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POWER MOSFETs CONTINUE TO EVOLVE

THANKS TO WAFER THINNING AND INNOVATIVE PACKAGING Page 24

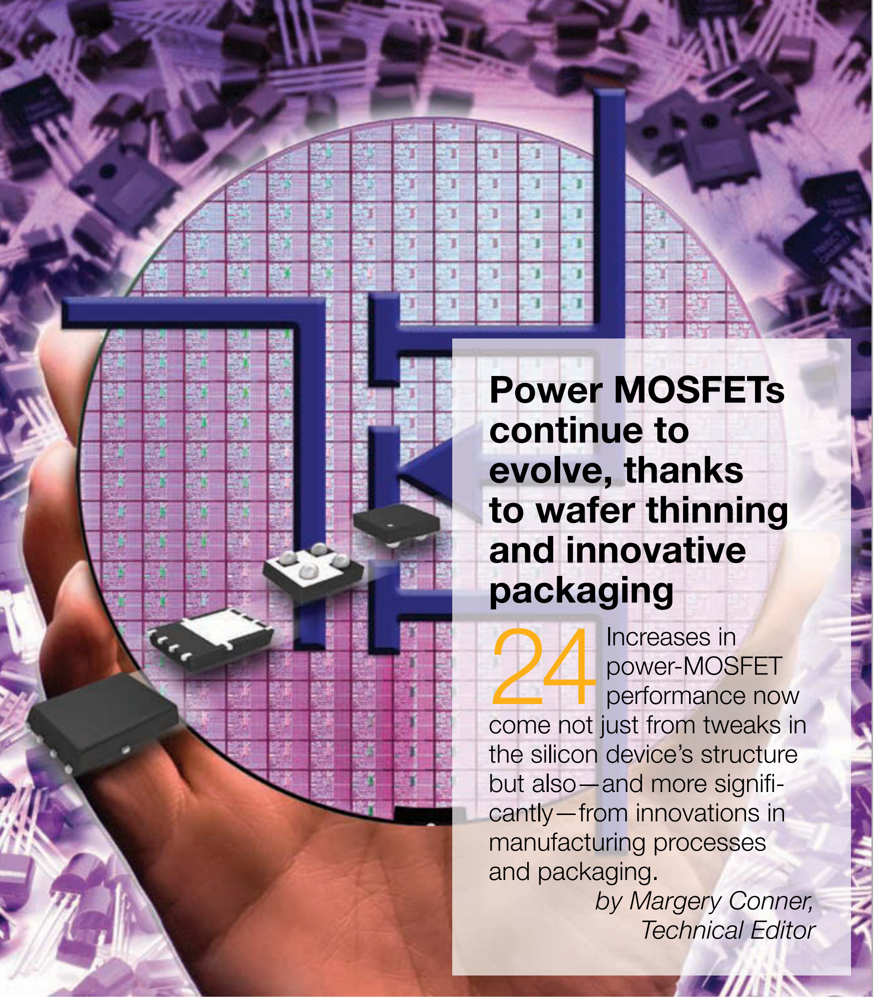
Exploiting subthreshold MOSFET behavior in analog applications Page 20

Balancing GBWP and quiescent current for dissipation optimization Page 30

Small-signal bandwidth in a Big Bandwidth era Page 35

EDN contents

2.2.12



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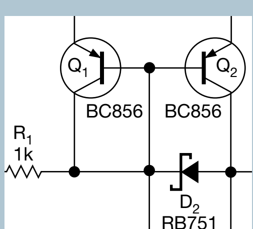
DESIGNIDEAS

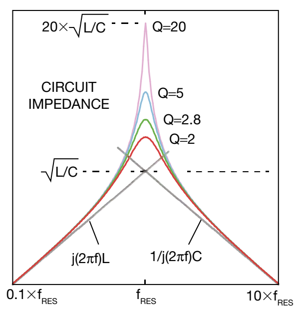


▶ Find out how to submit your own Design Idea: http://bit.ly/DesignIdeasGuide.

contents 2.2.12

pulse

DEPARTMENTS & COLUMNS



18

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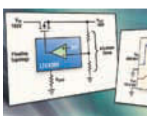
EDN online

JOIN THE CONVERSATION

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

In response to "Wall sockets still trying to drive stake through the heart of vampire power," a blog post by Margery Conner, http://bit.ly/x5MHpl, Bill Whitlock commented:

"Without exception, the 50- or 60-Hz transformers used in wall warts are designed to be dirt cheap. As a result, they run on the verge of magnetic saturation. This [situation] has two bad consequences: They heat up and waste power even if unloaded, and they radiate strong magnetic fields in all directions. Both [issues] can be vastly reduced by using a bit more core material and copper. Most such wall warts today run so close to saturation that all you have to do is raise the line voltage to about 130V ac, and they will usually heat so much that the one-time thermal fuse will open. What's lacking in these proposed solutions is perspective. What use is it to save little bits of energy here and there when products are intentionally designed to end up in the landfill in a year or two? Just look at what's happened to KitchenAid and many others in their race to the bottom. Truly sad."



In response to "Floating 'surge-stopper' IC clamps 500V and more, allows cool-down period," an article by Bill Schweber, http://bit.ly/x7wmgi, Bob Groh commented:

"Attractive-looking device, although I have not dug into the specification sheet. Now add some reverse-voltage protection and some surge-current-limiting mechanism, and we could really be talking about something exciting. Hmmm … maybe I could get out the design hat and do a little sketching in the design book. The point is that this device (with the external MOSFET, of course) might form a nice core for a complete power-line-protection system."

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

FUTURE OF COMPUTERS: THE POWER WALL

Continuing his take on the future of computers and multicore processing, processor expert Russell Fish turns his attention to the "power wall"—the increasing heat and power issues associated with increased CPU performance.

http://bit.ly/xqg58D

VIDEO FROM CES

EDN's Patrick Mannion attended CES and spoke to officials at some key companies, including Qualcomm and Toshiba. Check out his video reporting on *EDN*'s video module.

http://www.edn.com/video/video.php

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BY BILL SCHWEBER, CONTRIBUTING TECHNICAL EDITOR

Kodak's travails provide multiple lessons

You've undoubtedly seen the news that legendary company Kodak is in serious trouble. On Jan 19, the iconic brand filed for bankruptcy; it is down to just 20% of the employee count that it had a few decades ago. The company hopes to sell off a major part of its patent portfolio to raise some cash.

I neither lament the situation nor criticize past or current management. Plenty of commentators and pundits are already doing that. What bothers me is the number of after-the-fact geniuses who now say what a company like Kodak *should* have done. The most common refrain I see is along these lines: Kodak invented the digital camera but couldn't make a business of it. I'm not sure what "invented" means in this case, but it is true that the company has many digital-camera patents.

Sorry, folks, this line of reasoning just doesn't make sense to me. First, just because you invent something doesn't mean you are in a position to profit from it. More important, Kodak based its entire business model on repeat sales of consumables, including film, processing, and associated chemicals—in other words: blades rather than razors.

Even if Kodak had somehow designed a market-winning digital camera, what would the business model look like, and where would the profit lie? The cameras would have been made in a contract factory, and, although Kodak would have received a small cut, it would have been for a one-time purchase. Once you had a basic camera, you wouldn't buy anything else from the company.

The lessons is that disruptive technologies truly are so, and most companies can't—or shouldn't—make that transition. In the electronics world, for example, only a few vendors of vacuum tubes made it into the transistor world, and only a few of the transistor companies made it into ICs. Such is change.

Technologies that once looked as though they would last forever sometimes do not.

Not that long ago, the commentary-and-pundit class was worried—and fearful—that, as we entered the 21st century, IBM and its PCs running on Intel CPUs with Microsoft Windows operating systems would dominate. So where are we now, smart folks? IBM is out of the PC business, and both Intel and Microsoft, though still major players, face tough competition in both CPUs and operating systems for new smartphones, tablets, and embedded products.

Take heart, though; it's not just technology companies that can't face change. The latest numbers on movie-theater revenue for 2011 show that overall ticket sales were 5% down to flat compared with those of 2010. When you factor in the increase in ticket prices, however, theatergoer numbers were down 5 to 10%. Industry analysts say that the films may have been low-quality or that the weather was bad—always a convenient excuse.

I can't discuss film quality because it's a subjective topic, but many average people now have big, high-definition screens with surround sound at home and think it's crazy to spend $10 or more per ticket, plus those outrageous snack prices, to sit at a specific time with a bunch of noisy people chatting on their phones. At home, you can take a break at any time during a movie. Maybe the movie industry—and especially the theater folks—should stop believing that people will always want to go out to the theater and realize that things have changed in so many ways.

Markets and technologies that once looked as though they would last forever sometimes do not. The future is difficult to predict, and business has birth, life, and death cycles. So, before you put all your money into Facebook or Google, think carefully about the lessons of our industry and change. **EDN**

Bill Schweber is the editor of Planet Analog *and* Power Management Designline, *both on the Web site of* EE Times, *a sister publication of* EDN. *Contact him at bill.schweber@ubm.com, or comment on this column at www.edn.com/120202ed.*

EDITED BY FRAN GRANVILLE

pulse

INNOVATIONS & INNOVATORS

Handheld scopes' VGA displays reveal waveform details under all lighting conditions

Agilent Technologies has added two two-channel oscilloscopes to its portfolio of handheld instruments. According to the company, the 100-MHz-bandwidth U1610A and the 200-MHz U1620A are the industry's first handheld scopes to include 640×480-pixel, color VGA displays. With indoor, outdoor, and night-vision display modes, these instruments enable engineers to view signal waveforms by zooming in to capture glitches under all lighting conditions. The 5.7-in. transflective displays and outdoor-viewing mode make it possible to examine waveform details even in bright sunlight.

Key capabilities include maximum sampling rates of 2G samples/sec for the U1620A and 1G samples/sec for the U1610A. Memory depth on both models is 2M samples on each of two safety-isolated input channels. Analysis capabilities include the deep memory as well as 1000× zooming and dual zoom windows for simultaneous viewing of overview and detailed displays.

Other features include a DMM display with 10,000-count resolution, channel-to-channel isolation with Category III 600V safety ratings, the ability to log data on an external PC, and a user-interface system that allows operation in any of 10 languages. The devices measure 7.2×10.6×2.56 in. each and weigh 5.5 lbs each. A carrying case and probes are available. The supplied battery is a 10.8V lithium-ion rechargeable pack, which you can recharge either separately from or within the scope using a supplied ac/dc adapter. Runtime on a full battery charge is three hours. Prices for the U1610A and U1620A are $3100 and $3400, respectively.

—by Dan Strassberg

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

The 5.5-lb, 100-MHz-bandwidth U1610A (left) and the 200-MHz U1620A provide isolated inputs for safety and 2M-sample waveform memories with 1000× display zoom for viewing the details of complex waveforms.

TALKBACK

"Belt and suspenders always mean trouble. ROHS was intended to keep lead out of landfills. So did WEEE. Pick one. ... EU—and now China—are making our bed, and we have to lie in it. Where is the sanity check? What is next?"

—Electronics hardware design engineer Randy B, in *EDN's* Talkback section, at http://bit.ly/zeGWTZ. Add your comments.

Microchip targets active-current reduction in PIC24F expansion

Microchip has expanded its XLP (extreme-low-power) microcontroller portfolio with the 16-bit PIC24F GA3 family. The devices feature 150-μA/MHz active current and as many as six DMA (direct-memory-access) channels. The family adds a low-power sleep mode with RAM retention as low as 330 nA, and the devices are the first PIC microcontrollers with battery-voltage backup of the on-chip real-time-clock calendar.

The XLP technology has traditionally concentrated on reducing static current, according to Don Schneider, product-marketing manager with the advanced-microcontroller division of Microchip Technology. This development, however, reduces active current. Standard XLP modes include run, idle, doze and sleep, and deep sleep. The intermediate step between the sleep mode and the deep-sleep mode allows the devices to maintain RAM and allows some of the peripherals to operate at low current.

The new PIC24F units also integrate an LCD driver to directly drive as many as 480 segments, with an eight-common-drive capability, enabling more informative and flexible displays that include descriptive icons and scrolling. The 60×8-segment LCD driver improves on earlier units' 42×4-segment driver. The units also include a CTMU (charge-time-measurement unit) with a constant-current source for mTouch capacitive sensing, ultrasonic flow measurement, and many other sensors.

The device includes as many as 24 channels of 12-bit ADC. The ADC includes a threshold-detection function that allows the ADC to wake the CPU when it reaches a threshold window. The function is useful when using the CTMU in a capacitive-touch application. It allows you to monitor the button or proximity sensor when the device is in sleep mode and can wake when it reaches a threshold value. A couple of additional ADC channels operate internally for internal temperature sensors and similar functions.

The PIC24F GA3 devices target use in consumer thermostats, door locks, and home automation; industrial products, such as security, wired and wireless sensors, and controls; portable medical devices and medical-diagnostic equipment; and metering products, including e-meters, energy monitoring, automated meter reading, and meters for gas, water, or heat. Power meters are constantly on and monitoring the power. They must meet a 10 VA IEC current budget, and many power companies are asking for still lower-power numbers. To achieve the 10-VA target, a microcontroller can consume only approximately 10 mA or less. Many microcontrollers must operate at reduced speed to stay within this budget.

The GA3 family can operate at its full 16 MIPS with 4.9 mA. This ability allows the device to either add functions, perhaps running more complex code or a communication stack, or continue running at a lower speed and conserve even more power. The DMA channels on the device enable it to move data to peripherals in parallel with the CPU's operation, freeing the CPU for other functions. An example of a DMA operation could be the transfer of data from the device RAM to a serial channel for an RF-communication stack. Microchip has added these devices to its battery-life-estimator lineup.

Standard XLP modes in Microchip's new PIC24 units include run, idle, doze and sleep, and deep sleep.

To aid development, the PIC24FJ128GA310 plug-in module is available for $25 and works with the company's Explorer 16 development board. To evaluate or develop designs with a 480-segment LCD, the LCD Explorer development board is available for $125. Samples and volume production are available with versions having 64 or 128 kbytes of flash. The PIC24FJXXXGA306 devices are available in 64-pin QFN and TQFP packages; PIC24FJXXGA308 versions are available in 80-pin TQFP packages, and the PIC24FJXXXGA310 is available in 100-pin TQFP and 121-ball BGA packages.

—by Colin Holland

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

DILBERT By Scott Adams

Resistive touchscreens add multitouch capabilities

As a desire for touch features sweeps across all markets, many applications look to upgrade to multitouch technology but can't afford the high price of capacitive touchscreens. Thanks to new developments at Freescale Semiconductor, however, automobiles, appliances, medical devices, and low-end smartphones can now retrofit multitouch gestures to resistive-touchscreen designs or create inexpensive alternatives to capacitive-touchscreen products. By upgrading their controller chips to Freescale's new Ready-Play solution, users can take advantage of the Xtrinsic smart controller, which provides multitouch gesture recognition for any standard four- or five-wire resistive touchscreen and handles as many as four capacitive touchpads.

"As tablets become more popular, the capacitive-touchscreen business has been growing by over $200 million [per year], but the resistive-touchscreen market has been growing at almost the same rate [$167 million]," says John Weil, global-business manager for industrial microcontrollers at Freescale. "Adding a resistive touchscreen is a quick and inexpensive way to enrich [current] and new applications in medical, consumer, automotive, and other markets."

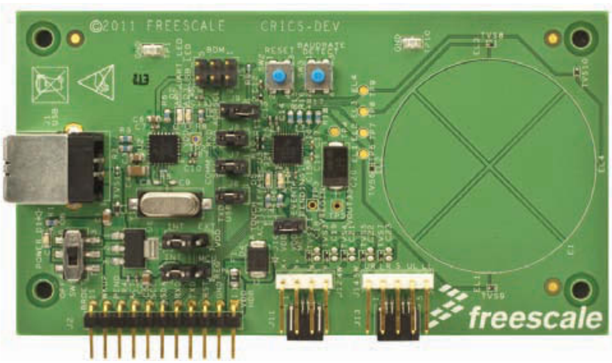
Using proprietary algorithms and some analog-hardware tricks, the new Xtrinsic CRTouch chip provides on-chip state machines that can recognize slides, two-finger pinches for zooming in and out, and multifinger rotations on standard resistive touchscreens. The controller chip also manages as many as four capacitive touchpads for realizing keypads, rotary dials, and linear sliders. "We believe that the CRTouchB12 is the industry's first single-chip controller to offer both gesture recognition on standard resistive touchscreens [and] capacitive-touch sensing," says Weil.

Freescale aims the new controller chip at human-machine-interface applications. The chip eliminates the need for keyboards for applications including point-of-sale terminals, automotive dashboards, low-cost netbooks, and mobile handsets, as well as in applications, such as medical, security, and harsh environments, in which users must wear gloves.

As a part of Freescale's Ready Play offerings, the CRTouch chip offers turnkey software integration with both Android and Linux operating systems. The 5×5-mm, 32-pin QFN package also offers configurable screen resolution and optional calibration and pressure detection for stylus input to resistive touchscreens.

—by R Colin Johnson

▷**Freescale**, www.freescale.com.



Freescale claims to have the first controller (center) that recognizes multitouch gestures on standard resistive screens. It manages as many as four capacitive-touch pads (right) on a reference-design board.

Osram enters pilot production with GaN-on-silicon high-power LEDs

Prices for HB (high-brightness) LEDs have been dropping sharply even as their lumens-per-watt figure has been increasing. In a development that should drive prices even lower, Osram Opto Semiconductors has announced that it is in the pilot stage of producing high-performance blue LEDs that the company grew in GaN (gallium-nitride) layers on 6-in. silicon wafers.

Blue LEDs combine with a dollop of phosphor to form the basis for white solid-state lights. Blue LEDs' production process now requires a sapphire—read: expensive—wafer.

Osram is currently testing its GaN-on-silicon LEDs under practical conditions, meaning that you'll see these LEDs reach the market in as little as two years. According to the company, the quality and performance of the fabricated LED silicon chips match those of sapphire-based chips, and 1-mm^2 chips operate at 350 mA.

In combination with a conventional phosphor converter in a standard housing—in other words, as white LEDs—these prototypes correspond to 140 lm at 350 mA with an efficiency of 127 lm/W at 4500K.

