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VOICE OF THE ENGINEER

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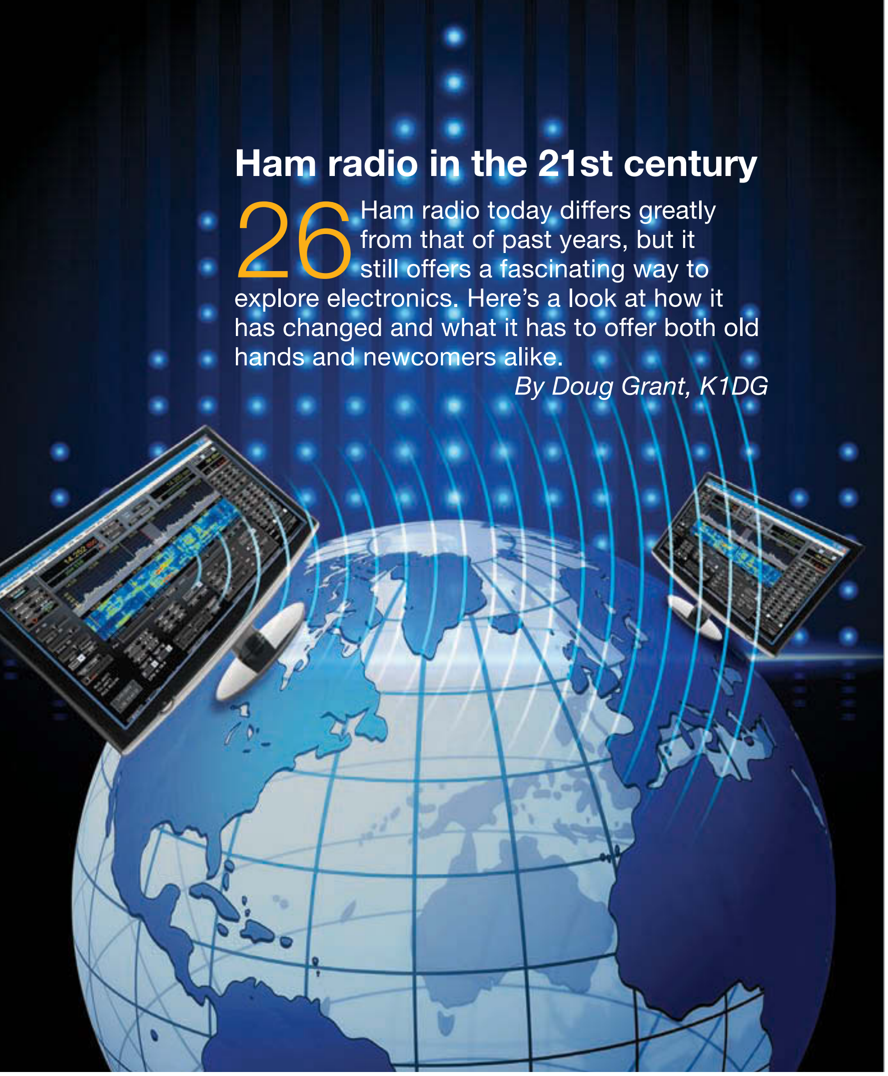


Ham radio in the 21st century

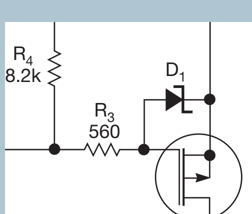
Advanced security prevents counterfeit products

Designing smarter for single-battery applications

Powering DDR memory and SSTL

COVER: IMAGE(S): THINKSTOCK, SHUTTERSTOCK

DESIGNIDEAS



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EDN online

JOIN THE CONVERSATION

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

In response to "Computer History Museum honors Jim Williams and Bob Pease," by Paul Rako, http://bit.ly/reR0YC, Joel Libove commented:

"Seeing Jim's workbench and reading his and Bob Pease's great articles gave me comfort in our company's equally messy and overcrowded but very productive labs. Instead of being distracted with fluff and appearances, Bob and Jim focused on the key engineering ... issues ... and thereby encouraged the right mix of creativity and rock-solid design methodology in a generation of us newer engineers. I deeply miss them both."

In response to "Silicon's not irrelevant after all!" by Patrick Mannion, http://bit.ly/oHWRh7, Meredith Poor commented:

"I've been programming since 1970. The first CPU I worked on was a direct ancestor of the 8008: the Datapoint 2200. This implementation predated DRAM; it used a solid-state recirculating memory.

I was always trying to figure out what the next iteration of Moore's Law would allow ... . Time and time again, I would believe that we would be able to run multiple concurrent tasks, avoid virtual memory, etc, only to find that the next generation of hardware didn't have enough oomph.

When I think of algorithms for recognizing various ... plants from video or still pictures ... a lot of software is needed, but this has got to finish well within one's lifetime, so the hardware resources are critically important. As the hardware resources have improved geometrically, more software is needed per dollar of hardware ... . However, as expectations rise, so does the need for hardware-level rocket science."

EDN invites all of its readers to constructively and creatively comment on our content. You'll find the opportunity to do so at the bottom of each article and blog post. To review current comment threads on EDN.com, visit http://bit.ly/EDN_Talkback.

CONTENT

Can't-miss content on EDN.com

VIDEO: ELECTRIC JUNKYARD GAMELON

Using coat hangers, rubber bands, and a piezoelectric transducer tethered to a microphone pickup, Terry from Electric Junkyard Gamelon used MakerFaire to demonstrate another of her musical creations, all constructed from everyday, well, junk.

http://bit.ly/pCPBV2

US-MADE LEDs MAKE THEIR WAY TO CHINA'S STREET LIGHTS

Cree, with its recent announcement that more than a million of the company's XLamp XP-G and XP-E HEW (high-efficiency white) LEDs went into China's first major highway LED lighting project, reported that it manufactured the LEDs in Durham, NC.

http://bit.ly/pyLQp0

ENGINEERING COMMUNITY

Opportunities to get involved and show your smarts

***EDN*'s VOICE OF THE ENGINEER BLOG** is all about giving you, the engineer, a voice. Open to our audience, we encourage engineers to share their perspectives on all matters of engineering, be that what's happening in the electronics industry, changes to design, what it means to be an engineer, or anything else of relevance to you and your peers. E-mail submissions to edn.editor@ubm.com and tune in to see what your fellow EEs have to say.

http://bit.ly/VoiceOfTheEngineer

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BY SUZANNE DEFFREE, MANAGING EDITOR, ONLINE

School daze: Do you need a degree to be a real engineer?

During a recent conversation over lunch with some co-workers, I made a statement that turned a few heads. One co-worker's daughter had plans to look at colleges over the weekend, and I noted that my husband and I don't expect our son to go to college. This comment was somewhat surprising because both my husband and I are college graduates who look back fondly on our days in school and because our son is a toddler and his college years are more than a decade away.

My point, however, was that, with the rising cost of a college education and so many success stories about people lacking a degree, he may choose a path that does not ultimately include a stop at college.

This lunchtime conversation occurred a few days after ESC (Embedded Systems Conference) Boston 2011, where *EDN* and its sister publications hosted a networking event for students and young engineering professionals as well as experienced engineers (**Reference 1**). About 25 people attended, including some of the smartest 20-somethings I've had the pleasure of meeting in the more than 10 years I've been covering the electronics industry.

Many of these newbies were from local universities, and all spoke positively about their schools. Yet, college for some of these young men and women seemed more like an avenue to opportunities than an isolated learning experience. In speaking with these students, I heard them talk more enthusiastically about their hands-on efforts at internships, student groups, lab time, or design competitions than about their classes.

For some, college can be a stifling experience. Apple co-founder Steve Wozniak made statements to that effect a few months earlier when he spoke at ESC Silicon Valley 2011. The late Steve Jobs also had made similar comments on numerous occasions.

If a company of such influence could be born with two of the founders lacking a sheepskin, I wonder: Do you need to go to school to be an engineer?

Two of the three minds behind Apple lack a college degree. If a company of such influence and that offers products that dominate the market on a worldwide scale could be born with two of the three founders lacking a sheepskin between them, I wonder: Do you need to go to school to be an engineer, or is that idea just a mindset?

Clearly, you must educate yourself and always be learning, but do you need to learn at a college or a university? Does an engineering hobbyist deserve the same respect as a professional electrical engineer?

By the time you read this column, my son will be 20 months old, a far cry from the 20-year-old students we chatted with at ESC Boston a few short weeks ago. However, because I work at *EDN* and sometimes read the articles to him instead of nursery rhymes, he's already—I am convinced—showing the early signs of STEM (science/technology/engineering/mathematics) talent. He takes apart everything he can, methodically categorizes his toys, and does some basic math. In other words, he has what *EDN* Technical Editor Margery Conner and Dilbert creator Scott Adams describe as "the knack."

My son will grow up to be what he wants to be, but, if he decides to pursue a career in engineering, will he need to go to college to do so? Please let me know so that I can start looking for a second—and, perhaps, a third—mortgage now. **EDN**

REFERENCE

1 Deffree, Suzanne, "Engineering the next generation," *EDN*, Sept 8, 2011, pg 10, http://bit.ly/reMSYH.

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IMAGE: THINKSTOCK


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EDITED BY FRAN GRANVILLE

pulse

INNOVATIONS & INNOVATORS

Handheld spectrum analyzer targets use in field maintenance of base stations

Rohde & Schwarz has developed a rugged, lightweight, and portable spectrum analyzer for maintaining or installing transmitter systems, checking cables and antennas, and assessing transmitted-signal quality. The FSH4 and FSH8 series of analyzers can also demodulate and analyze all signal bandwidths as high as 20 MHz that are defined in the LTE standard. Coupled with demodulation and analysis of 3GPP WCDMA, CDMA2000, and EVDO, the FSH series spectrum analyzers provide an all-in-one solution for field maintenance.

The analyzers check signal quality in the spectral and the time domains using channel power and pulsed signal measurements and measure the spurious emissions of mobile-radio base stations using the SEM (spectrum-emission-mask) function. Spurious emissions can interfere with adjacent transmitting signals, resulting in reduced signal quality and lower data rates. The FSH family supports all LTE measurements—from SISO (single-input/single-output) to MIMO (multiple-input/multiple-output) transmissions.

In addition, the family delivers spectrogram analysis of intermittent faults, distance-to-fault measurements on cables, and one-port cable loss measurements. The FSH series spectrum analyzers also measure antenna matching, test power amplifiers using full two-port vector-network analysis, and provide for a number of RF-power-measurement modes. The devices can serve as highly accurate RF-power meters at frequencies as high as 67 GHz when operating with the vendor's NRP power sensors. Using the FSH series power sensors, the FSH models can simultaneously measure the output power and matching transmitter-system antennas under operating conditions as high as 120W, and they normally eliminate the need for any extra attenuators. Prices for the FSH4 and FSH8 start at $9220 and $13,545, respectively.

—by Fran Granville

▷**Rohde & Schwarz**, www.rohde-schwarz.com.

The portable FSH4 and FSH8 spectrum analyzers help field engineers maintain and install transmitter systems, check cables and antennas, and assess transmitted-signal quality.

TALKBACK

"Here's a memorable expression my dad taught me that summarizes the gist of this article: 'Be not the first by which the new is tried nor yet the last to lay the old aside.'"

—Electrical engineer David Bogardus, in *EDN*'s Talkback section, at http://bit.ly/qaX1Q9. Add your comments.

Scopes with built-in function generators add AWG capability and more

A few months ago, when Agilent announced its moderately priced, 100- to 500-MHz InfiniiVision 3000 X series DSO/MSO family, the company also announced a built-in waveform generator. Although it is doubtful that the 3000 X series scopes were the first to include a waveform, or function, generator, it was the first function generator in moderately priced benchtop scopes from a major manufacturer and the first to integrate so well with the host instrument. Still, prospective users clamored for even more from the frequency-synthesizer-based signal sources, or function synthesizers.

The most widely demanded improvement was an AWG (arbitrary-waveform-generator) capability in addition to the original version's ability to produce more than a dozen fixed functions. Although they applauded the presence of the generator, critics wanted to know why they couldn't use it to output replicas of scope-captured waveforms, which could serve as stimuli for a system under test.

Now, only a few months later, Agilent has added the AWG capability, and customers who own 3000 X scopes with the waveform-generator option can obtain the new feature at no cost and install it themselves rather than send the scope to a service center. Agilent most likely had the AWG in mind from day one but needed more time to tweak the features before releasing it.

By taking advantage of the AWG, the manufacturer has added a family of options for such application-oriented tasks as power-system measurements and debugging and validating several popular serial buses. Moreover, unlike some competitive instruments, which can accommodate only one or two options at a time, these scopes work even when you install all available options; the options don't interfere with one another, and you need not uninstall any of them to make room for any other.

The scopes' waveform-generation capabilities do not eliminate the need for separately packaged generators. Although a well-designed generator in a scope costs less than a separate unit, can be easier to use, and can help to reduce benchtop clutter, a stand-alone generator can provide greater bandwidth, deeper waveform memory, greater vertical resolution, and such features as the ability to nest and conditionally insert waveform segments, thereby enabling the creation of far more complex signals.

The moderately priced InfiniiVision 3000 X series DSOs and MSOs are now capable of generating more than just fixed waveforms. The manufacturer has upgraded the optional built-in function synthesizer to enable generation of user-defined arbitrary waveforms, including replicas of captured waveforms.

The optional generator in the 3000 X scopes has relatively modest specifications—waveform memory of 8000 10-bit samples and a maximum output bandwidth of 20 MHz. Popularly priced, separately packaged generators usually offer waveform memory of 16,000 to 64,000 12-bit samples and 50-MHz or greater bandwidth. By comparison, the 3000 X series' top-of-the-line scope offers analog-acquisition bandwidth of 500 MHz and captures records as long as 4 million points in the interleaved half-channel mode. To output a captured waveform, you use the scope's highly advanced zoom capabilities to select the waveform segment you want the generator to reproduce. Usually, you must also invoke decimation, which can discard a large percentage of the acquired segment's samples so that the resulting record fits into the generator's memory and doesn't exceed the generator's output bandwidth. In other words, although the built-in generator is ideal for many scope users, those who need to produce longer signals or signals with more bandwidth or greater detail probably need separate generators.

US list prices for scopes in the InfiniiVision 3000 X series range from $2810 for a DSO with 100-MHz bandwidth on two analog channels to $11,590 for an MSO with 500-MHz bandwidth on four analog channels. You can convert any DSO to the corresponding MSO simply by licensing and activating software in the system memory. The AWG option adds $715, and BenchLink Waveform Builder Pro software costs $750. An advanced-math option adds $300. Application-oriented validation and debugging options cost $715 to $1500 each.

The manufacturer also offers promotional discounts on some models. One of these discounts allows purchasers of certain other products to obtain a four-channel, 350-MHz-bandwidth DSO at no additional cost.

—by Dan Strassberg

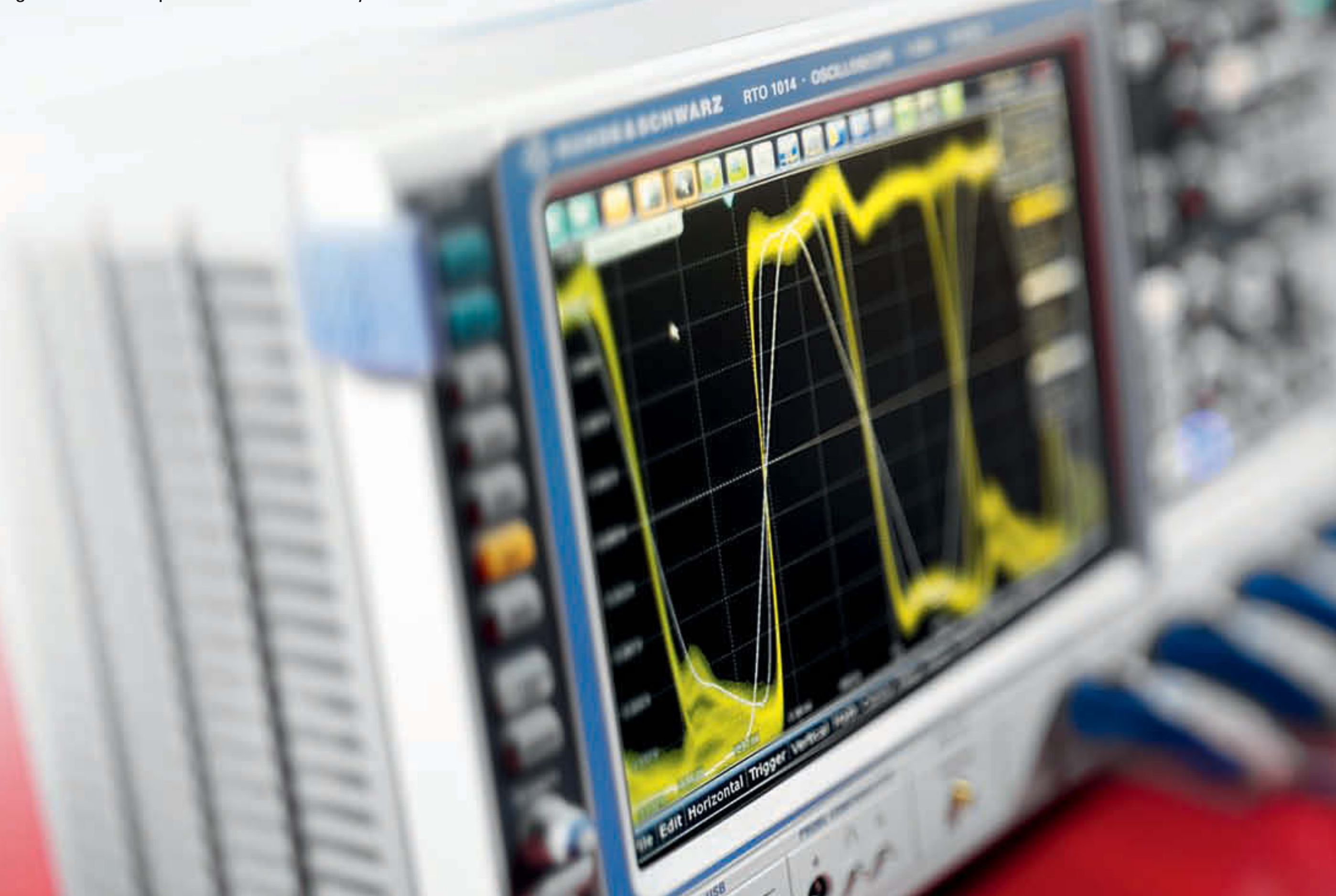
▷**Agilent Technologies**, www.agilent.com.

