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ONE POWERFUL ISSUE

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To provide the most current, accurate, and in-depth technical coverage of the key emerging technologies that engineers need to design tomorrow's products today.

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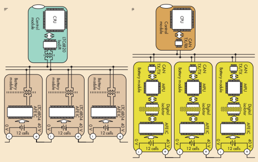

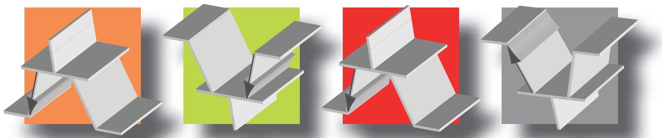

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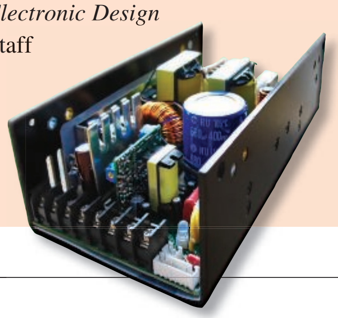

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DESIGN SOLUTION
pMEMS SENSORS MAKE WAVES WITHOUT THE CRYSTAL
Harmeet Bhugra | *Integrated Device Technology*

The piezoelectrically transduced pMEMS resonator can be used to replace quartz, particularly in high-frequency, low-phase-noise reference applications.

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MICRO-INVERTERS CAN BE DONE!
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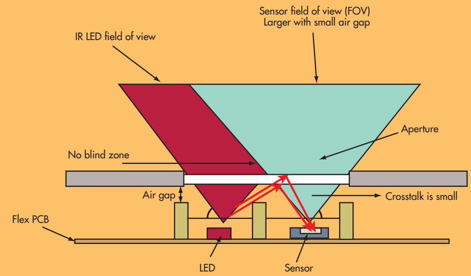
Designs have evolved to where small machines in white goods and HVAC equipment can be reconsidered for high efficiency and control beyond what a set of form A contacts or a triac can provide. Micro-inverter modules can help.



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ENERGY ZARR
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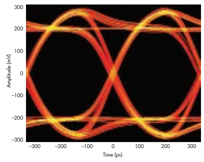

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Eddie Sinnott | *Wolfson*

Most major mobile OEMs have introduced dis-integrated audio architectures into their latest products and are beginning to roll them out across other smart converged devices.

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UNIVERSITY OF MICHIGAN'S FORMULA HYBRID SAE TEAM
Lee Teschler | *Machine Design*

The University of Michigan's Formula Hybrid SAE team has designed and built a high-performance racecar that also is an efficient hybrid electric vehicle. See the video at *engineeringTV.com*.

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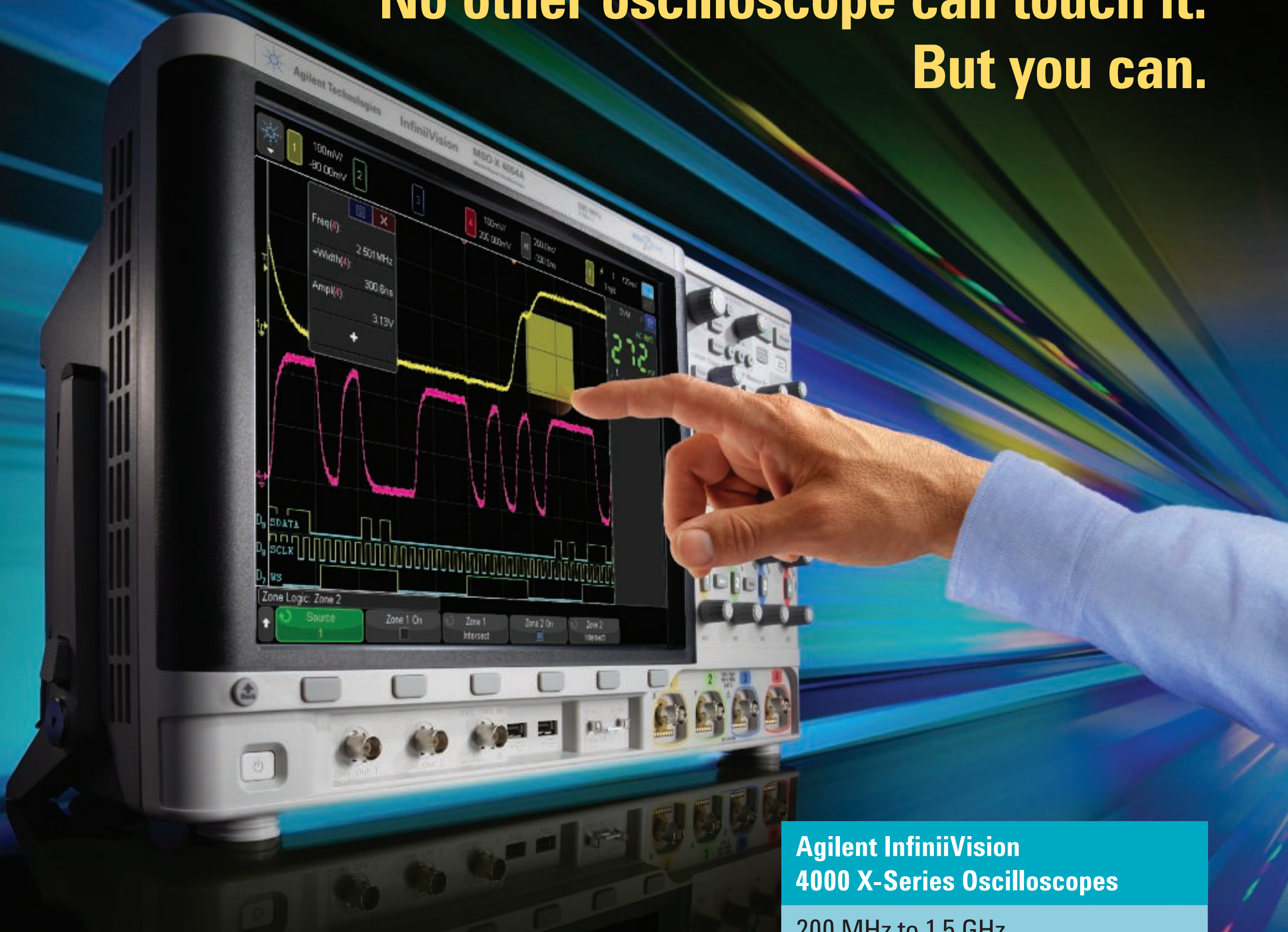

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New Ways To Charge Up Your Mobile Devices

CALL IT A Sandy hangover, but I've been paying much more attention to power lately. In particular, I've been investigating useful products for charging cell phones and tablets with battery packs, fuel cells, and unconventional wall sockets.

POWER IN YOUR POCKET

The first power pack I tried is from the FatCat mPower Travel Charger series. Called PowerBar 4200, since it's rated at 4200 mAH, it's colorful and looks and feels like a small cell phone *(see the figure)*. It can charge smart phones or iPods twice and handheld gaming systems up to 2.5 times.

I used it to charge my iPod Touch. If I had my Apple connector with me, I could have plugged it into the standard USB port on the PowerBar. Instead, I used a flexible connector system that comes with the product. In other words, I connected a standard Apple connector to one side of a wire and a standard USB connector to the other.

Rated at 4200 mAH, the FatCat PowerBar 4200 has enough power to charge any smart phone or iPod twice or any handheld gaming system 2.5 times.

My iPod, which showed a 50% charge when I plugged it into the charger, charged to about 98% in less than 45 minutes and to 100% shortly after. To charge the PowerBar itself, you connect it either to a USB port on a computer or another power source. The PowerBar accepts a charge via a micro USB connector on its side. Charging takes four to seven hours depending on input current.

The FatCat PowerBar uses lithium-polymer battery technology. It recognizes the power needs of the device you're charging and provides overcharging, over-discharging, over-current, and short circuit protection. It also comes pre-charged, so you can use it immediately. And since it has a lithium-polymer battery, it holds about 75% charge after one year of non-use, making it a great source of power for unexpected emergency situations.

The PowerBar 4200 has a suggested retail price of $69.95. Two other models, the 2000-mAH ChargeCard and 9600-mAH PowerBar 9600, sell for $49.95 and $119.95, respectively. They all are available at *www.fatcatgear.com*.

During the recent International CES, Lilliputian Systems VP of product development Alan Ludwiszewski demonstrated the nectar portable power system. This portable fuel cell uses small, replaceable butane pods to charge smart phones, tablets, and other mobile electronics.

The nectar can charge any type of consumer electronics device compatible with USB 2.0. Each nectar pod holds 55,000 mWH, which is sufficient to charge a typical smart phone at least 10 times and maybe more. When a pod runs out, you simply replace it with another one, and you're ready to charge again.

The technology is based on Lilliputian's Silicon Power Cell, which is manufactured by Intel. The butane fuel is fed into this solid-oxide fuel cell, which creates the power needed to charge the phone. In fact, the flexible cell can run on any number of high-energy fuels.

The nectar portable power system is expected to sell for a whopping $299, with the replaceable pods costing $9.99. When available, it will be sold through Brookstone. You can view my video interview with Ludwiszewkski at *engineeringtv.com/video/nectar-Portable-Fuel-Cell-Uses*.

USB IN YOUR ELECTRIC SOCKETS

Finally, Cooper Wiring Devices sent me one of its USB Duplex Tamper Resistant receptacles, which are designed to replace standard ac duplex receptacles. I pulled out my old receptacle and installed this one. It's a lot bulkier than a standard receptacle, but fits in the usual space, nevertheless—with a healthy push for my particular setup.

In addition to sockets for two three-pronged plugs, I now have two USB ports (rated at 2.1 A) for charging smart phones, tablets, and any other electronics that can be charged via USB. The neat thing about this receptacle is that wall warts are no longer necessary. The package doesn't include a USB cable, but many wall warts now come with detachable USB cables.

The receptacle can be used for commercial and residential applications, and it's available in 15-A and 20-A models. Tamper-resistant shutters on the ac sockets comply with 2011 NEC Article 406.12, which means they resist the insertion of foreign objects that could cause electrical shock. These receptacles are available from Web sites like *www.smarthome.com* for about $60. ed

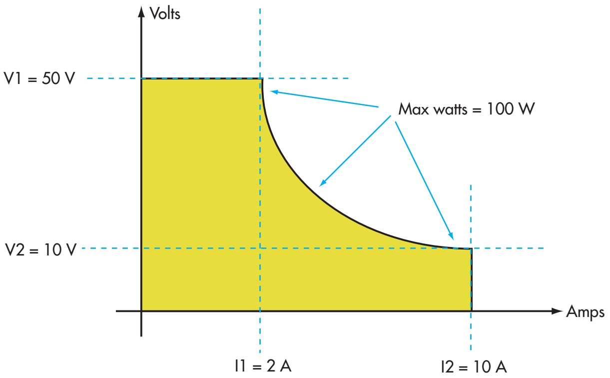
BOB ZOLLO | CONTRIBUTING TECHNICAL EXPERT bob_zollo@agilent.com

What Is An Autoranging Power Supply?

AUTORANGING POWER SUPPLIES, sometimes simply called autorangers, are designed to provide a greater range of operation than a typical supply. In my estimation, less than 10% of the power supplies on the market are autoranging. To determine if you have an autoranger, look at the maximum rated volts, amps, and output power. If the maximum volts times maximum amps is greater than maximum watts, you have an autoranger.

Figure 1 shows the output characteristic of a typical non-autoranging power supply. This is called a rectangular output supply, because the diagram looks like a rectangle. The power supply can operate anywhere within these limits of voltage and current. To determine if your supply can meet your sourcing needs, simply look at the ratings. If your required voltage is less than the rated voltage, and your required current is less than the rated current, you have what you need.

The issue is the size (i.e., power rating) of the supply. While the supply is rated for a certain maximum power, you can only draw that maximum power when operating at maximum rated voltage and maximum rated current.

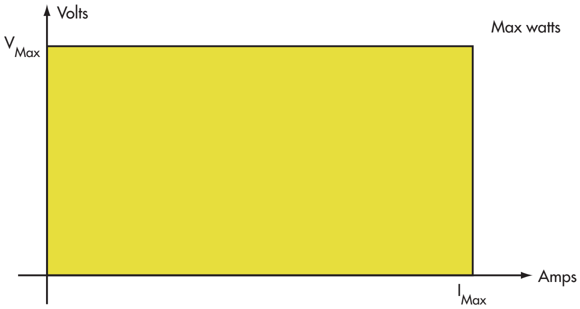


2. In this output characteristic of an autoranging power supply, V1 represents the maximum voltage and I1 represents the corresponding current such that I1 = max watts/V1. I2 represents the maximum current, and V2 represents the corresponding voltage such that V2 = max watts/I2. Along the curved portion, the available voltage and current is limited by max watts. The characteristic shown is for a 50-V, 10-A, 100-W 5:1 autoranging power supply.

AUTORANGERS EXPLAINED

Figure 2 shows the output characteristic of a typical autoranging supply. The diagram's key feature is the curve, which is the locus of points where voltage times current equals maximum power. At the ends of the curve, you will still have a limit on voltage and a limit on current. A figure of merit on autorangers is the ratio of voltage at the endpoints of the curve.

For the output characteristic shown in Figure 2, the maximum voltage (let's call this V1) is 50 V, at which you can draw 2 A because this is a 100-W supply. The maximum current you can draw is 10 A, at which the maximum voltage will be 10 V. (Let's call this V2.) The ratio of V1/V2 is 5, so this is a 5:1 autoranger. As this ratio gets larger, you have a more flexible power supply because it can operate over a wider range. Typical autorangers on the market today will be 2:1 to 5:1.



1. A rectangular output power supply can operate anywhere within the limits of V_{Max} and I_{Max}, but achieves max watts only at $V = V_{Max}$ and $I = I_{Max}$.

THE DOWNSIDE OF AUTORANGERS

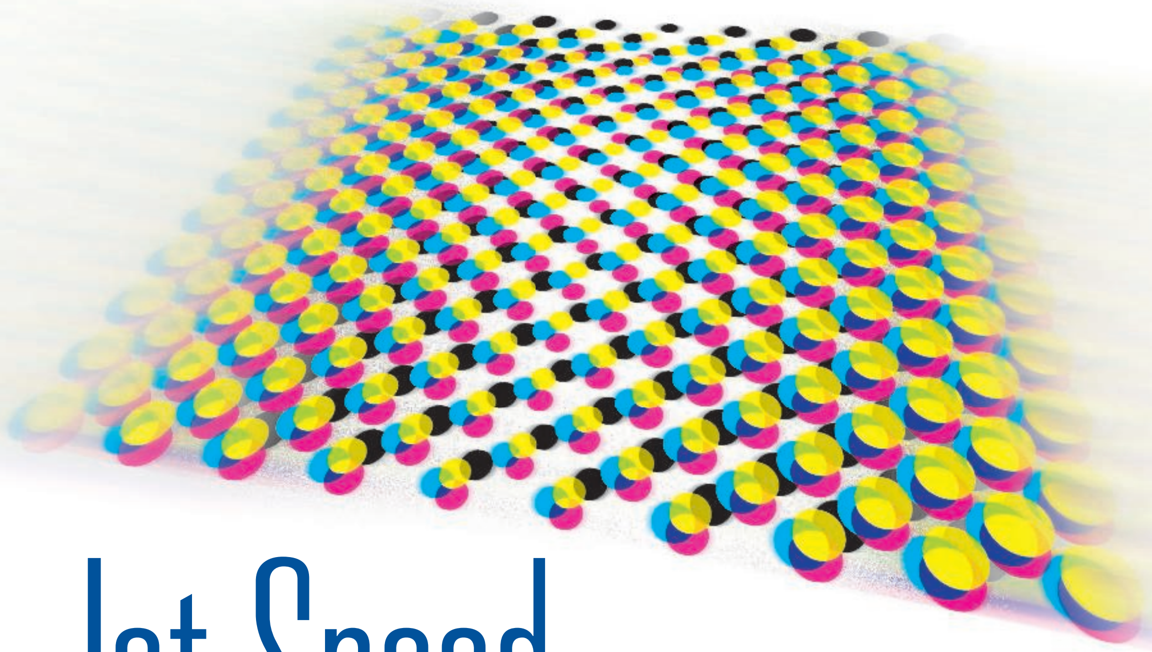
Basically, an autoranging supply is a rectangular supply that is power limited to one-half, one-third, or one-fifth of maximum voltage times its maximum current. While autorangers provide greater application flexibility, they suffer from issues with accuracy. Given the wide voltage and current range over which they operate, the built-in measurement system needs to operate too over this wide range.

In the previous example, the measurement system must be sized for 50 V and 10 A even though this is only a 100-W supply. Stretching the measurement system over a wider range means you have to live with the extra inaccuracy, especially at the low end.

Autorangers tend to be 20% to 30% more expensive than their rectangular equivalents for several reasons. First, they need to have an additional control loop to keep the output power within the power envelope of the supply. Second, the actual components involved must be rated for the highest voltage and the highest current, as these maximum conditions will appear at some point on the power components, although never at the same time. Lastly, achieving the best possible measurement accuracy over this wider operating range will mean a more costly measurement system.

AUTORANGER VS. RECTANGULAR

Because they operate over a wider range, autorangers can replace several rectangular output supplies of the same rating. Figure 3a shows how several rectangular output 100-W supplies are needed to match the ratings of a 100-W, 5:1 autoranger. However, another approach is just to use a larger rectangu-



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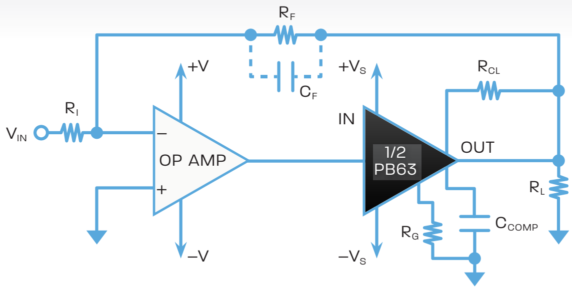

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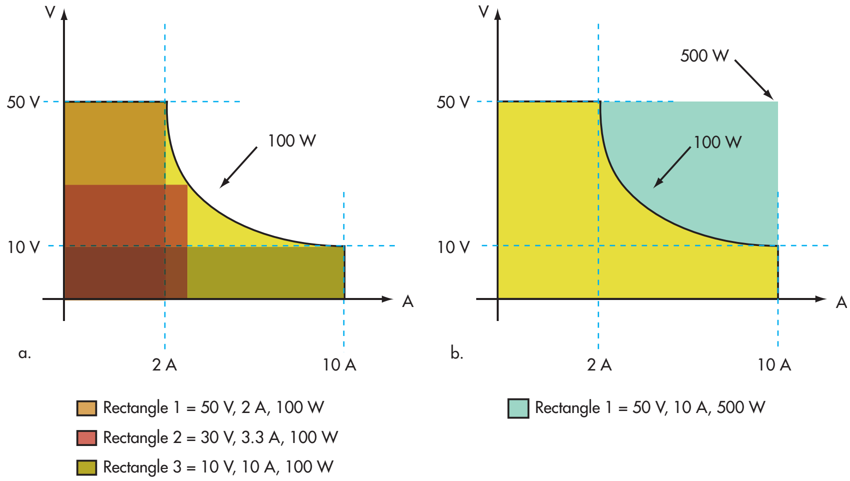
APEX MICROTECHNOLOGY



3. In section a, the same 100-W autoranging supply is compared to several 100-W rectangular output supplies. To cover the same wide range of output voltage and current, several rectangular output supplies are needed, which will be more costly and take more rack space than a single 100-W autoranger. In section b, a 500-W rectangular output supply is compared to the 100-W autoranging supply. Although likely to be larger and more expensive, the 500-W rectangular supply can cover all of the same operating points as the 100-W autoranger. It can also provide 400 W more power beyond the 100-W limit of a 100-W autoranger, which could potentially justify the higher cost and larger size.

lar output supply. Figure 3b shows how using a 500-W rectangular output supply provides the same operating points as the 100-W 5:1 autoranger.

While there is something appealing about the flexibility and efficiency of the 100-W autoranger, a larger rectangular output supply may not be the lesser choice. To decide which is better, compare the cost and the physical size of the two alternatives. While the autoranger may seem less costly and smaller than a supply of five times the output power, given today's modern switching power supply designs, the size and cost of a 500-W rectangular output supply may be similar to the 100-W 5:1 autoranger.

WHEN TO SELECT AN AUTORANGER

If your testing requires voltages over a limited range, the incremental cost of the autoranger means you're paying extra money for wide operating range flexibility that you don't need. For example, if you're testing a mobile phone normally powered by a lithium-ion (Li-ion) cell, its operating voltage will be between 4.2 V and 2.8 V. This is a pretty narrow range of operation, and having an autoranger would be wasteful.

Conversely, if your testing requires a wide range of operation, an autoranger could be a highly valuable tool because it gives you more flexibility with a smaller power supply. This can really save cost and rack space. For example, if you're a system integrator trying to create a flexible tester, you can probably justify the extra cost to give more flexibility.

Or, if you're a dc-dc converter manufacturer testing a family of dc-dc converters, you may need a dc source of 5 V to 72 V to cover the input requirements of the whole family. Finally, if measurement accuracy isn't critical, perhaps because you add your own external measurement system to the power supply, then the reduced accuracy you may have with an autoranging supply won't matter to you. ed

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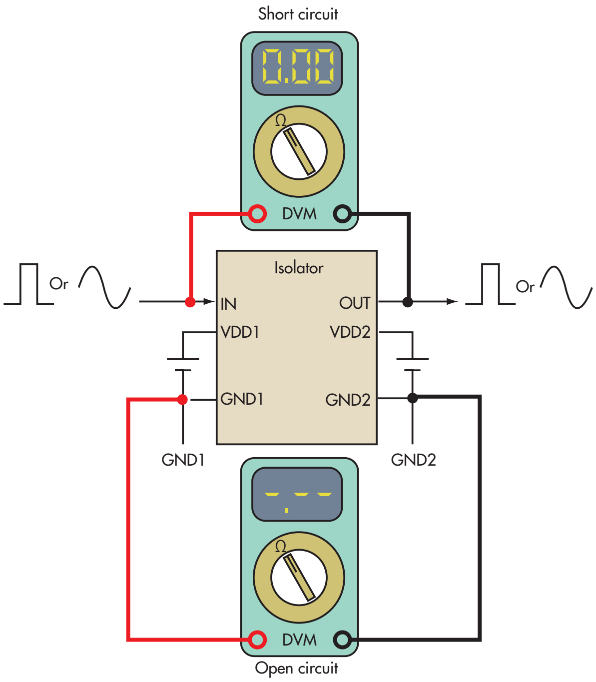
With Proper Isolation, You Won't Need To Do The Safety Dance

WHEN WE WERE kids, my sister had a lamp with a yellow plastic base topped with a white globe—very cool, very 1960s. I loved turning it on and watching the globe glow. One day the plug had partially worked its way out of the wall. When I went to plug it back in, my small fingers grabbed both of the prongs on the plug, and I received a nasty electric shock. I remember lying on the floor, looking at the ceiling, and wondering what happened. Getting shocked was no fun.

