumped from that swing, you tested your knowledge of gravity, the nature of inelastic collisions, and bruised ankles. Such doings shape the mind of a budding engineer. I mean that in a serious way.

Any kid who really rides a bicycle, and I mean slides, skids, hops over curbs, sails off ramps on one wheel—always pushing the envelope—can become a terrific hardware designer. The visceral connection between your hands on the bars and the movement of the bike is probably more important to your understanding of dynamic systems than a graduate degree in differential equations. Of course, mastery of mathematical syntax helps quantify your work, but the fundamental principles behind most electrical circuits are as simple as riding a bike.

The connection between your direct physical knowledge and electrical-circuit operation shows up plainly in everyday engineering terminology. A power supply, for example, is "stiff" if you can "pull" a lot of current without "moving" its output. A large capacitor forms a "heavy" load. An electron "falls" into a potential well. These mechanical analogies depend upon shared cultural experiences from childhood. The experiences provide a rich tapestry of knowledge from which you can extract nuggets of wisdom later in life.

I asked my friend Bill Paseman what it takes to raise a great software engineer. He says that, under ideal conditions, the child would grow up in a house with large yellow footprints painted on the floor between the bed, bath, and kitchen. As long as the child keeps both feet centered on the footprints, all is well. If he steps off the path even once, the parents administer an electric shock sufficient to induce total blackout. The child then wakes up in bed, unable to recall what happened.

Bill says that this system, although obviously inhumane, would produce the greatest software engineer the world has ever seen. He's probably right, but it sounds brutal.

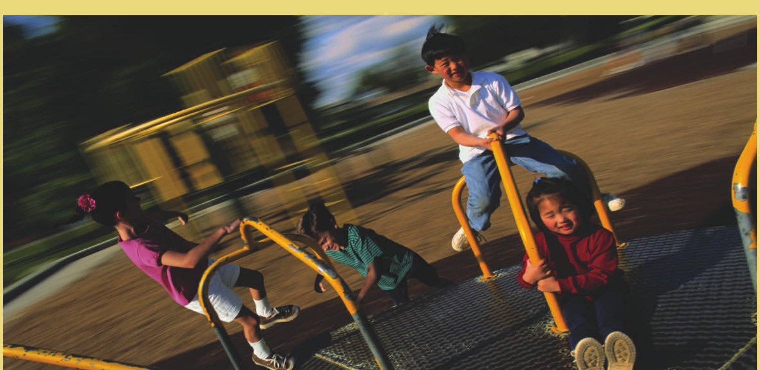
I'd rather break my arm. EDN

PLAYGROUND LESSONS

I recently visited a modern "kid-safe" playground. Gone is the old metal merry-go-round. The monkey bars now stand amid a spongy, rubber-filled pit. The swings have seat belts. Those changes have so watered down the playground experience that a child could hardly hurt himself there if he tried. How, then, can he learn anything important?

Lawyers and politically correct parents made all these changes. Resist them. Healthy children deserve the pleasure of laughing on the merry-go-round as they desperately claw their way toward the center, making the wheel spin faster and faster until the centrifugal force hurls the weakest child off into the dust. That's part of how we, as a species, learn.

People who spend their formative years huddled in the library searching for loopholes in the physical-education requirements for junior-high graduation should not design playgrounds.



Howard Johnson, PhD, of Signal Consulting, frequently conducts technical workshops for digital engineers at Oxford University and other sites worldwide. Visit his Web site at www.sigcon.com or e-mail him at howie03@sigcon.com.

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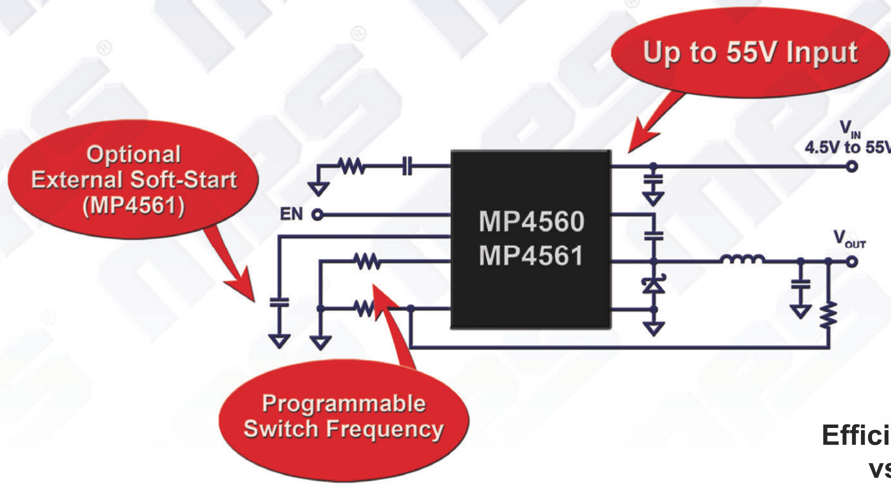

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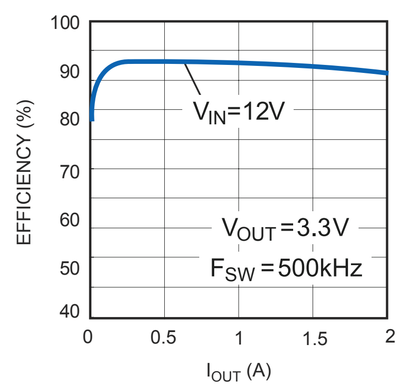
- *Internal Soft-Start (MP4561: External Soft-Start)*
- *Up to 95% Efficiency*
- *Available in 3x3mm 10-Pin DFN and SOIC8 Packages*

Efficiency vs. Output Current



Part Number	Programmable Frequency	V_{IN}(V)	I_{OUT} (A)	Quiescent Current (µA)	Soft Start	Package
MP2560	Up to 4MHz	4.5 - 42	2.5	100	Internal	DFN10 (3mm x 3mm) SOIC8E
MP2565	Up to 4MHz	4.5 - 50	2.5	100	Internal	DFN10 (3mm x 3mm) SOIC8E
MP4462	Up to 4MHz	4.5 - 36	3.5	100	Internal	DFN10 (3mm x 3mm) SOIC8E
MP4560	Up to 2MHz	4.5 - 55 (60V Max)	2.0	120	Internal	DFN10 (3mm x 3mm) SOIC8E
MP4561	Up to 2MHz	4.5 - 55 (60V Max)	1.5	120	External	DFN10 (3mm x 3mm)

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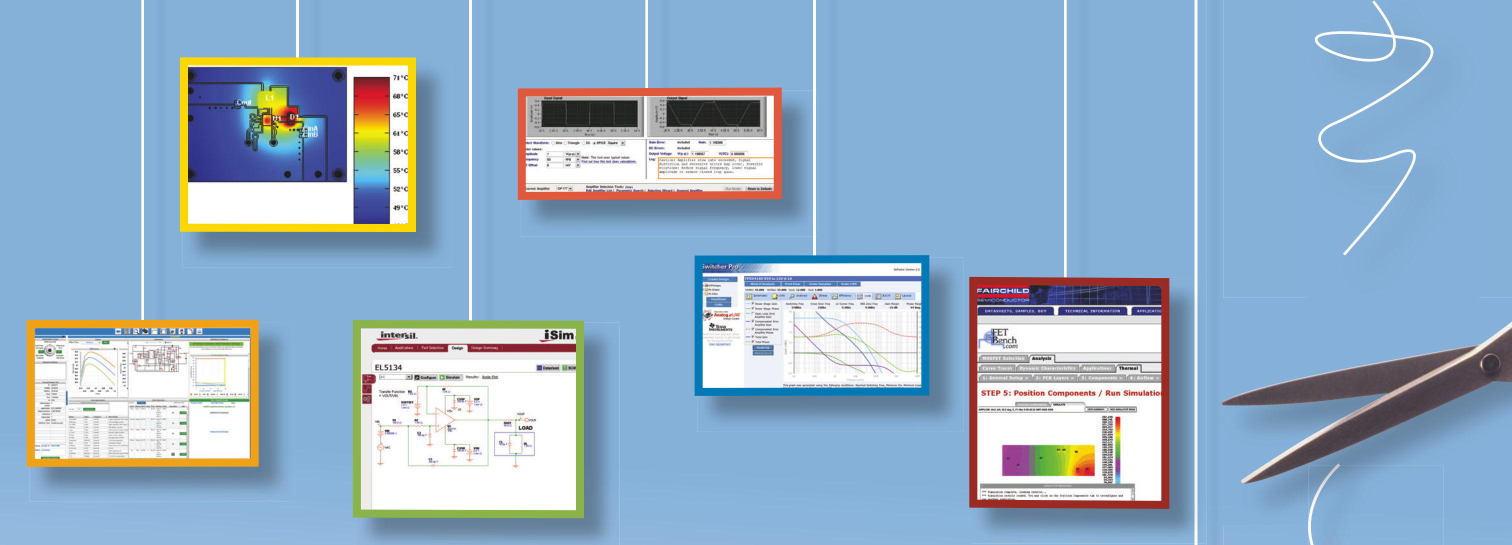
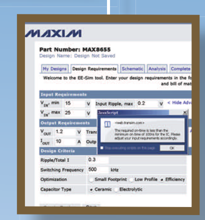


ONLINE TOOLS HOME IN ON ANALOG DESIGN



ANALOG DESIGN GETS EASIER AND MORE CONVENIENT, THANKS TO FREE WEB APPLICATIONS AND DOWNLOADABLE TOOLS.

BY PAUL RAKO • TECHNICAL EDITOR

Since the advent of circuits, electronics engineers have used various implementations of simulation tools. These tools are especially important in analog design, for which specifications may span many decades of magnitude, and changing one component can have unknown effects on other—perhaps unrelated—components. Analog systems are also becoming more complex: Switching regulators once operated at 20 kHz, but modern chips can work at 4 or even 8 MHz. Modern signal paths also have stringent noise and accuracy requirements. Interface signals clock data at gigahertz frequencies. These signals can interact or be susceptible to interference from both internal and external sources, causing circuits to behave unreliably. These signals may also radiate excessive noise, preventing your product from passing FCC (Federal Communications Commission) certification.

Tools to aid designers of analog circuits have been around for a long time, with each decade bringing innovations in analog-design help. For example, analog designers as far back as the 1950s simulated circuits using Teledeltos, an electrosensitive paper that responded to an electric current by turning from light gray or blue to dark black. In the 1960s, IBM's ECAP (electronic-circuit-analysis program), with 7000 program lines, was available to help engineers with their circuit designs. A decade later, in the 1970s, a team at the University of California—Berkeley created Spice, which is now available as packaged software that you buy or lease. The most well-known variations of Spice are PSpice, which Cadence now owns, and Intusoft's ICap4 analog- and mixed-signal circuit-simulation package. Altium also offers a version of Spice, and National Instruments' Electronics Workbench Multisim Spice has attained great popularity in academia due to its intuitive and novel user interface.

Analog-simulation tools have evolved immensely since the early days. For example, in 1972, Berkeley Spice required you to type a netlist on punch cards using a mainframe. Today, National Instruments' Electronics Workbench lets you draw a schematic and then drag virtual test equipment over the nodes to simulate and evaluate circuit performance. National Semiconductor's Webench simulation package runs on the company's servers to perform analysis of the circuits you design online, and Analog Devices' Web package uses Multisim to perform the same tasks. Another noteworthy Spice version, Linear Technology's LTSpice, excels at simu-

AT A GLANCE

- Tools to aid designers of analog circuits have been around for a long time, with each decade bringing innovations in analog-design help.
- Packaged tools lack the immediate application assistance that you can achieve by running an application on the Web.
- By the 1990s, selector guides had evolved into downloadable programs that would allow parametric searches.
- The broad-market analog companies are not the only ones that provide design tools.
- Many companies make it easy to register for the tools.
- The prominence of online-design tools is evident in the way that the major analog companies organize their home pages.
- A smart FAE (field-application engineer) is the best free design tool there is.

lating switching power-supply circuits, a difficult proposition, considering the nonlinear nature of the rectification diodes and transformer magnetic components these power supplies employ.

Other forms of packaged software tools include The MathWorks' Matlab and PTC's MathCAD. These math programs use generalized circuit equations or even Z transforms to solve for the response of digital-power chips. Field solvers use a physical model and Maxwell's equations to predict the performance of your circuit (**Reference 1**). Engineers use all these tools to help with analog design, but packaged tools lack the instantaneous application assistance that you can achieve by running an application on the Web.

WEB TOOLS DEBUT

Web tools began to emerge a decade ago when companies began to publish data sheets on their Web sites in PDF (portable-document-format) files. Engineers no longer needed to squeeze data books under copy-machine covers to document their designs; they could easily print them from manufacturers' Web sites. Companies then began to offer not only data sheets, but also selector guides to help customers select parts. Many of these selector guides started life as printed handouts.

By the 1990s, however, selector guides had evolved into downloadable programs that would allow parametric searches. National Semiconductor developed one of these programs, a Windows application that uses the Perl programming language to perform parametric searches. The company also developed the PalmGuide, which runs on Palm and Hewlett-Packard PDAs (personal digital assistants). The nonintrusive program does not use the Windows registry or leave any files or other detritus on your computer. And, for every parameter you enter in the selector guide, Palmuide indicates how many parts fit within all the parameters (**Figure 1**). For example, if you ask for some impossible combination of parameters—say, noise of 1 nV/$\sqrt{\text{Hz}}$ and current consumption of 1 μA—you would immediately see that no such part exists. With these tools, FAEs (field-application engineers), for example, can keep selection guides, such as National Semiconductor's guide for amplifiers, on their PDAs so they can easily help customers find the right parts without using laptop computers. Texas Instruments, Analog Devices, and a host of other companies also offer programs to help engineers select parts.

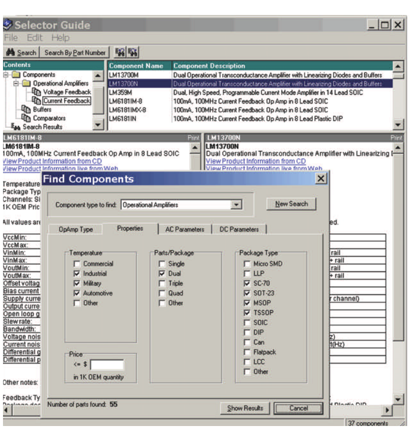


Figure 1 National Semiconductor's amplifier-selection guide shows you how many parts still match your criteria so you don't waste time looking for parts that don't exist.

The next logical step for manufacturers was to publish the selector guides on the Web. These Web tools require no software downloads, and, because little data traverses the Web in either direction, the programs worked even back in the days when engineers used dial-up connections to access the pages. Today, all analog companies offer Web-based selector guides, many of which provide the same functions as packaged software and allow semiconductor manufacturers clues about which selector guides and parts are popular with customers.

The next step in the evolution was the emergence of online-design programs. National Semiconductor led the way with Webench. The development of this online tool was a natural outcome of the DOS software that the company had developed in 1993 to help engineers design systems with its Simple Switcher product family.

In 2000, the company introduced WebTherm, which it co-developed with Flomerics. The tool simulates the thermal behavior of an electronic PCB (printed-circuit board) with components (**Figure 2**). Also in 2000, the company enhanced Webench with Build-It, a feature that allows engineers to order a custom power-supply kit or a fully assembled and tested board matching their design requirements to verify their designs. Webench runs Intusoft Spice in the background on National's servers, yielding the benefit of not overloading your machine. Today, tools are available to help you design filters and amplifier circuits, to select the signal path for temperature or pressure sensors, and to design LED-driver circuits (**Figure 3**).

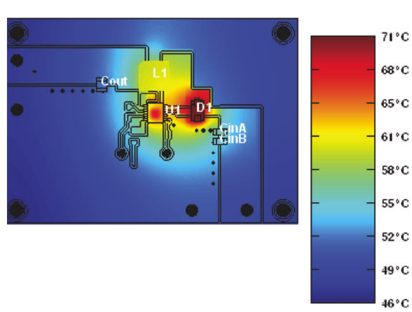


Figure 2 National Semiconductor's Webench online-design simulator analyzes the thermal performance of your switching-power-supply design.

Other vendors followed National

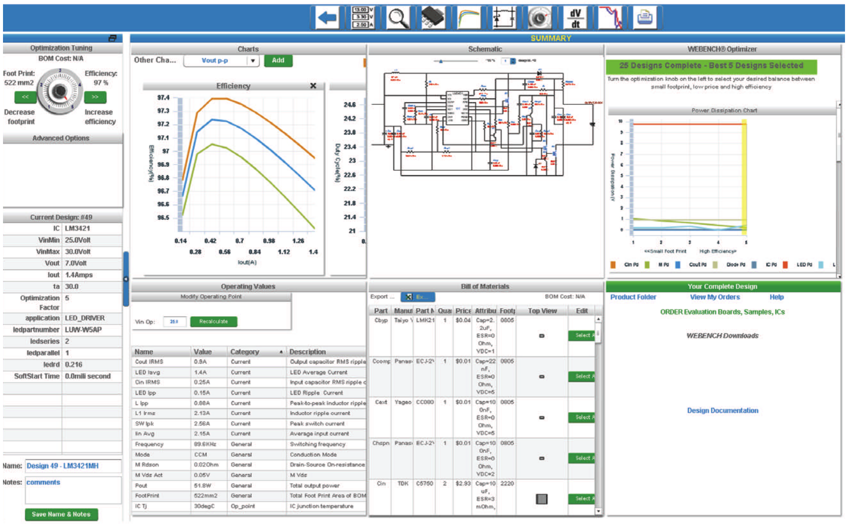


Figure 3 Webench has an LED-driver-design function with a powerful interface (courtesy National Semiconductor).

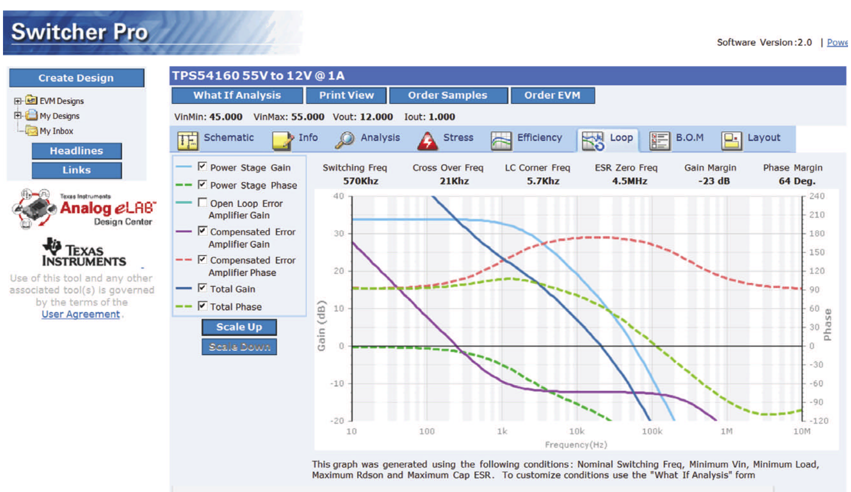


Figure 4 Texas Instruments' new SwitcherPro design software works both online and as a downloadable executable for your computer.

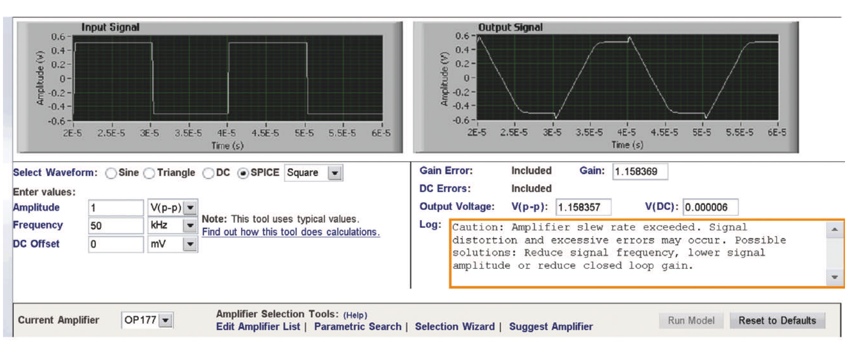


Figure 5 Analog Devices' ADIsim warns you if you have created a condition in which the design would not work.

Semiconductor's lead. For example, Texas Instruments offers both a selector guide and the downloadable Tina-TI Spice program. TI developed Tina-TI Spice in partnership with DesignSoft, which offers the Tina simulator. In addition, TI offers the downloadable FilterPro filter designer, a mathematical-analysis program that indicates the theoretical performance of filters using characteristics about their passive components and amplifiers. TI also offers the online or downloadable SwitcherPro switching-power-supply designer (**Figure 4**). With the tool, engineers who are not working online can continue to design their circuits. Both the downloadable and the online versions of the tool offer approximately the same speed, according to Rich Nowakowski, a TI product-marketing engineer.

To complement this power-supply-design program, the company also offers the downloadable ADCPro, ClockPro, and MDACBufferPro programs for multiplying DACs and publishes a variety of simple online tools to help you design electronic systems. For example, the JavaScript-powered, four-band-color-coded calculator illustrates a conventional through-hole resistor and lets you identify the color bands using drop-down menus. The program then gives you the value of the resistor with that color code.

TI has also developed dozens of online calculators to help you with everything from choosing two standard resistors to achieve a user-specified voltage-divider value to more complicated tasks, such as calculating the component values to design a single-ended to fully differential amplifier circuit. Rounding out TI's offerings are downloadable tools for calculating ISM (industrial/scientific/medical)-band loop filters and programs for selecting the component values for buck-switching regulators.

Another successful analog company offering online tools, Analog Devices, has teamed up with test-and-measurement powerhouse National Instruments to create the ADIsim online-design program to help you design op-amp and switching-power-supply circuits (**Figure 5**). Invoking two levels of calculations, the tool helps you select parts and then calculates the performance of a circuit

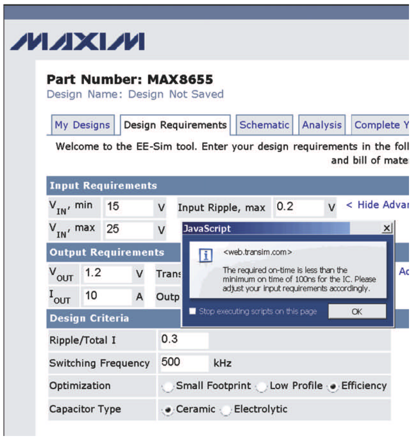


Figure 6 Maxim's EE-Sim provides a dialog box to warn you that the circuit will not work unless you change the specifications or the part.