This development follows the move in power MOSFETs, in which GaN-on-silicon devices are beginning to appear from companies such as International Rectifier, EPC, and Transphorm. In the MOSFET world, the ability of GaN devices to routinely switch in the megahertz-plus range is the draw.

—by Margery Conner

▷**Osram Opto Semiconductors**, www.osram-os.com.

Osram Opto Semiconductors is in the pilot stage of producing high-performance blue LEDs that it grows in GaN layers on 6-in. silicon wafers rather than the current, more expensive sapphire wafers.

Floating surge-stopper IC clamps 500V and more, allows cool-down period

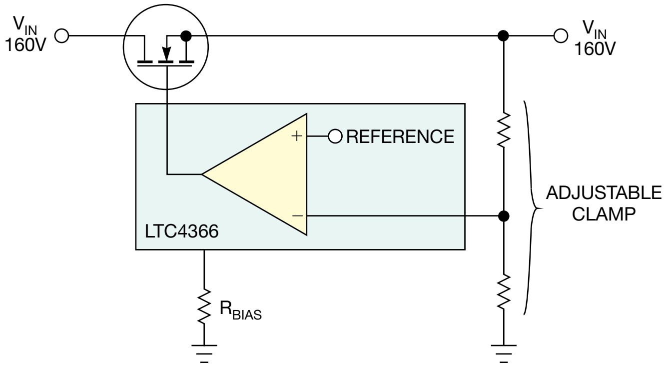
Transients and surges are unpleasant, unavoidable, and even hazardous concerns in industrial, auto, and avionic applications, due to motors, coupled overvoltages, supply failures or misconnections, and other real-world impositions. You can address these problems by using a combination of inductors, capacitors, fuses, and transient-voltage suppressors. Alternatively, you can use an IC such as the LTC4366 from Linear Technology. This floating surge stopper operates from 9 to 500V and higher, employing an adjustable topology to allow for high-voltage operation that is independent of the IC's voltage rating. The associated resistors' and MOSFETs' breakdown ratings set the maximum operating voltage. The IC uses two internal shunt regulators, which work with external voltage-reducing resistors to generate the IC's supply rails.

In operation, the LTC4366 reacts to input-supply overvoltage by switching the gate of the external N-channel MOSFET and regulates the output to a user-defined level during the transient. The load remains operational and powered when the overvoltage across the MOSFET decreases. The LTC4366-1 latches and remains latched after a fault, whereas the LTC4366-2 automatically retries after a 9-sec cool-down. In shutdown mode, the LTC4366's supply current drops to less than 20 µA.

The LTC4366 is available in eight-lead TSOT and 3×2-mm DFN packages. It operates in the 0 to 70°C commercial, –40 to +85°C industrial, and –65 to +150°C automotive ranges. Prices begin at $2.66 (1000).

—by Bill Schweber

▷**Linear Technology Corp**, www.linear.com/product/LTC4366.



The LTC4366 floating surge stopper operates from 9 to 500V and higher, employing an adjustable topology to allow for high-voltage operation that is independent of the IC's voltage rating.

Single-chip, nine-axis INU targets consumer devices

A new nine-axis INU (inertial navigation unit) from Invensense combines an accelerometer, a gyroscope, and a magnetometer in a single 3-D chip stack for use in consumer devices, such as smartphones, touchscreen tablets, gaming controllers, and wearable motion-tracking modules. The module eliminates the errors that accumulate when using separate inertial sensors from different vendors, according to Steve Nasiri, chief executive officer and founder of Invensense. "The MPU-9150 motion-tracking module will be a boon to any consumer motion-processing application, from location-based services to gesture recognition," he says.

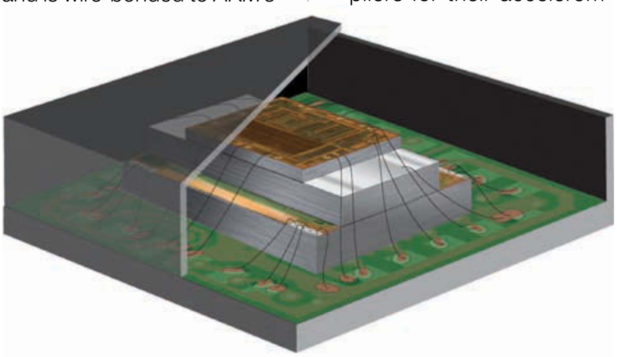
The product combines the MPU-6050 gyroscope chip with the AKM8975 magnetometer from AKM (Asahi Kasei Microdevices) Corp. The 3-D chip stack includes an ASIC containing the electronics and motion-processing accelerator on the bottom, with the MEMS die for the accelerometer/gyroscope in the middle, and is wire-bonded to AKM's magenetometer on top. The accelerometer, the gyroscope, and the magnetometer each have three axes, and the module comes with smart sensor-fusion acceleration in a 4×4×1-mm LGA package.

"Traditionally, designers have specified different suppliers for their accelerometers, gyroscopes, and magnetometers," says Nasiri. With the new device, he explains, OEMs can choose one vendor's precalibrated product, saving time to market; in one package to save PCB space; and with built-in sensor-fusion algorithms to ensure optimal performance.

Invensense MotionFusion firmware offers a turnkey product for OEMs, and its MotionApps software platform, which comes with the product, simplifies the system-integration task for popular operating systems, including Google's Android. AKM's proven magnetometer finds use as a digital compass in everything from Apple's iPhone/iPad to Samsung's Galaxy S/Tab. Samples are available now, and volume production is planned by the end of this quarter.

—by R Colin Johnson

▷**Invensense**, www.invensense.com.



The nine-axis MPU-9150 INU combines an accelerometer, a gyroscope, and a magnetometer in a single 3-D chip stack for use in consumer devices.

HTML5 platform for infotainment systems debuts at CES

QNX Software Systems recently unveiled its Car 2 application platform at the 2012 CES (Consumer Electronics Show). The product allows automotive developers to harness the user experience of HTML5 on a software foundation that is in use in millions of vehicles. Enabling rapid development of in-car infotainment systems, the Car 2 platform introduces a new autocentric HTML5 framework. Automakers

The QNX concept car, designed to demonstrate the capabilities of the QNX Car platform, is based on a Porsche Carrera.

are beginning to embrace HTML5 to enable them to keep their vehicles fresh with new content and features, to address consumer demands for the latest mobile apps and services, and to leverage a huge developer community—helping automakers customize the user experience and simplify access to mobile apps.

The QNX Car 2 application platform permits developers to easily and effectively rework entire user interfaces—essential to projecting a unique brand identity—and do it cost-effectively for multiple model lines. It also allows them to blend HTML5 applications with those created with Qt, OpenGL ES, and other user-interface technologies—all on the same display and even at the same time. This flexible architecture for building a unified user experience enables manufacturers to leverage their software investments and tap into HTML5.

"At Audi, we see HTML5 as an essential ingredient for creating the next generation of user experiences in the vehicle," says Mathias Halliger, head of architecture for Audi's MMI (multimedia-interface) System. "As cars become the new mobile platform, it is increasingly important for automakers to keep pace with the growing array of mobile applications to ensure a rich, customized in-vehicle experience and to offer new features based on the latest technology, such as cloud-based software updates for the car. Support for HTML5 in software platforms such as QNX Car 2 can help automakers achieve this connectivity quickly and cost effectively." Audi uses QNX software technology in its MIB High infotainment system, which is shipping in cars today.

According to Thilo Koslowski, automotive practice leader at Gartner, automakers will base successful connected-vehicle strategies on the principle of "controlled openness," which employs current standards and flexible architectures to create unique and differentiated customer experiences. HTML5 allows automotive companies to embrace this principle and to create connected vehicles that are upgradable and can evolve with overall software and technology advancements.

In addition to the new HTML framework, the QNX Car 2 application platform pre-integrates an array of technologies, including the QNX Neutrino real-time operating system, which provides a multimedia framework, an acoustic-processing library for hands-free systems, and hundreds of software services and utilities. Ecosystem partners TeleCommunication Systems, Texas Instruments, and Vlingo back the platform.

With the QNX Car 2 application platform, developers can build both browser-based and browser-less applications in HTML5 and even use HTML5 to build applications that require no connectivity to the Internet. The platform includes an optimized WebKit-based HTML5 engine that supports audio and video, geolocation, Web sockets, offline applications, session storage, canvas, and other standards, such as CSS3 and JavaScript. Optimizations beyond WebKit include pixel-accurate zooming and high-performance panning, which is ideal for maps and navigation; physics-based scrolling; and other advanced features.

"The QNX CAR 2 is … a platform for achieving the next level of connectivity between the car and mobile devices, between the car and the cloud, and between the car and the consumer," says Derek Kuhn, vice president of sales and marketing at QNX Software Systems. "With its autocentric HTML5 framework, the platform can help automakers create more enjoyable and convenient user experiences and to connect to the host of HTML5 applications available on smartphones, tablets, and other platforms." QNX plans general release of the Car 2 platform for mid-2012.

—by Rick DeMeis

▷**QNX Software Systems**, www.qnx.com.

02.02.12

BATTERIES LAST LONGER, THANKS TO MONITORING DEVICE

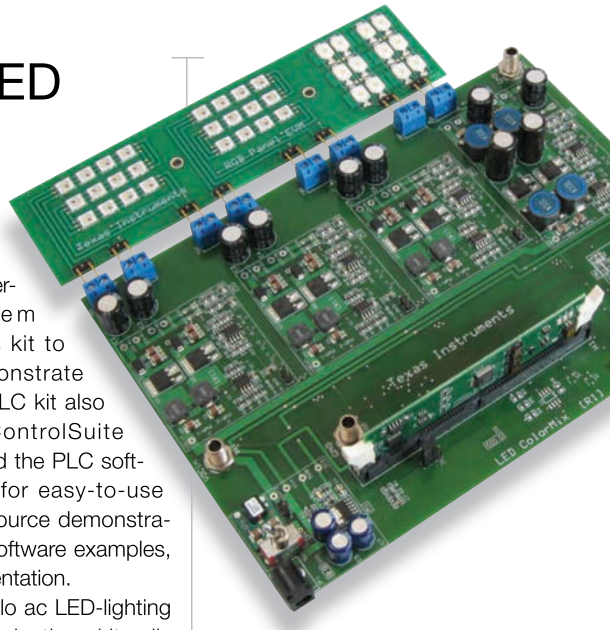
STMicroelectronics' new STC3105 battery-monitor IC delivers high-precision measurement of battery voltage and current in a 2×3×0.8-mm package. Targeting use in mobile phones, multimedia players, digital cameras, and other space-constrained portable gadgets, the device uses open-circuit voltage and coulomb-counter methods to estimate the battery capacity and to supervise and track the battery's charge and discharge status. Accurate predictions of battery state of charge and time to empty help avoid unnecessary recharging, extend operating time between charges, and lengthen the battery lifetime in portable systems. The STC3105 boasts typical supply currents of 60 μA and integrates a programmable alarm output to alert the system when the battery's state of charge is below a certain level. The device sells for $1 (1000).

—by Fran Granville

▶**STMicroelectronics**, www.st.com.

The STC3105 battery-monitor IC acts as a "gas gauge" for handheld devices.

Piccolo development kit targets LED lighting and communications



Texas Instruments recently announced the F2802x 32-bit TMS320C2000 Piccolo microcontroller ac LED-lighting and communications developer's kit. The kit provides a differentiated platform for ac-mains-powered intelligent luminaires. It includes hardware and software support for remote connectivity, walking developers through implementation examples of leading lighting-communications protocols, such as DALI (digital addressable-lighting interface), DMX512, and PLC (power-line communications). The kit also features the C2000's modular ControlCard concept, which allows developers to experiment with various C2000 microcontrollers to fit price, performance, and peripheral-set requirements. ControlSuite software provides easy-to-use open-source demonstration GUIs, software examples, and documentation for full closed-loop control of an ac/dc power supply, multistring-LED control, and advanced communications.

A separate F2802x PLC add-on kit enables users to experiment with PLC in lighting using PLC-Lite. The PLC kit adds cost-effective energy metering, remote diagnostics, or remote control without the need for additional wiring or external communications modules. It features a plug-in PLC daughterboard and a drop-in replacement Piccolo F2803x microcontroller, enabling the hardware support and control performance necessary for PLC. It also communicates with C2000 power-line-modem developer's kit to easily demonstrate PLC. The PLC kit also includes ControlSuite software and the PLC software suite for easy-to-use and open-source demonstration GUIs, software examples, and documentation.

The Piccolo ac LED-lighting and communications kit sells for $699; the PLC add-on kit sells for $215. ControlSuite software is free; PLC software and documentation are also available.—**by Fran Granville**
▷**Texas Instruments**, www.ti.com.

The new Piccolo LED-lighting and communications kit includes hardware and software support for remote connectivity, walking developers through implementation examples of leading lighting-communications protocols.

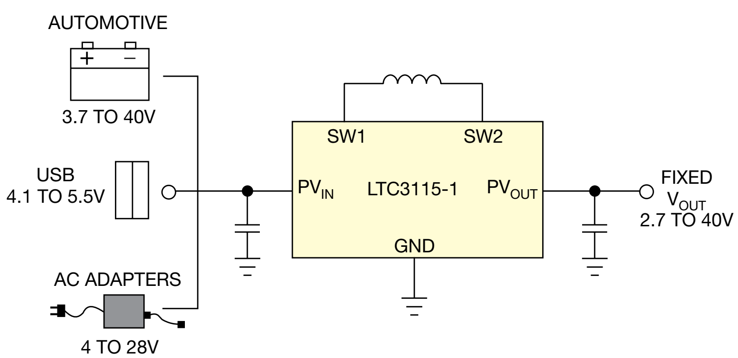
Buck-boost converter does 2.7 to 40V input/output, provides bump-free transitions

Targeting the challenge of supporting a wide range of input voltages and delivering a wide range of output voltages, the LTC3115-1 dc/dc buck-boost converter from Linear Technology Corp delivers as much as 2A continuous current. It handles power sources spanning a single-cell lithium-ion source, to 24/28V industrial supplies, and to 40V automotive sources, and it provides a regulated output from inputs that can be above, equal to, or below the desired output value. It also provides jitter-free transitions between buck and boost modes.

The low-noise, high-efficiency LTC3115-1 has an advanced PWM and low-noise switching algorithm and circuit. It includes four MOSFETs that provide as much as 95% efficiency, with a burst mode of operation that drops quiescent current to 50 μA for better light-load efficiency and longer runtime.

You can selectively turn off the burst mode for extremely noise-sensitive applications. The device has an operating envelope of 1A output current for input voltages of 3.6V or more and output voltages of 5V and an envelope of 2A output current in step-down operation for input voltages of 6V or more. Other attributes include internal soft-start operation, 3-μA supply current in shutdown mode, and programmable input-undervoltage lockout.

The LTC3115-1 is available in a 4×5×0.75-mm DFN package and in a thermally enhanced 20-lead TSSOP for $5.35 and $5.55 (1000), respectively; industrial-grade versions operating at –40 to +125°C are also available.—**by Bill Schweber**
▷**Linear Technology Corp**, www.linear.com/product/LTC3115-1.



The high-efficiency, 40V-input/output LTC3115-1 buck-boost dc/dc converter has low noise and advanced PWM switching algorithms.

BY HOWARD JOHNSON, PhD

Parallel resonance

A child sits on a swing, feet dangling, perfectly at rest. Give him a gentle push. The child moves forward to a maximum height, reverses course under the influence of gravity, and then swings back and forth. The height of the child's excursions depends on the energy, E_1, supplied by your initial push. Damping forces, such as air resistance and the child's foot-dragging, rob energy from each cycle. These damping forces control the ride's duration but have little to do with the size of the initial excursion. Mathematicians define the damping constant, Q, as the ratio of energy stored within the system divided by energy lost per radian of oscillation. The higher the damping constant is, the lower the rate of energy loss, and the longer the ride.

If you push the swing repeatedly in sync with its natural movement, the oscillations grow. They keep growing until the amount of lost energy during each cycle, which varies with oscillation size, balances the fixed amount supplied by each push. This phenomenon is called resonance.

Figure 1 illustrates an electrical circuit that resonates. This circuit might represent part of a power system, perhaps the interaction between the total effective series inductance of a bypass capacitor array, L, and the bulk capacitance of a power-and-ground-plane pair, C. Resistance R represents the various damping factors throughout the system. A step-current waveform excites the circuit. Note that the size of the first excursion varies only modestly, going from 0.75 to 0.95 as the damping constant ranges a full order of magnitude—from two to 20. Like a swing after one push, the damping constant determines the rate of decay but has little to do with the size of the first perturbation.

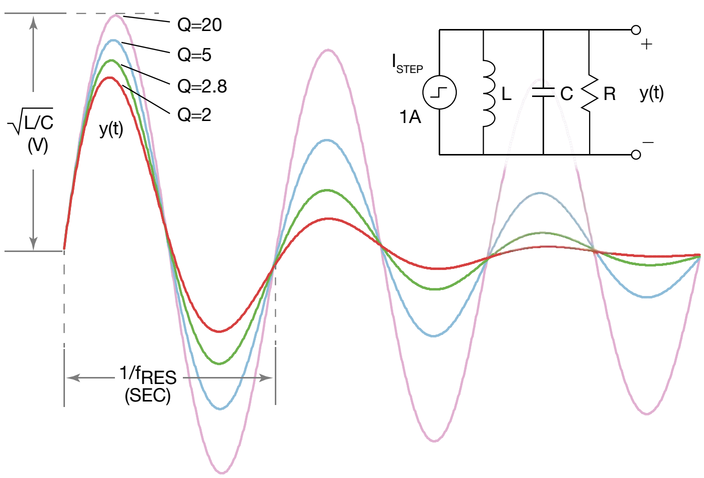


Figure 1 The output of this circuit never exceeds a certain limit, regardless of the damping factor.

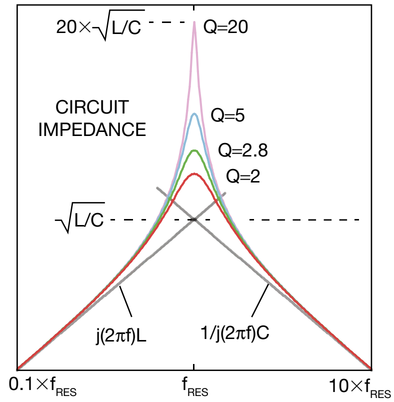


Figure 2 A repetitive input at resonance makes the output soar in proportion to the damping factor.