DILBERT By Scott Adams

Your question:
Why full bandwidth up to 1 mV/div?

Our answer: For high signal fidelity and measurement accuracy on fast, low-amplitude signals.

The R&S®RTO oscilloscopes offer high vertical input sensitivity of up to 1 mV/div. They always operate at high measurement accuracy because the full bandwidth of the oscilloscope can be used at even the lowest sensitivity levels. Furthermore, the R&S®RTO oscilloscopes do not use software-based zooming. They show the signal's real test points at all sensitivity levels.



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ROHDE&SCHWARZ

Drivers cover range of dimmable-LED lights, form factors

Marking what looks like the first introduction of a National Semiconductor part under the new Texas Instruments banner, TI has announced two new LED drivers—one with a National Semi heritage and one from TI. The two parts roughly sort themselves out into two power categories: The National-developed LM3448 targets 2 to 8W, dimmable-LED-lighting drivers, and the TI TPS92070 suits 6 to 20W, dimmable-LED-lighting drivers. Both products feature thermal shutdown, power-supply undervoltage lockout, cycle-by-cycle peak-current limit, and LED open protection.

The adaptive, constant-off-time, ac/dc, constant-current LM3448 LED regulator integrates a 600V MOSFET that targets integrated-LED-lamp form factors that require low-component-count, high-performance dimmable-LED drivers. It includes a phase-angle dimming decoder compatible with leading-edge TRIAC and trailing-edge electronic dimmers, allowing full-range LED dimming. An integrated 600V, avalanche-protected, high-voltage, low-on-resistance MOSFET reduces design complexity and improves LED-driver efficiency. The LM3448 can operate in both isolated and nonisolated systems employing buck, flyback, or buck-boost topology and using either active or passive, or valley-fill, PFC circuits.

The flyback, ac/dc, constant-current TPS92070 LED-driver controller suits use in both uniform- and dimmable-LED drivers. It includes TRIAC-dimmer-management circuitry that decodes dimmer-conduction angles and produces a visually pleasing exponential-LED-current profile. The TPS92070 targets applications requiring valley switching and driver-to-driver LED-current regulation of less than 5% during deep dimming. The innovative secondary-side feedback eliminates the need for optocouplers and error amplifiers that isolated designs require, reducing size and cost and enhancing safety reliability. The TPS92070 can operate in both isolated and nonisolated systems employing the flyback topology and allows flexible external-component selection for size, cost, and regulatory requirements. The TPS92070 can detect the presence of a TRIAC and disable the external valley-fill- or active-PFC function for improved dimming performance.

The highly integrated LM3448 and TPS92070 LED-driver ICs ease design complexity.

TI offers an online navigation tool that delivers a complete LED-driver design that designers can tune to their applications, adjusting for ac-input voltage, fixture type, isolation, and dimming requirements. The tool also recommends a configuration, along with design materials, such as data sheets, application notes, and evaluation boards.

The LM3448 and the TPS92070 are available in 16-pin SOIC packages and 16-pin TSSOPs, respectively. The LM3448 sells for $1.10 (1000), and the TPS92070 sells for 75 cents (1000). The higher price for the National part is likely due to the integrated FET.

—by Margery Conner

▷**Texas Instruments**, www.ti.com.

RF transistors use LDMOS technology for better saturation

STMicroelectronics' new RF power transistors use a proprietary technology that increases performance, ruggedness, and reliability in applications such as government communications, private mobile radio for use by emergency services, and L-band satellite-uplink equipment. Equipment such as wireless base stations and repeaters must achieve high RF power output at high frequencies and produce low distortion. These conflicting targets can complicate design and impose extra costs. LDMOS (laterally diffused metal-oxide-semiconductor) technology has proved successful in enabling designers to meet these targets, and STMicro has now further advanced the technology to enable equipment designers to increase system performance.

The LET family of RF transistors uses ST's latest STH5P LDMOS technology to achieve increased power saturation, which minimizes distortion at higher power levels.

The LET family of RF transistors uses the company's latest STH5P LDMOS technology to achieve increased power-saturation capability, which minimizes distortion at higher power levels. The devices can operate at frequencies as high as 2 GHz with major linearity, ruggedness, and reliability improvements. The family also has 10 to 15% better efficiency and 3-dB-higher gain than devices using earlier LDMOS processes, simplifying amplifier design and minimizing parts count. Other features include an increase in breakdown voltage to 80V from 65V and improved thermal performance, leading to greater reliability and increased load-mismatch capability.

Six devices in the LET family are currently in full production, and five more will enter production during this quarter. Available in the industry-standard bolt-down or eared package styles, they cost $31 to $128.70 (1000).

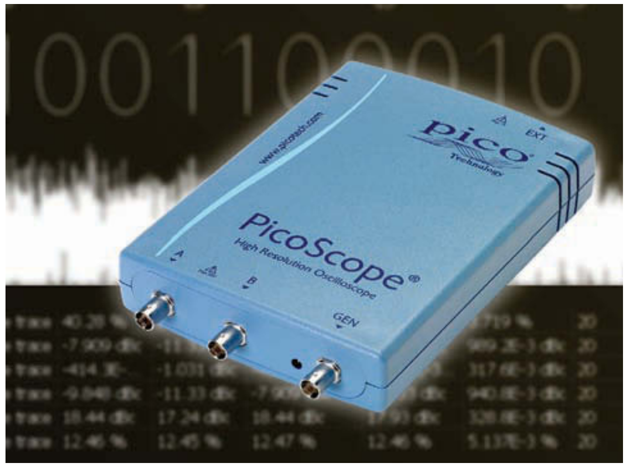
—by Fran Granville

▷**STMicroelectronics**, www.st.com.

USB-powered oscilloscopes feature real-time 1G-sample/sec rates

Pico Technology recently introduced the USB-powered PicoScope 2000 series oscilloscopes, which have real-time sampling rates of 1G samples/sec. Targeting engineers and technicians needing a complete test bench in a single unit, the devices feature two channels, bandwidths of 50 to 200 MHz, a built-in function generator, an arbitrary-waveform generator, and an external trigger input.

The scopes are supplied with a full version of PicoScope oscilloscope software. In addition to standard oscilloscope and spectrum-analyzer functions, PicoScope includes additional features, such as serial decoding, mask-limit testing, segmented memory, and advanced triggers. Other advanced features include intensity- and color-coded persistence displays, math channels, automatic measurements with statistics, and decoding of I^{2}C, UART, RS-232, SPI, and CAN-bus data. The vendor frequently releases free software updates.



PicoScope 2000 series oscilloscopes have real-time sampling rates of 1G samples/sec.

The PicoScope 2000 series devices use digital triggering, which ensures lower jitter, greater accuracy, and higher voltage resolution than the analog triggers on many other scopes, according to the vendor. The advanced trigger types include pulse width, interval, window, window pulse width, level dropout, window dropout, runt pulse, variable hysteresis, and logic.

A free software-development kit allows you to control the scopes from your own custom applications. The kit includes example programs in C, C++, Excel, and LabView. The software-development kit and PicoScope are compatible with Microsoft Windows XP, Vista, and Windows 7.

Prices range from £349 (approximately $550) for the 50-MHz PicoScope 2206 to £599 (approximately $942) for the 200-MHz PicoScope 2208 and include a five-year warranty.

—by Fran Granville

▷**Pico Technology**, www.picotech.com.

11.03.11

Virtual target eases software development

A virtual target from Altera employs virtual-prototyping products from Synopsys and targets developing device-specific embedded software for Altera's SOC-FPGA devices. The PC-based SOC-FPGA virtual target is a binary- and register-compatible, functionally equivalent simulation of an Altera SOC-FPGA development board. Familiar Linux, VxWorks, and ARM development tools support the virtual target, maximizing legacy-code reuse.

The prebuilt virtual target features the same dual-core ARM Cortex-A9 MPCore processor and system peripherals as those in Altera's Cyclone V and Arria V SOC FPGAs, along with board-level components, including DDR SDRAM, flash memory, and virtual I/Os. To enable application-software development targeting both the hardened processor system and customer-designed FPGA-based IP, the company provides an optional FPGA-in-the-loop extension of the virtual target. This extension uses an Altera FPGA development board that connects to the PC-based virtual target over a PCIe interface.

The virtual target and the FPGA-in-the-loop extension let users add custom peripherals and hardware accelerators to the processor subsystem, create device drivers for them, and integrate them with application software before final hardware availability. Embedded-software developers can boot Linux using a prebuilt Linux kernel image with device-driver support for all of the major components of the SOC-FPGA development board. Free downloads of a prebuilt GNU tool chain and Linux source also are available.

A VxWorks BSP (board-support package) will become available this quarter for the virtual target, with more BSPs to follow for other embedded operating systems. Other supported development tools for the virtual target include the ARM Development Studio 5, the Lauterbach Trace32 debugger, and the Wind River Systems Workbench. As a simulation model, the virtual target offers more visibility into the system during debugging; allows users greater control of the target execution, especially in multicore systems; and performs many debugging tasks that are difficult or impossible to do on hardware.

—by Colin Holland

▶**Altera**, www.altera.com.

BY HOWARD JOHNSON, PhD

IMAGE: THINKSTOCK

What quality is—and isn't

It's time to order up a new, custom-built truck. I live on the dry, sunny, eastern side of Washington state, at the end of a long, winding gravel road high up in the Cascade Mountains near the Canadian border. The road is as rugged as they come. It punishes vehicles—to the point at which their parts fall off onto the roadway.

My old truck held up to such mistreatment for 10 years before falling prey to a pair of teenage daughters. They added whole new dimensions of deterioration, including a permanent odor of perfume, cigarette burns, and dents and gashes on all four sides—all eliciting the same plaintive defense: "It wasn't me, Daddy!"

My new truck will need a manual four-wheel-drive transmission—something hairy with a bristling array of sticks and levers at floor level. Those features should protect it from further teenage abuse because the girls won't have a clue how to drive it.

The new truck will need a reliable engine. The Cummins 4BT turbocharged diesel looks good. With only four cylinders, this low-rpm, multifuel workhorse is not going to win any drag races, but it's not made for them. It's made to just keeping spinning reliably for a long time. It's tough. With a proper air intake, this baby would run underwater.

What's next on my list of requirements? No computers: A purely mechanical device suits me just fine. I know too much about computers to think that a vehicle becomes more reliable when you add electronics. It doesn't. It becomes a rolling, dirt-ingesting, overheating pile of silicon and programming that subjects your driving experience to the mercy of wires; more wires; software geeks; and, worst of all, wire connectors.

Please don't accuse me of being prejudiced against electronics. I'm not. I'm just experienced. I know quality when I see it, and I don't see it lurking behind the fancy flat-screen displays popular in automotive showrooms. Neither more features nor better gas mileage yields quality.

Quality is the feeling you get when you slam the door on a Rolls-Royce. It's the sound of a Mossberg pump-action shotgun. It's the solid, reliable look of a Bell System 2500 telephone, a product built to last for 40 years, the kind of heavy, substantial hunk of electronics that you could use, if necessary, to ward off an attacker. Let's see you do that with a cell phone.

Quality is not the result of comprehensive computer simulations. Quality is the result of knowing and anticipating, through experience, how an end user will actually use a product.

My old friend Ben Yamada, an industrial designer, told me that his first professional design task was an electric knife. He dutifully produced a bland, run-of-the-mill product with a buzzing, vibrating blade that, at least in the TV commercials, effortlessly sliced through turkey and ham. Later that year, he encountered the Hamilton Beach hole-in-the-handle electric knife. It was rounded, smooth, and beautifully colored, and it came with a stainless-steel blade. The hole-in-the-handle design offset the motor below the handgrip, improving the balance and allowing the cook to easily grip the slim handle. It was a masterpiece of quality design. It won awards. It sold like hotcakes. Ben was floored. He knew that somewhere, deep within Hamilton, lived an engineer who had chosen not to merely grind out another perfunctory design but had approached every aspect of the product with unrelenting dedication to style and quality—and it paid off. Ben cherished that inspiration for the rest of his career.

I don't see quality lurking behind the flat-screen displays in car showrooms.

When I look under the hood of my next truck, I want to see some quality. What will you see when you look under the hood of the product you are designing? **EDN**

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

ADVANCED SECURITY PREVENTS COUNTERFEIT PRODUCTS

BY DAVID RICHETTO • INSIDE SECURE

STRATEGIES AND TECHNOLOGIES ARE AVAILABLE TO HELP ENGINEERS DEVELOP AND IMPLEMENT SECURITY MEASURES TO PREVENT COUNTERFEIT PRODUCTS FROM ENTERING THE SUPPLY CHAIN.

Product counterfeiting has been an issue in many industries, from consumer products to ICs. In many instances, the counterfeit products affect only the bottom line and a company's reputation. High-end luxury consumer goods, such as handbags, wristwatches, and other products, are among the most susceptible to counterfeiting, and the brand holders spend large amounts of money to trace and eliminate the counterfeit products and the people responsible to ensure that fake products don't sully their brands. The IACC (International Anticounterfeiting Coalition) estimates that brand holders lose approximately $600 billion of revenue annually due to counterfeiting. According to Michael Danel, the secretary general of the World Customs Organization, if terrorism did not exist, counterfeiting would be the most important criminal act of the early 21st century.

IMAGE: THINKSTOCK

The effect of counterfeiting is always greater than the value of the counterfeit product itself. By damaging consumers' perception of the performance, reliability, and safety of branded devices, counterfeiting tarnishes brand image, customer loyalty, and satisfaction. It also has broader negative effects, such as reducing the value of intellectual capital, eroding profitability, and stifling innovation. It hurts not only the companies making the components but also the financial health and ability to invest in future innovation of all companies across multiple industries—from intellectual-property-right holders of the embedded software, firmware, and codecs in these devices to proprietary SOC architectures.

Furthermore, counterfeits of electronic components and system-level products as well as mechanical products and prescription medications can also affect personal safety and security. Counterfeiters often sell an inferior product as the genuine article, and the fake products typically fail to meet the full range of genuine product specifications and performance standards. Unfortunately, counterfeit electronic products, including ICs and battery packs, have also found their way into military, health, and transportation systems, and those systems could fail in the field, jeopardizing military and civilian lives.

SECURITY OPTIONS

Engineers can use multiple approaches to preventing counterfeit products from functioning in a system and thus prevent potential damage. At the simplest level, a product such as a battery or an ink cartridge can include an electronic signature that the host system must recognize for the product to work. To add an extra layer of security, the product can include an encrypted identifier to ensure that the counterfeiters cannot duplicate the signature.

Containers holding prescription medications or stand-alone mechanical products also could be "tagged" by attaching a secure electronic ID tag. These tags can prevent counterfeit products from entering the supply chain. Manufacturers in the luxury-goods market can embed contactless tags that contain a security handshake in an ID tag that either attaches to or is permanently embedded in the product. The tag must also be small and be available in various form factors to accommodate the shape of various products—wine bottles, handbags, or jewelry, for example.

AT A GLANCE

- At the simplest level, a product such as a battery or an ink cartridge can include an electronic signature that the host system must recognize for the product to work.
- Properly implemented authentication using asymmetric cryptography—the core technology behind digital signatures and certificates—offers the robust protection that can thwart counterfeiters.
- Whether designers use an off-the-shelf product or design their own, the chip they use should include a secure RISC CPU; a hardware random-number generator; a hardware cryptographic-acceleration engine; a secured block of nonvolatile memory for secure storage of keys, certificates, user data, and other information; and communication interfaces, such as I²C or 1-Wire.
- Only an authentic product with knowledge of the private key can produce a correct digital signature.