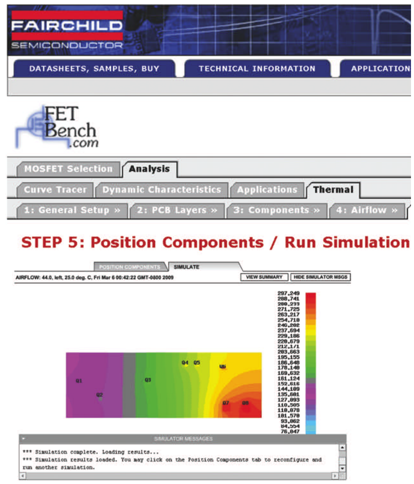


Figure 7 Fairchild's FETBench lets you see thermal performance on a PCB that you specify.

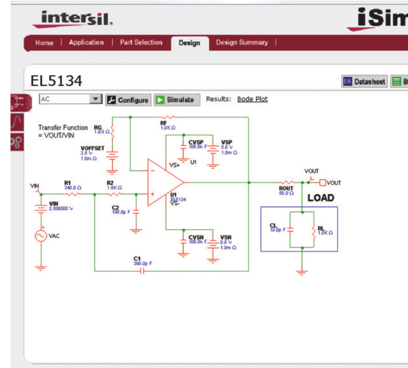


Figure 8 Intersil's iSim program can help you design both switching power supplies and amplifier circuits.

from specific design equations. Once you are happy with this approximation, you can invoke a full Spice simulation that uses the Multisim simulator from National Instruments subsidiary Electronics Workbench. Analog Devices also lets you download a free version of Multisim that works with the company's parts. The company also offers the ADIsimDAC DAC-design tool and ADIsimRF, the downloadable version of which can help you calculate RF parameters, such as gain, noise figure, and power consumption. Another downloadable tool, ADIsimPLL, provides design help and evaluation for PLL (phase-locked-loop) design.

New to the online-simulation-tool-provider list is analog stalwart Maxim Integrated Products. Although the company has only recently begun to provide powerful online tools, it has made up for its late entry by getting many things right. As with most analog-semiconductor manufacturers, Maxim prefaced its online-design-tool development with an online-parametric-selection guide. The tool recalculates the screen and changes with the subsequent selection sliders whenever you make a selection, meaning that you will always have choices, according to Erin Mannas, the company's Web-content engineer.

Maxim also now provides the EE-Sim online-design environment (**Figure 6**), which the company envisions as a further step in product selection. Once you select a part that the software supports, you receive a link to start the EE-Sim application. As of March, the environment supported only four parts, but Maxim plans this year to add an array of supported parts. Rather than use a classic Spice engine, Maxim uses SIMetrix Technologies' Simplis. This package does not do matrix math in an iterative fashion like Spice. Instead, the models are piecewise-linear approximations of diode curves and transistor characteristics. The simulations run at high speed, more than making up for the small sacrifice in accuracy. According to Eric Schlaepfer, Maxim's strategic-application engineer, the program reaches results in 10 times less time than does a classic Spice program. You can download the program so you can work on simulations without hooking up to the Web. Like TI, Maxim offers a variety of simple design calculators, such as a tool for creating the data to drive a pattern generator for making waveforms.

The broad-market analog companies are not the only ones that provide you with design tools. Microchip, for example, offers MAPS (Microchip advanced parts selector), and Power Integrations offers the downloadable PIExpert tool to help you design switching power supplies, including high-power resonant supplies that also have PFC (power-factor correction). Fairchild offers the FETBench online program, which it developed with Transim Technology and which Intersil and NXP also employ. The FETBench environment can help you choose FETs; then, you can use Fairchild's Ansys-powered WebSIMThermal application to see the thermal performance of the part in a specified environment of board size, airflow, and part arrangement (**Figure 7**). Fairchild even lets you define your own parts so you can use this tool for any PCB thermal problem. Intersil offers the iSim Web tool, which helps you design and simulate power-supply and op-amp circuits (**Figure 8**). A downloadable version lets you capture schematics and evaluate circuit performance.

International Rectifier offers a suite of online-design tools that can help you design PFC circuits and simple buck regulators. These tools lack the ability to perform full thermal analysis, but they can save time when you need to design this type of circuit. When you hit the "analyze" button, the application generates a PDF file of your design that you can submit to your manager or use in a design review. International Rectifier also offers calculators for motor control and downloadable software to help you design lighting ballasts, along with bus-converter-design assistants that pro-

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vide a selection of parts for various converter topologies, such as full-bridge, half-bridge, and forward converters. The company's Web site offers design support for the iMotion motor-control engine, which lets you develop custom control algorithms.

ASSURING YOUR SECURITY

Like all other professionals, engineers are very concerned about the security and privacy of their online data. Many companies make it easy to register for their tools. Maxim, for example, requires only an e-mail address and a password. Analog Devices, on the other hand, requires no registration to use its online tools. The company once tried requiring users to register, but users wouldn't stay at the Web site long enough to do so. "We could tell by click rate that a user would go to the registration page and then say 'to heck with it' and go away," says Dave Kress, director of application engineering. He estimates that the percentage of would-be customers bailing out before registering is 30 to 50%. "We felt that we were not getting the job done," he says.

The prominence of online-design tools is evident in the way that the major analog companies organize their home pages. For example, both TI's and Analog Devices' home pages have three broad categories—products, applications, and design support—with the support category leading to all their tools. Intersil's Web page has both product and design-resource columns. National Semiconductor has integrated Webench into its entire site, allowing you to enter the tool from the top down or from a part-specific area. Entering the tool from National Semiconductor's LM5574 part area calls up a function in Webench that lets you use a knob to dial in the efficiency or the size of the design.

Online and downloadable design tools are just two arrows in your quiver. Many analog companies also offer online Spice models, reference designs, IBIS (input/output-buffer-information) models, BSDL (boundary-scan-description-language) models, and technical libraries. For example, TI has introduced the E2E Community, allowing engineers to share their success stories and—just as important—their failures. Also, keep in mind that FAEs will help if you ask. A smart FAE is the best free design tool there is. **EDN**

REFERENCE

1 Rako, Paul; "Beyond Spice," *EDN*, Jan 18, 2007, pg 41, www.edn.com/article/CA6406716.

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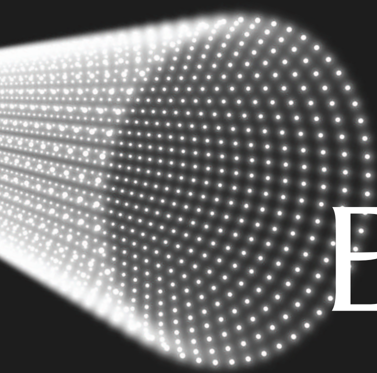
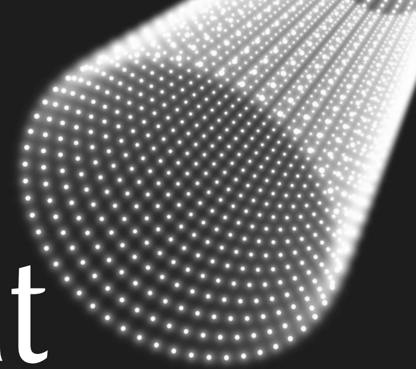

Enlightenment *on* LEDs

Practical, inexpensive HB LEDs (high-brightness light-emitting diodes) are here. Now, what can we do with them, and what will be their impact on electronics and consumers? With their promise of high efficiency, high reliability, and long life, HB LEDs are in the news because of the US government's push toward "greener" approaches to today's energy and economic challenges. Lighting currently accounts for 10 to 20% of all electricity use worldwide. A highly efficient, long-lived, and rugged SSL (solid-state-lighting) device, such as an HB LED, offers a new lighting technology that can reduce our energy usage without any painful habit changes in lighting. Is that the scenario that will occur, though? In the first article in this supplement, you'll read about the research of Jeff Tsao of Sandia National Laboratories. His research shows that lighting, rather than being based on consumers' needs, is a historically constant percentage of the GDP (gross domestic product). What are the implications of this finding, and how will the adoption of new lighting technologies play out worldwide?

HB-LED components do not exist in a vacuum; they require sophisticated current drivers to ensure that the multiple LEDs they employ have similar currents and thus create uniform light output. In addition, because of HB LEDs' susceptibility to damage from heat, thermal management is important. In another article, Jeff Perry, senior manager at National Semiconductor's Webench group, covers how to choose an HB LED and how to protect that device with temperature sensors that feed back to the current-drive circuitry.

John Betten, a long-time contributor to *EDN*, looks at a common power scenario for LEDs in which the input and output voltages around the HB-LED driver can overlap and are often "dirty" as they come off the ac line, as in automotive applications. He suggests an architecture that drives the LEDs negatively.

And Silvestro Fimiani, product-marketing manager at Power Integrations, suggests that careful attention to power conversion, and especially to PFC (power-factor correction), is possible with careful electronics power conversion for current control of an incandescent-lamp replacement. (The Energy Star draft for SSL will probably mandate this PFC requirement.)

—Margery Conner, Technical Editor

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OVTL01 Watt Optimal I Series

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OVQ Series

This LED light strip is a flexible and scalable lighting solution using high brightness LEDs. Up to 16 feet (5 meters) can be operated with a single 12V power supply. Dual-sided tape provides easy installation in most indoor applications and allows for many different configurations.

Features:

- Operating life longer than fluorescent and incandescent light sources
- Easy installation in most indoor applications
- Low power consumption
- Environmentally friendly light source (no mercury)

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Model ILL5A0002

The ILL5A0002 is a fully integrated power strip module with driver electronics and a heat sink. This module is rugged and sealed with similar outputs to that of a 20-watt incandescent bulb. With its low-power consumption of less than 6 watts, it is ideal for architectural, track, point of purchase, cabinet, display, vehicle interior and outdoor lighting applications.

Features:

- No IR or UV emissions
- Shock and vibration resistant
- 50,000 hour operation life

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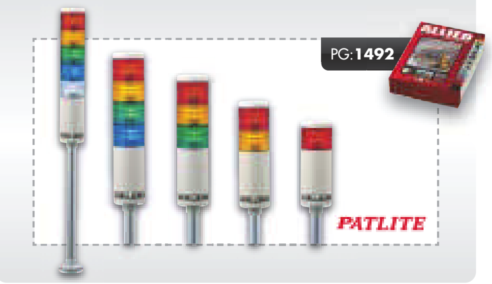

LME Series

The LME 60 mm diameter light tower series is interchangeable and stackable. The units are completely pre-wired and pre-assembled for easy installation.

Features:

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- Ultra bright LEDs
- Fast and easy assembly
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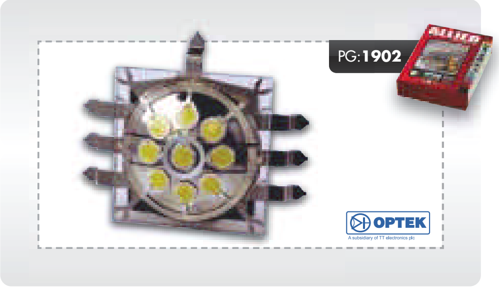

OVTL09 10-watt Optimal X Series

This exceptionally bright 10-watt, nine LED assembly features a compact energy efficient design. This 3-dimensional domed lead-frame device offers low thermal resistance, enabling full-power LED operation with a long lifespan.

Features:

- High luminance up to 423 lumens
- Offers 120° viewing angle
- Low thermal resistance (2.5°C/W)
- Exceptional spatial uniformity

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What are the advantages of LEDs?

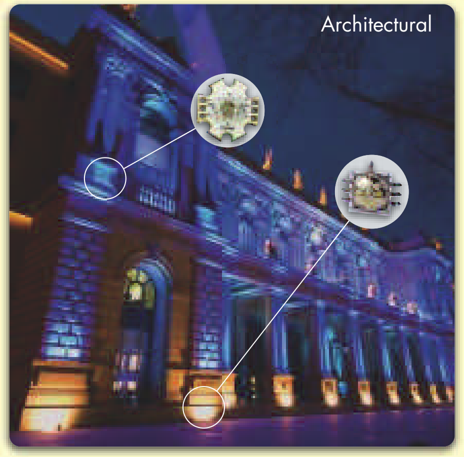
Excellent Control for Exciting Designs
LEDs provide almost limitless choice of light. Color, intensity and distribution are beyond anything possible with traditional light sources.

Reduced Energy Consumption
LEDs can be as much as 20 times more efficient than incandescent lights and five times more efficient than fluorescent lighting, leading to substantial energy savings.

Improved Reliability
Unlike light bulbs, LEDs gradually dim over time but don't blow. Most single color LEDs can exceed 50,000 hours, with some offering over 100,000 hours of use.

Tough and Durable
Being a solid-state device, LEDs are highly resistant to vibration, offer long life and can be encapsulated into weather-proof housings, making them ideal for indoor and outdoor use.

Lower Maintenance Costs
Expensive maintenance work is not required with solid-state lighting systems. Delivering continuous life and no need for replacement, LEDs are ideal for inaccessible applications.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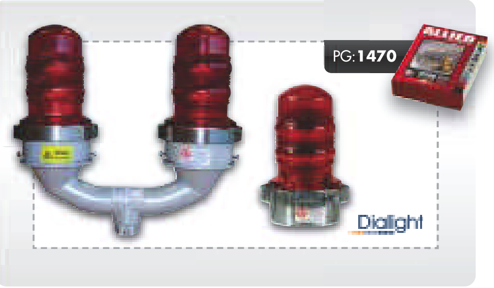

860 Series

The Dialight 860 Series is the FAA type L810 obstruction light. Designed for steady burning, this fixture is used to mark obstructions that may present hazards to aircraft navigation. The LUXEON® LEDs have a life span around 100 million hours with low lumen maintenance.

Features:

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LED Spotlight Engine

Features:

- Low power consumption – less than 6 watts
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- No IR or UV emissions
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Light Line ILL6A08A

Features:

- 18" LED strip light complete with mounting base, screw holes and lens
- Two versions - cool white and warm white
- 12 volts

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Optimal IV Star Series

Features:

- Four individually addressable LED die in a star package
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OVM18F4 Series 4-LED Module Strings

Features:

- Low power consumption
- Rated for 18V power supply
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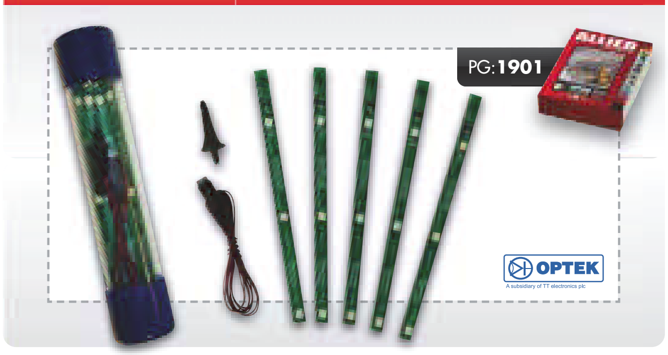

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This self-contained kit enables designers to configure LED placement for uniform illumination in any application. It is a flexible and scalable solution that provides high luminous flux with no additional heatsink requirements.

Includes:

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- Hand insertion tool for terminating wire harness to PCBs

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Complete LED Solution

LED Design Kit

This plug and play kit is perfect for testing a variety of different lighting options. The modules offered in this kit are ideal for illuminating small and medium size areas at close or long distances where lighting intensity and reliability are essential.

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MARGERY CONNER TECHNICAL EDITOR

Solid-state lighting and efficiency from a global perspective

What is the world's appetite for light? What if an increase in lighting efficiency does not result in less energy consumption but in more lighting for the same amount of energy? Jeff Tsao, a researcher at Sandia National Labs who studies the technology and economics of lighting, posed this question at the opening session of the Strategies in Light conference last February. Tsao examined data on the worldwide consumption of artificial light for the past 300 years, which covers the introduction of candle, kerosene, gas, incandescent, and fluorescent/high-intensity-discharge lighting.

Over the past 300 years, the world has spent a constant 0.72% of its GDP (gross domestic product) on artificial lighting. This observation translates in the United States to the equivalent of 17 100W light bulbs turned on per capita, per waking hour. Africa's usage equivalent is one 0.5W light bulb burning for every person's waking hours. (Tsao notes that this 0.5W light consumption is the same as the amount that the citizens of London used in 1850.)

This relationship between GDP and lighting usage accounts for increases in the COE (cost of energy) because COE affects the lighting-usage equation by driving down the GDP. That is, people consume less energy for lighting only if the COE increases or their standard of living in general decreases, not because lighting becomes more efficient. As lighting becomes more efficient—that is, cheaper—then lighting usage increases. This conclusion follows intuitively from knowing that, in general, people consume more as costs go down. So, the move toward LED-based SSL (solid-state lighting) may be an effective strategy for lowering energy consumption, but only if it's paired with an increase in productivity.

COE plays a major role in GDP, but it's not the only factor: Another way to increase GDP is to become more productive. Throughout history, lighting has helped productivity. As lighting technology advanced—from kerosene to gas lamps to electricity—lighting became cleaner, light sources took less time to turn on and off, light-induced heat decreased, and fire hazards decreased. The conclusion Tsao reaches is that efficiency alone does not result in a decrease in energy consumption. An increase in productivity must accompany that efficiency.

Here's a likely conclusion we can draw based on this study: The killer app for LEDs won't be a replacement bulb for 40W home lights because that application won't increase anyone's productivity. Rather, the opportunities for LED lighting will be in applications that have inherent intelligence and can interact with their environments and humans in ways that make both more productive and intelligent.

I discussed Tsao's study in my Feb 22, 2009, *Power-Source* blog (see "LEDs for lighting: Efficiency is not enough," www.edn.com/090409leda). Many readers posted comments, some agreeing and some disagreeing with Tsao's conclusions. Several readers and people at the conference who had heard Tsao's presentation assumed that, by making people more productive, LED lights automatically conserve energy, such as when you network them to automatically turn on and off or dim during premium energy-usage periods. Based on the connection of productivity to GDP, however, it seems more likely that Tsao was referring to LED systems that directly and significantly affect human work output.

"Think … about the undeveloped world not currently on grid electricity, [often] using kerosene lamps and hardly consuming light at all [compared with] the developed world," he says. "Their productivity would be increased in so many ways … if they had access to more light." Clearly, Tsao believes that a direct connection exists between access to clean, safe, efficient light and quality of life.

Undoubtedly, the affluent, light-rich world would benefit from the coming shift to SSL. But that benefit will be nothing compared with families and workshops in undeveloped countries, who will no longer have to use dangerous, expensive kerosene lighting to finish a day's work or start a night's schoolwork.

If you're interested in how LEDs will acquire intelligence and enhance productivity, consider attending *EDN*'s free Designing with LEDs workshop, which will take place on April 30, 2009, at the Hyatt Regency in Santa Clara, CA. Go to www.edn.com/leds for more information.

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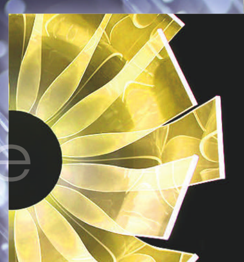

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BY JEFF PERRY, NATIONAL SEMICONDUCTOR

A fail-safe approach to LEDs

Choose the right high-brightness LED and protect it from overtemperature conditions.

Spurred by the increasing cost of energy and concerns about climate change, governments and industry are pushing for higher-efficiency lighting. HB LEDs (high-brightness light-emitting diodes) provide an excellent option due to their high efficiency and long lifetime. At the same time, LED technology is undergoing a period of rapid change and innovation.

Fortunately, online tools for LED selection and implementation make it easier to choose an LED and an LED driver. But, even with these tools, the user should have an understanding of the parameters affecting LED selection.

The first step is choosing a color for the LED. Colored LEDs are characterized by their dominant wavelength and are available in wavelengths from UV (ultraviolet) to IR (infrared). Manufacturers specify white LEDs by their color temperature, with warm-white LEDs, often used for room lighting, in the 2800 to 3500K range. An ordinary tungsten-filament light bulb offers about 3000K. Also available are cool-white LEDs in the 6300 to 7500K area and white LEDs in the mid-range of 3600 to 6200K.

HOW BRIGHT SHOULD IT BE?

Luminous flux, in units of lumens, is the usual measurement for the brightness of LEDs. It indicates the amount of light emitted in the spectrum to which the human eye is sensitive. Table 1 shows typical luminous-flux values for some light sources.

HB LEDs typically have luminous-flux values of less than 100 lumens, although this figure is climbing rapidly. So designs typically combine LEDs into arrays to achieve higher brightness values. You can arrange multiple LEDs in parallel strings using one current-control driver, but doing so can lead to differences in brightness in the strings due to the slight variance in each LED's forward voltage and thus current in each string. Therefore, it is preferable to use LEDs in series for consistent brightness and color. However, the series voltage gets higher with more LEDs, affecting which driver topology you can use: buck or boost.

Also keep in mind that LEDs are directional in nature, according to the viewing angle, or the point at which the brightness falls to 50% intensity. In directional applications, the actual brightness you perceive will be higher than a point source of light with a spherical emission pattern. Conversely, if you desire a spherical emission pattern, you must design the array accordingly.