In the frequency domain, the response looks different (**Figure 2**). A sinusoidal waveform repeats endlessly, bringing the system to a full and complete resonant balance. The peak response to a sinusoidal excitation varies in almost direct proportion to the damping constant.

Now consider a computer system. On a graph of power-supply impedance versus frequency, the highest peaks—the sharp resonances—draw your attention. With a step excitation, however, the peak response depends almost entirely on the values of capacitance and inductance, not the damping factor.

A circuit theorist looks at the value of circuit impedance, defined as $\sqrt{L/C}$. You can determine the circuit impedance for any frequency-response impedance graph from its inductive and capacitive asymptotes: j2πfL and 1/j2πfC, respectively (**Figure 2**). The place at which these two straight lines cross is the circuit impedance, Z_C. In response to a single step input, the initial perturbation does not exceed the current times the impedance.

My point? A huge resonance in the power system is sometimes OK, provided that you stimulate it only once. EDN

EXPLOITING SUBTHRESHOLD MOSFET BEHAVIOR IN ANALOG APPLICATIONS

ROBERT CHAO • ADVANCED LINEAR DEVICES INC

IMAGE: ISTOCK

Engineers consider many forms of current leakage in electronic systems to be unusable. This thinking is starting to change as designers begin to explore new frontiers in ultra-low-power devices through precise control of subthreshold leakage currents of MOSFET devices for analog applications. Analog engineers can harness the subthreshold-voltage characteristics of MOSFET devices and use them in the nanopower region, opening an array of possibilities for useful and repeatable circuits, according to John Skurla, director of marketing at Advanced Linear Devices Inc. Subthreshold voltage is still difficult to control, but, as the era of nanopower dawns and starts to expand, engineers can begin to use leakage current that they previously deemed unusable, he says. Energy harvesting, for example, is a rapidly expanding field of R&D. Efforts are now just beginning to unlock the possible applications of a field that benefits from nanopower operations. Engineers have yet to tap the potential for this technology, however, because of the limitations of harnessing, storing, and distributing micropower energy. The ability to store energy with minimal leakage is a key factor in the continuing advancement of applications in this area.

YOU CAN NOW SPIN MOSFETs' "UNUSABLE" LEAKAGE CURRENT INTO "GOLD."

Engineers commonly consider a device to be off when current drops below the gate-threshold voltage (see **sidebar** "Threshold-voltage background"). For example, they would consider unusable any current lower than a gate-threshold voltage of 1V. Historically, it has been difficult to control this leakage current below the threshold voltage, or subthreshold leakage current, within a certain range. To understand the limitations holding back the development of nanopower, consider a MOSFET device or any similar device in which the gate voltage falls below the gate-threshold voltage. Any remaining voltage below the gate-threshold voltage is in the device's subthreshold region; however, current drops off exponentially when there is even a relatively minimal drop from 1 to 0.9V. Designers usually refer to this drop as 100 mV/decade of current, so for every 0.1V drop in voltage, current drops by 10 times, or an order of magnitude.

Subthreshold current as a function of subthreshold voltage can be approximately 110 mV/decade of current from 1 μA to 10 pA. For example, for a threshold voltage, V_{GSTH}, of 0.5V, when the gate-to-source voltage, V_{GS}, is 0.5V, the drain current, I_D, is 1 μA. When V_{GS} is 0.4V, I_D decreases from 1 μA to 150 nA. When V_{GS} further decreases by 100 mV, to 0.3V, I_D continues to decrease by about another order of magnitude, to 20 nA. For such a device, when V_{GS} is tied to ground potential, or 0V, I_D is now approximately 0.03 nA. For many applications, ground potential is not only a convenient reference voltage but also an accurate one (**Figure 1**).

Therefore, a MOSFET device with a V_{GS} of exactly 0.5V has a drain-to-source current, I_{DS}, of 0.03 nA when its gate is grounded. When gate voltage dips to 0V, current has decreased by approximately 30,000 times below threshold. It's easy to imagine why engineers would consider it to be off.

This reduced current, however, operates on a well-behaved curve. When you turn off a switch, power is still behind the gate of the circuit below threshold, so the device is often not completely off. This same concept enables cell phones to operate in sleep mode, for example, conserving battery life when not in use and then waking up when receiving a call or a text message. In a similar fashion, many security systems, such as battery-powered alarm backups, sometimes must operate in deep-sleep mode for as long as five or 10 years and then wake up to complete their functions when they sense a specified event or behavior.

The ability to operate this type of circuit in nanopower in the subthreshold region can greatly extend battery life by preserving battery power in sleep mode, thus enhancing security abilities. Further, working in the subthreshold region is imperative for unlocking the benefits of nanopower and for driving innovation in energy harvesting and many other fields.

AT A GLANCE

- The subthreshold-voltage characteristics of MOSFET devices allow you to harness this voltage and use it in the nanopower region.
- Working in the subthreshold region is imperative for unlocking the benefits of nanopower and for driving innovation in energy harvesting and many other fields.
- One major advantage of operating in the subthreshold mode is the ability to generate low levels of current between the source and the drain, thereby creating a high-value resistor.
- Nanopower is not a panacea because it involves less current to work with and requires acute sensitivity.

ANALOG DESIGN

When a design does not require a subthreshold current, that current becomes parasitic leakage current, which dissipates power for the circuit without serving any useful purpose. This parasitic leakage joins and combines with other types of leakage currents, such as junction leakage, gate-oxide leakage, package-level surface leakage, and PCB leakage currents. Most of these leakage currents, however, are the products of contamination and imperfection in manufacturing and fabrication. These leakage currents are generally targeted to be minimized or eliminated with only a maximum value, but usually with no minimum value. In other

THRESHOLD-VOLTAGE BACKGROUND

Engineers usually define the threshold voltage of a MOSFET as the gate voltage in which an inversion layer forms at the interface between the insulating oxide layer and the substrate of the transistor device. In an N-channel MOSFET, the substrate of the transistor comprises P-channel-type silicon, which has positively charged mobile holes as carriers. When you apply a positive voltage on the gate, an electric field develops, causing the interface to repel holes and creating a depletion region underneath the gate. Further increasing the gate voltage eventually causes electrons to appear at the interface in an inversion layer to form a conducting channel between the drain and the source terminals. The gate voltage at which the electron density at the interface is the same as the hole density in the neutral bulk material is the threshold voltage.

Practically speaking, the MOSFET turns on when there are sufficient electrons in the inversion layer to make a low-resistance conducting path between the MOSFET's source and its drain. Subthreshold conduction, subthreshold leakage, or subthreshold drain current encompasses the current that flows between the source and the drain of a MOSFET when the transistor is in the subthreshold, or weak-inversion, region, when the gate-to-source voltage is below the threshold voltage.

In micropower analog-MOSFET circuits, weak inversion is an efficient operating region, and subthreshold is a useful transistor mode of operation around which to design circuit functions. In analog-circuit designs, the weak inversion provides a high transconductance value for a small change in drain current, which in turn provides a maximum voltage gain. It also provides a high bandwidth for a given capacitive load.

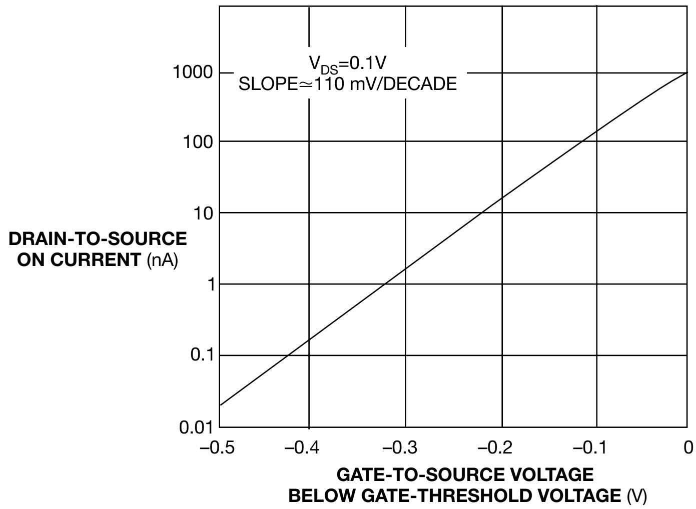


Figure 1 For many applications, ground potential is not only a convenient reference voltage but also an accurate one.

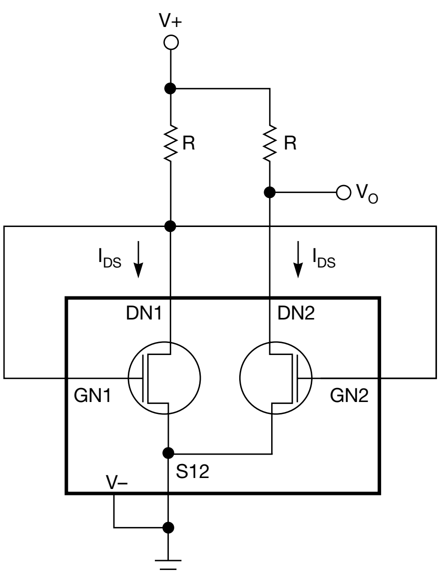
words, a leakage current of exactly 0A would be ideal.

For analog-circuit design, subthreshold leakage currents differ from these other types of leakage currents. A 0A value for this subthreshold leakage current is unacceptable because the resistor value becomes infinitely large when the current denominator is zero. Engineers, therefore, minimize it and treat it as a "junky" current. When you control V_{GS} and V_{GSTH}, you can then control and reproduce the leakage current. When you control this current within a certain maximum and minimum range, then it becomes a resistive element that you can use.

This ability becomes important when the resistive element has a value that exceeds that of most commonly available resistors. For nanopower applications, high-value resistors are common to limit circuit power dissipation. One major advantage of operating in the subthreshold mode is the ability to generate low levels of current between the source and the drain, thereby creating a resistor with a value on the order of hundreds of megohms to gigaohms. For example, to build a 500-MΩ resistor would require you to string together 23 22-MΩ resistors. This high-value resistor can bias a MOSFET device to generate low-level current sources; however, the resistor value is fixed at only one precise input gate voltage and is valid for only a specific threshold voltage.

The same high transconductance of the weak inversion mode also produces a resistor but with high variation in its resistor value as a function of the applied V_{GS} and V_{GSTH}. Both of these voltages significantly affect a resistor value, producing a resistor that generally varies in value too greatly to be usable as a circuit element.

An infinitely large resistor value is simply an "open circuit," which would not lend itself to being useful as an analog-circuit element. A resistor element, therefore, must have a maximum and a minimum value to have any meaningful circuit function. MOSFETs have low threshold voltages and precise tolerance ranges, and the devices can be electrically trimmed at the factory for these



NOTES:
FOR LOW TEMPERATURE COEFFICIENTS, SET I_{DS} AT APPROXIMATELY 68 μA.
FOR V+ OF 5V, R IS APPROXIMATELY 47 kΩ.

Figure 2 This circuit shows nanopower MOSFET pairs that connect as a differential pair. The gate-threshold voltages of the two MOSFET devices match so that you can bias both in subthreshold mode. You can use one device as a reference and the other for comparison purposes.

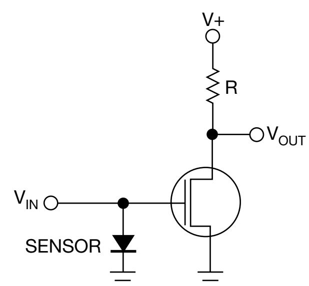


Figure 3 This circuit takes direct advantage of the subthreshold characteristics of a MOSFET device. Assume that a sensor has two open-circuit voltage-output levels that represent the on and off states—0.5 and 0.25V, respectively. A MOSFET device with a gate-threshold voltage of 0.5V can simultaneously act as an input buffer, an amplifier, or a voltage comparator with a built-in reference voltage.

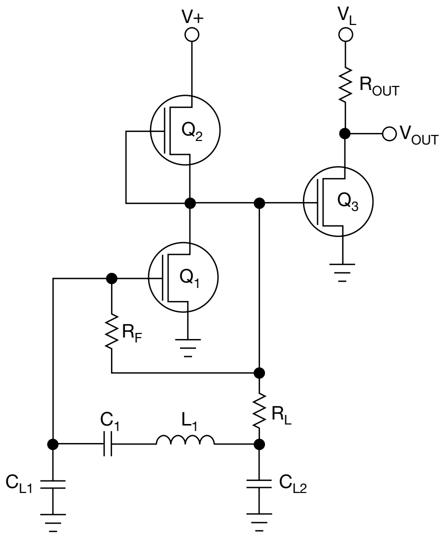


Figure 4 This circuit oscillates with simple resistor, inductor, and capacitor components, with MOSFET devices Q_1 and Q_2 biased in the subthreshold mode.

precise specifications. These devices play an important role in many analog circuits, such as current sources, current mirrors, discrete differential amplifiers, and analog multiplexers. With such precise design techniques, manufacturers can produce MOSFETs with a V_{GS} of 0.2V±0.02V at 1 μA, 0.4V±0.02V at 1 μA, or even 0.8V±0.02V at 1 μA. You can use the threshold voltage and the relative subthreshold voltage of a MOSFET as a voltage comparator and a voltage reference. Historically, you would have needed both a voltage reference and a voltage comparator for this task.

Analog engineers seeking an advantage for operating their designs below gate threshold will soon discover that nanopower is not a panacea because this approach provides less current to work with and requires acute sensitivity. For example, a threshold voltage may vary between 0.4 or 0.1V. If an engineer sees a 0.3V drop in input voltage, current will have decreased by 1000 times. This example underscores the importance of precision control in subthreshold voltages and gate voltages. When a current can fluctuate so greatly, it is difficult to build a tangible circuit.

Ultraprecise enhancement-mode MOSFET arrays provide designers with accuracy in controlling V_{GS} and V_{GSTH}. With extremely low V_{GSTH} characteristics, these devices are essential in creating nanopower circuits. Examples include quad and dual N-channel, matched-pair enhancement-mode MOSFET arrays, which provide a V_{GSTH} of 0.4V and precision tolerances of ±20 mV.

Subthreshold voltage was previously unusable because MOSFETs had too wide a tolerance of V_{GSTH} range. For example, with a V_{GSTH} of 0.5V and tolerances of ±0.2V, the device has too little precision to capture subthreshold voltages (**figures 2**, **3**, and **4**).

The ability to control the subthreshold characteristics of certain devices yields the ability to repurpose some leakage currents as useful sources for a variety of low-power circuits. This ability is unlocking the potential of new areas in nanopower circuitry and allowing electronic systems to use less power from a power source. As designers become more aware of the subthreshold characteristics of MOSFET devices and how more precise tolerances can help control voltages and currents that they previously deemed unusable, they will be able to tap little-used resources and open new developments in nanopower design.EDN

AUTHOR'S BIOGRAPHY

Robert L Chao founded Advanced Linear Devices Inc in 1985 and is currently serving as president and chief executive officer. He holds a master of science degree in electrical engineering from the University of California—Berkeley and has been a leading authority in the analog-semiconductor industry for more than 30 years. A founder of Supertex, Chao was instrumental in inventing the analog circuitry that enabled the residential smoke detector. He filed a patent in 1979 and worked with Underwriters Laboratories, product-design companies, and Sears to bring the technology to market. With his passion for all things analog, Chao holds 10 patents and has pioneered several industry firsts, advancing technologies that otherwise would have taken years or might not have existed at all.

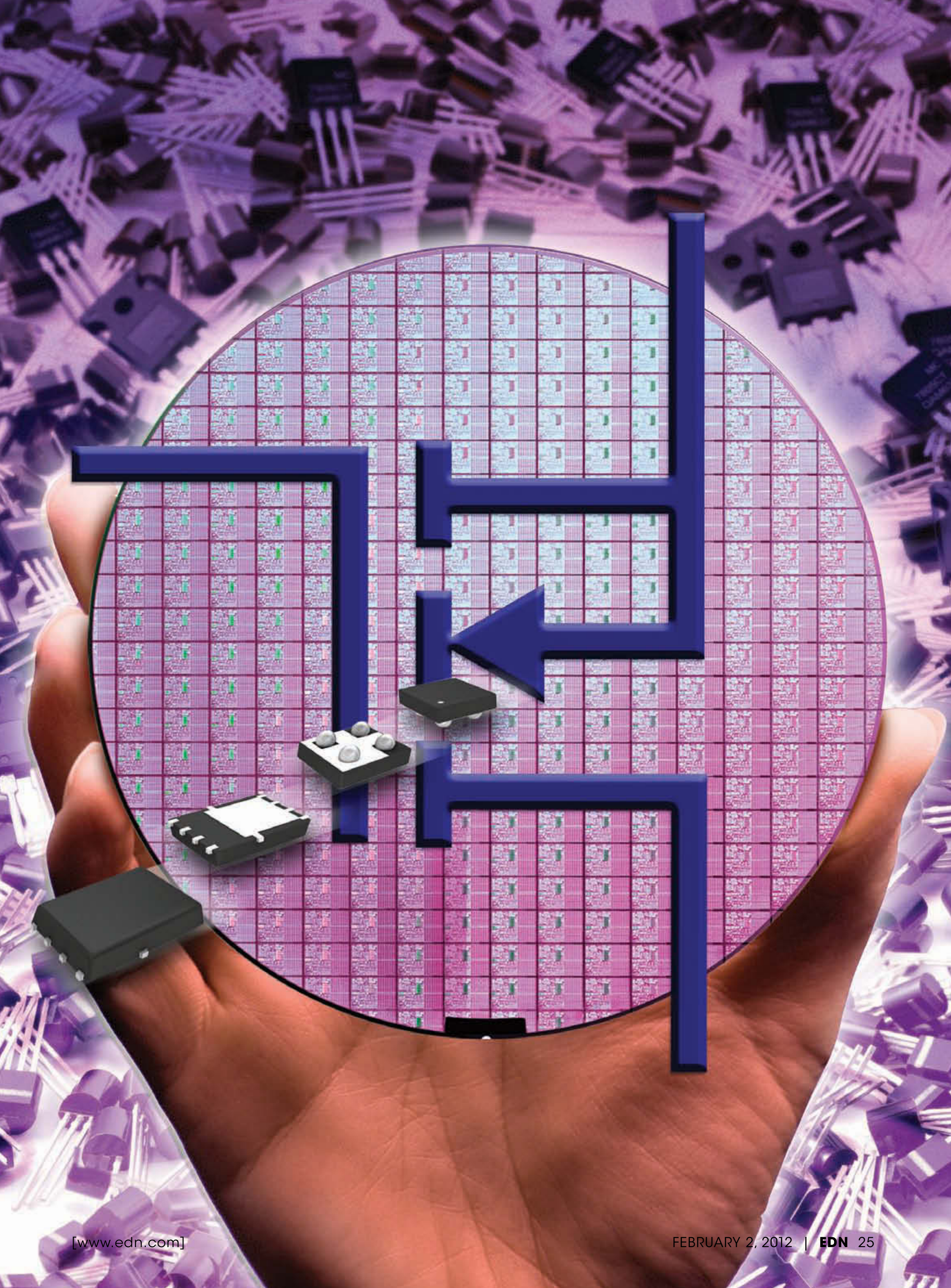
POWER MOSFETs CONTINUE TO EVOLVE, THANKS TO WAFER THINNING AND INNOVATIVE PACKAGING

BY MARGERY CONNER • TECHNICAL EDITOR

INCREASES IN POWER-MOSFET PERFORMANCE NOW COME NOT JUST FROM TWEAKS IN THE SILICON DEVICE'S STRUCTURE BUT ALSO—AND MORE SIGNIFICANTLY—FROM INNOVATIONS IN MANUFACTURING PROCESSES AND PACKAGING.