Various approaches can be used to minimize the influx of counterfeit products into the supply chain. Technologies such as holograms and simple RFID transmitters are no longer adequate because counterfeiters keep up to date on the latest copying and code-breaking techniques. Using sophisticated manufacturing equipment and technologies, well-organized groups have now shifted their targets to include more low-margin, high-volume products, such as consumer electronics and consumables.

One of the main trade-offs of these authentication systems is the cost of protection versus the value of the protected product. This trade-off is especially critical when it comes to relatively low-cost products, such as toner cartridges, batteries, and other consumables. This cost factor has played a major role in preventing consumer-electronics manufacturers from successfully employing what is perhaps the best technology for protecting their products: asymmetric authentication.

Thus, more advanced security technologies are necessary to prevent the illegal copying of products. These more-robust approaches employ strong cryptographic techniques and strong authentication to protect some high-value products. Until now, however, these approaches have been too costly and complex to implement in lower-cost, high-volume products, such as ink and toner cartridges for printers and batteries for mobile devices. Such technologies add cost and complexity to the products they protect, and designers must walk the fine line between the product's cost and the overhead to protect the product.

For instance, a host can include an embedded, secure microcontroller to communicate with a secure chip in the ink/toner cartridge or the battery pack. The controller incorporates firmware to allow strong authentication between the printer and the cartridge or the system and the battery pack and can lock out cloned counterfeit products. Such a scheme, though, requires a communication channel between the printer and the cartridge or the host and the battery, and that requirement means the use of at least one or two more pins on both ends, which also drives up the system cost.

Going wireless can help eliminate the pins but can be a slightly higher-cost approach. For example, NFC technology, using the NFC-enabled product and standardized secure contactless tags and readers, can play a role in this market. Manufacturers can use such approaches to protect themselves and consumers by strengthening the anticounterfeiting arsenal.

GO ASYMMETRIC

Properly implemented authentication using asymmetric cryptography—the core technology behind digital signatures and certificates—offers the robust protection that can thwart counterfeiters. Asymmetric cryptography has proved to be so useful that it has become a common part of everyday life. Every Internet e-commerce Web site using a secure server employs asymmetric cryptography to secure transactions.

Asymmetric algorithms employ a public key and its corresponding, intrinsically linked private key. A counterfeiter cannot derive one key based on knowledge of the other key. Thus, only a toner cartridge that "knows" the private key can respond correctly to a printer's challenge, and the printer can determine this knowledge using only the corresponding public key. If a counterfeiter cannot obtain the private key, then a printer can "assume" that any toner cartridge responding correctly is authentic.

IMPLEMENTING ECC REQUIRES A SIGNIFICANT INVESTMENT IN HARDWARE AND SOFTWARE, INVOLVING A TRADE-OFF BETWEEN THE COST OF PROTECTION AND THE PRODUCT'S VALUE.

Although asymmetric cryptography offers superior security, it is by nature also demanding, complex, and costly to implement. The strength of technology provided by asymmetric cryptography is directly proportional to the key length used. As the key gets longer, however, so does the computational and software complexity. Increased complexity, in turn, demands more computational power, which demands larger, more complex and costly chips.

However, as the microprocessors available to counterfeiters wanting to hack these systems continue to become faster and cheaper, a key length that seemed adequate a few years ago may no longer offer adequate security, and the currently recommended RSA (Rivest/Shamir/Adleman) key size is 2048 bits. For this reason, effective asymmetric implementations have been too costly for all but the most high-end applications.

Enter the ECC (elliptic-curve cryptosystem), an emerging alternative to public-key cryptosystems, such as RSA, DSA (Digital Signature Algorithm), and Diffie-Hellman, for performing asymmetric authentication. ECC provides higher strength per bit than any other current cryptosystem, and the longer the key, the greater the difference. A 244-bit ECC key has the equivalent strength of a 2048-bit RSA key for security; a 384-bit ECC key matches a 7680-bit RSA key. Greater strength for any given key length enables the use of shorter keys, resulting in significantly lower computational loads and memory requirements, faster computations, smaller chips, and lower power consumption—all beneficial for implementations of asymmetric authentication in low-cost systems.

Nevertheless, implementing such a system requires specialized knowledge and a significant investment in hardware and software development. Again, the trade-off between the cost of implementing such technology and the value of what this technology is protecting has prevented most manufacturers from employing it.

BUY OR ROLL YOUR OWN?

Developing a custom chip or programming a microcontroller to execute the ECC can be a lengthy process. However, vendors including Infineon, Inside Secure, NXP, Renesas, and STMicroelectronics can deliver off-the-shelf security products. Most of these off-the-shelf products are based on technologies developed for the banking and smart-card industries.

Whether designers use an off-the-shelf product or design their own, the chip they use should include a secure RISC CPU; a hardware random-number generator; a hardware cryptographic-acceleration engine; a secured block of nonvolatile memory for secure storage of keys, certificates, user data, and other information; and communication interfaces, such as I^2C or 1-Wire (**Figure 1**).

These products should also include many dedicated antitampering schemes to protect against simple- and differential-power-analysis attacks and against physical attacks, including active shield, which actively protects your computer from trojans, spyware, adware, trackware, dialers, key loggers, and even some special kinds of viruses. It should also include environmental-protection systems, such as voltage, frequency, and temperature monitors; light protection; and secure management and access protection to prevent reverse-engineering or cloning. A collection of advanced-security firmware routines should ease the implementation of fully user-defined, nonvolatile storage of sensitive or secret data; set up identity-based authentication with user, administrator, and manufacturer roles; and perform authentication, digital-signature, and other advanced cryptographic operations using keys and data from the file system.

HOW DOES IT WORK?

The manufacturer of a toner cartridge or a battery embeds a chip such as an ASIC with similar features in each of its prod-

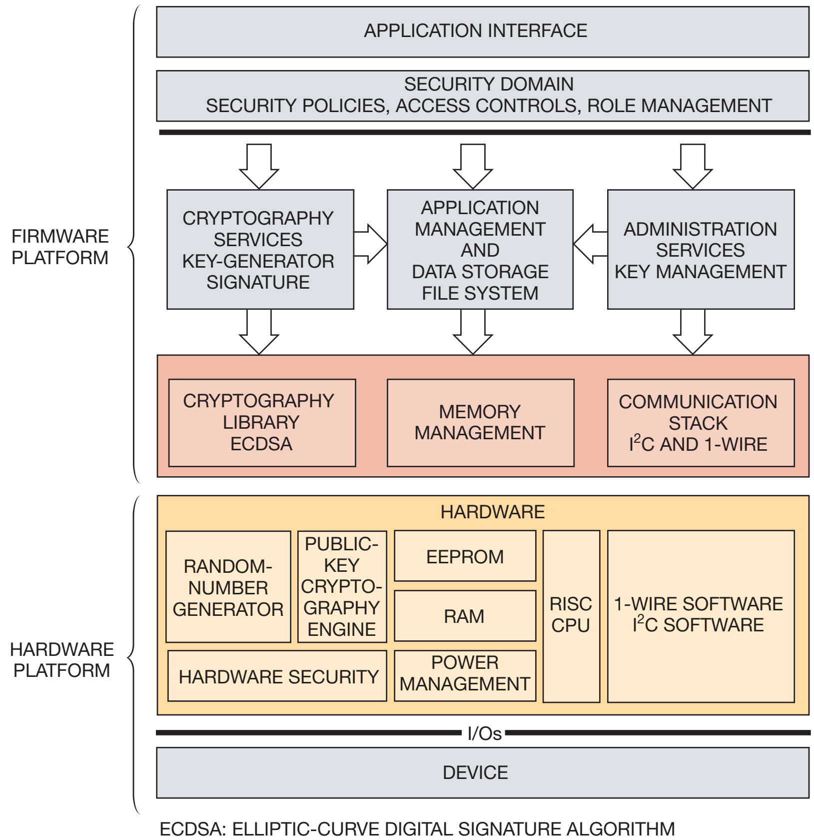


Figure 1 A security IC contains a dedicated cryptographic engine, a random-number generator, a RISC CPU, and simple serial I/O. Firmware layers above the hardware manage the memory, communications, and cryptographic library (courtesy Inside Secure).

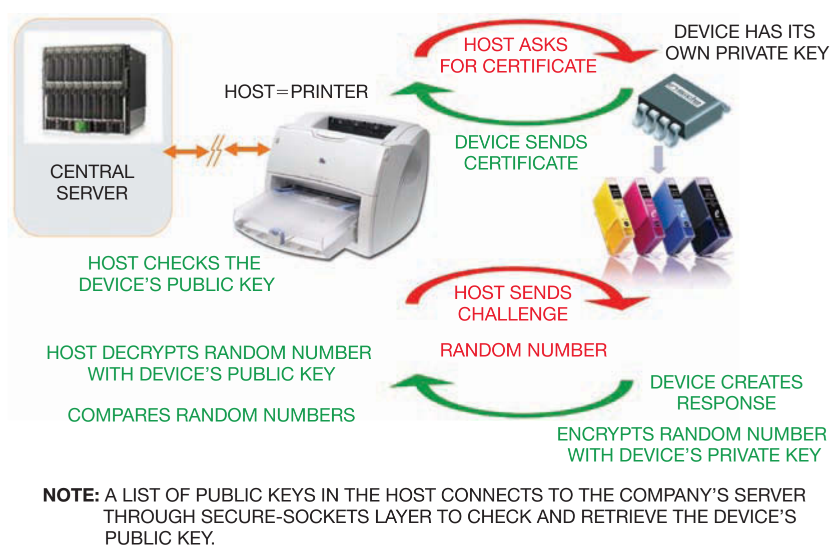


Figure 2 The IC uses its securely stored private key to compute the elliptic-curve digital signature of the challenge message and sends this digital signature back to the host. Using the corresponding public key, the host verifies the signature.

ucts. Each chip contains a private key and a certificate that has the approval of the printer, laptop, or mobile-phone manufacturer, as well as identifying information about the product, such as the model number. When a user inserts the consumable product into the host product, the host software first requests a random number from the IC's onboard random-number generator, along with a public key.

The host then combines that number with the public key to create a challenge message, which the host sends back to the accessory product. The IC uses its securely stored private key to compute the elliptic-curve digital signature of the challenge message and sends this digital signature back to the host. Using the corresponding public key, the host verifies the signature (**Figure 2**). Only an authentic product with knowledge of the private key can produce a correct digital signature. Using the result of the verification, the host decides whether to authenticate the accessory. The host can also determine whether this model number is correct for use with the host and could also use the product to track, for example, how many pages the printer has printed and use that information to send a replacement notification when the ink cartridge is nearly empty.

Manufacturers can implement a version of the security chip with an NFC interface, and this version can operate on induced power for a reader. Vendors would use this approach for products, such as wine bottles or designer handbags, for example, that have no built-in power source. Vendors can use dedicated readers at the point of purchase or even built-in NFC interfaces in the latest cell phones to activate the embedded NFC chip to authenticate the product. A typical NFC interface can transfer data at rates as high as 106 kbps, and such a chip might have a memory-storage capacity of approximately 1.5 kbytes. **EDN**

FOR MORE INFORMATION

Infineon
www.infineon.com

Inside Secure
www.insidesecure.com

IACC
www.iacc.org

NXP Semiconductors
www.nxp.com

Renesas
www.renesas.com

STMicroelectronics
www.st.com

World Customs Organization
www.wcoomd.org

AUTHOR'S BIOGRAPHY

David Richetto has more than 12 years of experience in the smart-card market and the development of secure ICs. He currently manages the application labs at Inside Secure (Aix-en-Provence, France) and the marketing activities for the company's anti-counterfeiting products. Previously, Richetto was application manager for smart-card and secure ICs at Atmel SMS, specializing in the SIM (subscriber-identity-module), bank, ID, and embedded-security markets. He has also managed the development of the first software layer of Gemplus (now Gemalto). He started his career at Motorola Semiconductor (now Freescale) in 1994 as a design engineer. Richetto has a degree in electronics and system engineering from École Nationale Supérieure d'Ingénieurs—Caen (Caen, France).

HAM RADIO IN THE 21ST CENTURY

HAM RADIO TODAY DIFFERS GREATLY FROM THAT OF PAST YEARS, BUT IT STILL OFFERS **A FASCINATING WAY TO EXPLORE ELECTRONICS**. HERE'S A LOOK AT HOW IT HAS CHANGED AND WHAT IT HAS TO OFFER BOTH OLD HANDS AND NEWCOMERS ALIKE.

BY DOUG GRANT • K1DG

Many of today's experienced engineers got their start in electronics through amateur, or "ham," radio. (Many theories exist over the origin of the term "ham radio," but there is no consensus.) Over the years, however, the demands of these engineers' work, families, and communities took precedence, and many hams lost interest and let their licenses lapse. Meanwhile, with the rise of personal communications and Internet connectivity in homes, many young engineers never needed ham radio as a way to explore electronics. They've missed the opportunity that this fascinating hobby presents.

The first wireless communicators were by definition all amateurs. Guglielmo Marconi himself, generally regarded as the inventor of radio, once famously remarked that he considered himself an amateur. In the early days of radio, commercial, government, and amateur stations shared the same spectrum, sending broadband spark-generated transmissions modulated by on/off keying using Morse code to convey messages. This practice resulted in a horrendous amount of interference among services until the government stepped in and assigned various services to specific bands.

IMAGE(S): THINKSTOCK, SHUTTERSTOCK

Government and commercial stations were assigned the supposedly more useful, less-than-1500-kHz, long- and medium-wave spectrum, and the amateurs were banished to the less-than-200m wavelengths with frequencies higher than 1500 kHz. The experts of the day regarded these bands as worthless for long-distance communications.

The amateurs soon discovered that long-distance communications were actually *easier* at these frequencies. New allocations were then created to give government and commercial stations some of the "good" spectrum. However, a handful of slices of the spectrum were reserved for the amateurs. In the late 1960s, amateurs laid claim to all of the apparently useless frequencies higher than 30 GHz. Since then, as technology has marched on, other services have discovered that these frequencies are useful; amateurs currently enjoy exclusive rights to the frequencies greater than 300 GHz.

In the United States, Part 97 of Title 47 of the Code of Federal Regulations controls the amateur-radio service (**Reference 1**). It expresses the fundamental purpose of the amateur-radio service in the following principles: recognition and enhancement of the value of the amateur service to the public as a voluntary, noncommercial communication service, particularly with respect to providing emergency communications; continuation and extension of the amateur's proven ability to contribute to the advancement of the radio art; encouragement and improvement of the amateur service through rules that provide for advancing skills in both the communications and the technical phases of the art; expansion of the reservoir within the amateur-radio service of trained operators, technicians, and electronics experts; and continuation and extension of the amateur's unique ability to enhance international goodwill.

LICENSING

Part 97 requires that amateur stations obtain licenses before they can transmit. The process for getting a ham-radio license has evolved over the years. Long ago, an applicant had to pass a rigorous technical exam that included drawing schematics from memory. The exams have changed considerably. All of the questions are now multiple-choice and cover technical, operating, and regulatory topics, and all of the questions and answers—both right and wrong—are available in the public domain. Furthermore, the governments of many countries—notably, the United States—have effectively outsourced the job of testing.

In the United States, volunteer examiners now administer the examinations. Volunteer-examiner coordinators arrange for testing sessions at convenient places and times (**Figure 1**). Upon successful completion of an exam by an applicant, the coordinators forward the required data to the Federal Communications Commission, which then issues licenses, with call signs—to identify each licensee and his or her location of license using a prefix and a suffix. In the United States, three classes of license now exist, each conveying a set of privileges, including permitted bands, modes, and power levels. Passing a more advanced exam entitles the licensee to more privileges.

The US amateur-licensing process no longer requires knowledge of Morse code for any class of license. This requirement has historically been a major impediment for many technically skilled individuals who were interested in ham radio but who could not or would not conquer Morse code. Ironically, the portions of the bands reserved for CW (continuous-wave) operation are busier than ever, as new licensees discover that narrowband modes are more effective for weak-signal work than are wider-bandwidth modes, such as SSB (single-sideband) voice.

Many amateurs make contacts using voice modes, primarily SSB mode on HF and FM on VHF and UHF. The signal-processing capabilities of a sound-card-equipped PC that connects to an HF SSB or a VHF FM transceiver have driven the emergence of new modes. Even a modestly equipped PC has sufficient speed to generate and decode the FSK signals for conventional radio teletype. Experimenters have created modulation schemes and accompanying protocols, complete with forward-

AT A GLANCE

- The US amateur-licensing process no longer requires knowledge of Morse code—historically, a major impediment for many individuals.
- The signal-processing capabilities of a sound-card-equipped PC that connects to an HF single-sideband or a VHF FM transceiver have driven the emergence of new modes.
- Most high-performance HF and VHF transceivers now use digital-signal-processing technology for at least some of the modulation, demodulation, and filtering functions.
- Ham operators have always been enthusiastic tinkerers, often building their equipment from discarded pieces of consumer electronics they find in their neighborhoods.
- Ham radio brings new aspects to other hobbies, such as mountaintop hiking and orienteering.

