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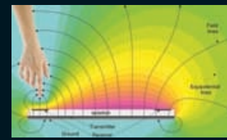
EDN

DEC 2012
www.edn.com
Issue 18



HOT TECHNOLOGIES

LOOKING AHEAD TO 2013

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Optimizing operating life for LED-based lightbulbs

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BEST OF CLASS: BROADEST OVERALL PRODUCT SELECTION
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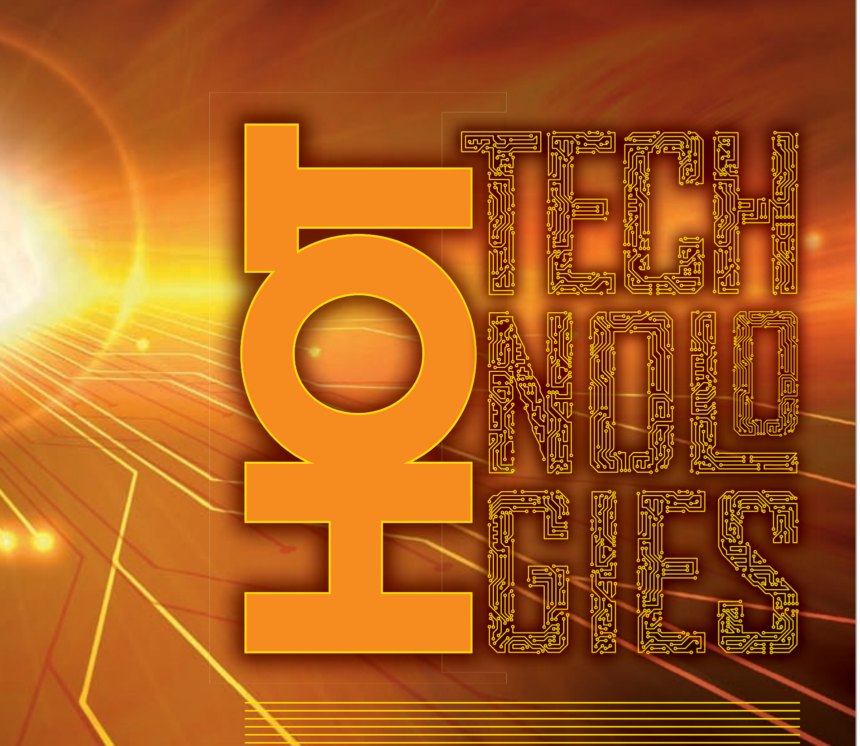


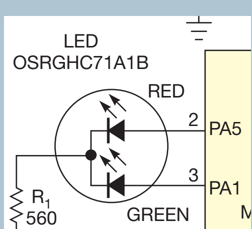
Hot technologies: looking ahead to 2013

Hot 100 products of 2012

COVER: GIULIA FINI-GULOTTA / SHUTTERSTOCK

Optimizing operating life for LED-based lightbulbs

DESIGNIDEAS



▶ Submit your own Design Idea to edndesignideas@ubm.com.

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EDN® (ISSN# 0012-7515) is published semimonthly (January–June) and monthly (July–December) by UBM Electronics, 600 Community Drive, Manhasset, NY 11030-3825. Periodicals postage paid at Manhasset, NY, and at additional mailing offices. SUBSCRIPTIONS—Free to qualified subscribers as defined on the subscription card. Rates for nonqualified subscriptions, including all issues: US, $150 one year; $250 two years; $300 three years. Except for special issues where price changes are indicated, single copies are available for $10 US and $15 foreign. For telephone inquiries regarding subscriptions, call 847-559-7597. E-mail: edn@omeda.com. CHANGE OF ADDRESS—Notices should be sent promptly to EDN, PO Box 3609, Northbrook, IL 60065-3257. Please provide old mailing label as well as new address. Allow two months for change. NOTICE—Every precaution is taken to ensure accuracy of content; however, the publishers cannot accept responsibility for the correctness of the information supplied or advertised or for any opinion expressed herein. POSTMASTER—Send address changes to EDN, PO Box 3609, Northbrook, IL 60065-3257. CANADA POST: Publications Mail Agreement 40612608. Return undeliverable Canadian addresses to APC, PO Box 503, RPO West BVR CRE, Rich Hill. ON L4B 4R6.

Volume 57, Number 18 (Printed in USA).

EDN online

JOIN THE CONVERSATION

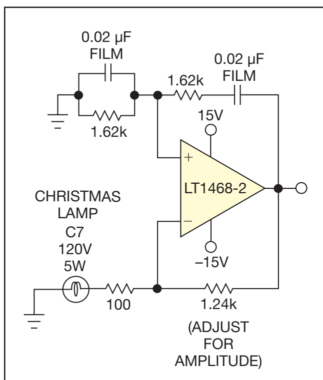
Comments, thoughts, and opinions shared by *EDN*'s community

In response to "Forgotten circuits (that should be brought back)," a post in Dennis Feucht's Outside the Box blog at www.edn.com/4401105, kg5q commented:

"The reason some of these analog processing circuits went away is that the A/D converters and linear front-end processing circuits got faster, better, [and] cheaper, and it's easier for today's digital and software whiz kids to simply bring in the raw data and fix it all in software. Do any curve fitting and math that way and you don't have to worry about drift and offset and thermals, etc. It just works day in and day out. Wish we could have had that in the '70s, '80s, and '90s. I am not going to wish for the old days, because a lot of today's products do work better."

In response to "Injection-lock a Wien-bridge oscillator," a Design Idea by Glen Brisebois at www.edn.com/4400342, WKetel commented:

"Definitely an elegant solution to the problem. It also points out how sensitive an oscillator can be to external influences, both stabilizing and destabilizing. That is the other benefit of using phase-locked loops; it is the phase stability."



EDN *invites all of its readers to comment constructively and creatively on our content. You'll find the opportunity to do so at the bottom of each article and blog post.*

CONTENT

Can't-miss content on EDN.com

SIMPLE TESTER CHECKS CHRISTMAS-TREE LIGHTS

Why is it that you always test 48 bulbs before you find the bad one in a 50-light string? The simple circuit in this Design Idea allows you to divide and conquer, greatly reducing the time it takes to find the bad bulb.

www.edn.com/4359491

SOCIAL MEDIA MEETS MORSE CODE

Steve Hicks and Greg Jurrens explain what went into designing the ultimate, easy-to-use ham radio and how advances in analog electronics made the difference.

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BY PATRICK MANNION, DIRECTOR OF CONTENT

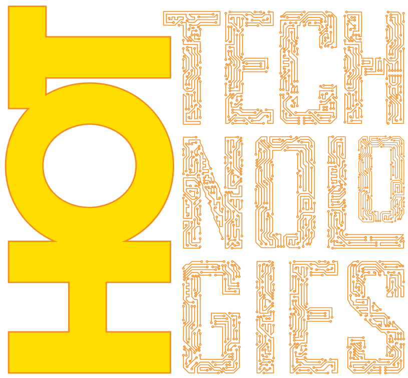
Wild rides and hot technologies

It's safe to say that 2012 has been a wild ride for all of us. The macroeconomic climate, from Europe across the oceans to China, has seen so much uncertainty and stagnation that corporations and analysts alike, for fear of missing their numbers, are making the most conservative forecasts possible. Indeed, many have already ratcheted back their expectations for 2013.

We had hoped the US election would lift the veil on at least some of the uncertainty. Alas, however, the "fiscal cliff" looms, and as of this writing there is no resolution in sight. We can only hope Congress and the administration opt not to kick the can down the road, because anything short of a full agreement only keeps the uncertainty alive—and cripples our ability as individuals, small businesses, and corporations to innovate around the flaws of any decision that does come down.

Speaking of innovation, this issue of *EDN* highlights the best of what you, our engineering community, had to offer this year, from the Hot 100 products (see pg 53) to the hot technologies (see pg 34) that you helped propel forward. In 2013, those developments and products will form the foundation of what looks to be a landmark time for electronics engineering. Massive shifts are coming next year that will reflect and build on the turmoil of the year that's now almost past.

This year's Apple v. Samsung drama is a case in point. Samsung "lost" round one, but so what? Right now, Samsung and Apple (read: Android and iOS) are all that matter in the smartphone/mobile-computing/tablet landscape. Nokia is fading fast, and for Research in Motion the writing has been on the wall for some time. Microsoft's Surface is pushing to make headway but won't be a major factor anytime soon.



So what's the upshot? Four implications come to mind. First, mobile digital processing options will gel around whatever Samsung and Apple choose to back; their picks will become almost de facto standards. If you're not designed into one of their devices or platforms, you have a tough road ahead. Just ask Texas Instruments and its OMAP team.

Second, apps continue to rule the roost and keep absorbing the neuronal firings of our youngest and brightest. Who wants to waste time studying EE basics when an app can make you rich? With so many apps flooding the market, the shine may be coming off that brass ring, but we're coping with the aftereffects. Who's dreaming up the next big system design win that doesn't depend on a Samsung or Apple platform and so will reignite the demand for parts—from passives to processors—to keep the industry humming again? Why bother designing a full system when you can take the base platform on a tablet or smartphone, with all its processing power, sensors, interface wizardry, and connectivity, and just add your idea or IP in the form of an app?

Third, it's all about the cloud now, and not just for IT services. As TI's Gene Frantz points out in his take on the cloud in this issue's cover story, opportunities abound for designers to innovate within what Frantz calls the "clutter" around the cloud. Read on if you're stuck for ideas on where to focus next.

The first three implications lead to the fourth: analog. While the layoffs across the analog industry may indicate otherwise, analog is hot. If you're an engineer with a solid background in analog design and an understanding of software and analog design software tools, prep your resume. Heck, we're even in the process of hiring a full-time analog designer right now here at UBM Tech. We're looking for an LED engineer, too, by the way.

So, while it's been a crazy year, you've not stopped doing what you do: identifying opportunities and engineering the best paths to leverage them. We've had a bit of fun this year, too, relaunching EDN.com and spotlighting all the conversations and contributions you have offered over the year.

In recognition of those contributions, Linear Technology has kindly partnered with us to offer $5,000 to the winner of the 2012 Jim Williams Contributor of the Year Award, in recognition of the person who best embodies what contributing to the community is all about. We look forward to announcing the winner early in 2013 as part of our ACE Awards at DESIGN West.

In the meantime, from myself and the *EDN* staffers you've come to know even better in the past few months—Rich Pell, Suzanne Deffree, Amy Norcross, Steve Taranovich, Stephen Evanczuk, Carolyn Mathas, Jessica MacNeil, Janine Love, and Diana Scheben—have a great holiday and a peaceful and prosperous New Year. **EDN**

Contact me at patrick.mannion@ubm.com.

EDN

pulse

INNOVATIONS & INNOVATORS

DSOs, MSOs let you use your tablet for display, control

The list of features embodied in Agilent Technologies' InfiniiVision 4000 X-Series of DSOs (digital storage oscilloscopes) and MSOs (mixed-signal oscilloscopes) raises the bar for a class of instruments that has seen a steady rise in capabilities.

The 16-model series, whose members Agilent says are fully upgradable, comprises two- and four-analog-channel units with bandwidths of 200 MHz to 1.5 GHz. The MSOs add 16 digital channels, each with a maximum sample rate of 1.25G samples/sec and a memory depth of 2M samples. US prices range from $5600 to $22,000.

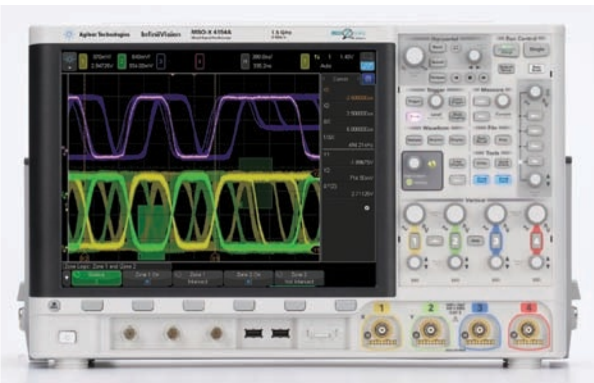
With all analog channels active, the maximum real-time sampling rate is 2.5G samples/sec. In the interleaved mode, in which only half of the channels are active, the maximum rate is 5G samples/sec, and memory depth is 4M points. A standard feature is the ability to segment memory to capture, in one acquisition, multiple iterations of short-duration signals. The scopes also incorporate the manufacturer's proprietary MegaZoom IV technology, with which the instruments can capture 1 million waveforms/sec, a key to finding anomalous signals that occur only infrequently. To avoid aliasing (display of nonexistent components in signals that contain frequencies above half the sampling rate), most users will prefer to use the interleaved mode for viewing signals that have significant content above 1.25 GHz.

The scopes have an 800×600-pixel, 12.1-in. capacitive touchscreen that supports gestures, such as dragging panels to desired locations on the screen. The MSOs perform five functions: scope, logic analyzer, protocol analyzer, optional dual-channel 20-MHz waveform generator with arbitrary-waveform-generation capabilities, and optional three-digit DVM (digital voltmeter). All of the scopes incorporate a zone-touch trigger facility that lets you use the touchscreen to define rectangular zones containing waveform features on which you want the scope to trigger.

The feature with the biggest wow factor, however, is likely to be the ability to use a device such as an Apple iPad or any tablet that uses Google's Android OS in place of the scope's own touch-sensitive screen and many of the instrument's front-panel controls. You connect the tablet to the scope via Wi-Fi; a wired connection would only get in the way.

Imagine working with a scope on a complex setup and being unable to get close enough to the scope's screen to observe tiny waveform details. With these scopes, you can tilt back in your chair, tablet in hand, and get as close a look as you want.**—by Dan Strassberg**

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



The 200-MHz- to 1.5-GHz-bandwidth DSOs and MSOs in Agilent's moderately priced 4000 X-Series have a capacitive touchscreen that supports gestures, but users can also use an iPad or Android tablet.

TALKBACK

"It's all very well to look back to superannuated circuits, but it's ultimately a fool's game. Even if a useful 40-year-old circuit were discovered, it would have to be shoehorned into modern devices and seriously tweaked to meet modern performance goals."

—Commenter atemp, responding to the Outside the Box blog post "Forgotten circuits (that should be brought back)," at www.edn.com/4401105. Add your own comment.

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NATIONAL INSTRUMENTS

Microchip elevates HMI design with e-field-based 3-D gesture-recognition chip

Microchip Technology Inc unveiled its GestIC gesture-based noncontact technology with the recent announcement of what it says is the first electrical-field-based 3-D gesture-controller IC, the MGC3130, enabling a new class of noncontact user interfaces. Based on technology acquired with Microchip's purchase earlier this year of Germany-based Ident Technology, the MGC3130 offers always-on gesture recognition with minimal power requirements, permitting its use in battery-powered mobile and portable designs.

At its most basic level of operation, the MGC3130 can detect motion at 200 samples/sec and 150-dpi resolution within a sensing area defined in the x-y plane by sensing electrodes and extending into the z plane from 0 to 15 cm above the sensing area. Beyond that basic, "3-D touchpad" capability, the MGC3130 uses its on-chip software library to analyze its acquired x/y/z motion data and deliver a real-time stream of recognized 3-D gestures to a host MCU.

Using external electrodes and the host MCU, the MGC3130 combines both hardware and software to offer a complete 3-D gesture-recognition solution with minimal external components. Delivered in a 5×5×0.9-mm, 28-lead QFN package, the mixed-signal device integrates a signal-processing unit, 32-kbyte flash, 12-kbyte RAM, and one transmit and five receive channels.

The MGC3130 offers I²C and SPI links for streaming sensor x/y/z data or post-analysis gesture information to the host MCU. The chip consumes 9 μA in deep-sleep mode, 45 μA in programmable self-wakeup mode, and 30 mA in processing mode (all typical values at 3.3V).

Tx signal generation uses frequency hopping between 70 and 130 kHz to find the optimal operating frequency in the presence of noisy environmental conditions. Each of the five identical Rx channels includes a signal-conditioning circuit that filters and amplifies the analog signal before driving it to a dedicated ADC.

At the heart of the MGC3130's implementation of the GestIC technology, Microchip's on-chip Colibri software performs sensor-data analysis and gesture recognition. Stored in the MGC3130's 32-kbyte flash, the Colibri software library uses a hidden Markov model algorithm—similar to the method used in voice recognition—for recognizing gesture patterns.

The MGC3130 combines both hardware and software to offer a complete 3-D gesture-recognition solution with minimal additional external components.

The initial release of the Colibri library identifies predefined hand gestures, including flick, circular, and symbol gestures (such as a "check mark" hand movement).

On-chip hardware- and software-based power-management features combine to enable "always on" gesture detection while maintaining low-power operation for battery-powered applications. In this method, called approach detection, Colibri uses the device's built-in self-wakeup mode to alternate between sleep and scan operation. When an object in the e-field exceeds specified threshold values, the MGC3130 will switch to processing mode and wake up the host MCU as needed.

Within the approach-detection sequence, the device performs an approach scan, typically requiring only one Rx channel to minimize power consumption. Engineers can set the time between approach scans, typically in a range from 20 to 150 msec for most applications. Although the device automatically handles temperature compensation, the MGC3130 can also perform a calibration scan, which is required for applications using basic x/y/z position data. Here, the device activates several Rx channels to calibrate sensor signals. To reduce power consumption, engineers can reduce the interval between calibration scans during periods with low user activity.

For MGC3130 evaluation and development, Microchip offers the Sabrewing Single-Zone Evaluation Board, which contains MGC3130 reference circuitry and two sets of selectable frame electrodes (5 and 7 in.). The development kit also comes with Microchip's Windows-based Aurea control software, which includes MGC3130 real-time sensor data display, 2-D and 3-D visualization of position, visualization of recognized gestures, AFE parameterization, and a GestIC library loader.

Microchip has provided a video demo of GestIC technology and the MGC3130 in action, viewable from the online version of this article at www.edn.com/4401197.

Samples of the Microchip MGC3130 are available now, and volume production is expected in April 2013, with high-volume pricing at $2.26 each. The Microchip Sabrewing MGC3130 Single Zone Evaluation Kit is available now for $169. The Aurea graphical user interface is available now via free download.

—by Stephen Evanczuk

▷**Microchip Technology**, www.microchip.com

DILBERT By Scott Adams

GainSpan simplifies wireless audio with audio app dev kit

GainSpan Corp, a specialist in low-power embedded Wi-Fi for the Internet of Things, is offering an audio ADK (application development kit) for integrating audio-streaming services into end products based on GainSpan Wi-Fi modules.

The audio ADK is a complete reference design that promises to accelerate time to market—while allowing flexibility of design and customization—for products that deliver music and live audio over Wi-Fi. With the ADK, users can stream audio (MP3 format or real-time voice) between a Wi-Fi-enabled device and an iOS-based smartphone.

The kit includes an audio application board, complete hardware-design package, and software suite with reference source code for the GainSpan audio embedded firmware and iOS-based mobile applications.

The kit includes an audio application board, complete hardware-design package, and software suite.

An audio application evaluation kit is also available; the kit provides a binary version of the software and can be used to demonstrate various application use cases.

The audio board features the GainSpan Wi-Fi module, which communicates with an audio codec chip over the SPI bus; a microphone; an amplifier to drive external speakers; and a walkie-talkie button. The board has line-in ports to connect to external audio sources and line-out ports for connecting to external speakers or headphones, a WPS button for easy setup of the wireless network, serial flash for storage of custom Web pages and/or backup firmware, and status- and mode-indicator LEDs.

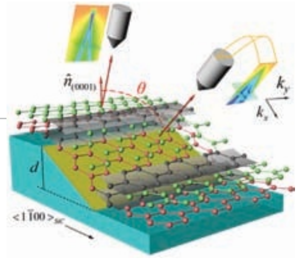
The embedded software that runs on the Wi-Fi module offers complete Wi-Fi functionality, including the entire networking stack and services, wireless security, and provisioning software.