New switching power transistors using wide-bandgap semiconductors, such as SiC (silicon carbide) and GaN (gallium nitride) on silicon, will likely continue to significantly increase power-conversion efficiency (**Reference 1**). However, good ol' silicon power MOSFETs currently dominate the market and will continue to do so for several more years. APEC (Applied Power Electronics Conference), which this year takes place on Feb 5 through Feb 9 in Orlando, FL, is traditionally the biggest showcase for power-switching devices and a good venue for checking in on power-MOSFET technology.

IMAGE: SHUTTERSTOCK/YOSHI HOHOKABE



Power MOSFETs tend to break into segments aligned with their blocking-voltage (V_B) range, with common segments being less than 40, less than 100, and less than 600V. The largest market segments for power MOSFETs are the consumer and server/laptop markets, so the blocking voltage of less than 100V is typically the bellwether for MOSFET-performance trends.

In the past, developments in silicon power MOSFETs could ride on the coattails of digital-silicon processes. Like digital ICs, which benefited from the increase in transistor density that Moore's Law predicted, the economies of scale meant that performance increased even as prices fell. Those halcyon days are over, though; silicon MOSFETs seem to be reaching the performance limits of silicon technology.

"The trend is to spend more and more to get less and less improvement in performance," says Stéphane Ernoux, director of International Rectifier's power-management-devices business unit. "By 'spending more,' I mean developing more complex silicon technology. A ripple effect of this [situation] is that, as the silicon gets better, the package becomes a limitation. If you look back five, 10, or 15 years ago, all the focus was on the silicon, and the contribution of the package to MOSFET performance was small, but the silicon is now so good [that power-MOSFET manufacturers] have to focus on package improvement."

AT A GLANCE

- Improvements in on-resistance and gate-charge specs are becoming more difficult to achieve and more expensive.
- Silicon is far from dead as the technology of choice for power-switching devices and still has a few remaining generations of further improvement.
- Look for performance improvements to come from wafer thinning and packaging innovation.

Three factors are enabling the increase in power density: Silicon structures still have, as Ernoux points out, a few more remaining spins of improvement. Wafer thinning is another improvement in technology, and packaging innovations are the third. In general, semiconductor manufacturers purchase a wafer that has gone through one slicing and polishing step by a wafer supplier. The MOSFET-production process builds up the MOSFETs on the wafer. Because power MOSFETs are vertical devices, it's important that the wafers be as thin as possible to reduce on-resistance. Thinning, which is a grinding process, takes place at the end of the wafer processing, just before dicing. Manufacturers built the first generation of MOSFETs on 8-mil-thick wafers, whereas 2-mil-thick wafers are now common.

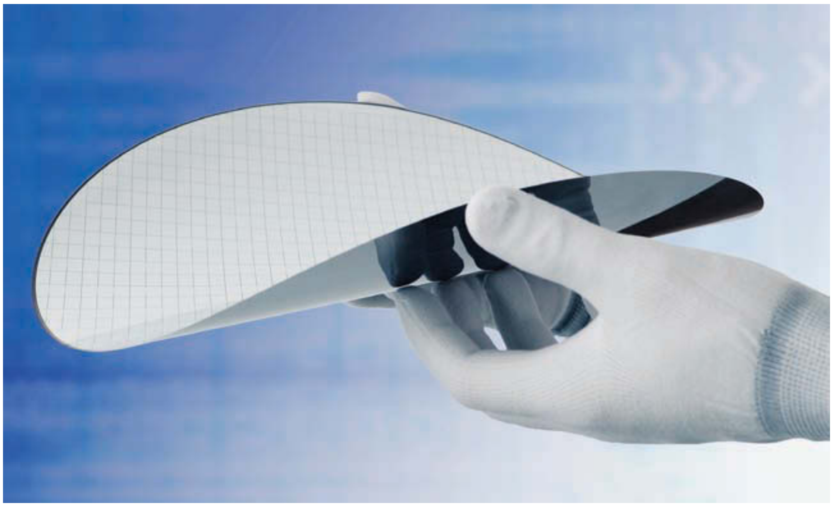


Figure 1 Infineon recently produced power MOSFETs on thin, 300-mm-, or 12-in.-, diameter wafers. These chips reach the same specifications as equivalent devices on 200-mm wafers.

Semiconductor manufacturers have been using wafer thinning for manufacturing IGBTs for about 10 years. Unlike power MOSFETs, IGBTs benefit from thinning to hold the breakdown voltage rather than to reduce resistance. Manufacturers typically make IGBTs on 6-in. wafers, which are less prone to warp, and thinning is less complicated. Power MOSFETs, which once did not use thinning, moved a few years ago to 8-in. wafers. Thinning and handling thin 8-in. wafers initially resulted in poor yields due to breakage. MOSFET manufacturers have had to develop their own IP (intellectual property) based on using mechanical carriers to handle thinned wafers.

IN THE PAST, DEVELOPMENTS IN SILICON POWER MOSFETs COULD RIDE ON THE COATTAILS OF DIGITAL-SILICON PROCESSES. THOSE HALCYON DAYS ARE OVER.

Infineon late last year produced the first examples of power MOSFETs on thin, 300-mm-, or 12-in.-, diameter wafers at its power-development site in Villach, Austria (**Figure 1**). These chips reach the same specifications as equivalent devices on 200-mm wafers, according to the company (**Reference 2**). Due to wafer thinning and ongoing advances in silicon-device structure, power MOSFETs' resistance is now so low that the packaging resistance and parasitic inductance for attaching the die to the lead frame have become significant. Relatively thin, fragile wire bonds are limiting factors in removing high currents from a MOSFET; clips are instead becoming standard in high-power, high-performance devices.

Clips lower both on-resistance and parasitic inductance, which can lower the switching speed of the device. On-resistance and gate charge combine to make the commonly used FOM (figure of merit) for MOSFETs: $FOM=R_{DSON}\times Q_G$, where R_{DSON} is on-resistance and Q_G is gate charge. Gate

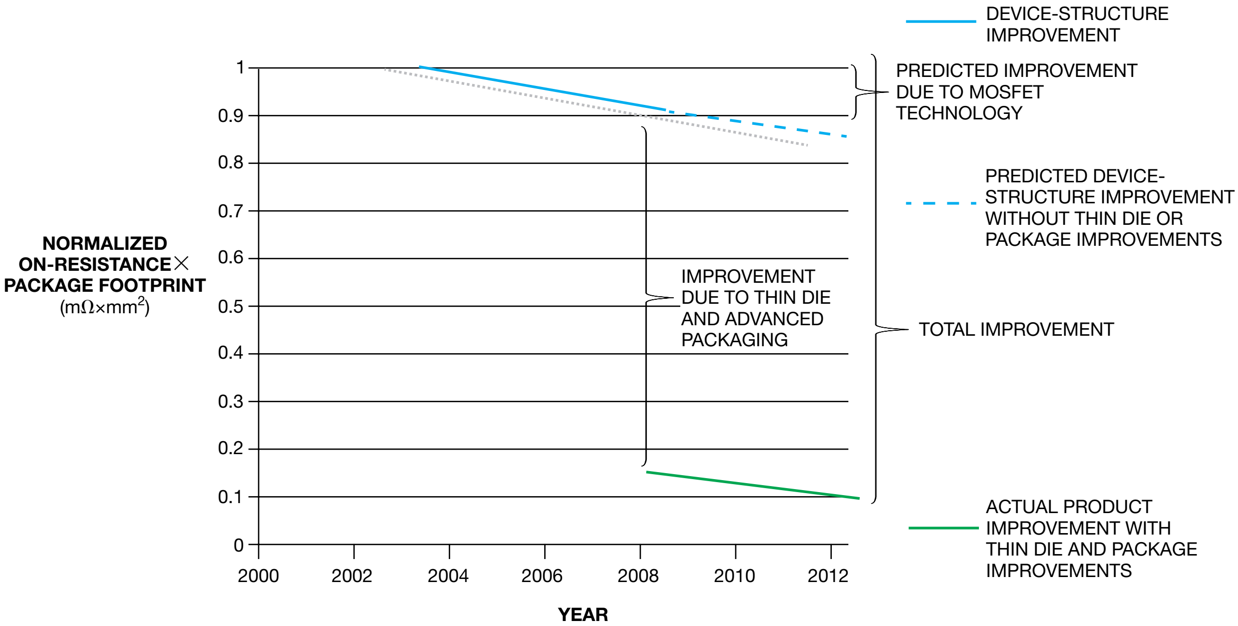


Figure 2 Until recently, improvements in silicon device structure drove improvements in power-MOSFET performance. Process improvements, such as wafer thinning and packaging innovation, now account for most improvements (courtesy Fairchild Semiconductor).

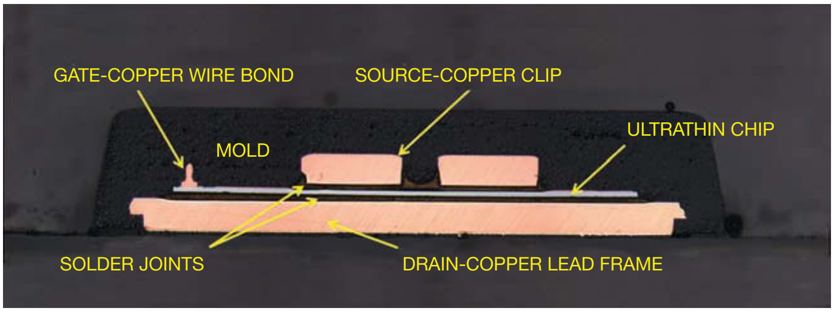


Figure 3 A SuperS08 package incorporates both clip technology for top-side mounting and diffusion-soldering techniques to reduce the conduction losses of the package as a system. The thinner bond layer of the diffusion solder complements the Infineon thin-wafer-MOSFET processes, which in current devices achieves 60-micron die thickness.

charge generally relates to the area of the current path within the silicon and usually varies inversely with on-resistance. In general, improvements in performance due to silicon-device structure come at the expense of either on-resistance or gate charge, and manufacturers tune devices for applications requiring minimum on-resistance or faster switching. Wafer thinning and die-bonding improvements in turn improve resistance and parasitic inductance without affecting gate charge. Thus, these developments have a greater effect on device performance than moving to the next spin of silicon-device structure (**Figure 2**).

"Wafer thinning provides about a 25% improvement in on-resistance, [whereas] moving from a conventional wire-bonding technique to a clip provides a 20% improvement," says Chris Rexer, vice president for low-voltage-MOSFET-technology development at Fairchild Semiconductor. "These [improvements] are very dramatic … in comparison to moving to another [silicon]-technology node."

Clips are not the only advancements in die attachment. Diffusion solder will also be important for bonding the bottom of the die to the package. In addition to having a thinner bond line and, thus, lower resistance and better thermal transfer than conventional soft solder, diffusion solder contains no lead, which is an important feature for "green" initiatives, such as ROHS (**Figure 3**). For example, stricter ELV (end-of-life-vehicle) ROHS directives pending implementation after 2014 may require 100%-lead-free packaging in European cars. Infineon has introduced the 40V OptiMOS T2 power MOSFETs, which combine diffusion solder and thin-wafer process technology that the company says exceeds current ROHS directives relating to lead-based solder to attach silicon chips to packages.

As a result of the increase in power density, which implies shrinking dice, and advances in packaging technology, MOSFET-driver packages are becoming increasingly practical. They were previously too large and too expensive for a product type that requires small footprints and low cost. Tuning low- and high-side switches is now a practical way to painlessly match switch characteristics. In 2004, Intel first proposed the design approach in the DrMOS-driver specification, but the concept's high cost and complexity hindered its adoption. Increases in power density now make the paired-switch technology feasible, however.

Texas Instruments' NexFET technology is unique in that the silicon-device structure is lateral rather than vertical. The lateral structure limits NexFETs to a blocking voltage of 25V. Although the technology can support high blocking voltages, doing so would require a larger die area, which would make for a prohibitive price increase. NexFETs also benefit from clever packaging. The PowerStack product comes in both a high-side and a low-side FET in a single package. Rather than a side-by-side configuration, the vertically stacked devices shorten the circuit path and thus lower the resistance and, more important, the inductance. This drop in inductance allows for a switching frequency of 800 kHz to 1 MHz. EDN

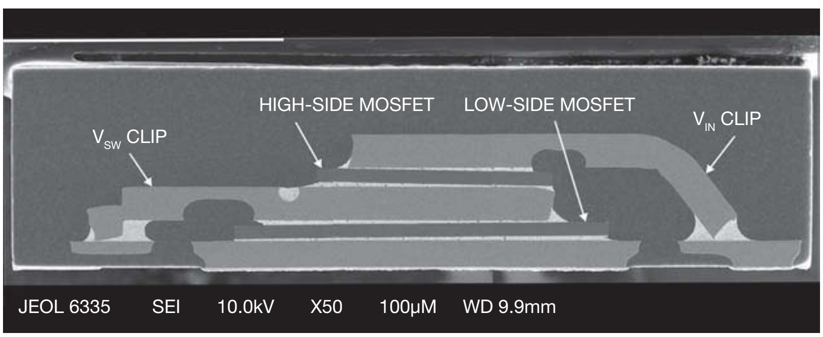


Figure 4 A cross-section of Texas Instruments' Power Block device using the PowerStack technology reveals thick copper clips that hold the high- and low-side MOSFETs in place. The low-side die attaches to the foundational pad of the lead frame, providing the ground connection for the low-side MOSFET. Such a construction delivers substantial benefits in board-space savings, current levels, power efficiencies, and thermal management.

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BY NAMRATA PANDYA • MICROCHIP TECHNOLOGY INC

Balancing GBWP and quiescent current for dissipation optimization

MINIMIZING POWER DISSIPATION IN ANALOG APPLICATIONS REQUIRES A CAREFUL BALANCE BETWEEN GBWP AND QUIESCENT CURRENT.

Although conceptually simple, operational amplifiers implement parametrically complex circuits that can pose numerous challenges to IC selection. Digital circuits dominate the power budgets of many familiar mains-powered system designs, and analog subsystems represent only a small fraction of the total dissipation. In these cases, your top priority for operational-amplifier selection is likely one or more signal-chain performance parameters. These parameters might include ac terms, such as distortion and broadband noise, or dc terms, such as input offset and offset drift.

In energy-constrained applications for which you must wring out every last bit of unnecessary power dissipation, however, the temptation is to start by looking for the operational amplifier with the lowest quiescent current. Unfortunately, this intuitively reasonable approach all too often identifies numerous candidates that meet the application's power requirement but not necessarily its GBWP (gain-bandwidth-product) needs.

For a given circuit topology, GBWP and quiescent current go hand in hand—essentially in direct proportion. The reasons for this behavior are several and involve the detailed topology of specific amplifiers. At the top level, however, consider that the operational amplifier you choose must charge and discharge internal capacitances at signal speed. The resulting displacement currents flow from the internal bias current of the amplifier, which determines the net quiescent current. Therefore, for a given topology, as bandwidth increases, the amplifier's quiescent current must also increase.

A HELPFUL FIGURE OF MERIT

The challenge for low-power design, then, is not simply to find low-power operational amplifiers but to find those that most efficiently provide bandwidth. A simple figure of merit to assess operational-amplifier bandwidth efficiency is the ratio of GBWP to quiescent current.

For example, a performance comparison and figure-of-merit calculation for four devices of similar architecture—the Microchip MCP644X, MCP640X, MCP628X, and MCP629X—shows a figure of merit that varies barely more

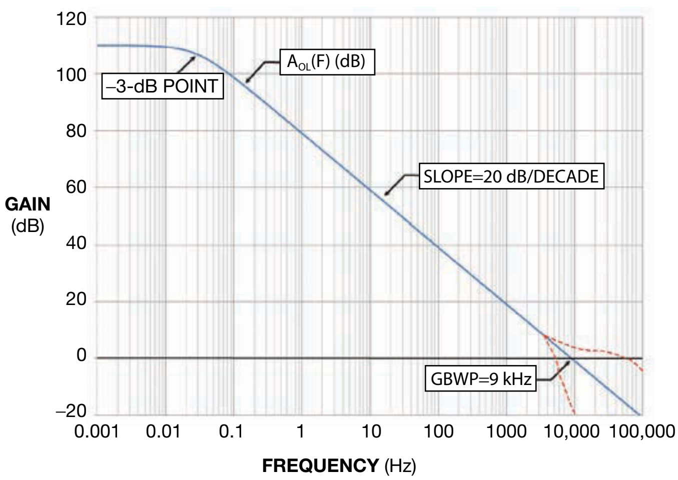

Figure 1 The open-loop gain of the Microchip MCP644X operational amplifier indicates a GBWP of 9000.