Figure 1 A group of prospective amateurs meets at a license-examination testing session.


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Figure 2 Yaesu's FTDX-5000 HF transceiver offers the highest receiver performance currently available.

Figure 3 The Elecraft K3 HF transceiver delivers high performance in a small package.

error correction, which enable direct keyboard-to-keyboard contacts even with low power and small antennas. The variety of FSK and PSK signals being used create unusual buzzing and chirping sounds when traveling to a speaker, and computers easily demodulate them and turn them into legible text. Some ingenious hams even use the PC's signal-processing capabilities to emulate the signals that World War II-vintage mechanical text-to-radio systems, such as Hellschreiber, generated.

Some hams also engage in transmission of full-motion video signals—usually on VHF or UHF bands, on which sufficient bandwidth is available. Others transmit still pictures on HF, using voice-bandwidth signals and a PC. Data networks have also evolved using various systems, including TCP/IP.

21ST CENTURY EQUIPMENT

Licensed amateurs can transmit in bands in the LF, MF, HF, VHF, UHF, and microwave bands. With a good antenna, amateurs' equipment can achieve worldwide communications on many of these bands.

Most amateurs buy their equipment from stores. Years ago, the best-known brands were mostly US companies, such as EF Johnson and Heathkit and the now-defunct Collins, Hallicrafters, and Hammarlund. Today, the most popular brands are mostly Japanese companies, including Icom, Kenwood, Yaesu, and Alinco (**Figure 2**). A few US manufacturers, such as Elecraft and FlexRadio, have entered the market in the past decade (**Figure 3**), and the first Chinese-made transceivers are beginning to appear, from manufacturers such as Wouxun.

The technology used in ham equipment has evolved significantly. Most high-performance HF/VHF transceivers now use digital-signal-processing technology for at least some of the modulation, demodulation, and filtering functions. A careful partitioning of both analog- and digital-signal processing achieves the best performance, and today's radios offer excellent sensitivity and 100-dB dynamic range, with digital-signal-processing-enabled selectivity. Although most radios still maintain the traditional format of a front panel with a large knob to control the frequency and lots of other buttons and knobs, some newer SDRs (software-defined radios), such as those from FlexRadio, abandon this tradition in favor of keyboard and mouse operation; they have no front-panel controls (**Figure 4**).

Handheld VHF FM transceivers have evolved to include multiband operation, embedded GPS, spectrum-analyzer displays to show signals on adjacent frequencies, and even Bluetooth. None have yet reached the level of sophistication of smartphones, but touchscreen-driven radios and Internet connectivity cannot be far off. Speaking of smartphones, hundreds of ham-radio apps are available for these devices, ranging from license-prep courses to satellite tracking to remote-station control.

However, not all hams buy their equipment off the shelf. Some prefer to build their own equipment. Ham operators have always been enthusiastic tinkerers, often building their equipment from discarded pieces of consumer electronics they find in their neighborhoods. Many hams understand concepts such as intermodulation distortion and phase noise, for example, because they have heard the effects of these signal imperfections, and they understand what happens when a nominally linear power amplifier enters hard compression.

Home-brewed radios can range from extremely simple transmitters and receivers to true state-of-the-art SDR systems. At the low end, one creative ham disassembled a compact fluorescent light bulb and discovered a high-speed, high-voltage switching transistor and assorted capacitors and inductors. By adding a 3.579-MHz TV color-burst quartz crystal, which sits conveniently in the middle of the 80m amateur band, he was able to construct a 1.5W CW transmitter from the parts (**Reference 2**).

Simple receivers are also easy to construct.

Figure 4 FlexRadio Systems' Flex-5000A software-defined radio has no front-panel controls at all.

Ham operator Charles Kitchin has developed a series of superregenerative receivers that are easy to build and that work surprisingly well (**Reference 3**).

The work of the High-Performance Software-Defined Radio Organization is at the cutting edge of radio design. This group has collaboratively developed a series of modules that use the latest high-performance components, including the RF amplifiers, mixers, ADCs, DACs, processors, and memory. For example, the Mercury receiver module enables direct sampling of the 0- to 65-MHz spectrum, using a 130M-sample/sec, 16-bit ADC and an FPGA to undertake digital downconversion. Open-source software performs all of the signal-processing and control functions, and the hardware also supports third-party software (**Figure 5**).

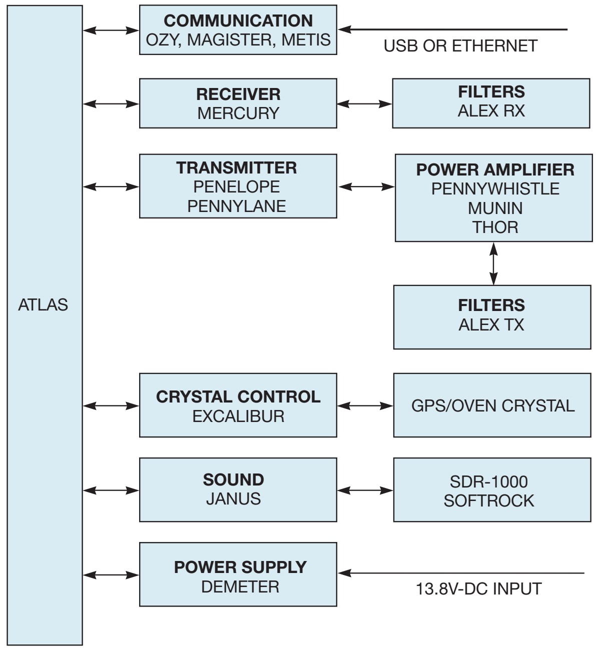

Figure 5 The OpenHPSDR provides a modular design for its open-source, collaborative software-defined radio.

An engineer interested in developing his own SDR radio can build or buy an RF front-end/quadrature downconverter and connect it to the audio input of a PC and buy or write appropriate software for the demodulation and detection functions. Connecting the baseband in-phase and quadrature outputs of the radio to the left and the right inputs of the PC completes all of the hardware work. Some hams have constructed SDR front ends in the form factors of USB memory sticks and draw their power from those sockets.

For those more inclined toward classic analog-radio design, OpenQRP is an interesting project. "QRP" is a ham abbreviation for low-power transmitter (**Figure 6**). The creator of the group, Steve Elliott, call sign K1EL, has developed an open-source hardware and software design for a simple low-power CW transceiver. He uses an Atmel microprocessor in the popular Arduino prototyping platform for the human interface and various control functions and provides a PCB and complete kit of parts. Elliott documented his trial-and-error design as it evolved, and his blog serves as an excellent tutorial on radio design (**Reference 4**).

THE STATE OF THE ART

Some segments of the ham-radio hobby allow you to impress your engineering friends, and maybe even your non-engineering friends. When you tell people you are into ham radio, they often ask, "How far can you reach with that?" The answer is complicated, and you may be able to give them some impressive answers. For nontechnical types, one answer I like to give is that, from my home in New England, my longest-distance contact for many years was Texas—the *long* way around. One morning about 20 years ago, I was operating on the 15m, 21-MHz band and had aimed my directional-beam antenna at Europe. A friend in Texas called in and said that he could hear me only when he pointed his antenna toward the Pacific. We tried various things and concluded that we were indeed talking to each other the long way around. HF propagation exhibits interesting behaviors at different times of day and season, and long-path contacts are relatively common.

Hams also experiment with other interesting and unusual terrestrial-propagation modes in the microwave region. In 2010, a group of French and Swiss amateurs took advantage of the evaporative duct—a horizontal layer in the lower atmosphere about 10 to 20m above the ocean's surface in which radio signals are guided, or ducted, and in which they experience less attenuation than they otherwise would. The amateurs used this duct to establish two-way SSB voice contacts between Cape Verde and Portugal at frequencies of 5.7 and 10 GHz—a distance of 2700 km, or nearly 1700 miles. Transmitter power was 15 to 25W, and the antennas were small—approximately 1m-diameter dishes.

A few years ago, Nobel Prize-winning astrophysicist Joe Taylor, call sign K1JT, developed the WSJT (weak-signal Joe Taylor) suite of protocols and modulation schemes for various types of VHF/UHF communications. Under normal circumstances, VHF and UHF signals can have path lengths of only a few tens or hundreds of miles long, depending on terrain, antenna gain, and power. WSJT changes that scenario.

One version of the protocol targets use in the RF-reflecting paths of ionized meteor trails, which last only a fraction of a second. It transmits a 30-sec-long sequence of four-tone FSK at a speed roughly equivalent to 100 words per minute, or 441 baud, in an effort to get enough bits over the short-lived path to enable an exchange of call signs and signal reports. Stations take turns

Figure 6 This low-cost, low-power continuous-wave transceiver uses a classic analog radio with a flexible programmable-control interface.

FOR MORE INFORMATION

Alinco
www.alinco.com

ARRL
www.arrl.org

Atmel
www.atmel.com

Elecraft
www.elecraft.com

Federal Communications Commission
www.fcc.gov

FlexRadio Systems
www.flex-radio.com

High-Performance SDR Organization
www.openhpsdr.org

Icom America
www.icomamerica.com

Kenwood
www.kenwoodusa.com

OpenQRP
http://openqrp.org

Wouxun
www.wouxun.com

WSJT
physics.princeton.edu/pulsar/K1JT

Yaesu
www.yaesu.com

transmitting and receiving, exchanging certain details to verify that each end of the path has successfully detected and decoded signals. Although the US military has for many years used meteor scatter, the mode generally requires huge antennas and high power to succeed. Taylor's system brings meteor-scatter communications to owners of relatively small stations.

Another WSJT mode is for earth-to-moon-to-earth, or "moon-bounce," communications, which uses the moon as a passive, and not very efficient, reflector. Signals at 144 MHz bouncing off the moon return to Earth about 2.5 sec later and approximately 250 dB weaker than when they left (**Figure 7**). That figure is not an error; the path loss is 250 dB.

Hams have for decades been bouncing signals off the moon, but only those with full-power transmitters, very sensitive receivers, and huge antennas could accomplish it using the traditional CW or SSB voice modes. Assuming a transmitter power of 1000W, or 60 dBm, and antenna gain of 20 dBi at both the transmitter and the receiver, the received signal is –150 dBm. A high-performance receiver can detect this weak signal in a narrow bandwidth. Amateurs have occasionally used the well-known 1000-foot radio-astronomy-dish antenna at Arecibo, Puerto Rico, for moon-bounce experiments. In the amateur band at 432 MHz, the dish has approximately 60 dB of gain and enables two-way contacts with simple stations on both SSB and CW modes.

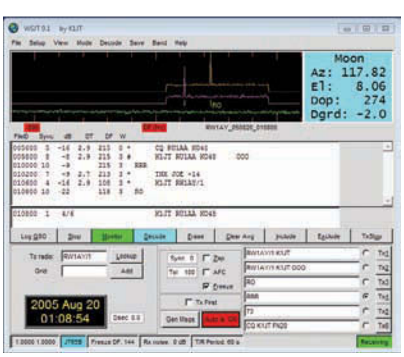

Figure 7 A two-way contact through moon bounce uses free WSJT software.

Taylor's WSJT moon-bounce system uses a nearly one-minute-long sequence of 65-tone FSK modulation, with a considerable amount of built-in coding and error correction. Fortunately, the coding and decoding are well within the processing capabilities of a modern PC, which can decode signals 24 to 28 dB below the noise in a 2.4-kHz bandwidth. Stations with simple 100W transmitters and antennas no bigger than TV antennas now routinely make contact with stations many thousands of miles away, as long as both are able to "see" the moon.

Radio amateurs have also used other satellites besides the moon for communication. Over the years, amateurs have designed, constructed, and launched more than 100 satellites, which usually carry one or more beacons; telemetry channels for various housekeeping functions and student-experiment payloads; and one or more transponders, which use one amateur band for the uplink and another for the downlink. ARISSat (Amateur Radio on the International Space Station Satellite)-1 was launched during a spacewalk by two cosmonauts. Many astronauts and cosmonauts have held amateur-radio licenses. The ARRL (American Radio Relay League) ARISS program frequently arranges demonstration contacts between astronauts aboard the ISS and school groups. The ARRL has been the national association for hams for almost 100 years. It publishes a range of books on virtually every facet of the hobby, along with study guides and manuals.

Ham radio can add a new dimension to a hobby you may already pursue. Some hams combine orienteering with radio-direction finding in "fox hunts." The organizers hide a series of small radio transmitters in a designated area covering a few square miles, and the competitors must use a portable radio and directional antenna to locate each of the "foxes." The combination of technical skill and running ability makes for a competitive sport. Another activity combines mountain hiking with the ham-radio hobby. Hikers carry lightweight, battery-powered radios and portable antennas to take advantage of the excellent signal propagation possible from high elevations. Both operators who get on the air from many summits and those who contact them can win awards in this sport. In addition, many sailors get their ham licenses and install amateur equipment on their boats for recreation and as emergency backups if all other onboard radio systems fail.

For those who are active in their communities, amateur-radio groups often coordinate with local and regional public-safety agencies to provide emergency communications when all else fails. Although most wired- and wireless-communications systems rely on infrastructure that may not survive natural or manmade disasters, a ham operator needs only a radio, a battery, and a piece of wire to get on the air. EDN

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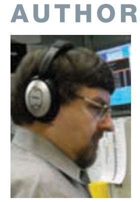

Doug Grant received his first ham-radio license from the FCC in 1967 and his bachelor's degree in electrical engineering from Lowell Technological Institute (now the University of Massachusetts—Lowell). He has more than 30 years' experience in the semiconductor industry, mostly at Analog Devices, where he worked in engineering; marketing; and product-line management for analog, mixed-signal, RF, and wireless products. He has logged close to 500,000 contacts with other radio hams in every country in the world. Grant is now an independent consultant specializing in semiconductor and wireless technologies.

BY JASON TOLLEFSON AND MIKHAIL VORONIOUK • MICROCHIP TECHNOLOGY
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Designing smarter for single-battery applications

DESIGNS USING ONE BOOSTED BATTERY CAN REDUCE A PROJECT'S OVERALL COST AND SIZE.

The vast market for battery-powered systems lends itself to a multitude of products in the consumer, medical, personal-care, and entertainment markets. Successful battery-powered products in these markets require intelligent control, maximized battery life, and minimal size and weight to support device portability. Rechargeable batteries can work well in devices that undergo frequent usage and operate at higher drain rates. For many applications, however, primary—that is, disposable, nonrechargeable—batteries can be the best fit because they support simpler and lower-cost implementation options that enable truly portable devices. Each iteration of battery-powered products, including blood-glucose meters, computer accessories, cameras, and wireless headphones, continues to become smaller.

A number of popular batteries are available to developers designing disposable batteries into their projects. Each battery option targets different devices and use cases (**Table 1**). Lithium-coin batteries—typically comprising lithium and manganese dioxide—feature packages in 13 sizes that fit within small, lightweight devices, such as timers and watches, which use relatively low amounts of energy and need a shelf life on the order of seven to 10 years.

Disposable alkaline and lithium-iron-sulfide batteries are available in cylindrical form factors. Alkaline batteries suit use in a variety of portable devices that exhibit a low to moderate drain rate. These batteries are more readily available and less expensive than other disposable batteries, and they are available in compact AA, AAA, and AAAA form factors. Lithium batteries are available in AA and AAA form factors and suit use in applications that exhibit medium to high drain rates or that must operate in cold temperatures. They provide highly reliable operation, are 33% lighter than alkaline batteries, and have shelf lives as long as 15 years—two to three times longer than that of alkaline batteries.

Although portable, battery-powered products continue to shrink, the size and shape of the battery cavity, which may house two or more batteries, is placing limits on the size of the batteries themselves. Therefore, to reach even smaller form factors, the ability to operate a microcontroller on one 1.5V battery is becoming increasingly valuable. Using a battery-boost converter in a design makes it possible to operate the system with one battery, whereas earlier designs relied on two or more batteries. A battery-boost converter, such as the Microchip MCP1640 power supply, boosts an input voltage up to a higher, regulated voltage, such as 2 to 5V.