> ADK users can stream audio between a Wi-Fi-enabled device and a smartphone.

The audio ADK can be used with the GainSpan GS1500M 802.11b/g/n solution or the GS1011M, an ultralow-power 802.11b solution for battery-operated devices. It's available now at $3000. The evaluation version of the kit is available for $250.—**by Clive Maxfield**

▷**GainSpan**, www.gainspan.com

Nanofabrication yields usable bandgap for graphene-based electronics



The diagram shows the experimental geometry of measuring graphene in silicon-carbide trenches. The measured electronic bandgap in the researchers' material exceeded predictions.

Georgia Institute of Technology researchers, working with a team from French national synchrotron facility Soleil, have fabricated graphene structures on nanometer-scale "steps" etched into silicon carbide to create an electronic bandgap that would be suitable for room-temperature electronics.

The researchers reported a measured bandgap of approximately 0.5 eV in 1.4-nm bent sections of two-layer graphene nanoribbons. They are uncertain why the nanoribbons become semiconducting as they bend to enter the roughly 20-nm-deep steps cut into the SiC wafers, but they point to lattice strain and electron confinement as likely factors.

The team used e-beams to cut trenches into SiC wafers and then used photolithography to grow tens of thousands of graphene ribbons across the steps. Confirmation of the bandgap came from angle-resolved photoemission spectroscopy measurements made at the synchrotron facility in France. Theorists had predicted that bending graphene would create a bandgap in the material, but the measured bandgap exceeded the predictions.

The technique could open the door to fabrication of all-graphene ICs without the need for interfaces that introduce resistance, according to the researchers. On either side of the semiconducting section of the graphene, the nanoribbons retain their metallic properties.

"We can make thousands of these trenches, and we can make them anywhere we want on the wafer," says Georgia Tech professor Edward Conrad. "This is more than just semiconducting graphene. The material at the bends is semiconducting, and it's attached to graphene continuously on both sides. It's basically a Schottky-barrier junction." By growing the graphene down one edge of the trench and then up the other side, the researchers could, in theory, produce two connected Schottky barriers.

Next, the team will look to build transistors and other devices with the approach. They hope to get a better handle on what creates the bandgap and how to control it. "There are probably a range of heights in which we can affect the bend," Conrad says.

—by Diana Scheben

▷**Georgia Tech**, www.gatech.edu

VOICES

Hybrid instruments and RF over fiber, viewed from 30,000 feet

Jerry Lomurno founded Eastern OptX in 1996 and shepherded its rise to market leader in microwave delay lines based on fiber-optic technology. After leaving the US Air Force in 1968, Lomurno joined a General Electric calibration laboratory, where he perfected a technique for verifying the accuracy of surface fuses. Building on his passion for microwave test, he founded Eastern Instrumentation of Philadelphia in 1972 and later founded EOX Sales; both manufacturers' reps today represent tier-one test vendors. In an interview for a new *EDN* series, Profiles in Test (www.edn.com/4399298), the Eastern OptX president shared his vision for hybrid test gear and RF-over-fiber installations in avionics, described the developments in his field that have surprised and sometimes frustrated him, and offered advice for new engineers.

Why did you get into this market?

A It all started with the Air Force in the late 1960s. They determine what your aptitude is, so they figured it out for me and set me up with radar. Before I knew it, I was in charge of a radar site on Long Island, where my job was to tweak the radar to make it work at its best.

In this position, I could buy all the test equipment I wanted; the frustration was that I wasn't able to calibrate range accuracy. I was dependent on sending an airplane out and having the pilot tell me where he was; then I would look at the screen to see if [the data] was the same.

At GE, I developed a technique to adjust for range accuracy on a missile's surface fuse, and I had to teach this technique to Air Force personnel. That's when I got the idea for the delay line: Wouldn't it be neat if we could have a signal go into an instrument and come out the exact same way, but at a later time?

Later, I started my own manufacturer's representative company, Eastern Instrumentation, because of my love of test equipment. In the 1990s, during the telecom boom, we found ourselves dabbling in the fiber-optic market. I realized that because of the low insertion loss of fiber-optic cable, we could spool many miles of cable and create the delay line that I'd been dreaming about for years. I founded Eastern OptX in 1996 and started delivery of the systems in 1997. It has taken off nicely.

What has surprised you over the years?

A Many engineers today believe everything can be solved with digital techniques. I'd like to point out that analog is still alive and kicking. There are some good things coming out of the digital era;

for example, virtual/synthetic instruments have done an incredible job of allowing you to reconfigure instruments.

I'm also surprised [by the] advances in microwave over fiber. Inspired by these developments, we are trying to marry the best of synthetic instruments with RF-over-fiber techniques to come up with interesting instruments for avionics and general-purpose test.

[For example,] a virtual instrument on the front end of an altimeter tester will give you range, but there are other things that you need to measure, such as phase noise, spurious, sweep linearity of the transmit signal, power levels, and receiver sensitivity. A good front-end virtual instrument in front of the delay simulation would be a winner, especially in the development labs.

What did you think we'd be able to do by now that we still can't?

A The first has to do with RF-over-fiber adoption. We can do some interesting things with RF over fiber, like take one fiber and route 16 or more RF signals over it using WDM technology. That could eliminate 16 RF cables, reducing the weight and cost of a military system. The frustrating thing is that the prime contractors and DOD are reluctant to pull out the coaxial cable and replace it with fiber.

Second, in the 1980s, Al Schwartzman, a visionary at Lockheed, predicted that all the signal processing would be done right at the antenna, without need for downconversion. We still aren't quite there.

Third, you still can't measure RF power to any degree of accuracy. You can get a voltmeter to seven digits, but RF measurement for power is at 5% accuracy or worse. Engineers look at their power meters and report the results confidently, but when you really look at the accuracy it's at 4% to 5%. Power-meter vendors' spec sheets can be very misleading, so perhaps people think they are getting more accurate power measurements than they really are.

What's next for avionics test?

A The hybrid instrument: marrying a virtual instrument with analog techniques. This will require a lot of creativity. Also, you will see fewer six-foot-tall test racks that are three bays wide because so much will be in one instrument, and it will be software driven.

Advice for new engineers?

A I help grade the senior projects at a local university. These kids know how to make a computer do all kinds of things, but they don't have a good handle on analog. My advice is to take RF/analog courses. RF engineering is black magic, and most of us doing it have gray hair. This is going to be a problem.

Also, young engineers should take courses to improve their communication skills, both verbal and written. [When they present their projects], many seniors are not able to tell me what the thing does or why they invented it, even if it is a great project.

—interview by Janine Love

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BY HOWARD JOHNSON, PhD

Ground loops

I design audio circuits. My mentor taught me to avoid ground loops at all costs, yet in digital products I see a solid ground plane holding hundreds of circuits. Between boards, I see a web of ground-referenced connections shooting off in all directions. How can this possibly work?

—Silence Dogood,
Analog rules

Imagine two parts of an electronic system. When device **A** sends to **B**, a signal current flows between them. At the same time, an equal and opposite current, called the returning signal current, flows back to **A** through the power or ground system. Current always makes a loop in that way. A ground loop is a situation where there exists more than one path for the flow of returning signal current.

Audio designers like single-point ground networks. Such a network of ground connections has the topology of a tree, with one main trunk and many branches and sub-branches. None of the branches touch, so it contains no loops. In this type of network there exists only one ground path between any two devices. When **A** sends to **B**, the returning signal current disturbs the ground along that path, affecting everything that touches that path or branches from it, but does not affect devices connected to other parts of the tree structure (**Figure 1**). That property provides a measure of isolation between devices.

In **Figure 1**, what happens if **A** sends to **C**? In that case, returning signal current must traverse a big section of the main trunk, polluting almost everything in the structure. Single-point ground networks provide isolation only when communications remain localized to isolated sections of the network.

Suppose the main trunk of the ground system comprises 12 in. of #18 gauge wire having a dc resistance of 6.5 mΩ. Assume that an audio-frequency current of 1A (that's 8W into an 8Ω speaker) traverses the main trunk. The ground noise observed from one end of the ground wire to the other equals 1A×6.5 mΩ, or 6.5 mV. Compared with an audio reference level of perhaps 4V, the headroom in the circuit, defined as the difference between the standard reference level and the ground noise, equals a mere 56 dB—enough possibly for cheap consumer-grade audio, but not within a factor of a thousand of acceptable performance for high-end audio. Good audio equipment uses a single-point ground system *and* keeps disparate circuits confined to isolated sections of the tree.

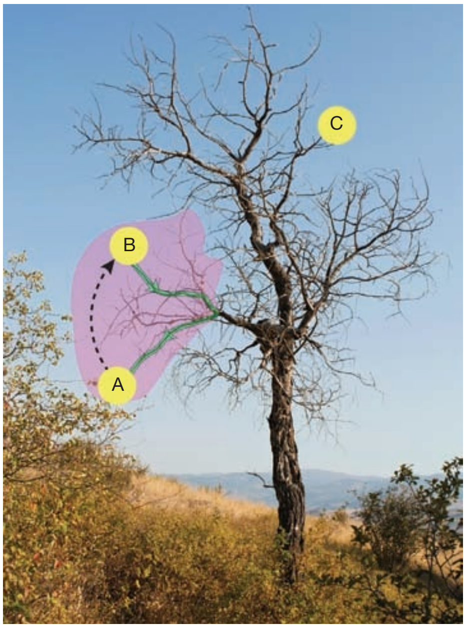

Figure 1 Communication from **A** to **B** pollutes all circuits that lie along the green path or branch from it; circuit **C** remains unaffected.

Single-point grounding provides isolation between localized regions.

In the digital world, the resistance measured from side to side across a solid-copper ground plane is on the order of 1 mΩ. A current of 25A induces ground-voltage differences on the order of only 25 mV or less. Digital circuitry easily tolerates that level of noise, so in most cases we simply do not need the complication of single-point grounding for ordinary digital logic.

In addition, all electronic systems suffer mutual-inductive coupling whose severity grows in proportion to the bandwidth of the signals involved. Because digital systems operate millions of times faster than audio systems, they suffer a correspondingly increased degree of inductive coupling, which, if not checked by the low-inductance properties of a solid plane, would incapacitate most modern digital electronics.

We must have solid planes to control inductive crosstalk in digital products; that is the planes' main function. EDN

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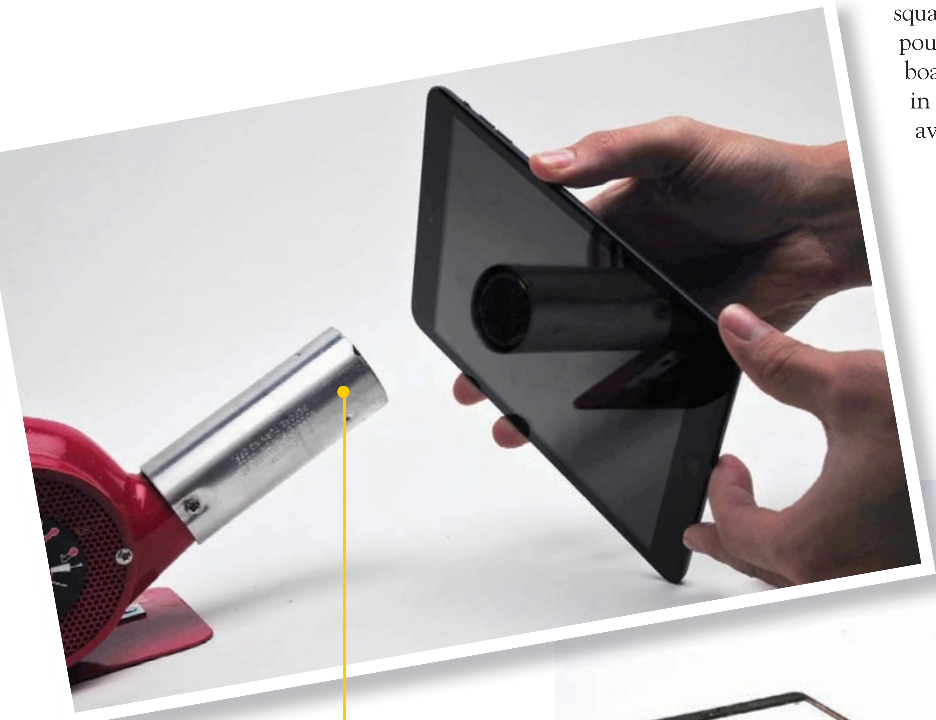
iPad mini: pint-sized iPad 2, or supersized iPod Touch?

Since its introduction of the iPad nearly two and a half years ago, Apple has held the lion's share of the tablet market. About a year ago, however, Amazon.com shook the tablet landscape by introducing the first sub-$200 tablet, the Amazon Kindle Fire, taking advantage of the vast library of online titles at its disposal. Soon after, search-engine leader Google parlayed its experience with previous electronics releases into the Google Nexus 7, another sub-$200 tablet featuring impressive specifications, such as a quad-core processor and a rich display that was unexpected at that price point. Subsequent upgrades of the upstart tablets, such as the Kindle Fire HD, caught consumers' attention.

With the 7-in.-tablet market growing at an exponential rate, it was only a matter of time before Apple addressed this product segment. Though Steve Jobs had argued that 7-in. tablets were "too big to compete with a smartphone, too small to compete with an iPad," on Oct 23 Apple CEO Tim Cook introduced the iPad mini.

Offering a 7.9-in. LCD display with 163 pixels/square inch, the iPad mini weighs in at 0.68 pound with a relative thickness of 7.2 mm. It boasts the same A5 dual-core processor found in the iPad 2, Wi-Fi accessibility, and the availability of an LTE-enabled model. Apple's



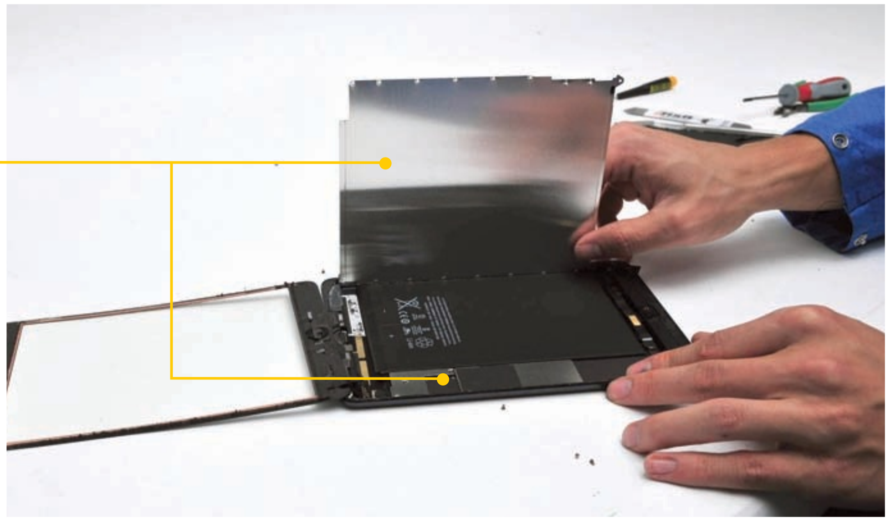
Using a heat gun softens the adhesive around the touchscreen. Once the glue is soft, the touchscreen removes rather easily.

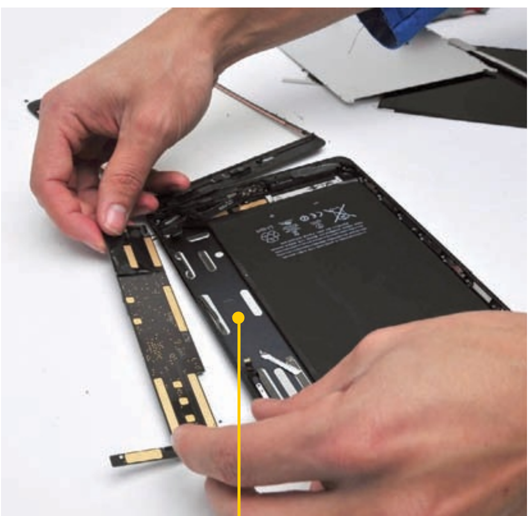
Separating the LCD panel from the metal enclosure requires the removal of screws.

designers drove the selection of the larger display size, believing the resultant bump up in screen area from 21.9 to 29.6 square inches would enhance the user experience of the iOS 6 operating system.

Looking at Apple's decision to forgo a Retina-based display and a faster processor from a functional perspective, one has to wonder whether the move simply was in line with Apple's concept of iterative improvements—whetting consumers' appetites for an iPad mini 2—or whether it was design driven, as a faster processor and more vibrant display might have put heavy demands on the 16.5-Whr battery and jeopardized the energy-conserving reputation of Apple products. The Apple pessimist will see the Pad mini as half an iPad 2; the Apple optimist will call the mini a supersized iPod Touch. The marketplace will decide whether the new tablet is worth its $329 price tag.

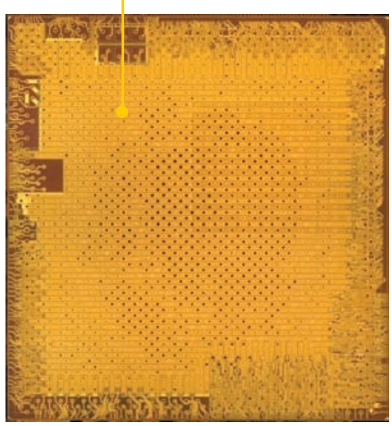
Once the metal housing plate of the LCD display is removed, the main battery and main board become visible. Apple claims 16.5 Whr and 10 hours of operation between charges for the iPad mini's battery, which it also says is the thinnest lithium-ion battery to date. Sizewise, however, the battery closely resembles that of the iPad 3.



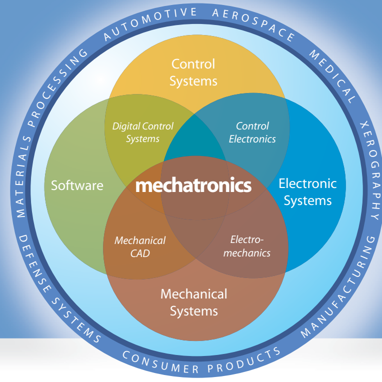


The main board is glued to the iPad mini's back, so the board's removal requires brute force.

The main CPU is the 32-nm Apple A5 applications processor, made by Samsung. Manufactured using a gate-first high-k/metal-gate process, this version of the A5 has a die with an area of 69.7 mm^2 and a thickness of 110 µm.



The Broadcom BCM5976, which has been found in the iPad 3, the MacBook Air, and the iPhone 5, has two sockets in the mini. Broadcom also scored a design win in the mini for its BCM4334 four-in-one combo wireless chip, which was also found in the Samsung Galaxy S3 and the iPhone 5.



Automatic code generation and Arduino

The combination is unbeatable for students and practicing engineers alike.

Kevin C Craig, PhD, is the Robert C Greenheck chairman in engineering design and a professor of mechanical engineering at the College of Engineering at Marquette University. For more mechatronics news, visit mechatronics zone.com.

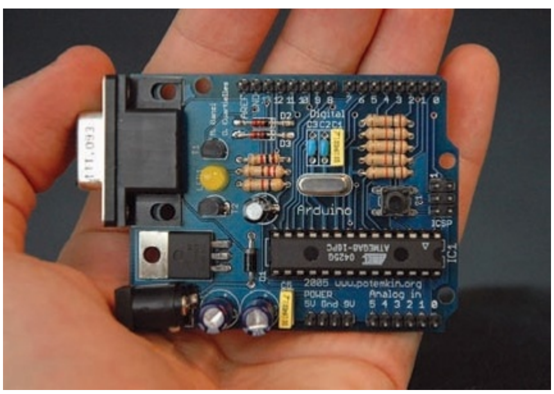
Two complementary concepts—automatic code generation and the inexpensive, open-source, single-board microcontroller—have reinvigorated innovation in engineering practice and education.

