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THIN AIR

ATSC RECEPTION ISN'T ALWAYS EASY

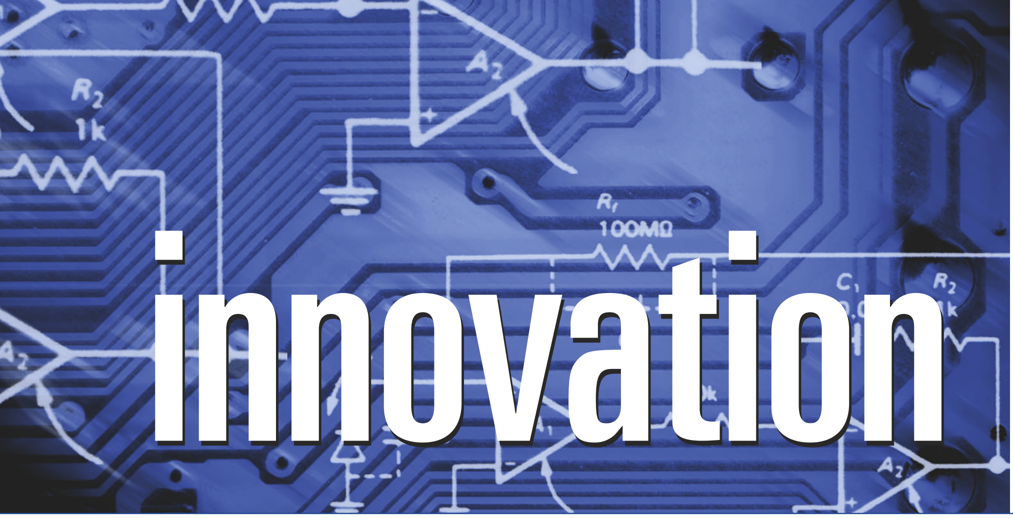
Page 20

ELIMINATE SALLEN-KEY STOPBAND LEAKAGE WITH A VOLTAGE FOLLOWER

Page 17

SPECIAL SECTION TOPS IN POWER

Page 41



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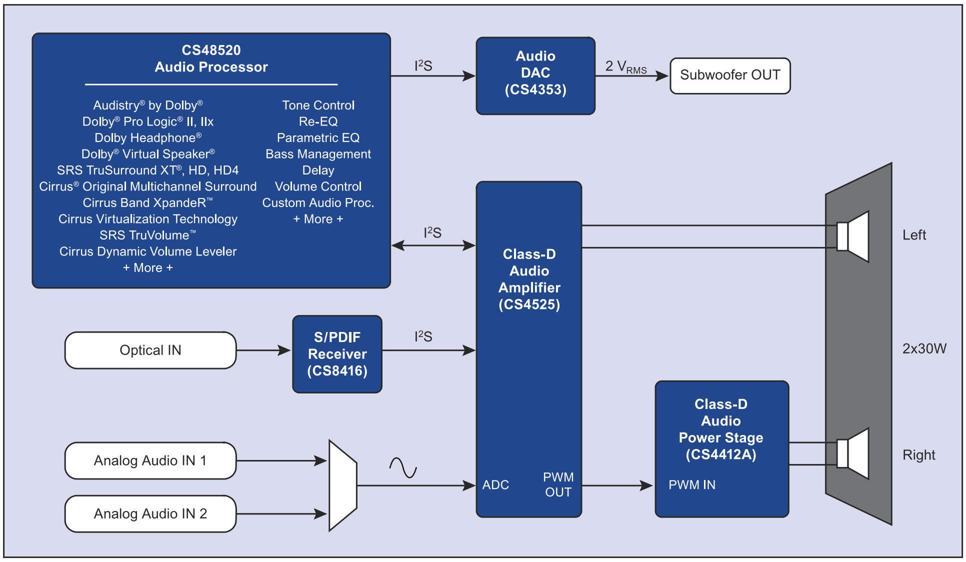
Home Theater System by Samsung®

This full-featured Samsung® soundbar gets its audio processing power from Cirrus Logic's CS48540 audio DSP, while the Cirrus Logic CS5345 stereo A/D converter handles the audio conversion.



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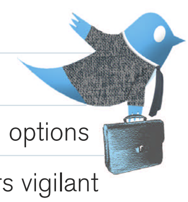
EDN
5.14.09
contents

contents 5.14.09

56

58

DEPARTMENTS & COLUMNS



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TOP 25
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Check out "Weathering the storm: how distributors help customers navigate rough seas," published as a special section in conjunction with NEDA (National Electronic Distributors Association) in our April 23 issue. Available as a 15-pg PDF, the special section also contains the Top 25 North American Electronic Component Distributors list.
→www.edn.com/top25distributors

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BY SUZANNE DEFFREE, MANAGING EDITOR, NEWS

What are you doing?

The question that people seem to be most often asking each other is, What are you doing? What are you doing in LEDs? What are you doing with your fabs? What are you doing to thwart the economy's impact on your business? What are you doing at *EDN* that my company can be a part of? That constantly posed question begs for information sharing. And, as part of *EDN*'s ever-striving effort to keep the electronics industry informed and ask as well as answer the question, we've joined Twitter, www.twitter.com/ednmagazine, the now-famous social-media tool that allows you to send short, microblog "tweets" to associates, or "followers."

EDN first checked out Twitter in early 2008 but put the fledgling tool on the back burner and instead focused our online efforts on our popular blogs, newsletters, RSS (really simple-syndication) feeds, and Web site as means to keep the electronics industry informed in real time. As with the in-depth coverage in *EDN* magazine, our engineering and executive audiences responded to, trusted, and respected these proven mediums. When we spoke with readers at the time, they brushed off Twitter as a flavor-of-the-moment site that spread mundane blips of life among its users, who seemingly had endless amounts of free time.

Now, a year later, Twitter has changed. It's grown up, in both its content and its audience. The tool gets approximately 10 million visitors a month, and the makeup of the audience driving that traffic may be a surprise. According to comScore Inc, it's not the early-20s, social-media early adopters pushing this site's growth. The Internet-marketing-research company reports that 45- to 54-year-olds, followed by 25- to 34-year-olds are the most likely groups to visit Twitter. So, it should come as no surprise that the tweets people have begun to post on the site have begun to match the maturity of the audience. Fewer posts are about the mundane blips of life, such as getting coffee or watching *Heroes*. More leaders and businesses are joining the site each day, contributing to the flock of companies that includes semiconductor-industry chiefs Analog Devices, Digi-Key, Fairchild, and Texas Instruments.

Twitter has changed. It's grown up, in both its content and its audience.

Twitter is far from perfect; anyone familiar with the "fail-whale" image will tell you that fact. The 140-character limit also poses a challenge. And, yes, many users do still post mindless chatter. But don't write off this tool as a preteen sensation that will be over faster than the next boy band. Like every other online medium, it's about aligning with the right partners. Do so, and you'll find that there's real value here in making connections, delivering information, and staying informed.

With www.twitter.com/ednmagazine, we'll give you instantaneous news updates, technical analysis, and quick tweets on our blogs, editors, and opportunities faster than you can get with *EDN*'s newsletters and RSS feeds. You'll still want these tools as well as our print magazine for the full industry picture, mind you, but it never hurts to have information readily at hand in this rapidly changing, fast-paced world in which we design, partner, and compete.

And here's our promise to you: We won't waste your time with insignificant blurbs or overload you with 50 tweets a day about every little thing going on in the *EDN* universe. We understand that you have better things to do. We'll hold our Twitter messages to the same high standards to which we hold all of our editorial products.

So far, *EDN*'s readers have embraced our leverage of Twitter. In fact, within 24 hours of promoting *EDN*'s Twitter activity, nearly 100 followers with bios ranging from engineers, to chief executive officers, to marketing execs, to professors and students, had signed up to receive our tweets, many of them taking the time to e-mail and tell us what they thought of the move.

Follow us at www.twitter.com/ednmagazine and find out what your peers and rivals are doing. And drop us a line. We'd like to know what you think and what you are doing. **EDN**

Contact me at sdeffree@reedbusiness.com.

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EDN

PRESIDENT, BOSTON DIVISION, REED BUSINESS INFORMATION
Mark Finkelstein, mark.finkelstein@reedbusiness.com
1-781-734-8431

PUBLISHER, *EDN* WORLDWIDE
Russell E Pratt, 1-781-734-8417;
rpratt@reedbusiness.com

ASSOCIATE PUBLISHER, *EDN* WORLDWIDE
Judy Hayes, 1-925-736-7617;
judy.hayes@reedbusiness.com

VICE PRESIDENT, EDITORIAL DIRECTOR
Karen Field, 1-781-734-8188;
kfield@reedbusiness.com

EDITOR-IN-CHIEF, *EDN* WORLDWIDE
Rick Nelson, 1-781-734-8418;
rnelson@reedbusiness.com

EXECUTIVE EDITOR
Ron Wilson, 1-510-744-1263;
ronald.wilson@reedbusiness.com

MANAGING EDITOR
Amy Norcross
1-781-734-8436;
fax: 1-720-356-9161;
amy.norcross@reedbusiness.com
Contact for contributed technical articles

SENIOR ART DIRECTOR
Mike O'Leary
1-781-734-8307;
fax: 1-303-265-3021;
moleary@reedbusiness.com

ANALOG
Paul Rako, Technical Editor
1-408-745-1994; paul.rako@edn.com

MASS STORAGE, MULTIMEDIA, PCs, AND PERIPHERALS
Brian Dipert, Senior Technical Editor
1-916-760-0159;
fax: 1-303-265-3187;
bdipert@edn.com

MICROPROCESSORS, DSPs, AND TOOLS
Robert Cravotta, Technical Editor
1-661-296-5096;
fax: 1-303-265-3116;
rcravotta@edn.com

NEWS
Suzanne Deffree, Managing Editor
1-631-266-3433;
sdeffree@reedbusiness.com

POWER SOURCES, ONLINE INITIATIVES
Margery Conner, Technical Editor
1-805-461-8242;
fax: 1-805-461-9640;
mconner@reedbusiness.com

DESIGN IDEAS EDITOR
Martin Rowe,
Senior Technical Editor,
Test and Measurement World
edndesignideas@reedbusiness.com

SENIOR ASSOCIATE EDITOR
Frances T Granville
1-781-734-8439;
fax: 1-303-265-3131;
f.granville@reedbusiness.com

EDITORIAL/WEB PRODUCTION
Diane Malone, Manager
1-781-734-8445; fax: 1-303-265-3024
Steve Mahoney,
Production/Editorial Coordinator
1-781-734-8442; fax: 1-303-265-3198
Melissa Annand,
Newsletter/Editorial Coordinator
1-781-734-8443; fax: 1-303-265-3279
Adam Odoardi, Prepress Manager
1-781-734-8325; fax: 1-303-265-3042

CONSULTING EDITOR
Jim Williams, Staff Scientist,
Linear Technology

CONTRIBUTING TECHNICAL EDITORS
Dan Strassberg,
strassbergedn@att.net
Nicholas Cravotta,
editor@nicholascravotta.com

COLUMNISTS
Howard Johnson, PhD, Signal Consulting
Bonnie Baker, Texas Instruments
Pallab Chatterjee, SiliconMap

PRODUCTION
Dorothy Buchholz,
Group Production Director
1-781-734-8329
Joshua S Levin-Epstein,
Production Manager
1-781-734-8333; fax: 1-781-734-8096

EDN EUROPE
Graham Prophet, Editor, Reed Publishing
The Quadrant, Sutton, Surrey SM2 5AS
+44 118 935 1650;
fax: +44 118 935 1670;
gprophet@reedbusiness.com

EDN ASIA
Luke Rattigan, Chief Executive Officer
luke.rattigan@rbi-asia.com
Kirtimaya Varma, Editor-in-Chief
kirti.varma@rbi-asia.com

EDN CHINA
William Zhang,
Publisher and Editorial Director
wmzhang@idg-rbi.com.cn
Jeff Lu, Executive Editor
jefflu@rbichina.com.cn

EDN JAPAN
Katsuya Watanabe, Publisher
k.watanabe@reedbusiness.jp
Ken Amemoto, Editor-in-Chief
amemoto@reedbusiness.jp

EDN. 225 Wyman St, Waltham, MA 02451. **www.edn.com**. Phone 1-781-734-8000. **Address changes or subscription inquiries:** phone 1-800-446-6551; fax: 1-303-470-4280; subsmail@reedbusiness.com. For a free subscription, go to **www.getfreemag.com/edn**. Reed Business Information, 8878 S Barrons Blvd, Highlands Ranch, CO 80129-2345. Include your mailing label.

Reed Electronics Group

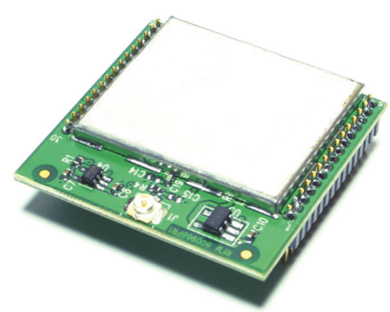
EDITED BY FRAN GRANVILLE

pulse

INNOVATIONS & INNOVATORS

Wireless module claims five-year battery life

With the proliferation of Wi-Fi networks, embedded-system designers are turning to wireless interfaces to eliminate the expensive wiring and installation costs for commercial and industrial sensing applications. The major challenge has been the relatively short battery life for remote sensors that interface through the wireless network. To address this problem, RF Monolithics recently announced the WSN802G Wi-Fi-sensor-networking module. With its ability to operate for years on battery power, the low-power, low-cost, 802.11 b/g module targets wireless-sensor-networking applications.



With its ability to operate for years on battery power, the low-power, low-cost, 802.11 b/g WSN802G module targets wireless-sensor-networking applications.

To achieve its low power consumption and long battery life, the WSN802G combines 1- and 2-Mbps data rates, which are appropriate for most sensing applications, with an advanced sleep-management feature that puts the module to sleep between active periods. Depending on the frequency of active periods, the device can operate on a single AA lithium cell with a battery life of more than five years. When the module is active, its current consumption is less than 200 mA, allowing a battery to adequately power the device. Its sleep-current consumption is less than 8 μA. Typical transmission ranges are 50m indoors and 250m outdoors. The WSN802G has a 1×1.05-in. footprint and sells for $69 (one) or $39 (10,000). The WSN802GDK developer's kit is also available.**—by Warren Webb**

▷**RF Monolithics**, www.rfmonolithics.com.

FEEDBACK LOOP

"So, they got in a Jeep and drove to the manhole where the (supposedly) two male connectors resided. Sure enough, the print was correct, and the installer had carefully mated the two male connectors as best he could and then wrapped it all in a great wad of electrical tape."

—Engineer and *EDN* reader Dave Thomson, in *EDN*'s Feedback Loop, at www.edn.com/article/CA6651606. Add your comments.

Highly integrated power converter combines efficiency, small footprint

The tiny, self-contained ENP53F8QI PwrSOC (power supply on chip) from Enpirion provides an ideal power source for electronic systems, especially in space- and power constrained systems, such as USB (universal-serial-bus) wireless data cards. The 1500-mA, synchronous, buck dc/dc converter integrates the control and protection circuitry with gate drive, power MOSFETs, a compensation network, and a power inductor to achieve a power density of 140 mW/mm² within its 3×3×1.1-mm QFN package.

The device requires some passive components, including capacitors and resistors; two of the resistors provide the resistor-divider network that sets the output voltage, which can range from 0.6V to the input voltage minus 0.5V. The 4-MHz switch-mode converter provides as much as 5.5W and achieves as much as 94% efficiency. It sells for $1.36 (10,000).**—by Margery Conner**

▷**Enpirion**, www.enpirion.com.

The tiny ENP53F8QI dc/dc buck converter achieves 140 mW per mm² within its 3×3×1.1-mm QFN package.

SchmartBoard offers prototype-PCB systems, modules, social networking, and more

SchmartBoard has developed a series of prototype PCBs (printed-circuit boards) that you can snap together into complete systems. To provide for prototyping using fine-line surface-mount components, the novel system uses a patented, extra-thick solder-mask layer. This layer provides a pocket that locates the parts and prevents solder-bridging between pins.

To solder the part to the board, you need only to run a soldering iron along the pad; this step melts the solder, forcing it under the board's IC pin. The same thick solder mask that locates the part also guides your soldering iron to ensure that there are no solder bridges.

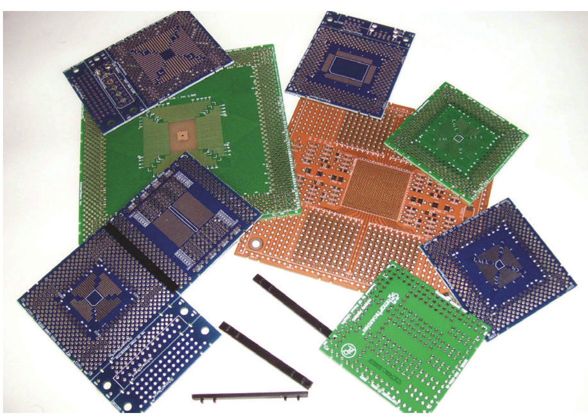
Available boards provide for 0.4-mm-pitch components. Others allow you to solder BGA components by using a via in each pad for the BGA. By heating from the underside of the board, you can wick away the solder to the BGA-solder ball and make a reliable contact.

In addition to prototyping boards for most surface-mount components, SchmartBoard also offers SchmartModules, which include Microchip (www.microchip.com) PIC microcontrollers along with the requisite support circuitry for USB (universal-serial-bus) programming. Other boards contain RS-232 drivers and various peripheral functions. By snapping the boards together, you can prototype an entire embedded system. SchmartBoard works with semiconductor companies to develop modules for their microcontroller lineups. Other boards provide for power, connectors, and switches.

SchmartBoard also offers a social-networking site, www.solderbynumbers.com, for electronics engineers and hobbyists. The site provides a way for experienced designers to post designs that use various SchmartBoard prototyping boards. With the site, you create solder bridges that wire the SchmartBoard designs across pads on a board. The pattern of these solder bridges defines a schematic, hence the solder-by-numbers moniker. Anyone wishing to build that design pays a $5 royalty to the developer. In exchange, the developer must answer any questions and provide e-mail assistance to the royalty purchaser.

SchmartBoard can also design and fabricate custom boards to provide for engineering, prototyping, or manufacturing. Prices are $5 for simple boards, $20 for a 10-pack of connector or power boards, and $49.99 for a 400-pin BGA prototyping board. Combo kits and accessories are also available **—by Paul Rako**

▷**SchmartBoard**, www.schmartboard.com.



The SchmartBoard prototyping system includes boards for surface-mount and through-hole parts, as well as modules for microcontroller systems and peripherals.