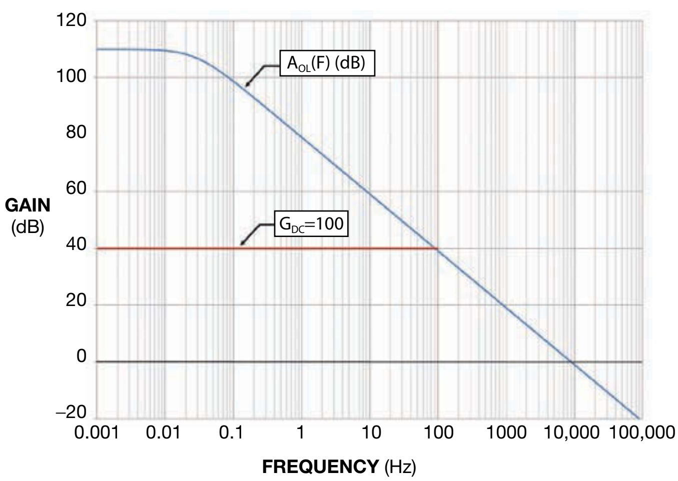

Figure 2 The magnitude of an amplifier's closed-loop gain (red) ideally derives only from the components in the feedback path.

than an octave, whereas the GBWP and quiescent current vary by a little more than three orders of magnitude (**Table 1** and **references 1** through **3**). Indeed, at the lower bandwidths, the figure of merit for these devices is nearly constant.

In practice, your selection process will focus, of course, on competing devices of similar GBWP—not a group covering several orders of magnitude. First, though, you must determine one key factor.

HOW MUCH IS ENOUGH?

The GBWP is an indication of an amplifier's open-loop gain as a function of frequency. The amplifier's Bode plot, which virtually all op-amp data sheets include, provides both the open-loop and the phase responses versus frequency and is a handy graphical tool for quickly assessing an amplifier's potential in your application. In this case, you need to consider only the open-loop-gain component of the Bode plot (**Figure 1**).

Note that the open-loop dc-gain level extends only to very small frequencies before the amplifier's dominant pole starts to roll off the open-loop-gain curve at a rate of 20 dB per decade. For most of the amplifier's bandwidth, open-loop gain falls by a factor of 10 for every factor-of-10 increase in frequency. The product of gain and frequency at any point along this part of the curve, then, is a constant: GBWP.

As expected, the curve crosses the 0-dB point at a frequency equal to the GBWP; thus, many references also call this quantity the unity-gain bandwidth. In reality, however, open-loop gain usually deviates slightly from the 20-dB/decade slope, when frequency approaches GBWP. The phase also isn't −90°, so the unity-gain bandwidth does not equal GBWP.

When you choose the dc closed-loop gain of a noninverting-gain op-amp circuit, closed-loop bandwidth is approximately GBWP divided by dc closed-loop gain. For example, using the MCP644X, you might expect that you could take a gain of 100 and see a useful bandwidth of 90 Hz (**Figure 2**), as the following **equations** show:

$$G_{DC}=1+\frac{R_F}{R_G}\cong 100;$$

$$BW_{CL}=\frac{GBWP}{G_{DC}}=\frac{9\ kHz}{100}=90\ Hz.$$

where G_{DC} is the closed-loop gain, R_F is the frequency resistance, R_G is the gain resistance, and BW_{CL} is the closed-loop bandwidth.

The gain over frequency, which derives directly from Black's formula (**Reference 5**), is expressed as

$$G(F)=\frac{V_O(F)}{V(F)_I}=\frac{A_{OL}(F)}{1+\frac{A_{OL}(F)R_G}{R_F+R_G}}=\frac{A_{OL}(F)}{1+\frac{A_{OL}(F)}{G_{DC}}},$$

where A_{OL} is the open-loop gain.

Loop transmission is the ratio of the open-loop gain to the ideal closed-loop gain. As the loop transmission increases, the gain in the first **equation** approaches the ideal gain in the third **equation**. The loop transmission greatly influences essentially all of the operational amplifier's closed-loop behaviors, including gain accuracy, linearity, distortion, output impedance, and, most notably, sensitivity to the value of open-loop gain, which is not a tightly controlled parameter (**Figure 3**).

As you push for lower and lower quiescent current, then, you must be more careful in assessing your circuit's GBWP requirements to prevent degradation of your circuit's performance. As your application's gain-accuracy requirement grows, so does the loop-transmission requirement.

As a general rule of thumb, you should ensure a minimum loop transmission of 10, which equals 20 dB, meaning that the open-loop gain is at least 10 times the forward, or closed-loop, gain. This limit keeps the gain error less than −1 dB, which suffices for most ac signal-processing applications. For more precise circuits, loop transmission of 100, or 40 dB, yields a gain error of only −1%, or −0.086 dB.

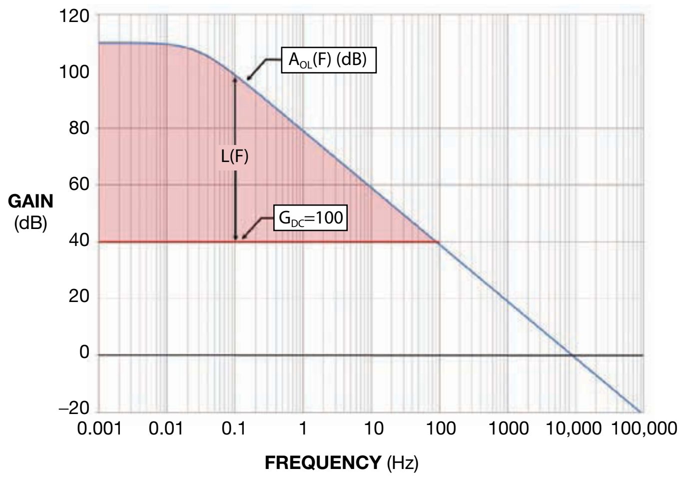

Figure 3 The loop transmission, L, is a measure of the ratio of open-loop gain to the dc gain. Plotting the factors open-loop gain, dc gain, and L on a logarithmic scale, which is the most common method, allows you to calculate the ratio by subtracting the factors' logarithms: log(L(F))=log(open-loop gain(F))−log(dc gain(F)).

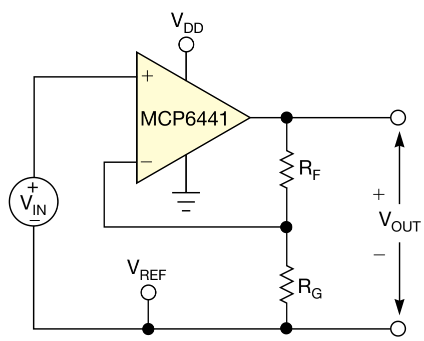

Figure 4 R_F and R_G form a resistive divider that sets the ideal forward gain. As long as the amplifier's open-loop gain is larger than the forward gain, this circuit's transfer function remains independent of signal frequency and the exact value of open-loop gain.

Precision circuits, such as those for metrology applications, require even greater loop transmission. You can calculate the forward gain error as a function of loop transmission:

$$\varepsilon_G(L)=\frac{G(L)-G_{DC}}{G_{DC}}=\frac{-1}{1+L},$$

where ε_G is the gain error and L is the loop transmission, both in decimal form.

As **figures 3** and **4** indicate, as signal frequency increases, the amount of loop transmission falls off, due to the downward trajectory of open-loop gain. As the flat dc-gain plot approaches the open-loop-gain curve, the operational amplifier's performance begins to degrade.

A simple method of maintaining a fixed-loop transmission is to add a single-pole lowpass filter to the amplifier's forward-transfer function (**figures 5** and **6**). This approach will cost you only one capacitor and prevents the amplifier's linearity, distortion, and dynamic-output impedance from increasing at the upper end of the circuit's bandwidth—important terms if you want the amplifier to feed, for example, an ADC.

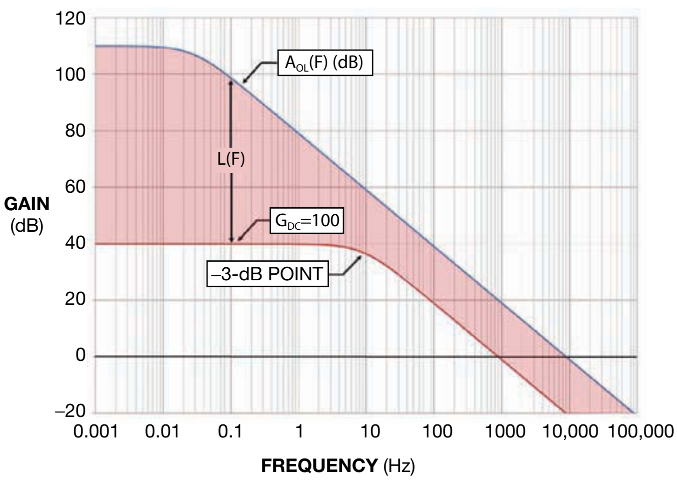

Figure 5 A single-pole lowpass filter fixes a circuit's signal bandwidth independently of open-loop gain and provides for a constant loop-transmission factor through the filter's transition band and stopband.

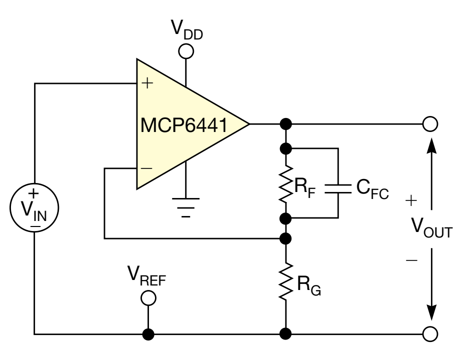

Figure 6 Adding a capacitor to the feedback network allows you to roll off the amplifier's forward gain and, in so doing, desensitize the circuit to variations in open-loop gain at the upper end of the circuit's signal bandwidth.

In this example, an amplifier has a GBWP of 9 kHz, and the application requires a gain factor of 100. The minimum loop-transmission factor is 10. Multiplying these factors yields the maximum signal bandwidth, which is a factor of 1000 smaller than the GBWP, or 9 Hz. This value is a factor of 10 below the 90 Hz that the first **equation** calculates because that **equation** does not take into account the selected loop transmission.

You often start your amplifier-selection process knowing the signal bandwidth, a forward gain, and a maximum gain-error requirement. From these data, you can calculate the required GBWP in two steps. First calculate the loop transmission from your maximum gain-error tolerance:

$$L=\frac{1}{\varepsilon_G}-1,$$

where ε_G is the gain-error tolerance. Then compute GBWP:

$$GBWP=F_S L G_{DC},$$

where F_S is the signal bandwidth.

BEATING THE NUMBERS

Consider a low-power application that requires a signal bandwidth of 20 kHz, a gain of 25, and a loop-transmission factor of 10. Multiplying these factors yields a GBWP of 5 MHz. Assume further that the MCP640X operational amplifier in **Table 1** would be attractive with its GBWP/quiescent current figure of merit of 0.022, were it not for the fact that its GBWP does not meet the requirement. If you could find a faster amplifier with the same gain-bandwidth efficiency, then you could expect it to draw 225 μA—five times the current of the MCP640X for five times the bandwidth.

This scenario sounds good. Unfortunately, however, amplifier vendors don't offer models with every conceivable GBWP, and different amplifier families use different topologies. Therefore, they offer different GBWP/quiescent-current figures of merit. If available amplifiers included only those in **Table 1**, your next stop would be the 5-MHz MCP628X, drawing 445 mA, which provides excellent performance but more than your application needs.

If power-dissipation optimization is a high priority, a small increase in circuit complexity can allow you to beat the numbers, in effect, by forming an amplifier that you can't buy. Cascading two operational amplifiers provides a total gain that is the product of the individual stages but that draws current that is only the sum of the two amplifiers.

TABLE 1 FIGURE-OF-MERIT COMPARISON

Amplifier	GBWP	Quiescent current	Figure of merit (MHz/μA)
MCP644X	9 kHz	450 nA	0.02
MCP640X	1 MHz	45 μA	0.022
MCP628X	5 MHz	445 μA	0.011
MCP629X	10 MHz	1 mA	0.01

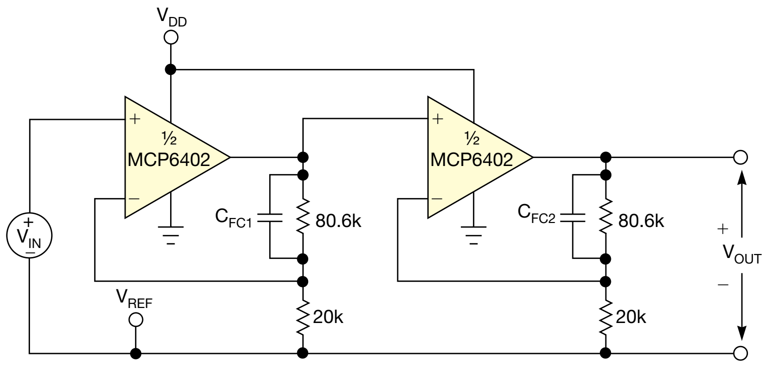

Figure 7 This cascade of two gain blocks provides a total gain that is the product of the stages' gains but draws a total quiescent current that is only the sum of the quiescent currents of the two amplifiers.

A cascade of two gain-of-five stages meets this application's gain requirements (**Figure 7**). The total quiescent current for the circuit is 90 μA—an 81% savings over the higher-current amplifier and a 60% savings over the hypothetical 5-MHz amplifier called for in the original analysis.

DUTY CYCLING

Many analog-signal-processing applications require only intermittent operation. For example, an ambient-light monitor requires only a fraction of a second to take a measurement, digitize the data, and transmit the data to a host processor. The data-density requirement for such a device may not demand continuous monitoring. It may perhaps require only one observation every couple of seconds. Between measurements, the system can disable the monitoring circuit to save power.

WHICHEVER WAY YOU CHOOSE TO POWER THE CIRCUIT BLOCK, BE SURE TO CHECK THE OFF-STATE LEAKAGE CURRENT OF THE BLOCK'S ENERGY SOURCE AND INCLUDE THAT TERM IN YOUR POWER BUDGET.

For example, if a light monitor can make, digitize, and transmit a measurement in, say, 10 msec and needs to do so, say, every 2 sec, then the measurement circuits can operate with a duty cycle of 0.5%. Neglecting leakage currents, this approach can reduce the average quiescent current by a corresponding factor of 200. You can implement the duty-cycle operation of operational amplifiers under digital control in one of two ways. You can power the amplifiers through an interruptible energy source, or you can use amplifiers that feature an enable pin.

Interruptible power sources come in three varieties, depending on how much load current they must provide. For high-current applications, a power converter or a regulator that features an enable pin can isolate a block of circuitry. For low-load currents, you can power a block directly from a microcontroller's I/O pin, thereby eliminating the dedicated power converter or regulator. For other cases, you can use a microcontroller's I/O pin to control a pass element, such as a discrete PMOS transistor.

Whichever way you choose to power the circuit block, be sure to check the off-state leakage current of the block's energy source and include that term in your power budget. This step is particularly important when powering circuits from small batteries or from energy-harvesting or -scavenging technologies.

The advantage of this approach is that you can use any amplifiers you want in the power-controlled block. The disadvantage is that it may be difficult to determine the time that the system must wait between powering up the block and using the settled accurate output of the analog subsystem.

The alternative is to use amplifiers that feature enable pins that turn off the amplifier, not just its output. These devices usually specify their turn-on time and can greatly enhance circuit efficiency by eliminating the need to pad your turn-on-time estimate. EDN

ACKNOWLEDGMENT

This article originally appeared on EDN's *sister site*, Planet Analog, *http://bit.ly/t65S5S*.

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AUTHOR'S BIOGRAPHY

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BY BILL LAUMEISTER • MAXIM INTEGRATED PRODUCTS INC

Small-signal bandwidth in a Big Bandwidth era

UNDERSTAND THE INTERPLAY BETWEEN BANDWIDTH AND OP-AMP SPECIFICATIONS.

The popular music of several decades ago typically required 12 to 25 musicians, so people refer to it as the Big Band era. Today, bandwidth increase is again a sign of the times. The explosion of Internet usage; network-capable cellular phones, including 3G, 4G, LTE (long-term evolution), and Wi-Fi units; music players; and digital videocameras has expanded consumers' expectations for bandwidth. We are on the cusp of wholesale data transfer to all portable devices. Bandwidth has become king, and we are therefore in the "Big Bandwidth" era. So, why discuss small-signal bandwidth?

Many operational amplifiers include a specification of small-signal bandwidth in their data sheets. All op amps have a "sweet spot" for better bandwidth, even if the data sheet does not mention it. Manufacturers typically base this specification on a signal amplitude of approximately 0.1V. At first glance, this figure seems primarily for use in comparison and for boasting rights with other op-amp companies. Some applications, however, can take advantage of the small-signal bandwidth, which can be many times greater than the large-signal bandwidth for an op amp. For example, the MAX4104 op amp has a small-signal bandwidth of 625 MHz at a signal amplitude of 0.1V or less and a large-signal bandwidth of 11 MHz at a signal amplitude of 2V p-p. Most applications use the large-signal bandwidth. Small-signal bandwidth is high because the op amp is operating in its midrange sweet spot (**Figure 1**).

The sweet spot for input signals is typically nearly one-half the power-supply voltage. The amplifier is most linear and produces the best signal quality in that region. Op amps have a large open-loop gain, and they employ negative feedback to control the amplifier by trading this open-loop gain for stability and linearity.

As the amplifier output approaches either power rail, less feedback is available, which in turn diminishes the ability of the feedback to linearize the amplifier response. As feedback decreases outside the sweet spot, the frequency response decreases, and distortion increases.

Op amps that offer rail-to-rail operation use special circuit configurations to minimize distortion near the power rails. A careful reading of the data sheet for a typical rail-to-rail output, however, shows that the output current diminishes to 0A at the rails.