Automatic code generation from system block diagrams has been around for decades and is an entrenched way of developing embedded control systems and performing hardware-in-the-loop testing at many aerospace and automotive companies; today, it is rapidly moving into other industries. The Arduino microcontroller debuted in 2005 and has quickly become a favorite of inventors and students.

Computer programming and implementation can seem so out of place in engineering problem solving that engineers often relegate the tasks to a specialist. "Engineer programmer" is an oxymoron.

I have said, however, that the human, the computer tools (software and hardware), and the problem should all be in perfect harmony throughout the problem-solving process. The combination of graphical programming using block diagrams, automatic code generation from the block diagrams, and implementation on an easily understandable yet powerful microcontroller comes close to that ideal.

Honeywell observed in 2005 that the typical software process injects 100 defects, due to both design and coding errors, per 1000 lines of source code using manual processes. The company has automated software manufacturing through automatic code generation and has demonstrated the achievement of six-sigma quality—that is, not more than 3.4 defects per million opportunities. Northrop-Grumman, for its part, has fine-tuned the process of going from the desktop directly to flight code on flight hardware. Rapid prototyping and hardware-in-the-loop testing are now the rule, rather than the exception.



The Arduino open-source, single-board microcontroller is a favorite of inventors and students.

What could possibly excite an engineer or engineering student more than solving a real-world problem? Seeing one's solution implemented in hardware does precisely that.

While teaching model-based design and controls over the past 20 years, I have not seen a more exciting, effective, and accessible problem-solving combination than graphical block-diagram programming, as is done in the Matlab/Simulink environment, and automatic generation of C code for a microcontroller, as is done using the Arduino microcontroller with the Simulink Coder. Today, all manner of robots and self-balancing transporters are conceived, modeled, simulated, controlled, and virtually prototyped before construction, in a way that all engineers embrace.

Ours is an age of diminishing meaningful human interaction. A university engineering program's value, then, lies in demonstrating the importance of such interaction through faculty-student mentoring and education in the context of real-world, human-centered, team-based problem solving.

Automatic code generation and the Arduino microcontroller should be a part of that strategy from the beginning of an engineering student's career. Innovative concepts, expressed graphically for all to see and understand, automatically become real-time instructions for a computer, and then become real-world actions that make a difference. EDN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OPTIMIZING **OPERATING LIFE** FOR LED-BASED LIGHTBULBS

LED BULBS PROMISE 25 YEARS OF SERVICE, PROVIDED DESIGNERS MANAGE TEMPERATURE, RELIABILITY, AND DIMMING CONTROL. THE KEY TO SUCCESS IS THE DRIVER IMPLEMENTATION.

SCOTT BROWN • iWATT INC

Government regulations around the world that mandate the phaseout of incandescent lightbulbs are powering a paradigm shift to solid-state lighting technologies. LED lighting offers significant advantages over alternatives, especially as LED bulbs' lumens-per-watt performance increases and their cost per lumen declines.

A longer operating lifetime and a lower operating cost per watt-hour are among LED technologies' main benefits over the traditional incandescent bulbs they replace. The robustness of solid-state lighting technology, compared with the relative fragility of incandescent and halogen bulbs, is a key selling point with consumers. An incandescent bulb typically has a life expectancy of 1000 hours (**Reference 1**). LED bulbs, by contrast, promise 50,000 hours of operating life or longer (**Reference 2**) while consuming only approximately 20% of the power for the equivalent light output.

IMAGE: THINKSTOCK

If designers don't take the necessary precautions, however, LED lighting may fall short of its promise of letting the consumer go nearly 25 years without changing a bulb. The complexity and reliability of LEDs and their driver circuits, which must be compatible with legacy dimmer technology, are areas of concern that designers must address in order to maximize LED-based lighting systems' operating life.

LEDs require constant dc current at voltages well below the rectified ac line voltage for proper operation and thus need to be driven by a circuit that converts the standard ac line voltage down to a usable level. In order to make LED-based bulbs compatible with standard light sockets, the designer must integrate the driver circuit into the bulb. If not handled properly, such integration increases an LED bulb's potential failure mechanisms.

The legacy drivers previously available for LED bulbs required large numbers of external components, costly isolation components, and special design strategies to prevent them from causing long-term degradation of key components (such as electrolytic capacitors). Integration of the driver circuit now makes the bulbs susceptible to reliability issues, such as infant mortality or degraded MTTF (mean time to failure) rates.

MTTF, the measure of the amount of time until first failure, is normally calculated based on the number and type of components, using the FIT rates (failures in time, measured relative to 1 billion hours of operation) of each component in the circuit. Because the driver circuit transforms a high ac voltage (100V ac/220V ac) down to a dc voltage that can be used to power the LEDs, electrical isolation is necessary for safety reasons.

In a typical electrically isolated ac/dc converter, a discrete optoisolator, or optocoupler, provides feedback from the secondary side to the controller on the primary side by converting an electrical signal to light, sending that signal across an isolation barrier, and then converting it back to an electrical signal (**Figure 1**). Because optocouplers have higher FIT rates than semiconductor components, they reduce the MTTF rating for the overall circuit.

Additionally, the optocoupler's current-transfer ratio can change over time and temperature as a result of aging effects. Such variation can affect the loop stability of the power supply and thereby shorten the life of the LED driver circuit. Though many LED lamps and luminaires can operate at an elevated PCB temperature, designers must eliminate the weak links in order to achieve the desired long lifetime.

Figure 2 shows iWatt's primary-side digital control technology, PrimAccurate. The proprietary approach uses real-time waveform analysis to sense the LED current via the primary side of the isolation transformer, eliminating the need for direct feedback from the output while maintaining tight constant-current regulation for the LED string.

An additional benefit of the technology is internal feedback-loop compensation, which simplifies the design and reduces the external-component count. In particular, elimination of the optocoupler—the component with the highest FIT rate—increases the reliability of the LED driver circuit and thus improves the overall reliability of the bulb.

AT A GLANCE

- LEDs require circuit drivers that convert standard ac line voltage to usable dc current and voltage.
- In order to make an LED-based bulb compatible with standard light sockets without compromising operating life, the designer must integrate the driver circuit in a way that does not increase the bulb's potential failure mechanisms.
- Because the driver circuit transforms a high ac voltage down to a dc voltage, electrical isolation is necessary. One approach uses real-time waveform analysis to sense the LED current via the primary side of the isolation transformer, eliminating the need for direct feedback from the output while maintaining tight constant-current regulation for the LED string.
- A two-step approach to driving LEDs uses an initial boost converter to provide the necessary impedance to load the dimmer—reducing potentially damaging inrush current—and to bring the input current back into phase with the line current, improving the overall power factor of the circuit.

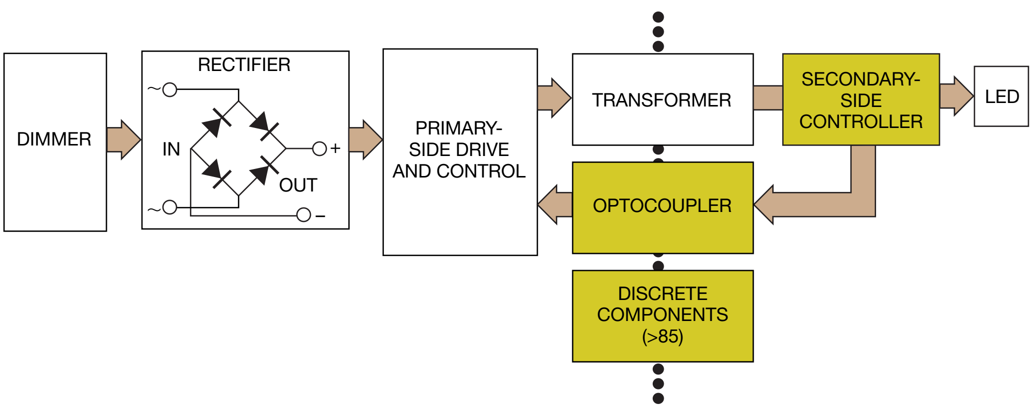

Figure 1 The feedback circuit in a typical offline LED driver circuit requires secondary-side regulation via an optocoupler and many discrete components, resulting in a large bill of materials and a lower overall lifetime for the LED driver.

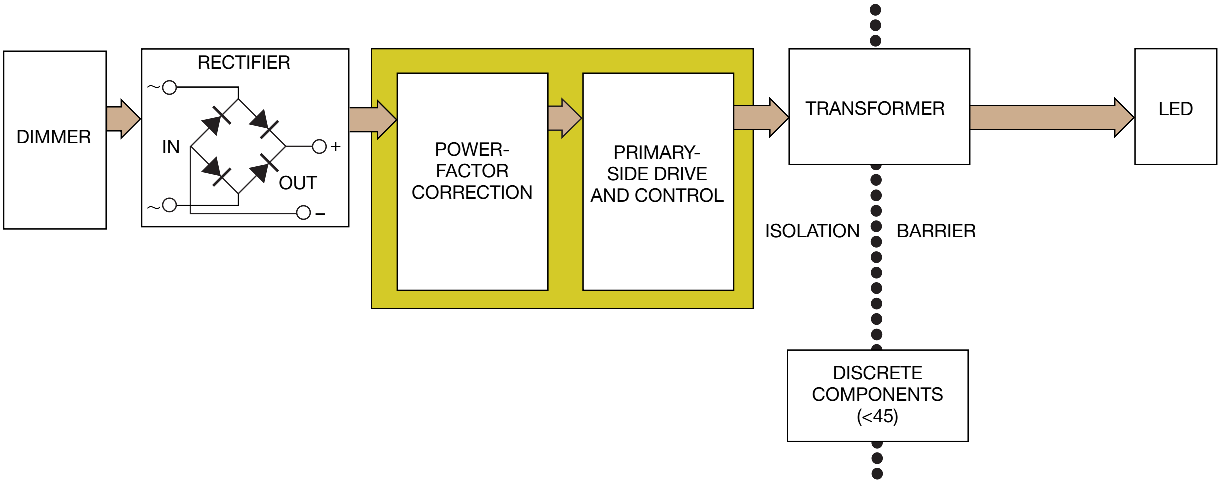

Figure 2 PrimAccurate primary-side digital control architecture reduces the LED driver circuit's external component count and eliminates the need for an optocoupler, thereby improving solid-state-lighting bulb reliability.

The LED bulbs being manufactured today must also be backward compatible with the lighting technology already in place in family homes. Dimmers provide ambience in the home, and one benefit of LED lighting as an alternative to incandescent bulbs is that LEDs can easily be dimmed to match incandescent-bulb characteristics more effectively than can compact fluorescent bulbs.

The LED driver, however, needs to manage several factors to support the dimmer function, including dimmer detection, compatibility, and light flicker. To optimize the operating life of the lighting system, a concern is the durability of the dimmer when used with an LED driver.

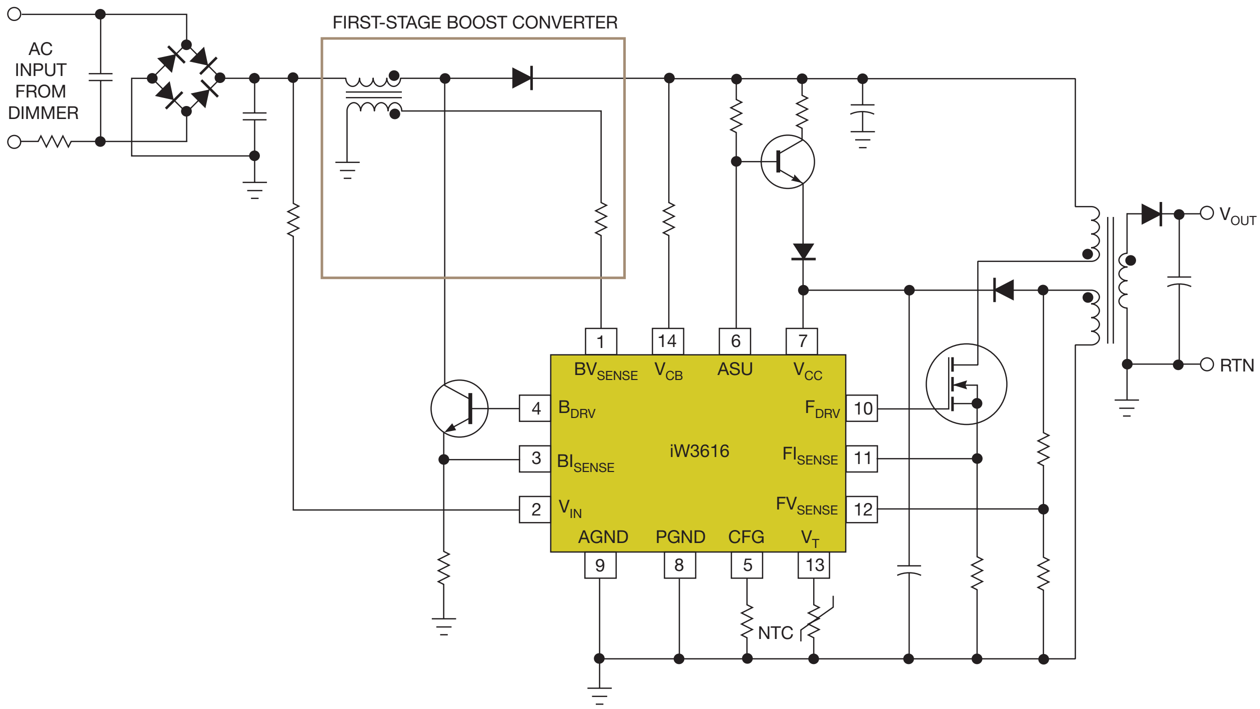

Figure 3 The circuit in this example of a two-stage, high-power-factor-correction LED driver (the iW3616) uses an NTC resistor to provide LED overtemperature protection and derating, thus extending bulb lifetime.

The typical Type A-lamp incandescent bulb is purely resistive. When a dimmer is used to control the brightness of a traditional A-lamp, the resulting load on the dimmer is also purely resistive, and the current through the dimmer is constant and controlled.

An LED driver is effectively a current source, however, and its input looks highly capacitive to the dimmer, which on startup will see a large spike of inrush current to charge up that capacitive load before stabilizing the current at a much lower level. This inrush current is potentially damaging to a standard dimmer and must be reduced to avoid compromising the dimmer-circuit lifetime.

One solution to the dimmer inrush problem is to use a two-step approach to drive the LEDs instead of using a straight flyback converter, which has highly capacitive input impedance. In the two-step approach, the initial stage increases the impedance to a manageable level and thereby reduces the inrush current, providing the safety and protection necessary for the dimmer.

The iWatt iW3616 LED driver (**Figure 3**) uses a two-stage approach with an initial boost converter whose function is twofold: first, to provide the necessary impedance to load the dimmer, reducing the inrush current, and, second, to bring the input current back into phase with the line current, improving the power factor of the overall circuit. The approach not only enables a longer-lasting dimmer but also can provide a high power factor. The digital control block that provides the primary-side control in the iW3616 contains algorithms for detecting and operating with virtually all dimmers available in the market. The same algorithms control the boost converter, optimizing the circuit's dynamic input impedance to increase the power factor and reduce the inrush current.

AN LED DRIVER IS EFFECTIVELY A CURRENT SOURCE, AND ITS INPUT LOOKS HIGHLY CAPACITIVE TO THE DIMMER.

An equally important concern when optimizing the operating life of LED-based bulbs is the expected lifetime of the LEDs themselves. As is the case for any semiconductor component, the higher an LED's operating junction temperature, the shorter its life expectancy. Electrolytic capacitors also have a life expectancy that is dependent on operating temperature.

One solution is to derate the current driving the LED and simply use more LEDs to generate a specific light output, resulting in less heat generation per LED and therefore a lower junction temperature. The approach extends the bulb operating life, but at a trade-off of a higher solution cost due to the higher number of required LEDs. Further, it does not accommodate external factors, such as the physical properties of the light fixture, that may contribute to higher-than-expected heat.

An alternative method is to optimize the maximum LED current by establishing a maximum junction temperature that would trigger a reduction in the LED current in order to prevent degradation. Digital LED driver controllers are available that implement a two-stage protection scheme, letting the designer use a single external device to program the maximum LED temperature. An NTC (negative temperature coefficient) resistor is placed physically near the LED cluster to act as a temperature monitor. The NTC resistor connects to the LED driver IC, which uses the temperature-feedback device to protect the LEDs.

The iW3616 shown in **Figure 3** uses an NTC device to protect the LEDs in an LED bulb. If the LED cluster reaches the programmed maximum-temperature threshold set by the NTC component, the controller reduces the LED current in 10% increments until the temperature stabilizes. If the temperature drops, the LED current steps back up to its maximum programmed value in equal and opposite 10% increments, with an appropriate amount of hysteresis to prevent oscillations. If a major failure event occurs, a fail-safe mode reduces the current through the LEDs to 1% of programmed output current. This overtemperature-protection topology offers flexibility in the design of the LED bulb and peace of mind that the bulb will be fully protected under extreme operating conditions.

LEDs have evolved to a point at which cost and light output have equalized across competitive solutions, and LED lighting is gaining momentum as a realistic replacement for incandescent lighting in the home. The key to the success of this new technology is in the implementation of the driver. Besides the obvious parameters of efficiency and cost that every designer strives to optimize, the additional factors of temperature, dimming control, and reliability are the true keys to guaranteeing the long operating life promised by LEDs. EDN

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AUTHOR'S BIOGRAPHY

Scott Brown, senior vice president of marketing at iWatt Inc, joined the company in October 2011 with more than 20 years of experience in the analog semiconductor industry. Before joining iWatt, Brown held marketing and management positions at National Semiconductor, Micrel, On Semiconductor, Catalyst Semiconductor, and Semtech. He holds a bachelor of science degree in electrical and electronics engineering from Brunel University (London).

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HOT TECHNO

LOOKING AHEAD TO 2013

LOGIES

This past year certainly saw its share of high-profile technology news. Headline-making items included the introduction of various consumer tablets and smartphones; the success of the Mars Curiosity rover; the discovery of the "God particle"; the release of the $25, credit-card-sized Raspberry Pi computer; and even a high-tech-enabled human base jump from the edge of space.

But there was also much more happening on the technology front. Here, *EDN* editors and guest contributors examine some of the hot trends and technologies in 2012 that will shape next year's technology news.

MOBILE TOUCH PROLIFERATES: IS UI DESIGN KEEPING PACE?

Rich Pell, *Executive Editor and Chief Technical Editor*

You know a technology is "hot" when tech giant Microsoft jumps on board, as it did recently with its Surface tablet computer (**Figure 1**). In this case, the hot technology isn't the tablet form factor—certainly a technology worthy in its own right—but the touch interface it sports.

There's no question that multitouch technology, typically in the form of capacitive touchscreens, has fueled the explosive growth in mobile devices. Microsoft's recent entry promises to further the trend, as touch-enabled products become available that blur the lines between PCs, notebooks, and tablets.

But it's not just about the hardware; a touch device's operating system and applications need to be designed with that touch interface in mind. Apple's elegant software user interface in its original iPhone largely achieved that five years ago, letting users easily and intuitively interact directly with their devices—and apps—in a new and powerful way.

So it's surprising to see so many new apps sporting UIs that look as if they were designed for a mouse, or featuring virtual representations of traditional hardware interfaces. The latter, of course, can make sense in cases where there may be no real alternatives—such as with a computer keyboard for inputting text, or a music keyboard for playing a virtual instrument—but they're hardly ideal.

What's with the continued use of virtual knobs for controls, for example? These are still prevalent in a lot of audio and music production apps (**Figure 2**). There's no question that their function is intuitively understood by everyone, but trying to manipulate a 2-D virtual knob effectively on a touchscreen is a different matter altogether. It's easy to imagine better touch design alternatives (**Figure 3**).