Protecting people from electrical hazards is serious business. There are numerous cases where people near hazardous voltages must be protected from them even in the event of a failure. Protection from these hazards can take many forms. For example, house wiring is covered with two dielectric insulating layers to protect the bare wire from being exposed.

In many cases, systems need to communicate across a high-voltage barrier to send information or control signals between a low-voltage domain and a high-voltage domain. The voltages being isolated can peak at several thousand volts and run continuously at up to 1000 V. This communication requires the domains to be linked but isolated from each other. Isolation in the form of optocouplers, transformers, or modern CMOS capacitive-based isolation can be used to accomplish this task.

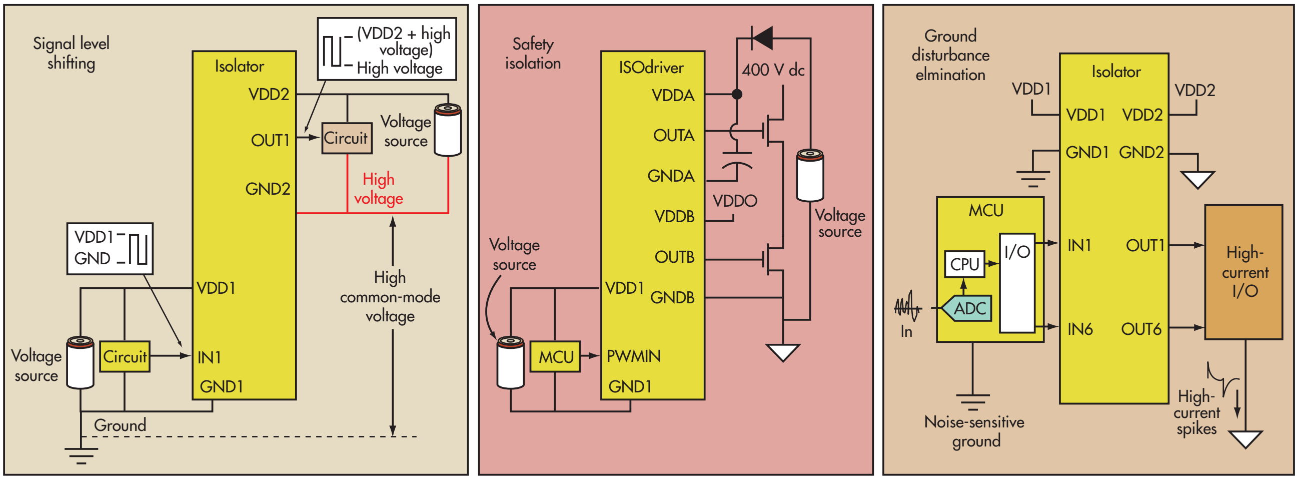


1. An ideal isolator offers an open current path for the signal while also appearing to be a short circuit.

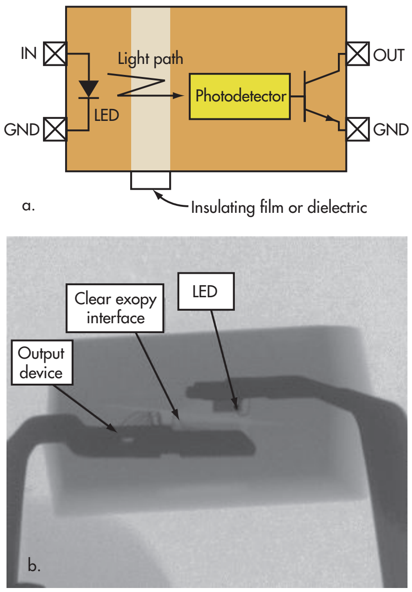
WHAT IS ISOLATION?

Isolation lets signals be passed across a barrier while maintaining a very high impedance to minimize current flow across the barrier. An ideal isolator looks like a short to the signal being transmitted but is open to the current path for that signal *(Fig. 1)*. Isolation can also be used in other tasks, such as level shifting a signal between a low-voltage microcontroller and a high-voltage power transistor driver or to remove ground noise in a precision measurement system *(Fig. 2)*.

One of the oldest and most commonly used isolation devices is the optocoupler. Optocouplers work by using an LED to shine light onto a phototransistor. The phototransistor decodes the signal to reconstruct the signal at the device output. To have a reasonable voltage rating, most optocouplers use a dielectric film between the LED and output transistor *(Fig. 3)*.



2. Isolation tasks include safety isolation, level shifting, and eliminating ground noise.



3. Optocouplers incorporate light emitting diodes, phototransistors, and an insulating dielectric film between these elements.

While optocouplers have served as primary isolating devices, they are plagued by a variety of issues including low operating speeds, poor channel densities, output current that varies over temperature and aging, poor device-to-device timing matching, and wear due to LED aging.

MODERN ISOLATION TECHNIQUES

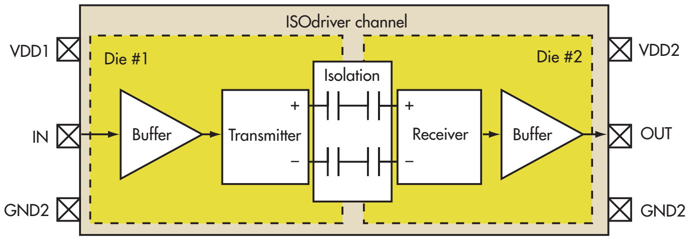
Modern semiconductor processes can be used to create extremely robust isolation barriers. While it may seem like a low-voltage CMOS cell-phone chip doesn't experience much electric stress, the CMOS transistors that are used in billions of cell phones are subjected to extreme electric fields during their operation.

Consider a low-voltage MOSFET transistor in a fine geometry process. It may only have a voltage of 1.8 V across it, but the gate insulation that prevents a short between the gate and the rest of the transistor is extremely thin, on the order of 4 nm. This results in extremely high electric field strengths across the insulating material. Fields can be on the order 4.5 kV/µm, and the insulation must withstand these fields without an electrical failure over nearly continuous operation.

To prevent a breakdown, the insulating material, which is silicon dioxide (SiO_2), must be extremely robust. By building a capacitor using SiO_2 as the dielectric material, information can be sent across the capacitor, while safely insulating against high voltages without breakdowns *(Fig. 4)*.

Using CMOS technology for isolation brings numerous advantages. CMOS is one of the most widely studied and used electrical materials. Foundries invest billions of dollars in fab process development and in characterizing the insulating properties of SiO_2. All of this R&D can be put to use building isolators for very high voltages.

By developing isolators in CMOS, other functions can be easily and inexpensively added to the isolation. Features like embedded MCUs, analog-to-digital converters (ADCs), and threshold detectors can be integrated into the device. Multiple channels can be implemented on the same die, reducing the solution footprint and improving the channel-to-channel timing. Also, these channels can be run at extremely high speeds, up to 10 times faster than a typical optocoupler.



4. Modern CMOS isolation devices incorporate SiO_2-based capacitors.

Using a semiconductor process to provide the insulation, rather than relying on dielectric tape inserted at packaging as used in an optocoupler, means that the insulation layer is well controlled and repeatably constructed. SiO_2 can withstand 10 times the electric field strength for the same thickness as the typical insulation tape used in an optocoupler.

CERTIFIABLY SAFE

Depending on the application, isolation devices need to be certified by regulatory agencies before they can be used in a system. For example, a high-voltage motor controller may need regulatory certification to verify that the system and its components are safe. Agencies such as Underwriters Laboratories (UL) in North America and the VDE Institute in Europe must be considered depending on the application and country.

Modern CMOS isolators are certified to numerous component industry standards such as IEC 60747-5. A version of this standard, IEC 60747-5-5, is intended exclusively for optocouplers, specifying minimum thickness for the insulating layers.

An updated version, the IEC 60747-5-10 (currently in working stage), encompasses modern technologies such as digital isolators. This version accounts for differences in technology such as the fact that modern isolators can operate with much thinner insulating layers to achieve the same level of performance as optocouplers. The new standard version stipulates the same rigorous test requirements and expected performance but removes the minimum insulation restriction.

CONCLUSION

As high-voltage electronics become more prevalent in systems such as electric drive trains, solar inverters, and motor controllers, the need to protect people who interact with these systems is crucial. Like all electronics, these systems are under pressure to reduce size, weight, and cost while allowing more features to be packed into an ever shrinking space.

CMOS semiconductor isolators are bringing the same disruptive forces to bear on high-voltage isolation that are driving more advanced features and size reduction in smart phones and tablets. By using modern CMOS isolation devices in these new high-voltage systems, manufacturers can ensure their smaller, improved systems don't give end users a nasty shock. ed

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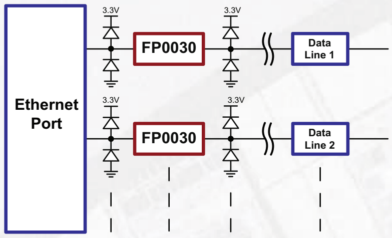
Supertex Fault Protection Switches

AC low side switches with current fold-back protection that protect components from short circuit conditions

FP0030



The Supertex FP0030 is a 20V current limiting protection device. It is designed to protect Internet devices from high transient voltages.

Applications:

- *Ethernet system protection*
- *Resettable fuses*
- *High side switches*
- *Data acquisition*

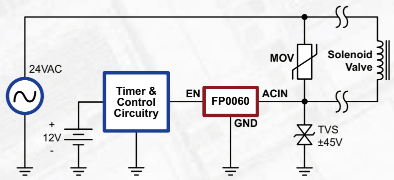
Features:

- *Low on-resistance: 4.5Ω typical*
- *Fast switching speed*
- *No external power supplies needed*
- *Simple, 3-Lead SOT-23 package*

Benefits:

- *Minimizes voltage drop to save power and maintain functionality*
- *Protects against abrupt short circuit conditions*
- *Simplifies board design*
- *Saves space, easier PCB layout*

FP0060



The Supertex FP0060 is a low voltage AC switch with current fold-back protection. It is designed to be used as an AC low side switch.

Applications:

- *Solenoid valve control*
- *AC relay control*
- *Relay replacement*
- *Resettable fuses*

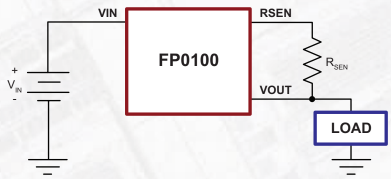
Features:

- *Low on-resistance: 4.5Ω typical*
- *Current fold-back protection*
- *Fast current fold-back response*
- *No external power supplies needed*
- *Simple, 3-Lead SOT-89 package*

Benefits:

- *Lowers power dissipation*
- *Protects against permanent damage*
- *Protects against abrupt short circuit conditions*
- *Simplifies board design*
- *Saves space, easier PCB layout*
- *Eliminates the need to replace blown fuses*

FP0100



The Supertex FP0100 is a high voltage fault protection switch with current fold-back. It is designed to protect system output power supplies against over-current or short circuit conditions.

Applications:

- *Power Supplies*
- *Fast, resettable fuses*
- *High side switches*
- *Data acquisition*

Features:

- *Up to 100V input voltage protection*
- *Low on-resistance: 4.5Ω typical*
- *Fast switching speed*
- *No external supplies needed*
- *Simple, 3-Lead SOT-89 package*

Benefits:

- *Guards downstream circuitry against overcurrent or short circuit conditions*
- *Minimizes voltage drop to save power and maintain functionality*
- *Protects against abrupt short circuit conditions*
- *Ease of use and minimized board space*
- *Eliminates the need to replace blown fuses*

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Market Shift From Laptops To Tablets Affects Battery Design-Ins

THE SHIFT IN the PC market since Apple introduced the iPad in 2010 has been dramatic. According to the January 2013 Quarterly Mobile PC Shipment and Forecast Report from NPD DisplaySearch, "Tablet PC shipments are expected to reach more than 240 million units worldwide in 2013, easily exceeding the 207 million notebook [laptop] PCs that are projected to ship." The same report says that in 2011, the combined market was split 75% notebooks/25% tablets, shifting to about 60% notebooks/40% tablets in 2012, and anticipated to be 45% notebooks/55% tablets in 2013.

Although not as obvious, this shift in end products also affects battery OEMs and engineers who choose and design-in batteries and multi-cell battery packs for other types of products. The notebook PC industry has, to a large extent, standardized on battery packs based on lithium-ion (Li-ion) cylindrical cell technology, with what are designated as 18650 batteries. (The 18 is the diameter in millimeters, the 65 is the length in millimeters, and the 0 denotes a cylindrical shape.)

THE LI-ION LEGACY

In commercial use since 1999, the 18650 typically provides 3.6 V nominal with a capacity that has gradually increased to 3000 mAh. Energy density by weight is impressive at 100 to 150 Whr/kg (360 to 540 kJ/kg), while corresponding energy density by volume is 350 to 420 Whr/L (1.25 to 1.5 MJ/L). Also important to users, these batteries and packs have great cycle life, a modest self-discharge rate of 2% to 5% per month, and many safety features.

Due to the enormous volume of these cells in use, the number of viable suppliers has increased (the numerous Chinese suppliers have improved their quality) and the price per watt-hour has dropped dramatically. In addition, their widespread availability has made them the preferred power source for many non-notebook applications like radios, credit card readers, barcode scanners, and even medical equipment, increasing their production volume even higher than just the notebook numbers indicate. The standard form factor means the cells are available from many suppliers and can support the long product life cycles seen outside the consumer electronics market.

Also, their widespread use means that the battery pack's performance and characteristics are well understood and field-proven through many diverse situations and circumstances. In terms of overall safety, while there were problems in some notebook PCs a few years ago with smoke and even fires (supported by credible reports of self-initiated fires, apparently due to internal battery defects), they have been largely overcome through manufacturing improvements, improved quality control, and much more sophisticated charging and monitoring circuitry. In fact, since the 18650 cell is the "flagship" product for most cell suppliers, it always is the first on the roadmap to utilize any new safety technology that gets introduced.

THE TABLET'S INFLUENCE

The tablet environment is changing the situation, however. Due to their form factor and design tradeoffs, the different tablet models often use custom lithium-polymer cells designed in flat packages. Because the chemistry and internal structure is the same as for conventional Li-ion cells, the front end of the manufacturing process is essentially unchanged. All of the same automated high-throughput equipment can be used.

The process diverges from conventional cells in assembly. Lithium-polymer assembly tends to be semi-automatic, giving it the advantage of faster and less expensive conversion to new cell sizes versus the highly automated cylindrical cell process, which makes changing sizes very expensive and time-consuming. Lithium-polymer batteries will become quite common, with manufacturers producing 1 billion cells per year by the end of this decade, according to NPD DisplaySearch.

Many of the design and usage "ground rules," which are well established due to the high volume and experience with 18650-based battery packs, don't apply to those lithium-polymer packs used in tablets for several reasons. Lithium-polymer cells are inherently more fragile and have tabs to weld to, for example.

Perhaps more important are the supply chain issues that will emerge as the standard cell becomes less so. The custom cells will almost inherently never reach the kind of volumes afforded by standardization. Therefore, there will be smaller price reductions and capacity improvements. Designers will need to work closely with battery vendors to get the packaging and performance they need (and a price they can accept).

The lack of a standard form factor will be extremely problematic for the designers of any portable equipment that is produced in volume too low to warrant a custom cell. Even if the designers of these products can "piggy back" on a cell designed for consumer electronics, they likely will face the potential of a cell's end of life well before their host product.

Traditionally, designers of diverse products have always benefited from the availability of high-volume, standardized, fully characterized, and well-understood power (and other) components that were initially designed for other applications and niches—think of those AA batteries, both rechargeable and non-rechargeable, that you can get almost anywhere.

The same applies to the ubiquitous 18650 battery, whether it's used singly or in multi-cell packs. As the market transitions from notebook PCs to tablets and also fragments in its design approaches, the same benefits of volume, cost, electrical, and thermal certainty may no longer be available to the same extent. ed

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Manhattan And Mr. Spock Offer Lessons In 3D FinFET Design

NEW YORK CITY'S borough of Manhattan is one of the most densely populated areas in the world, with more than 1.5 million residents in just under 23 square miles. But on weekdays, commuters and visitors more than double that number to above 3.6 million people, for an amazing density of over 157,000 people per square mile, or about 177 square feet per person.

That means if every person were standing equidistant in an equivalent open area, they would cover the entire space at just 13 feet apart! And that's not leaving any space for streets, cabs, restaurants, or bathrooms. The answer, of course, is that during a typical weekday in Manhattan, most of the people are either above ground in office or apartment buildings or below ground in the mass transit system. To maximize the utility of limited space, we need to think three-dimensionally.

INTO THE THIRD DIMENSION

2012 was another banner year for low-power design, and the most significant change in the industry was the move to 3D transistors, or FinFETs. They provide not only a significant speed boost, but also the capability to cut dynamic power by half and static power by as much as 90%.

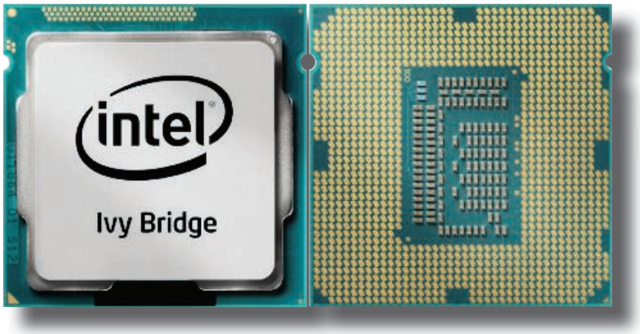
Intel's Ivy Bridge 22-nm processors debuted in late 2011 featuring 3D transistor technology ("Tri-gate" is Intel's name for its FinFET technology), with all main product families available by mid-2012 *(see the figure)*. Following close behind, the Haswell family will be further optimized at 22 nm for power efficiency, taking full advantage of the improving Tri-gate process technology.

TSMC is taking a slightly different route to 3D, instead focusing on its 3D IC die-stacking capabilities to improve on cost, space, and power and aiming for 3D transistors (FinFET) technology in the sub-20-nm nodes, starting with 16-nm test chips due this year. TSMC rival UMC has also announced plans for a 20-nm FinFET introduction later this year. On the Common Platform front, IBM, Samsung, and Global Foundries also announced FinFET support, with a roadmap through 14 nm, and eventually down to 10 nm.

While many of the product announcements are "forward-looking," it's safe to say that the industry is making a strong move in the 3D direction, in particular for the benefit of power efficiency. This is the next big thing in low-power computing, and it will impact all facets of semiconductor design and manufacturing for many years to come.

HURDLES AHEAD

Despite the promise of higher performance and better power efficiency, the move to FinFETs comes with quite a few new challenges. For example, the entire tool chain is impacted, including transistor-level process modeling and simulation, mask synthesis, physical extraction, and physical verification. This requires careful re-characterization and validation of models and libraries for higher levels of abstraction and design. One of the goals for the introduction of this fundamental change in process technology is to maintain as much compatibility with previous design flows as possible to enable quick and transparent adoption.



Intel's Ivy Bridge 22-nm processors were among the first 3D transistors to hit the market.

For IP designers, the fin's discrete sizing restricts the ability to tweak transistor widths for small changes in performance, one of today's most common tools for optimization. Channel length variation and body biasing are also limited in value due to the intrinsic characteristics of the FinFET technology.

So while much of the technology hoopla occurred in 2012, 3D transistors are just getting started as the new vehicle to propel Moore's law forward for the next decade. The next few years should be very interesting as the benefits of this technology are seen in products from smart phones to servers.

But as with most real-world phenomena, 2012 is just the year that 3D grabbed most of the attention. Originally proposed in 1999 by a group from the University of California, Berkeley, FinFETs have been 13 years in the making, with huge R&D investments in manufacturing technology and software support to get us to this phase.

In the epic space battle at the Mutara Nebula between Captain James T. Kirk and Kahn Noonien Singh in *The Wrath of Khan*, Spock observes of Khan at the critical turning point of the battle, "He is intelligent, but not experienced. His pattern indicates two-dimensional thinking." Luckily, we are intelligent, experienced, and thinking three-dimensionally! ed

CARY CHIN is director of technical marketing at Synopsys Inc., responsible for the Discovery Low Power Verification Solution. His background at Synopsys is in R&D where he has managed the Power Compiler, Primepower, PrimeTime PX, and Design Compiler FPGA products. He holds undergraduate and graduate degrees in electrical engineering from Stanford University. Also, he has taught computer science and programming classes at Stanford.

design FAQs

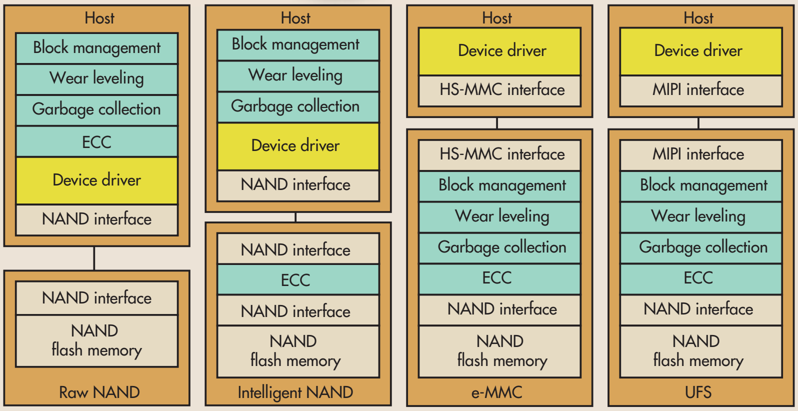
FREQUENTLY ASKED QUESTIONS

The Path To High-Performance NAND Flash

William Wong
Embedded/Systems/Software Editor

How can I take advantage of NAND flash?

NAND flash is available in a number of configurations *(see the table)* ranging from raw NAND flash to Universal Flash Storage (UFS). The different architectures split functionality between the host and storage device *(see the figure)*. Raw NAND flash requires a host to provide all services usually within the device driver. Intelligent NAND flash offloads error correction to the storage device.