By incorporating a battery-boost converter, a device can start up with an input voltage that is significantly lower than the operating voltage. For example, many microcontrollers cannot operate with a voltage that is lower than 2V, and

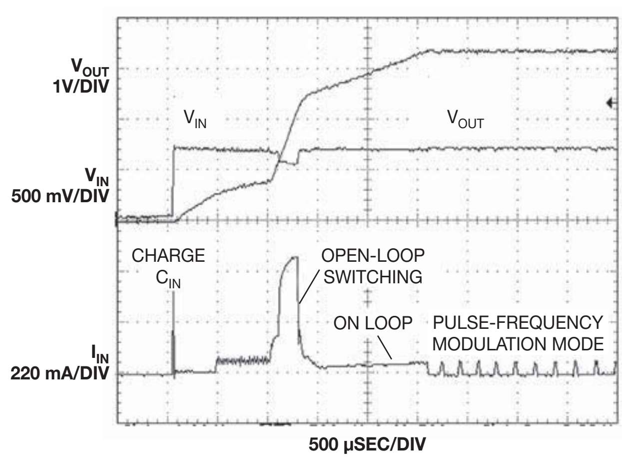

Figure 1 In a typical start-up waveform, the low-voltage start-up begins to charge the output voltage up to the input voltage. Once the output voltage is charged, the N-channel begins to switch, pumping up the output voltage, after which the internal bias switches from the input to the output.

TABLE 1 COMPARISON OF BATTERY TYPES

Battery	Key attributes
Cylindrical alkaline	Inexpensive; widely available; moderate drain rate; available in AA, AAA, and AAAA sizes
Cylindrical lithium	High performance, 15-year shelf life, high drain rate, extreme-temperature tolerant, high reliability, lightweight, available in AA and AAA sizes
Lithium coin	Small, lightweight, low drain rate, seven- to 10-year shelf life, available in 13 sizes

the battery-boost converter can provide the voltage that the microcontroller requires, with a start-up voltage as low as 0.65V (**Figure 1**). This feature enables an application using a boosted alkaline battery to start up at any point in its discharge curve, provided that it has enough remaining capacity to operate the device. Although a battery-boost converter may be able to deliver a consistent output voltage from input voltages as low as 0.35V, battery manufacturers do not recommend discharging alkaline or lithium batteries at voltages lower than 0.8V because doing so can damage the battery.

Using a single-battery implementation offers advantages that depend on which alternative-battery configuration you are comparing it with. The most straightforward approach is to compare one alkaline battery with two alkaline batteries. The most obvious differences are the volume and weight savings achieved by eliminating one battery. Using a battery-boost converter also maximizes the system power efficiency by providing regulated power over the battery's entire operating range. This regulated voltage can make the microcontroller more efficient by enabling it to run at a lower and flatter voltage. For example, reducing the microcontroller's operating voltage from 3.3V to 2.2V provides 1.8-times-lower power consumption on the microcontroller side. The boost converter also provides short-circuit protection through current limiting.

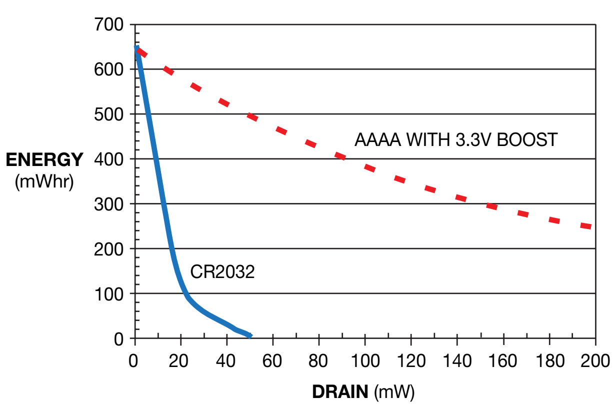

Figure 2 A single AAAA battery with boost delivers higher continuous-current draw than a lithium-coin battery when the current draw is higher than a few microamps.

The OEM cost for implementing the boost converter with one battery is slightly higher than the cost of two alkaline batteries, but the cost to the consumer for this approach is similar to that of using two batteries if the boost converter is operating at high efficiency. A single-alkaline-battery approach enables developers to make their product smaller without switching between battery chemistries from a legacy multibattery alkaline design. Working with one battery also simplifies the mechanical considerations of the battery housing and reduces the risk that the user will install the batteries incorrectly.

Designers comparing the pros and cons of implementing one alkaline battery versus a rechargeable lithium-ion-polymer battery will find similar but different reasons for selecting the single-battery approach. Because the boost converter provides a regulated power output, it allows you to tune the voltage to maximize system efficiency. Similar to the alkaline example, the boost converter provides short-circuit protection through current limiting. The 352-mm^2 AAAA alkaline battery is smaller than a 650-mm^2, or 31×21×3.5-mm, lithium-ion-polymer battery, even though the two battery types have the same volume, 2.3 cc, assuming a two-sided board design.

Using an alkaline implementation versus the lithium-ion-polymer device simplifies logistics because it avoids the need for charging circuitry and conforming to the regulations for shipping products containing lithium. For those applications in which using a replaceable battery is more convenient, implementing a boost converter with a single AAAA alkaline battery can cost 50 to 70% less for the battery portion of the system than that of a single lithium-ion-polymer battery plus a charge controller and a charger.

Comparing a single-alkaline-battery implementation with a lithium-coin battery demonstrates yet another advantage of the one-battery approach. This example compares an AAAA alkaline battery with a 600-mAhr capacity and a CR2032 lithium-coin battery with a 225-mAhr capacity. As in the lithium-ion-polymer example, using a single boosted alkaline battery avoids the need to conform to the shipping regulations for lithium batteries. Consumers are more familiar with cylindrical batteries, such as the AAAA, than they are with

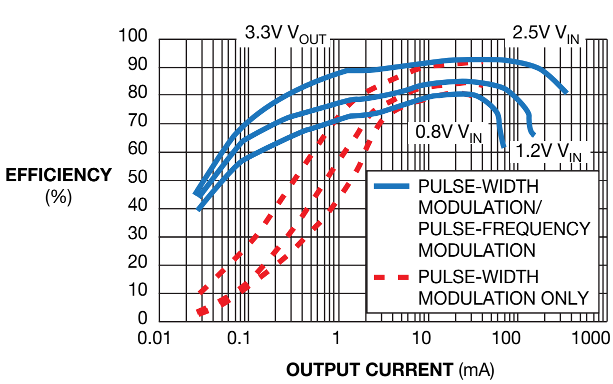

Figure 3 The efficiency of a boost converter depends highly on the current draw and the input and output voltages.

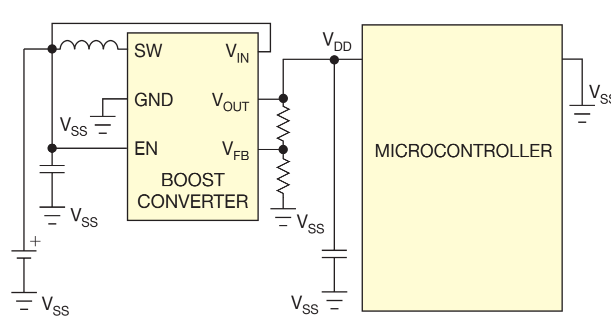

Figure 4 A typical battery-boost-converter configuration comprises a boost converter, two resistors, two capacitors, and an inductor.

coin batteries, increasing the chances of correct installation. The footprint of using either power source is similar, with the single alkaline AAAA battery taking approximately 352 mm^2, versus 314 mm^2 for the CR2032 lithium-coin battery, assuming a two-sided board.

The single alkaline battery continues to benefit from the tunable voltage to maximize efficiency and provide short-circuit protection through current limiting. However, the alkaline battery delivers a higher continuous current, whereas the CR2032 cannot. Specifically, the boosted alkaline battery can continuously source 150 mA, whereas the CR2032 can perform that task only for short pulses. Continuous current beyond 10 mA from the CR2032 battery dramatically decreases its usable capacity; even at 20 mA, it can deliver only one-fifth the energy that boosted AAAA batteries can (**Figure 2**).

TRADE-OFFS

Although using a battery-boost converter provides many advantages, such as enabling a microcontroller-based design to operate with a single battery, it is important to consider the system-level trade-offs between a boosted single-battery implementation and a multiple-battery design. The efficiency of the battery-boost converter highly depends on the current draw, as well as the input and output voltages. The dominant loss for a boost converter is resistance, so the efficiency of lower I/O voltages is lower than the efficiency of higher-I/O-voltage applications (**Figure 3**). Other factors that can affect the boost converter's efficiency are the resistive losses in the inductor and capacitors. Inductors with lower dc-series resistances and capacitors with low ESR (equivalent series resistance) allow higher efficiency; potential trade-offs are size and cost.

To support a lower system-current draw, the boost converter may include a low quiescent-operation mode, which typically draws 20 μA, and a shutdown mode, which draws less than 1 μA. With a microcontroller, a booster can provide a voltage to power the application in a sleep mode, using a "coast-down" method. The microcontroller turns on the boost circuit when the system voltage falls below a predetermined level and then shuts it off to eliminate the operating current of the booster and to continue to get power from the booster's output capacitor. Using this method, the total power consumption of the microcontroller and the boost regulator can decrease by as much as 87%.

Implementing a battery-boost converter enables a design to reduce the overall system area by the size of the second battery, with the trade-off of including the boost converter, two resistors, two capacitors, and an inductor (**Figure 4**). The weight of the boost converter and its accompanying components is negligible for most designs. The area of a typical boost-converter circuit is approximately 60 mm^2, which is considerably smaller than the 450-mm^2 area of a second AAA battery or the 352-mm^2 area of a second AAAA battery and still yields a 290- to 390-mm^2 area reduction in the overall system, assuming a two-sided board design. The OEM's cost for implementing the boost converter and its accompanying

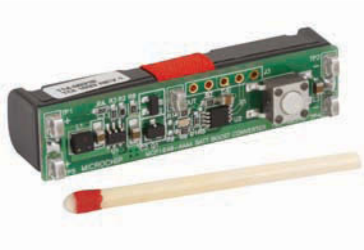

Figure 5 Reference designs can provide low-risk platforms for developers to more quickly understand how to use a boosted single battery in their designs.

components is approximately 20 cents, which may be offset by the alternative battery technology you are comparing.

Many semiconductor companies offer application notes, reference designs, or both for their boost converters. Microchip's MCP1640 single-AAAA-battery-boost converter reference design is one example (**Figure 5**). These reference designs help developers reduce their product's design cycle by providing a pre-engineered circuit that they can modify to meet their project's needs.

EXAMPLES

A boosted single-battery implementation not only enables differentiation through a smaller form factor for many applications but also provides a cost advantage over using coin or rechargeable batteries. The ability to minimize the width and weight of an electric toothbrush's handle, for example, enables the handle to feel more natural in a user's hand. Using a single battery also simplifies the mechanical-design effort to ensure that the user has correctly installed the battery.

Another benefit of boosted batteries is that the power supplied to the device is regulated, so it receives a flat voltage profile throughout the life of the battery. This approach enables the toothbrush to provide a consistent vibration throughout the life of the battery without a noticeable drop-off in vibration strength and, thus, performance as the battery discharges. The microcontroller can also modulate the vibration signal, such as generating pulsating vibration to signal to the user that the battery is approaching an end-of-life condition.

Flashlights, especially LED devices, can also benefit from a regulated supply voltage by using the boost converter to power a microcontroller, which in turn controls a more complex supply for the LEDs. The regulated supply can avoid a dimming of the flashlight as the battery discharges, hence providing consistent lighting through the battery's end of life.

Using one boosted alkaline battery can be appropriate in value-priced devices, such as a portable, wireless mouse. A value-priced mouse focuses on longer battery life by operating with low-frequency positioning updates appropriate for Web browsing and text editing, as opposed to higher-frequency updates for gaming. Wireless mice deliver a compact form factor with the single replaceable battery and have lower design and materials costs than do implementations that rely on a rechargeable battery. In addition to the cost difference among the battery technologies, using a replaceable battery means that the mechanical design avoids including an expensive connector for a recharging source.

Most consumers are familiar with and know where to acquire cylindrical AA, AAA, and AAAA batteries. Designs using these form factors can provide a simpler access hatch to replace the battery so that the user is confident the battery is installed correctly. Although other form factors, such as coin batteries, are not unusual, most consumers are less familiar with the notations for the coin devices' form factors and less familiar with how to install these batteries. The clear orientation for installing a cylindrical battery and the ease of acquiring replacement batteries provide an ease-of-use differentiation for a design.

An additional differentiation opportunity for boosted equipment is to incorporate RF connectivity in the volume gained from using only a single battery. Applications that can benefit include portable medical equipment, such as blood-pressure modules and blood-glucose meters, and beacons in industrial environments for tracking transportation containers.

The opportunities for delivering efficient energy through one battery span a range of applications. These applications demonstrate ways that a device using one boosted battery can enable a smaller form factor, lower weight, a lower cost of materials, and a simpler mechanical design than will a multiple-battery approach. Because consumers are more familiar with how to use cylindrical batteries, a single-battery system is more valuable. All of these benefits make it easier to consider migrating to a boosted single-battery implementation for the next iteration of your design. **EDN**

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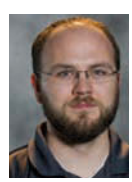

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BY PETER JAMES MILLER • TEXAS INSTRUMENTS

Powering DDR memory and SSTL

ALTHOUGH DDR MEMORY IS POPULAR FOR MEETING TODAY'S DEMAND FOR LARGE AMOUNTS OF HIGH-SPEED MEMORY IN SMALL FORM FACTORS, PROVIDING POWER TO DDR MEMORY CAN POSE SOME DIFFICULTIES.

Most modern electronics require some form of DRAM. By far, the most common DRAM is SSTL (stub-series-terminated-logic)-driven DDR (double-data-rate) memory. Conventional logic and I/Os use standard system bus voltages; however, DDR-memory devices need the precision that only local POL (point-of-load) regulators can provide. For sufficient noise margin, two of the five system supply voltages must reference other voltages. These voltages are the I/O V_{DD} (drain-to-drain voltage), the V_{DDQ} (drain-to-drain core voltage), the V_{DDL} (drain-to-drain logic voltage), the V_{TTREF} (termination-tracking reference voltage), and the high-current-capable midrail V_{TT} (termination-tracking voltage).

V_{DDQ}: THE SIMPLEST SUPPLY RAIL

Most DDR-memory devices use a common supply for core, I/O, and logic voltages; these terms are commonly combined and referred to simply as V_{DDQ}. Current standards include 2.5V for DDR and DDR1, 1.8V for DDR2, and 1.5V for DDR3. DDR4, which should debut in 2014, will have a voltage of 1.05 to 1.2V, depending on how far the technology advances before the release of the standard.

DDR memory's V_{DDQ} is the simplest supply rail. A variety of POL power sources can supply most DDR-memory devices because they allow 3 to 5% tolerance. Single-chip, onboard memory for small embedded systems might require only a linear regulator to provide 1 or 2A of current. Large multichip systems or small banks of DDR modules typically require several amps of current and demand a small switch-mode regulator to meet efficiency and power-dissipation needs. Large multimodule banks, such as high-performance processing systems, large data-logging applications, and testers, may demand 60A or more of V_{DDQ}, driving designers to develop processor-core-like, multiphase power supplies just to meet memory needs.

Although a conventional converter can typically support V_{DDQ}, it generally requires prebias support and the ability to regulate through high-speed transients as the memory switches states. No defined standard exists for prebias support, but it implies that the POL converter providing the V_{DDQ} must prevent sinking current from the V_{DDQ} supply if any voltage is stored on the V_{DDQ} bypass and output capacitors during V_{DDQ} power-up. This requirement is critical because SSTL devices commonly contain parasitic and protection diodes between V_{DDQ} and other supply voltages; V_{DDQ} can damage these diodes if it sinks current through them during start-up.

High-speed memory cells rapidly switch states. A memory chip or a module may change from a low-intensity sleep state, a standby state, or a self-refresh state to a highly demanding read-write cycle in just a few clock cycles. This rapid switching places another strong demand on the POL supply providing the V_{DDQ}. V_{DDQ} supplies should switch from only 10% of their maximum load current to 90% in 1 to 2 μsec. An array of small, local bypass capacitors near each V_{DD}, V_{DDQ}, and V_{DDL} input typically provides faster, cycle-by-cycle transitions to the memory device, and a combination of large output capacitors and high-speed control loops provides for sustained mode transitions and meets the tight accuracy requirements of DDR memory.

SMALL MEMORY SYSTEMS TYPICALLY USE A SMALL RESISTOR DIVIDER TO MINIMIZE ANY VARIATION IN THE THRESHOLD VOLTAGE.

V_{TTREF} REALIZES WIDER NOISE MARGINS

Whereas V_{DDQ} is a high-current supply that powers the core, the I/O, and the logic of the memory, V_{TTREF} is a low-current, precision reference voltage that provides a threshold between a logic high (one) and a logic low (zero) that adapts to changes in the I/O supply voltage. By providing a precision threshold that adapts to the supply voltage, V_{TTREF} realizes wider noise margins than those possible with a fixed threshold and normal variations in termination and drive impedance. Specifications vary from device manufacturer to manufacturer, but the most common specification is 0.49 to 0.51 times V_{DDQ} and draws only tens to hundreds of microamps.