Modern op amps are fabricated with processes in which transistors have multigigahertz bandwidths. An op amp, however, comprises tens or hundreds of transistors, resistors, and capacitors, and the net effect of that circuit structure is to reduce the overall bandwidth—often by an order of magnitude or more.

Among the effects of this natural bandwidth reduction are phase and amplitude errors due to stray interstage capacitance and resistance. Bandwidth reduction limits slew rate and is amplitude-sensitive, as you would expect. Thus, small signals have larger bandwidths than large signals.

Some applications, however, can use the small-signal bandwidth. In one such application—an impedance converter for a remote sensor—a small signal drives a relatively long cable. System requirements may include amplification of as much as 0.1V, as well as the ability to drive 50 or 75Ω coaxial cable. The first amplifier in the system usually sets the SNR. With the close relationship of bandwidth to SNR, using the small-signal bandwidth by limiting the signal amplitude may allow the use of a less expensive op amp that draws less power-supply current.

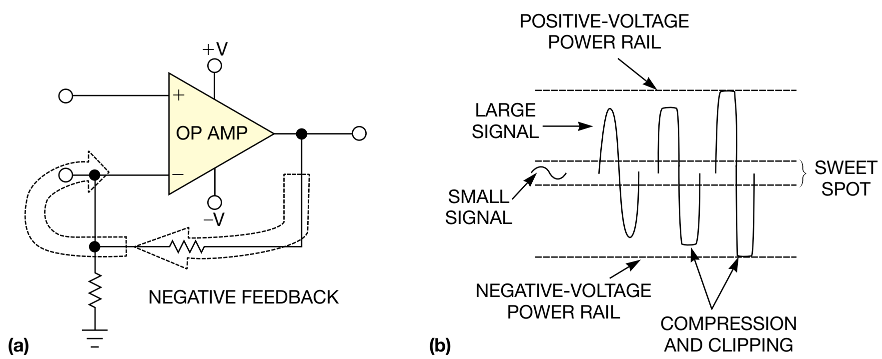

Figure 1 Signal conditions involving negative feedback (a) and compression and clipping (b) determine the bandwidth through an op amp.

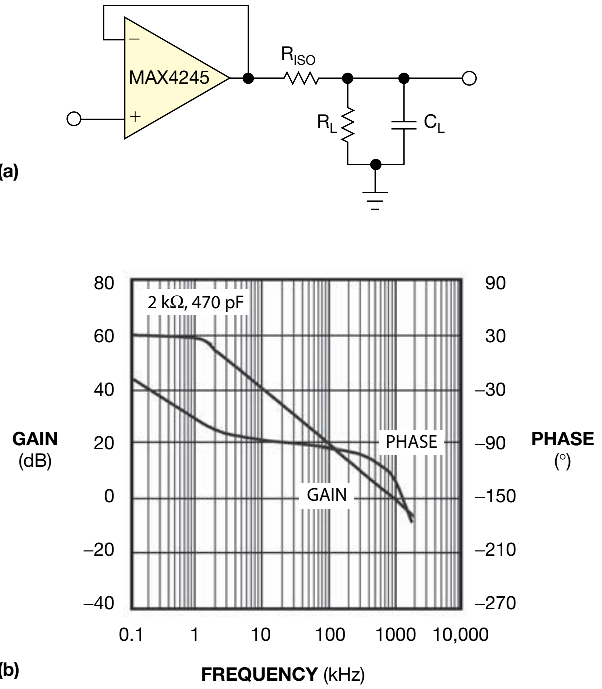

Figure 2 This circuit (a) operates with inexpensive op amps because it deliberately limits the signal bandwidth to 1 MHz, as the plot shows (b).

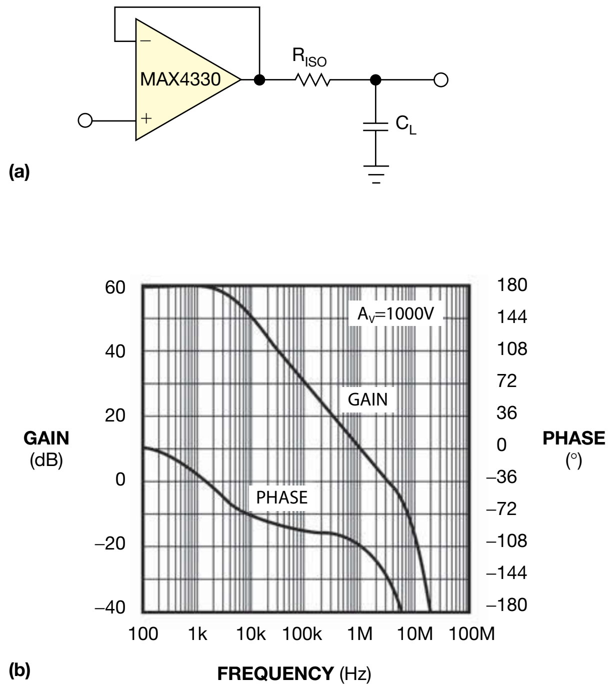

Figure 3 This circuit (a) operates with inexpensive op amps because it deliberately limits the signal bandwidth to 3 MHz, as the plot shows (b).

OP-AMP FREQUENCY CHARACTERISTICS

Although bandwidth limiting detracts from an op amp's performance, you can leverage bandwidth limiting to get the most from an inexpensive op amp. For instance, what if you need to limit the signal bandwidth with a simple 1-MHz lowpass filter? For noncritical applications, you might use an inexpensive op amp, such as the MAX4245 (**Figure 2**). For a 3-MHz lowpass filter, you could use the MAX4330 (**Figure 3**). For more critical applications, a Sallen-Key active filter that precisely controls the cutoff frequency and slope is more appropriate.

You can combine the lowpass bandwidth with other functions to reduce system cost. A precision rectifier comprising "perfect" diodes, for example, can smooth the edges of a signal by reducing the signal bandwidth. A perfect diode is an op amp with a diode in the feedback loop, which produces a diode response without the usual forward-voltage drop (**Figure 4**).

A circuit that converts differential to single-ended signals and that reduces high-frequency noise can also operate with an inexpensive op amp. As another example, you can construct a comparator with hysteresis—that is, a Schmitt trigger—that ignores high-frequency noise in its threshold voltage (**Figure 5**). The circuit ignores noise below the threshold, and positive feedback latches the output state until the circuit exceeds the opposite threshold. The op amp's response limits the output's slew rate.

Slow op amps tend to be inexpensive, and they can reduce system costs by combining functions that take advantage of the op amp's native frequency response. Bias and reference circuits for power supplies can take advantage of the lowpass characteristics to decouple noise and produce clean power. Op amps can isolate circuits from other circuits and act as lowpass filters.

In **Figure 6**, for example, op-amp voltage followers enable an ADC, a DAC, and other circuits to share a single voltage reference. The followers' high input impedance and low output impedance isolate the various circuits from one another. This isolation mitigates the effect of trace lengths on the PCB and prevents crosstalk between the circuits. Because the voltage-reference output should be one dc value, the low-

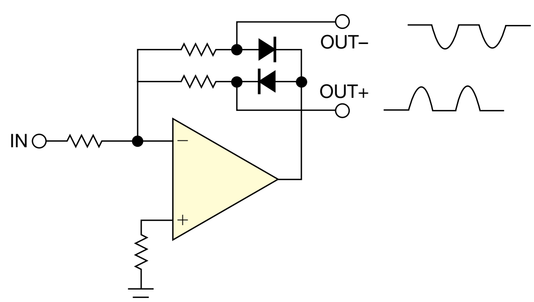

Figure 4 Diodes in the feedback path enable this op-amp circuit to perform full-wave rectification without the loss of forward-voltage drops in the diodes.

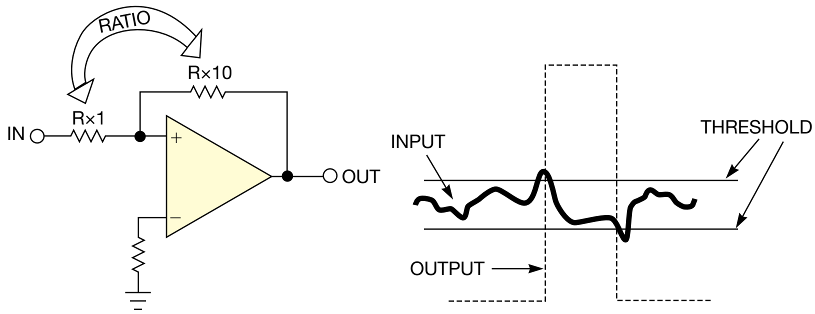

Figure 5 The modest bandwidth of this inexpensive op amp allows the Schmitt-trigger circuit to ignore high-frequency noise.

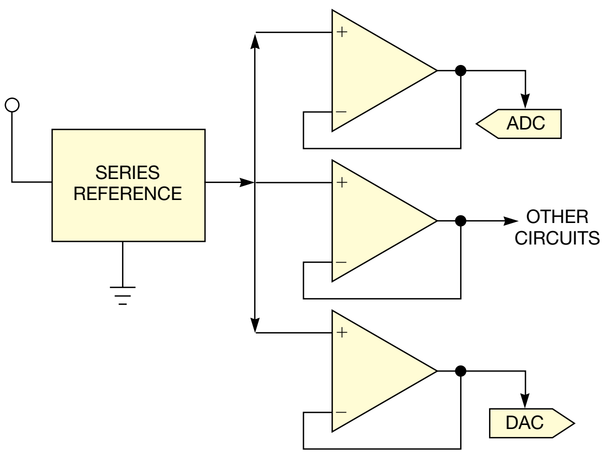

Figure 6 These inexpensive op amps distribute a single reference voltage to various circuits, and their low bandwidth serves as a welcome noise filter.

bandwidth op amps enhance its quality by acting as lowpass filters.

We are in the middle of an explosion in communications, in which consumers have come to expect high-speed communication networks to be widely available. In the United States, government agencies have begun to consider universal broadband availability, which is similar to the government's infrastructure mandates in the 20th century. This infrastructure—rural electrification, universal telephone service, and the interstate highway system—has greatly enhanced our standard of living.

When you think about wider and wider communication bandwidths, you should also think about all the systems that control that bandwidth. Circuits for equalization, channel selection, automatic gain and frequency control, and many others require slower, low-frequency control. Even in this Big Bandwidth era, low-bandwidth op amps have an established place. **EDN**

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AUTHOR'S BIOGRAPHY

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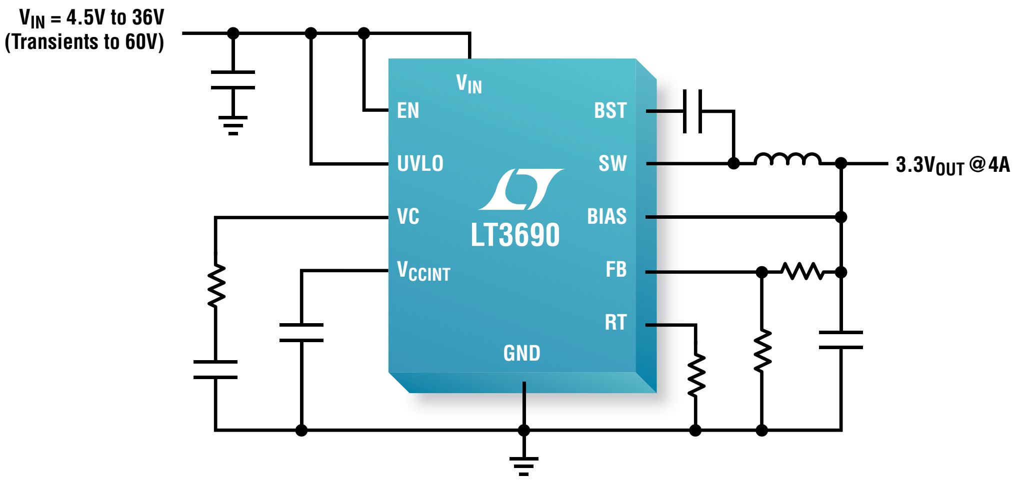
36V, 4A Sync Buck

Actual Schematic



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Stable pulse generator uses matched transistors in a current mirror

Bill Morong, Paoli, PA

Using CMOS gates to generate pulses sometimes causes timing uncertainty due to gate-threshold variations. For accurate pulse widths, you can use BJTs (bipolar-junction transistors). Basing the design on current comparison allows the circuits to operate at low voltages. Proper clamping of the timing capacitor avoids pulse shortening with increased repetition frequency. These circuits work with somewhat less accuracy at supply voltages lower than 5V.

The heart of this design is a current mirror using modern dual transistors. Process improvements have made many ordinary dual transistors inherently well-matched. Testing a statistically significant sample of PMBT856 devices typically yields a better-than-1-mV match and no mismatches at voltages greater than 2 mV. As has been true for decades, PNP-transistor pairs are better matched than NPN transistors. Testing PMBT3904 devices yields 2-mV matches, with none worse than 3 mV. The packages measure approximately 2 mm on a side, which gives good thermal coupling between the pair. A current mirror with devices having 2-mV mismatch has 8% error. Devices with 3-mV mismatch yield 12% current error. Even with these errors, the circuit makes pulses that are more predictable than those that CMOS devices make.

Figure 1 depicts a simple implementation of a current-mirror pulse generator. It provides good performance over a 0 to 100°C temperature range (**Figure 2**). The closely spaced traces in the waveforms of these circuits are the 0 and 100°C outputs. Source V_2 produces a 40-kHz square wave with a 33% duty cycle. The negative transition of this wave produces a peak current of 4 mA in timing capacitor C_1. A time constant of 4.7 µsec is set with the value of resistor R_1. The timing current of C_1 and R_1 passes through diode-connected

DIs Inside

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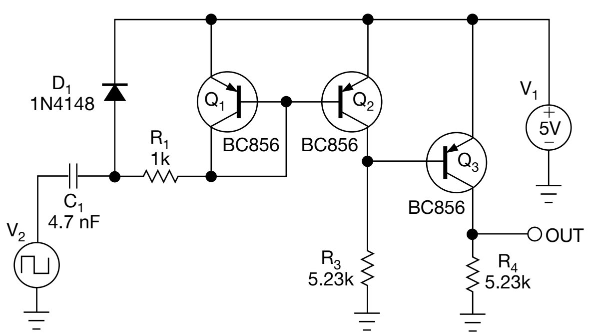


Figure 1 You can make a low-impedance pulse generator using a current mirror you fashion from discrete dual transistors.

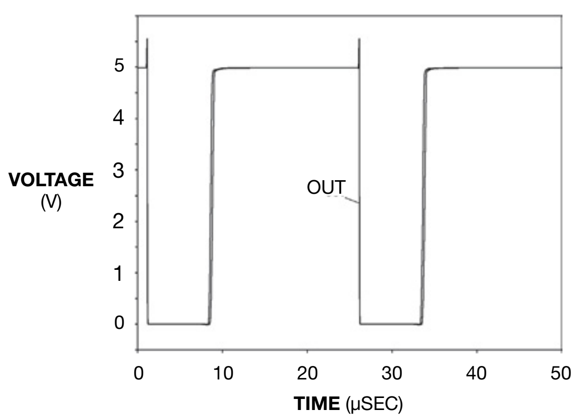


Figure 2 The circuit of Figure 1 makes stable repeatable pulses but has slow response.

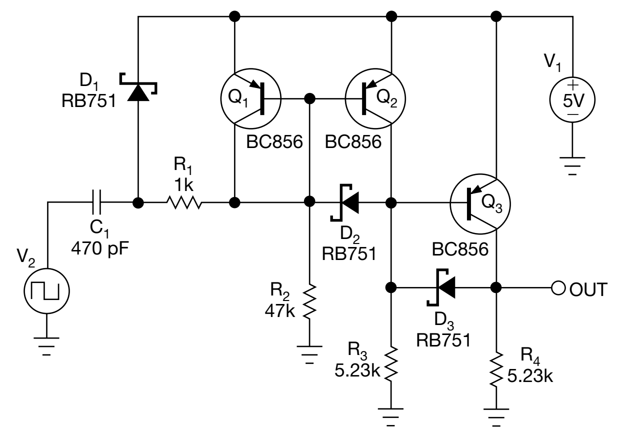


Figure 3 You can change D_1 to a Schottky type to reduce recovery time and add D_2 and D_3 to keep the transistors out of saturation. R_2 biases the current mirror out of the cutoff region.

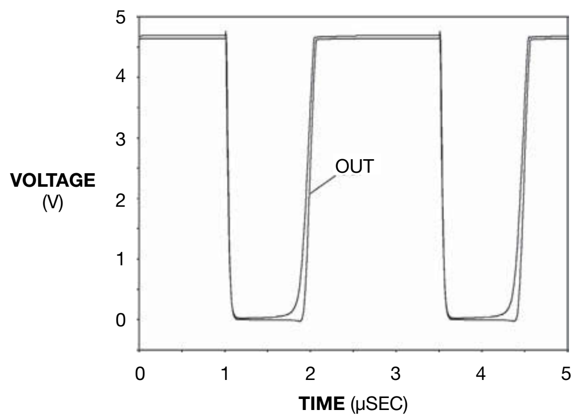


Figure 4 The improvements in Figure 3 allow the circuit to easily handle 2-μsec pulse periods.

transistor Q_1, which, being connected in parallel with the base-emitter junction of Q_2, forms a current mirror that replicates in Q_2 the timing current in C_1 and R_1. Because the base-to-emitter-voltage-to-emitter-current curves of Q_1 and Q_2 match and Q_1 and Q_2 are at the same temperature, Q_2 current matches Q_1 current. A quiescent current of about 0.85 mA is set in R_3. When the timing pulse increases Q_2's current to exceed R_3's quiescent current, Q_3 lacks base current and turns off, initiating a negative pulse across load resistor R_4.

When the timing current decays below the quiescent current of R_3, base current flows into Q_3, turning it on and terminating the pulse on R_4. Q_2 saturates early in this pulse and becomes less saturated as the timing current decays.

When V_2 transitions positive, it drives the bulk of its current into D_1, yielding a short recovery time constant. D_1 ceases to conduct at one diode drop above V_1's supply voltage, so the recovery tail from that diode drop to the quiescent base voltage of Q_1 depends on the current decay in R_1, which is a longer time constant. This simple circuit is stable, varying less than 4% over 100°C.