DILBERT By Scott Adams

05.14.09

LED-METAL SUBSTRATES GET STICKY WITH THERMALLY CONDUCTIVE ADHESIVE

Bergquist has introduced its Bond Ply 450 thermal-interface material, which eases heat removal from LED assemblies when you combine it with the company's Thermal Clad metal substrate. The peel-and-stick aspect of mounting an LED substrate is attractive for ease of assembly, but sticky-mounting approaches usually have two drawbacks: The stickiness degrades during the heat of solder reflow, and the adhesive generally acts as an insulator–a drawback when your goal is to remove heat from the LED substrate.

The Bond Ply 450 PA withstands solder temperatures and has a thermal impedance of 0.87°C in.^{2}/W. Although it's difficult to set a price on a product for custom designs, Bergquist estimates a price of approximately 12 cents/in.^{2} (10,00 to 25,000), including the Bond-ply material and its preapplication.

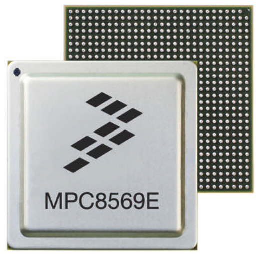
—by Margery Conner

▶**Bergquist, www.bergquistcompany.com.**

Bergquist combines its Bond Ply 450 thermal-interface material with its Thermal Clad metal substrate to ease heat removal from LED assemblies.

PowerQUICC boosts performance, delivers flexibility and lower-power operation

Freescale's MPC8569E communications processor, which targets wireless-access-infrastructure applications, expands the integrated QUICC (quad-integrated-communications-controller)-engine family of devices to processing support with as many as four internal RISC-processor engines, double the amount of RISC processing on previous QUICC devices. The devices maintain typical power consumption of less than 7 and 10W for the 800-MHz and 1.33-GHz cores, respectively. The QUICC-engine block offloads datapath tasks from the e500 core to handle termination, interworking, and switching between communication protocols and interface standards, such as GbE (gigabit Ethernet), ATM (asynchronous-transfer mode), HDLC (high-level data-link control), POS (packet-over-synchronous) optical network, PPP (point-to-point protocol) and PWE3 (pseudowire emulation edge to edge). The QUICC engine sports as much as 256 kbytes of instruction RAM and 128 kbytes of multiuser RAM and can operate as fast as 667 MHz to support as many as eight 10/100-Mbps or four 10/100/1000-Mbps Ethernet ports.



The MPC8569E communications processor targets wireless-access-infrastructure applications and expands the integrated QUICC-engine family with as many as four internal RISC-processor engines.

The e500 core operates as fast as 1.33 GHz and includes 32-kbyte instruction and data caches as well as a 512-kbyte L2 cache with ECC (error-correcting code). It includes support to access one 64-bit or two 32-bit DDR2/DDR3-memory interfaces with ECC, and the core supports double-precision floating-point operations. The integrated security engine supports ARC4 (alleged Rivest Cipher 4), 3DES (triple data-encryption standard), AES (advanced encryption standard), RSA/ECC (Rivest, Shamir, & Adleman/elliptic-curve cryptography), RNG (random-number generator), XOR (exclusive or), single-pass SSL/TLS (secure sockets layer/transport-layer security), Kasumi, and SNOW (scalable network of workstations).

Other integrated features include an 800-Mbps/pin data rate, a 16-bit local bus for SRAM/flash memory, full-speed USB 2.0, high-speed serial interfaces, dual SGMII (serial gigabit media-independent interface), and dual one-lane Serial RapidIO or PCIe (peripheral-component-interconnect-express) interfaces. The integrated scalable SERDES (serializer/deserializer) interconnect helps to reduce system cost. These integrated features allow designers to replace separate control-path and datapath processors with a single device.

The MPC8569E is software-compatible with Freescale's other PowerQUICC and QorIQ devices. The MPC8569E processor supports downloadable RAM-microcode packages that offer support for new functions or protocols. Freescale offers a modular-development system and a version of its CodeWarrior development environment for QUICC technology. Third-party vendors work with Freescale to offer RTOS support, compilers, debuggers, simulators, reference designs, and custom microcode for the MPC8569E family. The MPC8569E processor is available for sampling now, and prices begin at $80 (10,000).

—by Robert Cravotta

▷**Freescale**, www.freescale.com.

MODULE MERGES SUMIT INTERFACE WITH ISM FORM FACTOR

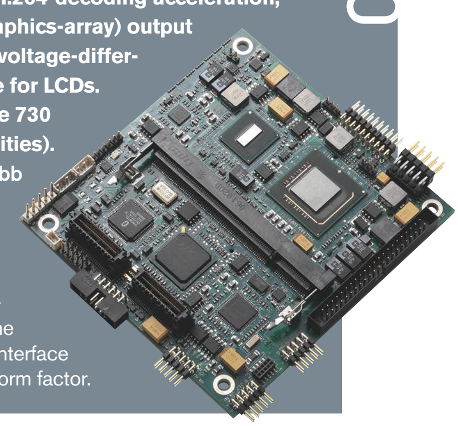
Taking advantage of the latest small-form-factor announcements, Adlink Technology recently introduced the CoreModule 730 single-board computer combining the SUMIT (stackable-unified-module-interconnect-technology)-standard expansion interface from the SFF-SIG (Small Form Factor Special Interest Group) with the newly defined ISM (industry-standard-module) form factor. SFF-SIG also defines ISM, a 90×96-mm form factor, similar to PC/104, which specifies only the board outline plus mounting holes and is flexible in allowable expansion interfaces.

Adlink based the new embedded computer on the low-power Intel (www.intel.com) Atom Z510 and Z530 processors and packs multiple PCIe (peripheral-component-interconnect-express) lanes, USB (universal-serial-bus) interfaces, LPC (low-pin-count) bus, I²C (inter-integrated-circuit) bus, and SPI (serial-peripheral-interface) bus into a fraction of the space that only the 33-MHz parallel PCI-104 bus previously occupied.

CoreModule 730 offers a choice of 1.1- or 1.6-GHz Atom processors; as much as 2 Gbytes of DDR2 RAM; GbE (gigabit Ethernet); four USB 2.0 ports; an IDE (integrated-drive-electronics) interface; a Compact Flash socket, eight general-purpose I/O pins; and an integrated graphics engine with H.264-decoding acceleration, an analog VGA (video-graphics-array) output and 18/24-bit LVDS (low-voltage-differential-signaling) interface for LCDs. Prices for the CoreModule 730 start at $400 (OEM quantities).

—by Warren Webb

▶**Adlink Technology, www.adlinktech.com.**



The CoreModule 730 single-board computer combines the SUMIT-standard expansion interface with the newly defined ISM form factor.

05.14.09

EDITED BY RON WILSON

Patterning method could aid scaling

Researchers at the Massachusetts Institute of Technology claim to have discovered an "absorbance-modulation" method for patterning lines onto a microchip that has produced lines just 36 nm wide. The key to the method is the use of interference patterns, in which different wavelengths of light sometimes reinforce and sometimes cancel each other. Researchers use a photochromic material, which changes its color and switches between transparency and opacity and vice versa by exposure to a pair of patterns, each of a different wavelength. The researchers admit that photochromic materials are not new but claim that they have found a way to create a mask with fine lines of transparency and that they can then use the mask to create a correspondingly fine line on the underlying material.

When the bright lines at one wavelength coincide with the dark lines at the other wavelength, narrow lines of clear material form, and they intersperse with the opaque material, according to the researchers. This banded layer then serves as a mask through which the first wavelength illuminates a layer of material underneath, similar to the way technicians make photographic negatives from prints by shining light through the negative onto a sheet of photo paper underneath. The researchers claim that absorbance modulation makes it possible to create lines that are only about one-tenth as wide as the wavelength of light used to create them. The researchers also claim that they could place many such lines a similar distance apart. MIT Research Engineer Rajesh Menon of the Research Laboratory of Electronics and graduate students Trisha L Andrew of the Department of Chemistry and Hsin-Yu Tsai of the Department of Electrical Engineering and Computer Science performed the research and reported it in a paper (**Reference 1**).

Such a technique "could have a significant impact on chip making," says Menon, and could help to enable new work in a variety of emerging fields that rely on nanoscale patterning, including nanophotonics, nanofluidics, nanoelectronics, and nanobiological systems. Menon expects the work to lead to commercial production within five years. The MIT team is also pursuing possible use of the research for imaging systems, with possible applications in biology and in materials science. MIT researchers are looking for ways of using the technique to create even smaller patterns, down to the scale of individual molecules. Grants from LumArray Inc (www.lumarray.com), where Menon is co-founder; the MIT Deshpande Center for Technological Innovation (web.mit.edu/deshpandecenter); and DARPA (Defense Advanced Research Projects Agency) partially funded the research.

—by Suzanne Deffree

▷**Massachusetts Institute of Technology**, www.mit.edu.

> "A photochromic material changes its color and switches between transparency and opacity.

REFERENCE

1 Andrew, Trisha L, Hsin-Yu Tsai, and Rajesh Menon, "Confining Light to Deep Subwavelength Dimensions to Enable Optical Nanopatterning," *Science* Magazine, April 10, 2009, www.sciencemag.org.

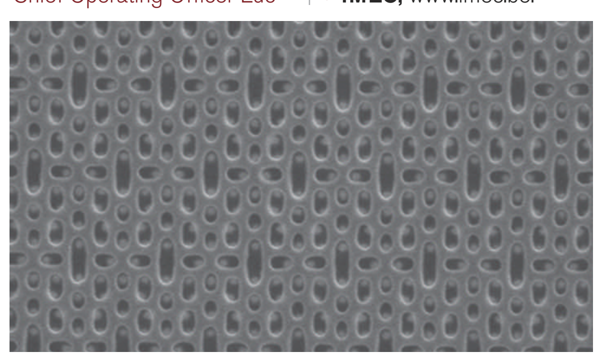
EUV prints critical layers for 22-nm SRAM

IMEC (Interuniversity Microelectronics Center) reports having used ASML's (www.asml.com) EUV (extreme-ultraviolet) Alpha lithography tool to print the contact and metal patterns for a 22-nm-node SRAM cell—apparently, the first application of the tool for multiple layers at this density. The SRAM cell is both tiny—at 0.099 micron²—and based on a complex FinFET structure. The exercise emphasizes both the image fidelity and the overlay accuracy of the lithography system.

The FinFET structure, which IMEC developed, employs a hafnium-dioxide dielectric with a titanium-nitrogen-metal gate, draped over a nickel-platinum-silicide source-to-drain fin. IMEC printed the contact and metal layers using the EUV tool and all other patterns using conventional 193-nm immersion lithography. The researchers report that the lithography system achieved acceptable overlay accuracy in this application.

Perhaps the most significant aspect of this result, according to IMEC Chief Operating Officer Luc Van den hove, is that the team was able to print all the patterns for the cell without resorting to multiple-patterning techniques. This advantage could give EUV—notably slow, expensive, and not yet ready for prime time—just the edge it needs for consideration as at least a follow-on to process nodes in the 22-nm region.**—RW**

▶**IMEC,** www.imec.be.



IMEC exposed a 32-nm SRAM device to various doses of EUV.

BY HOWARD JOHNSON, PhD

Driving-point impedance

In **Figure 1**, cut the PCB (printed-circuit-board) trace at its left end, disconnecting it from resistor R_0. Measure impedance Z_1, the impedance looking from your cut to the left back toward the driver. If the resistor is sufficiently close to the driver and there are no other impairments, you should see just the natural output resistance of the driver, R_S, plus the external series resistor, R_0.

In the terminology of circuit theory, you just measured the driving-point impedance of the circuit to the left of the cut. The circuit to the right is the circuit load.

In this example, assume R_S+R_0 equals the characteristic impedance, Z_0, of the perfect, lossless transmission line. That arrangement forms a perfect termination at the driver location. The perfect termination at the driver will absorb any signals reflected from the right end of the net, traveling back to the left. Such a circuit is known as a series-terminated net.

On the same PCB trace, repair your first cut and then make a second measurement of driving-point impedance, this time cutting the circuit in the middle. Do you suppose that Z_2 differs from Z_1? How could it? When making this measurement, every signal you inject travels to the left only to meet its death at the driver termination. Nothing reflects. No experiment reveals any information about the distance to the driver. In other words, because of the perfect source termination, the distance to the driver does not and cannot affect your driving-point impedance measurement. In a perfect series-terminated architecture, you can measure the driving-point impedance at the driver, in the middle of the line, or 100 miles away—assuming a perfectly lossless transmission line; the measurement always returns the same number, Z_0.

The endpoint effect delays the received signal in a predictable way.

I raise this topic because the driving-point impedance at the end of the line predictably distorts the received signal at the endpoint. Knowing that the driving-point impedance, Z_3, equals Z_0, a nearly pure resistance, you may recognize that the driving-point impedance, working in conjunction with the load capacitance, forms a simple RC lowpass filter. That filter disperses each rising and falling edge, imposing an additional delay on the circuit. The group delay of the endpoint filter for a series-terminated line equals Z_0C_L. For the special case of a series-terminated line, the same group-delay calculation applies regardless of transmission-line length.

The overall time of flight for a series-terminated net equals the raw, unloaded propagation delay of the transmission line plus the group delay of the RC endpoint effect. That simple calculation estimates the time of flight from the signal midpoint at the driver to the signal midpoint at the receiver. EDN

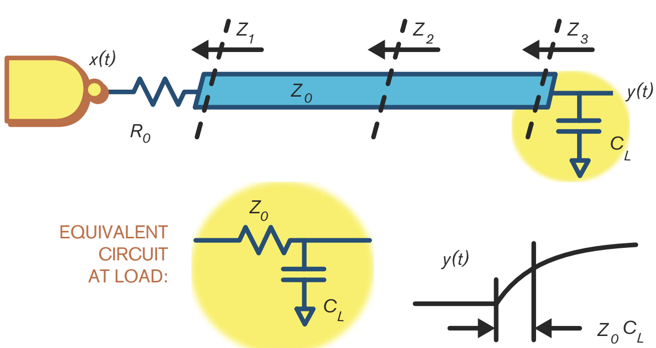


Figure 1 Cut the trace at any point to measure its driving-point impedance.

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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BY PALLAB CHATTERJEE, CONTRIBUTING TECHNICAL EDITOR

Selecting the correct process geometry and options

Most of the custom chips today, including ASICs, ASSPs (application-specific standard products), and special-purpose custom chips, have function blocks that do not require leading-edge processes. This situation has introduced the task of selecting which process node is the most appropriate for the design opportunity. The traditional metric for process selection is the speed requirement for the logic and the associated pin-to-pin clock rate. These criteria determine the minimum device geometry, the junction profiles, the number of layers of interconnect—which in turn determines the areal density of gates—and the type of substrate material. Most of the digital-only designs with fewer than 100 million gates use these criteria, and they work well.

Most new designs, however, incorporate more than just high-speed digital logic. Memory options, analog and mixed-signal blocks, and packaging and assembly options have now become critical factors in the fabrication-process selection. Power consumption is also a major factor in identifying an appropriate process node. As designers evaluate older processes, they must be aware of the intended operating voltage of the design as well as the threshold-voltage selections that are available.

Some older processes, particularly in mixed-signal devices, can support operation at a voltage as high as 12V with 0.7V threshold voltages. These processes may not be appropriate choices for a design aiming for 1.2 to 1.3V operation. Conversely, some nominally 3.3V-sensor applications may not work well with 65- or 45-nm technologies that are using 0.3V thresholds and device-breakdown voltages of 2.7V.

One area of misunderstanding in process selection lies in the interconnect and passivation options.

Some of the common high-volume processes, such as 180, 130, and 90 nm, are available in multiple process options. These options include standard logic, mixed-threshold logic, analog with special resistors and capacitors, RF with inductors and special FETs, high-density memory, and low-power and low-leakage process flows. Each of these options has a unique set of device models, design rules, layer lists, and IP (intellectual-property) libraries. The design blocks are not generally interchangeable among the processes. It is important that designers observe which option their teams have selected and which rules and device types apply to those designs and processes.

One area of misunderstanding in process selection lies in the interconnect and passivation, or back-end-of-line-flow, options. Processes of 0.25 micron and larger generally use only aluminum interconnect with a bimetal plug implant. Geometry processes at 130 nm and smaller usually use copper-only interconnect. Processes in the midrange, such as 150, 180, and 200 nm, support either all-aluminum interconnect, all-copper interconnect, or a mix of both. The selection of the interconnect can determine whether a focused-ion-beam tool can work on and repair the design. It can also influence the effectiveness of multilayer probing using an e-beam and what postprocessing, including thin film and other material deposition, is possible.

Most of the new bioelectronics chips and a number of the integrated MEMS (microelectromechanical-systems), sensors, and electronics designs require postprocessing steps. Many of these designs use specialty thin films and polymer-based films on the surface of the die, and these films require direct contact with the active circuitry at the metal, polysilicon, or diffusion layer. As a result, designers must carefully plan the use of metal fill, fill-blocking mask, and low-k dielectrics to accommodate contact with the thin-film layer in the postprocessing flow. Most of the etch steps for these deposition layers to contact the inner layers of the die are nonstandard and, thus, may alter the electrical performance of the design.

When selecting a process, designers must address these issues as well as backside-wafer processing, including etch, etch and gold, and "backlapping" to thin the wafer. It's not just about logic performance. **EDN**

Contact me at pallabc@siliconmap.net.

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The path of
least resistance
...for micro and
high speed
strips.
High Speed Edge Card
• Rugged Edge Rate™ contact system on .8mm pitch is robust when zippered during mating and unmating
• Rated at 10.5 GHz in differential pairs
• Vertical, right angle, horizontal designs
Razor Beam™ System
• Ultra fine pitch interconnects on .4mm, .5mm, .635mm pitch
• Minimizes board real estate – connector pitch (length) and width
• Low profile – down to 4mm board spacing
• Rated at 10 GHz in differential pairs
Tiger Eye™
• High reliability, three finger BeCu Tiger Eye™ contacts
• .8mm pitch, 6 to 10mm stack heights
• Shrouded, polarized, optional locking clips and weld tabs
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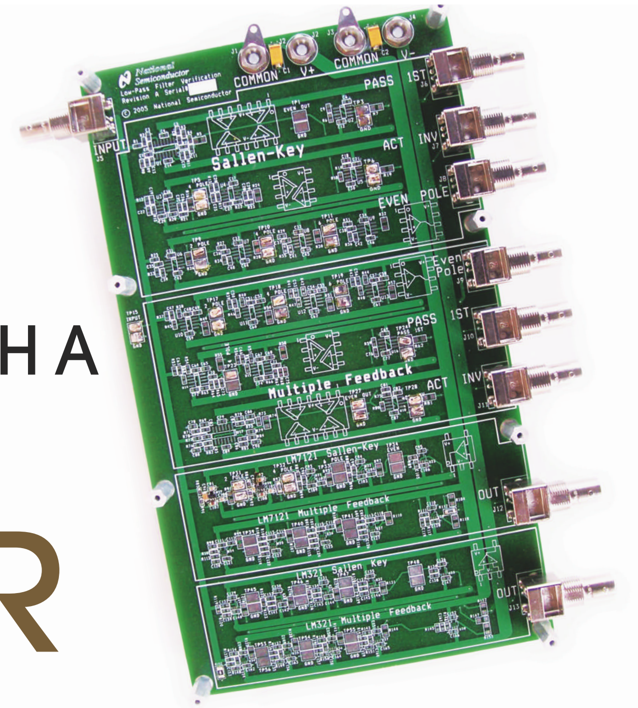
ELIMINATE SALLEN-KEY STOPBAND LEAKAGE WITH A VOLTAGE FOLLOWER

BY MARTIN CANO • NATIONAL SEMICONDUCTOR



This filter board allows the evaluation of various Sallen-Key- and multiple-feed-back-topology filters (courtesy National Semiconductor).