It's understandable why many developers may feel a need to mimic traditional hardware interfaces or use familiar mouse-driven-style interfaces in their applications. At first glance, these are comfortable and intuitive approaches for developers and end users alike, and—in the case of the former—can often look "cool." But they are not necessarily optimal for the touchscreen interface—often far from it—and certainly don't take full advantage of its potential.

Incredibly, Apple itself is at least partly to blame, having encouraged the use of "skeuomorphic" design—the idea of incorporating design elements of an older product into a new design, even though they no longer serve any purpose other than to provide a familiar and comfortable look. An example would be an e-book app that presents its content in a virtual paper book interface, complete with a folded "crease" down the middle and stacked "page edges" on either side.

This is a classic case

Figure 1 The Surface Windows touchscreen tablet from Microsoft is receiving praise for its hardware design; on the software/interface side, not so much.

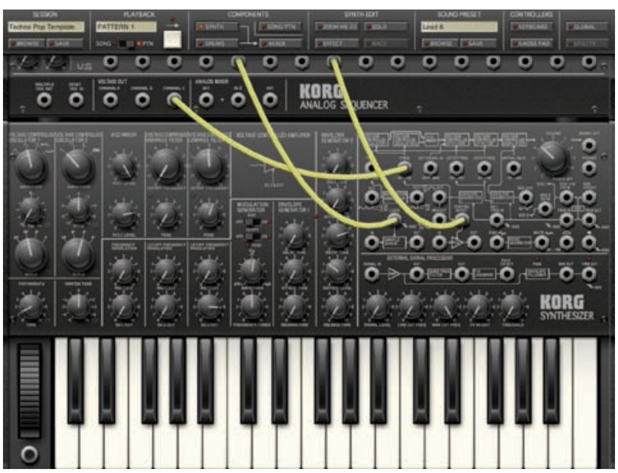


Figure 2 Though the use of virtual knobs (and cables) in this iPad version of a classic hardware analog synthesizer—the Korg MS20—is understandable, their continued use in many new synthesizer and music apps seems far less justifiable.

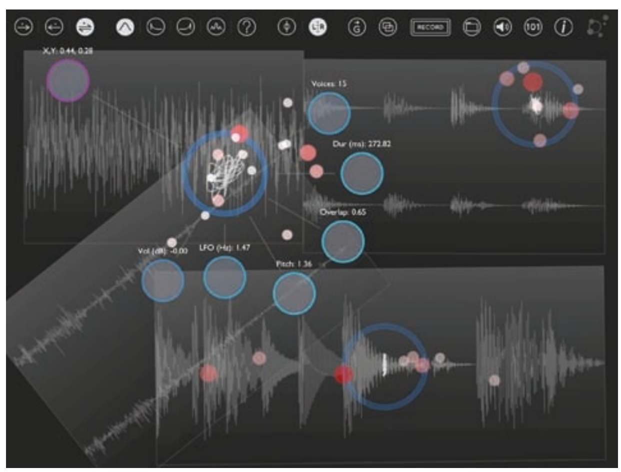


Figure 3 The Borderlands iPad granular synthesizer offers a unique, multitouch interface designed to let users "engage with sonic material on a fundamental level, breaking free of traditional interaction paradigms such as knobs and sliders."

Figure 4 Wireless charging is becoming an increasingly attractive option as battery-powered mobile devices and their associated wired charging accessories proliferate.

of form over function—an area in which marketing-centric Apple has stumbled in the past—and, ironically, a path away from Apple's trademark elegance and simplicity. Thankfully, a recent shake-up in Apple's executive ranks suggests we will see a renewed focus on cleaner, more functional UI designs from the company and, by extension, from app developers.

That's encouraging news for users of touch-based interfaces, and a sign that this hot technology won't be cooling down anytime soon.

Also watching:

- **Wireless charging.** Typically based on inductive coupling, wireless-charging technology—which enables devices to be charged by being placed on a charging surface (**Figure 4**)—has been used in some niche applications for some time. Now, an increasing number of wireless power solutions from major semiconductor vendors suggests that wireless charging may finally be catching on in the consumer market as mobile devices of various types proliferate.
- **The personal cloud.** Cloud-computing products and services aimed at individual consumers are changing the way we manage our data (**Figure 5**), whether it's through the use of public services, such as Dropbox or iCloud, or home NAS devices with cloud features that allow remote access. The trend is so obvious and unmistakable that it has led one research firm to predict the personal cloud will replace the PC as the center of our digital lives by 2014.

Figure 5 Enabled by products and services that allow us to store and access our data remotely, personal clouds promise to free us from many of the limitations of our mobile devices and PCs.

NEAR-FIELD COMMUNICATIONS TO GO FAR IN 2013

Suzanne Deffree, *Executive Editor and Chief Community Editor*

NFC, or near-field communications, has been around for 10 years, battling its own version of the chicken-and-egg question: Which comes first, the enabled devices or the applications?

The technology is there, yet there has been a major deterrent to NFC's market growth and consumer use: Why build into a device when no applications or services are available, and why offer applications or services when no devices have been built to utilize them?

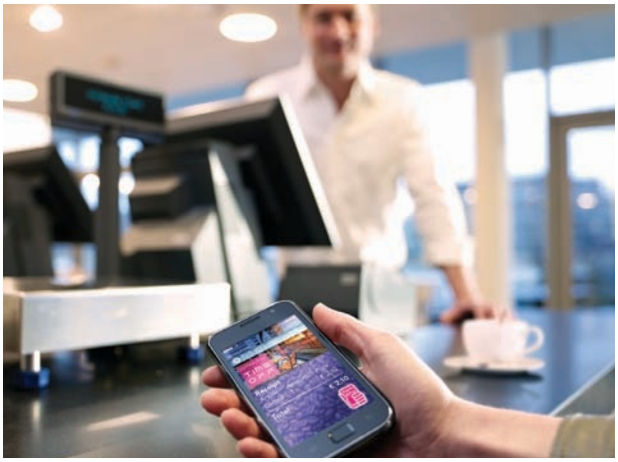


Figure 6 A consumer pays using an NFC-enabled mobile wallet, by far the most talked-about application of NFC.

In 2012, however, NFC started to break out of its shell. NFC-enabled devices rocketed up to 100 million shipped, a significant climb from 2010's 2 million devices sold. Estimates call for 300 million NFC-enabled devices to be sold in 2013 and for the billion-device mark to be reached in 2015.

To date, most such devices are smartphones. With many smartphone makers in the Android and now Windows camps getting on board with NFC, leading OEMs including LG, Nokia, and Samsung have begun designing NFC into products.

Notably, Apple left NFC out of its iPhone 5. As NFC Forum director Debbie Arnold observes, however, "Apple has about 15% global share of the market. With 85% leaning toward NFC … it's not something that keeps us up at night."

The NFC Forum formed in 2004, when the very short-range (5-cm) communications technology was in its infancy. Now, the forum's more than 170 member companies showcase an extensive base of semiconductor industry players, including Broadcom, Intel, National Instruments, NXP, and Texas Instruments.

Figure 7 NFC offers retail interaction by tapping a device to a sign or display, in this case to download a gaming demo.

In November, the forum introduced the NFC Controller Interface specification, which defines a standard interface within an NFC device between an NFC controller and the device's main application processor. The group expects the specification will help broaden the availability and eventually encourage the price competitiveness of NFC.

Figure 9 NXP's PN65 featuring an NFC radio controller and an embedded Secure Element is designed into such devices as the Google Nexus 7 tablet.

Now that the devices and specifications are hatching, flocks of applications and services are on their way. In fact, more have arrived than many consumers realize. Beyond the mobile wallet (**Figure 6**), NFC is seeing use in Bluetooth pairing and applications in various transportation terminals, interactive signs and displays, identification, and peer-to-peer exchange.

What remains an obstacle is educating consumers on yet another wireless communications technology that does not compete with but is complementary to Wi-Fi and Bluetooth. Samsung, for one, is playing up interactive displays and peer-to-peer sharing in advertisements for its Galaxy S III NFC-enabled phone by showing users scanning posters for free songs or tapping phones together to share contact information, music, and files (**Figure 7**).

"Some of these things, in creating physical shortcuts and ways for mobile applications to interact with physical retail establishments, start to unlock the fact that there are hundreds of millions of customers who have these devices," says Jeff Miles, Samsung's vice president of mobile transactions, which includes the company's identification business. "Tags and the different applications are an area that can explode. It's relatively simple to implement and is straightforward for consumers. Tap, and something magical happens."

Beyond smartphones, NFC is starting to be seen in other consumer goods such as tablets, PCs, printers, and even microwaves. Beyond the electronics vertical, sectors such as health care are starting to explore ways to utilize NFC.

"We often hear about the mobile wallet," says Arnold, "but NFC is going to go down so many different paths. Once we get over this hump, we are going to see this take off in a lot of different verticals."

Figure 8 3-D printers such as the affordable, easy-to-use Cube home printer could allow consumers to print many household products less expensively than they could buy them.

Also watching:

- **3-D printing.** This DIY maker technology has been around for some time, but now 3-D printers are becoming affordable for individuals, as well as lower-level educational institutions, to purchase for their workspaces (**Figure 8**). With everything from car parts to vital organs being talked about as possibilities for 3-D printing, we'll be seeing much more on this technology in 2013.
- **Inexpensive tablets and e-readers.** The newest iPad may start at $500, but not every tablet needs the shine Apple puts on its products (**Figure 9**). Harking back to ideas pushed forth by the XO laptop—part of the One Laptop per Child effort, which sought to provide low-cost technology to the masses—sub-$100 tablets and e-readers will offer more alternatives to pricey iPads and even to less-expensive Kindles.

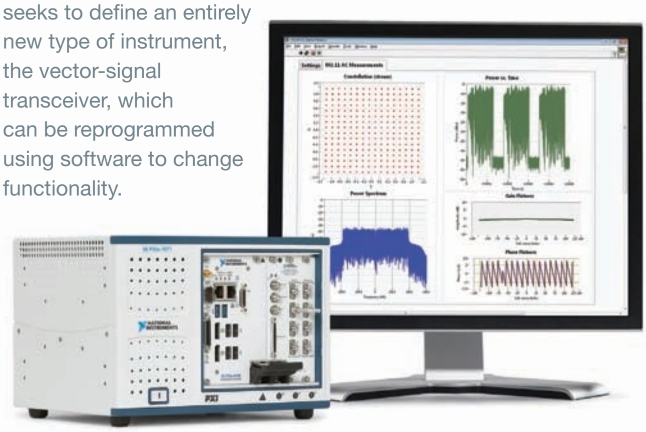
TEST IT YOUR WAY

Janine Love, *Editor in Chief,* Test & Measurement World

This year, as I walked the trade-show floors and met with test and measurement equipment vendors at their sites and mine, I was impressed by the increased capabilities of "alternative" test equipment. This category includes what has been dubbed virtual or software-defined instrumentation, providing programmable functionality that can change an instrument from an oscilloscope to a spectrum analyzer at the touch of a button. Product examples are available from such companies as National Instruments, Aeroflex, and Geotest.

This new class of instruments seeks to leverage the hardware that multiple traditional instruments have in common, using software to define the test functionality as needed. In addition to switching instrument functionality, some of the latest instruments incorporate FPGAs to speed test time and let designers define test setups, protocols, and triggers on the fly.

Figure 10 NI's PXIe-5644R seeks to define an entirely new type of instrument, the vector-signal transceiver, which can be reprogrammed using software to change functionality.



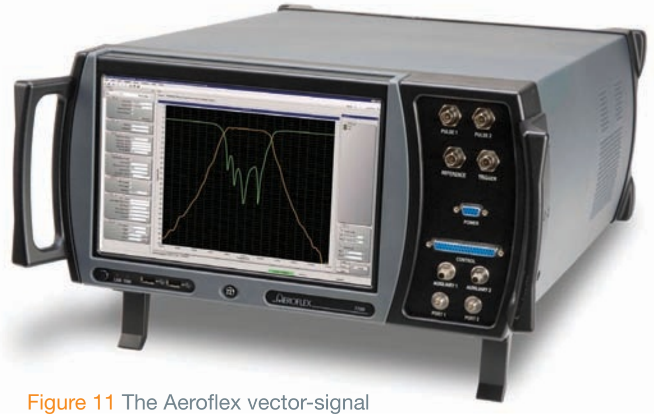


Figure 11 The Aeroflex vector-signal generator emulates a spectrum analyzer, vector network analyzer, oscilloscope, power meter, frequency counter, noise-figure meter, and microwave transition analyzer.

Never before have you had so much flexibility to define your test, your way, to get the job done.

For example, National Instruments staked a firm claim in software-defined instrumentation with the PXIe-5644R vector-signal transceiver (**Figure 10**). Introduced in August, the instrument combines the functionality of a vector-signal analyzer, vector-signal generator, and high-speed digital I/O in a single, three-slot PXI (PCI Extensions for Instrumentation) module. With an FPGA on board, the PXIe-5644R lets users modify software and firmware using NI's LabVIEW software.

Aeroflex has been working with synthetic instruments for more than 10 years. Some of its solutions, such as the 7700 series, are designed to speed production test by providing signal generation, measurements, and DUT control in a single unit (**Figure 11**).

Strides in FPGA technology are responsible for much of what is making programmable instrumentation possible. Geotest has developed a user-programmable FPGA-based product line that includes the GX3700 and GX3700e (PXI and PXI Express, respectively) instruments, which use Altera's Stratix III FPGA. The Altera device supports SerDes data rates up to 1.2 Gbits/sec, offers digital I/O clock rates of 700 MHz, and features more than 45,000 logic elements and 1.836 kbits of memory (**Figure 12**). Expect the power of software programmability to enable a whole new breed of instruments in the coming years.

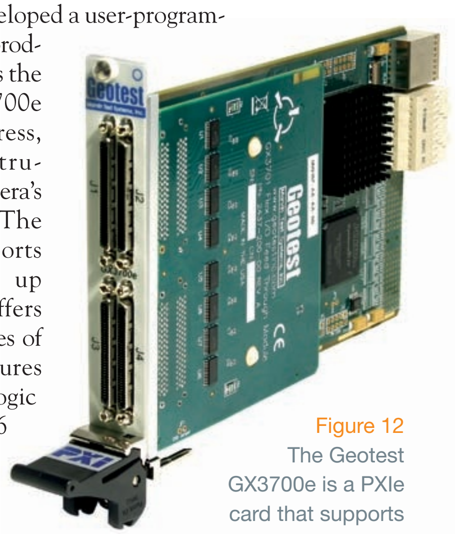


Figure 12 The Geotest GX3700e is a PXIe card that supports 160 I/Os for programmable instrumentation.

Figure 13 Tektronix has just introduced the H500 and SA2500 handheld spectrum analyzers, which display the live spectrum by respectively processing more than 2500 and more than 10,000 spectrum measurements per second.

Also watching:

- **Handheld test gear.** Surprising capabilities from handheld test equipment (**figures 13** and **14**) take advantage of new materials, innovation, and programmability to bring the high performance of benchtop instruments to bear at the top of a pole or the end of the line. This is truly not your father's handheld test instrument.
- **PXI.** The seemingly unstoppable force of the PCI Extensions for Instrumentation format continues to make inroads into new applications, from commercial to military, as evidenced by some of the latest PXI instruments from companies such as Aeroflex, Agilent, Geotest, National Instruments, and Pickering Interfaces. In many cases, the PXI format is combined with software-defined instrumentation, making for an impressive combination of test and measurement trends.

Figure 14 Agilent's FieldFox microwave vector network analyzer provides full two-port VNA measurements.

MORE-THAN-MOORE MEMORY GROWS UP

Brian Bailey, *Contributing Technical Editor*

Moore's Law may not be running out of steam, but it may be running out of money, as scaling to smaller geometries becomes more cost prohibitive. We also have an insatiable appetite for memory these days, but our tastes are changing from DRAM to nonvolatile memory—a market largely served by flash devices. Whereas DRAM can possibly scale down to 1 nm, we are already encountering floating-gate scaling problems for NAND flash. The answer to the scaling problem appears to be growing devices "up"; the question is how best to do it.

Three-dimensional die stacking uses a silicon interposer and TSVs (through-silicon vias) to connect the stacked dice electrically, allowing the integration of multiple, smaller dice—each processed using an optimal technology—within a package. Many memory manufacturers are already creating 3-D die-stacked chips in production quantities (**Figure 15**), and the technology's use for memories paves the way for its use elsewhere.

Indeed, we are already seeing the first general market utilization in FPGAs, using a slightly simpler construction;

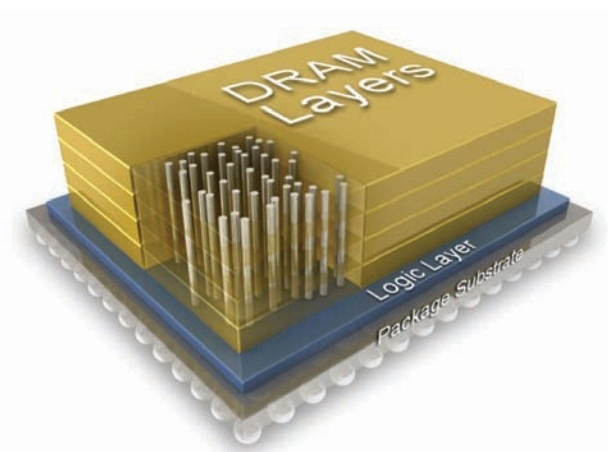


Figure 15 Use of 3-D stacking in memories such as this DRAM cube opens the door to the technique's use for other ICs.

the silicon interposer contains routing only and no active logic (**Figure 16**). This technology is likely to become mainstream within the next five years for stacking memory on top of processors.

Toshiba is pushing 3-D NAND processes with its p-BiCS (pipe-shaped bit-cost scalable) technology. Rather than stack multiple substrates and connect them using TSVs, the approach builds cells on top of each other to create U-shaped bit lines. Toshiba says the process becomes cheaper than traditional NAND processes when more than 15 layers are created.

Macronix is poised to unveil working 3-D NAND flash memory at sub-40 nm. The new architecture enables the use of a "staircase" bit-line contact formation method (**Figure 17**). The result is an eight-layer device with a word-line feature size of 37.5 nm, bit-line feature size of 75 nm, 64 cells per string, and a core array efficiency of 63%. The researchers say the technology not only is lower cost than

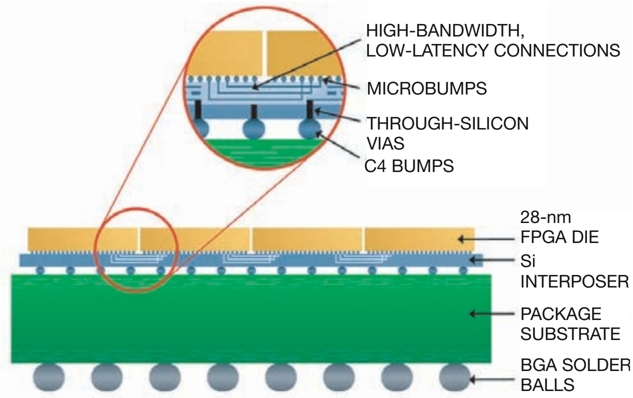


Figure 16 Die stacking in FPGAs uses a slightly simpler construction wherein the silicon interposer contains routing only and no active logic.

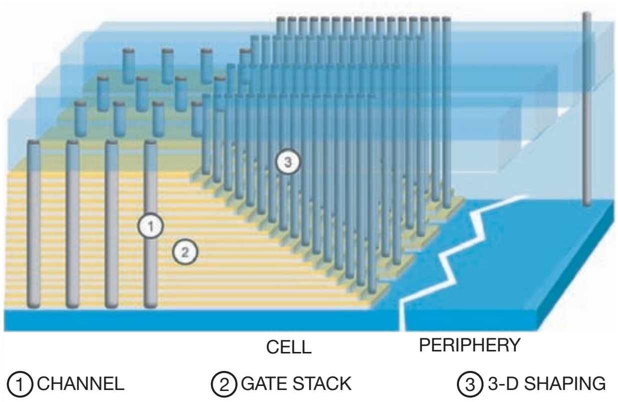


Figure 17 A staircase construction accesses layers in a vertical stack of cells.