A measure of efficiency of lighting elements is luminous efficacy, which is measured in units of lumens per watt. With the explosion of LED R&D, parts with values of 75 lumens/watt are readily available, and LEDs with 115 lumens/watt are new

TABLE 1 TYPICAL FLUX VALUES FOR COMMON LIGHT SOURCES

Type	Brightness (lumens)
40W tungsten bulb	500
100W tungsten bulb	1500
25W compact fluorescent	1500
55W halogen auto headlight	1500
35W high-intensity-discharge auto headlight	3250
150W projector bulb	5000
180W low-pressure sodium streetlight	27,000

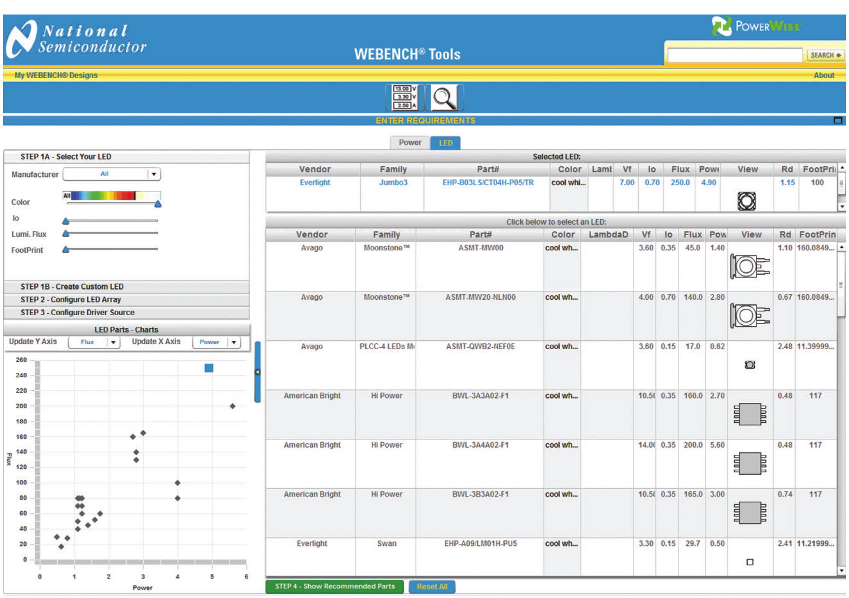


FIGURE 1 Comparing luminous flux with power aids in selecting the proper HB LED (courtesy National Semiconductor).

to the market. Tungsten-filament bulbs offer about 17 lumens/watt, CFLs (compact fluorescent lamps) offer 60 lumens/watt, and low-pressure sodium streetlights offer 100 to 200 lumens/watt (**Figure** 1).

The forward voltage of an LED is a characteristic of the manufacturing process; yellow/orange/red LEDs are in the 2 to 3V range, and blue/green/white LEDs are in the 3 to 4V range. The current through the LED controls the brightness and affects the color. Therefore, LEDs run in a constant-current mode. High-brightness LEDs typically come in currents of 0.35, 0.7, 1, 1.4A, and up. Also, consider the footprint and height of the LED. You must make provisions for heat sinking, which becomes vital in high-current applications. Cost is another critical parameter.

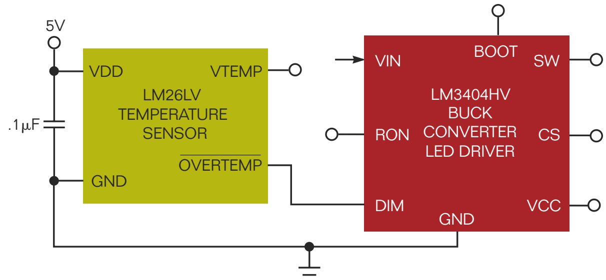


FIGURE 2 AN LM26LV silicon temperature sensor can sense an HB LED's overtemperature condition and throttle back the LM3404HV LED driver.

TEMPERATURE CONTROL FOR LEDs

Why do we need temperature control and monitoring for LEDs if they are supposed to be so efficient? Although LEDs are more efficient than tungsten-filament bulbs, they still generate a lot of heat. Incandescent lights generate heat that largely leaves the system as IR radiation. On the other hand, LEDs generate heat in the diode-semiconductor structure in addition to photons. This heat is not part of the radiated spectrum, and it must exit the system through conduction and convection.

If LEDs become hot, a number of issues arise. The brightness of LEDs decreases markedly with temperature. Also, the color of LEDs changes with temperature, which can lead to problems in applications that require consistent color integrity, such as RGB (red/green/blue)-generated white light. Electrical characteristics, such as the forward voltage of the LEDs, drift with temperature—a consideration when designing the driver circuitry. This change can also be an issue if the LEDs share current in parallel configurations. Constant exposure to high junction temperatures accelerates the degradation of LEDs and reduces their life and reliability. Thus, it is essential to design the system so it runs within the temperature specification of the LEDs. You normally accomplish this task using heat sinks, such as large copper areas on the PCB (printed-circuit board). You can also use attached-fin heat sinks, thermally enhanced/metal PCBs to mount the LEDs, or both. Forced airflow is also an option.

However, if an unusual event, such as extraordinary weather-related heat or the failure of a heat sink, occurs, you can implement a fail-safe mechanism. Most buck-topology LED drivers have thermal shutdown. Boost-topology drivers protect themselves but not the load when they shut down, so they require a crowbar circuit or other protection for LEDs. In any case, the LED temperature may be higher than that of the driver, and the LEDs thus require a temperature-sensor and monitoring circuit for fail-safe protection. This temperature-sensor circuit can reduce or turn off the current to the LEDs, turn on a cooling fan, or provide an alert mechanism to the user or maintenance personnel.

In general, temperature-sensor accuracy needs to provide enough margin to be able to detect an overtemperature problem but not trigger a false alarm under normal operating temperatures. For example, if a system is normally operating at as much as 80°C and you want to detect a fault condition at no more than 100°C, a temperature-sensor system with ±2°C accuracy set to trip at 98°C should be fine, but one with ±10°C accuracy set to trip at 90°C would be marginal.

Discrete temperature sensors appropriate for LEDs include thermistors, which change resistance as the temperature changes. Thermistors are inexpensive and have high sensitivity but are nonlinear and require initial calibration. They are available in the desired temperature range of 50 to 150°C. Another choice is a thermocouple. The voltage of these sensors changes as the temperature changes; they also generate a current, so they may not require a power source. They are less sensitive than thermistors but good enough for LED use. They come in a range of temperatures, well beyond what LEDs require, and see wide use in other applications. They cost more than thermistors. Both of these sensors require some analog circuitry either to interface with a microcontroller, which then can take action to correct the temperature problem, or to interface directly to the LED driver through a shutdown or dimming pin.

Silicon temperature sensors, which come in ranges of −50 to +150°C, are also useful for LED applications. These inexpensive sensors provide a variety of options, including analog-voltage output, which is proportional to temperature; temperature-triggered on/off output with hysteresis; and fan control.

TEMPERATURE-SENSOR APPLICATION

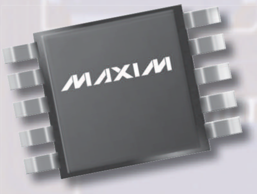
Figure 2 shows a simple circuit for interfacing a silicon temperature sensor directly to a buck-LED driver. The temperature sensor should be as close as possible to the LEDs. In this circuit, the Overtemperature pin of the temperature sensor is normally high when the temperature is below the specified value, but the pin goes low when the temperature is high, thus shutting off the LED driver through the Dim pin. When using the sensor's hysteresis feature, as the temperature goes back 5°C below the specified value, then the Overtemperature pin goes high, and the LED driver turns back on.

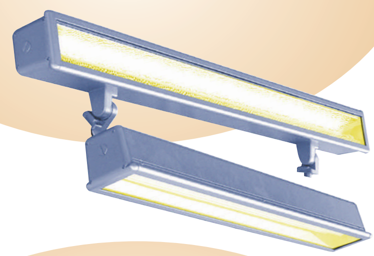
More sophisticated systems can proportionally reduce current to the LEDs without shutting them down as the LED temperature rises above a threshold. Alternatively, they can turn on a fan and increase speed after the LED temperature exceeds the specification. None of these systems are a substitute for good thermal design for the LEDs, but you can use them as a fail-safe shutdown to enhance LED life and reliability when the normal thermal controls fail.

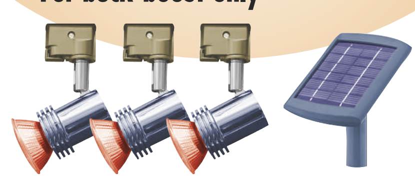
Acknowledgment

The author would like to acknowledge the help of Denislav Petkov, Wanda Garrett, Kristen Elserougi, and Emmy Denton.

Jeff Perry is the senior manager of the Webench online-design-tools group at National Semiconductor.







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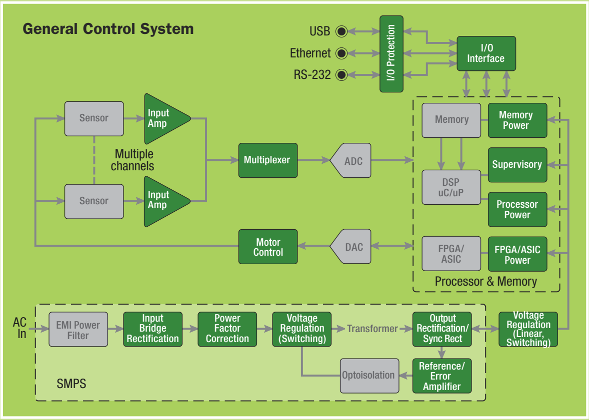

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BY JOHN BETTEN, TEXAS INSTRUMENTS

Inverting buck-boost converter regulates LED current

When input- and output-voltage ranges overlap and are "dirty" to boot, consider biasing on LEDs with a negative voltage.

Controlling the brightness of LEDs requires a driver that provides a constant, regulated current. To achieve this goal, the driver topology must be able to generate a large enough output voltage to forward bias the LEDs. So, what are your choices when the input- and output-voltage ranges overlap? In one case, the converter may need to step down the input voltage, and, in another, it may need to boost up the output voltage. These situations often arise in applications with wide-ranging "dirty" input-power sources, such as automotive systems. Several topologies work well in this buck or boost roll, such as the SEPIC (single-ended-primary-inductor converter) or a four-switch buck-boost converter. These topologies generally require a large number of components, increasing the materials cost of the design. Although most experts consider these choices acceptable, the converters provide positive output voltages. A negative-output voltage converter, however, can provide an alternative that you should not overlook.

Figure 1 shows the schematic of an inverting buck-boost circuit driving three LEDs in a constant-current configuration. This circuit has several positive attributes. First, it uses a standard buck controller, minimizing cost and facilitating possible system-level reuse. You can easily adapt this circuit to use an integrated FET buck controller or a synchronous-buck topology for improved efficiency. This topology uses the same number of power-stage components as a simple buck converter, thereby realizing the fewest components for a switching regulator and the lowest overall cost compared with other topologies. Because the LED output is light, it may not matter from a system level that the LEDs are biased on with negative rather than positive voltage.

The system regulates LED current by

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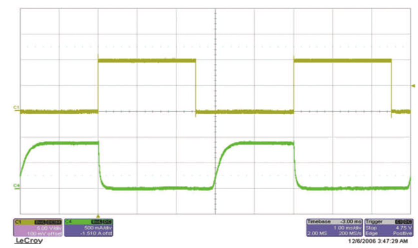

FIGURE 2 Shorting the soft-start capacitor to ground allows the PWM drive (top) to dim the LED by decreasing its current (bottom). For applications that don't require high-speed response or 100% PWM dimming, this method may suffice.

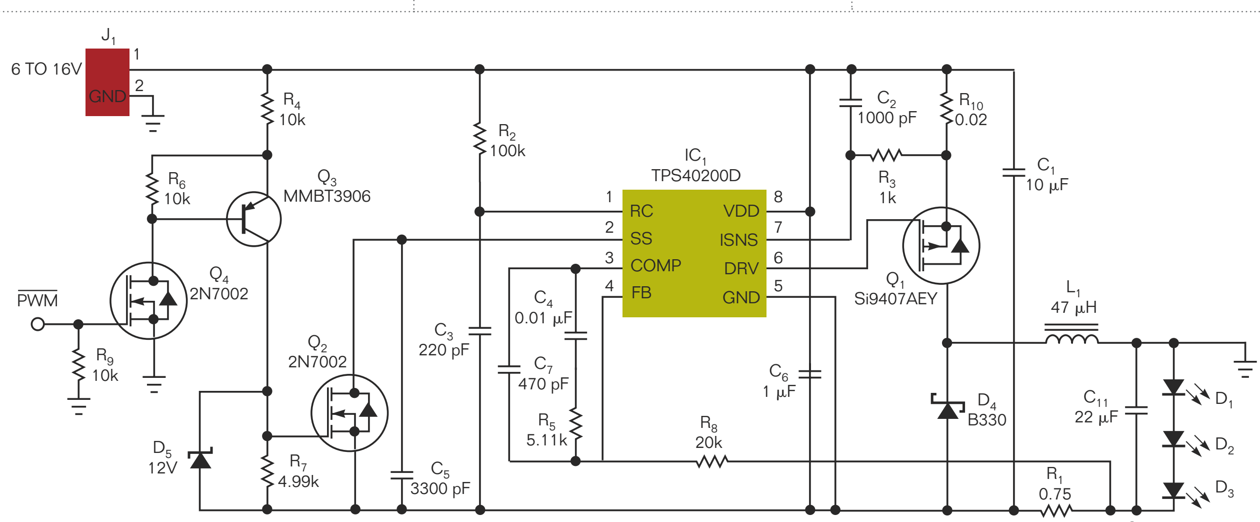

FIGURE 1 This buck-boost circuit regulates a constant LED current with a negative output voltage.

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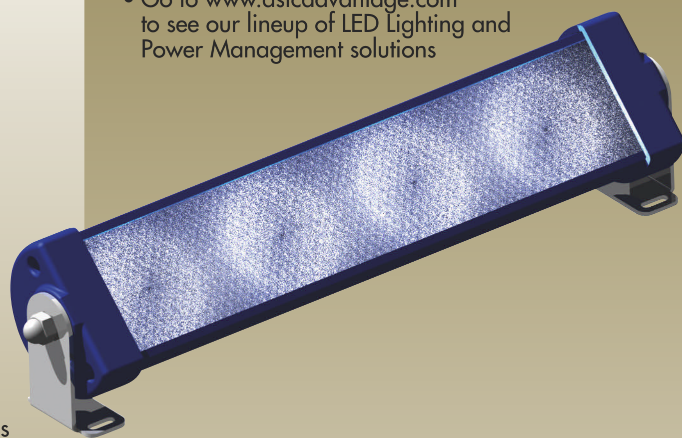

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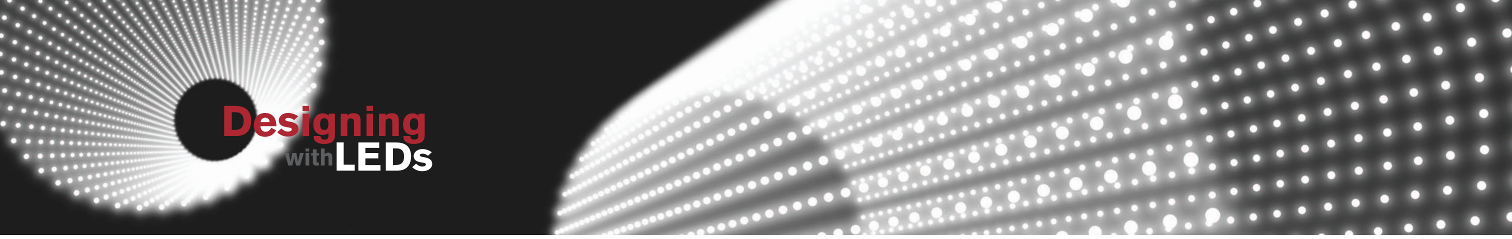

BY SILVESTRO FIMIANI, POWER INTEGRATIONS

Solving the LED-driver challenge for light-bulb replacement

The Department of Energy is offering a prize of as much as $10 million to create the first solid-state replacement for the 60W incandescent light bulb, so you know it's a problem. Here are some suggestions for how to address high-efficiency, power-factor, and phase-dimming-compatibility requirements.

The lighting industry is exploring ways to replace the standard 60W light bulb with a more energy-efficient, HB-LED (high-brightness-light-emitting-diode)-based design. LED lighting offers the prospect of a 10-fold efficiency improvement over incandescent lamps. With a potential lifetime of 100,000 hours, this improvement would virtually eliminate maintenance and replacement costs.

The US government has recognized the potential of LED lighting and intends ultimately to use LED lamps in all government buildings. To provide a stimulus for the development of LED lighting, the US Congress has mandated a prize of as much as $10 million for the first organization or individual to create and validate an LED-based screw-in replacement for the standard Edison-type, 60W incandescent bulb. The new bulb has to contain not only the LED chips, but also the driver circuitry—no easy challenge given the space constraints and potential electrical-noise issues. The lamp must achieve an efficacy of more than 90 lumens per watt, making power-supply performance critical to a successful design.

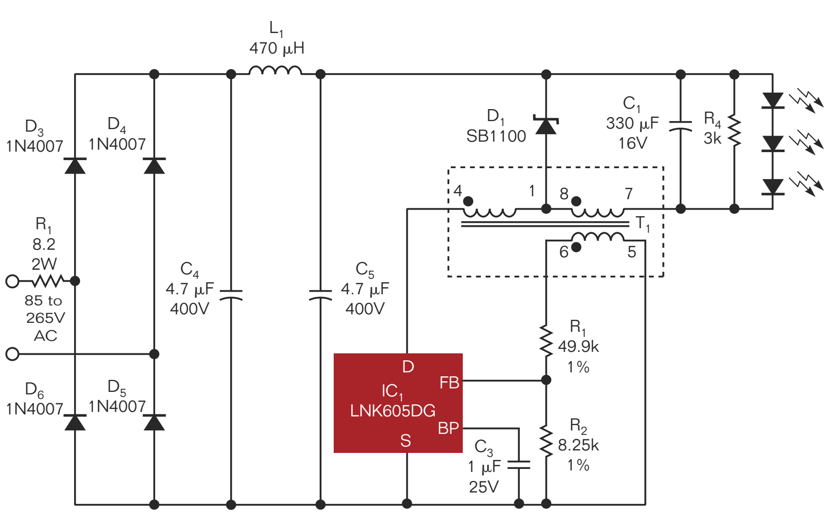

FIGURE 1 Power Integrations based this tapped-buck power supply on the LNK605DG switching IC, which uses just 16 components. This circuit operates over an input-voltage range of 85 to 265V ac, enabling the use of one lamp worldwide.

To provide an even spread of light, an LED lamp typically contains a dozen or more LEDs. The brightness of LEDs is a function of current flow, and LEDs have a typical threshold voltage of 3.4V, with a variation from 2.8 to 4.2V. The LEDs in a lamp connect in series strings, presenting the power supply with a CC (constant-current)-drive requirement across a potentially wide voltage range.

Several companies have recently developed primary-side switch-mode-control configurations, an example of which is the tapped-buck topology (**Figure 1**). The key advantages of the tapped-buck topology are that it lends itself to a smaller PCB (printed-circuit board), a smaller inductor core, and greater efficiency—more than 80% for 4.2W—than an isolated flyback converter. EMI (electromagnetic-interference) filtering is also simpler due to less common-mode noise generation. In the tapped-buck topology, the load connects in series with the inductor—in this case, T_1 windings 1, 2, 3 4, 7, and 8—and the primary switching element, a 700V MOSFET, which the SMPS (switched-mode-power-supply) controller, IC_1, incorporates. When IC_1, a Power Integrations (www.powerint.com) LNK605DG, turns off, the energy in T_1 induces a current to flow in the output winding (pins 7 and 8). The current in the output winding steps up by a factor of the inductor's turns ratio and flows from the output winding, through freewheeling diode D_1, and the load.

IC_1 switches at a rate as high as 88 kHz, minimizing the size requirements of the inductors and capacitors. In CV (constant-voltage) mode, the circuit generates 12V±5% to 350 mA when it switches into CC mode. This operating mode is the normal one for LED loads, and the circuit

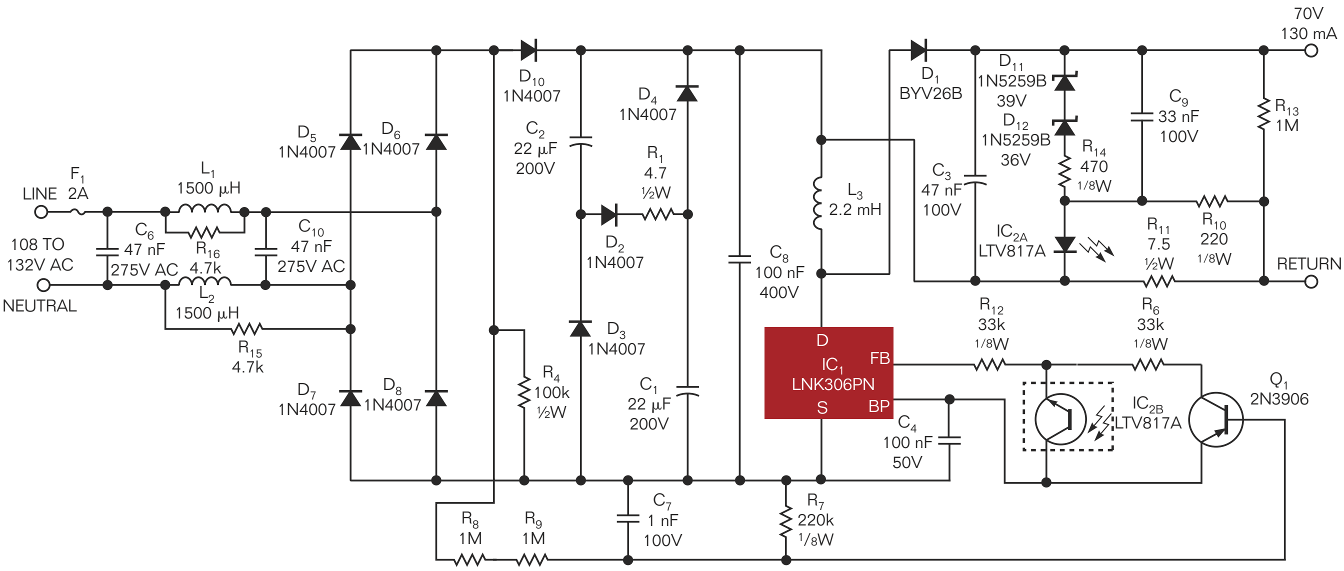

FIGURE 2 This 9W LED driver uses a valley-fill circuit for an improved power factor, which a draft version of the Energy Star requirements for solid-state lighting requires.

maintains 350 mA±10%. The key to this simple design is the control circuitry within IC_1. The circuit implements feedback control using only input from the bias winding (pins 5 and 6) in T_1. It requires no sense resistor to generate the CC output, and it needs neither an optocoupler nor secondary control circuitry. The control method compensates for variations in the inductor and other component tolerances and for input-voltage variations.