The Sallen-Key lowpass filter is a form of the VCVS (voltage-controlled voltage-source) topology. Unfortunately, the interaction of the op-amp output impedance with the filter input degrades stopband performance (**Figure 1**). If the output impedance of the amplifier were zero, the stopband would continue to drop indefinitely with increasing frequency. This behavior corresponds to the ideal stopband response. The stopband-leakage effect has been the topic of various articles. This article details a method of decreasing or eliminating the stopband leakage by modifying the feedback loop of the filter section itself, rather than by adding more filter sections. You can achieve 50-dB decreases in stopband leakage without loading or modifying the output of the filter circuit.

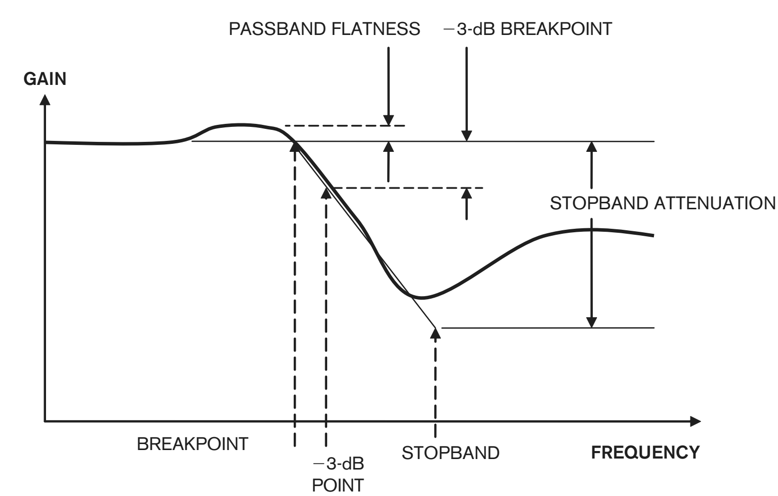


Figure 1 The Sallen-Key filter has peaking in the stopband. This well-known disadvantage limits the attenuation effectiveness and often fails your stopband specification.

The stopband feedthrough is a result of current injection into the output across capacitor C_1 (**Figure 2**). This current causes a voltage drop across the output impedance. The output impedance is inversely proportional to A_{OL}, the amplifier's open-loop gain over frequency. Because an amplifier's output impedance increases with frequency, the voltage drop across it, which the current injected through C_1 creates, becomes significant at higher frequencies.

You can estimate the general shape of the resulting stopband feedthrough by splitting the problem into two parts (**Figure 3**). One part is the forward-path response with no output impedance. In the other part, the forward path contributes nothing to the output, and the current injection into the output impedance generates all the output. This circuit approximates the interaction of the input with the impedance at the output. This interaction grows with frequency as the open-loop gain of the amplifier dictates. It does not include the nominal operation of the filter section. You can use the composite-gain plot of these two curves to approximate the stopband behavior (**Figure 4**). The first- and second-order pole locations, as well as the gain in the open-loop-

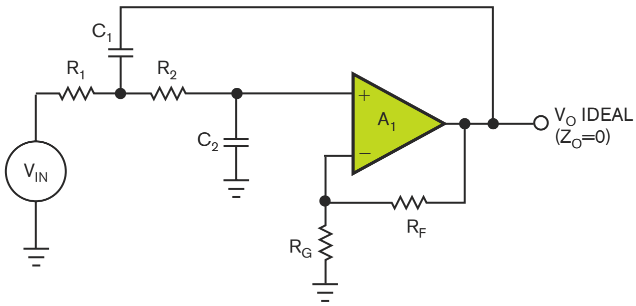


Figure 2 You make a conventional Sallen-Key filter using an op amp and two RC networks.

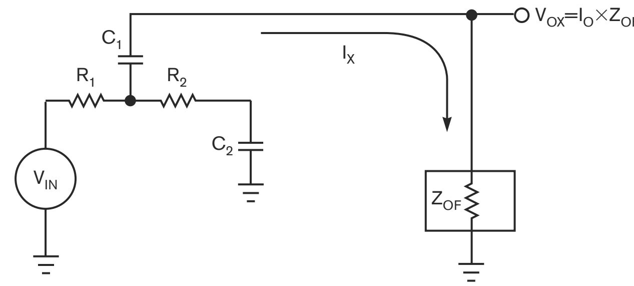


Figure 3 You can use an equivalent-circuit approximation to analyze the stopband-peaking effect.

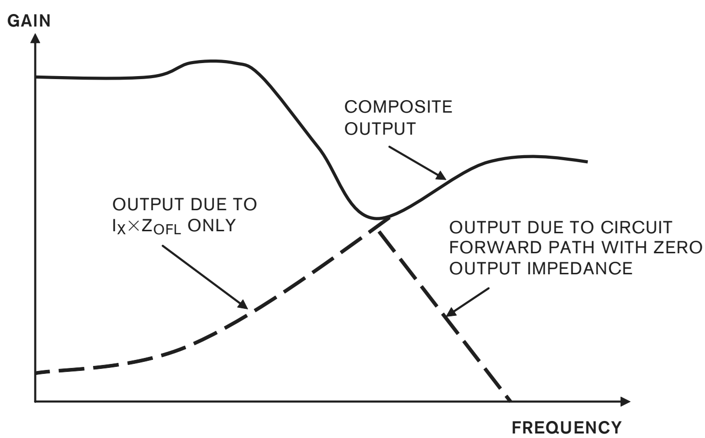


Figure 4 The observed peaking in the Sallen-Key section is a composite of two dominant effects. The ideal operation of the circuit combines with the interaction of the input reacting across the output.

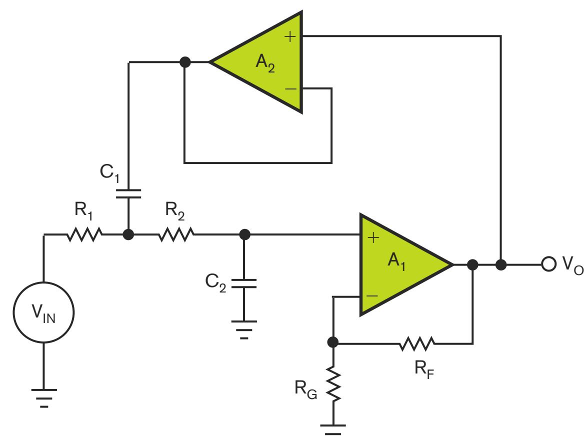


Figure 5 Adding a voltage-follower amplifier to the feedback loop does not affect the transfer function but does remove the interaction of the input with the amplifier's output impedance. This approach drastically reduces the stopband peaking.

transfer function of the op amp, play a role in determining the shape of the resultant feedthrough.

Experts have proposed various techniques for mitigating this effect, each with its advantages and disadvantages. One simple approach to this problem is to remove the interaction between the input current and the output impedance. You achieve this goal by adding a voltage-follower amplifier to the feedback path (**Figure 5**). This addition will extend the region of desired stopband behavior. The voltage drop across the output impedance due to input current through C_1 does not couple directly to the output impedance of the circuit. For this situation, it is helpful to visualize the buffer as a voltage source with the output impedance of A_2 in series connecting to C_1. A voltage drop will occur across the output impedance of A_2, but it does not directly couple to the output. The effect of the output impedance is inductive in nature; that is, it rises as frequency increases. You drastically improve the stopband leakage, but it still occurs at a much higher frequency.

Carefully consider the amplifier characteristics of the buffer. Near the response breakpoint, the feedback path comes into play. In the passband, however, the ac characteristics of the amplifier are less significant. You should use a low-cost wideband amplifier that extends as much as possible the monotonic roll-off in the stopband. The dc offset of the amplifier is not important because C_1 blocks the dc feedback.

In deciding whether to use this approach, weigh its benefits against its performance requirements and design options. In some cases, it might be more appropriate to use a different topology, such as the multiple-feedback filter. In some instances, you must use a noninverting configuration—for example, when the op amp that you use for the filter stage is a current-feedback amplifier. Because the multiple-feedback topology is incompatible with current-feedback op amps, a noninverting VCVS topology becomes more appropriate. You can then apply this technique to cure the stopband-leakage problem.

In this new configuration, the feedforward from the input capacitor to the output of the forward amplifier, A_1, occurs at a higher frequency. The most likely culprit is the common-mode capacitance of A_1, which creates a current path to the output of A_1. A detailed analysis of the capacitances yields a simple model for predicting where the peaking will occur for this configuration. This approach is

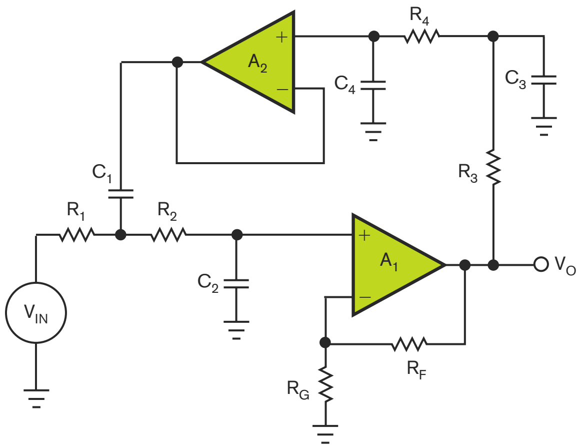


Figure 6 Lowpass filtering within the loop attenuates secondary stopband leakage at higher frequencies. Set R_3, R_4, C_3, and C_4 to cut off about 100 times the filter-design frequency but less than the 3-dB bandwidth of A_2.

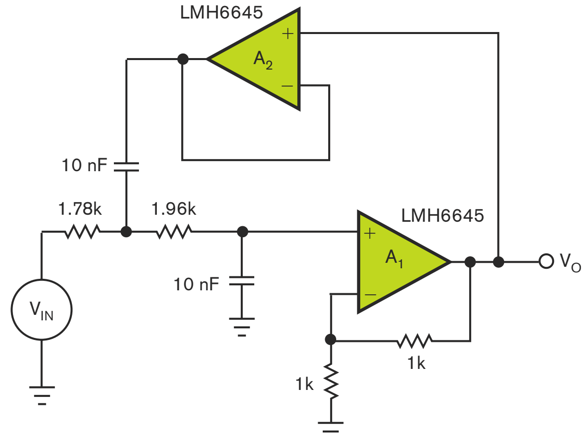


Figure 7 The experimental filter uses 55-MHz voltage-feedback amplifiers.

similar to the previous simplification that approximates the stopband leakage for the original circuit.

Amplifier-common-mode gain may have a significant effect on the response, so be sure that the amplifier you use has a good CMRR (common-mode-rejection ratio). If the buffer amplifier you select requires further reduction in stopband leakage, substitute different amplifiers and see what works best. You could also achieve significant attenuation by adding some high-frequency passive filtering between the output of A_1 and the input to the buffer (**Figure 6**).

The double-passive lowpass filter causes shunting to the current coming along the feedback path from the output, sending it to ground. This high-frequency filtering occurs well within the stopband, and you should set it before the bandwidth of the buffer but far enough away from the stage-designed breakpoint so that it doesn't affect the intended low-frequency breakpoint and transfer function shape. Setting the two resistors and two capacitors two decades away from the filter-breakpoint frequency should not affect the filter shape. Also, you should set the scaling of the resistors relative to the capacitors so that the capacitors do not cause any ringing. A resistor of 200Ω to 1 kΩ should prevent ringing and oscillation due to the capacitors. For example, for a 10-kHz filter, setting the double breakpoint at about 1 MHz with a 40-MHz buffer would be adequate.

For demanding applications, you can use separate packages for the forward amplifier and the feedback buffer. This approach prevents any paths that may couple signal through package crosstalk. This crosstalk always worsens with increasing frequency.

You can verify this theory by building the filters in real hardware. You can come up with component values and a filter configuration by using a filter-design tool, such as National Semiconductor's Webench filter designer. Once you have amplifier-part numbers and component values, you can build the filter in hardware. This test setup uses an Agilent/Hewlett-Packard (www.agilent.com/www.hp.com) 3562 dynamic signal analyzer along with an active filter-evaluation board. The filter uses 55-MHz voltage-feedback amplifiers (**Figure 7**). You can compare the results with those from the traditional VCVS by shorting out the feedback buffer, A_2. The overlaid bode plots show significant improvement in stopband loss extending past 10 MHz (**Figure 8**). The filter-cutoff frequency is 10 kHz.**EDN**

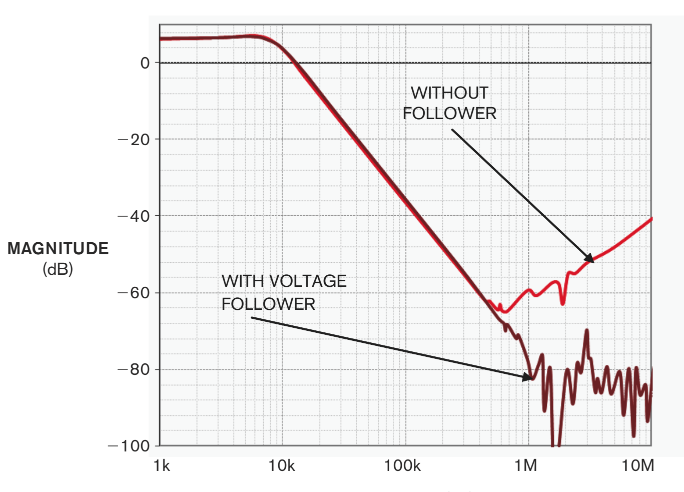


Figure 8 In the bench results for the circuit of Figure 7, the addition of A_2 improves the stopband performance by more than 40 dB at three decades past the 10-kHz breakpoint frequency.

AUTHOR'S BIOGRAPHY

Martin Cano most recently was a principal applications engineer at National Semiconductor, where he developed Webench tools and provided application support. He holds bachelor's and master's degrees in electrical engineering from Boston University's College of Engineering.

BY BRIAN DIPERT | SENIOR TECHNICAL EDITOR

Thin air

ATSC RECEPTION ISN'T ALWAYS EASY

THE LOOMING TRANSITION FROM ANALOG TO DIGITAL TELEVISION PROMISES HIGH-QUALITY IMAGES AND IMMERSIVE AUDIO, BUT REALITY CAN FALL SHORT OF THE HYPE, ESPECIALLY IN ENVIRONMENTS WITH CHALLENGING TOPOGRAPHIES OR CLIMATES.

An admitted tightwad when it comes to television content, I'm unmotivated to pay for a cable, satellite, or IPTV (Internet Protocol-television) subscription, and I can ignore—and, for shows I've recorded, skip—commercials. These characteristics explain my long-standing interest in obtaining OTA (over-the-air), "free," advertising-supported reception at my home. The technology's potential translates to reality only in robust reception environments, however. As anyone who has lived through the analog-to-digital cellular-telephony transition can attest by analogy, the all-or-nothing approach makes the digital version of OTA TV problematic in settings with sketchy signals.

The FCC (Federal Communications Commission) has stated that, in less than a month, all full-power NTSC (National Television System Committee) transmissions will cease in the United States. Many broadcasters have already gone to ATSC (Advanced Television Systems Committee)-only setups with FCC approval, citing motivations such as the desire to retire archaic analog-broadcast equipment and to avoid costly redundant analog and digital transmissions. Will the remaining stations follow the trendsetters' lead on June 12, or will the FCC further delay the transition, citing unacceptable numbers of consumers still unready to make the changeover to digital? A previous TV-themed article predated by a few weeks the original NTSC shutoff date of Feb 17 (**Reference 1**). I hope this article doesn't yet again jinx the FCC's plans, and I suspect that AT&T, Qualcomm, Verizon, the White Spaces Coalition, the Wireless Innovation Alliance, and other entities with plans for the freed-up spectrum would agree.

THE SIGNAL SOURCE

I live in the Sierra Nevada Mountains, northwest of Lake Tahoe on a ridge at an elevation of 7000 feet, southwest and about a 30-minute freeway drive away from Reno, NV, and I tune in stations whose broadcasts originate there (**Figure 1**). The signals I can reliably receive come from two sources: Peavine Peak to the northeast and Slide Mountain to the east (**Table 1**). I can't see Slide Mountain from my house because its summit is more than 1000 feet lower than—and on the opposite side of—an intervening chain of mountains. Topping this mountain chain is 10,776-foot-high Mount Rose, the second-highest peak in the Lake Tahoe Basin. However, thanks to single- and double-edge diffraction effects, I can usually receive with adequate strength the digital transmissions originating from most of the towers at Slide Mountain—specifically, the equipment operated by CBS (Columbia Broadcast System) affiliate KTVN and NBC (National Broadcasting Co) affiliate KRNV. To get a fuller sense of the geographic challenges involved, visit Google Earth and peruse the vistas from my starting-point location with GPS (global-positioning-system) coordinates 39.372025, −120.249603.

ABC (American Broadcasting Co) affiliate KOLO's tower is also on Slide Mountain, alongside its competitors, but the signals originating from it don't arrive at my location with sufficient noise margin. The same KOLO tower originally handled both NTSC transmissions on Channel 8 and ATSC beacons on Channel 9. Although KOLO shut off its analog signal in early January, it hasn't yet moved the digital signal to Channel 8. The fact that KOLO plans to move at all suggests the root cause of my reception woes. Although station engineers decline to provide specifics, KOLO's Web-site documentation implies that KOLO designed the antenna and other equipment for Channel 8 and that its operation on Channel 9 is suboptimal. Competitors suggest that the ATSC broadcast "footprint" isn't currently as omnidirectional as it should be.

Fortunately, this area is rife with "translators," low-power rebroadcasting equipment to fill in the "blank spots" that terrain issues cause and that are therefore common in mountainous regions. Such gear may also become common elsewhere in the future (see **sidebar** "A San Francisco Bay Area equivalence"). KOLO, for example, has a translator on Peavine Peak serving the community of Verdi, NV, below and southwest of it. Fortunately, my residence lies in almost a straight line to the southwest beyond Verdi. I can also tune in a Peavine Peak-based translator for PBS (Public Broadcasting Service) affiliate KNPB, whose main tower on Red Peak is receivable only in optimal atmospheric conditions. Fox affiliate KRXI placed its primary tower on Peavine Peak, too, and it therefore provides on average the most robust transmission of any local broadcaster.