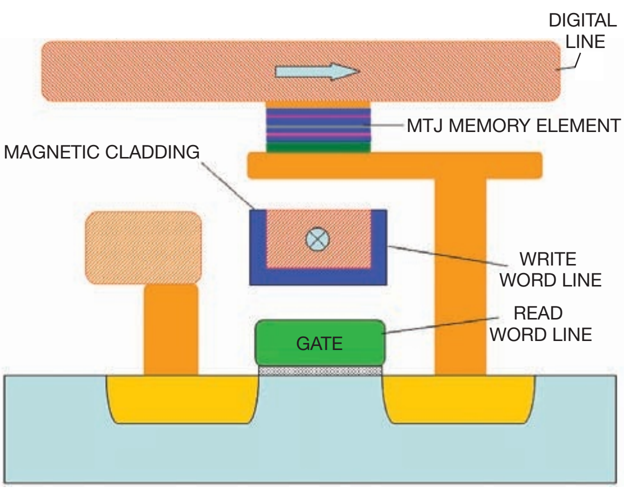


Figure 18 An MRAM cell can be created using a fixed magnet.

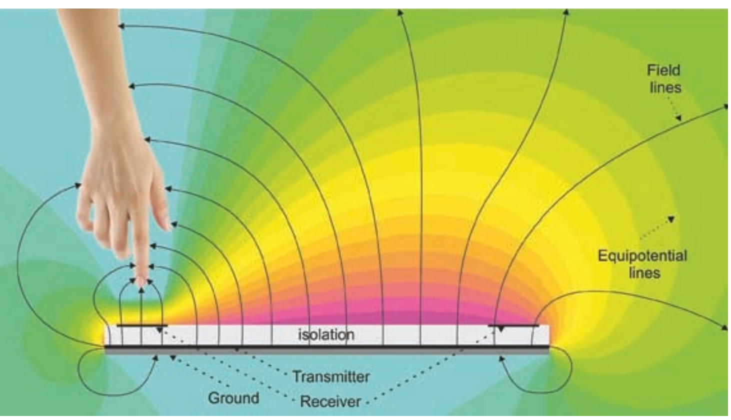


Figure 19 E-field HMI devices generate an electric field and monitor sensors that detect field perturbations due to movements of a conductive object, such as a human hand.

conventional, 2-D sub-20-nm NAND but also can provide 1 Tbit of memory if further scaled to 25-nm feature sizes. At that size, the Macronix device would comprise only 32 layers, whereas 3-D stackable NANDs with vertical channels would need almost 100 layers to reach the same memory density.

Also watching:

Some propose forgetting electrons and going back to magnetic memory, but what's the best way to program them? Two ideas:

- **Form memory cells** from two ferromagnetic plates, each of which can hold a magnetic field, separated by a thin insulating layer (**Figure 18**).
- **Create spin** in electrons using magnetic fields.

HUMAN-MACHINE INTERFACES ENTER THE THIRD DIMENSION

Stephen Evanczuk, *Technical Editor, Systems Design*

Don't throw out your mouse or abandon your touchpad just yet, but traditional human-machine interface devices that rely on two-dimensional, x-y positional information could soon share your desktop or phone with a coming wave of HMI devices that let you work as you move—in three dimensions.

Camera-based HMIs such as the Microsoft Kinect already offer mid- to far-field movement-tracking capabilities in games. The emergence of e-field-based gesture-recognition HMIs is an important trend not only for near-field sensing but also for recognition of a series of movements as specific gestures.

In this new kind of HMI, hand movement within a volume bounded below by 2-D sensor arrays results in perturbations in the e-field maintained within that sensing area (**figures 19** and **20**). The use of an e-field- rather than a vision-based system opens the door to embedded-sensing applications running the gamut from automotive and aerospace to industrial and consumer.

The most dramatic example of this new kind of device debuted in November with Microchip Technology's unveiling of a complete 3-D gesture-recognition IC, the MGC3130 (**Figure 21**), based on the GestIC technology that Microchip acquired along with its purchase of Ident Technology earlier in the year. Paired with a low-cost external elec-

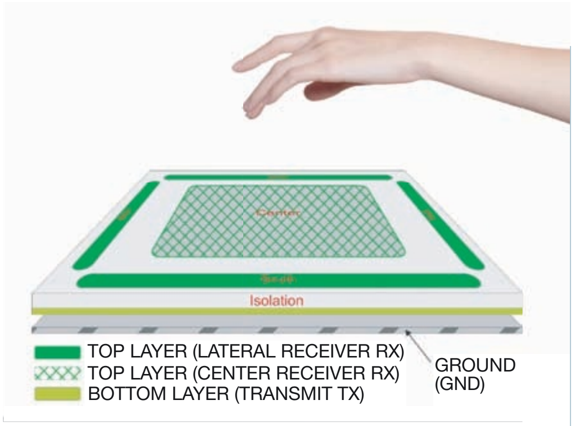


Figure 20 E-field HMI subsystems need only a simple array of electrodes to generate a relatively low-frequency electric field and measure its current status.

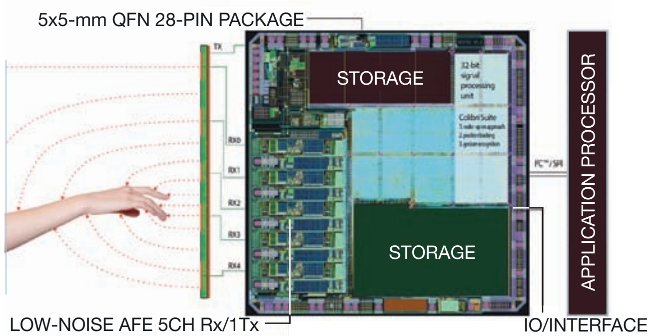


Figure 21 Based on Microchip's GestIC technology, the MGC3130 combines multiple dedicated sensor-signal-conditioning signal chains, a signal processor, and flash-based gesture-recognition software to convert hand movements into a stream of recognized gestures.

trode array, the GestIC device contains an analog signal chain that measures changes in the e-field to track hand movements in the 3-D sensing area and then uses its on-chip signal processor, running code from an on-chip software library, to determine how those movements combine to form one of a dozen or so preprogrammed, recognized gestures.

Microchip's GestIC isn't the only game in town for e-field sensors. Plessey Semiconductors introduced an e-field sensor last year, originally focusing on health applications; recently, the company began shipping a low-cost e-field sensor that promises to fuel a drive into high-volume consumer markets. Developers can combine the Plessey device with an embedded system to roll their own e-field 3-D HMI products, leveraging a rich field of pattern-recognition algorithms.

Don't count out camera-based gesture-recognition systems. Cameras have become nearly ubiquitous in mobile appliances. Further, the industry has barely scratched the surface for multisensor solutions that find synergy in combinations of different sensing modalities.

For example, Microsoft recently demonstrated a gesture-recognition system, called Digits, that combines camera and MEMS motion-sensing technology. Digits uses sophisticated analysis software to create a highly detailed software model of the hand in motion to track subtle gestures—something GestIC itself can't yet do.

The hardware is rolling into place, and the software is maturing, to offer a new form of HMI for which the sky is literally the limit.

Also watching:

- **Hybrid-core SOCs.** Compute-intensive applications such as big data and vision systems will gain a boost from systems-on-chip that combine one or more general-purpose RISC processor cores with one or more specialized cores, such as DSPs, video processors, and audio processors.
- **Hardware-based security.** In the notion of the Internet of Things, unsecured access to any "thing" is a real concern, but one mitigated by the trend toward hardware-based implementation of safety and security features in processors and subsystem controllers.

WEAR YOUR HEART MONITOR ON YOUR SLEEVE

Steve Taranovich, *Senior Technical Editor*

Just when you think ICs can't get any smaller, someone releases a more-compact, lower-power, better-performing solution, usually on a monolithic die. Analog front-end and

Figure 22 Runners can strap an e-compass, built with STMicroelectronics MEMS technology, on a wrist.

Figure 23 ADI's heart-monitor AFE targets applications ranging from professional health care to personal fitness.

Figure 24 The DuoFertility monitor, bottom, is worn under the arm; temperature data is sent to the handheld reader, top (courtesy Microchip).

microelectromechanical-system devices have led the pack in miniaturization innovation this year, and one result has been a spate of health and wellness monitors that users can wear as unobtrusive accessories.

A case in point is an e-compass enabled by MEMS technology from STMicroelectronics (**Figure 22**). The e-compass, or "geomagnetic module," integrates a three-axis digital magnetometer with a three-axis digital accelerometer, used for tilt compensation, in a single package.

EEG (electroencephalography) analog front ends are another example. Texas Instruments designed its ADS1299 AFE to help manufacturers of extracranial-biopotential measurement equipment reduce board space, design time, and cost while improving performance. The AFE can be used in EEG equipment to monitor bispectral index, evoked potentials, and event-related potentials to aid in diagnosing such conditions as brain injuries, strokes, and sleep disorders.

Among the *EDN* Hot 100 products in the analog category this year are heart- and fitness-monitor AFEs from TI (AFE4300) and Analog Devices Inc (AD8232). These and other AFEs are meeting the growing demand for fixed, portable, and even wearable devices that provide vital-sign measurements for athletes in training, users of home fitness equipment, or those engaged in remote health monitoring.

ADI's AD8232 for ECG applications eliminates the need for a right-leg drive lead so that a single lead can be used to monitor heart rate (**Figure 23**). Integrated filters for removing line noise and other interference improve performance. A multipole integrator rejects electrode offsets to maintain large dynamic range on an internal instrumentation amp. Operation on a single, 2 to 3.5V supply, directly from a battery, enables portability.

Wearable medical devices are becoming increasingly transparent to the user. The DuoFertility monitoring system (**Figure 24**), built with technology from Microchip Technology, comprises the company's small PIC16 MCU-based sensor, containing a temperature monitor and wireless transmitter, that is worn under the arm; a handheld reader that houses a wireless receiver, temperature monitor, and PIC24 MCU; and PC-based analysis software. The combination lets the user monitor her fertility cycle without requiring her to take her temperature every day.

Also watching:

- **Bluetooth Smart's arrival.** Developments in low-power wireless technology have hastened the advent of Bluetooth Smart ultralow-power portable devices. Implementing a single-mode, low-energy Bluetooth v4.0 dual-mode radio, the sensor-type devices run on button-cell batteries and typically are built to collect a specific piece of information—functioning, for example, as a heart-rate monitor or pedometer. An *EDN* Hot 100 product from a partnership between Stonestreet One and Freescale Semiconductor enables a turnkey radio module to hasten time to market for ultralow-power health-care devices.

- **MEMS' proliferation.** The past year saw an explosion of MEMS products, such as ADI's ADMP504 microphone IC, Freescale's Xtrinsic FXOS8700CQ six-axis sensor, and ST's LSM303D e-compass module. All were among *EDN*'s Hot 100 products for 2012.

Figure 25 Interdevice communications for both power and data would be more difficult without advances in mixed-bus connector architectures, such as USB and PoE, both encouraging and enabling the process.

THE FUTURE OF POWER MANAGEMENT IN THE INTERNET OF THINGS

Alix Paultre, *Director of Marketing and Communications, GlobTek Inc*

In the area of digital management and system communications, the electronic power-system industry is in the process of the largest technology integration since the introduction of the linear power supply. Digital power-management techniques have long been a facet of chip design on the client side, where the device controls its internal subsystems to maximize operating efficiency, and there have been special requirements for the power ICs that drive them. The migration of digital power management from the inside of the box to the outside of the box and the need to communicate with the various systems that inhabit the world outside will create the next level of challenge and opportunity for the industry.

This migration could not have occurred without certain core technologies, both hardware- and software-based. Digital power-management protocols such as PMBus could not move to the board level and provide real value to the designer before the introduction of intermediate-bus architecture to take advantage of the added level of control. Interdevice communications for both power and data would be more difficult without the advances in mixed-bus connector architectures, such as USB and PoE (power over Ethernet), both encouraging and enabling the process (**Figure 25**).

The external factors involved are based on both reality and desire, and in the area of power design they overlap strongly. Power efficiency translates to thermal efficiency, which aids sleek design, which challenges haptics,

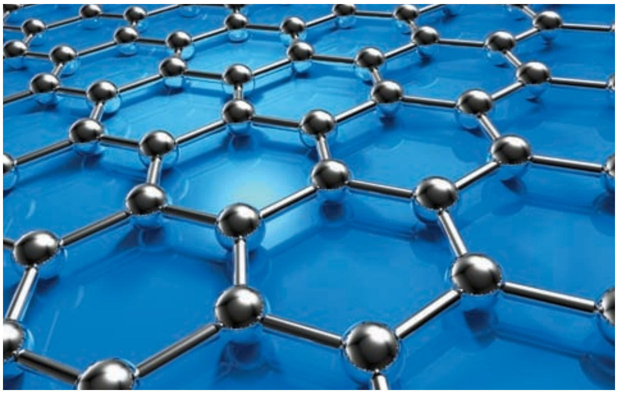


Figure 26 Nanotechnology is moving from a primarily materials-based technology to a core microdevice and microcomponent electronics and device technology.

which affects board layout, which affects available real estate for the power system and its cooling/shielding requirements. A system that can communicate with its power source can use extended power-management methodologies to raise overall system efficiencies. In the case of batteries and other energy-storage systems, communication also improves device safety and reliability. Market demands put USB connectors on most wall-mount chargers; why not use the bidirectionality of the format?

This pressure to provide functionality, coupled with the availability of advanced power-system methodologies, drives the migration of digital power management to macro systems. A device that can communicate with its wall charger will operate more efficiently than one that cannot; when that wall charger can communicate with the smart-house management system (or at least a smart power meter), the result is not only improved efficiency, but improved functionality and safety as well. This integration provides functionality not only for the user but also for the infrastructure, as it makes the device a part of the Internet of Things and all that it implies.

This ability of the infrastructure to be self-managing at the power level may be intrusive at some levels to some users, but the benefits are myriad. For example, if the power to homes located in hurricane-, tornado-, and flood-evacuation areas could be turned off at the subgrid level, secondary fires would be minimized, and dangers to first responders due to electrocution and water-based secondary electrical damage would be eliminated. The ability to turn off unused (by power signature or device self-reporting) devices in the grid would minimize brownouts and blackouts by reducing "vampire" standby drain.

The advance of cloud-supported, Web-based products increases the need for improved power and signal interdevice communication. As your smartphone takes on more of the role of a personal server, it will be called on to control and manage everything from your belt-mounted artificial pancreas to the speed of your pacemaker while still operating the remote-controlled car you drive around your desktop. Such systems function best when battery states and other operating parameters are part of system management and are accessible through the Web. Your doctor can monitor your medical-device performance, and even in the case of your toy, upgrades to the software and system troubleshooting data can be downloaded to the device.

What this means for you as a designer is that you increasingly will be called upon to ensure your designs function in a larger system infrastructure, and the higher you are able to have your device function in that device architecture, the more you will be able to address the expanded requirements of the Internet of Things. As system architectures and market demands increase the need to exchange data more actively between devices, having the power system participate in the conversation will pay large dividends across the market, from the individual chips inside the device to the power station down the road.

Also watching:

- **Nanotechnology.** Our grasp of what is possible is expanding exponentially, and as a result nanotech is moving from a primarily materials-based technology to a core microdevice and microcomponent electronics and device technology (**Figure 26**).
- **Energy harvesting and alternate power methodologies for small devices.** "Smart dust" sensor networks, parasitic energy-harvesting subsystems, and multisource power systems are all examples of ways power can be harnessed to increase system functionality and performance.

M2M BRANCHES BEYOND ONE-TO-ONE LINKS

Carolyn Mathas, *Editor, LEDs, Communications, and Sensors*

Machine-to-machine technology made great strides in 2012, and I expect an explosion of applications in 2013, making M2M the top hot technology to watch.

M2M is no longer a one-to-one connection but has evolved to become a system of networks transmitting data to a growing number of personal devices. The power and time necessary to transmit between machines has plummeted, even as business opportunities blossom across a broadening range of applications.

Today, sophisticated and wireless M2M data modules boast onboard GPS and such embedded features as M2M smart

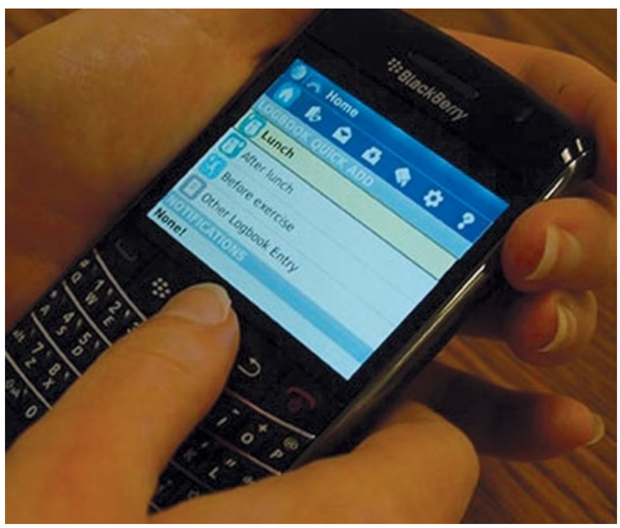


Figure 27 AT&T and Alere collaborated on a mobile-health solution that lets diabetes patients manage their disease in real time and on the go.

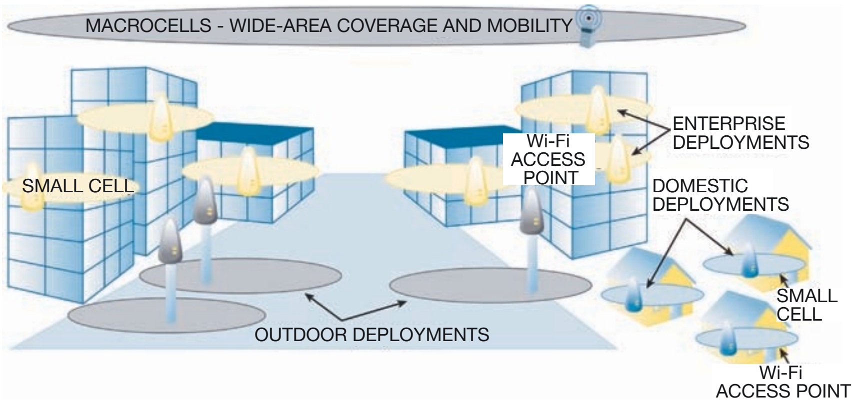


Figure 28 Operators can leverage Wi-Fi access points and strategically placed small cells to offload traffic from the macro network (courtesy Radisys Corp).

cards (MIMs, or machine identification modules) and embedded Java. The combination of technologies raises the bar.

Applications are multiplying rapidly based on the dramatic improvements in reliability and accuracy that often result when human intervention is removed. There have been several examples over just the past few months. Vodafone Ltd unveiled a number of advanced M2M technologies for smart meters and smart homes, demonstrating simple management of multiple connected devices through a single mobile application. The company's Global M2M Platform, running on IBM Corp's SmartCloud Service Delivery Platform, proved that a washing machine and other smart-home devices could be operated via mobile, becoming more intelligent with wireless Internet.

Telit Wireless Solutions' advanced M2M modules are monitoring groundwater worldwide for rural and municipal water departments and boards as well as mining operations. Schlumberger Water Services' Diver-NETZ wireless system manages groundwater monitoring and integrates field instrumentation with wireless data and communication management capabilities.