At the beginning of each switching cycle, IC_1 switches on, and current ramps up until it reaches IC_1's current limit, when the switch in IC_1 turns off. With IC_1 off, the energy in T_1 induces a current to flow in the output winding, not only maintaining the current through the load, but also stepping it up by means of the turns ratio. Capacitor C_1 filters the load current and removes the switching component. The on/off-control-state machine and switching frequency vary in response to the feedback voltages at the FB input. In CC mode, as the output voltage and, therefore, the flyback voltage across the bias winding increase, the feedback-pin voltage increases. This increase produces a reduction in the switching frequency, thus providing a constant output-current regulation. In CV operation, the controller regulates the output voltage using the on/off-state machine.

The CV characteristic of IC_1 operates at start-up as the IC ramps up to CC mode and ensures output-overvoltage protection. A fault condition can cause the part's die temperature to rise to more than a nominal 142°C, initiating a hysteretic thermal shutdown. The circuit is an efficient and effective approach to powering a plug-in Edison-replacement LED lamp, providing compliance with EMI standard EN (European Norm) 55015 Class B, with 10 dB of margin. At this power level, you can implement the Energy Star requirements for power-factor control using a valley-fill circuit (**Reference** 1 and **Figure** 2). Note that this circuit introduces additional passive components that increase the board size and, more seriously, reduce conversion efficiency.

A PFC CIRCUIT GIVES THE SUPPLY A POWER FACTOR GREATER THAN 0.92, WHICH MEETS THE REQUIREMENTS OF ENERGY STAR SSL FOR COMMERCIAL APPLICATIONS.

Energy Star recently introduced a proposal that SSL (solid-state-lighting) replacement lamps should be dimmable (**Reference** 2). Adding this function would require additional circuitry and would have a negative impact on efficiency. You can add the dimming capability by introducing a circuit to detect the phase of the rising edge that the SCR (silicon-controlled rectifier) generates, but you must carefully perform this task to ensure compliance with power-factor and harmonic-current limits. A buck-boost circuit can meet these requirements. The buck-boost supply provides a CC output as high as 9W at a maximum output voltage of 70V dc from 108 to 132V ac and includes phase-detection logic for use with SCR dimmer controls. A passive-valley-fill PFC (power-factor-correction) circuit gives the supply a power factor greater than 0.92, which meets the requirements of Energy Star SSL for commercial applications. The high-output-voltage design helps to boost efficiency and compensate for additional losses due to the valley-fill circuit. The supply also meets EN 55015B EMI requirements.

In this circuit, switching controller IC_1 uses an on/off control. Current-sense resistor R_{11} generates a voltage across the diode of optocoupler IC_{2A}. This feedback signal goes to IC_1's FB pin through IC_{2B} and R_{12}. D_{11}, D_{12}, and R_{14} clamp the output voltage under no-load conditions to approximately 80V, achieving a CV/CC characteristic. The phase-detection logic takes advantage of the on/off control to use the SCR phase angle to inhibit switching, thereby reducing the load current and accomplishing dimming. D_{10} isolates the

line voltage from the bulk capacitors, thus allowing you to obtain conduction-angle information. R_7, R_8, and R_9 form a voltage-divider network. C_7 averages the voltage across R_7. As a dimmer reduces the line voltage, the voltage across C_7 also decreases. This reduction in turn reduces the voltage on the base of Q_1 to less than 5.1V, at which point Q_1 turns on, pushes current into the FB pin, and inhibits switching.

D_2, D_3, and D_4, along with C_1 and C_2, form the valley-fill circuit and provide power-factor correction. The valley-fill circuit shapes the input current to improve the power factor. C_1 and C_2 charge in series as the line voltage rises and discharge in parallel when it falls. Thus, input-current flow remains the same from 30 to 150°C and 210 to 330°C. This continuous current greatly improves the system's THD (total harmonic distortion) and power factor.

These applications illustrate two approaches to implementing an LED replacement for the standard incandescent light bulb. The first example requires few components and produces a universal lamp for all supply voltages. The second application adds a dimmable lamp and perhaps a more compatible replacement for the standard light bulb. Although more complex, it is still capable of better-than-85% efficiency at full load. Alternative approaches to dimming, such as three-wire systems or replacing SCR dimmers with IGBTs (insulated-gate bipolar transistors), offer less compatibility but are more technically elegant and efficient. For further information on power supplies for LED lighting, see **Reference** 3.

References

1 "Energy Star Program Requirements for Integral LED Lamps, Draft 1-16-09," Jan 16, 2009, www.energystar.gov/ia/partners/prod_development/revisions/downloads/lighting/ESIntegralLampsCriteria_Draft1.pdf.

2 "Low-Cost Dimmable LED Ballast Using the Valley-Fill Current Shaping Circuit," Power Integrations Inc, www.powerint.com/sites/default/files/PDFFiles/di171.pdf.

3 "LED Driver ICs," Power Integrations Inc, www.powerint.com/applications/led-lighting.

Silvestro Fimiani is product-marketing manager of appliance and industrial applications at Power Integrations. Before joining the company in 2005, he served as director of engineering of high-power products at International Rectifier. He holds a bachelor's degree in physics from the University of Naples (Italy).

CONTINUED FROM PAGE 31

sensing the voltage across sense resistor R_1 and using it as feedback to the control circuit. For this direct feedback to work properly, you must reference the controller's ground pin to the negative output voltage. Referencing the controller to system ground would require a level-shifting circuit. This "negative ground" places several restrictions on the circuit. The power MOSFET, diode, and controller must have a higher voltage rating than the sum of the input and the output voltage.

Second, external interfacing with the controller, such as enable, requires level-shifting the signal from system ground to controller ground, resulting in additional components. For this reason alone, it is best to eliminate or minimize the use of unnecessary external controls.

Finally, an inverting buck-boost converter places additional voltage and current stresses on the power devices compared with a four-switch buck-boost circuit, reducing relative efficiency. But the stresses are comparable to that of the SEPIC. Even so, this circuit achieved 89% efficiency. You can achieve additional improvements of 2 to 3% by making the circuit fully synchronous.

A simple way to dim the intensity of the LEDs is by rapidly turning the converter on and off via shorting out soft-start capacitor C_5. **Figure** 2 shows the PWM input signal and the actual LED current. This PWM-dimming technique is efficient because the converter is off and consumes little power when the SS pin is shorted. But this method is also relatively slow because the converter must ramp the output current up in a controlled fashion each time it goes on, introducing a nonlinear, finite dead time before the output current rises. This action also reduces the minimum on-time duty cycle to 10 to 20%. In LED applications that do not require high-speed and 100% PWM dimming, this method may suffice.

This inverting buck-boost circuit provides an additional option for driving LEDs. Using a low-cost buck controller and a few parts makes this alternative suitable for more complex topologies.

John Betten is an application engineer and senior member of the technical staff at Texas Instruments and has more than 23 years' worth of ac/dc- and dc/dc-power-conversion-design experience. Betten received his bachelor's degree in electrical engineering from the University of Pittsburgh and is a member of IEEE.

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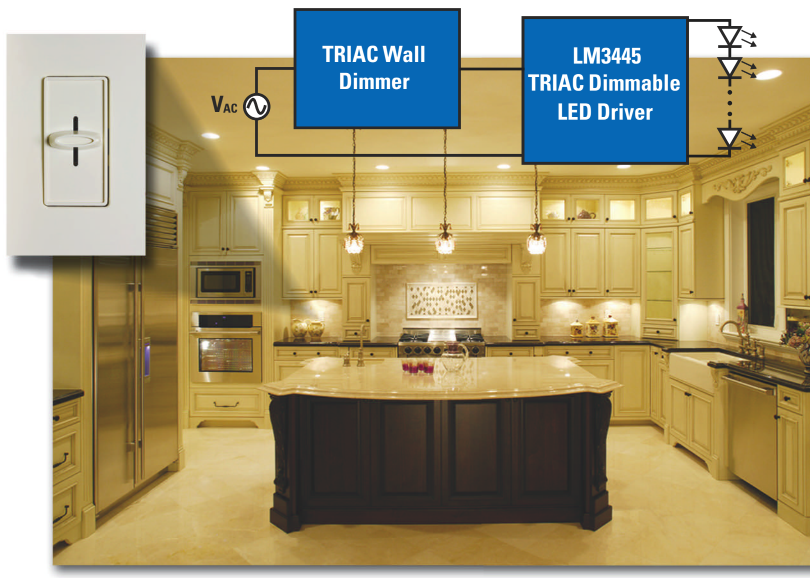

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BY STEVE SCHEIBER | CONTRIBUTING TECHNICAL EDITOR

4G TELECOMMUNICATION TECHNOLOGY CARRIES EXPLICIT REQUIREMENTS FOR MINIMUM NETWORK SPEED. DESIGNERS MUST FIND A WAY TO RELIABLY AND COST-EFFECTIVELY REACH THOSE TARGETS.

GETTING TO 4G THROUGH DESIGN AND TEST

As TODAY'S telecommunication technology proceeds forward to 4G (fourth generation), it requires a minimum network speed of 100 Mbps in high-mobility situations and 1 Gbps in low-mobility scenarios. The goal might seem more manageable if 4G represented an ultimate goal—that is, a finish line. Instead, it is only the latest point in a continuum that stretches beyond the foreseeable future (**Figure 1**). Whatever level of performance engineers can deliver, customers will find reasons to demand more. In short, data expands to fit the available bandwidth. In other words, if you build it, the data will come, and the infrastructure to support that performance must also evolve.

In addition, 4G designers using 3G (third-generation) technology as a base find themselves shooting at a fixed target from a moving train. Enhancements to 3G, including 3.5, 3.75, and 3.9G, do not erase the line that separates them from the Holy Grail of 4G but may reduce the appeal of the generational transition. Adding to the mix are the two primary flavors of 4G, based on LTE (long-term evolution) and WiMax (worldwide interoperability for microwave access).

BUMPING AGAINST THE STANDARDS

The ITU (International Telecommunications Union) describes 4G's proposed key features, most of which leave much room for maneuvering. The ITU calls for worldwide commonality and compatibility, interoperability with other radio-access systems, user-friendly applications, and the like, describing a range of actions rather than a standard for compliance. Only the target speed truly represents a sharp departure from its predecessor. Hence, designers are tempted to implement some of the anticipated 4G features and declare intermediate generations that remain short of true 4G.

Even the target speed to qualify as 4G isn't set in stone. The 1-Gbps speed is not only limited to low-mobility or stationary applications, but also requires ideal radio conditions and, more significant, as much as 100 MHz of bandwidth. The frequency spectrum is sufficiently crowded that myriad 100-MHz-wide bandwidth


TEST

bundles may prove difficult to find. Not everyone even agrees on what 4G is. Whether a configuration qualifies may depend on the agenda of the person you are asking. Mark Buffo, director of business development for Keithley Instruments, considers the current use of the term to represent more marketing than technical specification. "Some existing technologies will coalesce into 4G," he says. "They may not start out with all of the theoretical functionality, evolving over time. Right now, what a lot of people are describing as 4G does not actually represent a uniform and consistent level of performance."

The two leading candidates for 4G have somewhat different pedigrees. The developers of so-called LTE-Advanced based the technology on UMTS (universal mobile-telecommunications system), which the 3GPP (Third Generation Partnership Project) defines. "Officially, LTE is still a 3G standard, despite the fact that people refer to it as 3.9G and that it has nothing in common with UMTS," says Moray Rumney, lead technologist with Agilent Technologies. LTE-Advanced's developers in December 2008 froze the standard for base stations, network infrastructure, and other centralized functions and plan a proposed standard for Release 10 of the 3GPP specifications in September 2009. The group intends LTE-Advanced to be compatible with LTE and other earlier technologies to ease the transition. One goal of the transition will be to simplify the system architecture and the maintenance requirements to reduce costs, according to Phil Medd, product manager for UMTS test systems at Aeroflex's Test Solutions, Wireless Division. The backward compatibility will facilitate that effort. "LTE initially will be a data-only service," he says. "Users will continue to access conventional GSM [global-system-for-mobile communication] for transmitting voice."

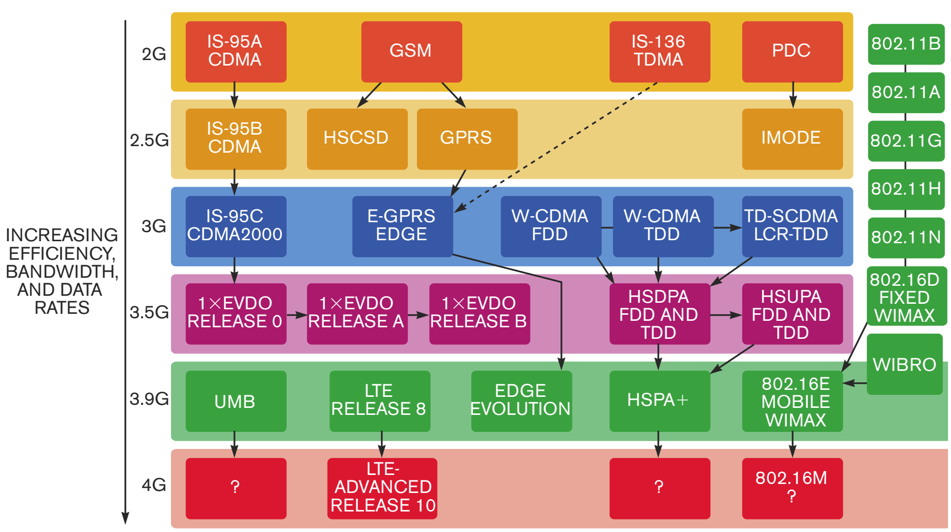
AT A GLANCE

- The 1-Gbps speed of 4G (fourth-generation) technology is not only limited to low-mobility or stationary applications, but also requires ideal radio conditions and as much as 100 MHz of bandwidth.
- The two leading candidates for 4G—LTE (long-term evolution)-Advanced and WiMax (worldwide interoperability for microwave access)—have somewhat different pedigrees.
- The realities of the infrastructure and the economics of managing a major transition mean that 4G adoption will prove slower than its proponents might like.
- The transition to 4G will require multiband transmission and reception, increasing power consumption.

WiMax evolved from the IEEE 802.11 WLAN (wireless-local-area-network) standard. The 4G Mobile WiMax will come in the form of IEEE 802.16m, which in turn came from 802.16e. The differences between the two 4G technologies reflect their origins. "WiMax is trying to establish a broad standard," says Keithley's Buffo. "LTE is more focused. LTE comes from the telecommunications world, whereas WiMax comes from data communications." Many of the larger service providers, such as Verizon, have committed to adopting the LTE version of 4G. Some of the smaller players, including Sprint, have opted for Mobile WiMax.

Design engineers may have a hard time navigating this uncertain environment. They should remember, however, that their world is far removed from the pronouncements of the standards bodies, according to David Hall, a product manager at National Instruments. The standards establish higher data rates as their ultimate goal. He suggests that cellular systems are so complex that few engineers will base their designs on that criterion alone, preferring to rely on such metrics as better power-amplifier efficiency, EVM (error-vector magnitude), adjacent-channel power, quadrature skew, noise figure, and sensitivity. "In the end, the winning 4G technology will be determined more by a handshake than a field test," says Hall.

Lynne Patterson, a business-development manager for wireless-infrastructure test-and-measurement products at Anritsu, contends that the relative success of LTE-Advanced and Mobile WiMax will differ from country to country. "Currently, North America doesn't need the broadband access that Mobile WiMax is offering," she says. "Here,



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GPRS: GENERAL PACKET-RADIO SERVICE
GSM: GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS
HSCSD: HIGH-SPEED CIRCUIT-SWITCHED DATA
HSDPA: HIGH-SPEED DOWNLINK-PACKET ACCESS
HSPA: HIGH-SPEED PACKET ACCESS
HSUPA: HIGH-SPEED UPLINK-PACKET ACCESS
IS: INTERIM STANDARD
LCR-TDD: LEAST-COST ROUTING/TIME-DIVISION DUPLEX
LTE: LONG-TERM EVOLUTION
PDC: PERSONAL DIGITAL CELLULAR
TDD: TIME-DIVISION DUPLEX
TDMA: TIME-DIVISION MULTIPLE ACCESS
TD-SCDMA: TIME-DIVISION SYNCHRONOUS-CODE-DIVISION MULTIPLE ACCESS
UMB: ULTRAMOBILE BROADBAND
WCDMA: WIDEBAND-CODE-DIVISION MULTIPLE ACCESS
WIBRO: WIRELESS BROADBAND
WIMAX: WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS

Figure 1 Wireless-telecommunications technology will have advanced dramatically by 2010 (courtesy Agilent).

we can already access broadband communications easily. In parts of the world that don't have immediate access to either fixed or mobile broadband, however, Mobile WiMax offers significant advantages."

Implementing the next big step may be tempting. The realities of the infrastructure and the economics of managing a major transition, however, mean that 4G adoption will prove slower than its proponents might like. In 112 countries, 252 operators have adopted HSPA (high-speed packet access), the 3G technology that currently provides the highest available mobile bandwidth. Even if 4G represents the revolutionary advance that its supporters claim, it must overcome a great deal of inertia to displace that sizable installed base. Verizon, for example, has committed to deploy some small LTE-Advanced systems later in 2009 and to launch commercial service in 2010.

In addition, achieving simplicity of architecture may prove elusive. "For the foreseeable future, handset manufacturers will have to provide triband and quadband phones that can handle, say, European and US versions of GSM," says Keithley's Buffo. "Users will demand seamless transitions. The devices themselves will have to figure out which band they need to address in real time."

Figure 2 Test equipment such as the Rohde & Schwarz radio-communication tester plays a prominent role in 4G technology.

SIZE MATTERS

Designing for this new world and verifying that the design works will depend heavily on the makeup of the telecommunications network itself. Whether a piece of equipment addresses the 700-MHz band, which analog-television stations are currently abandoning, or the 3.2-GHz band will determine the size of the antenna it requires and the effect of intervening objects, such as buildings or geographical objects in the signal's path, on its range. Lower-frequency signals can travel farther than their higher-frequency counterparts with the same amount of power. Unfortunately, no good deed ever goes unpunished. Antenna size depends on the signal's wavelength. Lower frequencies have longer waves and, therefore, need larger antennas. Building an adequate low-frequency antenna into a cell phone may prove impractical, although designers may be able to fit such an antenna into the lid of a laptop computer.

Power consumption depends on more than frequency. The transition to 4G will require multiband transmission and reception. Multiband performance also increases power consumption, reducing battery life in cell phones and laptop computers. Maintaining throughput and network capacity to accommodate the higher data speeds and volumes will rely on MIMO (multiple-input/multiple-output) antennas, another power drain. Tony Opferman, engineering program manager for Rohde & Schwarz, speculates that, at least initially, cell phones will not include MIMO antennas. Mobile-broadband data cards for laptops and other computers and televisions with broadband capabilities will be more likely candidates.

And what about cost? Development and deployment of the 4G technology will likely prove tremendously expensive. How much will customers be willing to pay for 4G? Will it turn out to be a luxury with only a niche market? How will designers balance the demand for features with the call to lower costs? Keithley's Buffo speculates that end customers will continue to demand the smartest phones with the highest data rates, transferring more data faster with less latency, and be willing to pay premium prices for the privilege. Mobile Internet users will demand the same experience that they can get with a wired device. "Industry prognosticators have asked [why people will need that level of performance] in response to every revolutionary technological change," he says. "Using Amazon's Kindle as an example, innovative products stimulate their own demand." Buffo recognizes that the current state of the economy will slow the implementation but insists that, five years from now, we will wonder how we could ever have doubted that it would happen.

At the same time, demand for high-end performance will vary widely between the developing and the developed world. In emerging markets, in which people have less disposable income, the price-versus-performance trade-off will have to skew toward keeping costs down. The economic downturn has made even customers in developed countries more careful about spending their money. To meet their needs, designers will want to find ways to provide equivalent features for the same or lower prices.

The other end of the network presents formidable challenges, as well. Massive increases in data traffic will place enormous demands on the communications infrastructure. The Apple iPhone's introduction caused massive network traffic jams, dropped calls, and other problems. In migrating to 4G, operators must remain cognizant of its overall effect.

Designers for this next generation may have to rethink the structure of the network itself. Until now, mobile operators

Figure 3 A signal analyzer's spectrogram function shows a 3-D representation of an LTE signal. Vertical cursors allow users to select a particular slice of data in the time domain, and horizontal cursors allow users to designate a frequency of interest (courtesy Anritsu).

have tried to increase system capacity by increasing peak and average data rates, an expensive and eventually inadequate approach. Increasing capacity by reducing cell size can also prove an expensive alternative. Agilent's Rumney suggests the need for a paradigm shift employing femtocells. Each cell might cover only a couple of buildings. The user would purchase the base station, a highly integrated commodity product costing perhaps $100 and offering a range as long as 10m. Although not a low-cost approach, it dramatically changes the dynamic of how users and providers spend their money.

The companies making base stations today, accustomed to "big" design, might resist such a shift. The emergence of numerous new players that lack the historically high overheads of the traditional players has forced their hand, however. After some hesitation, operators and traditional base-station manufacturers have begun to embrace the femtocell approach.

TESTING THE UNKNOWN

In the middle of all this turmoil, how do you test the base stations and end-user equipment for this new technology? The standards are constantly changing. Each standards body will establish its own test criteria. Buffo contends that LTE's requirements are clear. With WiMax, the features are still evolving, so it is harder to determine what the final version will look like.

The new technologies have created the need for a new type of test tool that is flexible enough to adapt to whatever is the latest version, according to George Reed, vice president of marketing and product management for Azimuth Systems. Designers have no choice but to rely on the current status of the standards, designing against them and making necessary modifications as the standards evolve. Still, the overall goal of test hasn't changed. Engineers must functionally verify the end products. Expecting a test-equipment manufacturer to constantly introduce new hardware would be impractical. Nevertheless, the communications products and the testers are radio systems, and all radio systems have traits in common (**Figure 2**). An RF instrument can acquire many types of signals and apply a measurement algorithm specific to the standard under test. A manufacturer can modify a versatile system that incorporates high-performance DSPs, upconverters, ADCs, and so on, along with a software-defined radio, in response to changes in the standards or the technology.