INTERMEDIARY ATTENUATORS

Under ordinary circumstances, airborne precipitation doesn't appreciably degrade the OTA-TV signal traversing from a source tower to a destination antenna. Moisture tends to affect UHF (ultra-high-frequency) transmissions more than it does VHF (very-high-frequency) signals. The circumstances in this loca-

tion are far from ordinary, however. The winter of 1938, for example, dumped 819 inches, or 68.25 feet, of snow on Donner Summit, just a few miles west and less than 300 feet higher than my home office. And Echo Summit in South Lake Tahoe holds the record for the second-heaviest 24-hour snowfall accumulation in the United States, at 67 inches, or nearly 6 feet, on Jan 4 and 5, 1982. Granted, recent years haven't delivered such snowfall extremes, but the daily peaks and seasonal averages are still substantial.

Equally important, the snow originating from storms coming off the Pacific Ocean is notoriously known as Sierra Cement for its high water content. Even when the weather is comparatively balmy, cloud caps and snowstorms over the Mount Rose Range suppress signals to the degree that my equipment sometimes can't reliably receive the transmissions. The precipitation attenuation potential is especially critical when you consider that ATSC broadcasts tend to be substantially lower-power than their NTSC predecessors, even more so for the translator-sourced weak signals that focus on the Verdi, NV, community more than 3000 feet below them. Although intermediary vegetation isn't a substantial factor in my location, neighbors with moisture-rich aspen and pine trees between them and broadcast towers need to sometimes relocate antennas, vegetation, or both to optimize reception.

If it weren't for the "bending" capabilities of VHF signals, the formidable hunk of intermediary granite known as the Mount Rose Range would obstruct any

AT A GLANCE

- Analog television's "snowy" pictures will cease to exist as the ascendant digital age either clears up the images or causes them to disappear.
- Translators fill in reception gaps that geography causes; discovering their existence and physical-channel details, however, can be a challenge.
- Don't underestimate the deleterious impact of airborne, vegetation-captured, and antenna-resident moisture on incoming signals.
- Carefully inspect antenna specifications to avoid the traps of marketing hype.
- Coaxial-cabling attenuation can thwart your television-viewing aspirations, and boosters can cause more problems than they solve.
- Consumer gear's user-interface simplifications are of little help and can further confuse the situation when reception goes awry.

broadcasts I might receive from Slide Mountain beyond it. One other potential distortion source, Prosser Hill, has GPS coordinates of 39.375644, −120.225964 and is less than two miles away from my house, and its summit is approximately 100 feet higher than my house.

Prosser Hill straddles the straight-line paths from my residence to both Slide Mountain and Peavine Peak, although it doesn't directly block the signals from either location's towers to the house. However, those same signals also travel from the towers to Prosser Hill, where they're reflectively redirected my way, thereby resulting in multiple time-shifted received copies of each transmission. Man-made "mountains," such as tall buildings, also cause this phenomenon, *multipath distortion*. It can both degrade the incoming signal due to destructive interference and confuse the receiver. Counteracting multipath interference's effects through the use of multiple reception antennas and other techniques is a primary focus of the recently approved mobile-ATSC standard (**references 2** and **3**).

ANTENNAS AND ORIENTATIONS

In searching for an antenna that could deliver adequate reception but that was also both diminutive and aesthetically attractive, I came across Antennas Direct at the 2008 NAB (National Association of Broadcasters) conference. The company subsequently sent me a ClearStream 2 unit (**Figure 2**). Antennas Direct promotes the ClearStream series as "designed and optimized for 2009 frequencies associated with the DTV [digital-television] transition." With that description in mind, I initially believed that the ClearStream 2 handled 44- to 88-MHz, low-band VHF channels 1 through 6; 174- to 216-MHz, high-band VHF channels 7 through 13; and 470- to 698-MHz UHF channels 14 through 51. In attempting to receive all possible Reno-area transmissions, I "split the difference" between Peavine Peak and Slide Mountain, essentially pointing the antenna directly at Prosser Hill.

This first-pass strategy turned out to be flawed for several reasons. UHF signals are more receptive (pun intended)

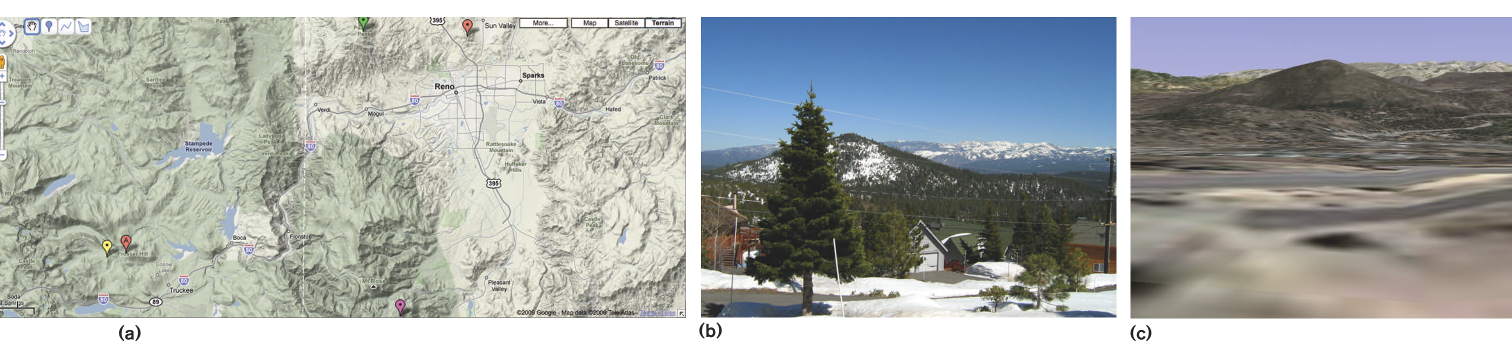


Figure 1 Google Maps serves up a from-above cyberperspective of the reception landscape (a); my residence (yellow), Peavine Peak (green), Red Peak (orange), Slide Mountain (violet), and Prosser Hill (orange A). A digital camera provides a more horizontal vista; Peavine Peak is near the left-hand side of the image, and Slide Mountain is behind and to the right of Mount Rose, the tallest peak on the right side of the range (b). Google Earth creates a passable approximation of the real-life view (c).

than their VHF counterparts to precise antenna orientations that point directly at the originating towers, no matter how wide the antenna's primary reception lobe may be (**Figure 3**). I also hadn't yet driven to Slide Mountain and therefore didn't realize that it wasn't visible from my porch (**Reference 4**). What I initially thought were the towers of ABC, CBS, and NBC were in reality microwave gear on Relay Peak, which is south of and on the same ridgeline as Mount Rose.

A reader of my blog had also pointed out that ClearStream 2 looked like a UHF antenna and that the published gain and voltage-standing-wave-ratio graphs cut off at 400 MHz, beyond the upper threshold of the VHF band. When I forwarded this feedback to Antennas Direct, Robert Schneider, company president, responded, "The TV engineer is correct that the tapered-loop element is optimized for the core-UHF frequencies and is almost flat in … directivity and beam pattern between 470 and 700 MHz." He also confirmed that, although the element has some nominal VHF performance, the graph doesn't show the high-band-VHF data. It was impossible, he said, "to incorporate a VHF element into the design without severe compromises to the UHF performance (electrical coupling and insertion losses)." So, the company's engineers redesigned the PCB (printed-circuit-board) balun to allow the feed line to act as a high-VHF radiator. Schneider claims that this approach provides "modest VHF performance" from 174 to 216 MHz. "We have found [ClearStream 2] to be a significant improvement over traditional UHF/VHF-combination designs," he says.

(a) (b) (c) (d)

Figure 2 Antennas Direct's ClearStream 2 was useful only for receiving UHF stations (a), thereby necessitating the additional inclusion of an AntennaCraft Y5-7-13 (b). Both antennas are fairly unobtrusive (c). An alternative viewpoint shows the Y5-7-13 installation (d).

For my reception needs, the ClearStream 2's claimed high-band-VHF capabilities were insufficient. So, I reoriented the ClearStream 2 directly at Peavine Peak, and I added an AntennaCraft Y5-7-13 to the hardware mix to handle the VHF broadcasters. Fortunately, the horizontal beam to which I mounted the Y5-7-13 points directly at Slide Mountain, resulting in a cosmetically acceptable end result. Even more fortuitously, the UHF broadcasts all originate from Peavine Peak, and the VHF signals all come from Slide Mountain, so I didn't need to install a rotor for either antenna. A notable downside to my chosen VHF-antenna location once again involves snowfall. Even with clear skies between Slide Mountain and my house, accumulated snow on the antenna notably attenuates the broadcasts. As soon as I sweep off the snow, however, the received-signal strength substantially improves.

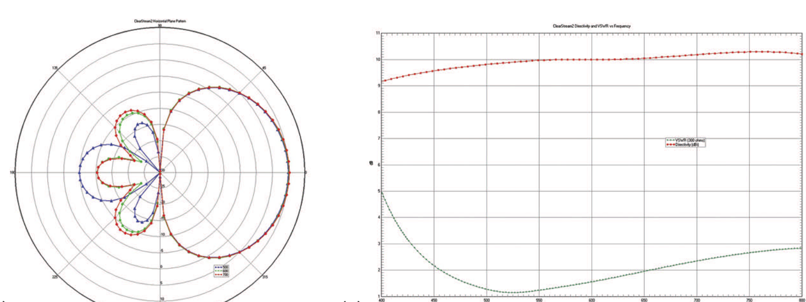

(a) (b)

Figure 3 The ClearStream 2 has a fairly wide primary-lobe-reception angle (a), but its voltage-standing-wave-ratio specifications notably degrade below UHF Channel 14 (b). Note, too, that Antennas Direct doesn't bother publishing high-band VHF data, even though the company claims the antenna can receive those signals.

CABLING SHORTCOMINGS

The two antennas' outputs merge by means of a passive combiner before entering the house. Jack Antonio, KTVN's chief engineer, and members of his staff brought with them several useful pieces of measurement gear during several visits to my residence. With that equipment, I determined that the house's internal coaxial-cable topology further degrades the

signal on a frequency-dependent basis ranging from a few decibels to nearly 10 dB of loss. In initially attempting to receive KOLO's primary transmission from Slide Mountain, I installed a Motorola model 484095-001-00 signal booster at the outside junction between the passive combiner and the exterior wall of the house (**Figure 4**). However, I was still unable to receive KOLO's broadcasts, and the Motorola device overboosted KRNV's already-strong signal, causing me to also lose reception of it. This regression was upsetting because I wanted to watch the Summer Olympics coverage on NBC, which was due to begin in a few hours, so I hurriedly disconnected the Motorola signal booster.

A few months later, with a better understanding of both the local broadcasters and my reception situation, I tried again. This time, I chose Antennas Direct's CPA-19 booster. Like the company's ClearStream antennas, it focuses its amplification on UHF and high-band-VHF spectra, which was fine because I wanted to improve ATSC reception

A SAN FRANCISCO BAY AREA EQUIVALENCE

The problems I confronted and surmounted while researching this article aren't unique to rural mountainous environs. Exemplifying that reality, the AntennaWeb Web site asks would-be users whether there are any buildings, steeples, towers, or other structures taller than four stories within four blocks of their location; airports within two miles of their location; or nearby trees taller than 30 feet. Natural and man-made structures in urban settings can also distort OTA (over-the-air) television transmissions by creating both direct-blocking attenuation and reflective-multipath-interference effects.

Take, for example, the San Francisco Bay area. Longtime *EDN* readers Lou Dorren and Noland Lewis recently completed an in-depth study of DTV (digital-television) reception in that area. You can find download links to both portions of their report at a post on *EDN* Technical Editor Paul Rako's Anablog (www.edn.com/blog/1700000170/post/1950040795.html). I question Dorren's repeated assertion that he and his partner have no ax to grind with respect to ATSC (Advanced Television Systems Committee) technology. I think, for example, that the two authors paint an overoptimistic picture of the viewer acceptability of the "snowy-picture, good-sound" yellow regions of the Santa Cruz Mountains and East Bay Hills in their analog-TV-reception plots (Figure A).

Nonetheless, the "RF-shadow" attenuation of signals originating on Mount Sutro by Mount San Bruno and vice versa is evident in the results. The "cliff effect" that transforms marginally acceptable analog transmissions into nonexistent digital presentations is also obvious. Mount San Bruno is particularly problematic because it is higher and wider than Mount Sutro and has a larger population residing behind it. I wonder whether Bay area broadcasters will end up installing translators to supplement the primary transmitters on Sutro Tower. Monument Peak in the South Bay near Fremont, CA, which already contains several stations' primary towers, would be a logical location for such translators if their power output were sufficient to reach all areas that Mount San Bruno's RF shadow affects.

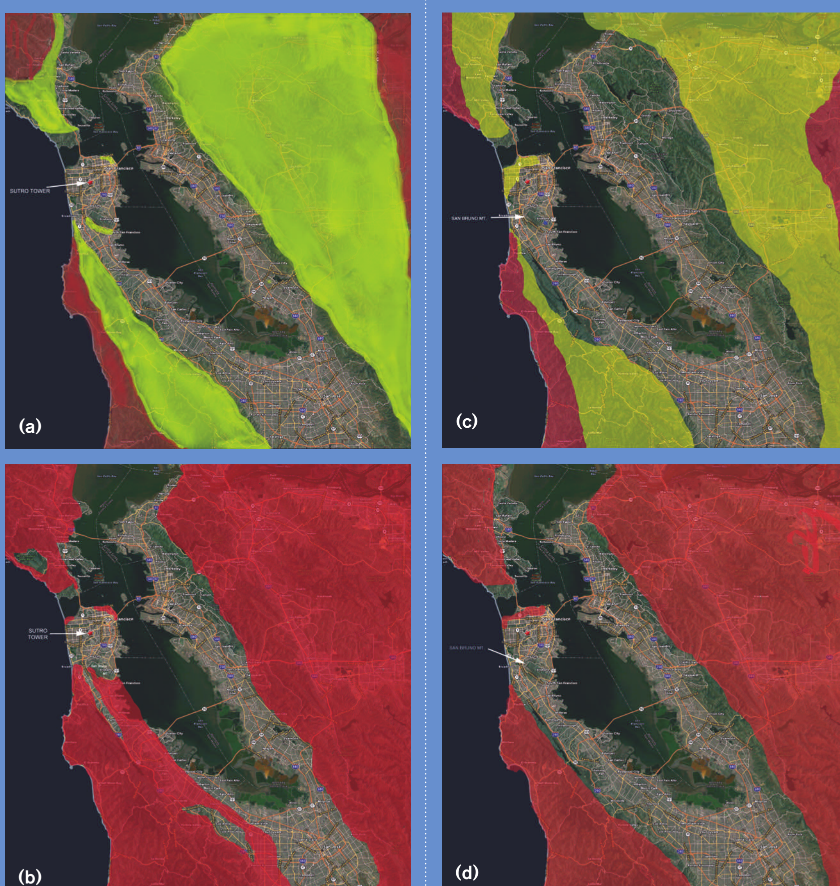


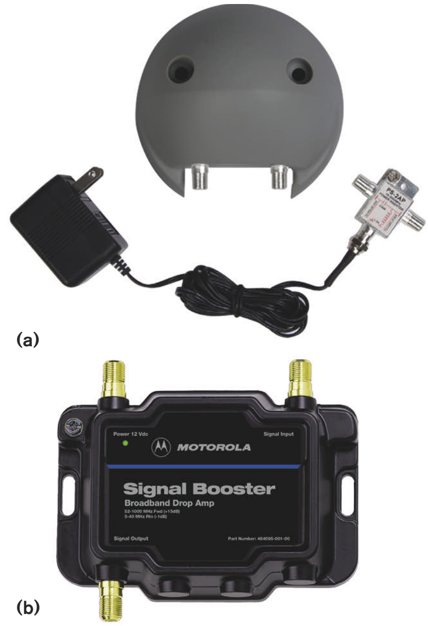
Figure A Mount San Bruno's degradation of analog-TV transmissions originating at San Francisco's Sutro Tower (a) becomes even more critical in the digital era, due to "cliff-effect," unrecoverable distortion of the binary bit stream (b). Similarly, Mount Sutro casts an RF shadow that affects the stations whose towers reside atop Mount San Bruno (c), although both Mount Sutro and the population living behind it are comparatively small, leading to fewer digital-era downsides (d).

and didn't care about NTSC reception. Unlike Motorola's unit, however, the CPA-19 didn't overboost signal inputs. According to Schneider, the CPA-19 has only slightly higher gain—17 to 19 dB—than the company's other preamps. That fact is incidental, however, because any gain greater than 10 or 12 dB in a residential application is almost overkill. He says that the goals of the CPA-19 preamp include lower noise of approximately 1.5 to 2.1 dB; higher resistance to overload, given that the signal ratio at the antenna between a high-power nearby station and a distant station can be 500,000-to-1; better filtering and rejection of signals outside the 174- to 216-MHz VHF and 470- to 700-MHz UHF bands, such as cellular, wireless-broadband, and public-safety frequencies; and improved RF shielding.

"Often, amplifiers can do more harm than good when they either introduce noise onto the line or … overload in the presence of a nearby transmitter," says Schneider. "The CPA-19 amp should have noise levels and overload resistance comparable to commercial-grade amps, but, as with all amplifiers, it's not a magic bullet. It cannot create a signal that doesn't exist at the antenna to begin with, but, [in the] worst case, it shouldn't do any harm." In contrast to my Motorola experiment, I installed the Antennas Direct CPA-19 inside the house on the other end of the long wiring run that originates above the front door, thereby enabling the unit to also counterbalance the coaxial cable's attenuation effects.

RECEIVER TRADE-OFFS

I have long used and enjoyed a time-shifting ReplayTV PVR (personal video recorder), so the conventional ATSC tuner in my 37-in. LCD TV felt like a substantial step backward. Because I own several Xbox 360 game consoles with built-in Windows Media Center-extender capabilities, I decided to turn a spare Windows Vista Ultimate-based laptop into my high-definition, digital ReplayTV successor (**Figure 5**). I had a Hewlett-Packard ExpressCard TV Tuner, and the ExpressCard slot in my Dell XPS M1330 notebook PC was empty, so I decided to use the HP device instead of a USB (universal-serial-bus)-based tuner. The driver CD that came with



(a)

(b)

Figure 4 Although I struggled with Antennas Direct's antenna, I had a much better experience with the company's CPA-19 signal amplifier (a), especially in contrast to Motorola's competitive product whose overboosting tendencies left me unable to receive formerly robust KRNV (b).

the unit was unreadable, but a Google search revealed the fact that the ExpressCard TV Tuner is an HP-relabeled twin of Hauppauge's HVR-1500, and this company provides downloadable drivers from its Web site.