NAND flash requires a number of features for reliable operation, including error correction and wear leveling. These services can be performed by the host or offloaded to the memory using standard interfaces like e-MMC and UFS.

Hardware can handle the error correcting code (ECC) support more efficiently, especially as the number of correctable errors rises. This support is needed because errors are more of a factor. Also, error-prone technologies such as multi-level cell (MLC) and triple-level cell (TLC) NAND flash are being used more.

Wear leveling extends the life of the overall storage device since each block supports a limited number of writes. Moving data around to different locations in the physical memory enables systems to more evenly distribute the number of writes. Garbage collection is used to recover unused blocks for reuse in this process. A system often will reserve blocks so the write lifetime of a device will be higher.

What are the advantages and tradeoffs of using NAND flash memory with more intelligence?

Intelligent NAND moves ECC support to the hardware because of the overhead that ECC imparts. Some CPUs include ECC hardware support, but most do not. ECC hardware is more efficient, reducing the overall system power requirements. Moving the other memory management functions to hardware boosts system efficiency and reduces the communication between the host and memory, reducing power usage as well.

Standard interfaces like e-MMC and UFS make it easier to choose storage devices because the underlying details such as the NAND flash technology being used are hidden from the developer. Likewise, the methodology used for things like ECC and wear leveling are transparent. Upgrading to higher-capacity devices is then easier since these higher-capacity devices may have a significant impact on the sophistication of services like wear leveling.

What other services can more advanced storage systems provide?

Features such as block protection and secure erase can be added more easily to storage devices with an advanced interface like e-MMC or UFS. It makes sense to incorporate features that can take advantage of custom hardware such as encryption.

NAND SOLUTIONS

	Raw NAND	Intelligent NAND*		e-MMC	UFS
NAND die	SLC	SLC	MLC	MLC	MLC
Interface	NAND	NAND	NAND	HS-MMC	MIPI M-PHY
Interface type	Parallel	Parallel	Parallel	Parallel	Serial
Interface speed	50 to 400 Mbytes/s	40 Mbytes/s	50 to 133 Mbytes/s	200 Mbytes/s	6 Gbits/s
ECC managed	No	Yes	Yes	Yes	Yes
Wear leveling	No	No	No	Yes	Yes
Bad-block management	No	No	No	Yes	Yes
Garbage collection	No	No	No	Yes	Yes
Capacities	512 Mbits to 16 Gbytes	1 to 8 Gbits	4 to 64 Gbytes	2 to 128 Gbytes	16 to 128 Gbytes
Host processor ECC requirements	1 to 24 bits+	None	None	None	None

*such as Toshiba's BENAND

What's the difference between e-MMC and UFS?

These two platforms have similar functionality but use a different interface and protocol. Both are JEDEC standards. A parallel interface is used with e-MMC while high-speed serial MIPI-PHY (M-PHY) is used with UFS. UFS also employs the SCSI Architecture Model and command protocols.

The e-MMC platform was available first, and its parallel interface was easy to implement using common microcontrollers. M-PHY is found on microprocessors targeting mobile devices, so UFS often makes more sense in these environments. M-PHY's lower pin count also benefits these types of applications.

What platforms offer interchangeable devices?

Raw NAND flash chips and proprietary chips come in a range of packages and capacities, which tends to limit the choices to an application designer's initial selection. The JEDEC standards for e-MMC and UFS include device specifications as well as interface specifications, so products with different capacities and products available from different vendors easily can be used in an application without a redesign.

What does e-MMC look like?

The e-MMC interface builds on SPI, which has a 1-bit data bus. There are 4-bit and 8-bit variants that provide a substantial boost in throughput. The interface is used on a range of removable flash memory cards such as microSD and miniSD.

What does the UFS interface look like?

The M-PHY interface used by UFS is designed to provide more performance than e-MMC while reducing the number of interface pins. M-PHY supports a range of protocols including PCI Express. It uses an embedded clock in its serial stream versus the explicit clock in e-MMC. Like PCI Express, M-PHY is a lane-oriented interface that can be scaled by adding more lanes.

Should new designs employ e-MMC or UFS?

The choice likely will depend more on the application and the choice of microprocessor or microcontroller. UFS is designed for higher-bandwidth systems. It can scale via multiple lanes. The link layer has minimal overhead, reducing size buffer requirements. ■

TechView

CHIPS LET ELECTRIC CAR MAKERS MODULARIZE BATTERY PACKS

Designers can use a new IC family from Linear Technology to break large battery packs into smaller modules for electric vehicles and other applications. The LTC6804 battery pack monitor analog front end (AFE) and its complementary LTC6820 controller can be used to monitor multiple batteries, while the LTC3300 and LTC8584 perform the battery balancing.

Modules are valuable because, otherwise, fitting 16 kWh worth of batteries into a single compartment would be problematic. Also, modularization can facilitate serviceability. It allows scalability as well, as sedans and sports vehicles may have different battery stacks made of common modules.

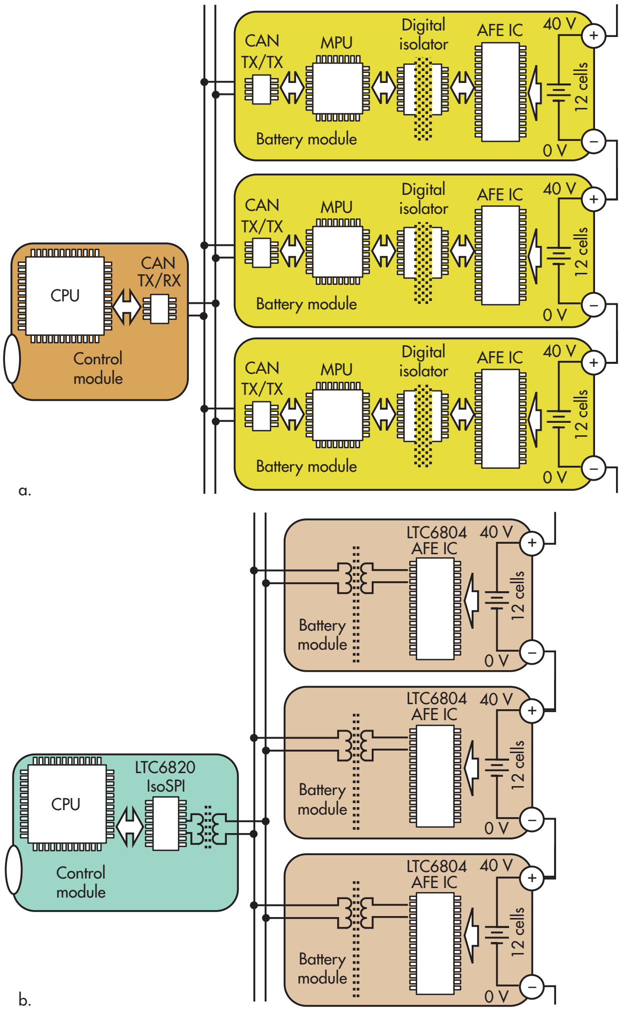
Modularization can lead to greater complexity in the wiring harness and potential electromagnetic interference (EMI) susceptibility related to longer copper runs. The standard approach to battery monitoring in modularized systems uses a CAN bus as the link and microprocessors to convert the CAN protocol to a simpler SPI or I^2C protocol for the monitoring AFE. A digital isolator IC that sometimes requires an isolated power supply provides isolation between modules *(Fig. 1)*.

Each LTC6804 battery pack monitor can measure up to 12 series-connected battery cells at voltages up to 4.2 V with 16-bit resolution and better than 0.04% accuracy. A sub-surface Zener voltage reference similar to references used in precision instrumentation maintains this precision over time, temperature, and operating conditions. For precision, the Zener is preferable in this application to a band-gap reference.

Stacked in series, LTC6804s enable the measurement of every battery cell voltage in large high-voltage systems. Six operating modes optimize the update rate, resolution, and low-pass response of the built-in third-order noise filter. In the fastest mode, all cells can be measured within 290 µs.

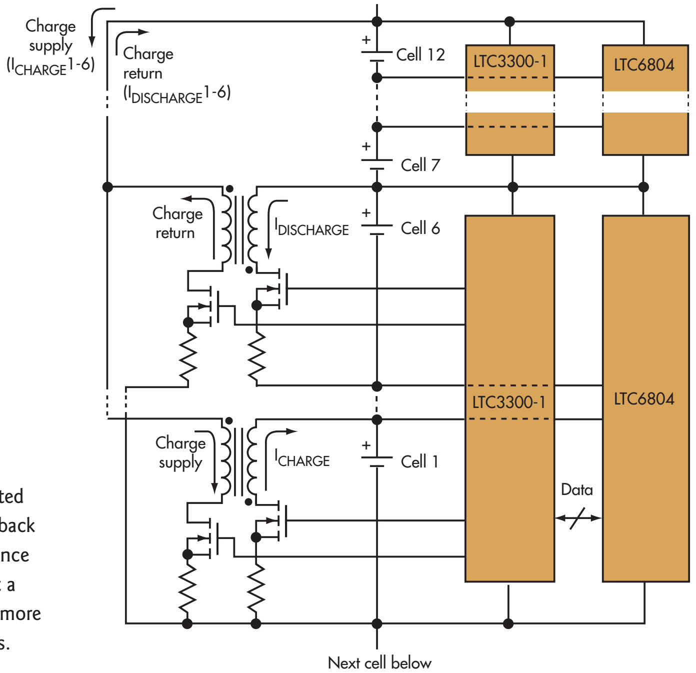
Multiple ICs are connected using Linear's proprietary two-wire isoSPI interface, by means of the LTC6820 isoSPI transceiver and an Ethernet transformer. This configuration provides for bidirectional transmission, at rates up to 1 MHz, up to 100 meters across an isolated barrier. Different dash-number LTC6820 devices can be daisy-chained with a single host processor connection for all, or else connected in parallel to the host processor, with each device individually addressed.

In sleep mode, each device draws less than 4 µA from the batteries. General-purpose I/O pins are available to monitor analog signals, such as current and temperature, which can be captured simultaneously with the cell voltage measurements. Additional features include passive balancing for each cell with a programmable balancing timer for up to two hours, even when the LTC6804 is in sleep mode.

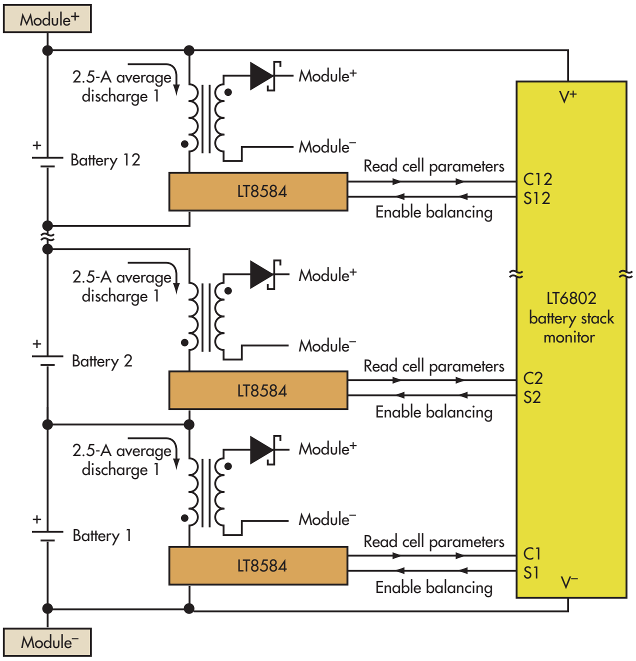


1. Contemporary production vehicles with modular battery packs have used a combination of CAN communications and digital isolators to interface the modules (a). In Linear Technology's alternative approach, multiple ICs are connected using the company's proprietary two-wire isoSPI interface, using the LTC6820 isoSPI transceiver and a simple Ethernet transformer (b).

The LTC6804 interfaces with external I²C devices such as temperature sensors, analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and EEPROM. Local EEPROM can be used to store serialization and calibration data, enabling modular systems.



2. The LTC3300 uses a non-isolated synchronous flyback topology to balance up to six cells at a time from 12 or more neighboring cells.



3. Linear's LT8584 flyback dc-dc converter accomplishes active balancing using a unidirectional topology.

Balancing is required in any array of series-connected batteries because self-discharge rates, electronic loads, and temperatures differ from cell to cell. Over many charge and discharge cycles, these differences result in imbalances in cell state of charge. In turn, this charge imbalance reduces pack capacity.

For example, if one cell has 10% more charge than the others, and a charging current is applied to the pack, this particular cell will reach the 80% state of charge limit while the other cells are charged to only 70%. In that case, the available energy in the pack has been reduced by 10%.

There are multiple solutions. Passive balancing, the dissipation of a single cell's charge through a load resistor, is the lowest cost and simplest way to balance mismatched cells in a series stack. Although it is simple, passive balancing is inefficient and slow.

Typical passive balancing currents range from 1% to 5% of the cell capacity. Dissipating 10% of the charge from a 40-Ah battery requires 10 hours at 400 mA, or, charging at 2 A, passive balancing generates 8 W of heat per cell. For large-capacity packs, the generated heat becomes unacceptable.

In contrast, active balancing not only speeds charging with less heat, it also helps recover capacity that cells lose as they age. Over time, each cell ages differently, due to gradients in pack temperature and differences in cell manufacturing.

The significance of this is that, with passive balancing, a pack's weakest cell determines its capacity because the pack is balanced and charged to 80%. The discharging of the pack is halted when the weakest cell reaches 20%.

A properly designed active balancing system will efficiently redistribute charge throughout the stack as needed to ensure that the 20% and 80% points are reached based on the average-capacity cell rather than the lowest-capacity cell.

To maximize battery pack run time, cells must be balanced during both the charging and the discharging of the battery stack. The LTC3300 addresses this bidirectional active balancing need *(Fig. 2)*.

With the LTC3300, balancing currents up to 10 A are possible. Charge is transferred from one 12-cell module to the next by interleaving the secondary side connections of each flyback transformer. Transfer efficiencies above 92% are achievable, along with better than 80% capacity recovery for typical cell-to-cell mismatch conditions. The LT3300 can be controlled via a serial port on the LTC6804.

Alternatively, the LT8584 monolithic flyback dc-dc converter accomplishes active balancing using a unidirectional topology *(Fig. 3)*. The unidirectional approach redistributes charge from a given cell to the entire stack of cells. An integrated 6-A power switch supports 2.5 A of average balance current. The LT8584 can also measure balance current, die temperature, and cable resistance. Like the LTC3300, it connects directly to the LTC6804.

Priced at $10.95, the LTC6804 comes in an 8- by 12-mm surface-mount package. The LTC6820 is packaged in mini small-outline package (MSOP) and quad flat no-lead (QFN) formats and costs $2.29. The LT3300 and LTC8584 are sampling now. Firm pricing will not be set until April and May.

LINEAR TECHNOLOGY
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IMPROVED REAL-TIME SPECTRUM ANALYSIS REVEALS THE MYSTERIES OF RF SIGNALS

Wireless systems continue to get more complex with their high speeds, wide bandwidth, short bursts, frequency hopping, and modulation schemes, making them more difficult than ever to test. Measuring and detecting signals from these systems has become the number one challenge of the design and test engineer.

The solution to this problem is a high-performance spectrum analyzer with the appropriate frequency range, bandwidth, and responsiveness. Agilent Technologies' Real-Time Spectrum Analysis (RTSA) option for its new and existing PXA signal analyzers gives engineers a real-time view that resolves many testing problems.

The real-time spectrum analyzer (RTSA) option for the Agilent PXA lets users capture, see, and understand complex and fleeting RF signals at frequencies to 50 GHz with a bandwidth to 160 MHz.

Agilent's PXA top-of-the-line signal analyzers feature upper frequency ranges from 3.6 GHz to 50 GHz *(see the figure)*. With an external mixer, they can display signals out to 325 GHz. The RTSA option brings real-time capture and measure capability to the PXA line.

Real-time capability lets users see, capture, and display elusive signals, known or unknown. The instruments use high-speed ASICs and FPGAs to convert sampled signal data into signal spectra with FFTs, and this data is then combined to generate meaningful displays.

Real-time as defined here means that the input signals are captured and digitized as well as processed immediately for some measurement or trigger operation. Signals are sampled and computed concurrently in an RTSA, giving it five key attributes: gap-free analysis, high-speed measurements, consistent measurement speed, advanced composite displays, and frequency-mask triggering (FMT). The RTSA option offers:

- **Wider bandwidth:** The RTSA is offered in two wide bandwidth formats, 85 MHz and 160 MHz.
- **Improved dynamic range:** The spurious-free dynamic range is as high as –75 dB across the full 160-MHz bandwidth, allowing users to find and see intermittent signals even in the presence of larger signals.
- **High sensitivity:** Input sensitivity is –157 dBm at 10 GHz with no preamp, enabling users to see closely spaced or intermittent signals. Phase noise is –132 dBc at 1 GHz with 10-kHz offset.
- **Frequency-mask triggering (FMT):** Users can set up a spectrum mask that initiates triggering when a signal enters the mask region. This ability is an asset when searching for a specific signal.

The N9030A 3.6-GHz PXA signal analyzer with the real-time spectrum analyzer option and 160-MHz bandwidth starts at $96,304. The RTSA option prices alone are $7224 for 85-MHz bandwidth and $10,320 for 160-MHz bandwidth.

AGILENT TECHNOLOGIES

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PLL SYNTHESIZER OFFERS HIGH OUTPUT FREQUENCY AND LOWEST PHASE NOISE

The Texas Instruments LMX2581 phase-locked loop (PLL) frequency synthesizer integrates a voltage-controlled oscillator (VCO) that covers from 50 to 3760 MHz and offers perhaps the best phase-noise specification around *(see the figure)*. Normalized PLL phase noise is –229 dBc/Hz, and typical phase noise is –137 dBc/Hz at 1 MHz with a 2.5-GHz carrier. The normalized PLL 1/f noise is –120 dBc/Hz. The ultra-low phase noise is the result of design features such as its very high 200-MHz phase detector frequency.

The LMX2581 also offers the option of using integer or fractional PLL modes and optional dithering for spur reduction with the multi-order delta-sigma PLL. The integrated multicore VCO comes with its own tank circuit. The VCO may be bypassed in favor of an external VCO. A low-dropout regulator (LDO) is integrated to power the VCO.

Also included is a clock input divider and a programmable PLL output divider with a range of 1 (bypass) to 38. The noise floor is –155 dBc/Hz, and the in-band spur specification is –46 dBc. The chip has two 50-Ω differential outputs with programmable power levels from –4 to +10 dBm as well.

Applications include wireless infrastructure basestations, broadband wireless devices, test and measurement, and clock generation. The LMX2581 also suits a variety of radar and other defense and aerospace applications in addition to medical imaging. With the very low phase noise, the chip makes a superior precision local oscillator in an RF front end for excellent receiver sensitivity.

The LMX2581 comes in a 32-pin, 5- by 5-mm, quad flat no-lead (QFN) package. Suggested price is $7 in 1000-unit quantities. An evaluation module is available for $175.

TEXAS INSTRUMENTS
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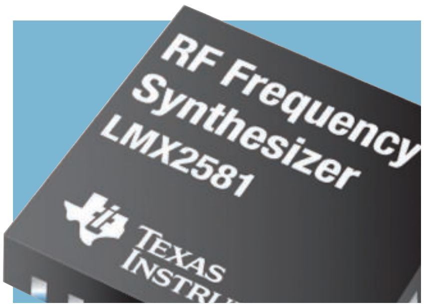


Texas Instruments' LMX2581 is a fully integrated PLL frequency synthesizer for wireless and other communications applications. It covers from 50 to 3760 MHz and features a low normalized phase noise of –229 dBc/Hz.

DON TUITE | ANALOG/POWER EDITOR don.tuite@penton.com

ONE POWERFUL ISSUE

INDUSTRY EXPERTS ASSESS POWER'S FRONTIERS

Leaders in data center power, the Smart Grid, and "classic" power supplies take on the future.

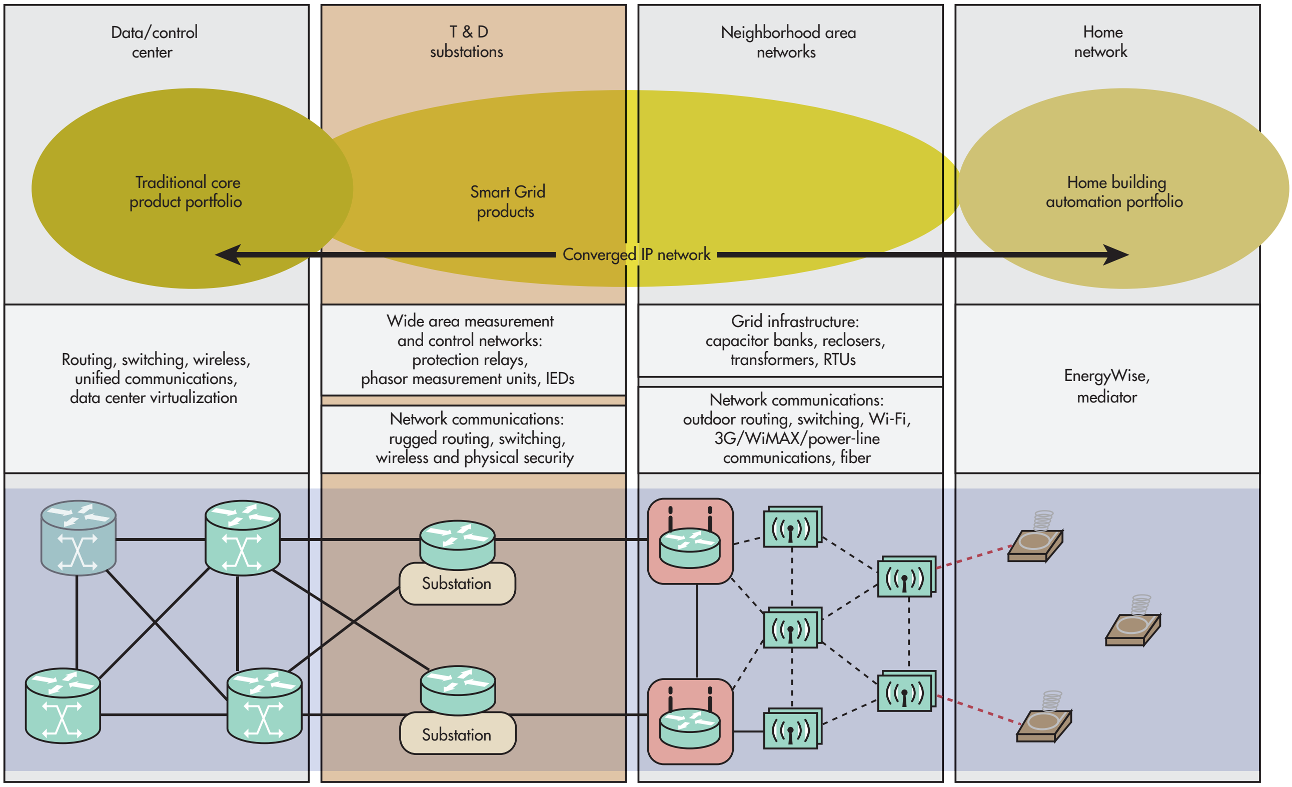
Everything you thought you knew about powering data centers is passé. The future of the grid is spelled IEC 61850, and many pieces of the infrastructure are available. And, greater efficiency and innovation are still on the way for the common ac-dc and dc-dc digital power supply *(see "The Future Of Power Efficiency," p. 36, and "Innovation In Digital Power Supplies" at electronicdesign.com)*. This news comes from a data center architect, the largest maker of hardware for Internet protocol (IP) communications, and executives from the largest European power supply makers.