A recent report by GlobalData indicates that M2M may become an important element in the reduction of health-care costs and the delivery of high-quality medical care to remote locations. The US Federal Communications Commission recently initiated steps to dedicate wireless spectrum to medical body-area networks that use sensors worn on the body to transmit critical patient data to a control device for remote patient monitoring.

Companies are collaborating to address the market. AT&T and Alere Health, for example, this year released a mobile diabetes-management solution that sends data via a mobile device to medical personnel and real-time feedback to patients (**Figure 27**). DebMed, for its part, is bringing M2M to life by equipping hand-soap and hand-sanitizer dispensers with RF technology that provides real-time compliance to track and report on the sanitizing habits of medical personnel.

Pulling technologies together, integrating their complexity, and making them speak to each other intelligently are no longer aspects of the future. I expect that in 2013, we'll see an amazing number of hot applications and even hotter breakthroughs. It will be an exciting year.

Also watching:

- **Seamless solutions for data offload.** En route to the 25 exabytes/year of traffic estimated by 2015, Wi-Fi and small-cell technologies will play important roles (**Figure 28**). Small cells, in the form of indoor femtocells and outdoor pico- and microcells, provide coverage and data offload, improving the capacity of the network. In 2013, we'll find these technologies jointly existing in indoor and outdoor spaces.
- **Sensor fusion.** This is yet another area where changes are taking place at breakneck speed. Not only is the "fusion" aspect challenging on its own, but the rapid evolution of the sensors themselves adds to the mix. Fusing ever-smaller motion sensors, 3-D environments, and augmented reality, for example, depends on continually overcoming stability, noise, jitter, and the remaining weaknesses in the individual sensors.

OPPORTUNITIES ABOUND IN CLOUD "CLUTTER"

Gene Frantz, *Principal Fellow, Texas Instruments*

The cloud means many things to many people, but irrespective of how you define it, the opportunities for engineers to innovate abound with regard to developing the technologies essential to the cloud and its enablement.

Before I elaborate on those opportunities and technologies, first let me separate the concept of the cloud into three aspects: the clouds, the clutter, and the communications pipes.

The clouds: One mistake we make is assuming the cloud is singular, when it is actually thousands of clouds selectively connected. My house has a cloud; my company has many clouds; every coffee shop has a cloud. (I have another story to share on this idea, but not here.)

The clutter: Several words have been used to describe those things attached to the cloud(s). I use the term "clutter" to suggest the lack of standardization and organization. It will just be clutter for now. Any attempt to organize it will tend to destroy innovation within that clutter.

The communications pipes: There will be communications between clouds, from clutter to cloud, and from clutter to clutter. Techniques will be chosen according to their ability to handle the communication link being made.

For the clutter, there are many technologies at our fingertips for enabling that—for example, ultralow-power processors. I reserve the right to give TI the credit for driving this aspect, recognizing that battery operation has been a focus of TI since the invention of the calculator in the mid-1960s. It really took hold as we drove into the digital cell-phone market.

Then there's power management to get the most out of our energy sources. Three aspects to consider here are energy scavenging (from such sources as solar, vibration, and the human body), efficient power conversion, and energy buffering. I use the term "buffering" (versus "storage") to keep us from jumping to the simple EE answers of batteries and capacitors. This approach broadens the possibilities to include any storage medium, such as springs, balloons, or gravity. This area is a huge one for innovation. Many of us have stored up energy ready for use in more abundance than we wish to talk about (think: fat).

The clutter also provides opportunities for innovations in wireless communications and smart sensors. I am careful to point out that wireless-communications does not automatically mean RF. There are many ways to do wireless communications beyond RF-based concepts. One might remember that the oldest wireless-communications method was not RF; it was smoke signals. Other wireless techniques include ultrasonic, electromagnetic, optical (for example, LED lights), and audio band (for example, ULF). All can be employed to connect to the cloud and to connect cloud-to-cloud.

THERE WILL BE TECHNIQUES FOR COMMUNICATIONS BETWEEN CLOUDS, FROM CLUTTER TO CLOUD, AND FROM CLUTTER TO CLUTTER.

Smart sensors have three components: the sensor itself; then the analog front end, to take the analog input from the sensor and output data; and the digital front end, to take the data from the AFE and create information for the central processor, which uses the information to make decisions. Sometimes, DFEs are called DSPs.

Other clutter areas include operating systems and development environments, which are vital, as the cloud needs to be accessible to "normal," nontechnical people. I call this the democratization of the cloud and of technology in general. It involves making it all easy to use so that it can pull in innovators who do not understand the technology but only want to use it. Toward that end, platforms such as Arduino are succeeding in pulling in the non-nerds.

That said, even though we have made it possible for a broader range of innovators to participate in the creation of the clutter, there will remain a need for the technical community to make it happen.

The cloud still needs to be very efficient, and it requires operating systems that have a small memory footprint and are easy to configure. (Note I used the term "configure" rather than "program.") Add in data-analysis engines, privacy issues, and low-power requirements, and it's clear that engineers have much to chew on, innovationwise, for many years to come.

That said, I'll keep it simple:

- **Drive for low power.**
- **Aim for ease of use.** EDN

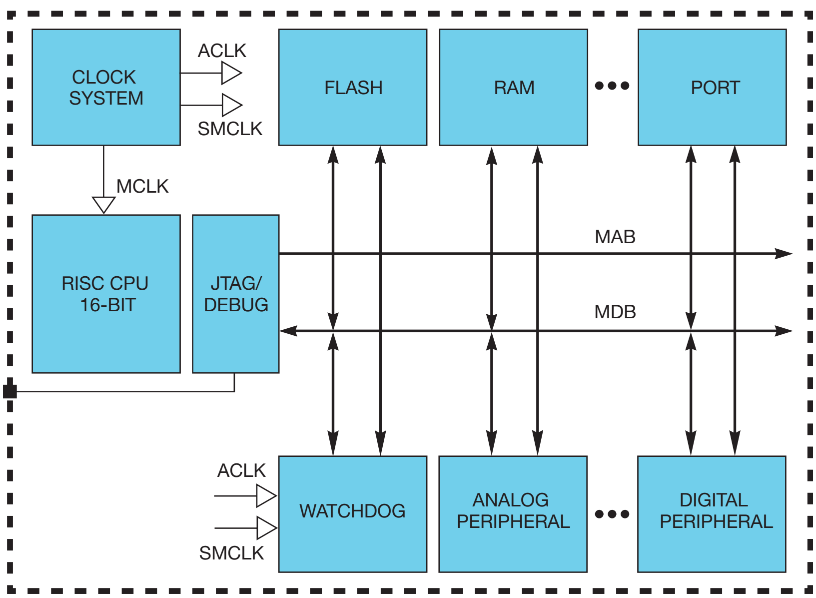


Figure 29 Ultralow-power processors, such as those represented by the MSP430-series MCUs from TI, are critical to enabling the proliferation of what could well be called the "clutter" around the cloud. Many of the current opportunities for engineers reside in designing that clutter.

DESIGN NOTES

Micropower Isolated Flyback Converter with Input Voltage Range from 6V to 100V

Design Note 509

Zhongming Ye

Introduction

Flyback converters are widely used in isolated DC/DC applications because of their relative simplicity and low cost compared to alternative isolated topologies. Even so, designing a traditional flyback is not easy—the transformer requires careful design, and loop compensation is complicated by the well known right-half plane (RHP) zero and the propagation delay of the opto-coupler.

Linear Technology's no-opto flyback converters, such as the LT®3573, LT3574, LT3575, LT3511 and LT3512, simplify the design of flyback converters by incorporating a primary-side sensing scheme and running the converter in boundary mode. The LT8300 high voltage monolithic isolated flyback converter further simplifies flyback design by integrating a 260mA, 150V DMOS power switch, an internal compensation network and a soft-start capacitor. The LT8300 operates with input supply voltages from 6V to 100V and delivers output power of up to 2W with as few as five external components.

The LT8300 operates in boundary mode and offers low ripple Burst Mode® operation, enabling the design of converters that feature high efficiency, low component count and minimal power loss in standby.

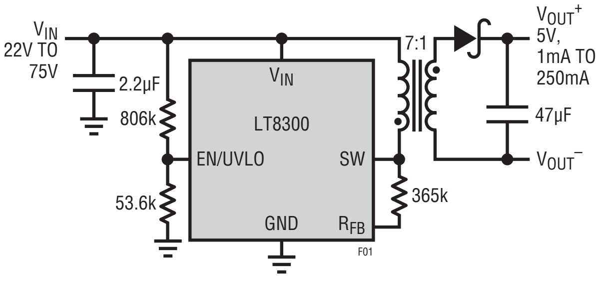


Figure 1. A Complete 5V Flyback Converter for a 22V to 75V Input

Simple and Accurate Primary-Side Voltage Sensing

The LT8300 eliminates the need for an opto-coupler by sensing the output voltage on the primary side when the output diode current drops to zero during the primary switch-off period. This greatly improves the load regulation since the voltage drop is zero across the transformer secondary winding and any PCB traces. This allows an LT8300-based flyback converter to produce ±1% typical load regulation at room temperature. Figure 1 shows the schematic and Figure 2 the load regulation curves of a flyback converter with a 5V output.

Very Small Size, Low Component Count Solution

The LT8300 integrates a 260mA, 150V DMOS power switch along with all high voltage circuitry and control logic into a 5-lead TSOT-23 package. The isolated output voltage is set via a single external resistor with compensation and soft-start circuitry integrated in the IC. Low ripple Burst Mode operation maintains high efficiency at light loads while minimizing the output voltage ripple.

The converter turns on the internal switch immediately after the secondary diode current reduces to zero, and turns off when the switch current reaches the predefined current limit; the diode has no reverse-recovery loss.

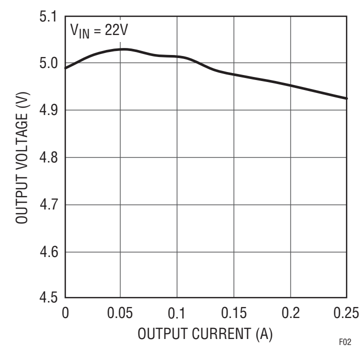


Figure 2. Regulation of a 22V to 75V Input to 5V Flyback Converter of Figure 1

Figure 3. Demonstration Circuit of 22V to 75V to 5V/0.3A Converter (See Figure 1)

Furthermore, since the switch is turned on with zero current, switching losses are minimized. The reduction in power losses allows the converter to operate at a relatively high switching frequency, which in turn, allows the use of a smaller transformer than would be required at a lower operating frequency. Overall, the LT8300 significantly reduces converter size compared to other solutions.

Figure 3 shows the standard demo circuit DC1825A for an isolated flyback using a small EP7 core transformer. The six key components are the input and output capacitors (C2, C3), output diode (D1), feedback resistor (R3), transformer (T1) and the LT8300. For the same application, a traditional flyback circuit would require, at minimum, eleven additional components, plus complicated start-up and bias power circuits in both the primary and secondary sides.

Low I_Q, Small Preload and High Efficiency

As the load lightens, the LT8300 reduces the switching frequency until the minimum current limit is reached, and the converter then runs in discontinuous mode. The LT8300 features an accurate minimum current limit and very small propagation delay. At very light loads, it further reduces the loss by running in low ripple Burst Mode operation, where the part switches between sleep mode and active mode. The typical quiescent current is 70µA in sleep mode and 330µA in switching mode, reducing the effective quiescent current.

The typical minimum switching frequency is about 7.5kHz, with the circuit requiring a very small preload (typical 0.5% of full load). Therefore, LT8300 power losses in standby mode are very low—important for applications requiring high efficiency in always-on applications. Figure 4 shows a solution that produces 20mA at 24V from a 12V input. Efficiency peaks at 87%, and remains high at 84% with a 20mA load, as shown in Figure 5.

Conclusion

The LT8300 is an easy-to-use flyback converter with a rich set of unique features integrated in a small 5-lead TSOT-23 package. It accepts a wide input voltage range, from 6V to 100V, with very low shutdown current and standby power consumption. Boundary mode operation reduces switching loss, shrinks converter size, simplifies system design and offers superior load regulation. Other features, such as internal soft-start, accurate current limit, undervoltage lockout and internal loop compensation further facilitate an easy flyback converter design.

The LT8300 is ideal for a broad range of applications, from battery powered systems to automotive, industrial, medical, telecommunications power supplies and isolated auxiliary/housekeeping power supplies. The high level of integration yields a simple, low parts-count solution for low power flyback converters.

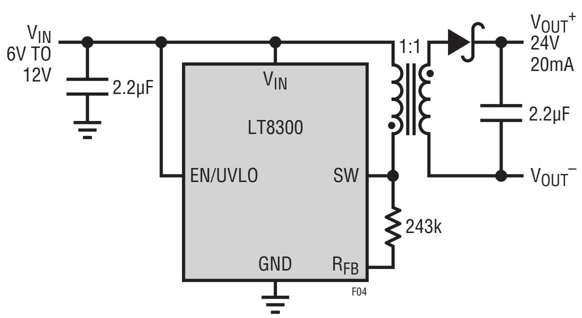


Figure 4. Flyback Converter Optimized for Low Standby Power (6V–12V to 24V/20mA)

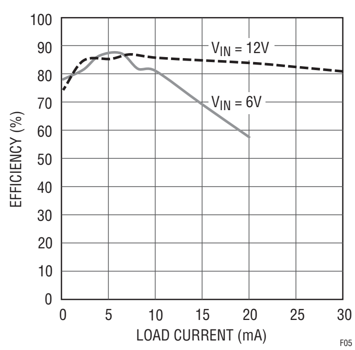


Figure 5. Efficiency of the Converter in Figure 4

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DESIGN NOTES

Simple Energy-Tripped Circuit Breaker with Automatic Delayed Retry

Design Note 495

Tim Regan

Introduction

A circuit breaker protects sensitive load circuits from excessive current flow by opening the power supply when the current reaches a predetermined level. The simplest circuit breaker is a fuse, but blown fuses require physical replacement. An electronic circuit breaker provides the same measure of circuit protection as a fuse without the single-use problem. Nevertheless, an electronic circuit breaker with a fixed trip current threshold, while effective for protection, can become a nuisance if tripped by short duration current transients—even if the circuit breaker self-resets.

One way to minimize nuisance breaks is to employ a slow-blow technique, which allows relatively high levels of current for short intervals of time without tripping the breaker. Ideally, the breaker's trip threshold would be a function of total transient energy, instead of just current. This article describes an electronic circuit breaker, combining current sensing with timing to create an energy-tripped breaker, which protects sensitive circuits while minimizing nuisance trips.

Higher Currents Permitted for Shorter Time Intervals

The circuit of Figure 1 has three distinct parts – circuit breaking, current sensing and timing.

The circuit breaking function can be any type of electronically controlled relay or solid state switch, properly sized for voltage and current ratings of the load being protected.

Load current sensing is achieved via an LT®6108-2 current sense amplifier with built-in comparator. The LT6108-2 converts the voltage drop across a small valued sense resistor to a ground-referenced output voltage that is directly proportional to the load current. The trip threshold is created by scaling the output voltage via resistor divider and feeding the result to the integrated comparator with a precision 400mV voltage reference. The comparator changes state when the load current exceeds the threshold.

To prevent short duration transients from causing nuisance trips, an LTC®6994-2 Timerblox® delay timer is

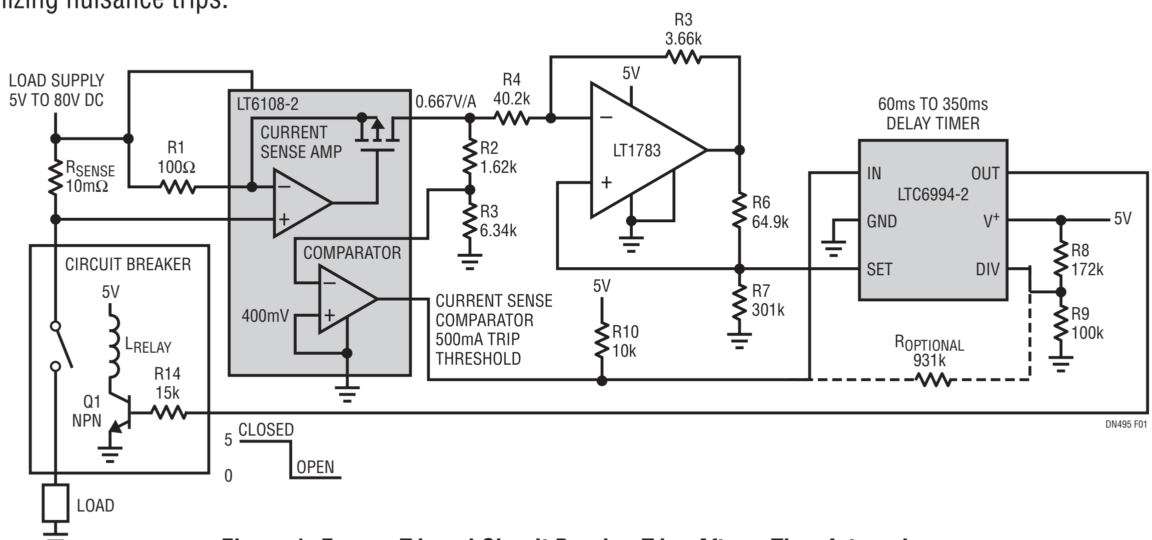

Figure 1. Energy-Tripped Circuit Breaker Trips After a Time Interval That Varies as a Function of Sensed Load Current

added between the comparator output and the circuit breaker. Once tripped, the comparator falling edge starts a variable time delay interval, which, if allowed to complete, signals the circuit breaker to open. Nothing happens if the transient duration is shorter than the delay.

A Current-Controlled Delay Interval

The LTC6994-2 delays from an edge appearing at its IN pin by a time ranging from 1μs to 33 sec. The delay time is controlled by the current sourced by the SET pin, which programs an internal oscillator frequency, while the bias voltage on the DIV pin selects a frequency divide ratio.

The LT1783 op amp circuit takes the output voltage from the current sense amplifier and adjusts the SET pin current, thereby making the delay time a function of the load current (see Figure 2). As shown, the current sense comparator trip threshold is 500mA. A current of 500mA creates a falling edge and starts a time delay of 350ms. Should the load current drop below 500mA before the delay time expires, the timer output remains high and the circuit breaker does not trip.

Higher load currents correspond to higher current sense amplifier output voltages, which in turn reduce the delay time interval (Figure 2). For instance, a 5A load current trips the circuit breaker in only 60ms. Depending on the average load current in excess of the 500mA threshold, the delay interval or trip time will fall somewhere between 30ms and 400ms.

Once tripped, the load current drops to zero. This resets the current sense comparator high. This rising edge is also delayed by the LTC6994-2. The minimum current sense

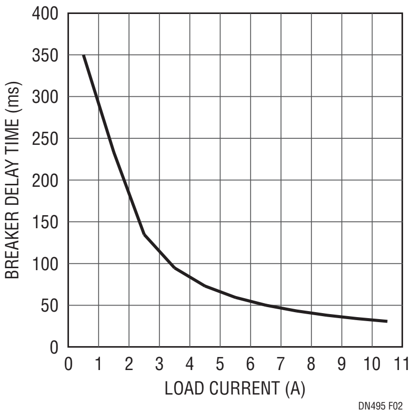

Figure 2. Low Current Transients Must Last Relatively Longer to Trip the Breaker. Higher Currents Trip the Circuit Breaker in Less Time

output voltage stretches this delay to a maximum time of ~1.3 sec. After this delay the circuit breaker closes and reapplies power to the load. This automatic retry function requires no additional components.

The response of the circuit to a 5A load current spike and automatic retry is shown in Figure 3. If the load current remains too high, the trip/retry cycle repeats continually. A current surge is fairly common when the circuit breaker is first closed and can trip the comparator. If the duration is less than the timer delay, the breaker remains closed, thus avoiding an endless loop of self-induced nuisance trips.