As with many products for consumers who are not technologically savvy, Windows Media Center hides technical details and advanced settings behind a slick, simple user interface. When everything's working as intended, it's an easy-to-use product, but, when glitches arise, finding and fixing them can be frustrating. For example, Windows Media Center, like much other DTV-cognizant software and hardware, reports only the virtual channel, not the physical channel it's tuning in. And, unlike some other TV-oriented software packages, Windows Media Center doesn't scan the VHF and UHF spectra for valid broadcast signals; instead, it relies on program-guide data that it downloads in response to a user's entered ZIP code. Thus, it was only by accident that I stumbled across the fact that Windows XP and Vista's Media Center database incorrectly reports that KOLO's primary ATSC transmission is on Channel 23. It's actually

Figure 5 A Dell XPS M1330 laptop (a) became my digital PVR in conjunction with the Media Center application that comes with Windows Vista Ultimate and a Hewlett-Packard-branded version of Hauppauge's HVR-1500 ExpressCard TV tuner (b). I also tried Pinnacle's USB-based PCTV HD mini stick (c), but it created artifact-filled recordings, counterbalancing the unit's robust software suite and integrated "signal booster."

on Channel 9 and will be on Channel 8 in the near future. Because this primary beacon is currently too weak for my needs anyway, the impact of this error has no effect on me, but it would prevent anyone in the Reno, NV, broadcast region from receiving KOLO's signal.

Windows Vista's Media Center application unfortunately also doesn't comprehend that, based on a user's ZIP code, a local translator signal on a different channel might be more appropriate for reception than the station's primary transmission. And overriding the default program-guide-supplied physical-channel information is neither well-documented nor easy to accomplish. Ben Reed, a Microsoft spokesman, explains the discrepancy by noting that, until Windows Vista OEM-only TV Pack update (whose functions will become more broadly available with upcoming Windows 7), the company relied on FCC-sourced data to derive physical-channel information. A search of the FCC archives reveals that KOLO's original ATSC assignment was Channel 23, although the relocation to Channel 9 occurred many years ago. Reed also promises that Windows 7 will add a substantial number of additional ZIP-code-derived database entries that will, for example,

TABLE 1 ATSC TOWER LOCATIONS, STATION ASSIGNMENTS, AND PHYSICAL AND VIRTUAL CHANNELS

Location	GPS coordinates	Compass orientation (true)[1]	Distance (miles)	Station	Transmitter	ATSC physical channel	ATSC virtual channel
Peavine Peak	39.588617, –119.930298	49°	22.9	KNPB (PBS)	Translator	47	5
				KOLO (ABC)	Translator	24	8
				KRXI (Fox)	Primary	44	11
Red Peak	39.583904, –119.800748	59°	28.3	KNPB (PBS)	Primary[2]	15	5
Slide Mountain	39.314547, –119.884033	101°	20	KOLO (ABC)	Primary[3]	9	8
				KRNV (NBC)	Primary	7	4
				KTVN (CBS)	Primary	13	2

[1] Compass and distance data courtesy of TVFool.com.

[2] Receivable at my location only in optimum atmospheric conditions.

[3] Not receivable at my location; reception may improve after KOLO moves to physical Channel 8.

better comprehend the presence of nearby translator beacons and that users will be able to more easily override suggested physical-channel assignments.

To evaluate the feasibility of netbooks as portable DTVs, I mated Pinnacle's USB-based PCTV (personal-computer-television) HD (high-definition) mini stick with my Micro-Star International Wind U100 (**Reference 5**). Because MSI based this netbook on conventional Windows XP, which doesn't include Media Center functions, I also installed Pinnacle's corresponding TVCenter Pro application suite. TVCenter Pro not only scans broadcast spectra so that you needn't rely on program-guide data, but also reports the physical channels it detects as either VHF or UHF values; online resources can easily translate these physical channels' frequencies into channel numbers. For example, TVCenter Pro let me determine the physical channels the translators on Peavine Peak use, whereas KNPB's Web site doesn't even document its translator. TVCenter Pro also provides more robust signal strength and quality feedback than the data from either Windows Media Center or my LCD TV's ATSC-tuner user interface.

I attempted to use the PCTV HD mini stick with the Dell XPS M1330, but this approach ultimately proved unacceptable. On the upside, the unit's built-in signal-booster feature noticeably enhanced the probability of receiving moderate- to marginal-strength incoming transmissions. After I put aside the PCTV HD mini stick and returned to the HP ExpressCard TV Tuner, I decided to experiment with Antennas Direct's CPA-19. Unfortunately, the PCTV HD mini stick injected random video artifacts into recorded shows—artifacts that I hadn't observed with the HP ExpressCard-based alternative. At first, I thought I was seeing degraded reception. After lots of experimentation across multiple stations and at various device settings and after noting that the artifacts were macroblock-based versus frame-wide, however, I concluded that the problem occurred after the ATSC signal reached the tuner.

The problem might have arisen from the hardware or a software driver, but I suspect that it came from occasional and inevitable USB contention and insufficient buffering to counteract the contention. Is Dell or Hauppauge, which recently took over Pinnacle's TV-tuner product, responsible for the fix, or do both companies need to make accommodations? Stay tuned to Brian's Brain blog to find out. **EDN**

For the references to this article, a list of resources, and other material, go to www.edn.com/090514cs.

You can reach
Senior Technical Editor
Brian Dipert
at 1-916-760-0159,
bdipert@edn.com,
and www.bdipert.com.


CMOS-NAND gates control sump pump

V Gopalakrishnan, Indira Gandhi Center for Atomic Research, Kalpakkam, India

With just a few NAND gates, you can control sump pumps and other pumps that keep your basement from flooding and maintain water levels in tanks. The circuit in **Figure 1** receives 12V signals from L_1, the lower water level, and L_2, the upper level, of an underground tank. You adjust the gap between these two levels to avoid short cycling of the pump. When the water level touches the maximum level of L_2, the pump switches on to fill up the overhead tank. When the water level falls below the low level of L_1, the pump switches off.

When the tank is empty, sensors L_1 and L_2 and Gate D are at low levels because the outputs of gates B and A are high. When the water level rises and shorts 12V through L_1, the gate outputs remain the same. When the water level further rises and shorts 12V with L_2, then the output of Gate A becomes low, which forces Gate D to a high level. That action, in turn, latches Gate B's output low. A low output on Gate B pulls down the SSR (solid-state relay), which turns on the sump pump (**Reference 1**). Simultaneously, the high output of Gate D turns on the gated oscillator and sounds the piezoelectric buzzer.

When the water level lowers below level L_2, the pump remains on because of the latched B and D gates. If the water level falls below sensor level L_1, the output of Gate B becomes high, which turns off the pump. This action

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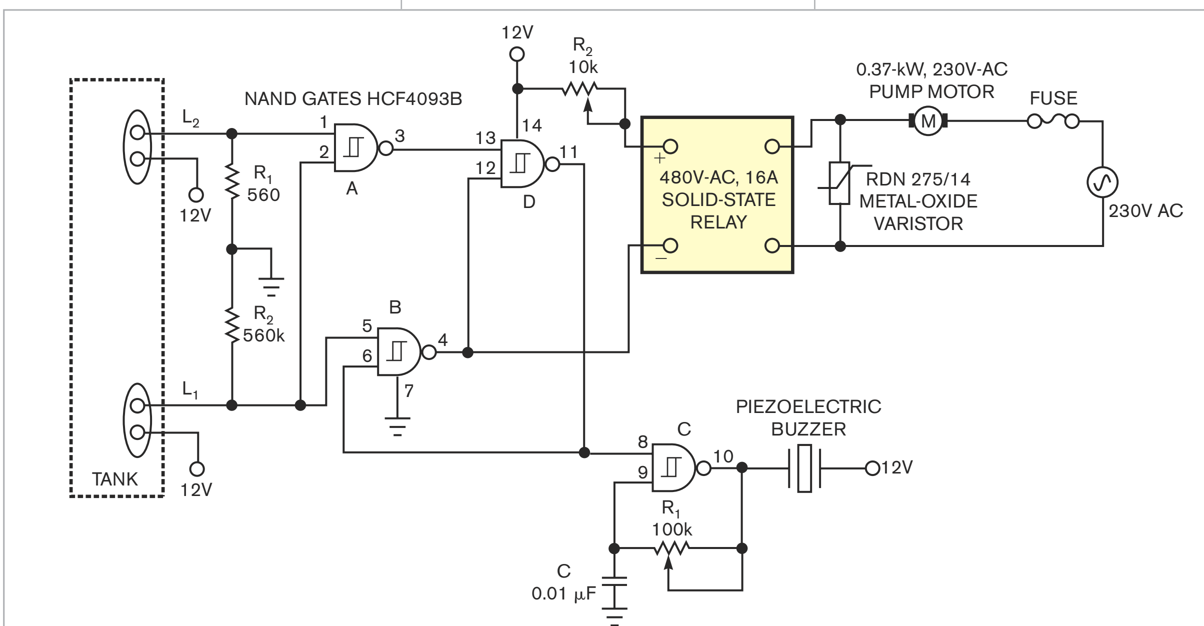

Figure 1 A sump-pump controller uses a quad-NAND gate to drive a solid-state relay.

LINEAR TECHNOLOGY
DESIGN NOTES

High Efficiency USB Power Management System Safely Charges Li-Ion/Polymer Batteries from Automotive Supplies – Design Note 464

George H. Barbehenn

Introduction

Automotive power systems are unforgiving electronic environments. Transients to 90V can occur when the nominal voltage range is 10V to 15V (ISO7637), along with battery reversal in some cases. It's fairly straightforward to build automotive electronics around this system, but increasingly end users want to operate portable electronics, such as GPS systems or music/video players, and to charge their Li-Ion batteries from the automotive battery. To do so requires a compact, robust, efficient and easy-to-design charging system.

Complete USB/Battery Charging Solution for Use in Large Transient Environments

Figure 1 shows such a design. This complete PowerPath™ manager and battery charger system seamlessly charges the Li-Ion battery from a wide ranging high voltage or USB source.

In this circuit, the LTC®4098 USB power manager/Li-Ion battery charger controls an LT3480 HV step-down regulator. The LTC4098's Bat-Track™ feature provides a high efficiency, low power dissipation battery charger from low and high voltages alike. The Bat-Track feature controls an internal input current-limited switching regulator to regulate V_{OUT} to approximately V_{BAT} + 0.3V which maximizes battery charger efficiency, and thus minimizes power dissipation by operating the battery charger with minimal headroom. Furthermore, the Bat-Track feature reduces charge time by allowing a charge current greater than the USB input current limit—the switching regulator behaves like a transformer exchanging output voltage for output current.

The LTC4098 can extend the Bat-Track concept to an auxiliary regulator via the WALL and V_C pins. When sufficient voltage is present on WALL, Bat-Track takes

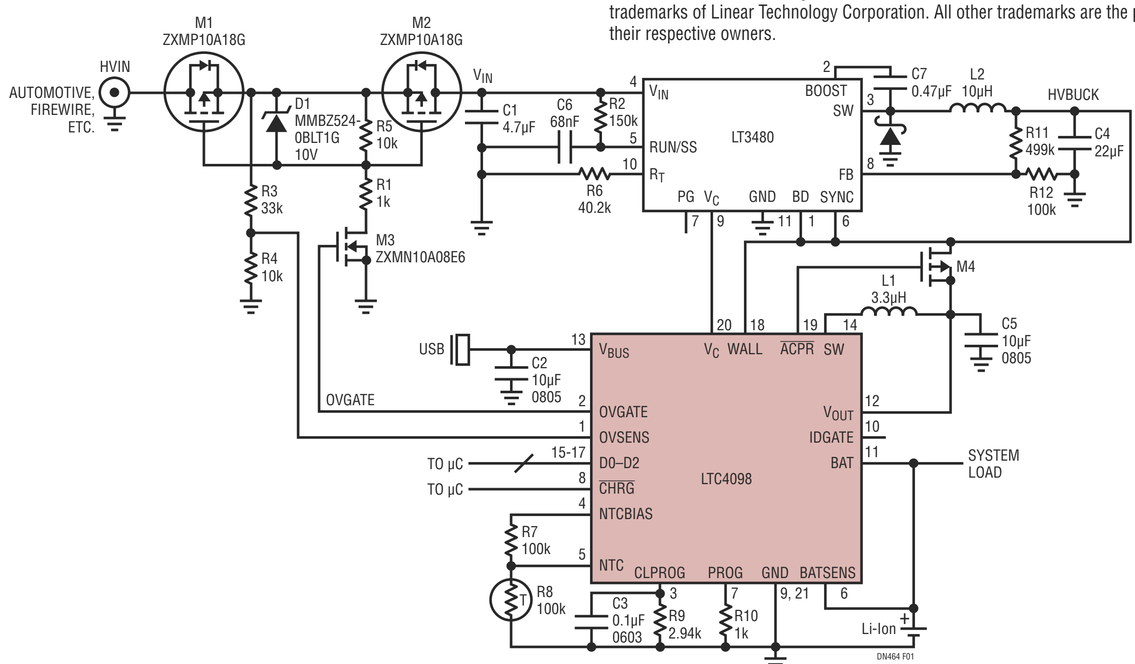

Figure 1. LTC4098 USB Power Manager/Li-Ion Battery Charger Works with an LT®3480 HV Buck Regulator to Accept Power from an Automotive Environment or Firewire System. Overvoltage Protection Protects Both ICs and Downstream Circuits

control of the auxiliary regulator's output via the V_C pin, maintaining the regulator's output at V_{BAT} + 0.3V.

The LTC4098 also includes an overvoltage protection function—important in volatile supply voltage environments. Overvoltage protection shuts off a protection N-channel MOSFET (M2) when the voltage at the OVSENSE pin exceeds approximately 6V. The upper limit of voltage protection is limited only by the breakdown voltage of the MOSFET, and by the current flowing into the OVSENS pin.

Overvoltage Protection Covers the Entire Battery Charger/Power Manager System

The overvoltage protection function of the LTC4098 can protect any part of the circuit. In Figure 1, the protection has been extended to the LT3480 V_{IN} input. The overvoltage shutdown threshold has been set to 24V. This threshold provides ample margin against destructive overvoltage events without interfering with normal operation.

In Figure 1, M1 is a P-channel MOSFET that provides reverse voltage protection, whereas M2 is the overvoltage protection MOSFET, and M3 level-shifts the OVGATE output of the LTC4098.

If the HVIN voltage is less than zero, the gate and source voltages of both M1 and M2 are held at ground through R3, R4, and R5, ensuring that they are off. If the HVIN voltage is between 8V and approximately 24V, the gate of M3 is driven high via the LTC4098's OVGATE pin. This turns on M1 and M2 by pulling their gates 7V to 10V below their sources via M3, D1, R1 and R5. With M1 and M2 on current flows from HVIN to V_{IN} and the system operates normally.

If the HVIN input exceeds approximately 24V, the LTC4098 drives the gate of M3 to ground, which allows R5 to reduce the V_{GS} of M1 and M2 to zero, shutting them off and disconnecting HVIN from V_{IN}.

M1, M2 and M3 have a BV_{DSS} of 100V, so that this circuit can tolerate voltages of approximately –30V to 100V. It will operate normally from 8V to approximately 24V. This combination is ideal for the harsh automotive environment, providing a robust, low cost and effective solution for Li-Ion battery charging from an automotive power system.

Finally, setting the OVSENS resistor divider requires some care. For an OVSENS voltage between approximately 2V and 6V, $V_{OVGATE} = 1.9 \bullet V_{OVSENS}$. OVSENS is clamped at 6V and the current into (or out of) OVSENS should not exceed 10mA. The chosen resistor divider attenuates HVIN by a factor of 4, so M3 has sufficient gate voltage to turn on when HVIN exceeds approximately 8V. When HVIN = 100V, the current into OVSENS is just 2.25mA—well below the 10mA limit.

As shown in Figure 2, V_{IN} is only present when HVIN is in the 8V to 24V region. Figure 3 shows a close-up centered on the load dump ramp. The ISO7637 test ramp rises from 13.2V to 90V in 5ms. There is a 220μs turn-off delay—OVGATE going low to the gates of M1 and M2—which results in an overshoot on V_{IN}. The maximum value of this overshoot is 3.5V ($V_{VIN(MAX)} \approx$ 27.5V). The magnitude of this overshoot can be calculated for different ramp rates, such that

$$V_{OVERSHOOT} = \Delta V/\Delta t \bullet t_{DELAY}$$

where ΔV = (90V – 13.6V), Δt = 5ms, and t_{DELAY} = 220μs, so, $V_{OVERSHOOT}$ = 3.36V.

If less delay, and thus less overshoot, is desired, an active turn-off circuit can reduce the delay from OVGATE to the gates of M1 and M2 to a few microseconds.

Conclusion

The LT3480 high voltage step-down regulator and LTC4098 Li-Ion/Polymer battery charger, combined with a few external components, produce a robust high performance Li-Ion charger suitable for portable electronics plugged into an automotive power source and maintain compatibility with USB power. The circuit provides all the functionality that customers expect, along with voltage protection from battery reversal and load dump transients.

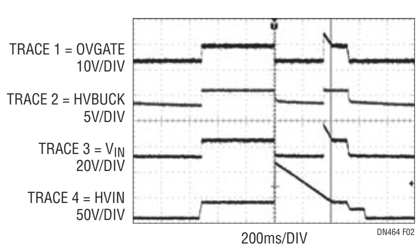

Figure 2. Overvoltage Protection Through Input Transients per ISO7637 Standards

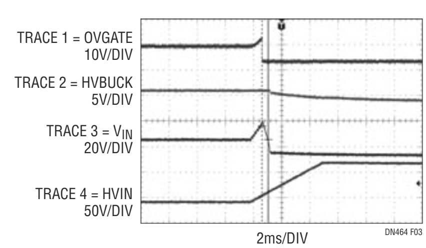

Figure 3. Closeup of Figure 2 Waveforms Showing Overshoot on HVIN

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makes the output of Gate D go to a low level, which stops the oscillator and thus the piezoelectric buzzer.

The circuit uses HCF4093B Schmitt-trigger-input NAND gates to square the slow signals. The input resistor, R_1, has a value of 560 kΩ. Checking the circuit with a glass of filtered water shows an improved conductivity for ground water. Raising the value of the input resistor to a higher value is also not objectionable after you account for pickup and the voltage drop across the resistor due to the input leakage current.

The solid-state relay may have back-to-back connected SCRs (silicon-controlled rectifiers), random turn-on, and snubber circuitry to handle the motor load (**Reference 2**). Choose an SSR with a voltage rating that is double the working voltage and five to 10 times the current rating of the motor for withstanding dV/dt and the surge current. You should also use fast-blow fuses or semiconductor fuses with less than the I^2t rating of the SSR, where I is the current and t is the duration of current flow in seconds. Choose appropriate SSRs for different ratings of pump motors.

THE PARALLEL SENSOR WIRES AVOID THE CHANCE OF A MOISTURE INTERFACE BETWEEN THE WIRES WHEN THE WATER LEVEL FALLS BELOW THE SENSORS.

This circuit uses sheathed, single-strand, thick-gauge, edge-stripped copper wires as sensors. You can connect the sensor wires in two-way porcelain connecters, which you house in a box and place at the top of the tank. The parallel sensor wires avoid the chance of a moisture interface between the wires when the water level falls below the sensors. You can also use any other high-conductivity and noncorrosive wire material in some configurations. The power supply is floating.