REVOLUTION IN THE DATA CENTER

At a recent Silicon Valley IEEE Power Electronics Society (PES) meeting, MegaWatt Consulting president and CEO K.C. Mares reviewed the latest trends in the data center and their effects on power distribution and conversion. Mares also is the CTO of the Unique Infrastructure Group, the company developing the Reno Technology Park, which will be the largest dedicated data center campus in North America with onsite renewable energy generation.

At MegaWatt, his services included data center site selection, design, and efficiency projects for Facebook, Google, Yahoo, Equinix, the National Center for Atmospheric Research, Lawrence Berkeley National Laboratory, the U.S. Department of Energy, and others. Overall, he has played a key part in the design of data centers worth cumulatively more than $10 billion.

Mares described a data center that's generations away from aisles of cabinets full of blade servers, sitting on raised computer floors



1. Cisco sees design opportunities across many network levels using IP. Note that there isn't necessarily any utilization of the tactically vulnerable conventional Internet in the critical functions at the left side of the diagram.

powered by multiple isolated and non-isolated voltage step-down stages from "front ends" to "bricks" and "POLs," all surrounded by temperature-control and humidity-control systems that maintain a shirt-sleeve environment for the humans who work there.

About the only thing that remains from this rapidly passing image of the data center is the power consumption, and that's going up due to the growing total capacity. Factors influencing this evolution include solid-state memory replacing disc storage, processors with ARM cores replacing Intel devices for the heavy lifting, and modularization of server arrays. Furthermore, more subtle in its effect is the realization that the cloud provides its own backup, which results in less demand for "six-nines" reliability.

At the meeting, Mares held up his iPhone and said, "Basically, this is a server." In terms of processing power and storage, the smart phone is the equivalent of a typical blade. The amount of heat it generates, of course, is somewhat smaller. Yet regardless of how much heat it generates, its environmental heat tolerance is far above what a human worker can long tolerate. There is no reason not to pack a large number of iPhone-size servers into boxes of far less internal volume than today's cabinets and provide only enough internal cooling to allow the internal temperature to rise no higher than 140°F. Full cooling, he said, is only necessary in the battery room.

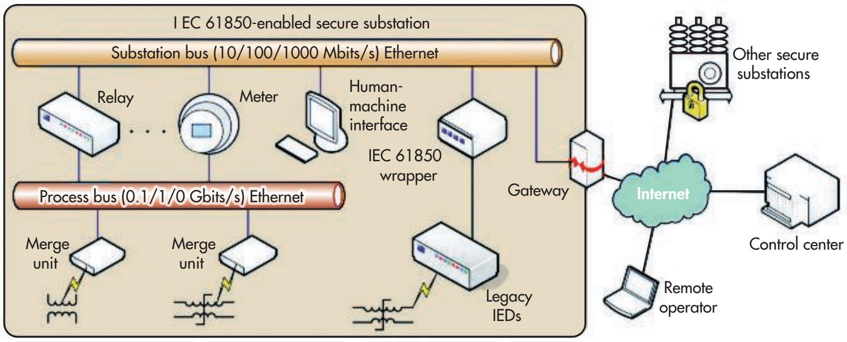
There only was one objection from that room full of power engineers when Mares said that humidity control wasn't necessary either. "How can you avoid electrostatic discharge (ESD) failures without some humidity?" one engineer asked. "Shoe straps," Mares replied. There was more discussion, but the point was that 100% enforcement of anti-discharge shoe strap discipline was considerably less expensive than installing humidity control.

Finally, Mares said that all of these changes will have an effect on uptime, but the redundancy of data in the cloud more than compensates for going from 0.999999 reliability to 0.99999 reliability at any one data center.

THE CISCO GRID

Ignoring "smart meter" controversies for the most part, Cisco notes that utilities are already investing in communications networks that improve situational awareness and facilitate control, automation, and system integration. The objective is to "smooth out" peak load demand, minimize the need for "spinning reserves," and avoid building new plants and putting in more conductors.

Cisco reckons that four characteristics combine to make a grid "smart," and these elements reside in the layer of digital superstructure that can be added to the traditional grid's analog infrastructure: observability, configurability, automation, and integration. Observability means providing real-time awareness of the grid state; configurability means being able to drive grid elements to new states; automation means doing this



2. IEC 61850 envisions a substation network connected to the outside wide area network via a secure gateway. Outside remote operators and control centers can use the abstract communication service interface (ACSI) to query and control IEDs in the substation. One or more substation buses connect all the IEDs inside a substation.

largely without human intervention; and, integration means system-wide interconnectivity.

Obviously, this kind of scheme isn't implemented all at once. Cisco says the utilities should start with automating substations. In a way, substation automation has been happening ever since the introduction of the microprocessor relay. The critical need now is to extend secure, scalable communications infrastructure beyond individual components. This will allow new applications for control and automation, such as condition-based and predictive maintenance programs.

Beyond the substations, the task is to maintain a variable energy supply in the wake of growing and uneven energy demands. Monitoring is provided by operational effectiveness metrics and system performance indices: traditionally the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI).

At a finer granularity, to manage outages, utilities deploy protection relays that provide for fault location identification and restoration. These relays greatly depend on deterministic communications for precise timing and fast network convergence to deal with voltage or phase imbalances. As for the infrastructure that communications and data will run on, it's already common for utilities to deploy their own dark fiber between sites for peer-to-peer protection communications.

In fact, with the advent of the IEC 61850 standards, station bus communications have already begun migrating to Ethernet for intra-substation protection, which facilitates interoperability and scalable network design, as well as reduces

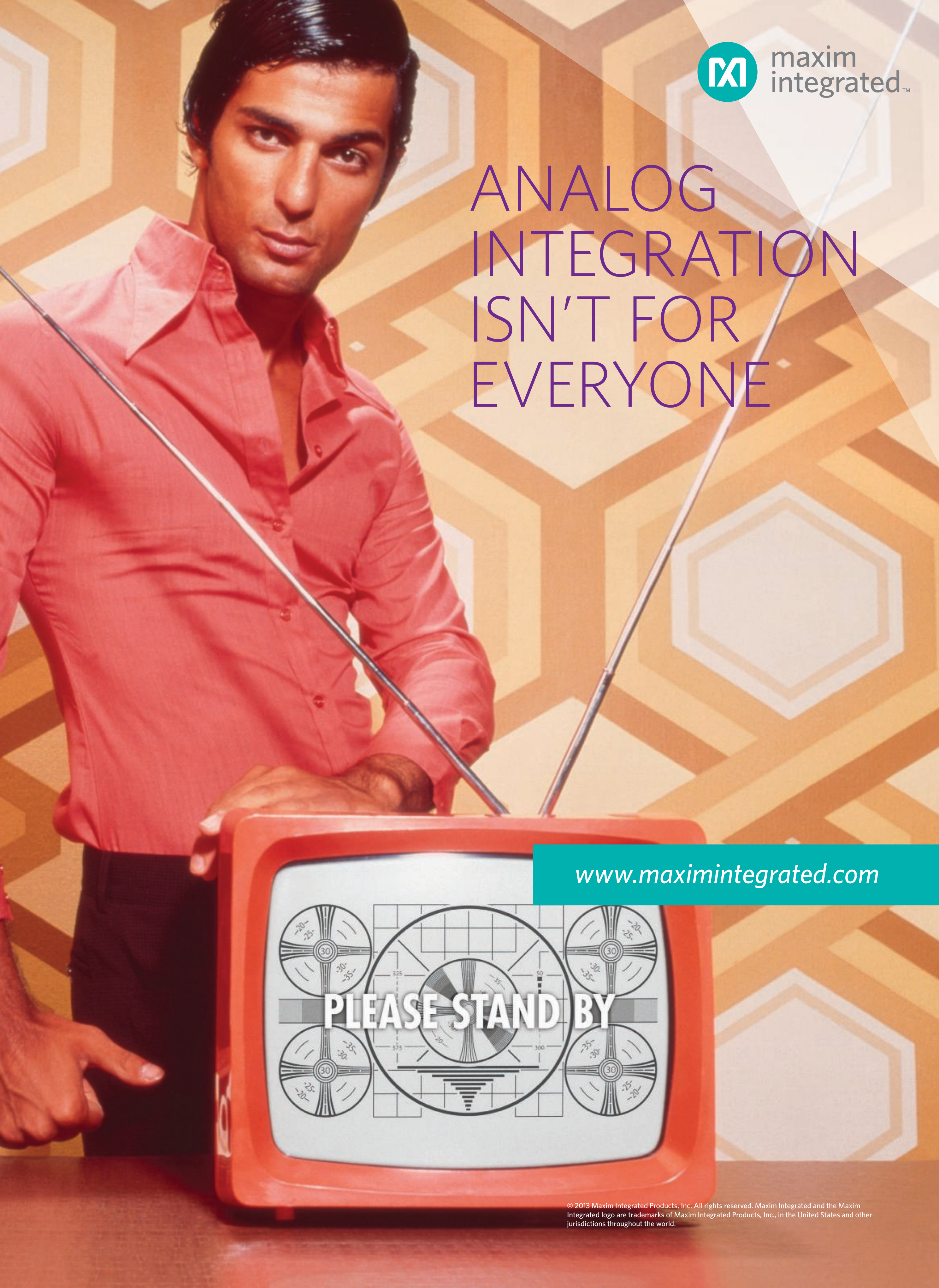
THE FUTURE OF POWER EFFICIENCY

WHILE UPGRADING THE grid and repowering the data center are grand, sweeping issues, it's important not to lose sight of basics. For an international perspective, we discussed future efficiency gains and advances in digital power with senior executives at European power supply companies: Jeff Schnabel, VP of marketing at CUI Inc.; Don Knowles, VP of engineering at N2Power; and Gary Bocock, technical director at XP Power.

DON TUITE: The efficiency of medium size ac-dc power supplies is now firmly in the mid-90% area. And while these efficiencies are impressive, the vast number of power supplies shipped each year means even small efficiency gains have a significant effect on our power consumption. Where do manufacturers go from here, and what limitations are in place?

DON KNOWLES: We see potential gains in four basic areas: interconnections, with their parasitic resistance and inductance, as well as copper and energy losses in the inductor; power components and topology; selection of semiconductors, such as enhancement-mode gallium-nitride-on-silicon FETs and SiC (silicon-carbide) diodes; and better magnetic components, with lower-loss core material.

GARY BOCOCK: In many ac-dc power supplies, the bridge rectifier generates the biggest single power loss. This is a low-cost, low-technology, reliable component, and replacing it with a more efficient solution is more complex and expensive. There are products that use bridgeless PFC (power factor correction) designs, though this tends to be limited to higher-power, higher-cost products. Higher-power products also utilize interleaved PFC designs, significantly reducing the losses at low



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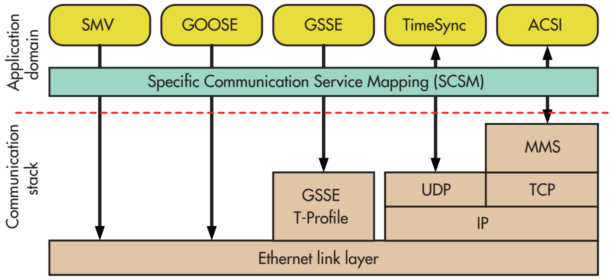

3. The IEC standard defines a communication structure with four communication profiles: ACSI, the generic object-oriented substation event (GOOSE), the generic substation status event (GSSE), and the sampled measured value multicast profile (SMV).

operating expenses. Another common communication need that can be found at the substation level is the identification of energized lines, especially ones that are down and may be a public safety hazard.

All this requires communication networks that can maximize situational awareness of grid conditions at all times. Remote workers need data and voice communications to report conditions to control centers and to first-responders. Substation technicians at remote sites require redundant, survivable communication paths.

Backing up these communications concepts, Cisco offers its Connected Grid portfolio of products and solutions designed specifically for a Smart Grid network. These products include the Cisco 2010 Connected Grid Router (CGR 2010) and the Cisco 2520 Connected Grid Switch (CGS 2520). These platforms are optimized for use in power substations and meet substation compliance standards including IEEE 1613 and IEC 61850-3 *(Fig. 1)*.

line input and reducing stress on the bulk storage capacitors.

JEFF SCHNABEL: I believe that tomorrow's innovations will occur through the discovery and implementation of new power topologies and materials such as gallium nitride (GaN) and silicon carbide. As an example, CUI's (dc-dc) Solus Power Topology currently is able to reduce switching turn-on losses by 75% and switching turn-off losses by 99% on the control FET when compared to a conventional buck converter. Our testing shows that it holds similar advantages when implemented in ac-dc, ultimately allowing for increased efficiency and reduced package size.

DT: How much of an improvement will we see during 2013, and what's likely in five years?

JS: We see that the biggest short-term gains in power supply efficiency, overall, rather than peak, will come as a result of reducing power consumption at the no-load end of the curve, i.e., when the device is in standby. We're not alone, however, and the regulation bodies have begun to make this a priority. Along with the introduction of new topologies, digital control in ac-dc supplies will have a significant effect over the next five years, allowing for greater power supply and power system optimization.

DK: We'll see an increase of one to two percentage points in efficiency in 2013 and two to three points in the next five years, along with improvements in power factor correction performance over a broader range of ac-line inputs. Perhaps most dramatically, the increased use of digital control loops—not just digital supervision of analog loops—will change performance levels, improve PFC, add flexibility, enable the supply to adapt to varying and complex line and load situations, and offer increased real-time reporting on the supply's operation and internal parameters.

GB: The latest designs include quasi-resonant PFC stages, resonant power converters, and synchronous rectification to minimize the switching and other losses throughout the power chain. New products reach efficiencies of 95% at high line input voltages and maintain efficiencies above 92% at minimum input voltage. The development of components and techniques will see this improve.

DT: What are the biggest challenges faced in improving system efficiency through power supplies?

GB: It is important to focus on low line efficiency and cost-effective methods for reducing power dissipation in the rectification and PFC stages. Market price remains a key driver, especially for lower-power products, as the cost of small efficiency improvements can be prohibitive. Continuing to reduce the size of products has an adverse effect on increasing efficiency and on product lifetime.

JS: The biggest challenge resides in the fundamental nature of switching conversion and the associated switching losses at turn-on and turn-off. The never-ending challenge of power supply designers will be to minimize these losses, whether through topology breakthroughs or component-level improvements.

DK: Current levels are increasing, so contact and lead resistance, internal IR drop, and related basics are becoming more severe. Operating the supply at a higher internal voltage is part of the answer for increased efficiency, but this brings new creepage, spacing, and safety issues. Increasing the frequency of operation will reduce size but not efficiency, due to increased core losses in magnetics and increased switching losses in the semiconductors.

DT: What are the key factors OEMs should specify if they are to improve the system efficiency through the power supply?

DK: First, don't oversize the supply for insurance headroom. If you run the supply at much lower loads than this zone, you'll actually be operating in a very inefficient region. Second, try to avoid active (forced air) convection cooling using fans since they waste power, add noise, and reduce reliability. Instead, use an efficient supply, properly sized, and mount it so unforced convection and conduction cooling will keep it within its rated temperature.

GB: The key is to look at power supply efficiency in the operational area of use, i.e., look for the detail rather than the headlines. If the equipment will be used throughout the global market, then the efficiency at low line is more interesting that the headline efficiency at 230 V ac. The load drawn in the application is important as products often offer their peak efficiency at higher percentage loads. There is a tradeoff between efficiency, size, and cost, which drives the product design.

JS: Because real-world systems typically do not operate at a steady state, OEMs should examine the power supply's complete efficiency curve and ensure that it is optimized to their application's loading profile. By doing so, they can best match the power supply to their system's needs. ■

IEC 61850

While Cisco is concerned with the evolving Smart Grid communications infrastructure, much of the opportunity for new products lies in the hardware for controlling transmission and distribution. In an effort that started in the mid-1990s, this is being standardized as IEC 61850, which standardized the design of automated electrical substations. It's part of the IEC Technical Committee 57's reference architecture for electric power systems. Its abstract data models can be mapped to various data protocols that run over TCP/IP networks and substation local-area networks (LANs) using high-speed switched Ethernet.

IEC 61850 is intimidating. The complete set of documents runs to 1400 pages. Electrical power experts from 22 countries wrote it, and it assumes intimate knowledge of how the components of an electrical power distribution network work. Happily, there is a document that makes it more accessible to electronic product designers. Released in 2009, "Understanding and Simulating the IEC 61850 Standard" by Yingli Liang and Roy H. Campbell of the Computer Science Department of the University of Illinois at Urbana Champaign is a model of clarity. (And it runs only 12 pages.)[1]

IEC 61850 AND IEDS

Intelligent electronic devices (IEDs) are at the core of the standard. Essentially, IED refers to microprocessor-based controllers for power system equipment that can receive or send data or control commands from or to an external source. While that makes an IED basically a PC, probably running Linux, it may also have some dedicated logic for domain-specific processing.

IEDs can be classified by their functions, such as relay devices, circuit-breaker controllers, recloser controllers, or voltage regulators. In a substation, the internal network is connected to the outside wide area network via a secure gateway *(Fig. 2)*.

The IEC 61850 standard defines an abstract communication service interface (ACSI) to be used by remote operators and control centers to query and control devices. One or more substation buses, in the form of a medium bandwidth Ethernet network, connect all the IEDs inside the substation.

The substation bus carries all ACSI requests and responses as well as generic substation events messages (GSE). A separate, high-bandwidth Ethernet process bus handles communication inside each bay and connects the IEDs to any dumb devices. A substation would typically have a single global substation bus and multiple process buses, one for each bay.

Most interactions inside a substation automation system are data gathering and setting, data monitoring, or reporting and event logging. To accomplish all that, the standard defines a communication structure *(Fig. 3)*. There are four communication profiles in addition to ACSI: the generic object oriented substation event profile (GOOSE), the generic substation status event (GSSE), the sampled measured value multicast profile (SMV), and the time synchronization profile.

As we have seen, ACSI services enable client-server interaction between applications and servers. GOOSE provides a fast way to exchange data on the substation bus. GSSE provides a method for substation-level status exchange.

Applications request all ACSI services, and servers respond to them. In the IEC 61850 data model, the server is the common point that links physical devices and logical objects. Usually, an IED hosts one instance of a server, though it can run more. Each server has one or more access points, which are the logical representation of a network interface controller. Also, each server hosts several files or logical devices. Clients can manipulate files in the server as if they were talking to an FTP server. ACSI services include querying an object set, getting or setting data values, controlling system objects, report manipulation, log manipulation, and other services, including file upload and download. ed

REFERENCE

1. "Understanding and Simulating the IEC 61850 Standard," Yingli Liang and Roy H. Campbell, University of Illinois at Urbana Champaign Computer Science Department, https://www.ideals.uiuc.edu/bitstream/handle/2142/11457/Understanding%20and%20Simulating%20the%20IEC%2061850%20Standard.pdf?sequence=2


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IMPROVED POWER ICs GIVE SUPPLY DESIGNERS MORE BANG FOR THE BUCK

As the use of electronics in all sectors of society grows, so does the need for more efficient, higher-level, and more cost-effective power sources. This in turn is spearheading the development of power discrete devices like diodes, MOSFETs, integrated-gate bipolar transistors (IGBTs), gate turn-off and integrated gate turn-off (GTO and IGTO) thyristors, and power modules. Gallium-nitride (GaN) and silicon-carbide (SiC) power devices also await.

Power-supply designers now can choose from a wide variety of power devices that pay handsome dividends for their designs. According to IMS Research's Power Semiconductors Discretes and Modules report, the total market value of these devices grew last year by 3.7% to $13.5 billion and continues to grow. MOSFETs and IGBTs will lead the growth, though IGBTs are expected to grow at a faster rate.

MOSFETS VS. IGBTS

MOSFETs and IGBTs are similar yet offer different performance levels. An IGBT combines the simple gate-drive characteristics of a MOSFET with the high-current and low-saturation voltage capability of a bipolar transistor. An IGBT combines an isolated gate FET for the control input with the bipolar transistor acting as a switch *(Fig. 1)*.

IGBTs are used in medium-power to high-power applications such as switched-mode power supplies (SMPSs), traction motor control, and induction heating. Typically, large modules include a number of IGBTs in parallel and feature current-handling capabilities of hundreds of amperes with blocking potentials of 6000 V and kilowatts of power handling capability.

One example, the 1.2-kV, 60-A MIXA60WH1200TEH converter-brake-inverter module from IXYS Corp., comes in an E-3 pack that's just 1.7 mm high. It combines bipolar power with what IXYS calls eXtremely rugged, eXtremely light Punch Through (XLP) IGBTs. It is designed for energy-efficient power supplies, uninterruptable power supplies (UPSs), motor control, and inverter applications.

There is a gray area where either MOSFETs or IGBTs can be used for applications involving blocking voltages of about 250 V to 1 kV and switching frequencies somewhere between 25 kHz and 250 kHz. Here, the chosen device is very application-specific, so cost, size, switching speeds, and thermal cooling requirements come into play.

There also are some drawbacks to IGBTs. Because of their on-state voltages, they feature a lower switching speed, especially at turn-off time. This is because during the turn-off period electron flow can be stopped rather abruptly, just as it can be stopped for a power MOSFET, by reducing the gate-emitter voltage below the threshold voltage.

In the case of an IGBT, holes are left in the drift region in IGBTs. This leads IGBTs to exhibit a tail current during turn-off time until all the holes are swept out or recombined.