Although stable, this circuit does not provide high-speed operation. In the circuit's quiescent state, there is no current in either Q_1 or Q_2, making for a low gain bandwidth. Also, Q_3 is in saturation, delaying the initial fall of the pulse across R_4 because the free carriers must leave the base region. Q_2 also saturates during the pulse, delaying the rise at the end of the pulse.

Figure 3 depicts an improved current-mirror pulse generator. In this circuit, the operation of C_1, R_1, and D_1 fol-

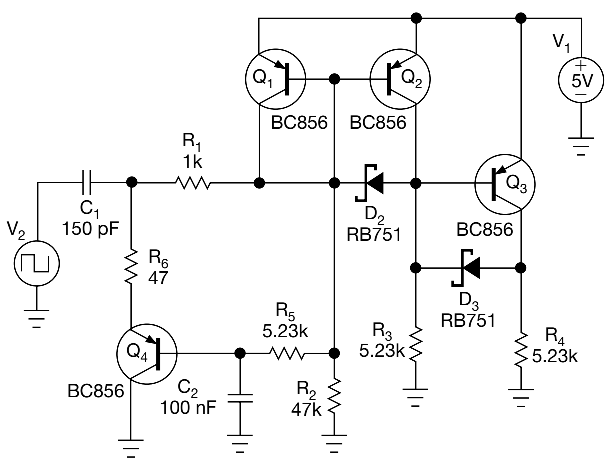


Figure 5 Replacing D_1 with a transistor circuit eliminates the tail-recovery time of the diode.

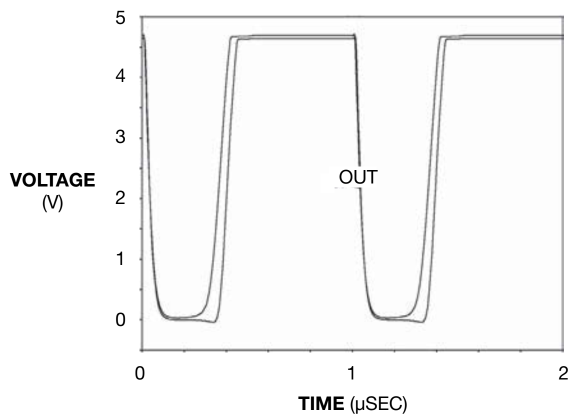


Figure 6 Figure 5's improvement allows the circuit to handle 1-μsec pulse periods.

lows that of **Figure 1**. Changing D_1 to a Schottky diode reduces the recovery-tail voltage that R_1 must dissipate. Add R_2 to draw a keep-alive current of 100 μA through Q_1 and Q_2, speeding turn-on. These keep-alive currents need not affect the timing. You can cancel out their effect with a slight reduction in the value of R_3. Fitting Q_2 and Q_4 with Schottky clamps D_2 and D_3, respectively, keeps the transistors out of saturation. These changes improve high-speed performance (**Figure 4**).

Although improved, the circuit still relies on D_1 for the final tail of recovery. To eliminate this problem, you can replace D_1 with a fourth transistor, Q_4 (**Figure 5**). Because transistors Q_1 and Q_2 are slightly conducting, a voltage one diode drop below that of supply V_1 is always present at their bases. You filter this voltage with R_5 and C_2 and provide it as a bias to the base of Q_4. This step keeps Q_4 nearer the threshold of conduction than would a diode to supply V_1. When source V_2 changes to a negative state, Q_4 is fully off and draws no current. When V_2 changes to a positive state, the emitter of Q_4 conducts at voltages above V_1 to catch the recovery transition, further reducing the recovery-tail amplitude.

BECAUSE Q_1 AND Q_2 ARE SLIGHTLY CONDUCTING, A VOLTAGE ONE DIODE DROP BELOW THAT OF SUPPLY V_1 IS ALWAYS PRESENT AT THEIR BASES.

R_6 may be used to limit Q_4's base current, but its omission is acceptable if source V_2 has sufficient output resistance. It may be destructive to apply source V_2 swings large enough to cause excess reverse voltage across the Q_4 base-emitter junction. Q_3 and Q_4 can share the same package. These additions further improve the pulse generator's high-speed performance (**Figure 6**). EDN

Implement an audio-frequency tilt-equalizer filter

Francesco Balena, Electro-Acoustic Design, Conselve (PD), Italy

In the 1970s, Quad Ltd developed a "tilt" audio-tone control, which first appeared on the company's model 34 preamplifier. The tilt control tilts the frequency content of the audio signal by simultaneously boosting the treble and cutting the bass frequencies, or vice versa (**Figure 1**). Only one knob is needed to tilt the frequency response around a pivot frequency, F_P (**Figure 2**).

Quad Ltd never published a transfer function for the filter. You need a Spice simulation and many trial-and-error cycles to tune it to your desired response. By deriving the transfer function, you can easily select the component values. Surprisingly, the transfer function also shows how you can make the tilt response asymmetric, with different amounts of boost and cut. You begin deriving the transfer function by expressing the input versus the output as a function of dc-feedback resistor, R_F, and Z, the complex impedance of the RC branches:

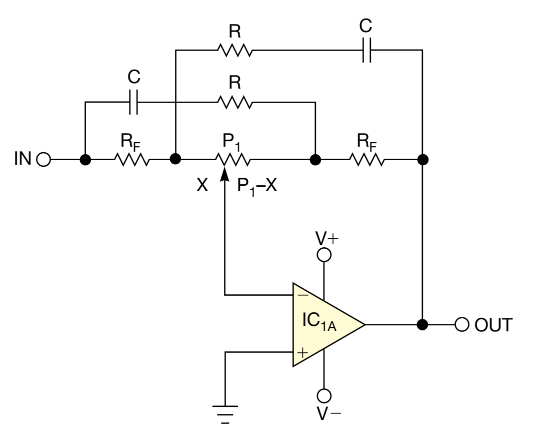


Figure 1 In a tilt audio-tone control, the tilt control tilts the frequency content of the audio signal by simultaneously boosting the treble and cutting the bass frequencies, or vice versa.

$$\frac{V_O}{V_I}=\frac{X\times(Z-R_F)-Z\times(P_1+R_F)}{X\times(Z-R_F)+R_F\times(Z+P_1)},$$

where X indicates the wiper position of potentiometer P_1 and the values of the resistors and capacitors define Z:

$$Z=R+\frac{1}{i\times 2\times\pi\times F\times C}.$$

The frequency response in **Figure 2** is for the extreme wiper positions, where X=0 or P_1. All of the other responses, with 0 less than X and X less than P_1, lie between those curves. To get the frequency responses in decibels, multiply the log of the absolute value of the transfer function by 20: $20\log(|T_F|)$. To get a log/log scale on the graph, substitute 10^F for F on the X axis. Pivot frequency F_P depends on component value, including the setting of potentiometer P_1, as it sweeps between an X value of 0 and P_1, where R_F must be greater than R:

$$F_P=\frac{\sqrt{(P_1+2\times R_F)}}{2\times\pi\times C\times\sqrt{(R_F-R)}\times\sqrt{(P_1\times(R+R_F)+2\times R\times R_F)}}.$$

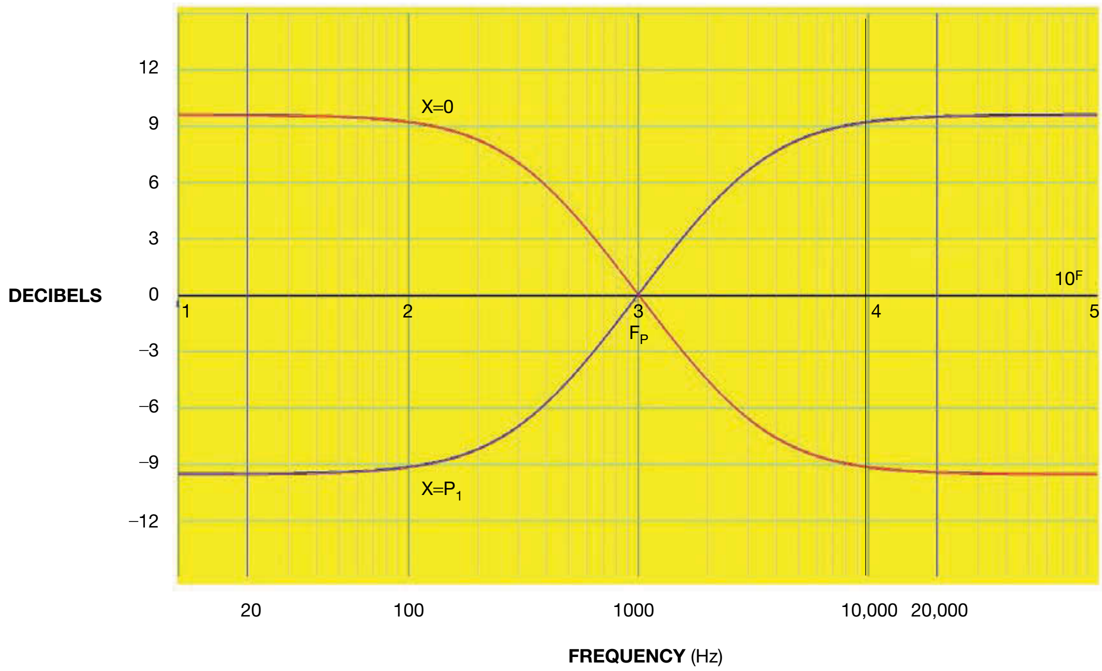


Figure 2 This frequency response is for the extreme wiper positions, where X=0 or P_1. All of the other responses, with 0 less than X and X less than P_1, lie between these curves.

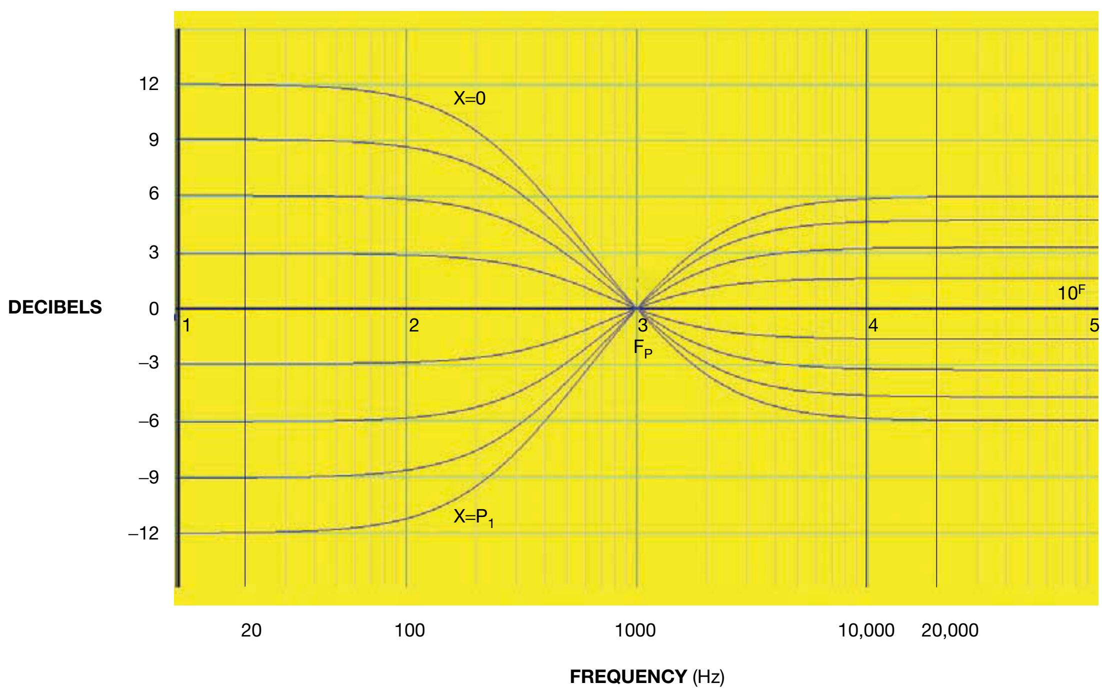


Figure 3 R_F is 16.66 kΩ, R is 7.14 kΩ, and C is 12.24 nF.

designideas

To calculate component values, you first define the maximum low-boost asymptote as M_L, when the frequency goes to 0 Hz and the potentiometer's value is also 0Ω. You then define the maximum high-boost asymptote as M_H, when the input frequency goes to infinity, and set the potentiometer to its maximum value. This step gives the component values for R_F, R, and C:

$$R_F=\frac{P_1}{M_L-1};$$

$$R=\frac{P_1}{M_H\times M_L-1};$$

$$C=\left\{\left[(M_L-1)\times\sqrt{(M_L+1)}\times(M_H\times M_L-1)^{3/2}\right]\times\sqrt{\left(\frac{M_H-1}{(M_L-1)\times(M_H\times M_L-1)}\right)}\right\}/$$

$$2\times\pi\times M_L\times P_1\times F_P\times(M_H-1)\times\sqrt{(M_H+1)}.$$

For the **equations** to work, M_L-1 and $(M_H\times M_L-1)$ must be greater than 0. You can choose any reasonable value of potentiometer P_1. For example, select a P_1 value of 50 kΩ, a desired pivot frequency of 1 kHz, a maximum low-frequency boost of 4, and a maximum high-frequency boost of 2. The **equations** yield an R_F of 16.66 kΩ, an R of 7.14 kΩ, and a C of 12.24 nF (**Figure 3**).

You take 20 times the log of M_L to get the response in decibels, so an M_L of 4 is the 12-dB maximum low-frequency boost, and an M_H of 2 represents the 6-dB maximum high-frequency boost. When you normalize the resistor and capacitor values to standard values, you get only a minor error in your desired response. By defining the variables M_L and M_H, you can make tilt equalizers that have an asymmetric response between boost and attenuation.

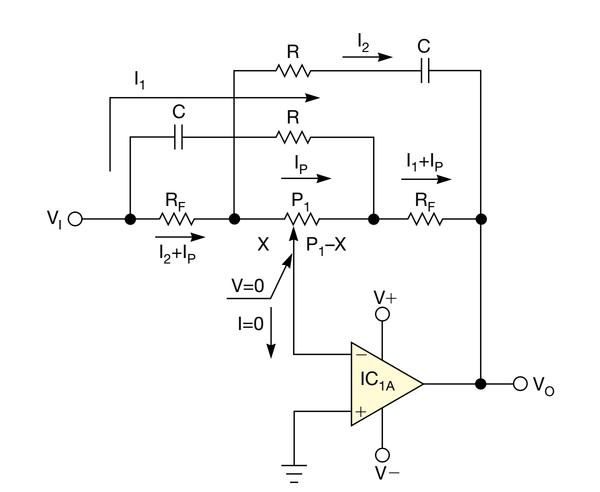


Figure 4 Voltages V_I, V_O, and V are all referred to ground.

THE GOAL IS TO FIND V_O/V_I; YOU NEED NOT SOLVE ALL OF THE UNKNOWNS.

A detailed derivation of the transfer function is included here. You begin by defining voltages V_I, V_O, and V, all referred to ground (**Figure 4**). In this case, I_1, I_2, and I_P are the minimal number of unknown currents. Because an op amp servos the output to keep the input pins at the same voltage, the potentiometer wiper is at 0V, a virtual ground. Further assume the infinite input impedance of the op-amp input pins so that the current at the inverting pin is 0A. V_I and V_O are unknown, letting you write a set of **equations** for the conditions:

$$V_I=I_1Z+(I_1+I_P)R_F+V_O$$
[Loop V_I→Z (input)→R_F (output)→V_O];
$$V_I=(I_2+I_P)R_F+I_2Z+V_O$$
[Loop V_I→R_F (input)→Z (output)→V_O];
$$V_I=(I_2+I_P)R_F+I_PX+0$$
[Loop V_I→R_F (input)→X(P_1 wiper)→virtual ground];
$$0=I_P(P_1-X)+(I_P+I_1)R_F+V_O$$
[Loop virtual ground→P_1−X(P_1 wiper)→R_F (output) →V_O];
$$V_I=(I_2+I_P)R_F+I_PP_1+(I_1+I_P)R_F+V_O$$
[Loop V_I→RF (input)→P_1→R_F (output)→V_O].

Remember that Zis the complex impedance of the RC branches. Now rearrange the **equations**:

$$V_I=I_1(R_F+Z)+I_PR_F+V_O;$$
$$V_I=I_2(R_F+Z)+I_PR_F+V_O;$$
$$V_I=I_2R_F+I_P(X+R_F);$$
$$V_O=I_PX-I_1R_F-I_P(P_1+R_F);$$
$$V_I=I_1R_F+I_2R_F+I_P(P_1+2R_F)+V_O.$$

From the first and second **equations** you can deduce that I_1 equals I_2. You can now substitute into the last three **equations** and rearrange them to get the final set:

$$V_I=I_1(R_F+Z)+I_PR_F+V_O;$$
$$V_I=2I_1R_F+I_P(P_1+2R_F)V_O;$$
$$I_1=(I_P(X-P_1-R_F)-V_O)/R_F;$$
$$V_I=2I_1R_F+I_P(P_1+2R_F)+V_O.$$

The goal is to find V_O/V_I; you need not solve all of the unknowns. If you substitute I_1 from the third **equation** above into the second **equation**, you can find I_P. You then substitute this I_P into the fourth **equation** and find the ratio of V_O/V_I, yielding the first **equation** in this Design Idea. This result is congruent with the actual numerical value of the examples in **Reference 1**. EDN

REFERENCE

1 Moy, Chu, "Designing a Pocket Equalizer for Headphone Listening," *HeadWize*, 2002, http://bit.ly/vveL7z.

Originally published in the May 5, 1979, issue of *EDN*

Circuit provides 70 dB of AGC

Ben Segal, Telecommunications Technology, Sunnyvale, CA

The circuit diagrammed in the **figure** provides a 70-dB automatic-gain-control range for input voltages of –60 to +10 dBm over a bandwidth of 55 Hz to 15 kHz. The worst-case distortion is 3%, but distortion typically measures less than 1% in the 100-Hz to 10-kHz range.