Testing MIMO antennas also introduces complications to a traditional test approach. National Instruments' Hall notes that vendors are introducing more flexible instrumentation hardware targeting the MIMO test challenge. New RF generators and analyzers allow synchronizing sample clocks and local oscillators, so that designers can address some of the more difficult MIMO measurements.

Another consideration is that designers of base stations that address the new standards often lack matching handsets to verify that they work. Conversely, handset manufacturers generally lack access to real base stations. Instead, they rely on emulators that mimic the behavior of the other end of the network. Emulation offers additional flexibility. Also, the introduction of 4G will not mean that all 3G technologies will suddenly vanish. New designs will have to work seamlessly with the existing infrastructure until sometime in the distant future when everything aligns with 4G standards. By that time, the state of the art will likely be 5G (fifth generation) or 6G (sixth generation), and the cycle will begin again. A base-station or cell-phone emulator can verify that any design remains compatible with earlier versions of the communications network (**Figure 3**).

Paul Goodling, product-line manager for Rohde & Schwarz, states that the developers of both LTE-Advanced and Mobile WiMax based them on the same physical layout. LTE has the more defined specification because of its history with 3GPP, which had established issues such as handover and signal security. Goodling believes that LTE will dominate in wireless communications, and that WiMax will more likely flourish in stationary applications, such as in-home telephone systems or laptops. "But when it comes to testing," he remarks, "you can consider them different flavors of the same platform. A single-box solution can address all of the current standards. That reality allows for a smoother transition."

The transition to 4G communications will proceed in fits and starts. Adoption will at first be spotty and will expand over time. It is the same pattern that occurred with the transition from 2 to 3G, and it will repeat again with the next generation. Designers must keep their creations nimble, able to respond to ongoing changes to the standards as they evolve. One thing is certain, however: The demand for communications performance will not stop with 4G, or with any other generation. A few years ago, an industry prognosticator predicted that the communications revolution of the next 10 years would make the computer revolution of the previous 10 years pale by comparison. Some would call that an understatement. EDN

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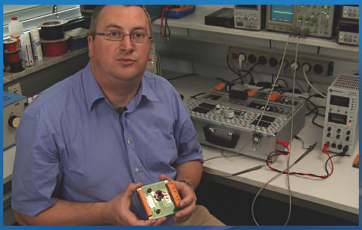

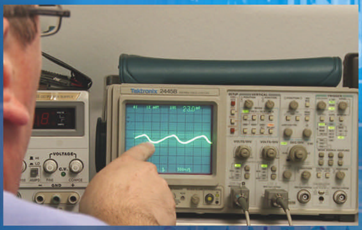

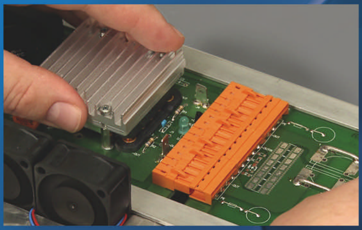

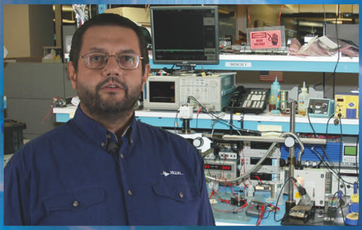

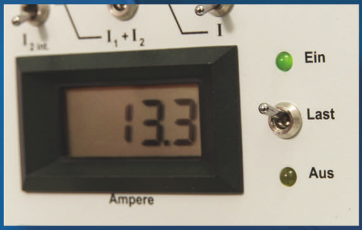
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BY MICHAEL KULTGEN • LINEAR TECHNOLOGY CORP

Managing high-voltage lithium-ion batteries in HEVs

SKYROCKETING ENERGY PRICES AND THE GROWING CONCERN OVER CARBON EMISSIONS HAVE FOCUSED ATTENTION ON ELECTRIC AND HYBRID-ELECTRIC VEHICLES. NEW LITHIUM-BATTERY DESIGNS WILL BE KEY TECHNOLOGIES FOR EFFICIENT EVs AND HEVs.

Safely getting the most energy and lifetime from a lithium cell requires some sophisticated electronics. One requirement, for example, is the ability to measure the voltage across every 3.7V battery cell in a stack of 100 series-connected cells. How do you cope with the 370V of common-mode voltage and reject 100V of common-mode switching transients? The design of battery-management systems for EV (electric-vehicle), HEV (hybrid-electric-vehicle), and UPS (uninterruptible-power-supply) applications requires solving many such problems.

How do batteries make cars "green," and why is there such a big fuss over lithium batteries? First, according to the California Cars Initiative (www.calcars.org), the cost of running a car on electricity is equivalent to paying 75 cents a gallon for gasoline. So, a purely electric vehicle has a low daily operating cost. Second, to drive farther than 100 miles, you still need a gasoline engine, and batteries improve gas mileage. Consider that the amount of energy your car can store limits the distance you can drive. With a large lithium pack, you can drive 100 miles after an eight-hour charging cycle. Gasoline holds 80 times the energy per kilogram as lithium-ion batteries, and you can fill a vehicle's gasoline tank in a few minutes. With enough coffee, then, you could drive forever. The peak efficiency of the internal-combustion engine, however, is only 30%, and the average efficiency is about 12% at high revolution-per-minute rates. Using batteries to supply torque during acceleration and recovering joules during braking means that the gas engine runs less often and runs at a higher efficiency, effectively doubling the miles-per-gallon rate.

A third reason to add batteries to cars is to reduce emissions. A gallon of gasoline produces 9 kg of carbon dioxide. Clean-energy sources, such as wind power, convert into electricity and produce no carbon-dioxide emissions. So, batteries hold the key to improving miles per dollar and reducing kilograms of carbon-dioxide emissions per mile. The more energy per kilogram the battery stores, the more effective the battery. Today's model-year 2009 vehicles use nickel-metal-hydride batteries. Switching to lithium-ion cells will improve energy-storage density by 150%. By model-year 2012, most hybrid cars and trucks will use lithium-battery technology.

HOW VEHICLES USE LITHIUM CELLS

When considering the use of lithium batteries in vehicles, you should examine the power-train block diagrams for series-hybrid, parallel-hybrid, purely electric, and other vehicle types. Fortunately, the lithium-battery pack looks much the same for any vehicle. The building block is a group of 100 to 200 2.5

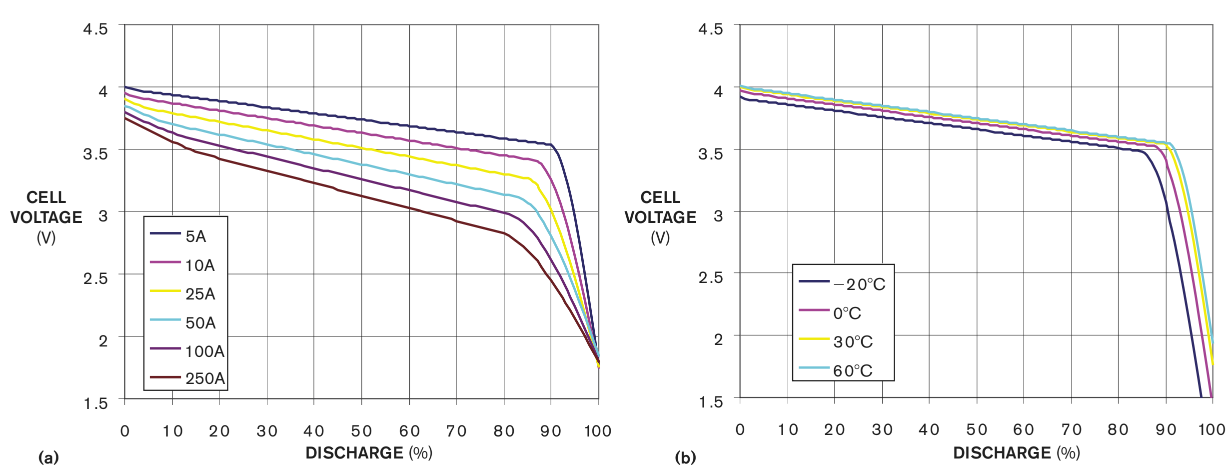


Figure 1 The charge-versus-voltage characteristics of a typical 5A-hr lithium-ion cell are shown at various discharge rates (a). The charge-versus-voltage characteristics for the same cell at various temperatures are shown during a 5A discharge (b).

to 3.9V, 4- to 40A-hr, series-connected cells. This dc-power source drives a 30- to 70-kW electric motor. The total pack voltage is high, so the average current is low for a given power level. Lower current requires smaller cables, less weight, and less cost. The pack should deliver 200A under peak conditions and be quickly rechargeable. In other words, the battery needs good power density as well as good energy density. Big systems, such as buses and tractor trailers, use as many as four 640V parallel packs.

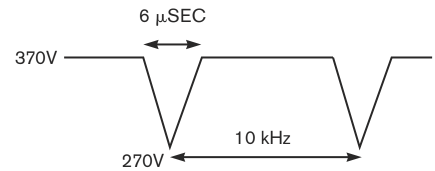


Figure 2 This simulation shows the battery-stack output with spikes from a 10-kHz inverter supplying an electric motor.

The design problem with lithium-battery packs is balancing performance, economics, and safety. The two key variables are the battery-cell design and the cell-management electronics. For example, say that you want to build an EV that goes 100 miles per charge with a battery pack that lasts 10 years before you have to buy or rent a new one. To meet the 10-year, 3650-charge-cycle goal, you can use only a portion—say, 40%—of the cells' capacity. To minimize vehicle cost, you want to use batteries with the fewest kilograms, and batteries are the most expensive components of the pack. To maximize performance, the cells must handle 200A peak charge and discharge currents. Above all, the chance of a rapid-oxidation event—that is, a fire—must be less than that for a gasoline-powered car.

Traditional lithium-cobalt cells, like those in laptop computers, have high energy density but tend toward thermal runaway when the separator material fails. Manufacturers are basing the new breed of lithium batteries on lithium-iron-phosphate, lithium-manganese, and lithium-titanate, which are thermally stable even when you puncture their packaging. Their prismatic form factor, which resembles a silver Pop-Tart, has low ESR (equivalent series resistance) to support high currents. They hold less energy than laptop lithium-cobalt cells but are still better than nickel-metal-hydride devices, and they last 10 to 15 years if you carefully monitor their charge and discharge levels.

STATE OF CHARGE

Battery-monitoring systems now come into play because they monitor the battery's state of charge, which in turn determines the battery's cost and performance. If you know the battery's state of charge, you can use more capacity from each cell, use fewer cells, and maximize the lifetimes of those cells. In a laptop computer, you perform this task by monitoring cell voltage and counting coulombs into and out of the stack of four to eight cells. Voltage, current, charge, temperature, and some math give a good indication of the state of charge. Unfortunately, you can't count coulombs in a car because the battery is driving an electric motor, not a motherboard. The current spikes are 200A, and low-level idling follows those spikes.

You also have 96 to 200 cells in series, in groups of 10 or 12. These cells age at different rates, come from multiple lots, and vary in temperature. These factors mean that they have different capacities, and cells with the same number of coulombs could have different charge levels. For these reasons, battery-monitoring systems in cars focus on cell voltage. You must accurately measure the voltage of every cell and then use current and temperature measurements to tweak the readings for ESR and capacity changes. You keep a running estimation of each cell's charge level. If some cells overcharge and others undercharge, you must adjust the level in each cell by bleeding off, or passively balancing, charge; another approach is to redistribute, or actively balance, the charge. When the cells reach a minimum state of charge, you are out of energy.

You need to figure out how accurately to measure the voltage. Start with the goal of knowing the state of charge within 1% over temperatures of −20 to +80°C. **Figure 1** shows the typical charge-versus-voltage characteristics of an average lithium-ion cell. Keep in mind, however, that the data varies considerably among manufacturers and chemistries. The voltage changes approximately 200 mV from 30 to 70%, or 5 mV per percentage point, of the state of charge. A measurement range of 0 to 5V requires 0.1% total measurement accuracy. Translating that figure into data-acquisition specs requires a 12-bit ADC with 1-LSB (least-significant bit), or 0.02%, INL (integral nonlinearity), plus a voltage reference with 0.05% of initial accuracy and 5 ppm/°C of drift—that is, 0.02% for 40°C changes in temperature.

The data-acquisition system also must reject switching noise and high common-mode voltage. **Figure 2** simulates the battery-stack output with spikes from a 10-kHz inverter supplying an electric motor. Spreading the transient equally over the 100 cells means that the top cell has a 370V

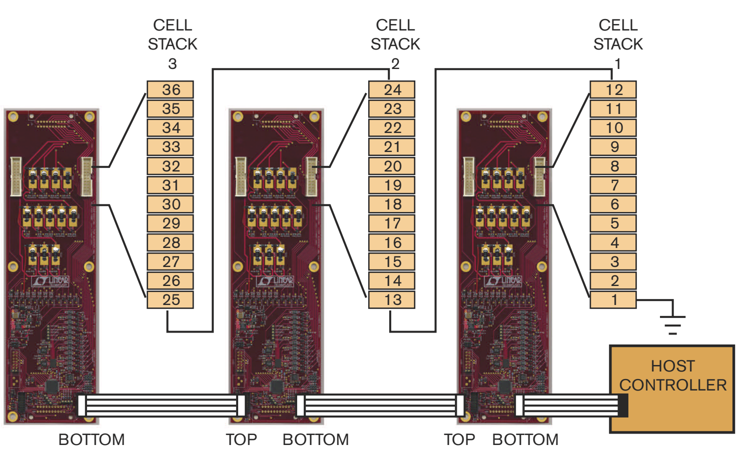


Figure 3 You can monitor a representative 36-cell pack in three groups of 12 cells each. The 12-cell module supplies local power and ground to the analog electronics. By breaking the stack into small groups, the analog circuits see a much smaller common-mode voltage.

common-mode voltage, 100V common-mode transients, 1V differential transients, and a 3.7V-dc value. You need to measure the 3.7V-dc value with 5-mV accuracy.

Most battery-monitoring systems use a combination of modularly arranged, off-the-shelf components. **Figure 3** illustrates how you can monitor a 36-cell pack in three groups of 12 cells each. The 12-cell module supplies a local power and ground to the analog electronics. By breaking the stack into small groups, the analog circuits "see" a smaller common-mode voltage. **Figure 4** shows an example of the discrete analog electronics. The LT1991 difference amplifier rejects the common-mode voltage and buffers the differential voltage across every cell. The outputs from the difference amplifiers are the cell voltages referenced to the LT1461. These 12 signals connect to the input multiplexer of a 16-channel, 24-bit delta-sigma LTC2449 ADC. The LT1461-2.5 supplies the 2.5V voltage reference. The MOSFET switches prevent drawing current from the cells when the ADC is in sleep mode. The difference amplifier's 75-dB CMRR (common-mode-rejection ratio), the difference amp's gain error of 0.04%, and the reference-voltage error of 0.04% combine to create a 0.3% worst-case error. The ADC errors are negligible. Calibrating the system at room temperature removes about 90% of the errors.

Figure 4 shows only a simplified voltage-measurement circuit. The complete battery-monitoring system also requires cell balancing, data communications, and self-test features, which seriously complicate the schematic. The high component count makes the use of off-the-shelf approaches costly and unreliable. **Figure 5** shows a similar modular-cell-measurement design, with one IC integrating most functions. The input multiplexer can tolerate 60V of common-mode voltage. Using switched-capacitor sampling techniques eliminates the CMRR limitation that most discrete designs face. The delta-sigma ADC is essentially ideal, leaving the reference voltage as the only component in the error budget. Without calibration, the LTC6802 achieves 0.12% room-temperature accuracy and 0.22% over a −40 to +85°C range. An initial factory calibration of the room-temperature error reduces the overall error to 0.1% over temperature. To gain more accuracy, you can add a low-drift external reference (**Figure 6**). Periodically measuring the LT1461's output and using this information to adjust the cell measurements, along with an initial calibration, reduces the errors to 0.03%, which is the noise floor of the ADC, over a −20 to +70°C window.

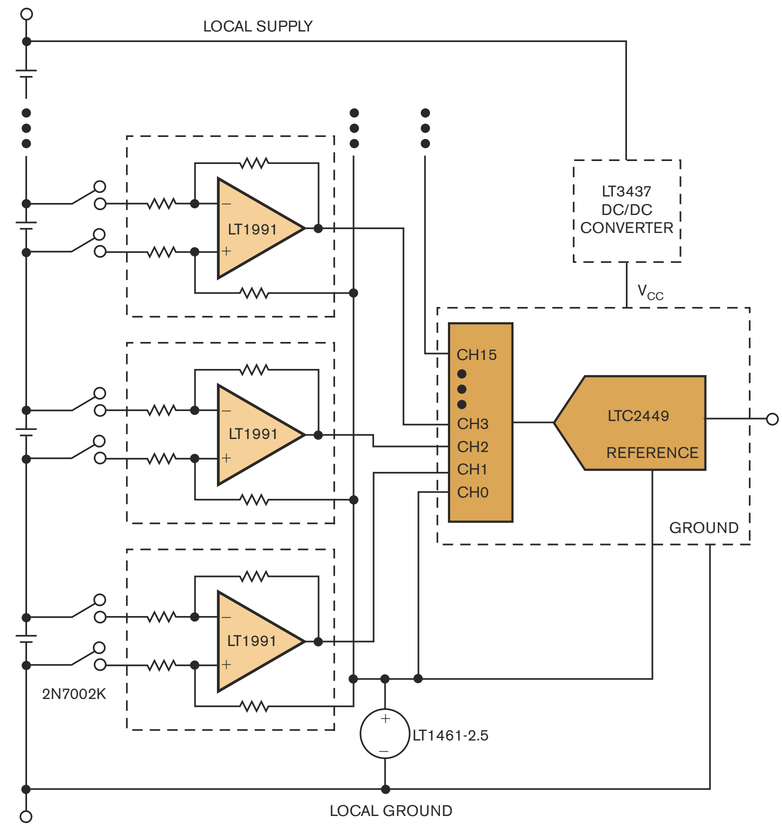


Figure 4 In a simplified voltage-measurement circuit for discrete analog electronics, the cell-voltage signals connect to the input multiplexer of a 16-channel, 24-bit delta-sigma LTC2449 ADC. The ADC errors are negligible, and calibrating the system at room temperature removes about 90% of the errors.

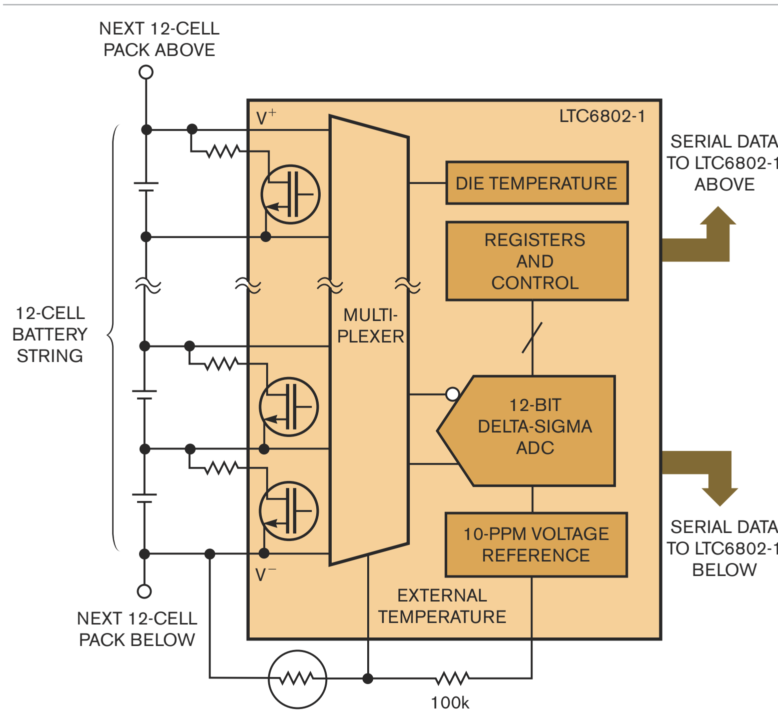


Figure 5 One IC integrates most of the functions in a simplified cell-measurement design.