Some IGBTs known as non-punch-through (NPT) devices incorporate an n+ buffer layer that quickly absorbs trapped holes. Those that don't are called punch-through (PT) IGBTs.

On-state latch-ups are another potential IGBT downside. They can be problematic for an IGBT when it is operated outside its data-sheet ratings and result in a failure mode where the IGBT no longer can be turned off by the gate.

IGBTs continue to improve their already low switching losses. The 650-V TrenchStop 5 process from Infineon Technologies reduces switching losses by more than 60% compared to current leading solutions. Its thin wafers provide what Infineon calls best-in-class IGBT performance. The 650-V devices produced on the process are available in TO-220, TO-220 FullPak, and TO-227 packages *(Fig. 2)*.

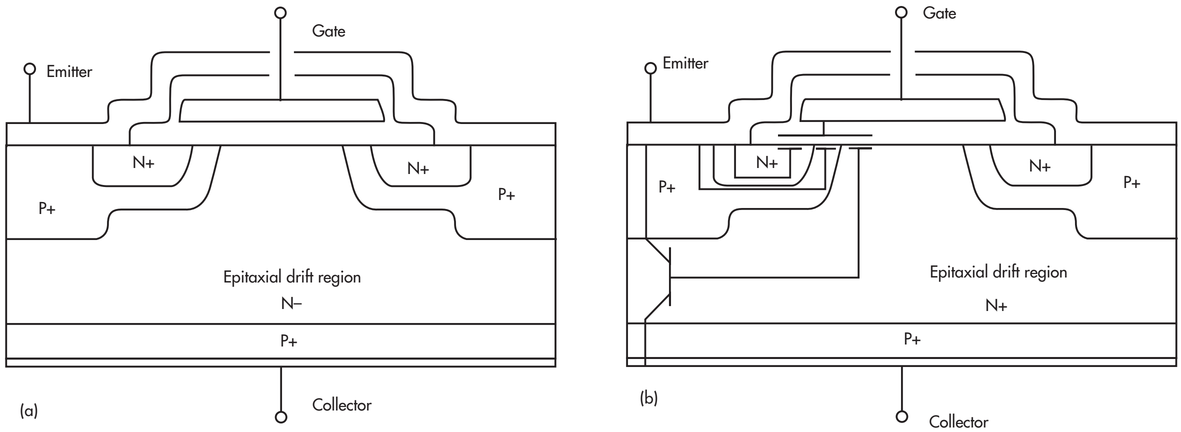
Fairchild Semiconductor's FGAxxSxxP shorted-anode 1.1-kV to 1.4-kV IGBTs target high-power and high-frequency applications like induction heating. Compared to typical NPT IGBTs, they offer a 12% lower saturation voltage and a 20% lower tail current. They also are optimized with intrinsic anti-parallel diodes for soft switching applications.

IGBTs are used in many industrial, transportation (railroads, heavy offroad equipment), automotive, military/aerospace, commercial, and geothermal applications. They offer reduced conduction losses and greater efficiency at higher currents than MOSFETs, according to International Rectifier, which makes both IGBTs and MOSFETs. IR's COOLi2R platform features silicon and packaging technology advances for hybrid and electric vehicles to help reduce the size, weight, and system costs of electric power train components while increasing reliability *(Fig. 3)*.

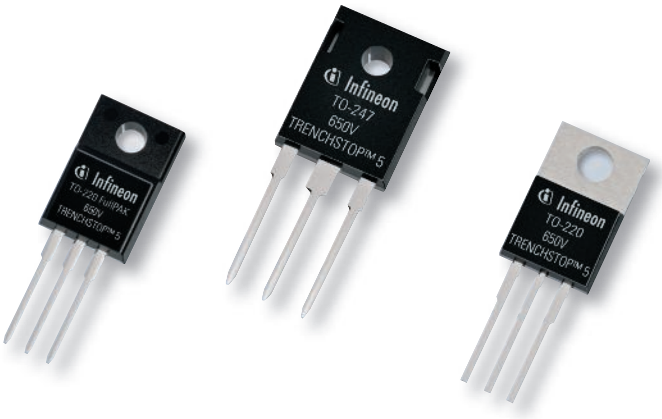
MOSFETs also are used in SMPSs and operate at frequencies in the hundreds of kilohertz. But unlike IGBTs, MOSFETs have no theoretical on-state resistance ($R_{DS(on)}$) limits. IR's IRPF4137P13F MOSFETs deliver benchmark $R_{DS(on)}$ performance of 69 mΩ and a total gate charge (Q_g) of 8.3 nC in TO-220 and TO-247 packages. The 70-A IRPF4868PF has an $R_{DS(on)}$ of just 32 mΩ and a Q_g of 180 nC in a TO-247 package.

Because a MOSFET has a body-drain diode, it is particularly useful in dealing with limited free-wheeling currents. But MOSFETs have generally been limited to blocking voltages of 250 to 300 V and can be found mostly in computer and consumer electronics products and digital logic circuits.

This lower voltage-blocking capability is beginning to change thanks to the development of super-junction MOSFETs from many power semiconductor IC manufacturers. This has allowed them to produce MOSFETs with 400-V+



1. An IGBT combines the simple drive characteristics of a MOSFET with the high-current and low-saturation-voltage capabilities of a bipolar transistor. It achieves this by combining an isolated-gate FET for the control input with the capability of a bipolar transistor as a switch in a single structure (a). Its construction is similar to that of an N-channel MOSFET except the N+ drain is replaced with a P+ collector layer to form a vertical pnp bipolar junction transistor (b). *(courtesy of Wikipedia.org)*



2. The Infineon Technologies 650-V TrenchStop 5 process reduces switching losses by more than 60% compared to current leading solutions. Thin wafers provide what Infineon calls best-in-class IGBT device performance. The devices come in TO-220, TO-220 FullPak, and TO-227 packages.

voltage-blocking capabilities. These newer super-junction MOSEFTs can be manufactured on smaller die sizes, making them less expensive to produce, and feature low on-state resistance levels. They're now being considered for hybrid and electric vehicle low-end designs. Marketing analyst Yole Développment foresees super-junction MOSFETs that can handle 1 kV by 2018.

The main difference between the present crop of super-junction MOSFETs and IGBTs is that the former has higher on-state losses at high current levels than the latter. Super-junction MOSFETs are simpler to manufacture and, thus, less expensive. IGBTs operate at higher temperatures than super-junction MOSFETs, but those MOSFETs are improving and catching up to the IGBT's maximum operating temperature.

Infineon Technologies makes available 400-V+ super-junction MOSFETs using its CoolMOS power platform. Producing them involves using multiple epitaxial layers and doping steps to create a locally doped island in the epitaxial layer. The doped region then diffuses and creates an N-doped pillar.

Other companies like Toshiba, Fairchild Semiconductor, and IceMOS Technology use reactive ion etching. This allows them to dig a trench that's filled with an N-doped material to create the super-junction MOSFET.

Toshiba's TK100S04N1L MOSFET suits high-speed automotive switching. It achieves a low on resistance of just 1.9 mΩ (at a V_{GS} of 10 V) and a low leakage current (I_{DSS}) of 10 µA maximum in a DPAK package. Toshiba credits its eighth-generation trench MOSFET technology and the use of low-on-resistance copper interconnects. The device is rated to operate at up to 175°C.

STMicroelectronics offers the Power Trench program. Its SuperMesh5 platform enables the development of 900-V (STx1N9DK5) and 850-V (STx20N95K5) MOSFETs for driving LEDs. They're aimed at eco-friendly designs and are available in IPAK packages. An 850-V variant, the STx23N85K5, is available in a PowerFlat 1-mm thick surface-mount technology (SMT) package *(Fig. 4)*.

Fairchild Semiconductor offers the FSL1x series of high-voltage FPS Green Mode Power Switches. These 650-V, 700-V, and 800-V devices are manufactured on the company's vertical DMOS platform and provide high efficiency levels for SMPSs.

A milestone in the development of highly integrated MOSFET power devices is the EN2300 from Enpirion Corp. The 4-A to 15-A buck converter module includes a controller, inductor, filter capacitors, and MOSFETs, all in a single quad flat no-lead (QFN) package *(Fig. 5)*.

Trench technology also is being used to make IGBTs. ON Semiconductor has expanded its portfolio of IGBTs made on its Trench Field Stop power platform to address hard-switching and soft-switching applications like motor inverter and induction heaters.

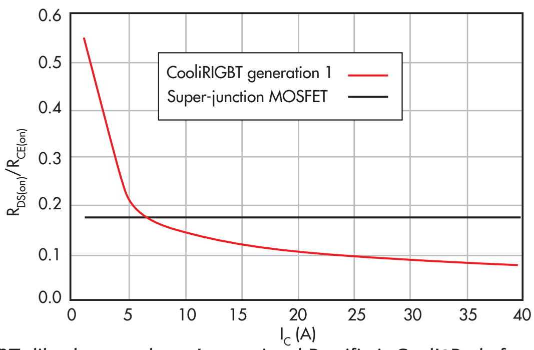
The devices are rated at 1.2 kV and can handle 15, 25, and 40 A. They feature switching frequency ranges of 2 to 20 kHz, 15 to 30 kHz, and 10 to 40 kHz, as well as low switching losses, a low Q_g, and a wide operating temperature range of –55°C to 150°C.

High efficiency and ruggedness are two of the characteristics of IGBTs as shown by IR's 1.2-kV IRGBCHxxxK10F family with best in class performance for industrial and energy-saving applications. Built on the company's Gen8 Trench Gate Field Stop platform, whose design allows record-setting low $V_{CE(on)}$ performance of 1.7 V, the thin wafer technology delivers improved thermal resistance and a maximum junction temperature of up to 175°C.

HERE COMES GAN

For theoretical and practical reasons, silicon cannot sustain the higher-voltage and current capabilities needed for future hybrid and electric automotive, industrial, rail-transportation, photovoltaic inverter, and high-temperature radiation-hardened military/aerospace systems. Wide-bandgap compound semiconductors like GaN and SiC can significantly outperform traditional silicon.

Developments abound in trying to make GaN and SiC more practical and cost-effective to mass produce. Although they're considerably more expensive, they're beginning to make a bid as legitimate devices to power such things as LEDs. Yole



3. IGBTs like those made on International Rectifier's CoolI2R platform offer reduced conduction losses and greater efficiency at higher currents than MOSFETs. *(courtesy of "IGBTs or MOSFETs: Choose Wisely" by Carl Blake and Chris Bull, International Rectifier)*

4. STMicroelectronics' SuperMesh5 900-V and 850-V MOSFETs are designed to drive LEDs in eco-friendly designs. They're available in IPAK packages. An 850-V variant is available in a PowerFlat 1-mm thick package.

Développment says that the market for GaN grew to nearly $10 million in 2012 and will grow to $500 million by 2016, up from $2.5 million in 2010.

GaN technology eliminates the need for packaging, slashing costs and wasted printed-circuit board (PCB) space, since it can be grown directly on a silicon substrate. The active GaN device can be isolated from the silicon substrate and completely encapsulated prior to singulation. And because it can be packaged in a flip-chip arrangement, thermal and electrical resistances are minimized.

Bulk GaN can be epitaxially grown on a CMOS process that it is compatible with, so relative newcomers to the power IC scene don't need to establish CMOS processes in-house. Instead, they can rely on CMOS foundries that can work with them. Device makers then will be able to easily accommodate future demands quickly and at a potentially lower cost as CMOS wafer sizes grow larger from the present 2-in. and 4-in. wafers being used.

In fact, that's exactly what's happening. Some GaN device manufacturers that have shown that such devices can be manufactured are working closely with semiconductor fabrication houses. For example, GaN devices are already showing up as drivers for LEDs.

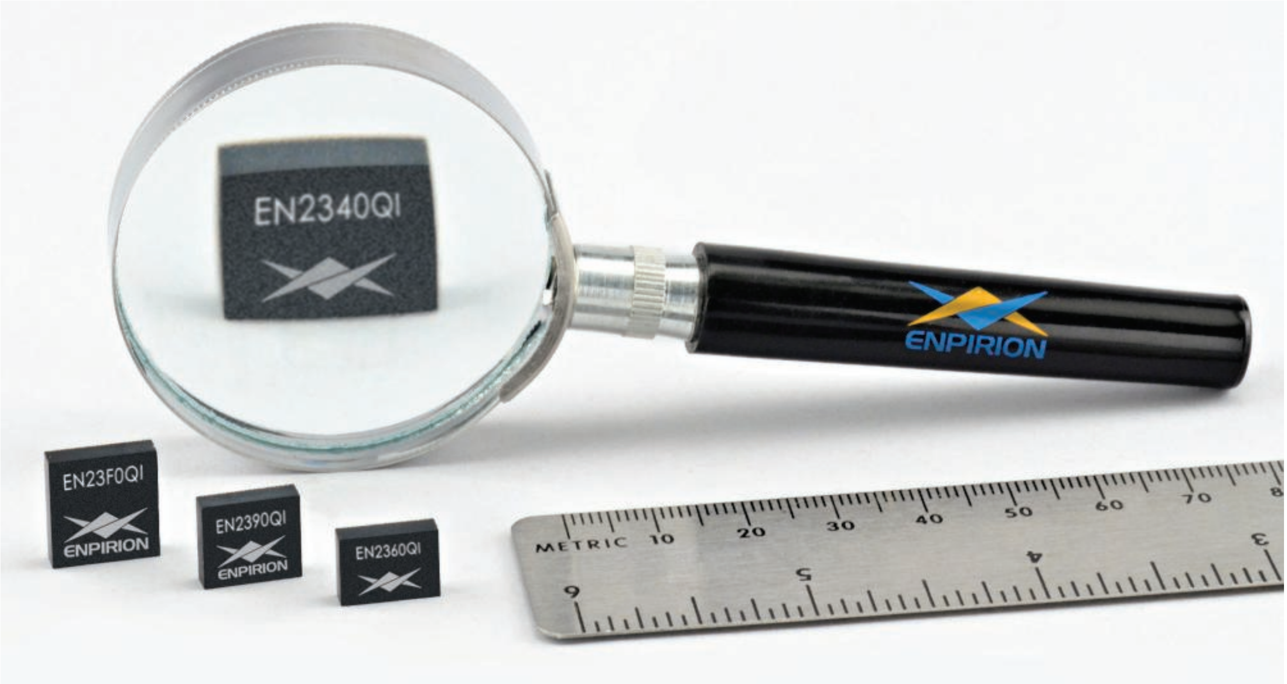
Toshiba is supplying mass-produced white light LEDs that use GaN chips manufactured on 200-mm silicon wafers. Together with Bridgelux Inc., Toshiba developed the process at a new production line at its Kaga Electronics Corp. in northern Japan.

Two ongoing process developments include growing bulk GaN on hybride vapor phase epitaxy (HVPE) GaN wafers. Another is growing bulk GaN on 2-in. and 4-in. ammonothermal GaN wafers. Both look promising in cost competitiveness with the growing of bulk GaN on larger 6-in. silicon wafers, when the much larger performance gains are factored in for using GaN wafers.

Efficient Power Conversion has already demonstrated that the production of GaN devices is possible using its 600-V eGaN devices. Using its EPC9102 demonstration board, EPC showed that its eGaN FETs can be used to make an eighth-brick (58 by 23 mm) fully regulated dc-dc converter that's more efficient than silicon and that the output power can be increased by 33% at a 50% higher switching frequency using just 100-V eGaN devices.

International Rectifier is already supplying its IP2010 and IP2011 Integrated Power Stage GaN modules. According to the company, these modules allow SMPS designers to build switching converters at five to 10 times the switching frequencies presently used while maintaining the same efficiency.

The question now is when we can expect bulk GaN to become competitive with silicon. Lux Research analyst Pallavi Madakasira points out that the future of bulk GaN is going to come down to how it faces off against silicon substrates in his



5. Enpirion's EN2300 4- to 15-A buck converter module includes a controller, inductor, filter capacitors, and MOSFETs, all in a single QFN package.

report, "Price or Performance: Bulk GaN Vies with Silicon for Value in LEDs."

Madakasira believes that by 2020, GaN grown on 2-in. wafers of HVPE can become competitive with bulk GaN grown on 6-in. silicon wafers, given the 360% performance improvements GaN on HVPE wafers offers over silicon *(Fig. 6)*.

The report also explores emerging materials such as aluminum nitride (AlN). It can be ideally suited for very low-wavelength ultraviolet LEDs, green laser diodes, and high-switching-frequency power electronics, and it may be an effective alternative to bulk GaN.

As with all emerging technologies, device modeling and characterization development tools are quickly emerging to validate the technology. A new version of the Agilent Technologies Integrated Circuit and Analysis Platform (IC-CAP) device modeling software for high-frequency characterization and modeling includes Angelov-GaN modeling and Python scripting.

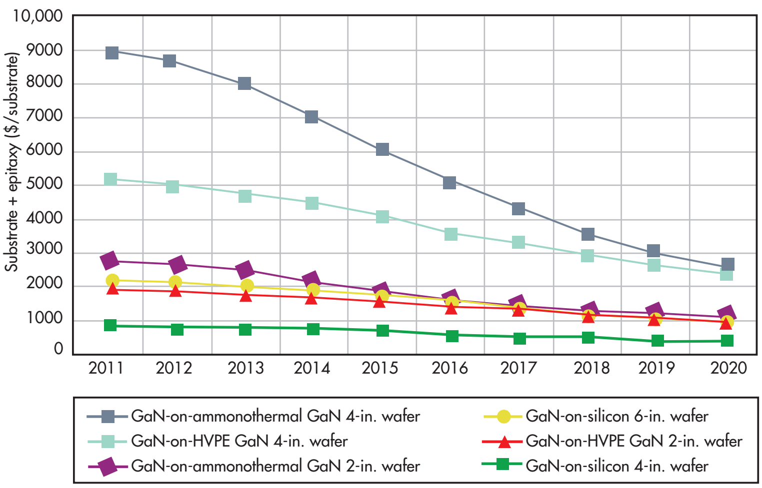
SIC COMING DOWN THE ROAD

Although the technology isn't cost-competitive with silicon, SiC R&D efforts are accelerating in the development and manufacture of SiC power devices. Companies such as Microsemi Corp. are offering samples of SiC power modules for high-temperature industrial applications. The APTxxxx family of modules boasts 1.2-kV and 600-V ratings that can handle 20 to 200 A in boost charger, phase-leg, and neutral-point clamped configurations.

Cree has shown that SiC can form the basis for impressive performance levels in LED lighting. Last year, the company used its S^3 technology to demonstrate a prototype LED light bulb that produces 170 lumens/W, topping the 152-lumen/W level that it previously announced. The S^3 technology platform is designed to enable significantly higher-efficiency and lower-cost LED light bulbs for use in luminaires.

For now, designers of power electronics systems can be assured of a wide variety of IGBT and MOSFET devices to choose from. The GaN era is on the horizon but could take a few more years to become widespread commercial reality. And for those in need of maximum performance levels that other technologies can't touch, SiC can deliver the goods. ed

6. GaN grown on 2-in. wafers of HVPE can become competitive by 2020 with bulk GaN grown on 6-in. silicon wafers, given the 360% performance improvements that GaN on HVPE wafers offer over silicon. *(courtesy of Lux Research).*



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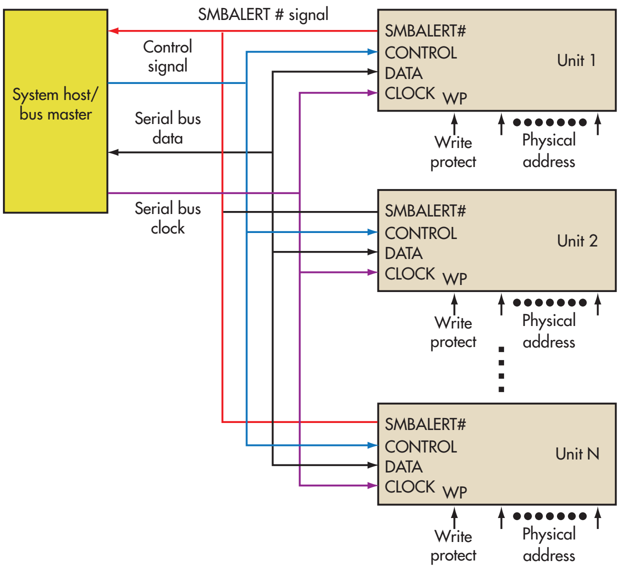
THE BASICS OF PMBus DESIGN

Understanding the PMBus standard is the key to digital power management in systems such as data centers that use multiple layers of power conversion.



1. Electrically, PMBus is I^2C with an added "alert" signal back to the controller.

The PMBus standard for digital power management is the result of collaboration between power supply and semiconductor companies. There are more than 50 members in the PMBus organization. In terms of hardware, PMBus "devices" may be ICs, power converters, or power supplies. No device is required to support all of the available features, functions, and commands, but all must meet certain requirements. Part I of the standard addresses transport, the electrical interface, and timing for hardwired signals. Part II describes the command language.

WHAT IT'S NOT

The PMBus standard does not address direct device-to-device communication such as analog current sharing, real-time analog or digital voltage tracking, or switching-frequency clock signals. It is not a standard for ac-dc power supplies, nor does it specify attributes such as form factor or pin-out, which are addressed by industry alliances such as the Point-Of-Load Alliance (POLA) and the Distributed-power Open Standards Alliance (DOSA). And, it doesn't deal with communication between one power source and another. This is an important point. That kind of communication remains the domain of semiconductor and power supply manufacturers.

PMBUS ROOTS

PMBus was released in 2003. By that time, the power supply community was adapting to new customer needs, particularly in the data center. While chipmakers continued to work on improving efficiency, they also had to respond to system designers who had embraced distributed power architectures (DPAs). DPAs are based on multi-level power distribution, where isolated dc-dc converters are followed by loosely regulated intermediate bus converters (IBCs) and non-isolated point-of-load (POL) converters.

DPA components were developed because the latest complex microprocessors and ASICs had multiple power rails for core, memory, and I/O. Each of these rails had different voltage requirements (often down to 1 V) and, for cores in particular, extremely fast di/dt swings. There were many power management issues as well. As a minimum, on power-up and power-down, a systemic approach was needed to sequence those devices to avoid back-biasing transistors on the die.

In addition to application in the final product, this kind of control was deeded in design and manufacturing where the use of voltage margining to test design robustness had increased. Meanwhile, the monitoring of converter output currents and temperatures became common practice to improve system reliability.

As needs grew, different power-IC designers responded in unique ways. Sequencing might be accomplished with "output enable signals," margining by switching trim-resistor values in and out. Elsewhere in the design cycle and in operation, currents and temperatures were sensed and digitized so FPGAs or microcontrollers could be programmed to manage all those processes.