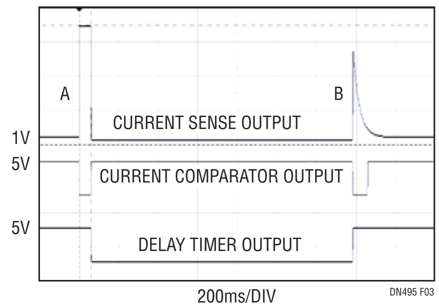

Figure 3. An Example Trip and Retry Sequence. At Time Point A, the 5A Load Current Spike Trips the Comparator and 60ms Later the Breaker is Opened. At Time B, After a Delay Time of 1.3 sec, the Timer Closes the Breaker. The Resulting Short Duration Spike of Start-Up Current Is Not Large Enough or Long Enough in Duration to Trip the Breaker Again

Extending the Retry Time Interval

The LTC6994-2 delay timer has eight divider settings for a wide range of timing intervals. Adding the single optional resistor shown in Figure 1 shifts the delay block to a new setting, increasing the retry time interval if desired. This can give any fault condition more time to subside. The circuit breaker response time interval is not affected.

For the values shown, when the circuit breaker trips and the current drops to zero, the comparator high level biases the DIV pin to a higher voltage level, resulting in a longer retry delay time of 10 seconds.

Conclusion

The circuit shown here can be easily modified to different timing requirements with a few resistor value changes. Other current sense devices such as the LT1999 can also be used to monitor bidirectional load currents with variable breaker timing functionality.

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Charge a nickel-cadmium cell reliably and inexpensively

Abel Raynus, Armatron International Inc, Malden, MA

Rechargeable NiCd (nickel-cadmium) cells are widely used in consumer devices because of their high energy density, long life, and small self-discharge rate. As a part of one project, I needed to design a reliable and inexpensive charger for a battery pack containing two NiCd AA-size 1200-mAh cells. In the process of the charger design, I needed to solve two main problems: first, setting a proper charge-current value, and second, stopping the charging process when the cell is full to avoid overcharging. This Design Idea describes a way to overcome both problems.

Most NiCd cells can be charged at two significantly different charge currents: either a fast charge with a high current or an overnight charge with a low current. Regardless of the charge speed, a steady charge current should be provided to the cell during the charging, and more energy must be supplied to the cell than its rated capacity to compensate for the energy lost as heat. The cheapest and safest way to charge a NiCd cell is to charge at 10% of the rated capacity per hour for 16 hours. Thus, the 1200-mAh cell should be charged at 120 mA. This approach does not require an end-of-charge sensor and ensures a full charge.

The charger schematic is shown in **Figure 1**. The current regulator—IC_3, an LM317—together with resistor R_3, generates a constant charge current. R_3's value is calculated as 1.25V/120 mA; the nearest standard value is 10Ω. The firmware of microcontroller IC_1 performs all of the necessary functions: time delay for 16 hours and charger-status reporting via LEDs. The microcontroller program is straightforward. The assembler code can be found with the online version of this Design Idea at www.edn.com/4402441.

Any kind of low-end microcontroller could be used in this project. This design uses the inexpensive, readily available eight-pin Motorola MC68HC908QT1 microcontroller. The bicolor OSRGHC-71A1B LED from OptoSupply indicates the state of the charger: Red means the cell is under charge; green means the charge is completed. You can add a buzzer as an optional feature to provide an audio signal when charging is complete.

This idea can be applied to charge any cell, with the resistor R_3 chosen accordingly. Because of limitations with the LM317, maximum charge current is limited to 1.5A. If the input voltage to the charger circuit is increased significantly above 9V dc, then power dissipation in the LM317 becomes a limiting factor. EDN

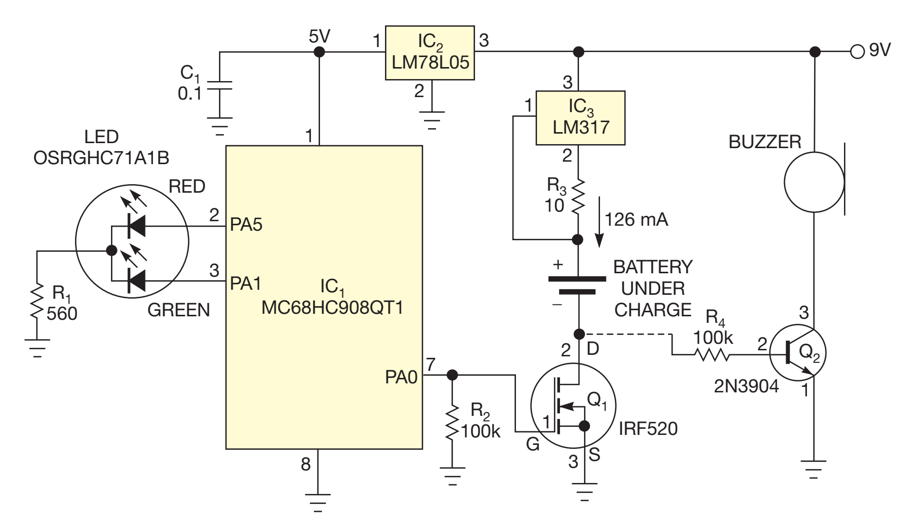

Figure 1 The MC68HC908QT1 functions as a 16-hour timer. The LM317 is configured as a current source with R_3.

DIs Inside

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Control your holiday lights with a magic wand

Vladimir Rentyuk, Zaporozhye, Ukraine

This circuit allows you to turn on your holiday bulbs with a wave of a "magic wand." The strings will flash in sequence.

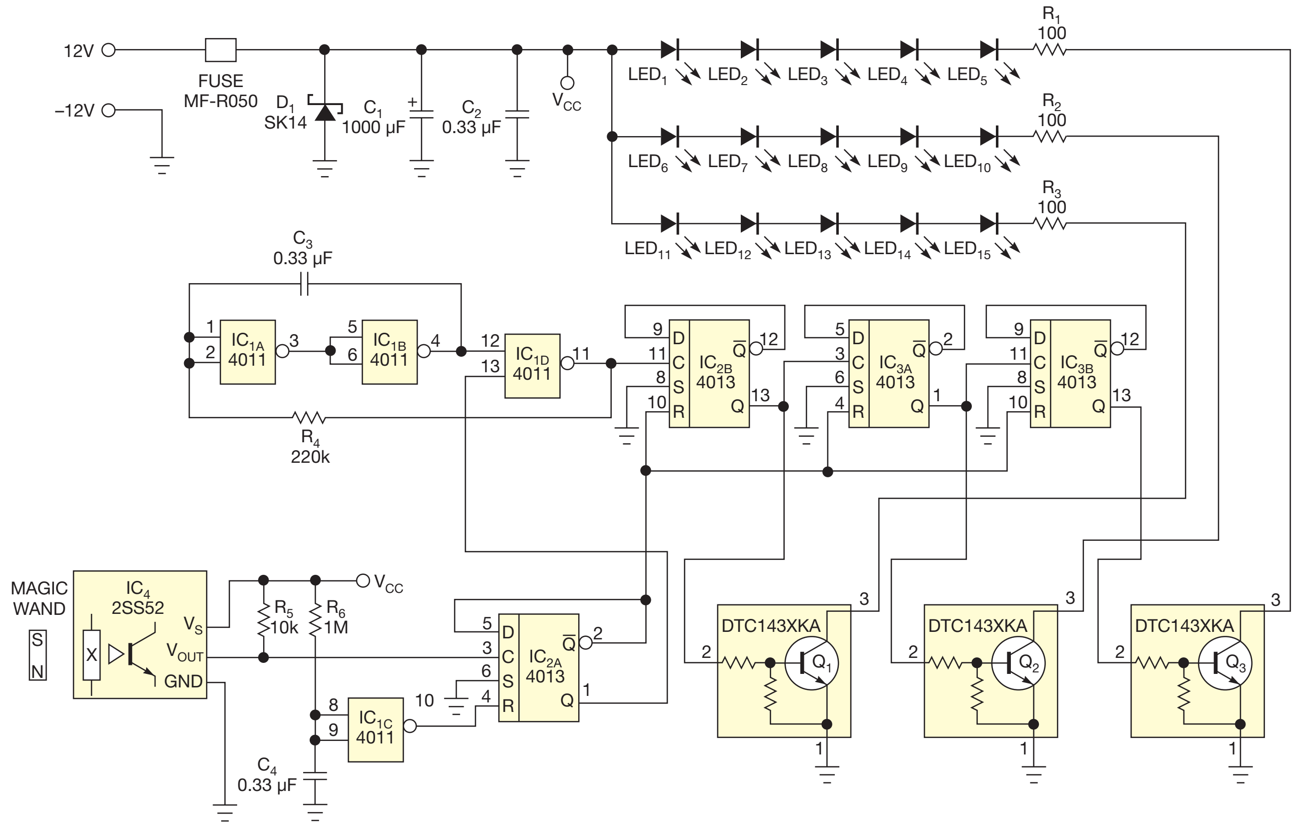
The main part of the circuit is a digital magnetoresistive sensor, IC_4 (**Figure 1**). Typical Hall-effect sensors are not suitable for this design, because they do not work over an extended sensing distance. They also do not switch when excited by either magnetic pole. The Honeywell 2SS52 sensor works from either the north or the south pole. It has good sensitivity to a magnetic field.

You start by placing a magnet into the end of your magic wand and then put sensor IC_4 in the PCB or housing of this device. The wand will work over a distance of 1 in. R_6 and C_4 preset the device to an off state at power up. This RC circuit gives a high-level output, which resets all of the D-flip-flop triggers via the R inputs.

You use capacitor C_3 and resistor R_4 to make NAND gates IC_{1A}, IC_{1B}, and IC_{1D} into a free-running oscillator. The reset circuit disables this signal generator at power up. When you move the magic wand near sensor IC_4, the trigger, IC_{2A}, will change its output. This enables the signal generator and a binary counter formed by IC_{2B}, IC_{3A}, and IC_{3B}. High outputs of the binary counter will open up the output drivers, Q_1, Q_2, and Q_3, and the LED's chains will sequence in a binary counting mode. You can adjust the counting frequency by changing the values of R_4 and C_3.

WHEN YOU MOVE THE MAGIC WAND NEAR SENSOR IC_4, THE TRIGGER WILL CHANGE ITS OUTPUT.

A second swipe of your magic wand will toggle IC_4, and the lights will turn off. You could adapt this circuit with optocouplers and ac triacs to drive LED lights meant for ac wall power. EDN



NOTES:
PIN 7 AND IC_1, IC_2, AND IC_3 SHOULD CONNECT TO GROUND.
PIN 14 AND IC_1, IC_2, AND IC_3 SHOULD CONNECT TO V_{CC}.

Figure 1 You can use a hidden magnet to toggle a Hall-effect sensor and sequence three strings of holiday lights in a binary counting progression.

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Regulate a 0 to 500V, 10-mA power supply in a different way

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Contemporary power supplies use switching techniques to achieve the desired output voltage from the primary source. Switching power supplies, however, are often too noisy to be used in sensitive analog circuits. You may find linear power supplies to be preferable in these cases.

A standard practice for a linear voltage regulator is shown in **Figure 1**. A higher-than-desired, unstable voltage is connected to the input, V_{IN}, and the series-pass transistor, Q_1, reduces the voltage to the desired level at output V_{OUT}. An error amplifier, IC_1, compares a fraction of V_{OUT} with a reference voltage, V_R, and controls Q_1 to keep the output fixed regardless of the load current, I_{OUT}, and variations of V_{IN}. Such a circuit is suitable only for a small range of output voltages.

When a wide range of output settings is desired, as in laboratory power supplies, the value of resistor R_{Q1} must be small enough to allow sufficient base current for transistor Q_1 at the high end of the output voltage range, but excessive power is dissipated at this resistor and transistor Q_3 when output voltage is reduced. Additionally, Q_3 must withstand the maximum V_{IN}.

You can use the circuit in **Figure 2** to overcome these problems. Two standard transformers, T_1 and T_2 (220V ac to 6V ac, 10W), are used to make an isolated replica of the mains supply, V_M. This replica is doubled and rectified using D_1, D_2, C_1, and C_2 to get about 560V at V_{IN} from 220V ac at V_M. As in the standard **Figure 1** connection, a series-pass transistor, Q_1 (BU508A), is used to reduce the unstable V_{IN} down to a fixed V_{OUT}, and IC_1 compares the divided V_{OUT} with V_R. Potentiometer R_3 sets V_R to allow for the adjustment of V_{OUT}, as given by the following **equation**: $V_{OUT}=V_R\times[(R_{FG}+R_F)/R_{FG}]$, where $R_F=R_{F1}+R_{F2}\ldots R_{Fn}$.

With 10 resistors (1 MΩ each) connected in series to form R_F and a maximum reference voltage of 5V, the output voltage can be set from 0 to 505V. The OPA364 operational amplifier is a rail-to-rail input type to allow proper operation, with V_R ranging from 0 to 5V, and is able to source a current of up to 40 mA.

To reduce the power dissipation caused by driving a series-pass transistor and expand the output voltage range, the driving of transistor Q_1 is done in an unconventional way using optical isolation. Two photodiodes, FD_1 and FD_2, operating in photovoltaic mode, provide the driving current for the base of transistor Q_1. Light falling on the photodiodes causes a current flow into the base of Q_1.

The maximum voltage from a single photodiode working in photovoltaic mode is not sufficient to drive the base; therefore, two photodiodes are connected in series. Photodiodes for infrared light at 870 to 950 nm are used, and two IR LEDs, LD_1 and LD_2, illuminate them. The LEDs are standard 5-mm, plastic-encapsulated types. To improve the transfer ratio of the current through the LED versus the current generated by the photodiode, cut off the tops of the LEDs and polish them to form a flat surface. Place the photodiodes in proximity to the surfaces obtained. The transfer ratio of this homemade optocoupler is about 0.05. (The current of 20 mA through the LED causes a current of 1 mA through the photodiode.) Alternatively, you can use a commercially available linear optocoupler—for example, an IL300, which houses two photodiodes. Its current transfer ratio is only about 0.007, so you should use several such components in parallel.

The current-limiting circuit formed by Q_2 and R_2 simply shorts the FD_1 and FD_2 photodiodes when the output current exceeds Q_2's turn-on threshold, and the limit is independent of the output voltage. Capacitor C_6 is added for compensation, and transistor Q_1 should be fitted with a heat sink of at least 5°C/W. The power supply for the operational amplifier and the reference voltage is provided from the ac signal between the two transformers using bridge rectifier BR_1 (50V, 1A); two filtering capacitors, C_7 and C_8; and voltage regulator IC_2 (LM7805). A shutdown of the output voltage can be made by a simple short circuit across capacitor C_5, making V_R equal to 0.

Those living in a 110V ac region can use locally available transformers, but they should modify the circuit to achieve 500V by adding yet another transformer, T_3 (the same as T_1 and T_2, all 110V ac to 6V ac, 10W), in such a way that the low-voltage windings are connected in parallel, while the high-voltage windings of transformers T_2 and T_3 are connected in series. The operation of the high-voltage windings can be verified using an ac voltmeter; if the voltmeter reads zero, the ends of the windings from T_3 must be exchanged. Alternatively, if a 220V/6V transformer is available, keep T_2 as 220V/6V and use 110V/6V at T_1.

Editor's note: High voltages of 500V and the available current of several milliamps can be lethal; exercise caution when building, testing, and using this circuit. EDN

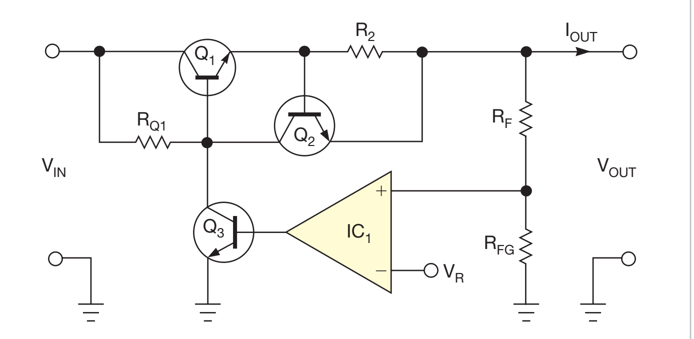

Figure 1 A standard linear voltage regulator connects the feedback directly to the series-pass transistor, Q_1.

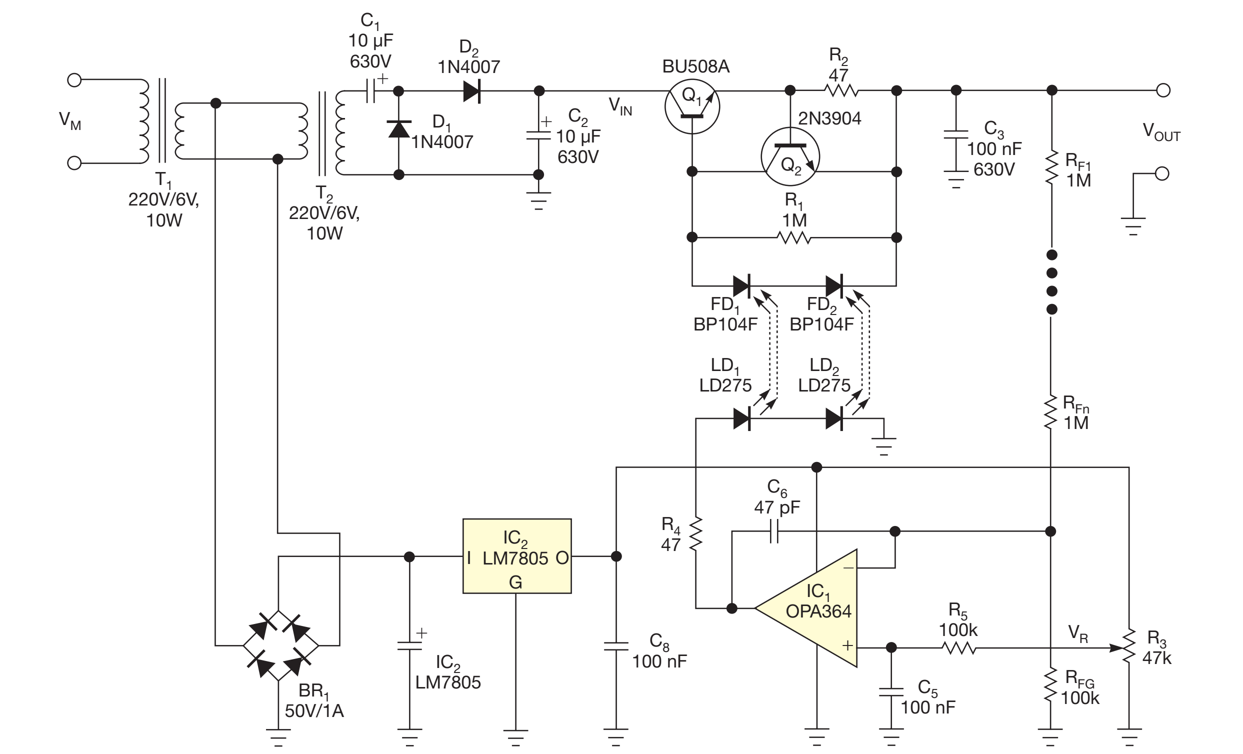

Figure 2 Optical coupling isolates the high voltage at Q_1 from the op-amp output.

Linear and switcher LED supplies combine, overcome disadvantages of each topology

Fabien Franc, On Semiconductor, Phoenix

To control their brightness, LEDs need a constant current; this can be done with a resistor placed in series with the LED string. Both the LED-string voltage and the supply voltage can vary, so a dedicated LED driver is a must to guarantee the current accuracy. Two solutions—each with advantages and disadvantages—are widely used: a linear constant-current LED driver or a step-down switching converter.