Small memory systems using one or a few ICs typically use a simple resistor divider, employing the low leakage currents of the reference input voltages to minimize any variation in the threshold voltage and achieve the 2% tolerance necessary to realize the best possible noise margins. Large systems using multiple memory modules, such as standard DIMMs (dual-in-line-memory modules), typically elect a less sensitive,

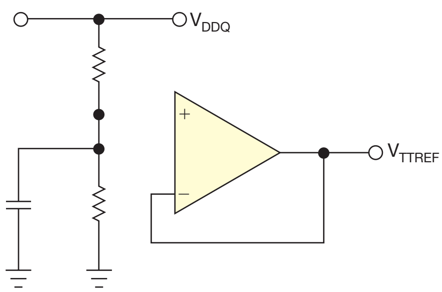


Figure 1 Large systems using multiple memory modules, such as standard DIMMs, typically elect a less sensitive, active approach to V_{TTREF}, such as an operational-amplifier buffer after the resistor divider or a voltage from a dedicated DDR memory, such as Texas Instruments' TPS51116, TPS51100, or TPS51200 switchers and low-dropout regulators.

active approach to V_{TTREF}, such as an operational-amplifier buffer after the resistor divider or a voltage supplied by a dedicated DDR memory (**Figure 1**), such as Texas Instruments' TPS51116, TPS51100, or TPS51200 switchers and low-dropout regulators.

V_{TTREF} should always be locally generated, referencing the V_{DDQ} at the source device to provide the most accurate threshold voltage and the widest possible noise margin. That requirement dictates that the memory's V_{TTREF} must reference the processor's V_{DDQ} and that the processor's V_{TTREF} must reference the memory's V_{DDQ}.

V_{TT} CLOSELY TRACKS V_{TTREF}

V_{DDQ} and V_{TTREF} are relatively straightforward power supplies. Most power converters source current to their output to maintain a regulated voltage or current at their output. This scenario is true even of a termination voltage for conventional logic, which is equal to the logic's I/O voltage.

The midrail V_{TT} in SSTL and DDR-memory devices is different. When the SSTL circuit generates a zero, an active pulldown device sinks current from the termination rail, and the termination supply acts as a conventional supply voltage, sourcing the required current to maintain the desired termination voltage. However, when the logic circuit generates a one, a pullup device sources current into the termination rail, and the termination supply must suddenly become a load, sinking current from the memory output. This sink-and-source requirement significantly increases the complexity of the V_{TT} design but provides a valuable feature to the memory device. Each logic one sources current into the termination, and each logic zero sinks a similar current from the termination. Therefore, the termination supply needs to support only the differential current—zeros minus ones—normalizing the load currents and improving signal integrity over rail-terminated logic.

Further increasing its complexity, V_{TT} must closely track V_{TTREF}. SSTL voltages are so low that small variations between V_{TTREF} and V_{TT} could quickly erode the noise margin and degrade signal integrity. Conventional regulators compare a divided version of the output voltage to a high-precision reference voltage to set an output voltage. V_{TT}, on the other hand, must compare an output voltage to the V_{TTREF} to ensure the widest possible noise margin, largest eye windows, and most accurate data transfer. This tracking requirement dramatically limits the range of available devices that can perform this task.

V_{TT} experiences more severe transients than most other power supplies that support similar current. V_{DDQ}, for example, might switch from 10 to 90% of nominal load in a few microseconds. If the data and address lines of a DDR memory switch from all zeros to all ones, however, the load seen by the termination supply rapidly changes from sourcing its maximum load to sinking its maximum load. This 200% load step makes transient performance critical for DDR-memory power.

For simplicity and load balancing, V_{TT} is usually generated using a tracking sink-source linear device, such as a high-current op amp or a dedicated sink-source low-dropout regulator. In such applications, V_{DDQ} commonly generates V_{TT}. This approach minimizes the power loss in a linear device by providing a low source voltage and normalizes the load current on V_{DDQ}. Any address line that does not draw current from the I/O function of V_{DDQ} by generating a one is sinking current from V_{TT}, which is drawing the same current from V_{DDQ}. Although not the most efficient approach, it does provide a consistent load equal to one-half- to one-times the V_{TT} current, I_{TT}, on the V_{DDQ} supply.

In large systems that terminate hundreds of lines, such as the long recording arrays in digitizing test equipment, or in extremely power-sensitive systems, such as battery-powered systems that must operate for extended periods without recharging, you can use a tracking synchronous buck switcher, such as TI's TPS40042 (**Figure 2**). A synchronous buck converter can draw current from its output, returning the recovered energy to its input voltage, much like a boost converter. This sink/source capability, along with the efficiency of a synchronous buck converter, makes the synchronous buck converter an ideal choice for high-current or high-efficiency termination. When using a tracking syn-

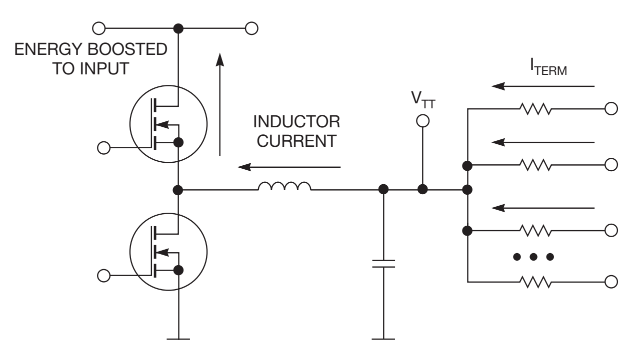


Figure 2 In large systems that terminate hundreds of lines, such as the long recording arrays in digitizing test equipment or in extremely power-sensitive systems, such as battery-powered systems that must operate for extended periods without recharging, you can use a tracking synchronous buck switcher, such as Texas Instruments' TPS40042.

chronous buck converter to realize the termination voltage, consider the source voltage for the termination converter. Although it is often a good idea to operate the V_{TT} regulator from V_{DDQ}, the low V_{DDQ} might make this approach impractical. Further, the cascade effect of double conversion can sacrifice some efficiency benefits that you might be able to realize with alternative schemes.

When V_{DDQ} is not used as the source for an active, switcher-based termination regulator, the termination regulator should share a common source with the V_{DDQ} regulator. This approach ensures that, when sinking current from logic ones, the active switcher cannot source more energy into its supply than the V_{DDQ} regulator is drawing. This step eliminates the need for the V_{TT} sourcing supply to also sink load current and prevents a dangerous overvoltage condition at the source of the V_{TT} regulator.

HOW MUCH POWER DO I NEED?

It's easy to figure out how much power your design needs, even if it's unclear after reading a data sheet. Consider, for example, the specifications provided for a 256-Mbyte SDRAM. The data sheet lists I_{DD} (drain-to-drain current), along with the expected input current for each state of operation. You could analyze the full operational cycle of the memory device, considering the worst possible rolling 10-μsec average, and design a power solution that can deliver only that much current. It is typically advantageous, however, to design a power solution that can provide continuous current equal to the maximum expected from the memory device.

When examining the data sheet's I_{DD} value, consider two key test conditions: output current and on-die termination. For example, a configuration with an output current of 0 mA with on-die termination disabled assumes no load and unterminated outputs. Any usable system, however, must have terminated outputs, and V_{DDQ} must be able to supply the full termination current when all outputs are high. The V_{DDQ} regulator must thus be able to source this maximum I_{DD} plus the full V_{TT} current.

A device with 16 data lines and as many as eight differential strobe lines has a maximum of 20 terminations, each of which can drive an output voltage as high as 1.8V into a typical 50Ω on-die or discrete termination resistor to a 0.9V termination voltage for 360 mA of current. This 256-Mbyte DDR2 memory chip might require as much as 680 mA of 1.8V supply current to maintain its I/O, logic, and core operations. For termination current on the V_{TT} supply, it is also necessary to terminate address, bank-address, clock, chip-enable, and other memory-logic lines for 38 terminations and 684 mA of termination current. You can ignore differential pairs because the termination current sourced by one will automatically sink into the other.

The V_{TTREF} leakage current, when V_{TTREF} is at a valid level—that is one-half of V_{DDQ}—is always less than 2 μA. If you plan to use a simple resistor divider, it is important to note that 2 μA of current across just 9 kΩ of resistance would introduce 18 mV of error, the total allowable error in the programming of V_{TTREF}, so relatively low resistor values should be used.

Power requirements become more complex as memory ICs are added. You need to consider whether the system allows multiple memory ICs or just one IC to operate in the high-power interleaved-read state at the same time. Typically, only one memory device sharing common address and data lines can be in this active state at a time. All other shared devices are in a lower-power state, such as a burst refresh.

After reviewing the worst-case operational state of each shared-memory device, add the I_{DD} for these states for all of the memory devices. For example, a 1-Gbyte memory system might use four of these 256-Mbyte ICs sharing the same address and data lines, with added logic to select which of the four memory devices the memory is accessing, effectively increasing the number of available address lines by two. After reviewing the operational states, you'll find that one device will be effective in continuous interleaved read, drawing 320 mA of current, but the other three devices will remain in burst refresh, drawing 180 mA each for a total of 860 mA of I_{DD} current. Because all of the outputs will share a common data bus and only one device drives these lines, 360 mA of additional V_{DD} current requires the same 20 output currents for a total of 1.22A of current from the 1.8V supply.

YOU CAN TRANSFORM MEMORY POWER FROM A DAUNTING TASK TO A VALUABLE ADDITION TO DESIGN BY MAXIMIZING NOISE MARGIN.

Termination current can share the termination lines, using common data, address, and bank selection. Chip-enable and command lines must be separate so that each chip can be accessed separately; therefore, each chip requires four additional terminations, bringing the total terminations to 50, for 0.9A of total termination current. With four chips, each able to sink 2 μA of V_{TTREF} current, even lower resistor-divider values must be used. An active V_{TTREF} buffer or a separate divider for each memory IC might also be desirable.

With attention to detail and care about the needs of each supply voltage, you can transform memory power from a daunting design task to a valuable addition to design by maximizing noise margin and improving accuracy. By understanding the function of each supply voltage, designers can more confidently select the power designs that best meet their overall design goals and balance among size, power, efficiency, performance, and cost.EDN

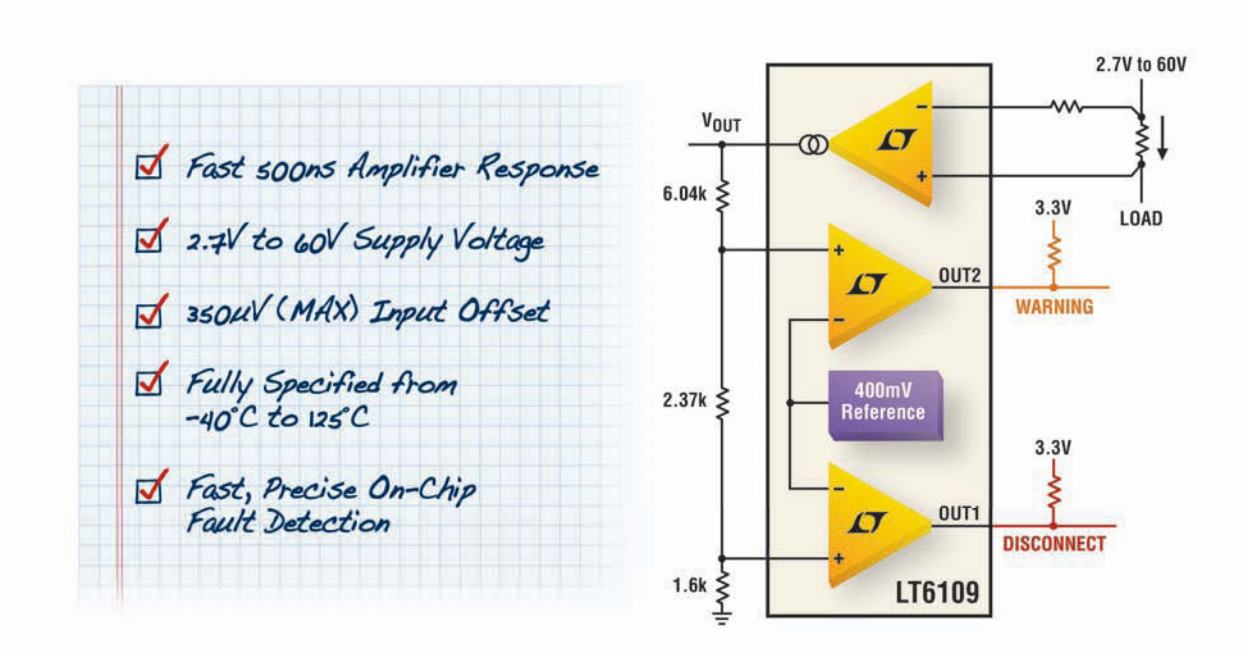
ACKNOWLEDGMENT

This article originally appeared on EDN*'s sister site,* Memory Designline*, http://bit.ly/n9oLAo.*

AUTHOR'S BIOGRAPHY

Peter James Miller is an applications engineer at Texas Instruments, where he supports technical applications for dc/dc controllers and evaluation-board design and develops internal and external application training for dc/dc controllers. Miller received both a bachelor's degree and a master's degree in electrical engineering from Worcester Polytechnic Institute (Worcester, MA).

Current Sense System



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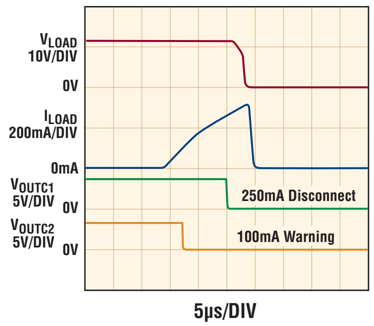
Current Sense Amplifiers

Part Number	Input Voltage (V)	Input Offset (µV)	Comments
LT1999	–5 to 80	750	Wideband AC CMRR
LT6100	4.1 to 48	300	5 Fixed Gain Settings
LTC®6101	4 to 105	300	Fast, High Voltage Monitor
LTC6102	4 to 105	10	Zero-Drift, Highest Precision
LTC6103	4 to 70	450	Dual Precision Amplifiers
LTC6104	4 to 70	450	Bidirectional Monitor
LT6105	–0.3 to 44	300	Monitors V_S Down to GND
LT6106	2.7 to 44	250	Lowest Cost, Simple
LT6107	2.7 to 44	250	Rated for –55°C to 150°C
LT6108	2.7 to 60	350	Includes Comparator + Ref
LT6109	2.7 to 60	350	Includes 2 Comparators + Ref

Response to Overcurrent Event



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LINEAR TECHNOLOGY

Circuit detects rapidly falling signals and rejects noise

Vladimir Rentyuk, Zaporozhye, Ukraine

Detecting a rapidly falling signal over some threshold is important for ultrasonic or location equipment as well as for seismology systems. You can combine a rail-to-rail operational amplifier with a Schmitt-trigger logic gate to perform this function (**Figure 1**). This example works well in an ultrasound machine. It controls a sample-and-hold amplifier that sets the gain of an AGC (automatic-gain-control) system.

The circuit works only with positive signals, so the signal must pass through a full-wave rectifier before it is applied to the circuit input. You configure the main part of the circuit, op amp IC_1, as a comparator with hysteresis. It produces a high-level output when an input signal is higher than the specified threshold. The output goes to a low level when the input signal begins to fall but only when the input falls faster than an established rate of change or if the level of the input signal will be lower than the established threshold of sensitivity. This circuit detects the moment when a signal is above the established threshold and the falling signal—or a mix of the signal and noise—has higher-than-specified speed.

R_1 and C_1 form an input lowpass filter to smooth the input signal. You set the values of R_1 and C_1 to create a filter roll-off for the input signal you are processing. Resistors R_3 and R_4 establish a small hysteresis, which is necessary so that slow signals with noise don't cause the output to change state. You set the threshold level with voltage divider R_6 and R_7. D_1, R_5, and C_2 form a peak detector. R_5 establishes a time constant of the discharge of C_2 and provides sensitivity to a falling signal's rate. You establish the circuit's sensitivity to a falling signal's rate of change using the time constant, which the values of C_2 and R_5 set. Hysteresis resistor R_4 is more than a decade larger than R_5, so the effect of resistors R_3 and R_4 is negligible.