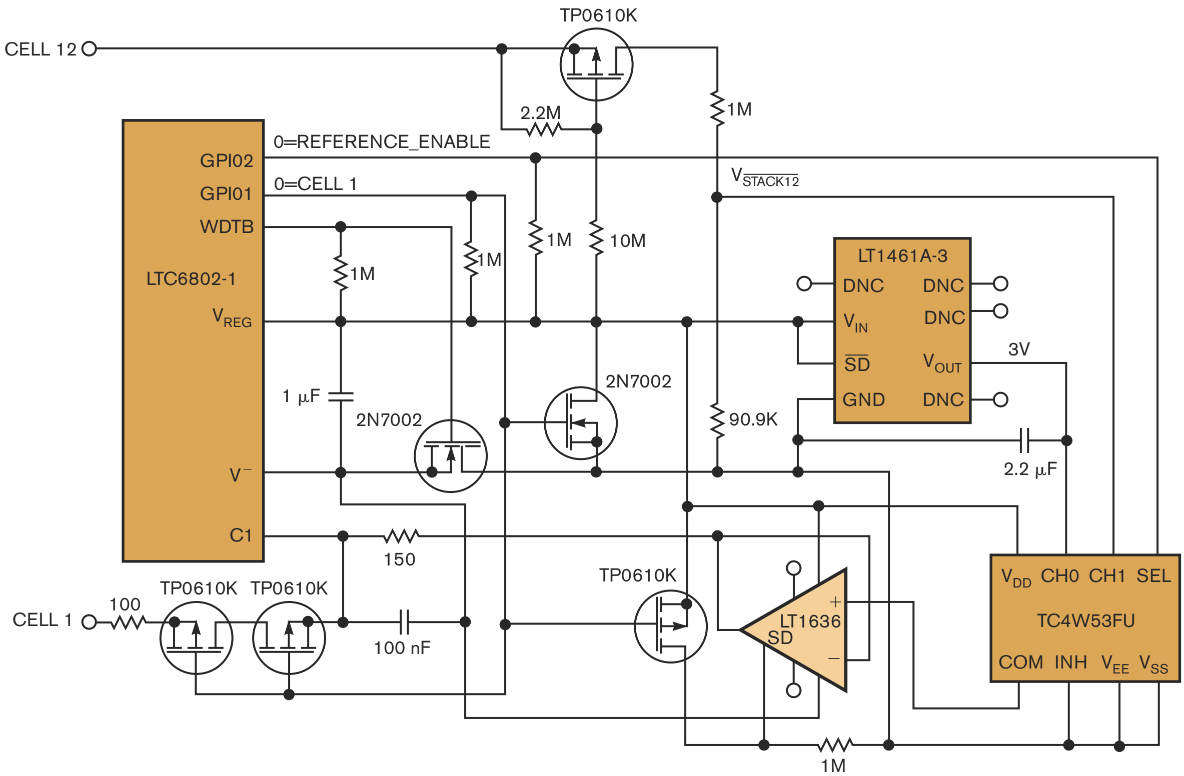
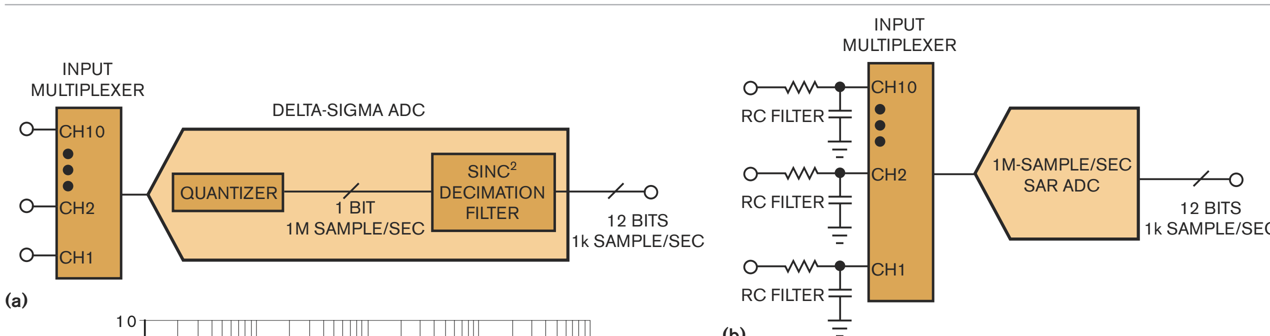


Figure 6 For greater accuracy, you can add a low-drift external reference. Periodically measuring the LT1461's output and using this information to adjust the cell measurements, along with an initial calibration, reduces the errors to 0.03%, which is the noise floor of the ADC, over a −20 to +70°C window.



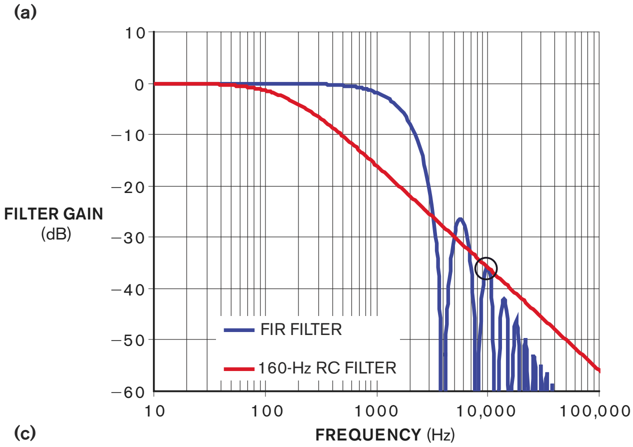


Figure 7 For a given amount of 10-kHz rejection, a 1k-sample/sec delta-sigma ADC (a) is equivalent to a 1M-sample/sec SAR ADC (b). Filtering determines the ADC's effective throughput, not the sampling rate (c).

The approaches thus far show delta-sigma ADCs performing the measurements. SAR (successive-approximation-register) converters offer a faster sampling rate in 12-bit systems, which would seem a necessity in a data-acquisition system with 100 channels. The harsh noise environment in vehicles, however, requires significant filtering. Consequently, the filtering determines the effective throughput, not the sampling rate. For a given amount of 10-kHz rejection, a 1k-sample/sec delta-sigma ADC is equivalent to a 1M-sample/sec SAR ADC (**Figure 7**). The LTC6802 multiplexer and 1k-sample/sec ADC sequence through 10 input channels in 10 msec. The ADC's built-in linear-phase digital filter provides 36 dB of rejection to the 10-kHz switching noise. A 1M-sample/sec SAR converter with a single-pole input filter needs an RC corner frequency of 160 Hz to get the same 10-kHz noise rejection. The 12-bit settling time of the RC filter is 8.4 msec. The SAR can sequence through 10 channels in 10 µsec, but scanning more than once every 8.4 msec is fruitless because of the response of the filter.

The delta-sigma- and SAR-ADC-measurement throughputs are equivalent, but there are some differences. The delta-sigma ADC has greater noise rejection and superior accuracy. Also, although the two systems have the same rejection at 10 kHz, the filter's rejection of higher harmonics is clearly greater than that of a simple RC filter. The delta-sigma-based system is more accurate because the input multiplexer is operating 1000 times slower than the SAR, eliminating crosstalk, common-mode rejection, and settling-time errors. The only advantage of the SAR is that the 10 measurements are almost simultaneous, whereas the delta-sigma measurements are sequential, creating a slight overhead in the software that computes battery impedance.

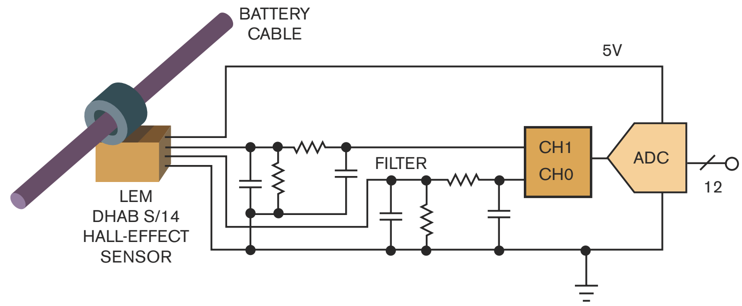


Figure 8 Because every cell connects in series, current is a single-point measurement in a battery pack. The measurement should be bidirectional with a wide dynamic range. In this typical approach, the LEM DHAB14s84 contains two Hall-effect sensors and an ASIC to linearize the outputs, which are proportional to the 5V supply.

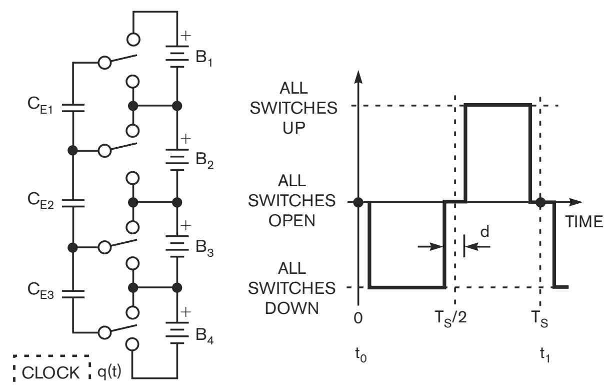


Figure 9 This capacitor-based scheme uses a capacitor that continuously switches between two adjacent cells. Current flows to equalize the voltage and, therefore, the state of charge of the two cells. Active balancing shuttles charge between cells and does not become wasted heat. It requires a storage element for the charge transfer.

To complete the state-of-charge computation requires measuring temperature and current. Temperature is a relatively easy measurement because it is slow to change, does not suffer from motor-noise pollution, and is galvanically isolated from high voltage. The only question is how many temperature probes to use. Some lithium-ion battery packs use one temperature sensor per cell because of the unknown thermal gradients between cylindrical batteries. Other pack designs use groups of 12 prismatic cells in an aluminum casing. The low thermal resistance between cells means that one or two temperature probes per group are sufficient. The most economical measurement scheme reuses the cell-voltage ADC (**Figure 5**). The thermistor is between cells. The voltage between the thermistor and the 100-kΩ resistor multiplexes into the ADC. The error budget includes the 1% absolute value of the reference voltage, the 1 to 5% tolerance of the resistor and thermistor, the 1 to 3% variability of the thermistor's B constant in ohms per degree Celsius, and the temperature difference between the probe and the inside of the battery. The uncalibrated accuracy is approximately 5%. Calibrating out the initial tolerances at room temperature leaves just the B-constant variation. From **Figure 1**, each 4% error in the temperature reading translates to a 1% state-of-charge estimation error.

The final quantity to measure is current, which is important for two reasons. First, the discharge rate affects cell capacity (**Figure 1**). Second, correlating changes in current with changes in cell voltage gives a measure of the internal resistance of the cell. You use your knowledge of the resistance to improve the state-of-charge calculation. Resistance is also the primary indication of the cell's life expectancy. Because every cell connects in series, current is a single-point measurement in a battery pack. The measurement should be bidirectional with a wide dynamic range. **Figure 8** shows a typical approach.

The LEM DHAB14s84 contains two Hall-effect sensors and an ASIC to linearize the outputs. The outputs are ratiometric to the 5V supply. One channel has a ±30A range, and the other has a −150 to +350A range. Both channels have approximately 10 bits of resolution. Combining the two channels gives an overall dynamic range of 30 mA to 350A. You should tailor the filtering of the current-sensor output to match the cell-voltage filtering and synchronize the current and voltage measurements.

CELL BALANCING

The charging/discharging of 100 series-connected cells must stop when any cell reaches its maximum or minimum allowable state of charge. Thus, a pack is only as good as its weakest link. If a weak cell receives the same number of coulombs as a strong cell during charging and discharging, it uses more of its available capacity, which in turn makes it even weaker. Keeping the capacity levels the same in all cells over time helps them age in unison. It would be unfortunate to have to replace an entire 100-cell pack because one cell prematurely runs out of charge cycles. If the battery-monitoring system can tweak the charge level in each cell, you can derive more energy and greater lifetime from the pack. Cell balancing is a critical feature in EVs and HEVs.

Small-capacity packs tend to use a simple passive-balancing technique to minimize cost. The technique places a bleed resistor across a cell when its state of charge exceeds that of its neighbors. Passive balancing doesn't increase the drive distance after a charge because the technique dissipates, rather than redistributes, power. However, passive balancing prolongs the life of the pack and is the norm in passenger HEVs. Discharge currents range from 10 mA to 1A, with 100 to 200 mA the most popular.

EVs use larger-capacity packs in which passive balancing can generate considerable heat. EV manufacturers are also concerned with drive distance per charge. Commercial HEVs, such as buses and delivery trucks, use multiple large packs. Given the expense of the vehicle—approximately $480,000 for a bus versus approximately $23,000 for a Prius—there is less cost pressure on the electronics. In these situations, more elaborate active balancing makes sense.

Active balancing means that charge shuttles between cells and does not end up as wasted heat. This approach requires a storage element for the charge transfer. Engineers are publishing and patenting such schemes using capacitors, inductors, or transformers (**Reference 1** and **Figure 9**). The capacitor continuously switches between two adjacent cells. Current flows to equalize the voltage and, therefore, the state of charge of the two cells. Using a bank of switches and capacitors, the voltage of all cells tends to equalize. The drawbacks are the large number of low-resistance switches necessary and the generation of the signals to control the switches. One advantage is the absence of software. The circuit continuously balances cells in the background as long as the switching clock is active. A transformer-based scheme transfers charge between a single cell and a group of cells (**Reference 2** and **Figure 10**). The scheme requires state-of-charge information to select the cell for charging and discharging to and from the group of six cells.

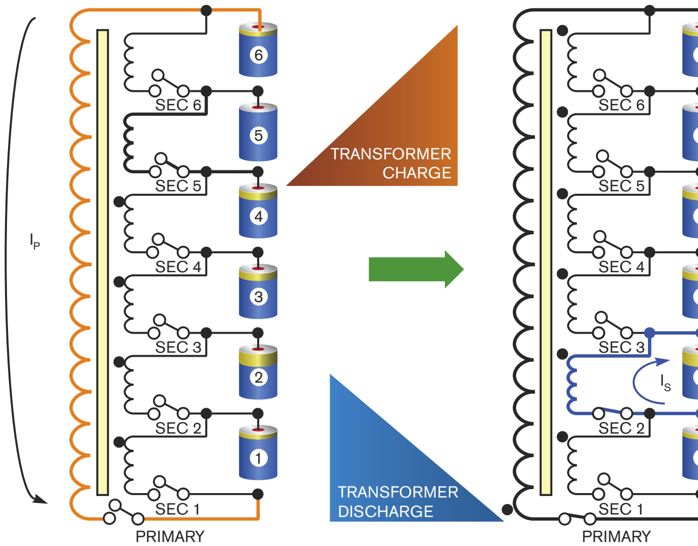


Figure 10 In another active-balancing scheme, a transformer transfers charge between a single cell and a group of cells. State-of-charge information selects the cell for charging and discharging to and from the group of six cells.

SIMPLIFYING ANALOG COMPLICATES THE DIGITAL

Breaking a 100-cell pack into modules makes it easier to integrate the analog circuits. Unfortunately, this approach leaves you with the task of getting the data from the measurement IC to the host controller when the difference in ground potential exceeds 300V. The most straightforward approach is to use a digital isolator between each module and the host controller (**Reference 3**). However, the digital isolator is expensive and requires an isolated power supply so that the battery cells need not provide power to the cell side of the isolator.

The LTC6802 integrates a daisy-chainable SPI, and the approach eliminates the need for digital isolators (**Figure 11**). The interface exploits the fact that the positive supply of module N is the same voltage as the ground of module N+1. It uses current to transmit data between adjacent modules. As with the analog circuits, the modular approach means that the data bus must deal with a fraction of the total pack voltage. The disadvantage of any daisy chain is that a fault in one module means a loss of communications with all the modules above it in the stack. Also, because there is no galvanic isolation between modules, the interface must handle the large voltages that occur during fault conditions. The LTC6802 interface relies on

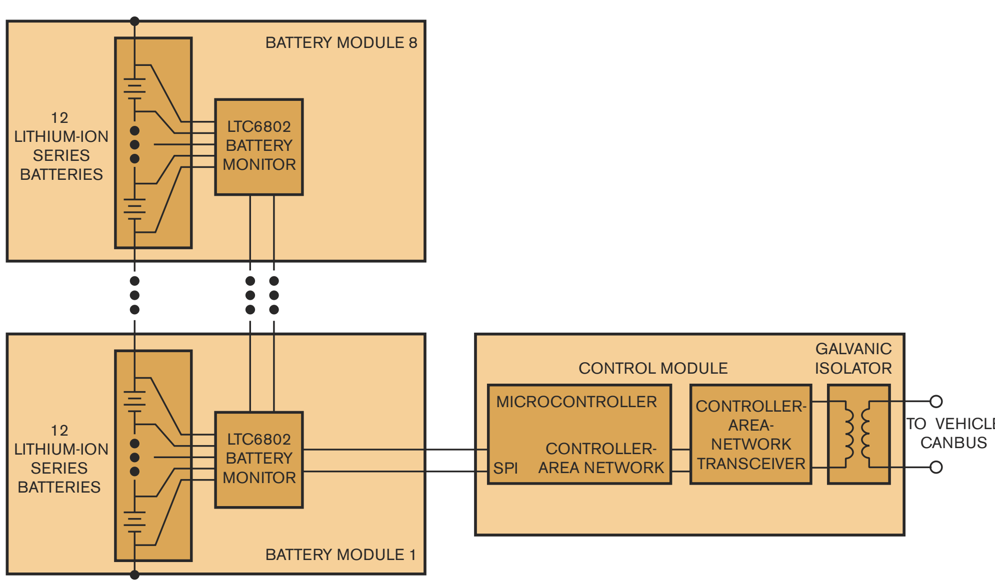


Figure 11 The LTC6802 integrates a daisy-chainable SPI and eliminates the digital isolators.

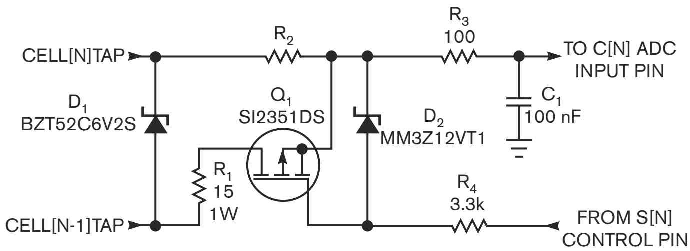


Figure 12 Pins in the LTC6802 balance battery cells.

external discrete diodes to block the reverse voltage during fault conditions.

MAKING MONITORS ROBUST

Automobile manufacturers must meet extremely high reliability standards, regardless of the power source their products use. Both the assembly of the battery pack and the pack's fault-detection requirements create challenges for the battery-monitoring system. The battery cells connect to the battery pack's monitoring and balancing electronics through a wire harness. During the assembly of the pack, the harness makes contact with the cells in a random order. Protection diodes and resistors are necessary for the electronics to survive the hot-socketing of the high-voltage, low-impedance cell stack. **Figure 12** shows an example of the components between the wire harness and the LTC6802 monitoring IC (**Reference 4**). Components Q_1, R_1, and R_2 provide passive cell balancing. The S(N) output from the LTC6802 controls these components. Components R_3 and C_1 comprise an antialias filter for the LTC6802 ADC. Diodes D_1 and D_2 and resistor R_4 provide protection. D_1 is a standard 6.2V, 500-mW zener diode, which automatically distributes safe voltages across missing inputs as contacts mate in the cell-connection process. The 6.2V rating of the zener diode is high enough to minimize leakage current from the battery but low enough to protect the IC. D_2 protects the gate of balancing MOSFET Q_1. R_4 protects the S(N) output in the event that D_2 is forced on.

During normal operation, the battery-monitoring system must satisfy the requirement that no bad-cell reading is misinterpreted as a good-cell reading. Two of the more common faults that can cause false readings are open circuits and IC failures. If there is an open circuit in the wiring harness and if there is a filter capacitor on the ADC input, the capacitor tends to hold the input voltage at a point midway between the adjacent cells. Some type of open-wire detection or cell-resistance-measuring function is necessary. One approach is to temporarily turn on the passive-balancing circuit. If the cell connection is open, the measured voltage will be 0V. A similar technique involves occasionally loading the cell with dc current from the monitor circuit to see whether the cell-voltage readings change. The LTC6802 has optional dc-current loads for this purpose (**Figure 13**).

The other common concern in battery packs is that an IC has an undetected failure. The host controller must be able to run diagnostics on all the modules during normal operation. If these periodic self-tests fail, then the control algorithm is suspect, and you must take the battery pack offline. For example, if the reference in the ADC changes value, then the readings are invalid. The only way to guarantee the accuracy of the voltage measurements is by periodically measuring a second independent reference (**Figure 6**). Another example is a stuck-at fault in the digital section of the ADC. There must be enough support circuitry or built-in test modes to guarantee that the ADC is functional over its complete input range.

To limit the possibility of taking the pack offline, most battery-monitoring circuits have robust self-testing as well as redundant measurement hardware. If the primary monitoring circuit fails a periodic self-test, the presence of the redundant circuit gives the user's equipment a chance to remain active until a technician fixes the problem. The level of redundancy is a topic getting much attention among battery-monitoring-system designers and vehicle suppliers.

You can expect the continued evolution of lithium-ion and lithium-polymer-based industrial batteries that combine energy density, power density, and cycle life for improved vehicle performance. Battery-management systems will progress in parallel with IC development, providing higher levels of integration and more accuracy at lower system cost. EDN

REFERENCES

1. Pascual, C, and P Krein, "Switched Capacitor System for Automatic Series Battery Equalization," *Proceedings of the IEEE Applied Power Electronics Conference*, 1997, http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?tp=&arnumber=575744&isnumber=12494.
2. Robler, Werner, "Boost battery performance with active charge-balancing," *EE Times Asia*, July 16-31, 2008, pg 1, www.eetasia.com/STATIC/PDF/200807/EEOL_2008JUL16_POW_CTRLD_TA_01.pdf?SOURCES=DOWNLOAD.
3. Douglass, Jim, "Battery management architectures for HEVs," *Electronic Products*, December 2008, www2.electronicproducts.com/PrintArticle.aspx?ArticleURL=fapo_LinearTech_dec2008.html.
4. Munson, Jon, "Reliable Li-Ion Battery Monitoring System for Hybrid/Electric Vehicles," *Automotive Electronics*, www.automotive-electronics.co.uk/current.asp.

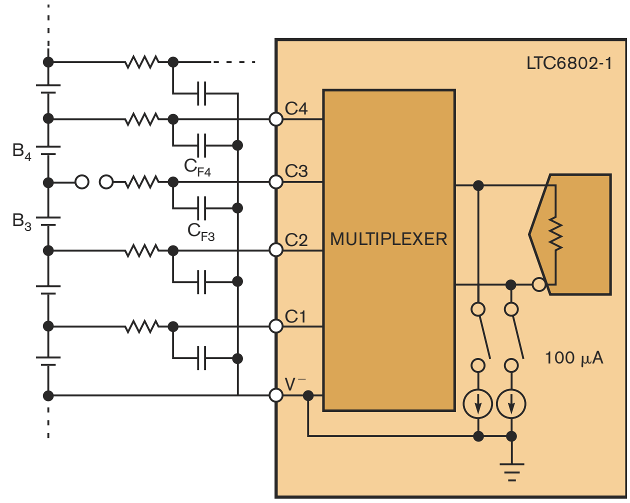


Figure 13 Ensuring that no bad-cell reading is misinterpreted as a good cell requires some type of open-wire detection, such as temporarily turning on the passive-balancing circuit. If the cell connection is open, the measured voltage will be zero.

AUTHOR'S BIOGRAPHY

Michael Kultgen has been designing ICs for automotive, aerospace, communications, and industrial applications for more than 24 years. During his 10 years with Linear Technology, he has contributed to more than 25 products, including amplifiers, monolithic filters, and silicon oscillators. Kultgen is currently design manager for Linear's industrial-signal-conditioning products. He holds five patents. He has a bachelor's degree in electrical engineering from the University of Missouri—Columbia and a master's degree in electrical engineering from the University of Texas—Arlington.

Twin-T power oscillators work as dc-biased ac sources

Tiger Zhou and Robert Dobkin, Linear Technology, Milpitas, CA

AC test equipment often needs a low-distortion signal source to excite the device under test. The common practice is to use a signal generator to produce a low-distortion reference, which you feed to a power amplifier to drive the device under test. This Design Idea suggests a less cumbersome alternative.