Linear drivers are simple solutions requiring few components and are essentially noise-free, but they dissipate heat proportionally to the difference between the supply voltage and the LED forward voltage. To protect against overheating, the driver package may require an additional heat-spreading area on the PCB, adding to the cost and amount of PCB real estate required and increasing the risk that the driver IC will enter thermal shutdown and turn

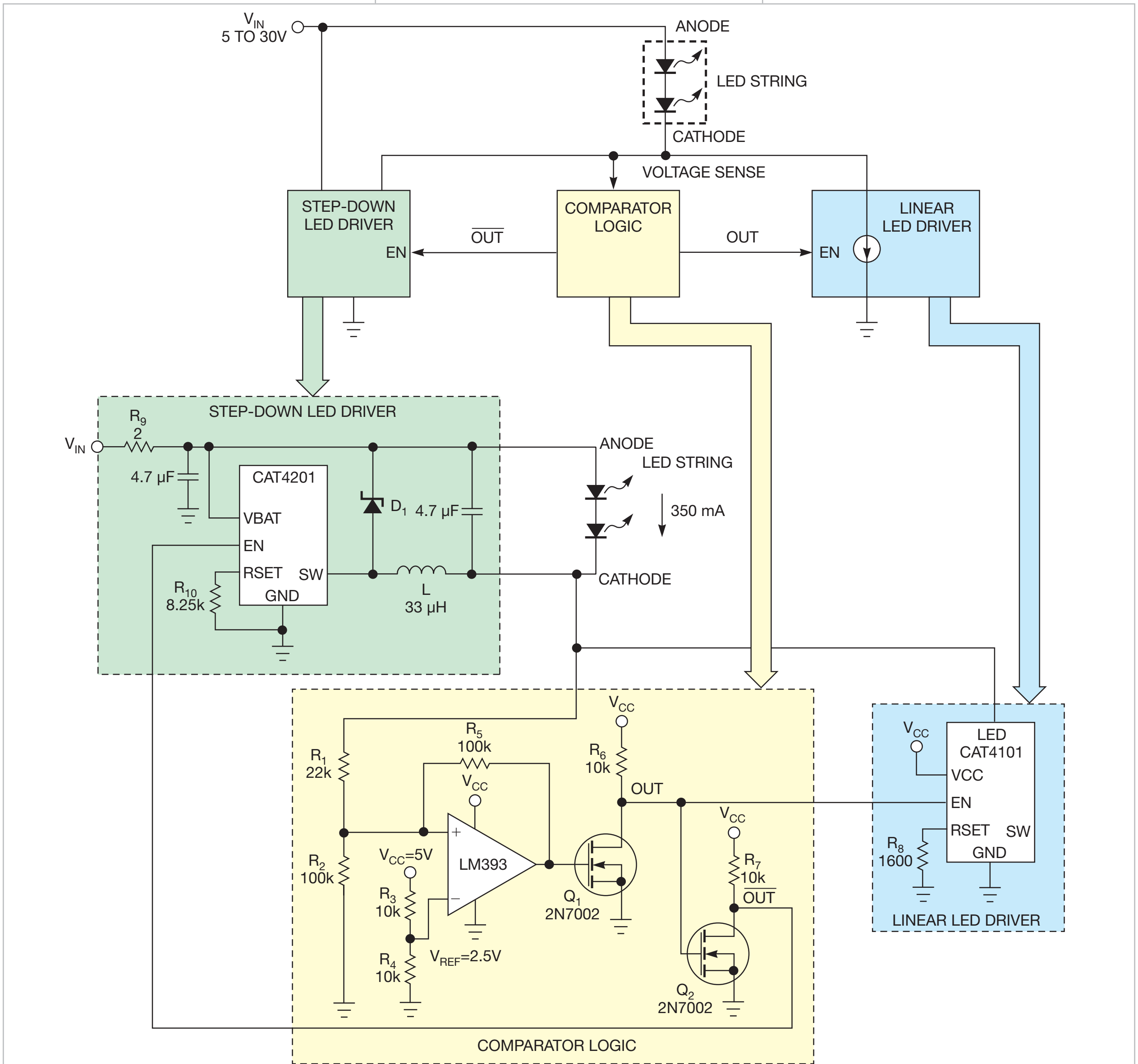

Figure 1 The LM393 comparator monitors the LED string's low-side voltage and enables either the buck regulator (CAT4201) or the linear regulator (CAT4101).

off the LEDs. If the driver is located next to the LEDs, the additional heat can cause the LEDs to operate at an elevated temperature, shortening their lifetimes.

Step-down, or buck, converters are efficient and generate little heat, but switching solutions require an inductor and a Schottky diode. The solutions also create noise, especially when the supply voltage drops and approaches the LED forward voltage. In automotive applications, RFI (radio-frequency interference) is a major concern. EMI/RFI filters are recommended in front of the switching converters to prevent high-frequency-switching conducted noise from going back into the supply, as it may interfere with other equipment, such as the AM/FM-band radio.

Linear-driver operation is at its optimum when the buck converter behaves poorly, running out of headroom. To benefit from both approaches without the disadvantages, you can adopt a combined linear/buck solution, which minimizes the switching noise without compromising efficiency.

Ideally, a battery voltage varies across a wide range, such as in automotive (8 to 17V) applications, where the linear/buck driver provides the desirable lower-noise operation and higher efficiency. Linear LED drivers convert to buck mode once the supply voltage increases above a limit, thereby protecting the linear driver from overheating.

The circuit described here selects each LED driver independently with adjustable threshold voltages when transferring between the switching and linear modes, with additional hysteresis for a smooth changeover. **Figure 1** shows the schematic using On Semiconductor's CAT4201 350-mA buck and CAT4101 1A, constant-current LED drivers; the comparator logic is also shown. Unlike the more common buck topology, with a high-side switch and a low-side diode, the CAT4201 swaps those devices.

As with a typical buck switcher, when the switch turns on, the current increases through the inductor, L, and the LEDs until it reaches a peak value equal to twice the average LED current; then the switch turns off. The charged inductor forces the current to continue to flow through the Schottky diode, D_1, and the LEDs until it drops to zero; the cycle then repeats. This switching operation is referred to as boundary conduction mode.

The R_1/R_2 resistor divider produces V+ at a fraction of the cathode voltage. If the comparator (LM393) input voltage is greater than a fixed reference voltage of 2.5V, then the output is high; OUT is low, disabling the linear driver and enabling the buck converter. If V+ is lower than the reference voltage, the comparator output is low and the linear driver is enabled, while the buck converter is disabled. The feedback resistor, R_5, adds some 0.6V hysteresis, such that once the cathode voltage rises above 3.6V, the buck turns on; as the cathode voltage falls below 3V, the linear driver takes over. Note that if the other half of the LM393 is not used for another LED power supply, good design practice dictates that all unused input and output pins on the LM393 be tied to ground.

Figure 2 shows the LED current regulation for the buck alone and the combination linear/buck driver. The linear/buck driver extends the LED current regulation down to a lower supply voltage below 8V, compared with the buck alone, allowing the LEDs to remain on, even as the battery voltage drops further. For a supply voltage below 11V, the buck alone loses its accuracy and also generates higher switching ripple current back into the supply. The lower-frequency ripple current is more difficult to suppress with an EMI filter. On the other hand, under the same supply-voltage range, the linear driver provides better regulation and noise-free operation.

In spite of the additional components, the combined linear/buck solution is valuable in applications where low-noise performance and the extended supply-voltage range are desirable. Linear-to-buck transition voltages can be set to optimize the thermal dissipation. EDN

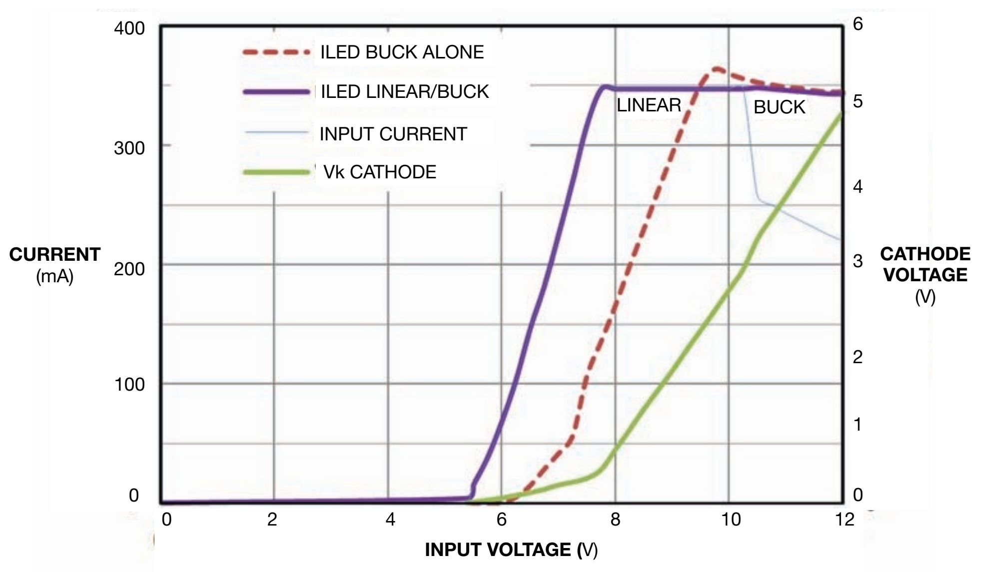

Figure 2 The linear/buck current sink extends the compliance range for current regulation down to a lower supply voltage (below 8V), compared with the buck regulator alone, and reduces EMI with low battery. As a result, the LEDs can remain on under low-battery conditions.

Originally published in the January 5, 1989, issue of *EDN*

Technique maximizes converter efficiency

Roger C Whipple, Hazeltine Corp, Braintree, MA

For a designer wishing to use a Linear Technology LT1072 switching regulator in the buck mode and being forced to deal with high input voltages, achieving the highest efficiency possible poses a problem. If, for example, you need to convert 20V to 5V at a relatively low power level of 1.25W, the quiescent current of the device itself (typically 6 mA) will become an important part of the circuit's power consumption.

Because the quiescent current is relatively unaffected by the input voltage, the power that the IC consumes is directly proportional to its applied supply voltage. If your system has an external low-voltage supply available, you could run the IC from it—the LT1052 operates down to 2.6V. If such an auxiliary supply is absent, you can operate the IC from its own output by incorporating a switch-over circuit (**Figure 1**). Adding this feature boosts the supply's overall efficiency from 77% to 83%.

When you first apply power to the supply, the regulator has no output: R_8 and D_7 hold C_6 discharged and the gate of MOSFET Q_4 at ground. Because Q_4 is turned off, the rising supply voltage pulls the gate of Q_3 up via R_5. As the supply voltage rises, Q_3 turns on, applying the full input voltage to the IC and allowing the regulator to begin operation.

Once the regulator starts and the output voltage rises, C_6 begins charging through R_8. When the voltage on the gate of Q_4 reaches about 2.5V, Q_4 turns on, pulling the gate of Q_3 to ground and shutting it off. This shutoff removes the input voltage from the IC. As C_5 discharges into the IC, D_5 becomes forward-biased and supplies voltage from the output to the IC.

AS C_5 DISCHARGES INTO THE IC, D_5 BECOMES FORWARD-BIASED AND SUPPLIES VOLTAGE FROM THE OUTPUT TO THE IC.

If a power glitch or a momentary short circuit causes the output voltage to drop below the minimum that the LT1072 needs to operate, diode D_7 will rapidly discharge C_6, allowing the input voltage again to be applied to the IC. When the voltage rises again, normal operation will resume. EDN

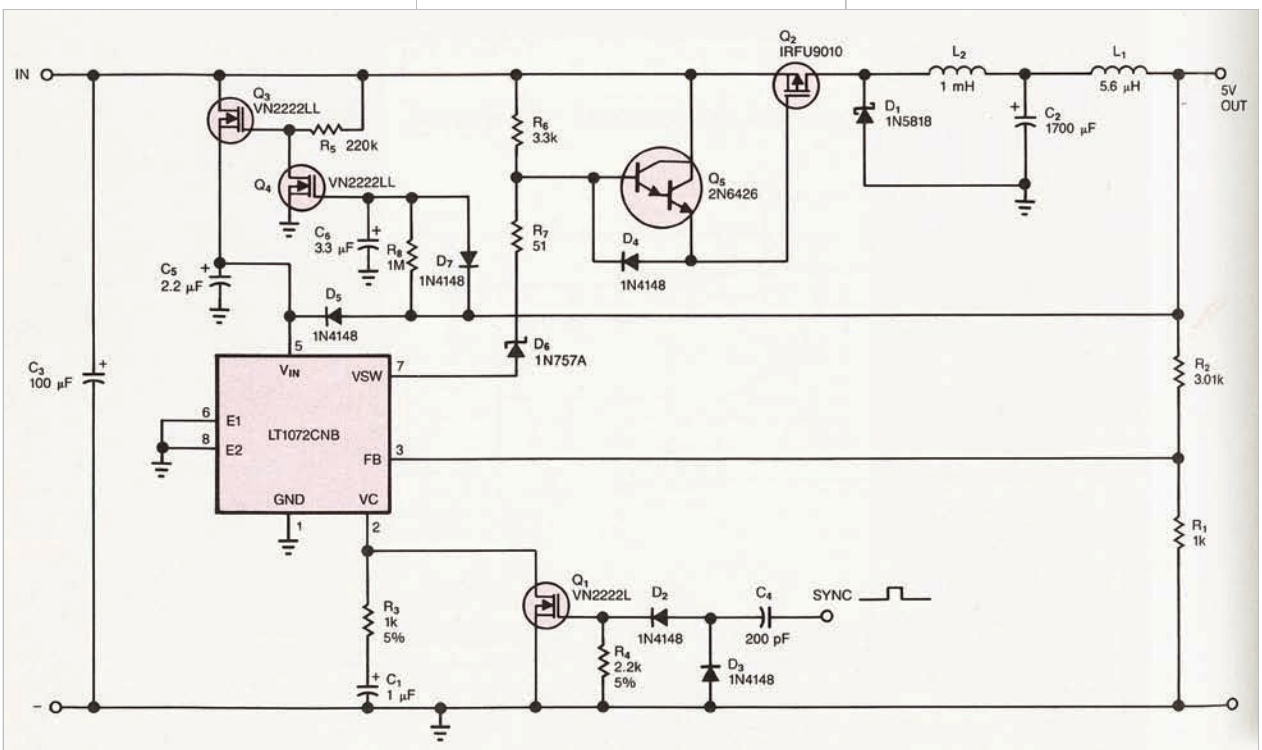

Figure 1 This switch-over circuit powers the regulator IC from the supply's output after the supply starts up. Running the IC from the lower-voltage output instead of the input raises the supply's efficiency from 77% to 83%.

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Out-of-spec problem with a long tail

In the mid-1960s, early in my career as an engineer, I found myself facing a problem that at the time appeared impossible to solve. My employer had been awarded a contract to design, develop, and produce specialized surveillance equipment related to the war effort in Vietnam.

Field testing on the initial units had gone well, and the company was in a full production swing when an unusual problem appeared. The returned modules contained a specially designed video amplifier showing inadequate gain. The only clue as to what might be wrong was a slightly out-of-spec dc bias level at the joined emitters of a long-tail pair of differential amplifiers housed in the amplifier module.

A review of the test data showed the units had met spec when they left for the field. A review of the design revealed no issues. The design used the values stipulated in the device data sheets, and the transistor data showed an adequate ac and dc beta that was within the specified temperature range.

I could find no errors in the way the units had been designed or in the selection of the parts used. I was stumped.

Keep in mind that all of this took place in the days predating the cubicle, when engineers were allowed to have offices with doors and usually shared them with an office mate. As luck would have it, my office mate happened to manage the IBM System/360 computer our company had recently purchased.

My office mate was also familiar with the problem I was troubleshooting and suggested we join forces and use the problem as a test case to show management the benefits of computer-aided analysis. (Again, these were the days when slide rules were still in common use.) The plan was for me to model the circuitry on paper and create simplified models of the devices and transistors. The transistors would be modeled in a hybrid-pi configuration using data from manufacturer data sheets.

I then wrote loop equations in matrix form compatible for programming and input into a subroutine program that inverted and processed the matrices. The input to the central IBM computer was via a time-shared teletype terminal.

The code was written in a BASIC language and comprised two parts: a separate dc simulation and an ac simulation with random number generators associated with the software to simulate the variations in parameter values due to the effects of tolerances and changes in temperature.

MY OFFICE MATE SAW THE PROBLEM AS A TEST CASE FOR PROVING THE BENEFITS OF COMPUTER-AIDED ANALYSIS.

After several Monte Carlo sensitivity runs—which incorporated a worst-case temperature spread on suspected components, including the transistor betas—we found that when we varied the dc beta to simulate the slightly out-of-spec dc level of the returned units, the dc-beta spread of the transistors associated with the long-tailed pair became slightly broader than the spread listed on the manufacturer's data sheet.

We set up a special test station in manufacturing and tested incoming transistors. Into one pile went the transistors that fell within a spread that was slightly smaller than that advertised in the data sheet to account for a degree of degradation. We rejected transistors that fell outside the stipulated range, as we suspected the failed units to be marginal cases.

Not long after this adjustment, the problem in the field essentially vanished. My office mate and I were hailed as heroes, the company was sold on computer-aided circuit analysis, and the experience taught me never again to put my complete trust in a data sheet. EDN

Paul P Wollam is an engineer living in northern San Diego County. His career has spanned a frequency range from dc to light wave.

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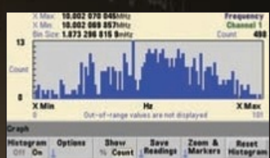

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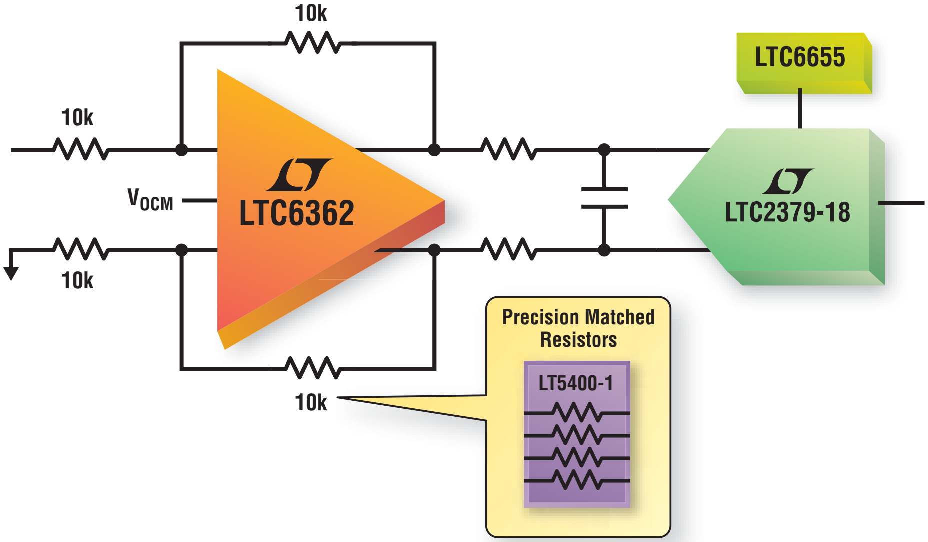

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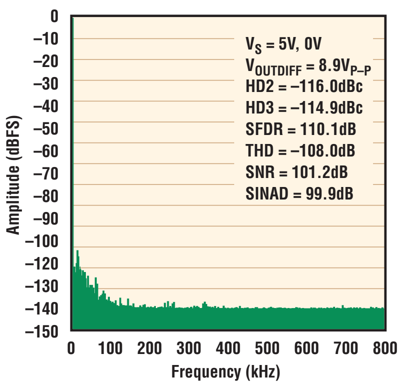

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