A rising input signal greater than the threshold charges C_2 to approximately the level of the input signal. The output amplifier is at a high level because the

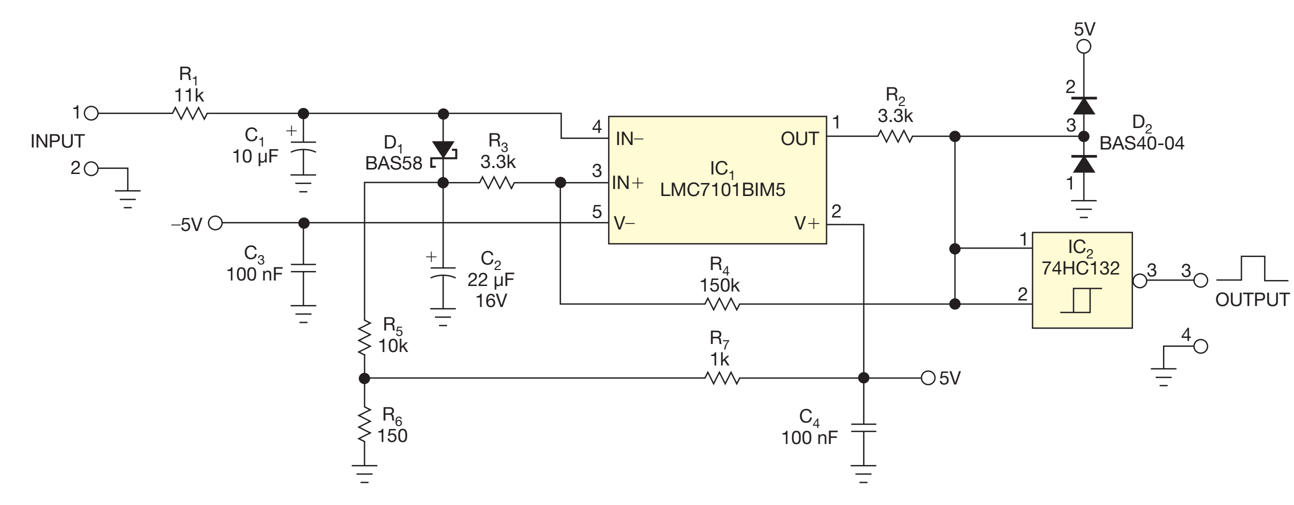

Figure 1 This circuit detects signal excursions higher than a set threshold and rejects noise and recognizes fast falling signals.

voltage on C_2 is always lower than the value of the rising input signal due to D_1's voltage drop. When the input drops faster than C_2 can discharge through R_5, the output level of the device changes to a low level because the voltage on C_2 is higher than the value of the falling input signal. If the input signal falls more slowly than the discharge of C_2 through resistor R_5, the output remains high. Schottky diode D_1 prevents the discharge of C_2 through the input. R_2 and D_2 clamp the amplifier's output to positive values. Feed the clamped signal to Schmitt-trigger logic gate IC_2 to give a logic-level output with fast transitions (**Figure 2**). EDN

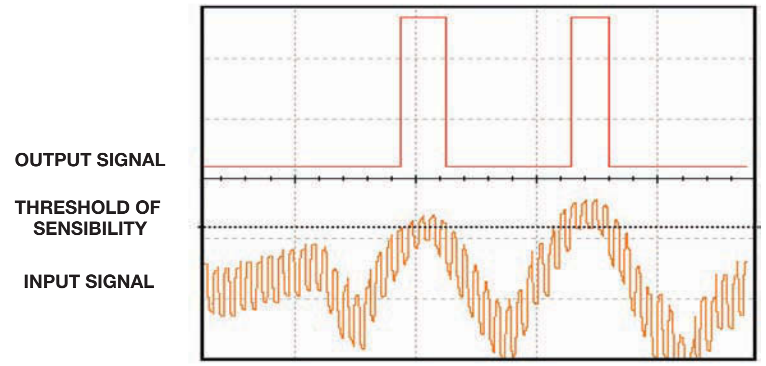

Figure 2 The circuit recognizes a pulse when it falls; noise is exaggerated for clarity.

Hack into a stopwatch to make a phototimer

Ralf Kelz, Seefeld, Germany

The exposure tester in this Design Idea measures the on time of a light source, whether an LED, an incandescent lamp, a halogen lamp, or another source. It can be made with an ordinary stopwatch and a few simple components (**figures 1** and **2**). An electronic stopwatch needs two pulses to operate; one starts the internal counter, and another one stops it. A light source provides only one pulse, corresponding to the time the light is illuminated. This circuit generates a short trigger pulse whenever the luminous intensity changes.

When the photodiode is not illuminated, capacitor C_1 charges to 1.5V (**Figure 3**). The charge initially comes through the base-emitter junction of Q_1 with a time constant that $R_1 \times C_1$ sets. Once C_1 charges to 1.5V minus the base-to-emitter voltage, R_3 tops off the charge on C_1 until it reaches 1.5V. Because R_3 and R_1 are in series during this time, this topping off occurs with a slower time constant that $(R_1+R_3)\times C_1$ sets.

When the photodiode is illuminated, photocurrent flows through R_1, raising its voltage to more than 0V, which drives the right side of C_1 above the 1.5V rail. The base of Q_1 is reverse-biased and has no effect. However, Q_2's emitter is now forward-biased because R_4 holds the base near 1.5V. As Q_2 turns on, the charge in C_1 dissipates across R_2, raising its voltage and creating a positive pulse. You convey this pulse to the stopwatch through R_5, which is necessary in the case of extreme illumination of the photo-

Figure 1 You build the circuit on a small prototype board that connects to the CG-501 stopwatch.

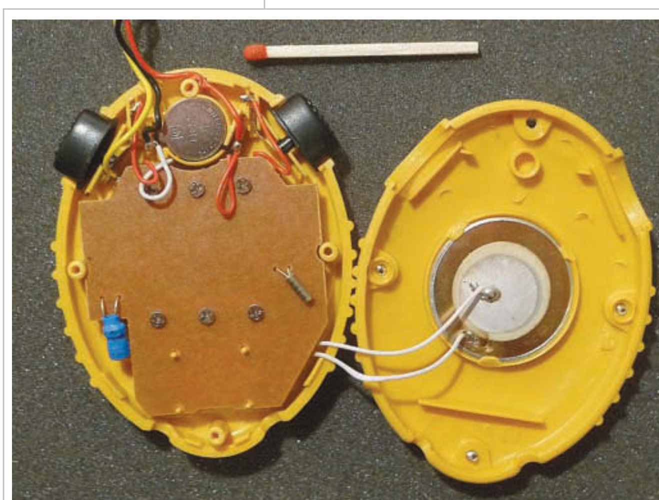

Figure 2 You can solder in pigtails to bring power, ground, and the trigger circuit to the prototype.

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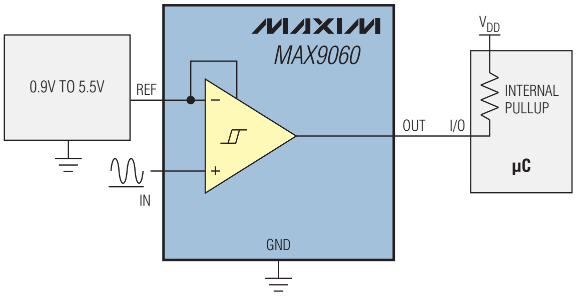

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www.maxim-ic.com/shop www.em.avnet.com/maxim www.digikey.com/maxim www.mouser.com/maximic diode. It limits the current into the stopwatch circuitry so that a large pulse cannot latch or overpower the internal stopwatch circuitry. The photocurrent creates a difference between 1.5V and the voltage of R_1; this difference causes C_1, under illumination, to enter a final voltage.

When the photodiode is not illuminated, no photocurrent goes through R_1, so C_1 can charge back up as its left side goes to ground and its right side goes first to a base-emitter drop below 1.5V and subsequently all the way to 1.5V. Because the initial charge conducts through the base-emitter junction of Q_1, that transistor again turns on, delivering a pulse across R_2 and halting the stopwatch.

Your selection of the value of C_1 depends on the exposure time to be measured and on the photodiode used. The response rate of this circuit is approximately 500 msec. This example uses an Everlight PD333-3C/HO/L2 photodiode with a large spectral bandwidth, but any other photodiode or even a photoresistor will also work. EDN

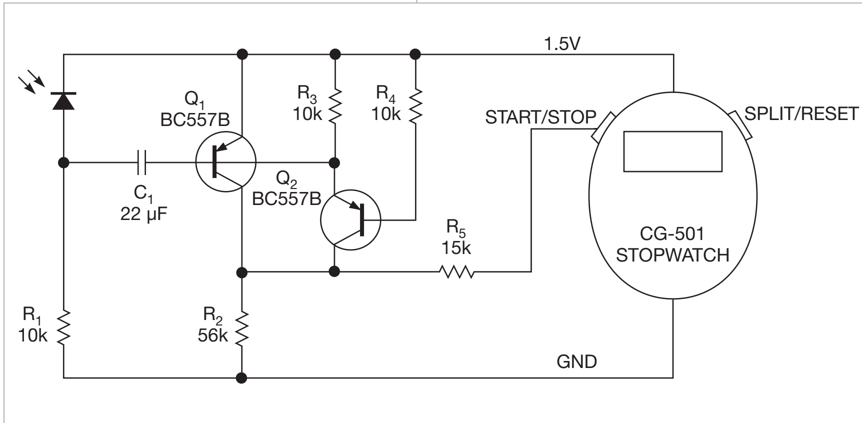


Figure 3 This simple circuit times a light source. When you illuminate the photodiode, Q_2 creates a pulse. When you remove the illumination, Q_1 creates a pulse.

Comparator directly controls power-MOSFET gate

Peter Demchenko, Vilnius, Lithuania

It is common practice to power a MOSFET with a comparator and with an unregulated voltage and to power the comparator driving it from a regulated one (**Figure 1**). Many loads are insensitive to driving voltage, so it would be a waste of money and power to use a regulated supply to drive the FET. It is also common practice to add resistors R_1 and R_2 to the comparator to put hysteresis in the operation, making the circuit less susceptible to noise, especially with slowly changing signals.

This circuit's comparator changes with changes in the unregulated power supply. You can correct this problem by adding diode D_2 and resistor R_5 to the circuit (**Figure 2**). This approach isolates the hysteresis circuit from the unregulated output and instead drives it from the same regulated supply that drives the comparator. When the comparator is on, it drives the FET just as the original circuit does, pulling the P-channel FET gate toward ground. In both cases, you connect zener diode D_1 to the FET gate to avoid exceeding the gate-to-source voltage. The improvements in the circuit in **Figure 2** become

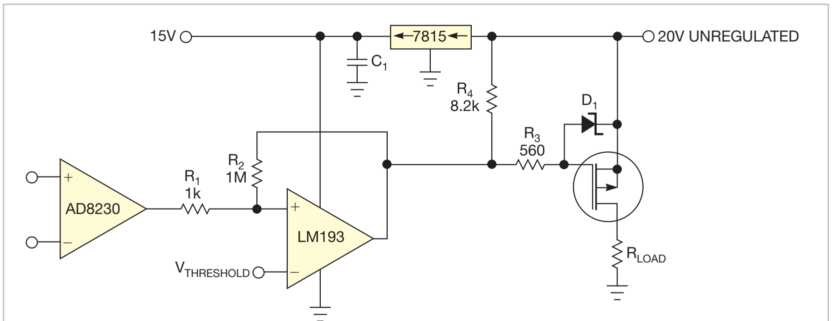


Figure 1 Hysteresis components R_1 and R_2 tie to the unregulated supply, causing the comparator's switching point to vary with the power supply.

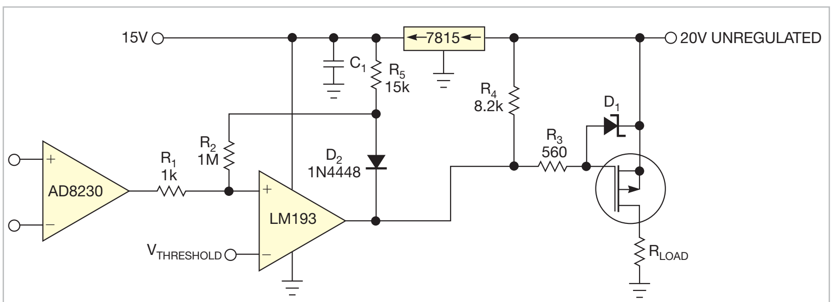


Figure 2 Resistor R_5 and an ORing diode isolate the hysteresis circuit from the power supply and keep the switching point constant no matter how the power supply changes.

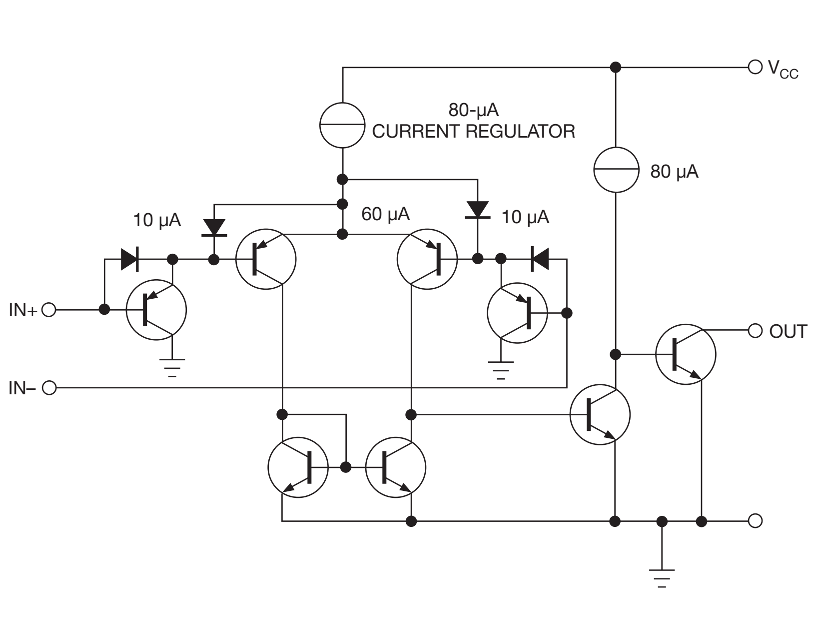


Figure 3 The internal design of the LM193 comparator requires that you keep the input pins 2V below the positive rail (courtesy Texas Instruments).

apparent when the comparator turns off. In either case, R_4 pulls the comparator's open-collector output up to the positive power supply. In **Figure 2**, however, the diode isolates the hysteresis circuit from the power supply so that R_4 pulls up R_5 to the regulated 15V, no matter how the power supply changes.

With a legacy comparator such as Texas Instruments' LM193, the common mode of the inputs must stay well below the power-supply rail (**Figure 3**). The circuit requires 1.5V head room at 25°C and 2V head room over temperature. Thus, for the circuits in **figures 1** and **2**, you cannot set the threshold voltage higher than 13V. If your circuit requires a threshold voltage closer to the power rail, consider using newer parts with rail-to-rail inputs. You must use an open-collector or open-drain comparator for this hysteresis-isolation circuit to work. It would be incompatible with a totem-pole-output IC. EDN

designideas CLASSICS

Originally published in the September 4, 1986, issue of *EDN*

AGC circuit uses an analog multiplier

Steve Lubs, Department of Defense, Washington, DC

In the AGC circuit of **Fig 1**, a 4-quadrant analog multiplier (IC_1), an amplifier stage (IC_2), an active, full-wave rectifier (D_1, D_2, R_4-R_7, and IC_3), and an integrator (IC_4) accomplish automatic gain control of V_{IN}'s amplitude variations in the audio-frequency range.

The multiplier's output is $-V_{IN}V_Y/10$, where V_Y is a negative voltage generated by the integrator IC_4. Together, the integrator and the rectifier extract the dc component (V_Y) of V_{OUT} for use as a feedback signal to the multiplier. The integrator sums signal current from the rectifier and control current from potentiometer R_9, which lets you adjust V_{OUT}'s signal level.

Circuit analysis yields the frequency-response **equation**

$$V_{OUT}=\frac{K_1AV_C}{10RC_3}\left(\frac{1}{s+\frac{10A}{RC_3}}\right),$$

or, in the time domain,

$$V_{OUT}=\left(\frac{K_1AV_C}{10RC_3}\right)\exp\left(-\frac{10At}{RC_3}\right).$$

In both **equations**, K_1 is the gain of amplifier IC_2, A is the peak amplitude of V_{IN}, and R is the resistance between the integrator input and the rectifier output. (For this circuit, R equals R_6 in parallel with R_7.)