Figure 1 shows an oscillator that generates a low-distortion sinusoidal signal with power-driving capability. The power oscillator consists of two major parts: a twin-T network and a high-power low-dropout regulator. The twin-T network has two T-type filters in parallel: one lowpass filter and one highpass filter. The twin-T network is highly frequency-selective as a notch filter. The low-dropout regulator amplifies the signal and drives the load. The regulator in this circuit incorporates a current-reference voltage-follower architecture. It is unity gain from the Set to the Out pins, and the current reference is a precision 10-µA current source. The R_{SET} resistor on the Set pin programs the output-dc level. By connecting a twin-T network between the Out and the Set pins, the resulting notch filter attenuates both high- and low-frequency content, allowing the center frequency to freely pass through. The resistors and capacitors program the center frequency, f_0: $f_0=1/(2\pi RC)$.

DIs Inside

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Small-signal analysis of the twin-T network indicates that the gain is maximum at the center frequency. The twin-T oscillator's maximum gain increases from one to 1.1 when the K factor increases from two to five (**Fig-**

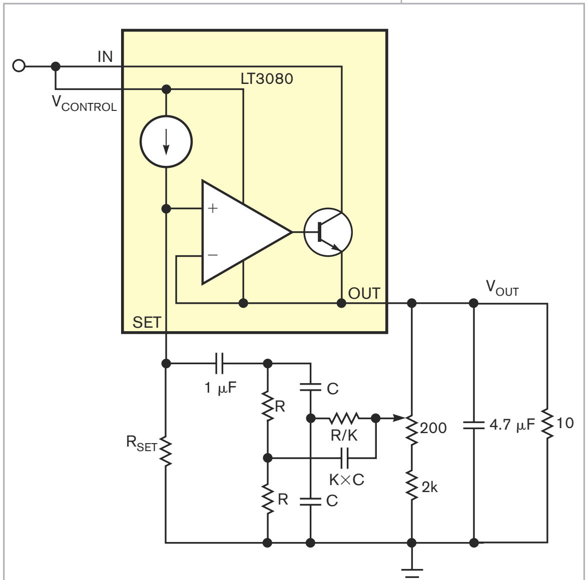


Figure 1 This oscillator generates a low-distortion sinusoidal signal with power-driving ability.

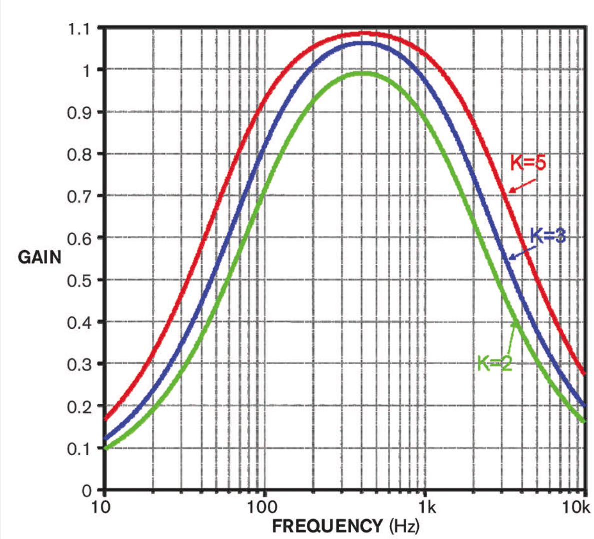


Figure 2 The twin-T network's gain changes with the value of K from Figure 1.

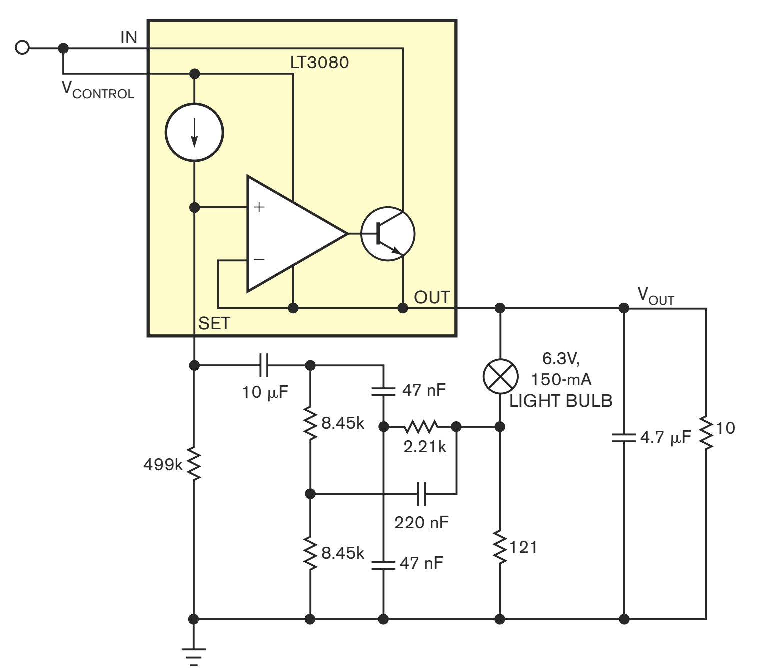


Figure 3 To automatically control the gain, you can replace the potentiometer with a light bulb.

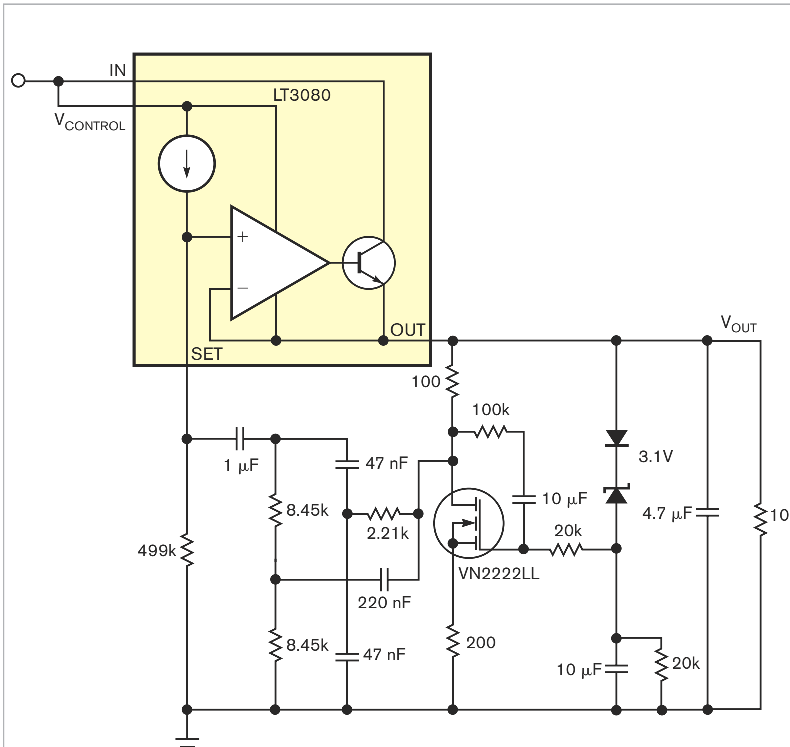


Figure 4 You can automatically control the gain by replacing the potentiometer with a variable-resistance MOSFET.

ure 2). The maximum gain decreases when the K factor is larger than five. Therefore, select a K factor of three to five for a gain larger than unity gain. The loop gain must be unity to maintain a steady oscillation. Thus, you need a potentiometer to tune the loop gain to control the oscillation amplitude.

The twin-T oscillator can drive inductive, capacitive, or resistive loads. The low-dropout regulator's current limit, which is 1.1A for the Linear Technology (www.linear.com) LT3080, is the only limit on the oscillator's drive capability. The load characteristics limit the maximum programmable frequency. For example, a 10Ω resistive load with a 4.7-µF output capacitor causes a 7% THD (total harmonic distortion) at a frequency higher than 8 kHz, although THD is 0.1% at 400 Hz in the circuit of **Figure 3**. The twin-T oscillator has the same performance in line and load regulation as the LT3080. It also works in a wide temperature range.

To automatically tune the gain, you can replace the potentiometer with a light bulb (**Figure 3**) or a voltage-modulated resistive MOSFET (**Figure 4**). The light bulb's resistance increases with the oscillation amplitude due to a self-heating effect, so it servos the loop gain to maintain the oscillation. In **Figure 4**, by detecting the peak voltage using a zener diode, the MOSFET resistance decreases when the oscillation amplitude is high. The loop gain also decreases to maintain the oscillation.

Figure 5 shows the test waveform of the twin-T oscillator using a light bulb. The output is tuned to a 4V-p-p voltage with 5V-dc bias voltage (**Figure 6**). The twin-T oscillator has a 400-Hz frequency and 0.1% THD. The most significant harmonic contribution is from the second harmonic at less than 4 mV p-p. **Figure 6** shows the test waveform of the twin-T oscillator using the MOSFET. The THD is 1% with a 40-mV-p-p second harmonic.

Start-up is another important aspect of the oscillator. Both circuits exhibit no low-frequency swing, which is common to other types of oscillators. The waveforms in **figures 7** and **8** exhibit little overshoot. The oscilla-

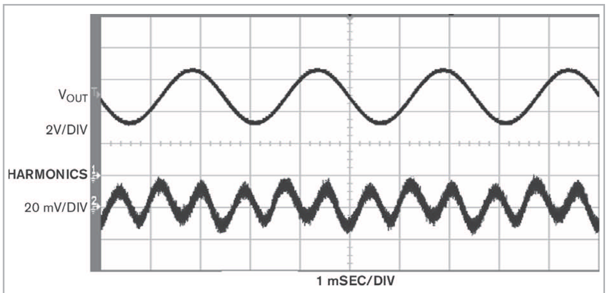


Figure 5 The test waveform for the oscillator in Figure 3 shows low distortion at a THD of 0.1%.

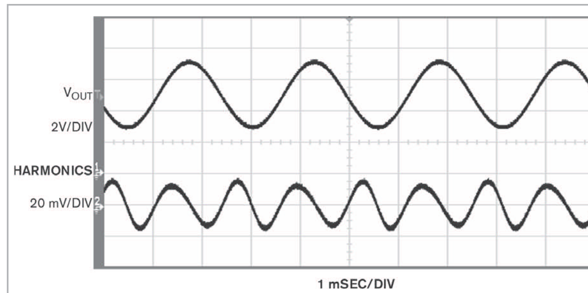


Figure 6 The test waveform for the oscillator in Figure 4 shows low distortion with a THD of 1%.

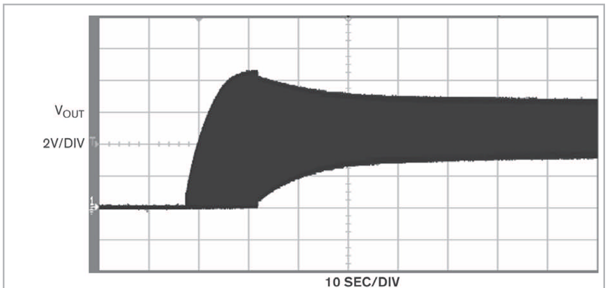


Figure 7 The waveform for the circuit in Figure 3 shows a slow start-up of the light-bulb oscillator.

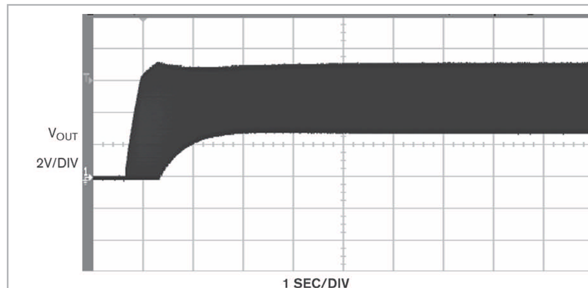


Figure 8 The waveform for the circuit in Figure 4 shows a quick start-up of the MOSFET oscillator.

tor using the MOSFET stabilizes faster than the one using the light bulb because the light bulb has a long thermal constant due to the heating effect. You can use the simple circuit as a dc-biased ac source in applications requiring low distortion and power-driving capability. EDN

ACKNOWLEDGMENT

The authors wish to thank Tony Bonte, Mitchell Lee, Jim Williams, and Todd Owen for fruitful discussions.

Diagnose LEDs by monitoring the switch-mode duty cycle

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

Engineers often monitor the forward voltage, V_F, of HB LEDs (high-brightness light-emitting diodes) to assess the LEDs' health. Big changes in forward voltage can indicate deterioration or even a complete failure of one or more LEDs connected in series. For several LEDs in series, the sum of their forward voltages can reach 40V or more, and, if you do not reference that voltage to ground, it requires a differential measurement. In addition to the challenges of high voltage and differential measurement, HB LEDs are often dimmed using PWM (pulse-width modulation). If so, you can't measure forward voltage during the low portion of the PWM duty cycle when the LEDs are unlit and the forward voltage is not present. For a hysteretic buck-LED driver driving three LEDs in series (**Figure 1**), you must measure the anode and cathode voltages of the string when the Dim pin is high.

To avoid the need for a differential high-voltage measurement, you can take the indirect approach of measuring the duty cycle at the driver pin, DRV. For this LED driver, a first-order estimate of forward voltage for

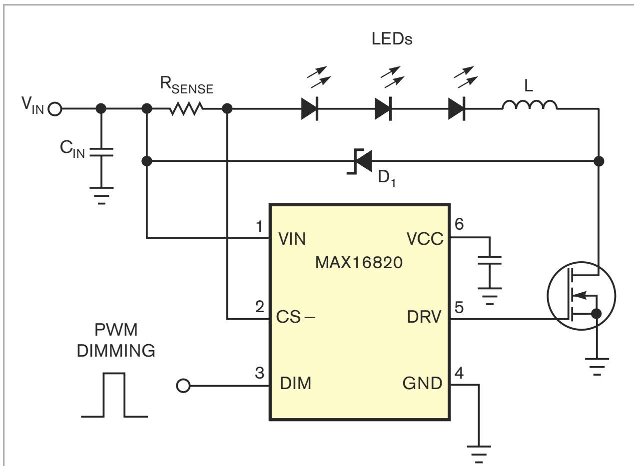


Figure 1 For a hysteretic buck-LED driver driving three LEDs in series, you must measure the anode and cathode voltages of the string when the Dim pin is high.

DESIGN NOTES

Reduce the Cost and Complexity of Medium LCD LED Backlights with a Single Inductor LED Driver for 60 LEDs

Design Note 462

Daniel Chen

Introduction

One inductor, one IC, one string of LEDs. This is the conventional way to build a boost LED driver for LCD display backlights. Although this is a perfectly acceptable solution for small LCD displays that only require a few strings, in larger displays the number of control ICs and inductors multiplies quickly, as do the expenses and PCB real estate requirements. This is a major hurdle in the race to replace CCFLs with robust, spectrally superior LEDs in medium sized, bright displays.

A better driver is needed to bring the cost and complexity of LED backlights in line with CCFLs. The LT3598 answers the call by driving six strings of ten LEDs at up to 30mA per string. It also has a built-in power switch to save space and design time. Efficiency is optimized via an adaptive feedback loop that monitors all LED pin voltages to provide an output voltage just high enough to light all LED strings. The LED current is regulated even when V_{IN} is greater than V_{OUT}. The LED current can be derated based on programmed LED temperature through an NTC resistor divider or by programming die junction temperature.

Typical Application

Figure 1 shows the LT3598's six channels driving 60 LEDs, with each string programmed at 20mA. The CTRL pin and PWM pin provide analog and digital dimming, respectively. True Color PWM™ dimming delivers constant LED color with a 3000:1 dimming ratio. Figure 2 shows the typical ±0.5% current matching between strings, which yields the uniform light distribution that is so important in large backlight applications.

Need More Current?

For applications that demand more than 30mA per string, multiple channels of the LT3598 can be easily combined for higher LED current. Figure 3 shows a configuration that drives two strings at up to 90mA per string. The 1000:1 PWM dimming waveform at 125°C junction temperature (worst case) is shown in Figure 4.

T_{SET} Pin for Thermal Protection

The T_{SET} pin voltage can be programmed to limit the internal junction temperature of the LT3598. Once this

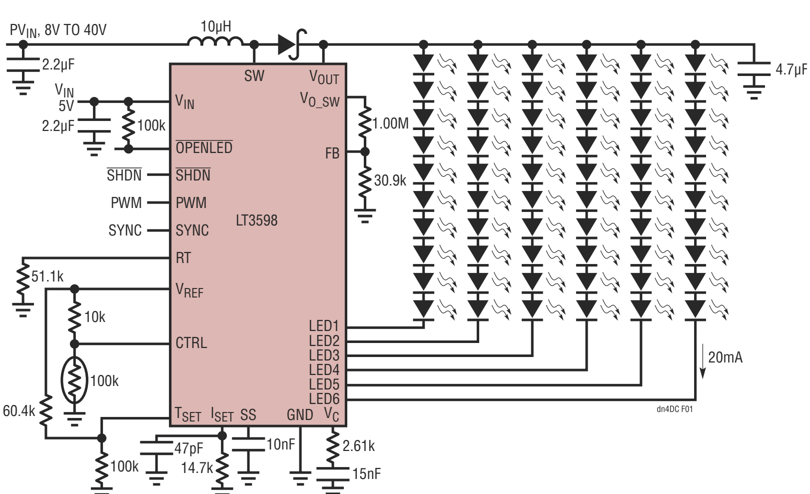


Figure 1. LED Driver for 60 × 20mA LEDs

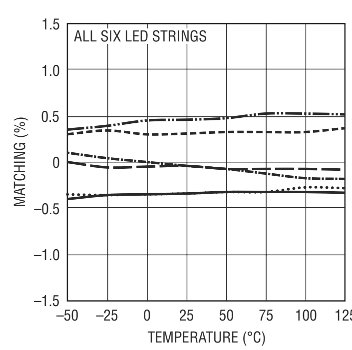
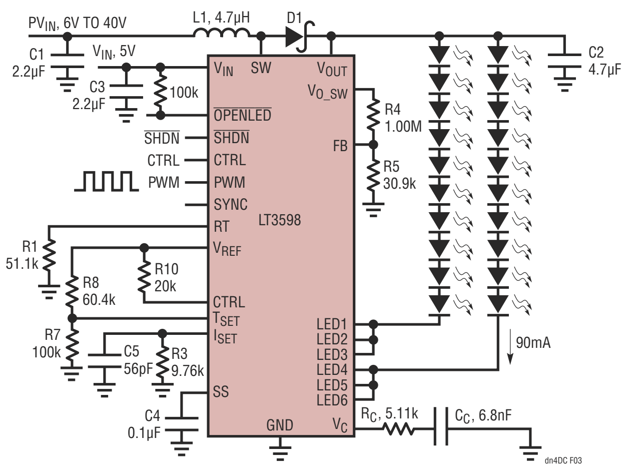


Figure 2. Current Matching for Figure 1

temperature is reached, the LED current will linerarly decrease if the junction temperature keeps increasing, as shown in Figure 5. This thermal regulation feature provides important protection at high ambient temperatures, and allows a given application to be optimized for typical, instead of worst-case, ambient temperatures.

Channel Disable Capability

Unused LED pins can be tied to V_{OUT} to disable them, so no current flows into the disabled channels. Fault detection ignores any channels tied to V_{OUT}. Figure 6 shows an application with two disabled channels that yields efficiency as high as 90%.



C1: NIPPON CHEMI-CON KTS500B225M32NOTOO
C2: MURATA GRM32ER71H475KA88L
C3: TAIYO YUDEN LMK212BJ225MG
D1: VISHAY SS3H9
L1: WÜRTH ELEKTRONIK 7447785004

Figure 3. LED Driver for Two Strings of 90mA LEDs

Conclusion

LT3598 is a versatile LED driver with a built-in power switch for multiple LED strings. High PWM dimming is possible even with its robust fault detection. Furthermore, a voltage loop regulates the output voltage when all LED strings are open.

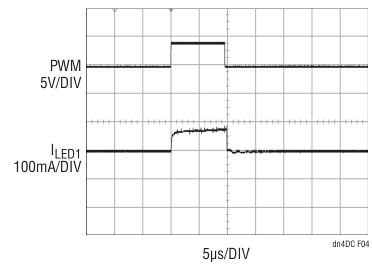


Figure 4. 1000:1 PWM Dimming for Figure 3 at 125°C

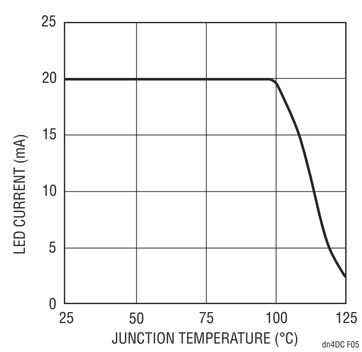


Figure 5. T_{SET} Function Reduces LED Current at High Temperatures

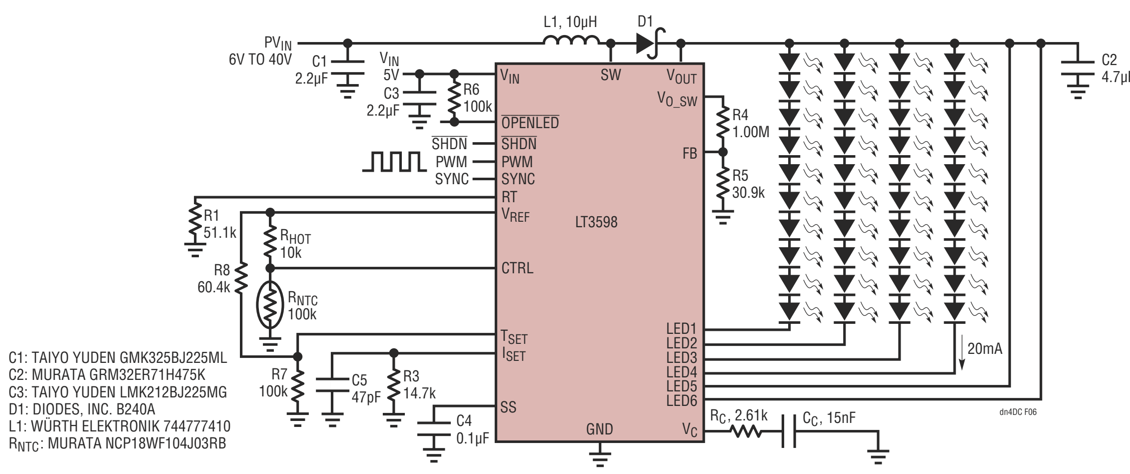


Figure 6. Four LED Strings with Two Channels Disabled

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the LED string is $V_F = D \times V_{IN}$, where D is an internal duty cycle that the IC's switch-mode section produces; do not confuse this duty cycle with that at the Dim pin. You reference the driver signal to ground and limit it to the power-supply voltage, V_{CC}, at 5V. That condition allows the use of low-voltage ADCs or comparators, which the LED driver's V_{CC} output, a maximum of 10 mA, can power.