With few modifications, the circuit in **Figure 2** can perform a slightly different function. Assume that you have a tank in which you want to maintain a level of water or any conductive liquid. Mount sensors L_1 and L_2 in the tank the same as those in **Figure 1**. Switching on the power supply causes the pump to begin to fill up the liquid in the tank. When the level reaches L_2, the pump turns off. The pump remains off until the level falls to L_1. When the level falls below L_1, the pump again starts filling the tank until it reaches L_2. The piezoelectric buzzer announces that the pump is running.

You can also control pumps with three-phase motors using a three-phase SSR or adding one appropriately rated single-phase SSR to this circuit. In this case, you can connect the inputs of the two SSRs in series. One SSR on each phase controls two of the phases, and you directly connect the third phase. EDN

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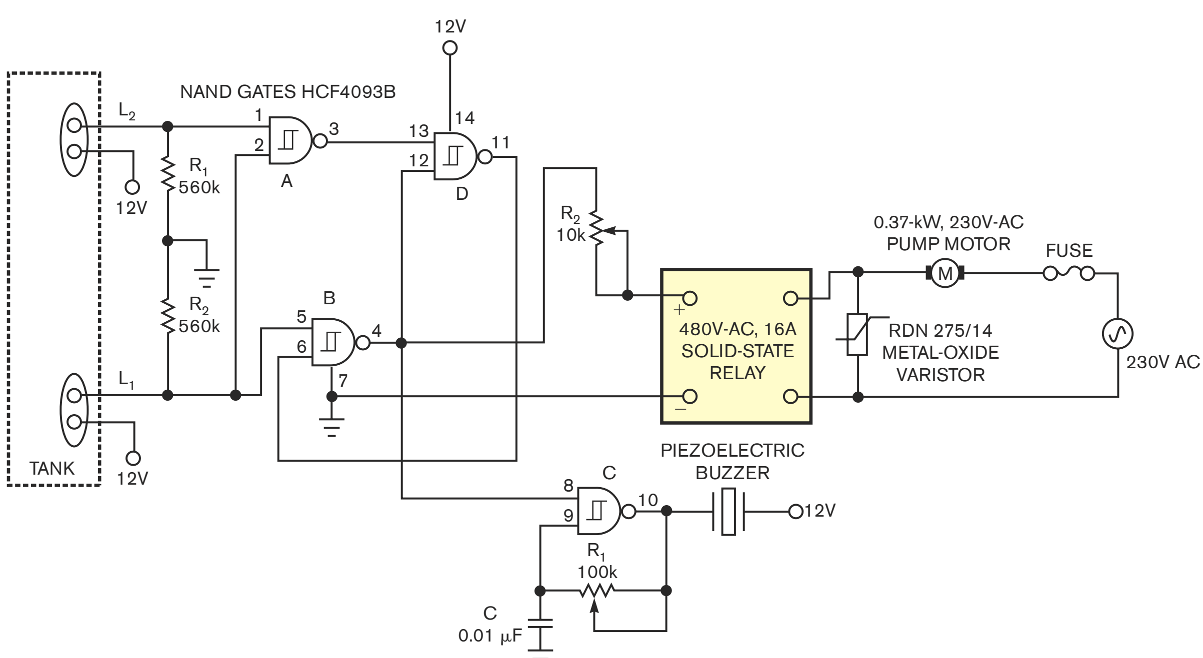


Figure 2 Connecting the potentiometer to NAND Gate B creates a water-level controller.

Use an LED to sense and emit light

Rafael Camarota, Altera Corp, San Jose, CA

LEDs in portable devices often show power status, battery status, or Bluetooth-connection activity. LEDs can be major factors in determining battery life because their intensity is directly proportional to power drain. Using a simple circuit, the MAX IIZ CPLD from Altera (www.altera.com) can measure the analog-light level of its environment and then drive an LED at a proportional analog intensity level. A single LED can both sense and emit light with the same LED and bias resistor. The circuit in **Figure 1** requires only 45 logic elements, and the programmability of the CPLD makes it easy to quickly adjust the parameters of the circuit to the characteristics of any LED.

You can reduce the power consumption of a flashing LED by increasing the flash period, decreasing the flash pulse width, or decreasing intensity. Controlling the LED intensity based on ambient light reduces LED energy usage by more than 47% without affecting appearance. **Figure 1** shows a circuit that uses an Altera EMP240ZM100C7N CPLD, LED, resistor, and clock source to blink an LED with an intensity proportional to ambient light. The circuit comprises a PWM (pulse-width modulator) for driving the LED, a light-intensity-measurement block, and a controlling state machine and timer.

The state machine includes one hot state comprising an 8-bit shift register initialized to the 00000001 binary. The carryout of Count 12, a 12-bit counter, generates an 8-Hz enable signal for state machine Shift 8. Thus, each of the eight states of the state machine is active for 125 msec. In State 0, the reset state, PWM Count 4 block and light-measurement block Count 8 are reset. State 1 is the light-intensity-measurement state, which enables a frequency counter, Count 8. Enabled for 125 msec, Count 8 counts the cy-

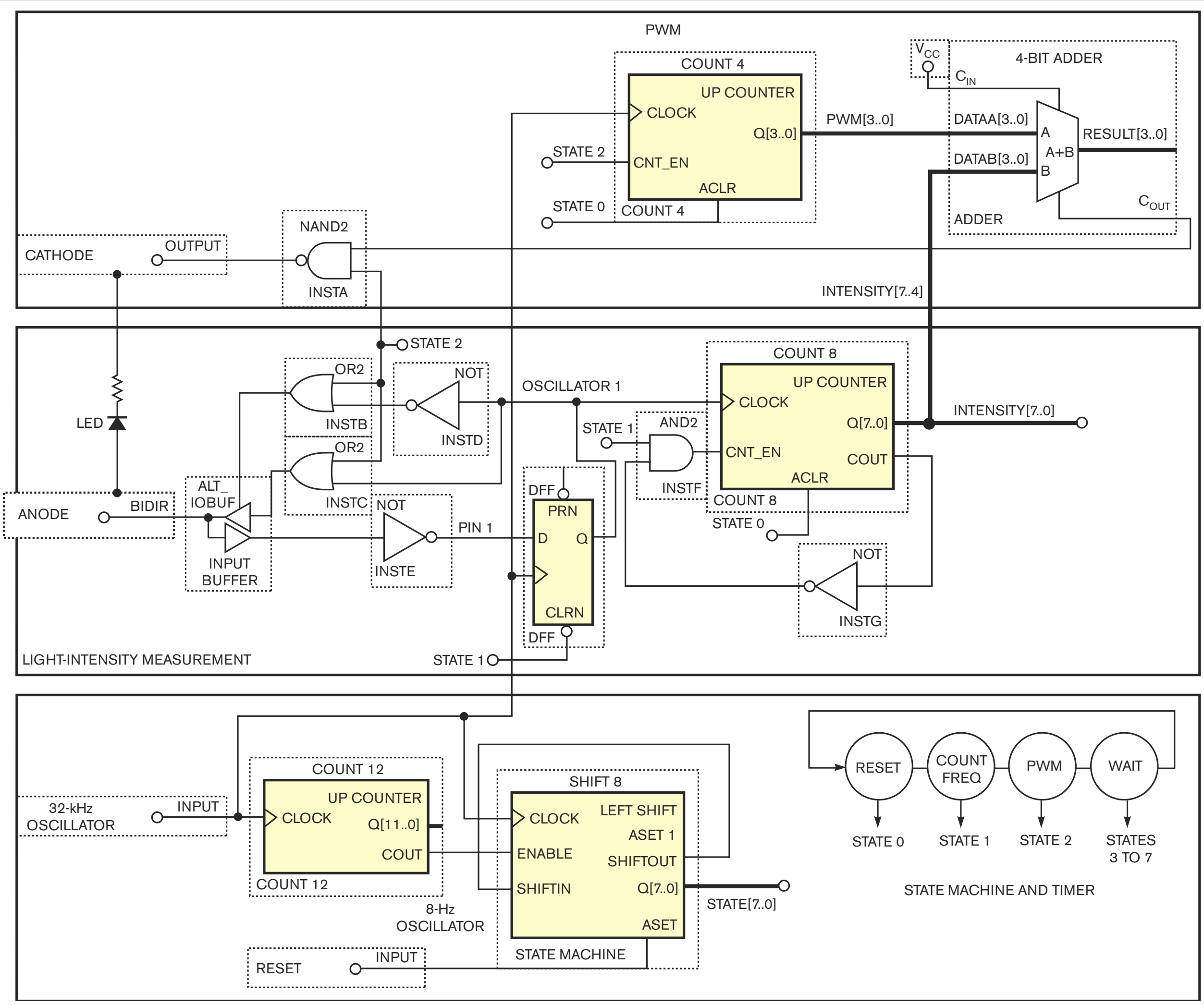
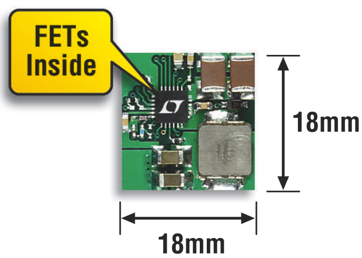


Figure 1 This simple MAX IIZ circuit uses an LED as an emitter and a sensor.

2A to 12A, High V_{IN} Synchronous Bucks



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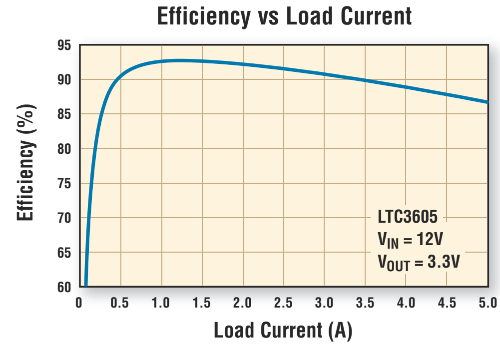

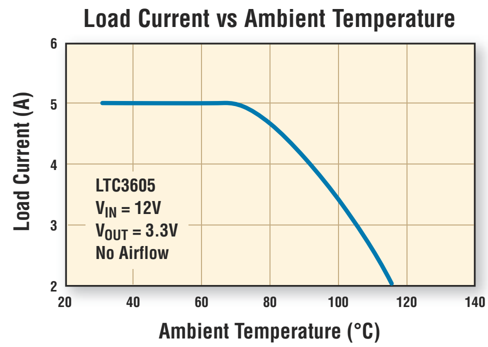

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High V_{IN} Monolithic Synchronous Buck Converters

Part Number	V_{IN} Range	Output Current	Switching Frequency	Synchro-nizable	Architecture	Package (mm)
LTC3601*	4V to 15V	2.5A	800kHz to 4MHz	Yes	Controlled On-Time	3x3 QFN-16, MSOP-16E
LTC3603	4.5V to 15V	2.5A	300kHz to 3MHz	Yes	Constant Frequency	4x4 QFN-16, MSOP-16E
LTC3605	4V to 15V	5A	800kHz to 4MHz	Yes	Controlled On-Time	4x4 QFN-24
LTC3609	4V to 32V	6A	300kHz to 1MHz	No	Controlled On-Time	7x8 QFN-52
LTC3608	4V to 18V	8A	300kHz to 1MHz	No	Controlled On-Time	7x8 QFN-52
LTC3611	4V to 32V	10A	300kHz to 1MHz	No	Controlled On-Time	9x9 QFN-64
LTC3610	4V to 24V	12A	300kHz to 1MHz	No	Controlled On-Time	9x9 QFN-64

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cles exiting the light sensor. The circuit senses the light by biasing the LED and current-limiting resistor such that the cathode lead of the LED is at logic one. The anode connects to a relaxation oscillator that starts with anode at logic zero. The LED pulls up the anode in proportion to the amount of light hitting the LED. The reverse-biased LED acts as a solar cell with output current proportional to light. Once the slow-rising anode signal reaches the threshold of the input buffer, the Pin 1 signal becomes a zero, and the D flip-flop, DFF, toggles to zero and drives the anode signal to zero, making Pin 1 a logic one and tristating the input buffer on the next clock cycle, allowing the anode signal to rise again.

The frequency of Oscillator 1 is proportional to light intensity, with typical frequency for bright light of approximately 2000 Hz. The Oscillator 1 signal drives the clock of Count 8. Count 8 resets in State 0 and then is enabled in State 1 for 125 msec. In bright light, Count 8 might count to 250 at the end of the measurement, and, in low light, it might count to only 16. The counter's C_{OUT} signal feeds back to the enable so that the count will saturate at a count of 255 and prevent high-intensity light from wrapping the counter back to zero and taking a false measurement.

State 2 is the LED's blinking state. This state blinks the LED for 125 msec at an intensity that a PWM controls. In State 2, the cathode and anode pins are bias to the emitter mode. The emitter mode forces the anode signal to V_{CC}. The cathode node connects to the PWM output. A logic zero on the cathode node lights the LED, and a logic one turns it off. The cathode signal is the inverted form of the PWM output.

In this example, the PWM is a 4-bit-resolution PWM, but you can use more or fewer bits. The PWM comprises binary counter Count 4 and a binary, 4-bit adder. The Count 4 counter is enabled in State 2, and the cycling output connects to the A input of the 4-bit adder. The B input of the adder connects to the four MSBs (most significant bits) of the light-sensor-frequency counter. The carryout of the adder is the PWM output. The carry-in of the adder is a constant logic one.

The following examples show how the PWM works:

- A logic zero from the intensity measurement results in a logic zero at carryout when Count 4 is zero through 14 and a logic one when Count 4 is 15. This 6.25% duty cycle is a very low-intensity level.
- A value of seven from the intensity measurement results in a logic zero at carryout when Count 4 is zero to seven and a logic one when Count 4 is eight to 15. This 50% duty cycle is a medium-intensity level.
- A 15 from the intensity measurement results in no logic zero at carryout for any Count 4 value and a logic one when Count 4 is zero through 15. This 100% duty cycle is a full-intensity level.

The only function of states 3 to 7 is to wait for the next LED-flash cycle. You can add or remove states to change the flash rate. EDN

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Two instrumentation amps make accurate voltage-to-current source

Frank Ciarlone, Analog Devices, Wilmington, MA

Many designs require precise voltage-controlled current sources, especially in the presence of variable loads. Common approaches, which use a few op amps and a handful of passive components, have inherent errors due to nonideal component characteristics, such as finite open-loop gain, common-mode rejection, bias current, and offset voltage. Designs using operational amplifiers may require precision resistors to set gain and additional capacitors for stability. In addition, some circuit designs provide currents that are not directly proportional to the input voltage. The voltage-to-current converter in **Figure 1**, for example, relies on the fact that the collector current is approximately equal to the emitter current and provides current in only one direction.

With two instrumentation amplifiers and two transistors, you can build a 0.01%-accurate voltage-controlled current source (**Figure 2**). This current source features a ±10V input-voltage swing that is directly proportional to the output current. It maintains high accuracy, even while delivering as much as 90 mA of output current. The AD620 low-power, low-drift instrumentation amplifiers from Analog Devices (www.analog.com) provide circuit control and error correction but are not part of the output circuit. Thus, you can substitute higher-power transistors for Q_1 and Q_2 to achieve higher output currents. You can configure the instrumentation amplifiers for any gain of one to 10,000 to accommodate input signals lower than 1 mV. Simply connect a resistor across the inputs of both IC_1 and IC_2 to achieve the desired gain.

The first instrumentation amplifier, IC_1, controls the base voltage of the push-pull output stage. The resistors

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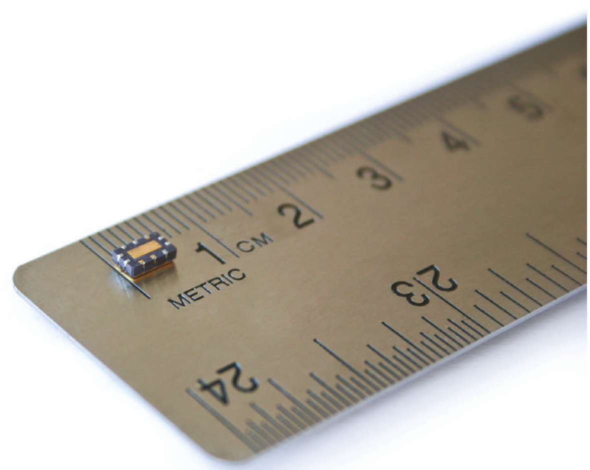

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and diodes provide bias to Q_1 and Q_2 to eliminate crossover distortion. IC_2 provides error correction and accounts for deltas in the base-to-emitter voltage. The error voltage, which you measure differentially from the D_1/D_2 junction to the output voltage, feeds into the reference pin of IC_1, summing it with the input voltage. The result is an output current that is directly proportional to the input voltage. This circuit achieves a 0.01% typical dc accuracy across a ±10V input span and 1.5% typical ac accuracy at 1 kHz with an output voltage of ±5V p-p.

The **equations** for calculating the output current are:

$$V_{OUT_{IC1}} = \left[\left(V^+_{IC1} - V^-_{IC1}\right)A_{IC1} + V_{REF_{IC1}}\right].$$

$$V_{REF_{IC1}} = V_{OUT_{IC2}} = \left(V^+_{IC2} - V^-_{IC2}\right)A_{IC2} + V_{REF_{IC2}}.$$

$$V_{OUT} = V_{OUT_{IC1}} = \left(V^+_{IC1} - V^-_{IC1}\right)A_{IC1} + \left(V^+_{IC2} - V^-_{IC2}\right)A_{IC2} + V_{REF_{IC2}},$$

where

$$V^+_{IC1} = V_{IN},\ V^-_{IC1} = 0;\ A_{IC1} = A_{IC2} = 1;\ V_{REF_{IC2}} = 0.$$

Therefore,

$$V_{OUT} = V^+_{IC1} + \left(V^+_{IC2} - V^-_{IC2}\right),$$

or

$$I_{OUT} = \frac{V_{IN}}{R_L}.$$

This circuit provides a wide output range, as well as output current that is directly proportional to the input voltage and high linearity and precision (**Figure 3**).EDN

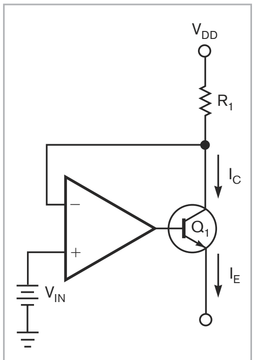


Figure 1 The voltage-to-current converter relies on the fact that the collector current is approximately equal to the emitter current and provides current in only one direction.