This AGC circuit is suitable for controlling the long-term variations of amplitude within a limited range. It doesn't respond uniformly over a wide dynamic range, however, because the time response is inversely proportional to input-signal amplitude. EDN

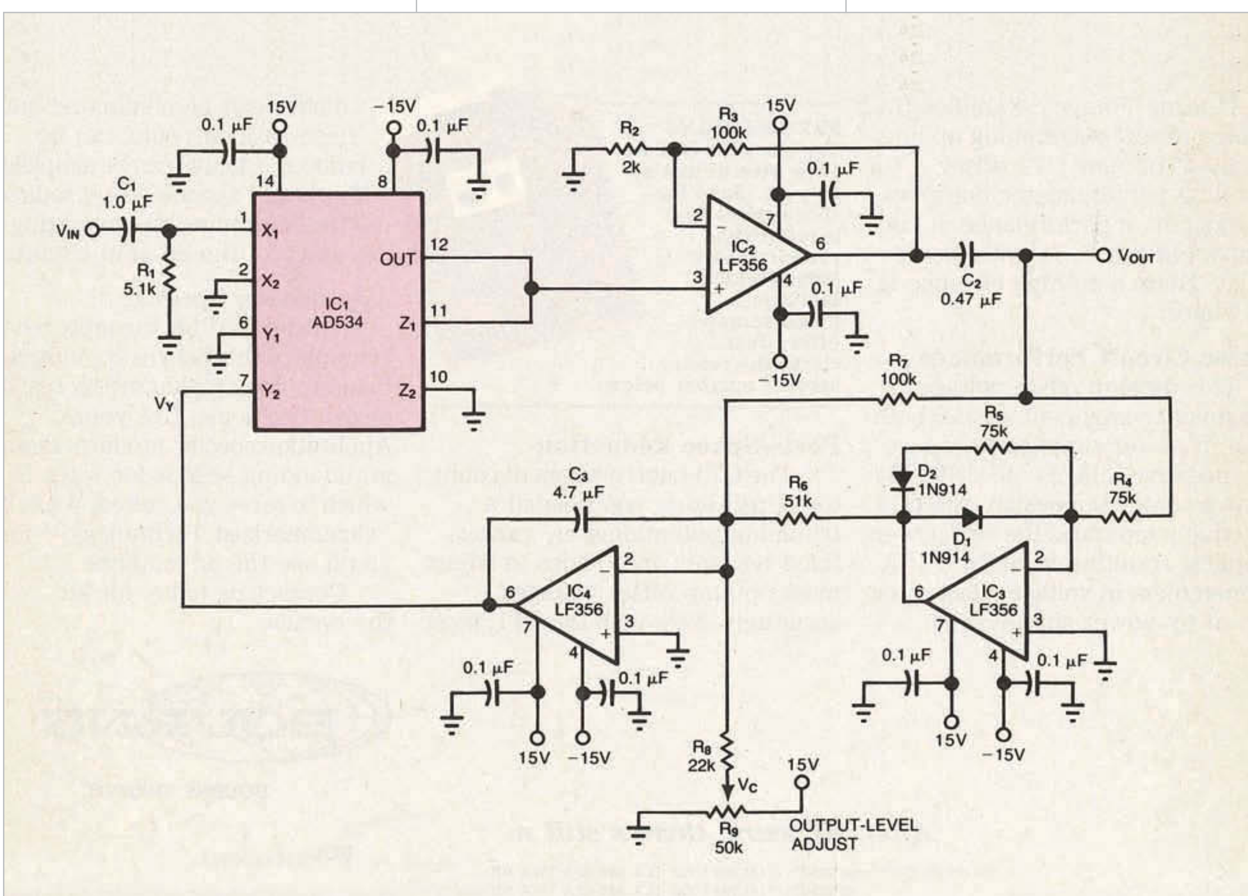


Figure 1 Analog multiplier IC_1 combines V_{IN} with a feedback signal V_Y to achieve automatic gain control.

IPC urges certification for conflict-free smelting

The IPC and its member groups continue to take active steps to reduce the electronics supply chain's burden of complying with conflict-minerals regulations. The IPC's moves follow on the Dodd-Frank Wall Street Reform and Consumer Protection Act, which legislators signed into law in July 2010 and which requires publicly traded companies to submit detailed reports to the US Securities and Exchange Commission on the origin of the tin, tantalum, gold, or tungsten in their products. The law largely aims to regulate relevant minerals coming from the Democratic Republic of the Congo and adjoining countries—so-called conflict areas.

In mid-October, IPC's SPVC (Solder Products Value Council) began urging tin smelters to become smelters of conflict-free minerals and recommended the EICC/GESI CFS (Electronic Industry Citizenship Coalition/Global e-Sustainability Initiative Conflict-Free Smelter) program. IPC estimates that the SPVC members produce 80% of the world's solder. As solder manufacturers, these members have a direct relationship with smelters of tin.

The move also follows separate plans from the IPC to develop a tool to standardize conflict-minerals tracking. That tool aims to allow companies to share data on conflict minerals and assist in the preparation of compliance reports (**Reference 1**). The IPC in September separately announced that it had agreed to participate in a pilot evaluation program to review and refine the Organization for Economic Cooperation and Development's due-diligence guidance for conflict minerals.

The IPC describes the CFS as an audit and certification program that will identify and publish lists of smelters that have been certified as using conflict-free minerals. IPC SPVC, the International Conference for the Great Lakes Region, and the United Nations have endorsed the CFS program. "Tin smelters can help the entire electronics-industry supply chain meet reporting requirements under the Dodd-Frank Act by engaging as soon as possible in a certification program, such as the EICC/GESI CFS," says Karl Seelig, SPVC chairman and vice president of technology at AIM Inc.

"Although the reporting requirements apply only to publicly traded companies, we now see requirements rapidly flow through the entire supply chain, similar in manner to the ROHS-compliance data requests," says Tony Hilvers (**photo**), IPC's vice president of industry programs. He says that the law does not require some companies to file reports, and those companies will likely

have to provide similar information to their customers to assist in their reporting efforts.

"These new regulations will affect not only US companies but also any company doing business or having customers doing business in the United States," Hilvers adds. "From a business perspective, smelters that participate in the CFS program will benefit from having been certified as conflict free."

Members of the IPC SPVC that endorse the CFS program include AIM, Amtech Inc, Cookson Electronics, Harimatec, Henkel, Indium, Inventec Performance Chemicals, Koki Co Ltd, Metallic Resources, Nihon Superior Co Ltd, Nordson EFD, P Kay Metal, Red Ring Solder, Senju Metal Industry Co Ltd, Shenmao Technology Group, and Yik Shing Tat Industrial Co Ltd. **—by Suzanne Deffree**

REFERENCE

1 Jorgensen, Barbara, "Tools in the works to standardize conflict-minerals tracking," *EDN*, Sept 8, 2011, pg 58, http://bit.ly/okQ28z.

OUTLOOK

SMARTPHONES' DRAM DEMAND TO SEE 700% INCREASE BY 2015

Shipments of DRAM for use in smartphones should see triple-digit growth in 2011, outpacing the expansion of the entire DRAM market by a factor of three, according to IHS iSuppli. DRAM shipments in smartphone handsets should rise to 1.7 billion in 2011, up over 150% from 672 million in 2010. By 2015, shipments will increase to 13.9 billion units, up 700% from 2011, the market-research company estimates.

"Compared to this year's stunning DRAM growth in smartphones, a shipment expansion amounting to a much less spectacular 50% is expected for the total DRAM market, which is dominated by sales to the PC business," says Clifford Leimbach, analyst for memory demand forecasting at IHS. "The major growth disparity between the two sectors explains why DRAM manufacturers are aggressively vying for a bigger piece of the cellphone DRAM market."

IHS iSuppli also estimates that smartphones' share of total DRAM consumption will grow to 7.6% this year, up from 4.4% in 2010. The company expects this figure to expand to 10.6% next year, 13.4% in 2013, 14.9% in 2014, and 16% in 2015.

—by Suzanne Deffree

productroundup

DISCRETE SEMICONDUCTORS

Diodes are driving the discrete-semiconductor industry, thanks to the current- and power-delivery requirements of high-speed interfaces, such as USB 3.0 and HDMI. IGBTs also continue to increase in popularity, according to figures from IC Insights, which predicts that the discrete-semiconductor market will grow 8% this year to reach $24 billion as these devices play key roles in applications ranging from portable devices to power-distribution equipment.

Major discrete-semiconductor vendors, including Littelfuse, On Semiconductor, and Vishay Intertechnology, recently announced diodes featuring ESD protection without degrading signal integrity. These diodes come in tiny packages to serve portable systems. Improvements in packaging and production have expanded the range of applications IGBTs can serve. Vendors are manufacturing these high-efficiency, high-speed switching devices to be more rugged to withstand harsh environments, such as those in automotive and industrial systems.—**by Ismini Scouras**

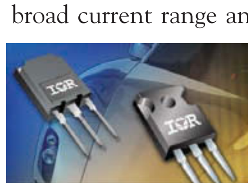
STMicro's STPS60SM200C rectifier targets high-efficiency power conversion

The STPS60SM200C dual Schottky rectifier targets use in ac/dc power supplies in telecom base stations and welding equipment. The device features a 200V maximum reverse voltage, operates at temperatures as low as –40°C, and achieves more-than-2-kV ESD protection. Other features include a repetitive peak reverse voltage of 200V, an average forward current of 60A, a maximum operating junction temperature of 175°C, and a typical forward voltage of 640 mV. The device comes in a TO-247 package and sells for $2.436 (1000).

STMicroelectronics, www.st.com

IR introduces automotive-qualified, 600V IGBTs

This family of 600V, automotive-qualified IGBTs targets use in variable-speed motor-control and power-supply applications in electric and hybrid vehicles. The devices cover a broad current range and offer a short-circuit rating of 5 μsec or greater. They feature low voltage drop for electric-



air-conditioning, main-traction-inverter, and other motor-drive circuits requiring power density of 24 to 160A. Other features include a square reverse-bias safe operating area, an integrated soft-recovery diode, and a junction temperature of 175°C. Prices begin at $1.78 (100,000).

International Rectifier, www.irf.com

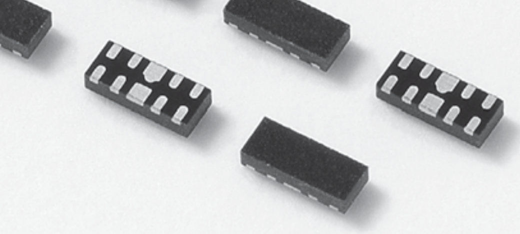
Vishay VCUT05D1-SD0 diode comes in compact package

The bidirectional-symmetrical VCUT05D1-SD0 ESD-protection diode provides 10-pF capacitance for protecting signal and data lines from transient-voltage signals in portable electronics. Featuring a 0.6×0.3-mm footprint and a package height of less than 0.3 mm, the VCUT05D1-SD0 targets use in portable gaming systems, digital cameras, MP3 players, mobile phones, smartphones, and other portable systems. At a working voltage of 5.5V, the diode offers a leakage current of less than 0.1 μA. The device clamps or shorts to ground any transient-voltage signal exceeding the typical reverse-breakdown voltage of 8V at 1 mA. The device features a maximum clamping voltage of 10V at 1A and comes in a CLP0603 package. It provides high surge-current protection and transient protection for one data line. It sells for $6 (100).

Vishay Intertechnology, www.vishay.com

Littelfuse SP3012 TVS-diode arrays protect USB 3.0 ports

The SP3012 series of TVS (transient-voltage-suppressor)-diode arrays provides ESD protection for high-



speed ports, such as USB 3.0. The devices offer a loading capacitance of 0.5 pF and provide ±12-kV ESD protection. Dynamic resistance is 0.4Ω. The SP3012 comes in a 2.5×1×0.5-mm µDFN package and sells for 28 to 88 cents, depending on quantity.
Littelfuse, **www.littelfuse.com**

Ixys expands high-gain IGBT line with XPT devices

The XPT IGBT line now includes the IXYH50N120C3, which has current ratings of 105 to 160A at a case temperature of 25°C, an emitter saturation voltage of 3V, typical current fall time of 57 nsec, and turn-off-energy-per-pulse values as low as 1.2 mJ at a junction temperature of 25°C. The device retains a positive-temperature coefficient at its collector-to-emitter saturation voltage, allowing designers to use multiple discrete devices in parallel. Applications include high-frequency power inverters, UPSs, motor drives, high-power lighting controls, welding machines, battery chargers, power-factor-correction circuits, and high-voltage switch-mode power supplies. The 1200V device sells for $7.40 (500).
Ixys, **www.ixys.com**

On Semi ESD7004 TVS targets notebook, tablet ESD protection

The ESD7004 TVS preserves signal integrity in 5-Gbps USB 3.0 and 6-Gbps eSATA applications in notebooks and tablets. With 0.4-pF

capacitance, the device features less-than-1-dB insertion loss at more than 8 GHz during S21 testing. Clamping voltage is 11.4V or less during ±8A transmission-line-pulse testing, and the ESD-contact rating is 15 kV. The device comes in a 2.5×1×0.5, 10-pin µDFN package and sells for $0.097 (10,000).
On Semiconductor,
www.onsemi.com

EPC expands eGaN-FET line with 100V EPC2007 transistor

The 1.87-mm², 6A EPC2007 eGaN FET has a 100V drain-to-source voltage and a maximum on-resistance of 30 mΩ. The device has greater immunity to fast switching transients than its predecessor. Applications include hard-switched and high-frequency circuits, such as isolated dc/dc power supplies, point-of-load converters, and Class D audio amplifiers. The device sells for $1.31 (1000).

Efficient Power Conversion,
www.epc-co.com

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Eastern dreams

DANIEL VASCONCELLOS

During the 1990s, I was the technical lead on a project to design a transmitter controller using radio pagers. The original pagers were receive-only devices. To get messages to the pagers, the systems would transmit the same signal—on the same frequency channel—on every transmitter of the pager's contracted coverage area. This area was sometimes a large part of the United States, requiring more than several thousand transmitters. Due to directional diversity and, in signal-overlap areas, power summation, using this many transmitters provided better area and building-penetration coverage than do today's cell phones.

This approach worked properly only if we placed a number of constraints on the system's operation. A fundamental one for the signal-overlap regions was that the modulation symbols had to arrive at the device in time alignment. In this way, the symbols would have a chance to reinforce, rather than interfere with, each other. For the systems in use in the 1990s, this requirement meant that every transmitter had to send the symbols aligned to within 1 μsec. Meeting this goal was not trivial because transmitters resided at various distances from the common source of the data, and the means of delivering the signals to them could vary among technologies ranging from wires to microwave links.

Our project's transmitter controller would automatically align the transmitters to allow for changes in deployment, equipment aging, and the addition of transmitters. The obvious approach was to fit each transmitter with a GPS receiver. At the time, however, the public use of such systems was rare and unreliable. I instead used an approach in which the controller transmitted a calibration signal to the transmitters; various fixed devices around the coverage area received these transmitters' radio transmissions. All of the signals that each fixed receiver received experienced the same propagation delay from the receiver back to the controller. To determine propagation time, we divided the distance between the transmitters by the speed of light. Using the round-trip measurements, we could therefore determine the relative delay from the controller to each transmitter. By providing the appropriate delay to each transmitter, we got them to align their symbols within the desired tolerance.

This system worked well for deployments in the United States and several overseas sites. One day, however, my boss informed me that a system in Tokyo was experiencing a problem. Rather than rush off to Japan—a destination that I regrettably still haven't visited—I contacted a technician involved with maintaining the network. It turned out that many of the transmitters were remaining properly aligned but that some were drifting at different rates as the day progressed. The measurements take seconds per transmitter, and the system must be offline during the measurement, so we took the measurements only at night. The system would transmit the messages it had accumulated during the measurement period and then take some more measurements.

The drifting was cyclic. The time differences would be zero after the nighttime calibration, would increase until early afternoon, and would then decrease back to alignment after dark. In addition to daylight and moisture, what else goes through cycles depending on the time of day? My answer: temperature! I then found out that many of the links to the transmitters were copper wire and that their length was changing throughout the day. The fix was to adjust the delay to each transmitter based on its "copper distance" and the temperature. **EDN**

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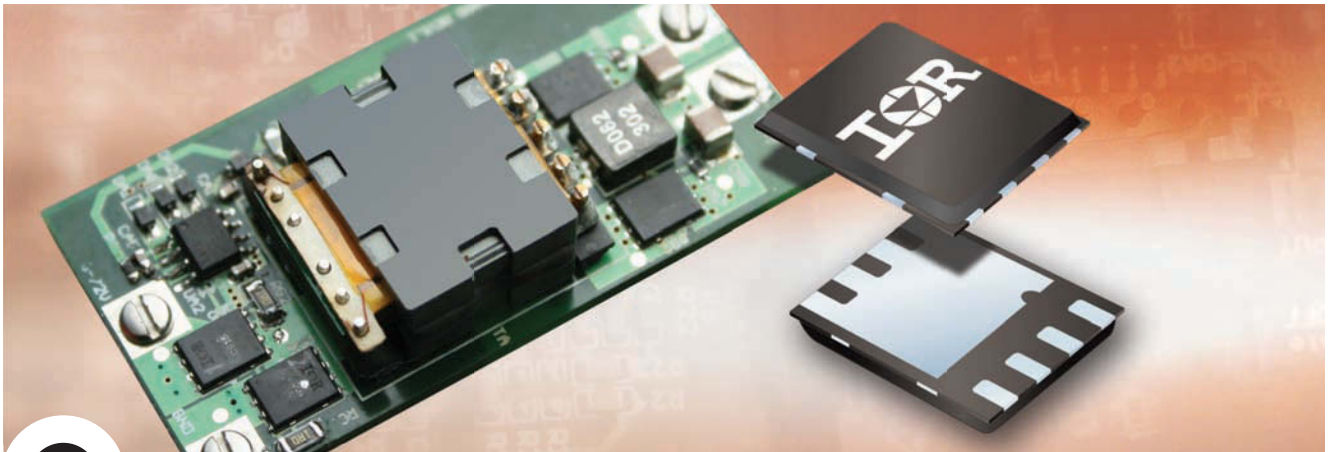

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