Figure 2 shows how to detect a short-circuited LED with the aid of a comparator. Filter R_1C_1 converts the ac PWM signal at the driver to a dc voltage, V_D, proportional to $D \times V_{CC}$. You should sample V_D when its value is greater than perhaps 90% of its steady-state value; this sampling requires a period of at least $2.3R_1C_1$. Because the comparator's LE (latch enable) latches the output when LE is low, LE should assert not earlier than $2.3R_1C_1$ after the Dim pin goes high. R_2, C_2, and D_2 ensure that LE deasserts immediately after the Dim pin goes low. The value of R_2C_2 is higher than that of R_1C_1, so the comparator enables when the input signal reaches at least 90% of its steady-state value. D_2 immediately discharges C_2 after the Dim pin goes low, which latches the output as soon as the LEDs turn off.

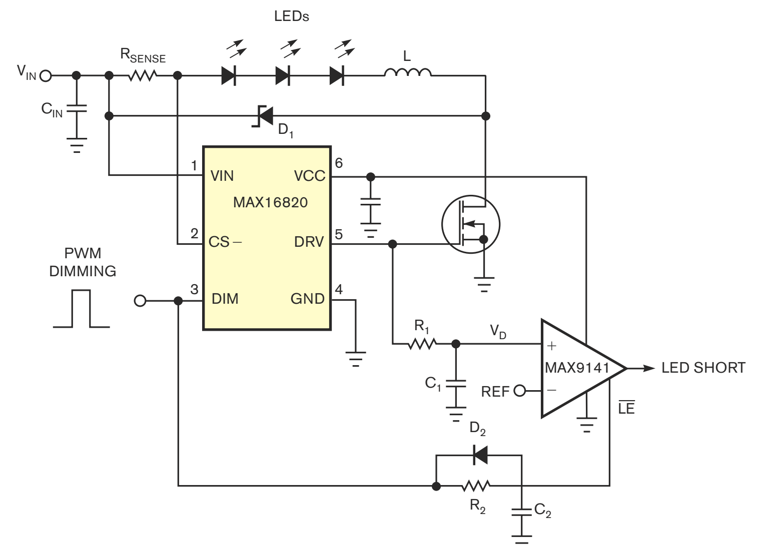

Figure 2 Adding this comparator circuit to the Figure 1 circuit provides detection of shorted LEDs.

Because the reference voltage is lower than $D \times V_{IN}$, the comparator output is normally low. If an LED fails shorted, its forward voltage drops and causes the duty cycle at the driver to drop. V_D then drops below the reference, causing the comparator's output to go high, indicating a shorted LED. Because the output latches when the Dim pin goes low, the error signal remains asserted even when the LEDs are off. **Figure 3** shows the filtered Dim pin and driver signals for normal operation versus a shorted-LED condition.

For a system with an input voltage of 12V and three LEDs in series, in which the forward voltage is approximately 3V per LED (**Figure 3a**), the filtered driver signal (green) stabilizes at approximately $D \times V_{CC} = (9V/12V)5V = 3.75V$. The comparator latches when the filtered Dim signal (yellow) goes lower than 2.5V, so the comparator begins interpreting the filtered driver signal after approximately 100 μsec. Clearly, V_D is higher than the threshold-reference voltage (red) when the comparator is active. After one of the LEDs shorts out (**Figure 3b**), V_D stabilizes at approximately $(6V/12V)5V = 2.5V$ and no longer exceeds the threshold. That condition causes the comparator's output to go high, indicating that one of the LEDs has become a short circuit.

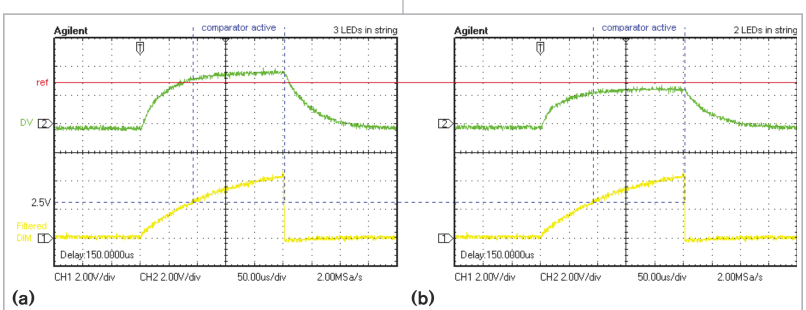

Figure 3 For a system with an input voltage of 12V and three LEDs in series, in which the forward voltage is approximately 3V per LED (a), the filtered driver signal (green) stabilizes at approximately $D \times V_{CC} = (9V/12V)5V = 3.75V$. The comparator latches when the filtered Dim signal (yellow) goes lower than 2.5V, so the comparator begins interpreting the filtered driver signal after approximately 100 μsec. Clearly, V_D is higher than the threshold reference voltage (red) when the comparator is active. After one of the LEDs shorts out (b), V_D stabilizes at approximately $(6V/12V)5V = 2.5V$ and no longer exceeds the threshold.

The choice of filter constants R_1C_1 and R_2C_2 depends on several parameters. The cutoff frequency should be low enough to properly filter the driver signal yet small enough to allow the filtered signal to stabilize near the steady-state value achievable within the shortest dimming pulse. You can easily adjust this circuit to detect open-circuit LEDs. When an LED breaks and stops conducting current, the driver's duty cycle goes to 100% when the Dim pin is high. If you then swap the comparator-input connections and put the reference voltage slightly below V_{CC}, the comparator output goes high in response to an open LED. EDN

Single pin controls relay, intermittent buzzer, and status LED

Kartik Joshi and Manik Chugh,
Netaji Subhas Institute of Technology, Delhi, India

Switching applications involving controlling devices or appliances using digital-I/O lines through a relay often need to indicate the change of state of the I/O line and, hence, the connected device. This indication could be in the form of a buzzer that turns on for a few seconds every time the line changes state. Designers generally employ an additional I/O pin to trigger the buzzer whenever the state of the primary I/O line changes. This Design Idea discusses a circuit that controls a device through a relay and an intermittent buzzer with only one digital-I/O pin.

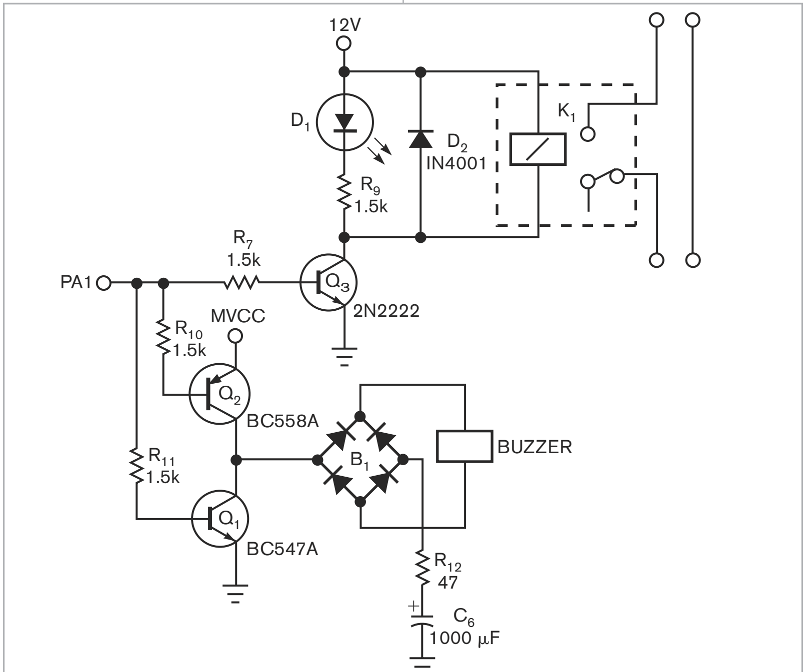

Figure 1 This circuit controls a device through a relay and an intermittent buzzer with only one digital-I/O pin.

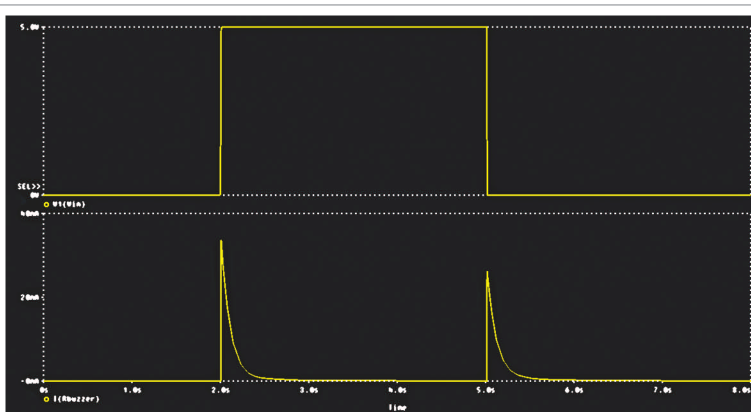

Figure 2 A Spice simulation of the buzzer circuit replaces the buzzer with 50Ω resistance and plots the current through the buzzer and the status of the I/O line.

Pin PA1 of the digital device controls a relay, which switches an appliance on and off (**Figure 1**). NPN transistor Q_3 activates the relay coil when the I/O line is in the high state. Status LED D_1 connects in parallel to the relay coil and turns on when the I/O line is high and off when the line is low.

The buzzer remains on for a small amount of time when the relay changes state. You accomplish this task by employing a push-pull-inverter topology using complementary BJTs (bipolar-junction transistors) NPN Q_1 and PNP Q_2. The output of this stage connects to a bridge rectifier with a buzzer as a load because buzzers usually are unidirectional. The bridge rectifier connects in series both with resistor R_{12} to regulate the maximum current through the buzzer and with capacitor C_1 to ensure that the buzzer "fades off." When the line is low, transistor Q_2 is on, the capacitor charges to a positive voltage, and the buzzer operates until the current through it is sufficient. When the line goes high, transistor Q_1 switches on, the capacitor discharges to approximately 0V, and the buzzer operates again for a short duration. The on-time of the buzzer depends on the values of R_{EQ}, the series combination of R_{12} and the buzzer resistance, and C_6. To change the time constant and hence the on-time of the buzzer, you should change the value of the capacitor rather than that of the resistor. You can also design this circuit using only one BJT instead of two, but the transistor would always draw some current at steady state.

This topology is useful when no separate I/O lines are available for controlling the buzzer. You can also employ this topology to indicate the change of state of any input stage directly by connecting it to the given circuit or through a buffer. **Figure 2** shows a Spice simulation of the buzzer circuit. This simulation replaces the buzzer with 50Ω resistance and plots the current through the buzzer along with the status of the I/O line. **EDN**

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Simple two-transistor circuit lights LEDs

Barry A Tigner, Michigan State University, East Lansing, MI

A previous Design Idea describes a circuit that uses an astable multivibrator to drive an LED (**Reference 1**). The circuit in **Figure 1** uses a simpler alternative approach. The circuit uses a 2N3904 NPN transistor and a 2N3906 PNP transistor, which operate as a high-gain amplifier.

The 1-MΩ resistor supplies bias current. The 1-kΩ resistor helps linearize the oscillator waveform into one that is close to a square wave with about a 50-to-50 duty cycle. The capacitor supplies positive feedback from the output of the amplifier to the noninverting input. The frequency of oscillation depends mostly on the RC constant of the feedback capacitor and the input-stage impedance. The circuit oscillates at 91 kHz with a 48% duty cycle. You can use almost any common NPN or PNP transistors, as long as they have moderate forward-current gain of 50 or more and can handle 100-mA collector currents.

The LED connects across the output transistor because this approach lets the inductive kickback voltage add to the battery-supply voltage and makes the LED brighter. This circuit operates well from approximately 0.8 to 1.6V, which is the useful range of an alkaline battery. The LED-light output decreases as the supply voltage decreases from 1.6 to 0.8V. EDN

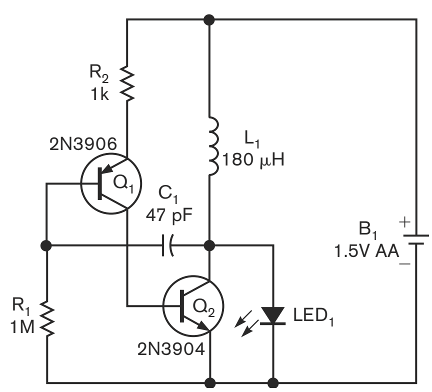

Figure 1 This two-transistor circuit operates as a high-gain amplifier to light LEDs.

REFERENCE

1 Bruno, Luca, "Astable multivibrator lights LED from a single cell," *EDN*, Aug 21, 2008, pg 53, www.edn.com/article/CA6586223.

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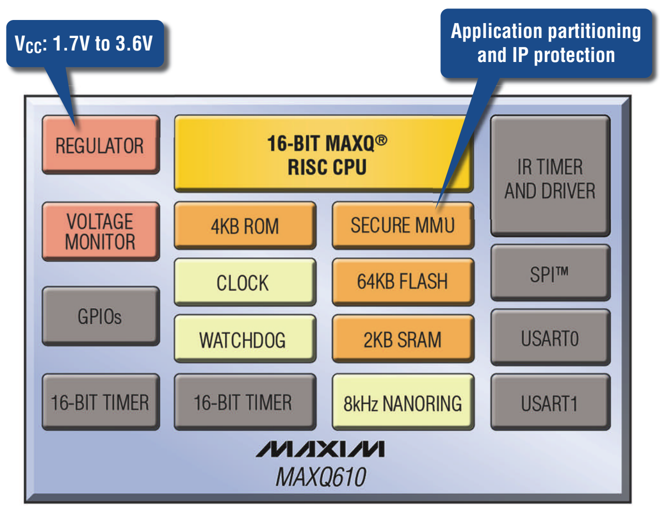

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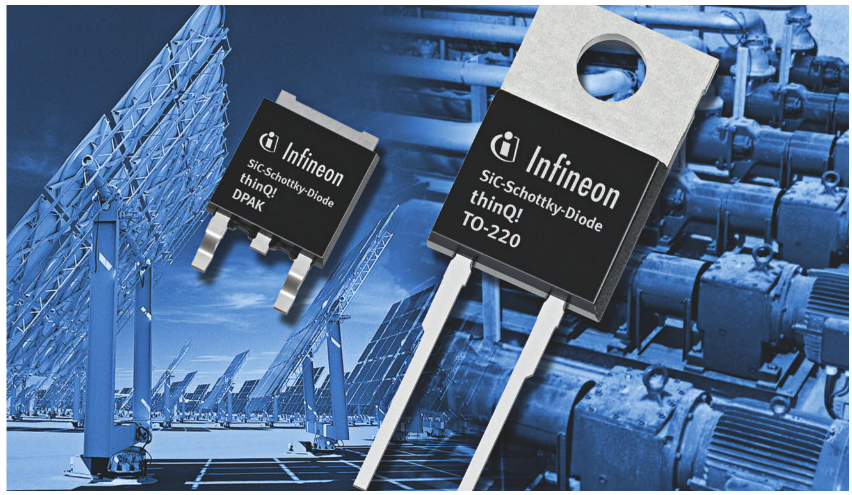

The diodes with 600V blocking voltages cost 85 cents at 3A, $1.19 at 4A, and $2.65 at 8A.

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BY HOLGER STEFFENS • IDENT TECHNOLOGY

Flip-flop flap

DANIEL VASCONCELLOS

I recently was a product engineer in a DRAM company and usually spent my time hunting bugs in other people's designs. Two years ago, however, I got an additional task: I had to design a measurement board with a couple of ICs, an ADC, and a DAC to set and measure voltages, clocks, and temperature. I figured that this task would give me a good chance to gain some additional design experience.

I decided to use an Altera (www.altera.com) FPGA as the central controller chip. The FPGA connected through an FTDI (Future Technology Devices International, www.ftdichip.com) USB (universal-serial-bus) chip to the PC on which the application software was running. The development ran smoothly, and we could soon read and write data through the USB to and from the FPGA. Unfortunately, though, after a few seconds, the board hung up. I restarted it, and everything was fine—again for about 10 seconds. It soon became clear that the FPGA wasn't properly responding to the USB chip.

The design operated with eight parallel data lines and four control signals that resided between the FPGA master and the USB-chip slave. The USB chip indicated when received data was ready for pickup by sending a receiver-flag signal. Using a transmitter-enable signal, it indicated whether the USB chip's transmitter FIFO had enough room for data to write to it.

When the system hung up, I hooked up a scope and saw that the USB chip indicated receive data by pulling the receiver-flag signal, but the FPGA didn't pick it up. Not being an experienced digital designer, I couldn't figure out the problem by examining the Verilog code. Simulations didn't show any issues, either. The beauty of an FPGA, however, is that it is programmable, so I could connect virtually any internal node to free I/Os and probe them with the scope. Luckily, I didn't have to wait too long for the hang-up; I could count on it. By probing all sorts of nodes, the scope showed that almost everything inside—except the interface to the USB—was running correctly. I could even probe the 4-bit state machine of the interface controller. In the case of the hang-up, it was in an undefined state—that is, one that wasn't encoded in the state table. How did it get there?

I consulted an experienced engineer on our memory-design team, and, after a long session with him, it became clear: The controller state machine depended on the flags of the USB chip. If the state machine is idle and the receiver flag is zero, the machine can issue a read transaction. So, I typed my Verilog code exactly like that statement: If (RX_flag#==0)state<= RxTransaction, where RX_flag# is the receiver flag. In Verilog, that code all looks fine; in hardware, however, my state machine had 10 states. Therefore, 4 bits, or four flip-flops, represent the current state. Each of the flip-flops had its own combinational logic to encode when to transition, and the flag goes to all of them. Some of those combinational blocks are longer and slower than the others, and the flag occasionally transitions at just the wrong moment. It happened that only three of the flip-flops recognized that the flag sampled at zero, but the fourth, slower one sampled it at one, and the state machine became lost.

Thanks to the experienced engineer, I learned that I had committed one of the big no-nos in digital design: using an external signal directly without synchronizing it with a flip-flop to the internal clock. That lesson really helped! EDN

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Counterfeit components find new markets

Although it's impossible to know for sure, industry experts estimate counterfeiting cost at $100 billion to $200 billion annually, or nearly 10% of all electronic equipment sold worldwide. Most industry experts claim that the problem is escalating and note that, although the federal government and several industry associations have taken measures to limit counterfeiting, it continues to plague the components industry.

Counterfeiters are even targeting low-cost, passive components. "Everything is getting counterfeited," says Robin Gray (**photo**), executive vice president of NEDA (National Electronic Distributors Association, www.nedassoc.org). "It's not just the high-value items, [such as] semiconductors. It can be connectors, resistors, anything that can turn a good profit, anything that's on allocation, anything that's in high demand."

In the past couple of years, counterfeiters have found a new market in hard-to-get parts and obsolete parts. One major market for obsolete parts includes the industries exempt from environmental-compliance laws, such as ROHS (restriction-of-hazardous-substances) directives. According to Tom Sharpe, vice president of independent components distributor SMT Corp (smtcorp.com), the military, aerospace, and medical industries are still using products containing lead. Many of these products are obsolete, and the chip manufacturers no longer support them, so counterfeiters target these parts.

Military purchasers in particular are turning to the open market to find non-ROHS parts. "A lot of counterfeiting comes from the fact that military customers cannot buy through the channels they are comfortable buying through," says Steve Schultz, director of strategic planning and communication at Avnet Logistics, a division of distributor Avnet Inc (www.avnet.com). "If I have 10 military customers, at least half of them will raise the question of counterfeiting."

–by Rob Spiegel

GREEN UPDATE

UNITED NATIONS TURNS UP HEAT ON MERCURY

The governing council of the UNEP (United Nations Environment Programme) is targeting a ban or strict restriction on mercury usage in product design through international controls. With more than 140 countries this year reaching an accord, UNEP recently announced that the governments unanimously decided to launch negotiations on an international treaty on mercury, which finds use in several consumer and medical electronics, as well as lighting sources.

The concurrence, which China, India, and many other Asian countries back, comes after the Obama administration announced that it had reversed the United States' stance on mercury and was now in favor of an international ban or strict restriction on the material. Until the recent change in administration, the United States had strongly supported voluntary initiatives instead of a treaty.

The EU (European Union) has called for its ban to start by 2011. The EU currently restricts mercury usage in electronics through the ROHS (restriction-of-hazardous-substances) environmental-compliance directive.

UNEP estimates that 6000 tons of mercury annually enter the environment and that every kilogram of mercury people remove from the environment triggers as much as $12,500 in social, environmental, and human-health benefits.**—SD**

OUTLOOK

PC INDUSTRY IN 2009 TO SEE SHARPEST UNIT DECLINE EVER

PC OEMs need to be ready for a double-digit decline in shipments this year, according to the research from Gartner Inc (www.gartner.com). The company reports that the PC industry will ship 257 million units in 2009, an 11.9% drop from 2008. Before this decline, PC units experienced their worst decline in 2001, when unit shipments declined 3.2% from 2000 levels.

"The PC industry is facing extraordinary conditions as the global economy continues to weaken," says George Shiffler, research director at Gartner. Gartner expects both emerging and mature markets to suffer unprecedented market slowdowns. The company expects emerging markets to post a year-over-year decline of 10.4% and a mature-market decline of 13% in 2009.

Gartner reports that worldwide mobile-PC shipments should reach 155.6 million units in 2009, a 9% increase from 2008. Desk-based PC shipments, however, should total 101.4 million units, a 31.9% decrease from 2008. Continued growth in mini-notebook, or netbook, shipments will substantially boost growth in the mobile-PC market. Excluding mini-notebooks, other mobile-PC shipments will grow just 2.7% in 2009, Gartner reports.**—SD**