The result was a kind of Tower of Babel. In 2004, Artesyn Technologies (now part of Emerson Electric) proposed the PMBus initiative. Early the following year, it was formalized as a special interest group (SIG) and opened to global membership. The protocol is now in the public domain, and the SIG, known as the System Management Interface Forum, is responsible for further developing and promoting the standard.

Artesyn framed the need for an industry standard at that time by noting that such an approach would fill a need for broad consensus on digital power management. At that point, several power supply manufacturers including Power-One, Zilker Labs (now part of Maxim Integrated), Primarion (now part of Infineon), and Silicon Labs had already announced digitally programmable point-of-load (POL) converters based on their own proprietary architectures and silicon—though just as PMBus was gaining traction, this situation would lead to a crisis that would bring PMBus implementations to a standstill for several years *(see "Power-One's Z-Bus And Patents," p. 52)*.

TABLE 1: REQUIREMENTS FOR PMBus COMPLIANCE
Meet all of the requirements in Part I of the specification
Support at least one of the non-manufacturer-specific commands in Part II of the specification
Execute functions exactly as specified in the PMBus command code
Either accept, acknowledge, and execute a PMBus command or reject it
At power-up, safely start and operate without communication with other PMBus devices
Use the SMBus for transport [1]
Support the Group Command Protocol used to send commands to multiple PMBus devices [2]
Respond if there is a change in the state of a hardwired signal [3]
Specify the accuracy of the output voltage and other parameters that can be set and reported in its product literature

[1] The specification lists some exceptions.

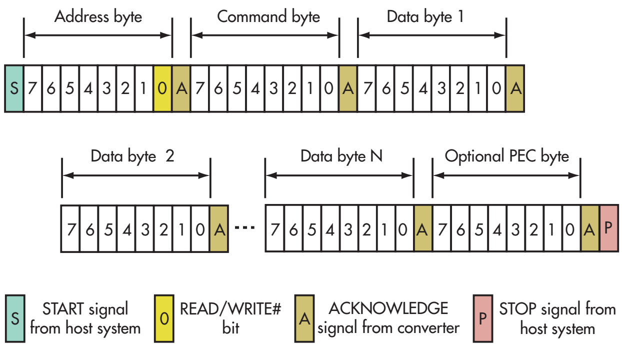
[2] These commands are received in one transmission. When the devices detect the STOP condition that ends the command, they all begin executing the received command.

[3] There are no specific response-time requirements.

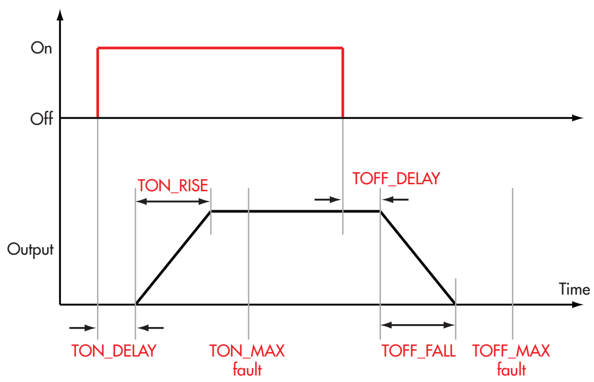
PMBUS BASICS

The PMBus protocol defines an open-standard digital power management protocol that facilitates communication with a power converter or other device by fully defining the transport and physical interface, as well as the command language needed to accomplish these definitions.

PMBus is about low-cost real-time control. Its transport layer is based on the SMBus (System Management Bus), a version



2. The standard master-to-slave communication sequence comprises multiple data packets.



3. Power-up/down sequencing typically involves just four PMBus commands.

TABLE 2: OPTIONAL PMBus FUNCTIONS

Use the SMBus Packet Error Checking (PEC) protocol
Devices may temporarily become bus masters and communicate with the host
Devices may notify the host that they want to communicate with it
Write-protecting signal inputs
Firmware upgradability via the SMBus interface

TABLE 3: OUTPUT VOLTAGE COMMANDS

Set the device to use either LINEAR, VID, or DIRECT modes. The command may also include information about the selected mode, e.g., which manufacturer's VID codes are being used
Set the device's: • Output voltage • Output voltage above which an output overvoltage fault is declared • Upper limit on the output voltage regardless of any other commands or combinations • Rate (in mV/µs) at which the output should change voltage • Rate (in mV/A) at which the output voltage decreases with increasing current • Output power (in W) that triggers regulation in constant power mode instead of constant voltage • Maximum allowed duty cycle (in %) of the power conversion stage • Switching frequency (in kHz) • Input voltage at which power conversion starts and stops • Ratio of the voltage at the current sense pins to the sensed current • Fan voltage • Fixed output offset voltage
Load the device with the voltage to which the output is to be changed when the OPERATION command is set to "margin high" or "margin low"
Trim the output voltage
Map devices between the commanded voltage and the voltage at the control circuit input, divided down to match a reference voltage
Arrange multiple devices to distribute their switching periods in time
Null out any offsets (in A) in the output-current sensing circuit

TABLE 4: OUTPUT-VOLTAGE SEQUENCING COMMANDS

Set the device time (all in ms): • After receipt of a start condition until the output voltage starts to rise • After when the output starts rising until the voltage starts regulating • After receiving a stop condition until the device stops transferring energy to the output • From the end of the turn-off delay time until the output voltage is zero
Set the upper limit of time (all in ms): • That the device can attempt to power up the output without reaching its output under-voltage fault limit • That the device can attempt to power up the output • That the device can attempt to power down the output without reaching 12.5% of the output voltage programmed at the time the converter is turned off
Instruct the device on action to take in response to a maximum on-time fault or a maximum off-time limit

of Philips' I^2C serial bus that adds packet-error checking and host notification. Importantly for PMBus, SMBus also provides a third signal line, SMBALERT, that allows slave devices such as POL converters to interrupt the system host/bus master. This is where PMBus has an advantage over polling systems.

Under PMBus, slave devices must store their default configuration data in nonvolatile memory or use pin programming. This means they power up without any bus communication, minimizing system startup times compared to schemes in which the bus master configures all slave devices on power-up. Slave physical addresses are defined by means of dedicated pins on the device package.

In addition to the SMBus clock, data, and interrupt lines, PMBus specifies two hardwired signals: a control signal used in conjunction with commands received over the bus to turn individual slave devices on and off, and an optional "write protect" signal that can be used to prevent changes to memory *(Fig. 1)*.

For bus-contention arbitration, SMBus employs wired-ANDs on all devices. For low cost and flexibility, all communications between host and power sources are conducted entirely via the bus. A "host" can take the form of the system's existing proces-

TABLE 5: FAULT-MANAGEMENT AND REPORTING COMMANDS

Clear any fault bits that have been set
Set the device output voltage threshold measured at the sense or output pins for: • Over-voltage or under-voltage faults • Low or high voltage warnings
Set the device's: • Output voltage for asserting and negating a power-good signal • Output current (in A) threshold to indicate an over-current warning or fault • Maximum allowable sink current (in A) before taking action
Set temperature (in °C) for device: • Over-temperature warning or fault • Under-temperature warning or fault
Set device input voltage threshold to cause: • Low or high input voltage warning • Input under-voltage or over-voltage fault
Set device input current threshold to cause: • High input current warning • Input over-current fault
Instruct the device on action to take in response to: • Output under-voltage or over-voltage fault • Output under-current or over-current fault • Under-temperature or over-temperature fault • Input under-voltage or over-voltage fault • Input over-current fault

It is possible to specify the voltage threshold for instances in which the response to an over-current condition is to operate in a constant-current mode unless/until the output voltage is pulled below the specified value.

sor, a low-cost general-purpose microcontroller, or an FPGA. During system design, it can be a PC, or during manufacturing, a piece of automated test equipment (ATE) gear.

Command packets comprise an address byte; a command byte; zero, one, or more data bytes; and an optional packet error code (PEC) byte *(Fig. 2)*. In a typical host-to-slave information transfer, the master uses single "start" and "stop" conditions to indicate the beginning and end of the process, and the addressed slave device uses a single bit to acknowledge reception of each byte.

The slave processes and executes a command immediately after it receives the "stop." Some 256 commands are potentially available, but PMBus devices do not have to support all commands. Most use only a few. Extensions are built in to allow for command extensions that permit 2-byte commands. One is reserved for device manufacturers' own use, the other for revisions of the protocol.

WRITING PMBUS CODE

Robert White, the protocol's major architect, describes how best to write power management programs in terms of sequencing, noting that only two PMBus commands are required to control a POL converter's startup sequence *(Fig. 3)*.[1]

"TON_DELAY programs a time for the converter to wait until starting to produce an output, and TON_RISE programs the time for the output to increase from zero to the final programmed value. The user simply programs each converter with its own turn-on delay time and turn-on rise-time. Similarly, only two commands (TOFF_DELAY and TOFF_FALL) are required for turn-off sequencing," White says.

Voltage margining demonstrates similar advantages. Previously, margin testing was highly iterative and time consuming, involving fitting different value resistors to dc-dc converters to vary their output voltage a few percent either side of nominal. PMBus-compliant POL converters simplify this process.

"Again, using just two commands (VOUT_MARGIN_HIGH and VOUT_MARGIN_LOW), each converter can be instructed to deliver tightly controlled test voltages, while the effect on board performance is monitored. This can significantly reduce production test times, help eliminate ambiguity, and produce clearly documented test results," he says.

PMBUS FUNCTIONALITY

PMBus-compliant devices have some must-have and some may-have functionality *(Tables 1 and 2)*. In terms of hardwired signals, devices may use pins for programming or for configuration such as a RESET pin or pins for setting the output voltage to high or low margin values. The hardwired CONTROL command, for turning the device on or off, can be configured as active high or active low. Either is optional, but at least one is recommended.

OUTPUT VOLTAGE COMMANDS

For flexibility, the PMBus standard provides three formats for commanding or reading output voltage or related parameters: LINEAR, VID, and DIRECT. Using LINEAR, scaling is based on a 2-byte unsigned binary integer with a scaling factor, like a mantissa and exponent. If a linear scale factor is too simple, the DIRECT format allows the use of device-supplied coefficients that can be applied to a nonlinear scaling equation. The VID format supports Intel's code format used by many microprocessor units.

For ground-reference consistency, PMBus treats all output voltages and output voltage-related as positive values. Table 3 summarizes more specific commands related to output voltage. Table 4 lists output-voltage sequencing commands.

FAULT MANAGEMENT AND REPORTING COMMANDS

PMBus includes the ability to program specific fault or warning levels. Fault conditions are more serious than warning conditions and may require the device to disable its output and stop the transfer of energy. Warnings support less urgent interventions.

For fault conditions, the options are to program the PMBus device to respond by shutting down immediately and latching off, shutting down and retrying, or continuing to operate for a specified delay time before shutting down. Table 5 provides a complete list of commands.

STATUS, PARAMETERS, AND HANDSHAKES

Read-only device-status and operating parameter commands are used during product design and in operation for fault diagnosis and for monitoring that goes beyond binary fault indicators *(Tables 4 and 5)*. There are also commands to store and retrieve the device manufacturer's inventory information. Typically, this is for the manufacturer of an assembled power supply or dc-dc converter rather than an IC. Several commands allow manufacturers to return device rating information, which serves as an electronic nameplate for the user's convenience.

The PMBus command language provides many base command codes and codes reserved for specific manufacturer and user commands, and there is space for future expansion of the base commands. It is unlikely that most PMBus devices will implement all of the PMBus commands.

Conversely, because a device only needs to support one command to comply with PMBus, there are provisions for notifying the PMBus master that a command is not supported. These include responding to a command code or a subsequent data byte with a negative acknowledgement (NAK), or responding with an ACK to the command and data, but then alerting the host that there was a problem.

The host, then, can read the package STATUS_BYTE to determine the support issue. This can be less ambiguous than a NAK, because NAK can mean

POWER-ONE'S Z-BUS AND PATENTS

WHEN PMBUS WAS envisioned, many experts thought the proliferation of proprietary buses would inhibit the adoption of digital power control because they would inevitably result in higher development costs and lock customers into a narrow supply chain. Something more complex happened in 2005, when Power-One brought suit against Artesyn's customers, claiming patent infringement.

The suit effectively warned all the semiconductor companies with PMBus products to withdraw those products from the marketplace. On November 15, 2007, a Texas jury found that both of the asserted patents were valid and that the Artesyn Technologies product infringed on Power-One's U.S. Patent No. 7,000,125.

In one sense, the decision was welcome because it removed many uncertainties and opened the door to licensing negotiations. As Emerson Electric (by then the owner of Artesyn) announced, the jury found that only one patent was infringed involving a product that Artesyn had never sold or offered for sale and that the market has never used. Specifically, the jury determined that any infringement wasn't wilful and that a total of $100 in damages would be awarded to Power-One in the event of any court judgement.

Explicitly, what was in the Power-One patents that the jury upheld? There are two patents, and the jury found all their claims valid. One was U.S. Patent 6,936,999 for the Z-Bus Digital Power Module, the controller. The other was 7,000,125, "Method and system for controlling and monitoring an array of point-of-load regulators." That's the one Power-One said Artesyn had violated in the product that Artesyn had never sold or offered for sale and that the market had never used.

Power-One's patent made 31 claims, but the judge got the parties to agree that the jury would only rule on several of them: multiple POLs; one or more bidirectional serial buses for programming, control, and monitoring the POLs; a user interface; memory with default settings; more details about programming; and the exact constituents of such a POL. The jury said that they were all valid.

August 2009 saw the first public announcement of a licensing agreement—with the Irish semiconductor company Powervation. In September 2009, CUI Inc. announced an agreement that involved Powervation's POLs. There may have been an earlier, unannounced agreement between Power-One and Texas Instruments.

Today, licensing agreements between Power-One and makers of PMBus products are routine.

"I did not hear you," "I can not support you," or "I did not understand you."

FLEXIBLE FORMATS

The PMBus specification allows engineering values to be encoded in at least two formats: literal and direct. The literal format exchanges data in engineering units of volts, amperes, milliseconds, or ºC. The direct method is based on the slave device's internal units. It simplifies the slave computational requirements at the expense of complexity for the host, which must have information about the translation of host units into internal slave units. The literal format requires the least effort from the master, but the slave must convert internal numerical values to engineering units.

In addition to literal and direct, output voltage can be represented in Intel's VID format. Although VID adjustments cannot meet the required timing for dynamic-processor power (because the bus bandwidth is too low), VID provides a simple way of managing voltage output and does not require a high level of complexity in either the host or slave devices.

The command language provides several ways to adjust power supply output and limits. First, the host calibrates the module and system to accurately set the output voltage. Next, it uses the VOUT_MODE command to configure the format of the output voltage format. Then the host can use the VOUT_COMMAND, VOUT_MARGIN_HIGH, or VOUT_MARGIN_LOW commands to set the output voltage. Which one it uses depends on the status of the CONTROL signal or on a prior OPERATION command.

OTHER COMMANDS

PMBus provides commands to set output voltage and voltage sequencing, as well as commands for fault management. Other commands check any fault-indication status the device manufacturer has included in the design or certain parametric values, if knowledge of them must be provided for. ed

REFERENCE

1. "PMBus—Panacea or Hype?" Bob White, Artesyn Technologies, *Electronic Products*, www.electronicproducts.com/Power_Products/PMBus_panacea_or_hype.aspx

TABLE 6: DEVICE STATES THAT THE PMBus CONTROLLER CAN READ
Device busy
Device not providing power to the output
Output over-voltage or over-current fault
Input under-voltage fault
Temperature fault or warning
Communications, memory, or logic fault
Output voltage fault or warning
Output current fault or warning
Input voltage fault or warning
Input current fault or warning
Negate power-good signal, if present
Output over-voltage fault or warning
Output under-voltage fault or warning
Attempt made to set the output voltage higher than allowed
Tracking error on power-up or power-down
Output over-current fault
Output over-current and low-voltage shutdown fault
Output over-current warning
Output undercurrent fault
Output current share fault
Device operating with the output in constant power mode at the power set by the maximum output power commands
Input over-voltage fault or warning
Input under-voltage fault or warning
Device is off due to insufficient input voltage
Input over-current fault or warning
Over-temperature fault or warning
Under-temperature fault or warning
Invalid or unsupported command or data
Packet error check failed
Memory or processor fault
Communication fault other than those listed
Fault of undetermined type
Fan fault
Input fuse or circuit breaker fault
Input OR-ing device fault
Output OR-ing device fault
Unspecified or unknown fault
Manufacturer-specific fault or warning

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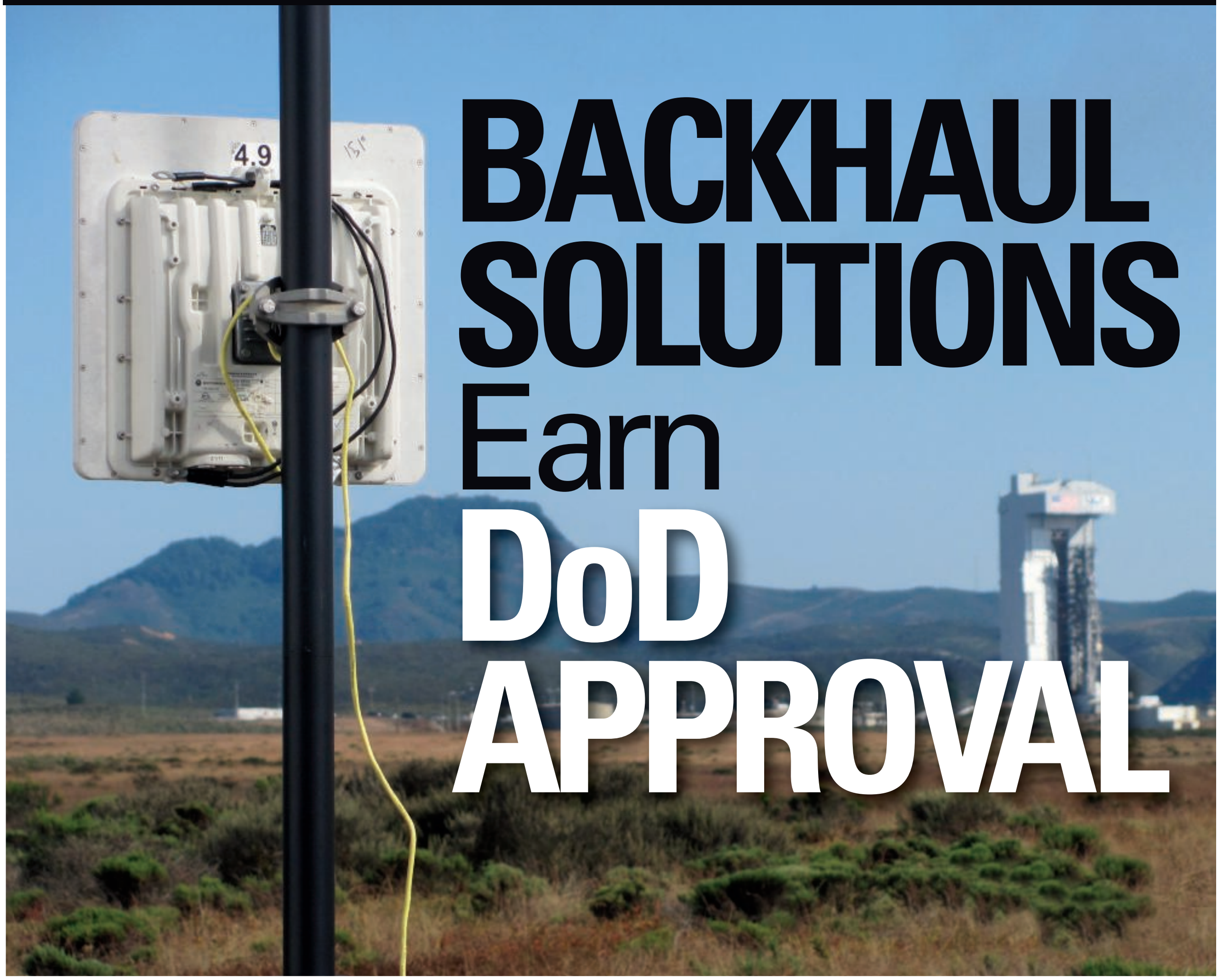

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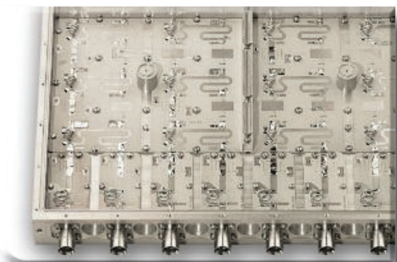

Defense Electronics

A SPECIAL SECTION TO PENTON'S DESIGN ENGINEERING & SOURCING GROUP

FEBRUARY/MARCH 2013

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BIG NEWS!
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0.01 to 6.0 GHz. Gain is 24 dB typical, output power is +25 dBm, 3rd order intercept +34 dBm. Reverse isolation -50dB. Operates on 15 VDC, 300 mA.
Broadband Amplifiers
Teledyne's ACP20015 Ultra-Broadband Amplifier
2.0 - 20.0 GHz, 10 dB gain, 16.0 dBm typical output power. 3rd order intercept +26 dBm. -55 to +85°C, fully-hermetic. Operates on 5 VDC at 76 mA. Military or space-level manufacturing/screening is an available option. EAR-99.
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Ultra low phase noise YIG Oscillators covering multi-octave bands up to 18GHz. Surface Mount or connectorized packages for commercial and military applications.
YIGs
Ku-Band SSPA
Exceptionally small size 15W P1 Ku-Band Solid State Power Amplifier for Satcom & CDL frequency bands. Product includes Forward power detect, Thermal Monitor, VSWR monitor and high speed blanking. Unit also incorporates a low output power mode.
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DARPA Sheds Light On Detection

Military strategy will continue to grow more complex over time, with battlefields already littered with threats that were once more imagination than reality. Staying one step ahead of adversaries' technological capabilities has long been a challenge for the US Defense Advanced Research Projects Administration (DARPA; www.darpa.mil)—albeit one that the organization has handled well.

DARPA has long supported improvements in proven strategic technologies, such as radio detection and ranging (radar) systems, which are used throughout the different branches of the US military for target detection. At one time, radar systems relied on mechanically moving antennas to scan a section of the horizon. But such advances as electronic beamsteering (see p. S20) have made it possible to control the amplitude and phase of transmitted radar signals so that the effect is equivalent to scanning a radar system's antenna or antennas through space.