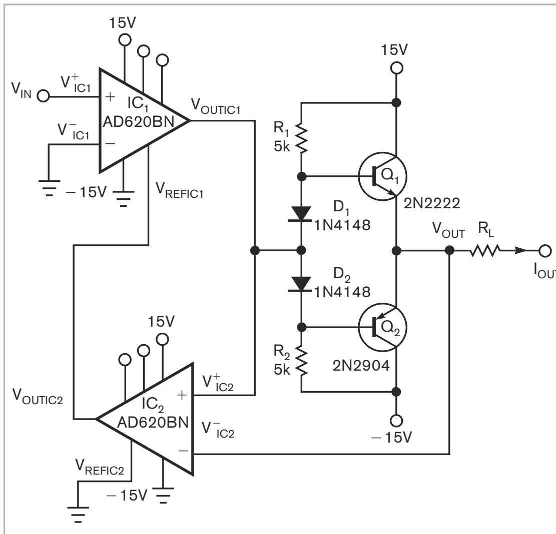


Figure 2 This handy voltage-to-current converter delivers high accuracy over a range of conditions.

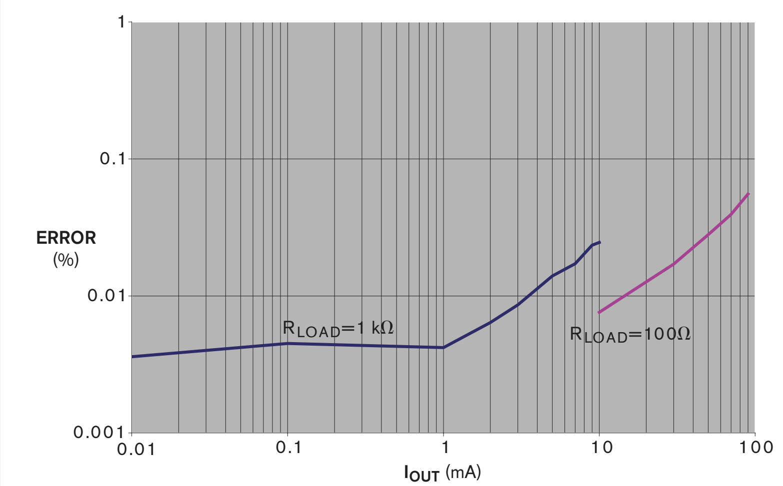


Figure 3 The circuit in Figure 2 provides a wide output range, output current that is directly proportional to the input voltage, and high linearity and precision.

Simple circuit indicates health of lithium-ion batteries

Fritz Weld, Friedberg, Germany

Lithium-ion batteries are sensitive to bad treatment. Fire, explosions, and other hazardous condition may occur when you charge the cell below the margin that the manufacturer defines. Modern battery chargers can manage the hazardous conditions and deny operation when illegal situations occur. This fact doesn't mean, however, that all cells are bad. In most cases, you can replace the discharged battery and increase your device's lifetime. **Figure 1** shows the circuit for testing battery packs.

When the supply voltage is lower than 2.6V, no current drives the base of the transistor. LED_1 lights up, and

LED_2 is off. When the voltage exceeds 2.6V, the transistor begins to short LED_1, turning it off and lighting LED_2. This condition indicates that the battery is below the allowed limit for recharging. The voltage margins highly depend on the type or color of the chosen LEDs. A standard red LED has a forward voltage of 1.7V; a green LED, about 2.1 or 2.2V. The circuit in this design uses red LEDs with forward voltages of approximately 1.6V at 2 mA. Other LEDs may require a simple redesign, mostly resulting in the requirement for a Schottky diode instead of the 1N4148 in this circuit. Even white or blue LEDs with 3V or more forward voltage make sense for certain applications.

Lower-value resistors increase the brightness of the LEDs but increase the supply current, as well. **Table 1** shows how this indicator provides three states of operation. Although this simple device draws little current, you cannot expect a long battery life if you use the device as a permanent display, especially when it is in storage. Although a fully charged 32-Ahr cell will expire after about a year, an empty battery of the same size but slightly higher than the allowed margin for charging will expire after one or two days.

You can build an array of indicators in one test module. By connecting to the measuring/balancing port of the pack, you can easily inspect a whole pack with one view. Adding zener diodes in series to the LEDs also makes this circuit a simple indicator for higher voltage levels. **EDN**

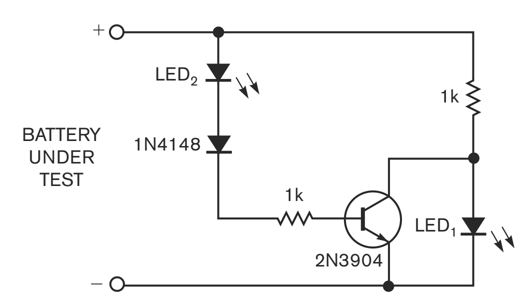


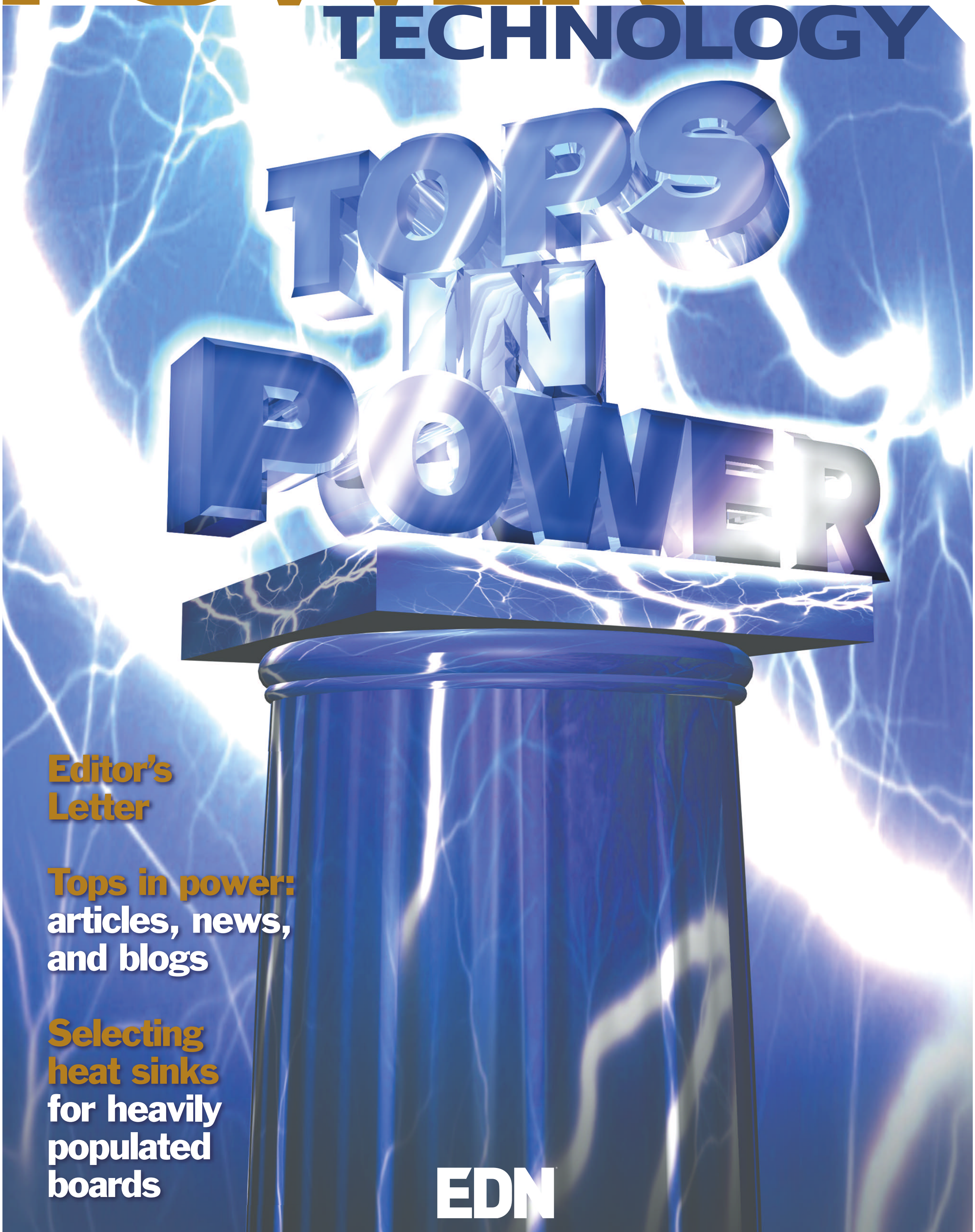
Figure 1 LEDs indicate the health of a battery based on its voltage.

TABLE 1 POSSIBLE LED CONDITIONS FOR BATTERY VOLTAGES

LED_1	LED_2	Indication	Condition
Off	Off	0 to 1.6V	Battery is empty, defective, or unusable.
On	Off	1.7 to 2.5V	Battery is below allowed limit for recharging.
Off	On	More than 2.6V	Battery is OK and can be charged.

AN *EDN* SPECIAL SECTION

POWER TECHNOLOGY



Editor's Letter

Tops in power: articles, news, and blogs

Selecting heat sinks for heavily populated boards

EDN

POWER TECHNOLOGY

MARGERY CONNER,
TECHNICAL EDITOR,
POWER SYSTEMS AND
COMPONENTS, EDN

Tops in power

This year's "Tops in power" special section focuses on the most popular power news, articles, and blog posts covering power technology for 2008. Power systems continue to be among the top technologies of interest to *EDN* readers, and, judging by edn.com traffic, the most interesting areas are in alternative energy and its enabling technologies. For that reason, *EDN* readers jump on all new battery-technology stories. And, in another twist on the lithium-ion-battery angle, one of the most popular blog posts was about the introduction of a lithium-ion super-capacitor.

There's more to power than energy storage, though, including how to handle the effects of high currents in small packages, which means heat removal. We finish this installment of "Tops in Power" with "Selecting heat sinks for heavily populated boards," a new article on heat-sink design that includes research results on high- and low-density passive heat sinks that are finding their way into high-brightness-LED-based designs.

We've rated these articles based on Web-site-traffic numbers from edn.com, which receives more than 1 million page views and 100,000 unique visitors a month. More than half of those visitors say that understanding power technology is a big part of their job. We're happy they come to *EDN* to help solve their power-related problems.

Ultra-Low Noise Microphone Amplifiers

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- Ultra-low noise performance (4.5uV RMS maximum, Cmic = SC, varies with gain)
- Ultra-low input capacitance—.25pF typical
- Low quiescent qurrent in sleep mode, (< 50μA)
- Chip-scale SMD bumped packaging (820μm x 1220μm, 350μm thick)

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- Multiple gain options (11dB, 14dB and 16dB)
- Ultra-low noise performance (4.5uV RMS maximum, Cmic = SC, varies with gain)
- Ultra-low input capacitance—.25pF typical
- Low quiescent current in sleep mode, (< 50μA)
- Chip-scale SMD bumped packaging (820μm x 1440μm, 350μm thick)

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Tops in power: ARTICLES AND NEWS

DON'T LIMIT YOUR CONCEPT of alternative energy to solar and wind power: Batteries, a prosaic technology that's been around since slightly before the invention of dirt, have been undergoing a rebirth. Lithium ion is currently the standard chemistry for high-power, high-energy, rechargeable batteries, but it's morphing into flavors: Lithium ion with a cobalt cathode continues to be standard for such high-energy-storage-density devices as laptops and cell phones, but lithium-ion-iron phosphate has emerged as the chemistry of choice for high-power devices ranging from cars to hand tools. None of these lithium-ion chemistries is ideal, though, and some new technology will come along from some university or research institution to move us closer to the ideal battery chemistry. Hence, the top power story for *EDN* in 2008 is "MIT researchers use plant-energy-storage system for solar-storage innovation."

"MIT researchers use plant-energy-storage system for solar-storage innovation,"
www.edn.com/article/CA6583673

"A solar panel on every building,"
www.edn.com/article/CA6524103

"Circuit makes simple high-voltage inverter,"
www.edn.com/article/CA419572

"Lithium-ion batteries prepare to take a giant leap forward,"
www.edn.com/article/CA6569183

"Solar-cell, semi-industry investments equal by 2010, iSuppli reports,"
www.edn.com/article/CA6572440

"High-brightness LEDs usher in new applications and standards,"
www.edn.com/article/CA6512150

"Power inverter is bidirectional,"
www.edn.com/article/CA149121

"Buck-boost converters change with the times,"
www.edn.com/article/CA6553622

"How to kill the home-networking industry,"
www.edn.com/blog/630000263/post/220026822.html

Tops in power: BLOGS

AS WITH *EDN*'s news articles and features, energy efficiency, especially discussion about the practicality of compact fluorescent lights, proved popular with readers. Other popular topics were *EDN*'s series on the power subsystem for the Phoenix Mars lander and an interview with a young engineer who's started a successful electronic-kit business. All of these articles were from the Power-Source blog, but two other posts were power-related topics in Paul Rako's Anablog.

"This was not the right application for a compact fluorescent light,"
www.edn.com/blog/1470000147/post/1420034342.html

"Not so easy to run an LED 'bulb' off of a dimmer switch—but here's how,"
www.edn.com/blog/1470000147/post/380022638.html

"Why diesel is so expensive,"
www.edn.com/blog/1470000147/post/560027656.html

"Lithium-ion capacitor: best of both worlds?"
www.edn.com/blog/1470000147/post/1110030711.html

"Electricity cost versus gasoline and the 135-mpg myth,"
www.edn.com/blog/1700000170/post/1490036349.html

"Feds call halt to new solar-plant permits, may give boost to municipal installations,"
www.edn.com/blog/1470000147/post/1290029129.html

"Wind power is great; government subsidies are not,"
www.edn.com/blog/1700000170/post/630032463.html

"Massive solar project garners protests from solar-energy industry,"
www.edn.com/blog/1470000147/post/960031696.html

"Power on Mars, Part 1: Dust devils clean up solar arrays,"
www.edn.com/blog/1470000147/post/1070028307.html

"15 steps to starting your own electronic-kit business,"
www.edn.com/blog/1470000147/post/1630025963.html

Heat sinks are important in complex systems in which the sink's impact on airflow matters as much as its thermal resistance.

Selecting heat sinks for heavily populated boards

BY BARRY DAGAN AND PHILIP RAYNHAM, COOL INNOVATIONS INC

When facing the task of cooling heavily populated PCBs (printed-circuit boards), designers must understand that careful management of airflow along the boards is the key to effective cooling. In these dense-PCB applications, pressure drop is as important as thermal resistance when it comes to selecting heat sinks. Designers regularly use the parameters of thermal resistance and pressure drop to quantify the performance of heat sinks. Thermal resistance, the temperature increase in degrees Celsius per watt, measures how effectively a heat sink transfers heat from the heat-generating device to the ambient environment. The lower the thermal resistance, the more effective the heat sink because heat sinks with low thermal resistance can cool heavier heat loads before the heat-generating device reaches its maximum allowed temperature. Thermal-resistance values for heat sinks are a function of the airflow through the heat sink. In other words, faster airflow results in lower thermal-resistance values.

The other parameter, pressure drop, is the resistance to the air moving through the heat-sink fins—that is, the difference between the airflow speed as it enters the heat sink's fin array and the airflow speed as it exits the array. The lower the pressure drop, the less airflow the heat sink "consumes" and the more airflow that's available to cool other devices on the board. With heavily populated boards, engineers need to balance the requirements for low thermal resistance and low pressure drop. Doing so requires an understanding of the relationships among heat-sink performance, heat-sink-fin density, airflow, and pressure drop.

The speed of the air stream as it ap-

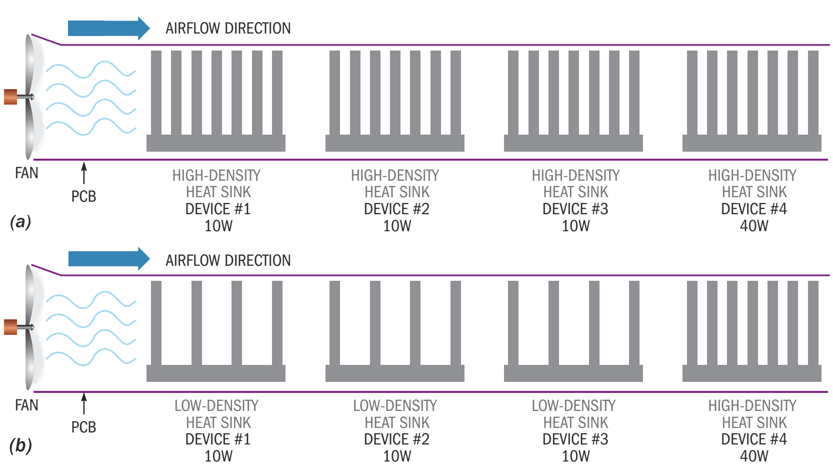
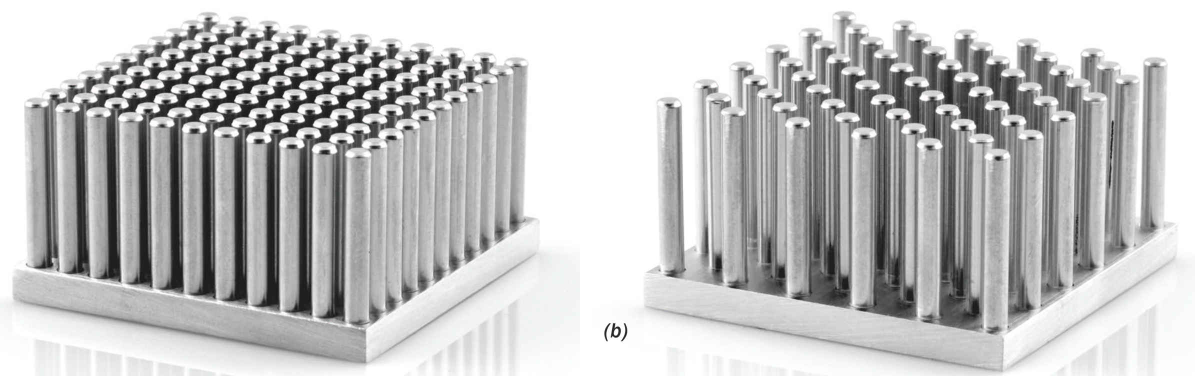


FIGURE 1 In two experiments, engineers lined up two sets of heat-generating devices and their heat sinks on a PCB in front of identical fans. The heat sinks differed only in their pin density—117 pins (a) and 61 pins (b). The densely configured heat sink contained substantially more surface area—167 versus 87 in.^{2}—and, thus, showed a higher pressure drop.



(a) (b)

FIGURE 2 At low air speeds, a densely populated heat sink with greater surface area (a) may perform worse than a sparsely populated device (b).

proaches a heat sink has a critical effect on heat-sink performance because, to remove heat, you must break the boundaries of still air encircling the surface of the heat sink. The faster the air stream, the more likely the boundary layers are to break and the more effective the heat sink is in removing heat. Conversely, in low-air-speed environments, the boundary layers of still air are less likely to break, resulting in a less effective heat sink. A densely populated—that is, high-pin-count—heat sink with greater surface area will likely perform worse at low air speeds than a sparsely populated heat sink with less surface area because the incoming air stream cannot penetrate the densely populated heat sink. That situation runs counter to the conventional thinking that more surface area always enhances cooling. Air speed has a tremendous impact: Some heat sinks are as much as 100 times more effective in thermal resistance in high-air-speed environments than in those with natural-convection cooling—that is, environments without airflow.