The signal autoranges to keep the input to the AGC section between –60 and –25 dBm; this procedure allows the FET to operate in its most linear region. A comparator performs the autoranging, comparing a –25-dBm reference with the signal from A_1 and A_2. A_4 furnishes the AGC action, settling a –15-dBm output as a reference voltage; A_5 provides a fixed 15-dB gain and an output of 0 dBm. A_6, A_7, and the FET constitute the AGC's feedback circuit. EDN

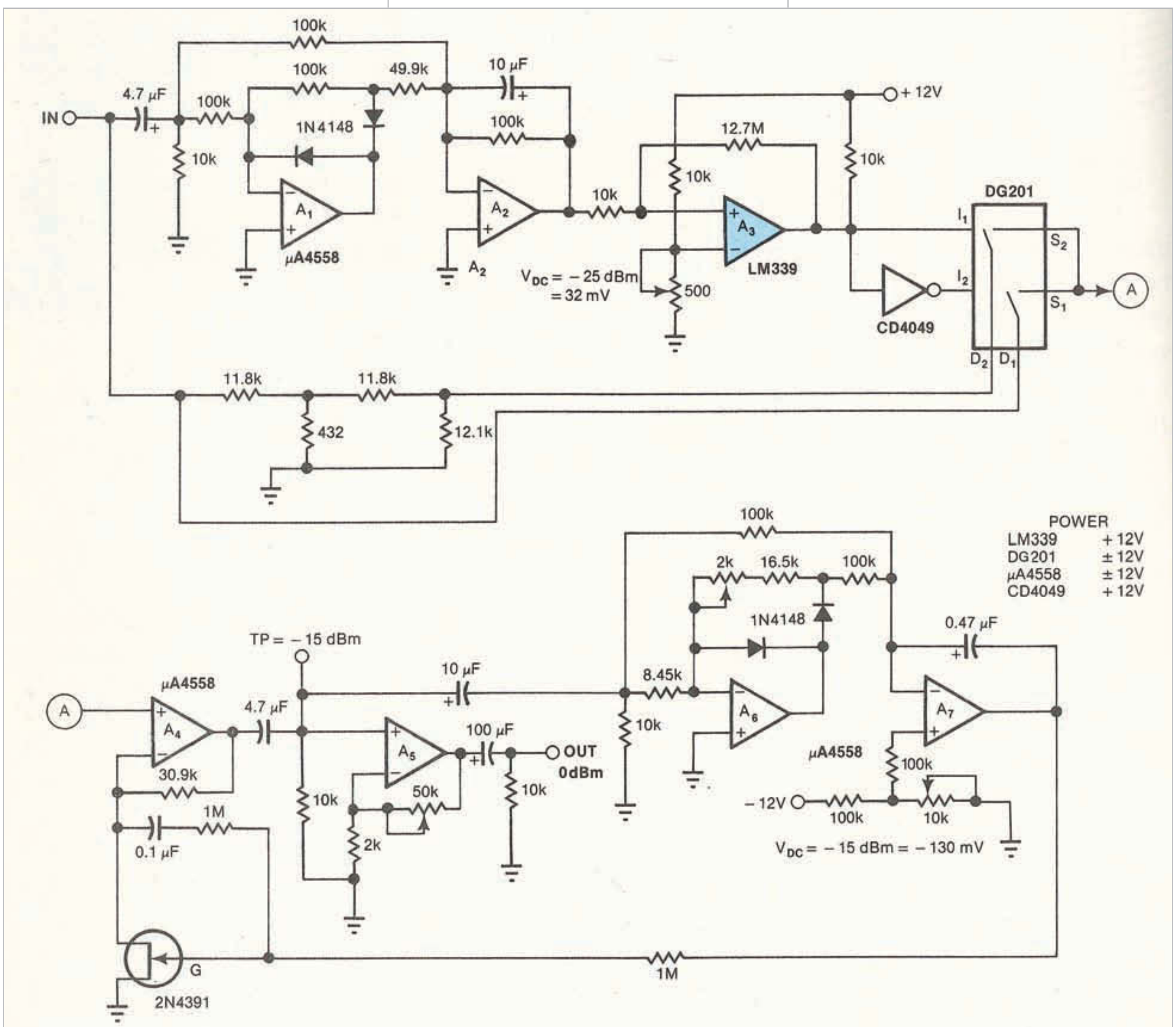


Figure 1 A comparator autoranges to ensure that the AGC sees a signal between –60 and –25 dBm, keeping the FET in its linear region.

Intel muscles into smartphones, tablets

After years of attempts, Intel Corp, the 800-lb gorilla of the semiconductor market, has finally entered the wireless court. The company says that three leading OEMs will design Intel processors into their smartphones and tablet PCs.

At the 2012 CES (Consumer Electronics Show) last month, Intel announced critical design deals with China Unicom Ltd, Lenovo Group Ltd, and Motorola Mobility Inc. These deals represent the company's first successful challenge of ARM Ltd in the market. China Unicom, Lenovo, and Motorola this year will roll out devices employing the Intel architecture. As a result, the leading semiconductor company will be getting the validation it has long sought as a player in the wireless industry.

"When great silicon and software technology meets great mobile and design innovation, amazing things can happen," says Paul Otellini (**photo**), Intel's president and chief executive officer. "Our long-term relationship with Motorola Mobility will help accelerate Intel architecture into new mobile-market segments."

These design wins for Intel have huge significance. The company initially fought vainly against the dominance of ARM architecture. Intel's PC-OEM customers worried about the emergence of another near monopoly if Intel gained a large following in the wireless-equipment market. They even speculated that the company's power-hogging processors, most of which target the PC market, would not work for the cellular-phone industry.

Efforts to prove the doubters wrong led the company to pour billions into acquisitions and product-development initiatives. Many of the acquisitions—some early in the last decade—failed to produce the desired results, and Intel could not make a dent in the sector. More recently, it began deploying its enormous internal engineering resources and the huge cash hoard it had built in the PC-microprocessor business. Intel has since developed chip sets and reference designs for the wireless market.

> The world is moving from a focus on personal *computers* to a focus on personal *computing*.

These efforts produced the Atom processor, which China Unicom, Lenovo, and Motorola will use. The agreements give Intel the bragging rights it has long desired and signal clearly that it won't walk away from the sector, despite the past failures. Few companies would like to have Intel as a rival, as Advanced Micro Devices can attest.

Meanwhile, in England, a nightmarish journey is beginning for ARM, the IP (intellectual-property) company that rapidly built up a commanding customer base in the wireless sector on the strength of patronage by customers seeking to ward off another monopoly. ARM has maintained its leading position in this market, but Intel's latest design wins will most certainly break the dam wall. If other OEMs and telecoms embrace the Intel architecture, ARM's market share could slip dramatically over the next few years.

Of course, Intel could face another failure if its chips don't catch on. In that case, the company would have to try again. According to Otellini, the world is moving from a focus on personal *computers* to a focus on personal *computing*. Intel cannot afford to be absent from this wireless world. Somehow, it must build on the toehold it has finally secured.

—by Bolaji Ojo, *EBN* Editor in Chief

This story was originally posted by EBN: *http://bit.ly/yUcV5A.*

OUTLOOK

INVENTORY ADJUSTS TO SLOW MARKET

DOI (days of inventory) dipped in the third quarter of last year, according to IHS. Semiconductor suppliers' chip inventories experienced a steady expansion during the previous seven quarters. Semiconductor stockpiles in the third quarter stood at 81 days, down 2.5% from 83 days in the second quarter.

IHS estimated that global semiconductor revenue in 2011 would rise by 1.9% compared with a forecast of 7% growth that the company issued early in the year. "For the third quarter, semiconductor suppliers began an inventory correction to alleviate an escalating oversupply situation on top of already-inflated stockpiles," says Sharon Stiefel, IHS semiconductor analyst.

DOI in the third quarter remained elevated in absolute terms—the highest of the last 10 quarters, dating to the fourth quarter of 2008—suggesting that stockpiles are still high. Further, the percentage of oversupply during the period rose to 12.1%, exceeding the 11.1% spike in oversupply during the fourth quarter of 2008. "Visibility continues to be murky in many sectors given the volatile world economy, and demand remains difficult to predict," Stiefel adds.

—by Suzanne Deffree

productroundup

PASSIVES

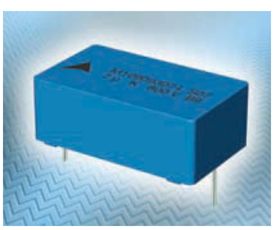
Triad Magnetics' CMT-8100 common-mode inductors eliminate noise in power-supply lines

Triad Magnetics' CMT-8100 series of common-mode inductors targets high-temperature applications in demanding electronics operating environments, such as industrial controls, plant instrumentation, and heavy-duty equipment. The devices have a dielectric strength of 1500V rms between windings and operate at −55 to +105°C; the rated current yields a temperature rise of approximately 35°C. Inductors in the series offer a minimum inductance per winding of 1 to 50 mH, a current rating of 1.7 to 20A, and a dc resistance of 0.006 to 0.45Ω. They come in rectangular packages measuring 0.76×0.425 to 1.7×0.9 in., with a height of 0.9 to 1.65 in. Prices start at $2.25 (1000).

Triad Magnetics, www.triadmagnetics.com

TDK's B32*6T film capacitors have low insertion height

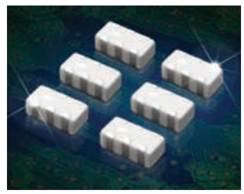
The B32*6T series of MKP and MKT film capacitors have insertion heights of only 15 or 19 mm and lead spacing of 37.5 mm. The components operate at voltages of 63 to 2000V dc and 250 to 400V ac; capacitance ranges from 0.1 to 82 µF. Depending on type and technology, the capacitors operate at maximum temperatures of 105, 110, or 125°C. Applications include dc-link circuits and dc or ac filtering in converters and power supplies, including induction cookers, photovoltaic microinverters, power supplies for flat-screen TVs, and LED lighting. With high mechanical resistance to vibrations and shocks, they are suitable for subassemblies in automotive electronics.



TDK-EPC, www.tdk.com

Murata's LFB182G45-BG2D280 filter targets 2.4-GHz wireless apps

The LFB182G45BG2D280 balanced-output-matching filter suits use in 2.4-GHz wireless applications using Bluetooth and ZigBee technologies. The device works with Texas Instruments' CC253x and CC254x SOCs for ZigBee and Bluetooth networking, respectively. The device's integrated filter components greatly reduce harmonic radiation. The six-pin device has mechanical dimensions of only 1.6×0.8 mm and replaces nine discrete 0402 components in the recommended discrete balanced/unbalanced-filter design. Sample price for the filter is 25 cents.



Murata Electronics North America Inc, www.murata-northamerica.com

Vishay offers IHLP-3232CZ-11 inductor in 3232 case size

The 3232-size IHLP-3232CZ-11 inductor measures 8.26×8.79 mm and has a 3-mm profile. Maximum dc resistance ranges from 1.62 to 205 mΩ, and standard inductance values range from 0.22 to 33 µH. The device also features a saturation current of 2.5 to 24A, a heat-rating current of 2.6 to 36A, and an operating-temperature range of −55 to +125°C. The ROHS-packaged device sells for 32 cents (10,000).

Vishay Intertechnology Inc, www.vishay.com

Kemet's T522 polymer capacitor features low leakage

The T522 polymer-tantalum capacitor series targets leakage-sensitive applications, such as battery-supported circuits. The devices feature an ESR of 25 to 40 mΩ, capacitance of 150 to 470 μF, voltage as high as 6.3V dc, and an operating temperature of −55 to +105°C. Other features include a nonignition failure mode, 100% accelerated steady-state aging, and a self-healing mechanism. Sample prices start at 95 cents.

Kemet Corp, **www.kemet.com**

Rohm's chip resistor measures just 0.3×0.15 mm

Rohm's 03015-size chip resistor measures 0.3×0.15 mm and offers dimensional accuracy of ±5 microns. Tolerance range is 10 to 91Ω or 100Ω to 1 MΩ, and resistance-temperature characteristics are ±300 or ±250 ppm/°C. Operating temperature is −55 to +125°C.

Rohm Corp, **www.rohm.com**

AVX's GX01 capacitor addresses dc-blocking issues

The GX01 ultrabroadband capacitor addresses dc-blocking issues from 160 kHz with a −3-dB roll-off to 40 GHz. The GX01 provides an insertion-loss value of less than 0.5 dB through at least 40 GHz. It features a standard EIA 0201 footprint and is available with X5R or X7S dielectric characteristics. Targeting use in semiconductor-data communications, optical-receiver subassemblies, transimpedance amplifiers, and test equipment, the GX01 is available in 100%-tin terminations. It sells for $1.50 to $2.50 (volume quantities).

AVX Corp, **www.avx.com**

AVX's StaticGuard automotive varistors have low leakage current

The AEC Q200-qualified automotive StaticGuard series varistors deliver capacitance of 40 to 200 pF at 0.5V and leakage current of 10 μA, providing ESD protection in CMOS, bipolar, and SiGe-based circuits. The varistors provide bidirectional transient-voltage protection in the on state and EMI/RFI attenuation in the off state, along with an ESD rating as high as 15 kV. The devices come in 0402, 0603, and 0805 case sizes, making them suitable for general-purpose drives, general-purpose logic, transceiver chips, and sensor applications. Typical prices range from 4 to 9 cents (volume quantities).

AVX Corp, **www.avx.com**

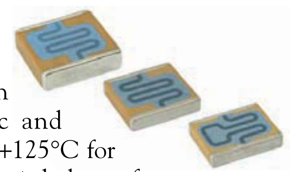
Tecate Group's MXCPB and MXCPT hybrids feature low ESR

The MXCPB and MXCPT series of aluminum-polymer hybrid-construction capacitors feature operating load-life ratings as high as 2000 hours. The MXCPB series is available with a capacitance value of 22 to 560 μF and voltage options of 6.3, 10, and 16V dc. The devices come in 8×10.5- and 10×10.5-mm cases and operate at −55 to +125°C. Load life is 2000 hours at 125°C. Capacitors in the MXCPT series come in capacitance values of 10 to 330 μF and voltage options of 25, 35, 40, 50, and 63V dc. The devices come in four case sizes ranging from 6.3×7.7 to 10×12.5 mm and operate at −55 to +135°C. At 135°C, the 6.3×7.7-mm parts' load life is 1000 hours. Both series' capacitance tolerance is ±20%. Prices are approximately 35 cents for the MXCPB series and 55 to 95 cents for the MXCPT series.

Tecate Group, **www.tecategroup.com**

Vishay's surface-mount MLCC features integrated resistor

The VJ CDC (controlled-discharge capacitor) offers voltage ratings from 1000 to 1500V dc and finds use in high-pulse-current applications, including detonation devices and electronics fuzing. The integration of a high-capacitance MLCC (multilayer-ceramic-chip capacitor) with a bleed resistor on its surface allows the VJ CDC to discharge rapidly while also reducing board-space requirements. Capacitance range is 33 to 560 nF. The device is offered in 3040, 3640, and 4044 case sizes, and is available with X7R and X5P dielectrics. The capacitor offers an operating temperature of −55 to +125°C and a temperature coefficient of capacitance of ±10% from −55 to +85°C with the X5P dielectric and ±15% from −55 to +125°C for the X7R. The device is halogen-free according to the IEC 61249-2-21 definition. Prices start at $15.



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The cows do the tipping, or how the West was won

Radar antennas used to guide missiles require rather tight specifications for bore-sighting—similar to aligning a firearm's sighting system with a barrel—usually in the area of 0.1° or less. Guided antiaircraft missiles fly at high speeds, so small directional errors can mean missing the target. In the 1970s, I was working for a company that was producing these radar antennas and missiles for the US government. After several years in the field, the antennas would return to our production facility or a government facility for refurbishment and any necessary repairs. Bore-sight specification was one of the tests we performed. At the government test facility, the bore-sight requirement was often out of spec. My boss sent me to the test site, located in one of the western states, to check out the test failures and find a solution.

A typical antenna test site, or test range, would have a transmitting source antenna on a tower and a receiving test site, in which the antenna under test was a specified distance away—in this case, about 1200 feet. At the transmitting site, the tower mounted on a small trailer that also housed the electronics equipment to generate the test signals we transmitted to the antenna under test at the receiving site. A motorized pedestal at the receiving site would hold the antenna so that we could measure antenna-pattern features and bore-sight errors.

Bore-sight measurements require stable structural alignment between the transmitting and the receiving sites. Testers generally use optical bore-sight scopes, similar to those on rifles, to set up and verify the alignment. The testers periodically check alignments to ensure good, repeatable measurements.

With help from a government engineer, I familiarized myself with the electronics test equipment at the transmitting and receiving sites. We put an antenna on the test pedestal and ran the required tests. The antenna failed the bore-sight requirements. We ran another antenna with the same results. Next, we checked the optical alignment, and, yes, it showed a misalignment of the transmitting and receiving sites, even though we had recently readjusted this alignment. After bore-sight test failures, technicians typically would realign the transmitting and receiving sites. This step would correct the problem for some time, but failures would then again show up.

After checking possible causes at the receiver site and coming up blank, we went out to the transmitting site to investigate. The test range was in wide-open country in the middle of open range, on which cattle are free to roam and graze, and there were a lot of them around. We again did the realignment, repeated the antenna measurements, and found the bore sight to be good.

The next day, the bore-sight readings were again out of spec. Going back out to the transmitting site, we noticed that the cows were close to the trailer, but they quickly moved away as we approached. We then realized that the cattle must be bumping into or leaning on the trailer and moving it off its footings. Even slight movement from a 1000-lb cow would be enough to disturb the 0.1° alignment of the transmitter site.

To fix the problem, we put a small fence around the trailer; it was no longer an open range. The small fence saved the costs of many realignments and test failures, and eliminated the need for multiple retests. We were happy, the government was happy, and the cows lost only a little of their open range. EDN

Arnold N Simonsen is a retired electrical engineer in Tucson, AZ. After serving in the Air Force as a meteorologist, he worked mostly in RF and microwave test-equipment design.

This Tale is a runner-up in *EDN*'s Tales from the Cube: Tell Us Your Tale contest, sponsored by Tektronix. Read the other finalists' entries at http://bit.ly/Talesfinal_EDN.

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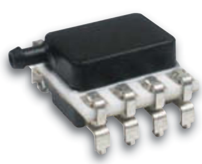

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