Of course, a radar system with the capability of electronically controlling amplitude and phase to that degree requires high-quality active and passive components. Luckily, component suppliers have responded over the years by enhancing their product quality, performance, and reliability to meet the needs of electronically steered, phased-array radar systems.

DARPA is also open to the use of other energy sources for target detection, such as light pulses for light detection and ranging (ladar) systems. Ladar systems typically use light pulses emitted at 904 nm but can also operate with different optical wavelengths. Why develop an optical ranging/detection system if radar systems continue to improve? Each detection approach has its benefits, but both have shortcomings as well.

For example, radar systems can take time to lock onto a target, and radar receivers can become saturated by the return of signals from large targets close to the radar transmitter. In contrast, ladar systems can lock onto a target faster than a radar system. They can effectively track deaccelerating targets, and are not plagued with the number of interference sources as a radar system. But targets with rounded surfaces are difficult for a ladar system to track.

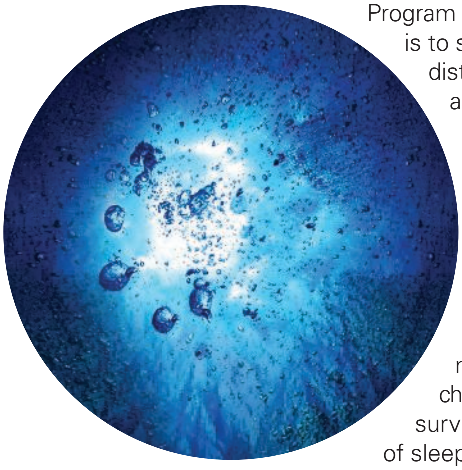
DARPA is clearly interested in advancing ladar system technology, and has performed work to that effect as part of its Diverse Accessible Heterogeneous Integration (DAHL) program. Among these is a two-dimensional (2D) optical phased array in chip form, packing 4096 optical nanoantennas (a 64 x 64 array) onto a device measuring just 576 x 576 μm. While it is clear that neither technology offers the ideal solution for target detection, it is not inconceivable to picture military weapons systems of the future employing both types of systems.

Jack Browne
Technical Contributor

Weapons Launch From Sea Bottom

Launching weapons from the bottom of the ocean may seem like science fiction, but it is actually part of the US Defense Advanced Research Projects Agency's (DARPA) Upward Falling Payloads (UFP) program to provide the US Navy with more advanced weapons capabilities. The UFP concept relies on unmanned, distributed weapons systems that "hibernate" in deep-sea capsules until needed, waking up when receiving their proper command signals and being deployed for operational support and situational awareness. As the program's name would infer, the weapons "fall upward" into the active theatre above the surface of the water.

According to Andy Coon, DARPA Program Manager, "The goal is to support the Navy with distributed technologies anywhere, anytime over large maritime areas. If we can do this rapidly, we can get close to the areas we need to affect, or become widely distributed without delay." Coon adds that "to make this work, we need to address technical challenges like extended survival of nodes after years of sleep, and efficient launch of payloads to the surface."



DARPA is currently seeking proposals for three key areas of the program: communications, the payloads, and deep ocean "risers" that will be used to contain the payloads (for more details, go to http://go.usa.gov/4Cjh). The government agency is hoping to draw from the expertise of the scientific community and industries involved with deep-ocean engineering (nearly one-half of the world's oceans are more than 4 km deep), the latter including the telecommunications and oil-exploration fields. The risers will feature ambient pressure containment, so no special pressurization will be needed for the payloads to accommodate the high pressures found in deep-sea locations.

DARPA hopes to receive proposals from a number of different technical communities, including those with expertise in unmanned platforms, electronic warfare (EW), information systems, distributed sensors and sensor packaging, and anti-submarine warfare. Payload systems are not intended as weapons, but expected to provide a range of non-lethal capabilities; these include situational awareness and networking, including small UAVs that could be launched to the ocean surface in small capsules. Coon notes: "We are simply offering an alternative path to realize these missions without requiring legacy ships and aircraft to launch the technology, and without growing the reach and complexity of unmanned platforms."

DARPA, Rockwell Seek Smaller GPS

Rockwell Collins (www.rockwellcollins.com) and DARPA have been collaborating on Global Positioning System (GPS) technology for close to 30 years, dating back to the former's early work with the US Air Force. The firm has developed more than 50 GPS products since then, delivering more than 1 million GPS receivers for commercial avionics and government applications. The company's most recent development is an all-digital miniature GPS receiver under DARPA contract, employing a microscale oscillator technology developed under the Dynamics-Enabled Frequency Sources (DEFYS) program (https://www.fbo.gov/spg/ODA/DARPA). One of the goals of the DEFYS program is to design miniature frequency sources capable of maintaining low phase noise over a wide temperature range and under conditions of high acceleration and vibration.

One of the application areas that will benefit from smaller GPS receivers is miniature unmanned area vehicles (UAVs). Rockwell Collins has been testing some of the oscillators resulting from the DEFYS program (initiated in 2009) on new, smaller GPS receivers. The DEFYS effort has yielded microscale oscillators nearly 30 times smaller than the sources currently employed in GPS receivers. These miniature oscillators also consume 320 times less power than the current generation of oscillators, and are 30 times more stable under high levels of vibration.

John Borghese, Vice President of the Rockwell Collins Advanced Technology Center, explains: "Never before has a microscale oscillator been able to acquire and track GPS. This capability opens a new frontier in embedding GPS in very small items and continues our commitment to provide precision position, navigation, and time solutions to newly identified and yet-to-be-imagined applications." In addition to GPS applications, these oscillators may find use in many other defense-related applications, including for precision munitions systems and portable radios.

CSAR Radio Receives Upgrade

The tactical radio for the US Air Force Air National Guard (ANG) HH-60G Combat Search and Rescue (CSAR) helicopter has been upgraded by Rockwell Collins (www.rockwellcollins.com) to the next-generation ARC-210 Gen5 radio. The Gen5 radio is based on a software-defined-radio (SDR) architecture with Software Communications Architecture (SCA) multiple-waveform security. It boasts a classified Ethernet data interface and extended frequency range to 941 MHz. The ARC-210 Gen5 radio is a form-and-fit replacement for the ARC-210 radios currently installed on more than 180 different platforms in 45 countries around the world.

Modifications on the CSAR helicopters were completed at the Rockwell Collins Aircraft Certification Center at the Eastern Iowa Airport (Cedar Rapids, IA). Modifications included installing four ARC-210 Gen5 receiver-transmitters on the CSAR helicopter **(see figure).** According to

The US Air Force ANG HH-60G CSAR helicopter now has an advanced, next-generation SDR-based tactical radio system.

Bob Haag, Vice President and General Manager of Communication and Navigation Products for Rockwell Collins, "with the addition of the next generation, modernized ARC-210 Gen5 radio, the HH-60G platform will have greater communication capabilities that will play a vital role in CSAR along with being ready for new IP-based networking waveforms and connectivity in the future."

JLENS Sensors See Surface Moving Targets

A recent demonstration sponsored by Raytheon (www.raytheon.com) showed that operates of the firm's Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS) can observe surface moving targets in real time. The demonstration featured a mock "terrorist" planting an improvised explosive device (IED). JLENS is an elevated over-the-horizon sensor system which can fly as high as 10,000 ft. and integrates radar electronics to detect and track a wide range of targets, including cruise missiles and UAVs. It can also provide ascent phase detection of tactical ballistic missiles and large-caliber rockets.

During the demonstration, a MTS-B Multi-Spectral Targeting System integrated on a JLENS was used to track multiple targets. The MTS-B relies on electro-optical/infrared (EO/IR) sensor technology to track targets, while the JLENS employs radar technology. Video from the MTS-B was passed through the aerostat's tether, enabling operators to watch live feed of trucks, trains, and cars from miles away. As part of the demonstration, operators also used the MTS-B's EO sensor to watch Raytheon employees simulate planting a roadside IED. By integrating the EO/IR payloads on the JLENS, both technologies were used to simultaneously provide information about potential threats and targets. Dave Gulla, Vice President of Global Integrated Sensors for Raytheon's Integrated Defense Systems business, remarks: "Integrating the proven MTS-B on JLENS makes JLENS multi-mission capable and enables the warfighter to better defend the battlespace and protect critical infrastructure and waterways."

Cyber Battleground Expected To Expand

Warfare techniques have changed dramatically with technology, and most studies point to cyberspace as the next great battleground. According to an analysis study by Visiongain (www.visiongain.com), the cyber warfare market will reach a level of $16.9 billion in 2013, with investments from different governments around the world to protect their computer networking capabilities from outside and internal networking threats. In addition, the firm's studies forecast that this cyber warfare market will grow continuously over the next decade.

The Visiongain report, which covers the market period from 2013 through 2023 (www.visiongain.com/Report/949/Global-Cyber-Warfare-Market-2013-2023) notes that the United States is the largest portion of this growing market, although countries in the Middle East represent an increasingly important segment of the market. The report describes the market projections in terms of US dollars. It contains 121 tables, charts, and graphs, provides profiles of 20 leading companies currently involved with cyber warfare, including interviews with experts at two leading companies: Lockheed Martin Corp. (www.lockheedmartin.com) and Symantec (www.symantec.com).

Mikros Helps Build Submarine Networks

As part of the Consolidated Afloat Networks and Enterprise Services (CANES) program, Northrop Grumman (www.northropgrumman.com) has selected Mikros Systems Corp. (www.mikrossystems.com) to assist in the design of wireless communications networks for US Navy submarines. Mikros, which has supported the installations of wireless networks aboard multiple US Navy ships, was chosen as a small-business partner for the Northrop Grumman CANES team.

Mikros President Tom Meaney remarks: "We are excited to work alongside the rest of the Northrop Grumman CANES team and provide dedicated, professional expertise in this area. We have worked closely over the years with the Navy's technical community to develop specific knowledge and software tailored to meet the unique demands of installing and operating wireless networks in shipboard environments." Mikros brings a great deal expertise to the CANES team, including communications engineering, radar systems engineering, and computer and intelligence engineering.

System Serves Vehicular Navigation

KVH Industries (www.kvh.com) has received two new orders for its TACNAV tactical navigation systems worth more than $7.2 million. The orders, from an international military customer, are expected to begin shipping late in 2013 and continue through 2015. TACNAV is a jam-proof vehicular navigation system that provides navigation, heading, and pointing data, and can also serve as a source of heading and positional information for situational awareness. The contract covers the firm's TACNAV II fiber-optic gyro navigation systems, which feature a compact design; continuous heading and pointing data output; and a flexible architecture that provide extremely accurate dead reckoning navigation, regardless of Global-Positioning-System (GPS) signal availability.

According to Dan Conway, Executive Vice President of KVH's Guidance and Stabilization Group, "KVH's TACNAV tactical navigation solution is an important tool for US and allied warfighters, providing precision navigation as well as coordination of vehicles in critical situations." He adds that "the system serves as a crucial resource for navigation and battle management and even as a backup in GPS-denied environments, keeping soldiers safe and out of harm's way wherever they travel. These new orders reaffirm the value of KVH's TACNAV products for international militaries, and add to our backlog for the coming years." The TACNAV vehicular navigation systems are currently in use by the US Army and Marine Corps, as well as many allied customers.

Block MEMS Detects Buried Explosives

The US Army's Joint Improvised Device Defeat Organization (JIEDDO) has awarded a multi-million-dollar contract to Block MEMS LLC (www.blockeng.com) to detect underground explosives, such as improvised explosive devices (IEDs). As part of the contract, Block MEMS will adapt its LaserScan™ spectrometer to electronically sift through suspicious sites, including recently dug-up roadside soil, in search of IEDs and other hazardous explosive threats.

The contract brings product development awards to the firm from the US Department of Defense (DoD) to more than $7.8 million. In support of the JIEDDO, the contract will be managed by the US Army's Night Vision and Electronics Sensors Directorate and the Sentel Corp. The LaserScan spectrometer employs tunable lasers and laser absorption spectroscopy to detect submicron films on the surfaces of materials, such as explosives, based on their infrared (IR) absorption characteristics.

"Buried IEDs have been a major cause of death to our troops at our theaters of operation," says Petros Kotidis, the firm's Chief Executive Officer. "Although techniques exist to find buried objects, these techniques can often be fooled. Our LaserScan will provide the soldier with another important tool to avoid triggering these IEDs.

"This new contract will enable us to miniaturize and ruggedize to military specs the LaserScan so it can be used by dismounted soldiers," Kotidis continues. "Eventually this product will also be mounted on ground vehicles, including small robots, to aid route clearance operations and protect military convoys."

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WILLIAM WONG
EMBEDDED/SYSTEMS/
SOFTWARE TECHNOLOGY EDITOR

Cyber Warfare Affects All Aspects Of Design

Although attacks against computers and software seem more prevalent in sensitive industries such as banking, cyber warfare can be just as dangerous to the military.

The term "cyber warfare" may suggest virtual worlds like those depicted in movies like *Tron*, or the "fire sale" in *Live Free or Die Hard*. But while these fantasy renditions are far from reality, actual cyber warfare is no less fantastic. Indeed, it is a very real concern…and one very important to those in the Armed Forces. One only needs to look at the plethora of viruses and worms in the wild, and the extent of antivirus industry, to understand the extent of the ongoing cyber war. Connectivity and the Internet has changed the scope of the discussion.

In the military there is a well-known saying: "Tactics wins battles, but logistics wins wars." This is just as true for cyber warfare, where computer security is paramount, as in a physical battle. These days the virtual and real worlds overlap, because every major system employed by the military (short of a knife) incorporates or is related to a computer—from night-vision scopes to fly-by-wire aircraft. In the past, many systems were physically isolated, allowing physical defenses to be employed for protection of a system. But the push for connectivity in the modern military is extreme. It allows pilots of unmanned aerial vehicles (UAVs) to be located on the far side of the planet from their aircraft (**see figure**).

It is important that the low-level tactics of cyber warfare—like multiple independent levels of security (MILS) and computer viruses—do not overwhelm the strategic aspects. The challenge is that cyber warfare needs to address not only defense, but offense as well. To quote Sun Tzu in *The Art of War*: "In battle, there are not more than two methods of attack—the direct and the indirect; yet these two in combination give rise to an endless series of maneuvers." That tends to be almost an understatement when it comes to computer-based attack and defense. Combine this with the fact that the computers involved may directly or indirectly control weapons, men, and material, and the effect it can have on a fighting force can be significant.

The challenge for a country like the United States is the breadth of technology involved. The US Department of Homeland Security (DHS; www.dhs.gov) has an Office of Cybersecurity and Communications (http://www.dhs.gov/office-cybersecurity-and-communications), but this targets only one aspect of the discussion, and it favors preventive measures. More covert civilian work is commissioned by US government groups like the Central Intelligence Agency (CIA; www.cia.gov) and the National Security Agency (NSA; www.nsa.gov).

The US Strategic Command (STRATCOM; www.stratcom.mil) and its Cyber Command oversees cyber security for the US Army, Navy, Air Force, and Marines. This includes the US Navy's Fleet Cyber Command (http://www.fcc.navy.mil/), the 24th Air Force (http://www.24af.af.mil/units/index.asp), the US 2nd Army's Cyber Command (http://www.arcyber.army.mil/index.html), and the Marine Corps' Cyber Command. These groups are tasked

The push for connectivity in the modern military is extreme. To give but one example, it allows pilots of unmanned aerial vehicles (UAVs) to be located on the far side of the planet from their aircraft.

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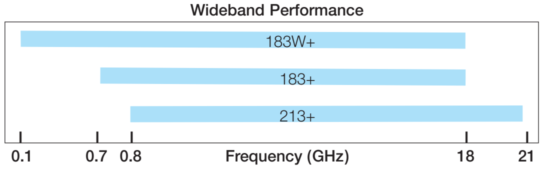

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In the military there is a well-known saying: "Tactics win battles, but logistics win wars." This is just as true for cyber warfare, where computer security is paramount.

with network defense, as well as attack and exploitation of enemy systems. They even participate in joint training exercises—among them Cyber Flag, conducted at the Air Force's Red Flag Facility at Nellis Air Force Base, Nevada. The competition was virtual, but the prospect of a group penetrating the opposition's network—gaining access to a wide range of command and control—is all too real.

The tools of the trade are well known but not heavily publicized, unlike some high profile military ventures. This is true for military intelligence in general, which means most—even in the electronics industry—will be unaware of the detailed tactics or strategy being employed. The work also tends to be more far reaching, from tracking of personal data and social networks to control of digital litter and digital devices. Much of this can be done remotely and in front of a computer screen, but the importance of field work should not be discounted. Device designers need to be aware of both the technology and techniques.

Computer attacks on soft targets, like bank websites, are highly publicized and affect thousands (or even millions) of customers. That same kind of publicity occasionally occurs in other areas, although often the culprit remains anonymous. The Stuxnet computer worm is a good example: This malware spreads through computers running the Microsoft Windows operating system (OS) and targets Siemens supervisory control and data acquisition (SCADA) systems. It includes a programmable-logic-controller (PLC) root kit, designed to hide the attack. Stuxnet's potential target was Iran's nuclear research facilities, which utilized SCADA.

Unlike a typical computer virus or worm, Stuxnet uses a multilevel approach. It first attacks a Windows system, typically via a Universal-Serial-Bus (USB) key or, alternately, through a network using a number of zero-day exploits, including those based on device drivers signed using stolen digital key certificates. Root kit technology hides Stuxnet on the Windows machine, but the eventual target is a Windows system with SCADA control software.

The Stuxnet payload is very specific because it is looking for a variable frequency drive control operating between 807 and 1210 Hz. That is just what one needs for a gas centrifuge. Siemens released a detection and removal tool, but that is just part of the story. Flame, a new worm, has been found in 2012. Flame and Stuxnet highlight why the defense-in-depth approach is needed. Intrusion detection systems (IPS) and antivirus software are important parts of this, but a multilayer system needs to address this issue at all layers.

On the plus side for defenders, the common toolset is becoming more security friendly. UEFI and secure boot are being utilized on consumer platforms, making them more readily available to designers. They are found in commercial-off-theshelf (COTS) systems, negating the need for custom hardware. Likewise, encrypted hard drives and other hardware are making the designer's job significantly easier. They are not the be-all, end-all solution but, rather, one part of a much larger approach that can be eventually managed with a high-level strategy.

Embedded developers need to maintain awareness, and utilize newer technologies (e.g., IPv6 and DNSCrypt) that are more resistant to attacks. IPv6 is more robust than the more common IPv4 in security as well as other aspects of its design. The open source DNSCrypt provided by OpenDNS (http://www.opendns.com) works to protect the domain name service that is critical to the Internet, as well as most networked embedded devices. This means that protocol stacks must support these types of technologies, and developers need to utilize them in more than just their default configurations. As any security expert will warn, all the links in the defense change need to exist and work properly, or else most (if not all) of the system can fall apart.

Expect to see more government work in this area, as well as the rise of "digital privateering." These privateers are crackers for hire by governments and other organizations. Attacks or creation of attack technology is just one of the possible services these groups might offer. One reason for this is cyber attacks are more of an art because of how quickly technology changes and how arcane the gaps in a defense may be. Much of this expertise is limited to a few individuals.

Currently, cyber warfare exists in the form of a cold war, but goverments and military organizations are expected to become much more active in 2013 moving forward in building up their cyber arsenals. The US government is fully aware of the potential harm that could come from a cyber attack on a critical target, such as a nuclear power plant or a water-treatment facility. Unfortunately, the US Congress tends to move slowly concerning the defense of what it perceives as more of an imaginary threat than a real one. Cyber warfare may be a computer-generated threat, but it has the capability to cost lives if proper defenses are not installed, especially if an attack takes place against such a critical target as a nuclear power plant.

Cyber warfare may seem like an esoteric issue for many designers working in defense electronics but, like security in general, it is an aspect of designing electronic systems that must be incorporated from the start in order to be efective. Strategy can only take advantage of tactics that are possible. The low profile of cyber warfare may make it difficult as sequestration takes hold and groups work to minimize the effect of defense spending cuts. DE

JACK BROWNE
TECHNICAL CONTRIBUTOR

STARnet Invests In Electronic Evolution

ThE DARPA program will invest more than $40 million each year in major universities to help with the evolution of various electronic technologies.

The Defense Advanced Research Projects Agency (DARPA; www.darpa.mil), working with key companies and academic organizations, is hoping to guide the evolution of electronics. This combination of DARPA and other team members will be fueled by at least $40 million each year in basic research funding, establishing the Semiconductor Technology Advanced Research Network (STARnet).

DARPA Program Manager Jeffrey Rogers notes: "STARnet is composed of six collaborating multi-university teams taking a fresh look at the challenges we face, to find those ideas that will drive innovation for the next several decades. Each of these six centers is composed of several university teams jointly working toward a single goal: knocking down the barriers that limit the future of electronics. With such an ambitious task, we have implemented a nonstandard approach. Instead of several different universities competing against each other for a single contract, we now have large teams working collaboratively—each contributing their own piece toward a large end goal."

These six academic teams are comprised of the following centers: the Function Accelerated Nanomaterial Engineering (FAME); the Center for Spintronic Materials, Interfaces, and Novel Architectures (C_SPIN); Systems on Nanoscale Information Fabrics (SONIC); the Center for Low Energy Systems Technology (LEAST); the Center for Future Architectures Research (C-FAR); and the TerraSwarm Research Center (TerraSwarm).

The FAME center will be tasked with pursuing nonconventional materials and devices incorporating nanostructures with quantum-level properties to enable analog, logic, and memory devices for beyond-binary computation. It is hosted at the University of California, Los Angeles, with the Massachusetts Institute of Technology (MIT); Yale, Cornell, Purdue, Rice, and North Carolina State Universities; and several other California institutions as collaborators.

The C_SPIN center will explore electron spin-based memory and computation with the potential to overcome the power, performance, and architectural constraints of conventional CMOS-based devices. It will be hosted at the University of Minnesota with such collaborators as Cornell, MIT, the University of Michigan, and Johns Hopkins University.

The SONIC center will pursue different models in computation and communications, with target applications including image processing and communications that do not require 100% error-free computation. The SONIC research will be hosted at the University of Illinois, Urbana Champaign with collaborators that include Stanford, Princeton, Carnegie Mellon, and Oregon State Universities.

The LEAST center will have low-power electronics as its mission, examining quantum-engineered devices and nonconventional materials as means for achieving new forms of low-power electronic devices and systems. LEAST is hosted at Notre Dame University, with collaborators that include Carnegie Mellon and Penn State, in addition to the Georgia Institute of Technology (Georgia Tech); Purdue University; and the Universities of California, Berkeley, San Diego, and Santa Barbara.