For boards containing one device, heat-sink selection is simple: The only relevant engineering parameter is the heat sink's thermal resistance. However, for boards that contain a large number of devices, you must take into account the allocation of available airflow along the board. You accomplish this task by considering the heat sink's pressure drop and thermal resistance. Two simple experiments using pin-fin heat sinks illustrate the importance of airflow management on heavily populated boards. In these experiments, engineers lined up two sets of heat-generating devices and their heat sinks on a PCB in front of identical fans (**Figure 1**). To analyze the effect of pressure drop on the thermal performance of a system, the engineers chose heat sinks of the same construction but with different pin densities.

The heat sinks had identical footprints, heights, and pin diameters, each measuring 2×2×1.1 in. with 0.125-in.-diameter pins. The heat sinks differed only in pin count. The densely populated heat sink (**Figure 2a**) had 117 pins, and the sparsely configured version had 61 pins (**Figure 2b**). The densely populated heat sink contained a 167 in.^{2} surface area—and, thus, higher pressure drop—than the sparsely populated heat sink, with 87 in.^{2} of surface area. In both experiments, the board contained four heat-generating devices directly in front of a fan blowing air at 1000 lfm (linear feet per minute) in free air. The first three devices dissipated moderate heat loads of 10W, whereas the fourth device dissipated 40W. The experimenters intended that this "hot" device would mimic the main CPU on a PCB. The goal of this experiment was to optimize for thermal performance on the hottest device.

In the first experiment, the engineers placed four sparsely populated heat sinks on the four devices. In the second experiment, they placed three sparsely populated heat sinks on the first three devices—those with moderate heat loads—and another densely populated heat sink on the fourth device, with the heavy heat load. In the first experiment, the first three devices provided an outstanding level of cooling. However, the last device, which is the critical one due to the high power it dissipates, was too hot: The temperature rose 44°C, significantly higher than the maximum 35°C increase that many typical applications can tolerate. The large temperature increase stemmed from the fact that

TABLE 1 PERFORMANCE OF FOUR HIGH-DENSITY HEAT SINKS

	Device 1	Device 2	Device 3	Device 4	
Heat sink	3-202011R	3-202011R	3-202011R	3-202011R	Cumulative pressure drop
Pressure drop (mm water)	2.1	2.1	2.1	2.1	8.4
Thermal resistance (°C/W)	1.1	1.1	1.1	1.1	
Power dissipation (W)	10	10	10	40	
Temperature rise (°C) at case	11	11	11	44	

Notes: Airflow approaching Device 4 is 210 lfm.
The 3-202011R is a densely populated heat sink.

the cumulative pressure drop was too high to drive enough air through the heat sink. In this case, only 210 lfm of air reached the fourth device (**Table 1**).

In the second experiment, the first three devices were warmer than those in the first experiment, but the cooling power was sufficient because they dissipated only moderate loads of heat, and, in both experiments, the temperature increase was substantially lower than the allowed maximum of 35°C. However, due to the superior pressure drop of the three sparsely populated heat sinks in the second experiment, the air speed approaching the fourth device—320 lfm—was higher. As a result, the temperature increase of the fourth device was only 32°C versus 44°C, even though the fourth heat sink was identical in both experiments (**Table 2**).

The two experiments illustrate the importance of airflow management in boards that contain multiple devices. In the first experiment, the experimenters did not manage airflows at all. However, in the second experiment, through the use of sparsely populated heat sinks that obstruct less air, more air was available for the fourth device, which needed greater cooling. Along with the performance results, it's worth noting that the airflow management in the second experiment would result in a more cost-effective design. To achieve sufficient cooling of the critical device in the first experiment would have required an expensive heat pipe or fan sink to reduce the device temperature because the speed of the approaching air stream was too low. What's more, the heat sinks in the second experiment were less expensive than those in the first because sparsely configured heat sinks use less metal and are therefore cheaper than dense heat sinks.

FIGURE 3 Splayed-pin-fin heat sinks extend cooling performance with their unique shape, which provides lower thermal resistance and lower pressure drop than do most traditional heat sinks.

MINIMUM-COOLING-POWER APPROACH

As the experiments illustrate, every heat sink on a heavily populated board affects not only the device it resides on, but also the other devices on the board. So, to properly select a heat sink, you must take into account both thermal resistance and pressure drop. One way to make this selection is with the minimum-cooling approach—selecting a heat sink that achieves the lowest pressure drop and provides the least amount of required cooling. Because pressure drops along the board add up, following this method for every heat sink significantly improves the overall cooling of the board.

You can achieve the minimum-cooling-power approach by identifying a heat-sink technology that offers low pressure drop for a given level of cooling. Once you have identified an appropriate heat-sink technology, the next step is to select a heat sink with the lowest possible fin density. Employing the minimum-cooling approach, an efficient heat-sink technology provides low pressure drops and low thermal resistance. In obtaining low pressure drop, no simple formula is available to guide designers in heat-sink selection. Nevertheless, a few heat-sink characteristics are worth examining. For example, the heat sink should have an omnidirectional structure that enables air to enter and exit the fin array from all directions and therefore eliminate directional constraints.

The second property is fin shape: The more aerodynamic the fin structure, the less resistance it presents to surrounding air streams as they enter or exit the fin array. For example, round pins provide lower resistance than do square fins due to the round pins' smooth, aerodynamic nature. The use of highly conductive materials is also beneficial because these materials provide better cooling—that is, lower thermal resistance—than do nonconductive materials without affecting pressure drop. Some cases warrant the use of copper or copper-and-aluminum combinations rather than a lower-cost, all-aluminum design. With materials selection, as with other aspects of heat-sink specification, keep in mind that better heat-sink performance leads to greater PCB-layout flexibility. This fact, in turn, may help you to avoid significant pressure drops that affect the cooling of hot devices.

FIN-DENSITY SELECTION

An important distinction exists between heat-sink technology and fin density. Although heat-sink technology refers to the shape of the fins, fin density refers to the number of fins

TABLE 2 PERFORMANCE OF THREE LOW-DENSITY HEAT SINKS AND ONE HIGH-DENSITY HEAT SINK

	Device 1	Device 2	Device 3	Device 4	
Heat sink	3-202011M	3-202011M	3-202011M	3-202011R	Cumulative pressure drop
Pressure drop (mm water)	1.2	1.2	1.2	2.7	6.3
Thermal resistance (°C/W)	1.5	1.5	1.5	0.8	
Power dissipation (W)	10	10	10	40	
Temperature rise (°C) at case	15	15	15	32	

Notes: Airflow approaching Device 4 is 320 lfm.
The 3-202011M is a sparsely populated heat sink.
The 3-202011R is a densely populated heat sink.

per given footprint. And, whereas comparing the pressure drop of heat sinks of technologies can be complicated, comparing the pressure drop of heat sinks from the same technology is a simple task. The lower the fin or pin count, the lower the pressure drop is. Consequently, following the minimum-cooling approach with a given heat-sink technology is fairly straightforward. Start by identifying the semiconductor devices in your system that need cooling. Then, determine the maximum case-to-ambient temperature ratios that will keep these devices within their safe operating ranges. Using those maximum temperatures and the devices' expected levels of power dissipation, you can determine the thermal resistance required for each heat sink.

Then, select the most sparsely finned heat sinks that provide the necessary values of thermal resistance, given the expected airflow and mechanical constraints of your design. When selecting heat sinks, remember the experiments and start off assuming that there will be less airflow for devices downstream than for those devices closest to the fan.

Looking for superior heat-sink technologies that provide lower pressure drop for a given level of cooling is becoming an increasingly important task as boards become denser and heat loads become heavier. Adopting such technologies can give designers a competitive edge, allowing them to build ever-more-complex equipment. One example of a new advanced technology is the splayed-pin-fin heat sink (**Figure 3**). Splayed-pin-fin heat sinks extend cooling performance with their shape, which provides lower thermal resistance and lower pressure drop than do most traditional heat sinks. Splaying, or bending, the pins outward increases the spacing between the pins, which lowers pressure drop without changing surface area or heat-sink footprint.

Authors' biographies

Barry Dagan is chief technology officer at Cool Innovations, where he has worked for 13 years. He is in charge of heat-sink design, development, and manufacturing and oversees Cool Innovations' technical-support-engineering team. Dagan has a bachelor's degree in mechanical engineering from the Technion-Israel Institute of Technology (Haifa). His personal interests include "green" energy.

Philip Raynham is an applications engineer at Cool Innovations, where he has worked for two years. He provides technical assistance to customers and performs product development, testing, and validation. Raynham has a bachelor's degree in applied science from the University of Toronto (ON, Canada). His personal interests include history and robotics.

ROHS changes keep design engineers vigilant

New changes to the European Union's ROHS (restriction-of-hazardous-substances) directive will force design engineers to carefully watch their BOMs (bill-of-materials) costs, as the industry targets the phasing out and expiration of a number of ROHS exemptions in the coming years. For now, the EC (European Commission), with guidance from its technical consultants Öko Institute (www.oeko.de) and Fraunhofer IZM (www.izm.fraunhofer.de), has permitted exemptions in cases in which no technical alternative exists. Overall, the EC seeks to eliminate exemptions, however.

"The theory is [that] it will stimulate efforts to find alternatives that are more environmentally friendly," says Gary Nevison, director of legislation and environmental affairs at UK-based Farnell (http://uk.farnell.com) and its US sister company Newark (www.newark.com). The EC proposes to withdraw six of the directive's 29 exemptions (see **sidebar** "Withdrawn ROHS exemptions"). "The announcement of the exemption eliminations is likely to be in 2010, and the Öko Institute is suggesting an 18-month grace period for manufacturers to comply, so we're looking at 2012," says Nevison. That time frame gives manufacturers little time to comply if alternatives are not readily available.

Moves to retire exemptions will likely continue over the coming years, and the industry will likely add restricted substances to the ROHS directive over time. "This is a trend," says Fern Abrams (**photo**), director of environmental policy and government relations at IPC—Association Connecting Electronics Industries (www.ipc.org). "It was clear from the beginning that the EC did not want to give any exemptions," she says. "[It] resisted exemptions and viewed them as evasive. The fact that there were exemptions showed that some part of the Commission was receptive to reality and what was technically feasible."

One of the big challenges for engineers comes when a product has a long life cycle because there is always the possibility that exemptions will change during the lifetime of a product. These challenges particularly affect industries such as automotive, aerospace, and medical equipment because of the long life cycle of the products.

Much of the compliance responsibilities with ROHS and other directives such as the European Union's REACH (registration/evaluation/authorization-of-chemicals) regulation fall on the shoulders of engineers who select components for design-in, and doing so is more difficult than choosing ROHS-compliant parts when exemptions are changing. "People will have to redesign some of their products because of restrictions," says Ken Stanvick, vice president of Design Chain Associates (www.designchainassociates.com), which helps manufacturers with environmental compliance. "You may lose one of your suppliers because an exemption went away," he says. "It becomes a guessing game as to what will affect your product, so you need a system to alert you."

Some engineers use consultants for help in predicting whether components will be safe from changes in environmental laws. Others turn to their distributors "If you're designing a product that will have a long lifetime, you need to have a process in place that assigns someone to look at all of the changes and check them against your BOM so you can accommodate these directives sufficiently in advance," says Steve Schultz, director of strategic planning and communications at Avnet Inc (www.avnet.com). "We take a high-level view, but we also zoom down to the individual component and work with our customers to review their BOMs," he says.

So far, it seems that the electronics industry is coping well with the announcement of the elimination of six of the exemptions. "I haven't heard any calls in real panic or even mild panic," says Abrams. The quiet phones at IPC may indicate that the industry has simply become accustomed to progressive restrictions in substances contained in components.

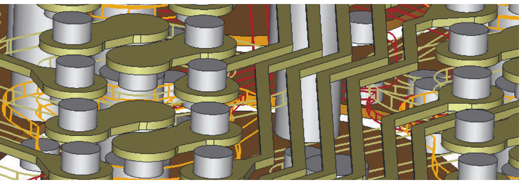
–by Rob Spiegel

WITHDRAWN ROHS EXEMPTIONS

The industry is withdrawning the following ROHS (restriction-of-hazardous-substances) exemptions from its list:

- **lead in linear incandescent lamps with silicate-coated tubes,**
- **lead as an activator in the fluorescent powder,**
- **lead with lead/bismuth/tin/mercury and lead-indium-tin-mercury in specific compositions as the main amalgam and with lead/tin/mercury as the auxiliary amalgam in compact energy-saving lamps,**
- **lead oxide in the glass for bonding front and rear substrates of flat fluorescent lamps in LCDs,**
- **lead oxide in the glass envelope of black-light blue lamps, and**
- **lead alloys as solder for transducers in high-power loudspeakers.**

Exemptions for decabrominated diphenyl ethers and hexavalent chromium are already obsolete.



productroundup

CONNECTORS

Module has embedded POE+ controller

Suiting use in gigabit-Ethernet switches, routers, hubs, and industrial Ethernet switches and routers, the HyperJack 1000 POE (power-over-Ethernet)+ IC module integrates magnetics for supporting 10/100/1000-Mbps Ethernet. The multiport module embeds the POE+ power-management function in an RJ-45 connector and combines controller silicon for managing and delivering 30W POE with Gigabit POE+ magnetics; thermal management; and protection against ESD, EFT, and EMI. The module design meets the pending POETec Version 2.0 protocol, allowing for easier industrywide adoption. The POE technology allows users to power and communicate with network devices over an Ethernet cable, requiring no additional power supplies. The 15W IEEE 802.3af standard powers connected Ethernet devices, such as VOIP phones, wireless-access points, and security cameras. The HyperJack 1000 POE+ IC module costs $7 per port (1000).

Molex Inc, **www.molex.com**

Contact improves high-frequency-signal transmission

The Universal GPS dry-circuit pressure contact maintains true contact-beam positioning with no conductivity to side walls. The device provides a 0.3N mating force with a 0.1-mm beam movement. Integrating GPS features for handheld devices, the contact enables transmission and reception of signals with greater-than-1.8-GHz frequency between the antenna and the PCB without distorting the signal's wave or length. The single-piece, stamped and formed device is available with a 0.9-mm deflection and a 1.8-mm free height, and prices range from 7.5 to 9.5 cents.

ITT Interconnect Solutions, **www.ittcannon.com**

Connectors meet shock and vibration standards

Passing shock and vibration testing according to military standard 202 Method 204 and IEC 60512 Test 8d requirements, the 1.27-mm-pitch Rib-Cage connectors use a multipoint, gold-plated receptacle design suiting industrial, instrumental, military, and medical applications. The connector has a two-row mezzanine, surface-mount, board-to-board-connector system supporting three PCB-stack heights and offers options for right-angle mounting. Aiming at devices requiring connection to flexible and rigid circuits, the device features a

1A current rating, as well as 200-cycle durability sustaining reliable mating and unmating. Available in connector sizes ranging from 10 to 100 positions, the Rib-Cage connectors cost 4 cents (1000).
FCI, www.fciconnect.com

Board-to-board connectors resist vibration and drop shock

The low-profile 5846 board-to-board-connector series features a 3-mm-form-factor stacking height with a 0.4-mm-pitch contact. The pinched-contact structure features an insulated bottom plate to protect the contacts, making the device resistant to vibration, drop shock, and short circuits in respect to printed tracks on the PCB. Additional features include a 0.3A-rated contact current, 50V-rated contact voltage, gold-plated beryllium-copper contacts, UL94V-0 heat-resistant insulator material, and a −40 to +85°C temperature range. The 5846 board-to-board connector series costs 50 cents.
AVX Corp, www.avx.com

Interconnects enable 90° or planar board-to-board interfaces

Adding a hinged version to the vendor's 25A PowerStrip/25 system, the high-power FMPS/FMPT interconnect series suits applications requiring blind mating. The interconnects enable 90° or planar board-to-board interfaces and a 90° mating radius. This flexibility allows you to mate the connectors at an angle suiting production and rotating to the final permanent required orientation. Available with as many as eight pins on a 5.08-mm pitch, the device achieves a 25A-per-contact current rating at 75°C. The PowerStrip/25 system costs 25 cents per 25A pin. Optional locking clips and a screw-down configuration for the socket are also available.
Samtec, www.samtec.com

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 BY WAYNE MILLER • WAYNE MILLER ASSOCIATES LLC

Filter-feedthrough-failure flash

DANIEL VASCONCELLOS

I had been working as a consultant for a number of years, and most of my clients were microwave companies. Each client had its own product specialties, so I had no problems with possible conflict of interest. There were commonalities among the various companies, however, in that most of their products looked like aluminum bricks of various sizes and proportions, with a variety of coaxial connectors and filter feedthroughs sprouting from one or more of the surfaces. My main contribution involved the bits of circuitry to interface between the microwave portion and the customer interface. This interface always involved filter feedthroughs to carry the dc power and to monitor both internal and external control functions. As I went from client to client, I found that this same common construction was embedded into their culture, and it haunted me wherever I went.

It is difficult to avoid the use of filter feedthroughs in these applications. They require good RF and microwave shielding, and, in many cases, the units require environmental sealing. I was in a unique position to be able to see the suppliers to each company, how each company handled them, and how the companies tested the equipment. The only common element that I could find was a high failure rate.

Finally, I got the break I needed. A major client had shipped hundreds of units to a customer in Indonesia. They began to fail in large numbers. The client elected me to go and determine the cause of the problem. Indonesia is close to the equator and comprises more than 10,000 islands surrounded by water. It defined to me in a completely new way the meaning of the term *hot and humid*. This type of weather turned out to be an important factor in the failures.

When I installed myself in the lab and began to evaluate the failures, I found that they were almost all because of shorted filter feedthroughs. To further investigate the cause of the feedthrough failures, I applied the rated voltage to one of the shorted units. It flashed like a small bolt of lightning. I thought I had blown it completely, but further testing revealed that I had "fixed" it; it was no longer shorted and still functioned as a filter. Further microscopic examination of other failed units revealed a silver path on the surface of the insulator that had been formed in the humid environment of Indonesia as the silver plating on the body of the feedthrough migrated across to bridge the gap, driven by the dc voltage I had applied to the center pin. I was able to prevent further occurrences by applying conformal coating to the feedthroughs after the units were installed in the system.

Here's a hint: As previously noted, you use filter feedthroughs to pass a voltage—usually with a dc component—through a housing wall to give RF isolation and an environmental seal against humidity. It stands to reason, then, that most filter feedthroughs spend at least some of their lives with a dc voltage applied and in a humid environment. In this common application, all silver-plated filter feedthroughs are destined to fail unless you further protect them from humidity by applying a conformal coating after soldering a wire to the center pin. A more practical approach is to specify feedthroughs with gold or palladium plating. EDN

Wayne Miller is a technical consultant at Wayne Miller Associates LLC (Stanhope, NJ). You can reach him at wlm@wlm.name.

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