The C-FAR center will investigate highly parallel computing implemented in nonconventional computing systems, based on current CMOS integrated circuit technology. It is based at the University of Michigan with collaborators that include Harvard and Duke Universities, MIT, and Georgia Tech.

Finally, the TerraSwarm center will attempt to develop technologies that provide city-scale capabilities via the deployment of distributed applications during disasters. The TerraSwarm center will be hosted at the University of California, Berkeley with collaborators that include the California Institute of Technology (Cal Tech) and the University of Washington. DE

DARPA SEEKS SDR IMPROVEMENTS

DARPA has long been involved in improving the security of radio communications, and the organization's Spectrum Challenge program (www.darpa.mil/spectrumchallenge) offers new challenges for companies in 2013. It is a competition for involved teams to create software-defined-radio (SDR) protocols that work effectively in the presence of other users and interference. The Spectrum Challenge is not focused on developing new radio hardware, but instead is targeted at finding strategies for guaranteeing successful communication in the presence of other radios. The team that finds the best strategies for guaranteeing successful communications in the presence of other competing radios and interference stands to earn as much as $150,000.

Dr. Yiftach Eisenberg, DARPA Program Manager, explains: "The Spectrum Challenge is focused on developing new techniques for assured communications in dynamic environments—a necessity for military and first-responder missions. We have created a head-to-head competition to see who can transmit a set of data from one radio to another the most effectively and efficiently, while being bombarded by interference and competing signals." The competition is open to any US academic institution, business, or individual.

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• ZHL-100W-GAN+	20-500	42	79	100	2395	2320
• ZHL-50W-52	50-500	50	40	63	1395	1320
• ZHL-100W-52	50-500	50	63	79	1995	1920
LZY-1+	20-512	43	37	50	1995	1895
• ZHL-20W-13+	20-1000	50	13	20	1395	1320
• ZHL-20W-13SW+	20-1000	50	13	20	1445	1370
LZY-2+	500-1000	46	32	38	1995	1895
NEW ZHL-100W-13+	800-1000	50	79	100	2195	2095
ZHL-5W-2G+	800-2000	45	5	6	995	945
ZHL-10W-2G	800-2000	43	10	13	1295	1220
ZHL-30W-252+	700-2500	50	25	40	2995	2920
ZHL-30W-262+	2300-2550	50	20	32	1995	1920
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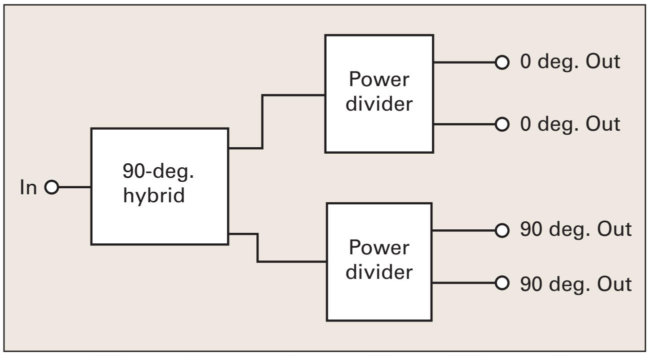
Balancing Needs For Beamforming Networks

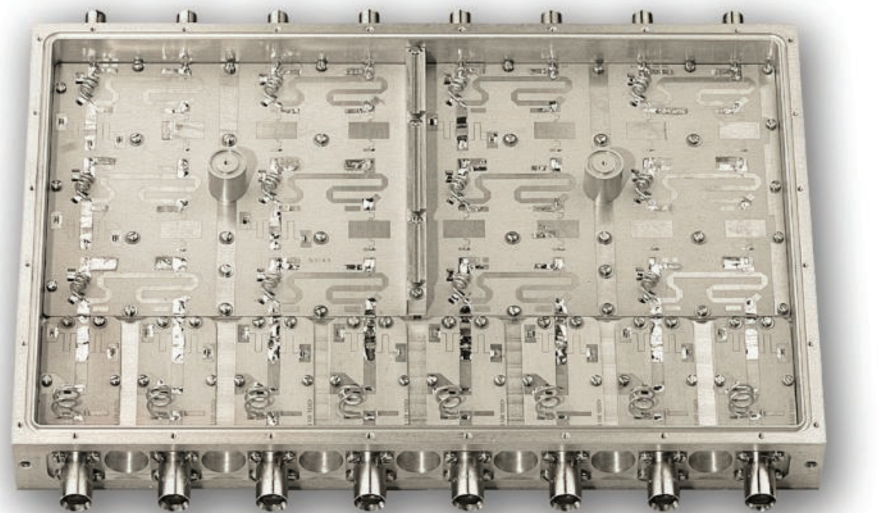
Passive beamforming networks are compact multiple-component assemblies that provide a way to move an antenna's beam in space, without having to move the antenna itself.

Beamforming networks are commonly employed in both commercial and military systems, and are used in ground, airborne, and space-based applications. They are ideal for controlling multiple antennas in a system, such as a phased-array radar antenna. They make use of the ease and reliability of electronic steering in numerous systems—including fourth-generation (4G) cellular, direction-finding (DF), signal-intelligence (SIGINT), and electronic-intelligence (ELINT) systems—as an alternative to mechanical steering. Although beamforming networks can sometimes suffer drops in gain under certain steering conditions, they generally offer much longer and reliable operating lifetimes than mechanically steerable antenna arrays. Providing reliable and repeatable beamforming networks still relies on proven and consistent manufacturing and testing capabilities.

A beamforming network makes it possible to electronically steer a system's antenna beams without mechanically shifting the antenna. A passive beamforming network is typically formed of passive RF/microwave components, such as power combiners/dividers and phase shifters, to provide the required phase and amplitude characteristics for the signal energy between the system antenna and the system's transceivers. Passive beamforming networks, which are fabricated with traditional circuit technologies [such as microstrip, stripline, and coplanar-waveguide (CPW) transmission lines], can be placed close to an antenna or even integrated within the antenna. Newer design approaches are also including advanced circuit techniques, such as substrate-integrated-waveguide (SiW) circuits, in attempts to miniaturize passive beamforming networks for a given frequency range.



1. This schematic diagram shows a simple 1 x 4 beamforming network.



2. This is a commercial 8 x 8 beamforming network designed to operate within two frequency bands from 1025 to 1095 MHz. [Photo courtesy of TRM Microwave (www.trmmicrowave.com).]

Beamforming networks perform vector manipulation on two or more input signals to generate the same number of processed output signals. The output signals are fed to an antenna array to produce the three-dimensional antenna beams that might otherwise result from physically moving or steering the antennas. In essence, the beams are being steered rather than the antennas. Beamforming networks make use of the reciprocal nature of antennas, and support both transmit and receive functions. In some systems, received signals may be frequency downconverted to intermediate-frequency (IF) signals before being applied to a beamforming network.

Antenna beamforming is accomplished by adjusting the amplitudes and phases of the signals for the different elements found in an antenna array. Rather than moving the antenna to move the beam,

the amplitude and phases of the elements are varied to move the antenna beam. These element feeds are shifted electronically so that the antenna's main beam and its sidelobe levels are effectively controlled, and its beams are steered.

Beamforming networks have the advantage over a mechanically steered antenna of producing multiple beams simultaneously. This gives the system engineer more flexible signal processing options. A fixed passive beamforming network can produce several beams simultaneously, all performed for a fraction of the cost of a traditional fully electronically scanned beamformer. Passive beamforming offers an effective bridge between price and performance.

Passive beamforming networks, which are fabricated with traditional circuit technologies, can be placed closed to or even integrated within the antenna.

The passive components used in the beamforming network, such as power dividers/combiners and phase shifters, must be manufactured to tight and repeatable mechanical tolerances. Such tolerances, and their electrical performance, can be checked with the aid of proper high-frequency test equipment—including RF/microwave vector network analyzers (VNAs)—and by analysis of their S-parameters. Companies such as TRM Microwave (www.trmmicrowave.com) design and manufacture beamforming networks in compact housings, achieved by combining many of the required passive components into a single integrated microwave assembly (IMA).

To understand the operation of a beamforming network, **Fig. 1** shows the schematic diagram of a simple 1 x 4 beamformer that can be formed with a pair of power dividers and a 90-deg. hybrid. As the relationship of the input port to the output ports shows, the network generates pairs of in-phase (I) and quadrature (Q) outputs from a single input signal. The circuit is simple enough to manufacture to excellent mechanical tolerances and can be designed for surface-mount housings or for a package with coaxial connectors.

A Butler matrix is a more complex form of beamforming network, typically with 4, 8, or 16 inputs and the same number of outputs with high isolation among them. It is a passive reciprocal network which works in a similar fashion whether transmitting or receiving. A simple 4 x 4 Butler matrix can be assembled with quadrature couplers or a combination of

180- and 90-deg. hybrids; in each case, the amount of phase shift achieved at the output ports depends on which input port is sampled (in the present example, four separate antenna patterns are generated simultaneously).

The progressive phase shifts at the output ports can be used to create an antenna beam or radiation pattern, depending on the phase shifts and which input is used. Quadrature couplers and hybrid junctions are passive components that can be designed and manufactured with fairly broad bandwidths, high isolation between ports, and relatively low loss in the signals, above the normal reduction in power levels suffered as a result of signal divisions.

For example, a 4 x 4 Butler matrix built from four quadrature couplers (along with their 90-deg. phase offsets) and appropriate phase shifters can generate four output signals at 45-deg. phase offset increments with one port used as the input, 135-deg. phase offset increments with another port as the input, 270-deg. phase offset increments with the third possible input port used as the active input, and 315-deg. phase offset increments with the fourth input. The relationship of the amplitudes from input to output can also be adjusted, with the design of a Butler matrix targeting the use of such passive components as couplers, hybrids, and phase shifters for a specific center frequency and bandwidth.

Model BM88701 is an 8 x 8 beamforming network constructed from 180-deg. hybrids and coaxial lines (**Fig. 2**). It achieves fixed phase delays and operates within two specific frequency bands from 1025 to 1095 MHz with excellent electrical performance. It can handle 8 W average power and as much as 400 W peak power and exhibits input and output VSWR of 1.30:1. Using proven passive components, the 8 x 8 beamforming network suffers insertion loss of only 1 dB or less (above its nominal power division) and provides at least 18-dB isolation between ports.

The performance of a beamforming network is usually dictated by its application in particular, the antenna array or system with which it will be used. A number of different passive RF/microwave design topologies are available when considering a beamforming network for a particular application. Manufacturers such as TRM Microwave will rely on appropriate circuit materials and transmission-line approaches—including suspended stripline, stripline, airstrip, and microstrip technologies—to meet a customer's requirements for mechanical layout, size, weight, and electrical performance. **DE**

Editor's Note: This article is based on a more detailed white paper from TRM Microwave. To receive a free copy, complete the request form at www.trmmicrowave.com/request-white-paper.

JACK BROWNE / TECHNICAL CONTRIBUTOR

Strive To Improve Spectral Measurements

Modern spectrum analyzers offer enormous functionality and capability for capturing and displaying the many types of RF/microwave signals used in defense-electronics systems.

Spectrum analyzers are among the most essential of RF/microwave instruments, showing in the frequency domain what a high-speed oscilloscope might show in the time domain. Spectral measurements can reveal a great deal about the performance of a system and its components, provided that those measurements are performed realistically and with a proper understanding of a spectrum analyzer's capabilities and limitations. As an aid to spectrum-analyzer owners—and for those considering the addition of a spectrum analyzer to their instrument arsenal—Agilent Technologies (www.agilent.com) recently made a free 12-page application note (No. 1286-1; "8 Hints for Better Spectrum Analysis") available on its website. Those hints, combined with solid fundamental knowledge of a spectrum analyzer's key performance parameters, can help make the most of spectrum analyzer measurements whether in the field or in the laboratory.

Modern spectrum analyzers are available with a wide range of analog and digital signal-processing functions across frequency ranges extending from the high-frequency (HF) range through millimeter-wave frequencies. The N9010A EXA signal analyzers from Agilent Technologies, for example, are available with a number of different frequency-range options, with the broadest-frequency model spanning 10 Hz to 44 GHz (**see figure**). Spectrum analyzers provide their operator with a number of different adjustments that can impact the accuracy and reliability of a measurement, including resolution-bandwidth (RBW) filters, sweep times, input attenuation, and even preamplifier and intermediate-frequency (IF) amplifier gain.

Signal analyzers in the N9010A EXA series offer tremendous capability and numerous options, with the broadest-frequency model spanning 10 Hz to 44 GHz. [Photo courtesy of Agilent Technologies (www.agilent.com).]

The N9010A EXA analyzers have RBW filters with 3-dB bandwidths as narrow as 1 Hz to as wide as 3 MHz. The selection of the filter depends on the type of signal under study and the frequency span occupied by the signal. Sweep times for frequency spans greater than 10 Hz can be set from 1 ms to 4000 s, while sweep times for zero (0-Hz) spans are adjustable from 1 μs to 6000 s. The EXA signal analyzers offer an input attenuation range of 0 to 60 dB in 10-dB steps in standard instruments, and the same 0-to-60-dB attenuation range in 2-dB steps as an option. At the lower end of their dynamic range, the N9010A EXA signal analyzers achieve a typical displayed average noise level (DANL) of −140 dBm or better with high IF amplifier gain and 0-dB input attenuation, and the DANL can be dropped to −160 dBm by using a preamplifier with high gain.

By adjusting a spectrum or signal analyzer's settings, such as the RBW filters, the measurement accuracy can be optimized. A narrow RBW filter can make it possible to display low-level signals at the expense of sweep speed. But if the RBW filters are too narrow, sideband information for signals with wideband modulation can be lost. Wider RBW settings yield faster sweep speeds for a given spectrum analyzer, but narrower RBW filters lower the DANL, improving the signal sensitivity of the analyzer and expanding its dynamic range. If noise may be possibly obscuring the measurement of a signal, switching to a narrower RBW filter will lower the noise floor and better extract the signal from the noise.

Changing a RBW filter can impact the measurement accuracy of a spectrum analyzer, depending upon the quality of an instrument. In better-quality analyzers, amplitude uncertainty will be consistent across the different filter bandwidths, but variations can exist for different filter bandwidths in lower-cost analyzers. Additional passive components in a test setup, such as coaxial cables and external filters, can also influence the measurement accuracy of a spectrum analyzer. Any amplitude errors that are introduced in a test setup (due to coaxial cables and other passive components) can be cancelled with the aid of an analyzer's built-in amplitude correction function, along with an external test signal source and a power meter. Most newer spectrum analyzers allow a user to store the amplitude response of different passive components and measurement setups so that calibration is not necessary every time that test setup is used.

When measuring low-level signals with a spectrum analyzer, any noise generated within the analyzer will limit its capability to detect and measure small signals. The instrument's low-level sensitivity and DANL can be improved by minimizing the input attenuation, using the narrowest RBW filter practical, and using a low-noise preamplifier with suitable frequency range. By using a preamplifier with low noise figure and adequate gain, the measurement sensitivity of the analyzer can be improved. If the gain of the preamplifier is sufficiently high, the noise floor of the analyzer/amplifier combination will be determined by the noise figure of the preamplifier.

Spectrum analyzers are often called upon to measure distortion, and distinguishing distortion products from fundamental-frequency signals can sometimes pose measurement challenges. The analyzer's dynamic range indicates the maximum separation that the instrument can distinguish between signal and distortion or signal and noise. Any improvement in dynamic range is a matter of switching to a narrower RBW filter, albeit with some sacrifice in sweep speed. Measuring a low phase noise for a test signal, for example, may require setting a narrow RBW filter width, such as the use of a 1-kHz RBW filter. The compromise in using such a filter will be the limit in sweep speed.

For measurements of transient signals, the spectrum analyzer's sweep speed is critical and the instrument parameters that impact sweep speed must be adjusted accordingly. The setting of the RBW filter will largely dictate the spectrum analyzer's sweep time. Narrower RBW filters typically require longer sweep times, which translate into a tradeoff between sweep speed and sensitivity. For example, a ten times change in RBW on a modern spectrum analyzer can translate to an approximate 10-dB improvement in sensitivity. By switching to narrower RBW filters, the measurement sensitivity for continuous-wave (CW), as well as for transient signals, can be dramatically improved.

Newer spectrum analyzers may offer Fast Fourier Transform (FFT) functions that provide a good balance between sweep speed and sensitivity. When using FFT analysis, the sweep time is dictated by the frequency span rather than the setting of the RBW filter. Using a spectrum analyzer's FFT mode, where available, can significantly speed measurements of relatively narrow spans (such as 20 MHz).

Modern spectrum analyzers are available with a wide range of analog and digital signal-processing functions spanning frequency ranges.

Spectrum analyzers function with a number of different display detection modes and, depending upon the type of signals to be analyzed, the choice of mode can have a bearing on the accuracy of the measurement. Following an analyzer's input RF/microwave circuitry, with downconversion mixers, input signals are digitized by means of a high-speed analog-to-digital converter (ADC) at either the IF stage following the mixer or following the spectrum analyzer's video filtering. The analyzer's display is driven by this digitized data, and the choice of which portion is emphasized on the instrument's display depends on the display detector following the ADC. Display detectors include positive peak, negative peak, and sample detectors.

As the Agilent application note states, these data are considered to fall within a "bucket," and the detectors work with the data within each bucket. A sample detector uses data within the center of the bucket to feed the analyzer display. As a result, sample detection mode is effective for showing noise, but not as accurate when displaying CW signals with narrow RBWs, and can miss portions of such signals. Positive peak detection, which is effective for CW signals, displays the highest-power portion of the data bucket. Negative peak detection, which is good for signals with amplitude modulation (AM) or frequency modulation (FM), shows data from the lowest-power part of the bucket.

Some spectrum analyzers include a detection mode known simply as "normal" detection, which is a sampling mode in which inputs are dynamically classified as either signals or noise. Such a detection approach will not miss signals or portions of signals in the manner of conventional sample detection, and can provide a better visual display of random noise when using peak detection mode on the spectrum analyzer.

Spectrum analyzers that offer average detection can show signals based on their average power or voltage levels. This type of detection can be useful for measuring the power levels of complex signals, in which their power is time varying, or for electromagnetic-interference (EMI) testing, where voltage levels can vary over time. In general, average detection is effective for analysis of a wide range of modulated signals, such as pulse-modulated signals in radar systems or signals with AM.

The Agilent application note provides clear details on eight different measurement scenarios with a spectrum analyzer and can be instructive even for regular users of these instruments. RF/microwave signals used in modern communications, radar, and electronic-warfare (EW) systems are increasingly complex, using time gating to vary the information carried by a transmitted signal from moment to moment. Understanding some of the measurement capabilities of a modern RF/microwave spectrum analyzer can at least reduce the time required to capture these signals, and can contribute a great deal toward improving the accuracy of those measurements. DE

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Backhaul Solutions Earn DoD's UC APL

These rugged N-way power dividers/combiners have been designed to handle the most challenging environments, all the while delivering reliable electrical performance through 500 MHz.

Microwave backhaul systems such as the PTP 600 series of wireless Ethernet bridges from Cambium Networks Ltd. (www.cambiumnetworks.com) are invaluable for both licensed and unlicensed links. Designed for licensed use in the 2.5-, 4.5-, and 4.9-GHz bands (with license holders such as NATO) and unlicensed use in the 5.4-, 5.8, and 5.9-GHz bands, these point-to-point (P2P) systems support data rates to 300 Mb/s at distances to 124 miles.

2. At higher frequencies the PTP 800 outdoor radio unit, indoor RF unit, and compact modem work to provide secure backhaul communications.

Of particular significance to secure communications, the PTP series of links are especially well suited for Department of Defense (DoD) applications; they have gone through a two-year development and testing program, met and exceeded Unified Capabilities Certification Office (UCCO) certification, and earned a place on the official DoD Unified Capabilities Approved Products List (UC APL). In fact, the PTP 600 system is the first and only UC-APL-certified microwave backhaul solution for use by the DoD. It provides reliable communications for any number of government and law-enforcement agencies requiring the reassurance of a secure solution.

1. The PTP 600 wireless backhaul radios are available as integrated modules and compact units with connectors.his is a caption

PTP 600 Series radios (**Fig. 1**) are wireless Ethernet bridges encased in ruggedized, commercial-grade metal housings. Their primary purpose is to provide secure Internet Protocol (IP) data, voice, and video communications, even in non-line-of-sight (NLOS) environments, over water and desert terrain, and in extreme weather conditions.

Because Cambium Networks (formerly a division of Motorola Solutions) had deployed thousands of radios throughout the DoD since 2004, PTP 600 radios had become the predominant backhaul choice for DoD and numerous federal agencies. In addition to good NLOS performance in the 4- and 5-GHz bands, these backhaul systems feature small, simple form factors, high system gain of 167 to 199 dB, and orthogonal-frequency-division-multiplex (OFDM) capability with 1024 subcarriers. They are wind tested to 202 mph for durability and have received IP 66/67 certification. In addition, PTP 600 Series radios have a built-in spectrum analyzer with dynamic spectrum optimization to ensure reliable radio performance.

The DoD's UC APL is established in accordance with the UC's requirements document, UCR 2008, Change 3, which is available at the agency's website (www.disa.mil/ucco/). The purpose of the UC APL is to establish a single list of products that have Interoperability (IO) and Information Assurance (IA) certification. The DoD's UC APL helps to simplify the design and maintenance of DoD network infrastructure equipment. The UC APL is the only listing of equipment by the DoD to be fielded in DoD networks.

DoD network systems must be sup-

Table 1: FIPS 140-2 security-level specifications.

Cambium PTP 600 security-level compliance	
Security requirements section	**FIPS 140-2 Level**
Cryptographic module specification	3
Module ports and interfaces	2
Roles, services, and authentication	3
Finite state model	2
Physical security	2
Operational environment	NA
Cryptographic key management	2
EMI/EMC	2
Self-tests	2
Design assurance	3
Mitigation of other attacks	NA

3. Anti-tamper labels are strategically located on a PTP 600 module with connectors.

ported by purchasing APL products, provided that a product on the list meets the system's requirements. This means the APL must be consulted prior to purchasing a system or product.

The UCCO serves as the staff element for the NS2 Capabilities Center to manage acquisition of products from the UC APL. The UCC provides process guidance, coordination, information, and support to vendors and government sponsors throughout the entire process, from the registration phase to the attainment of DoD UC APL status. The UCCO also manages the APL End of Life (EOL) List (available on www.disa.mil/services), which consists of products that have been removed from the DoD's UC APL. As NS2 moves towards a distributed testing environment, the UCCO will be the primary point of contact (POC) for scheduling and coordination of partnering Testing Centers of Excellence locations.

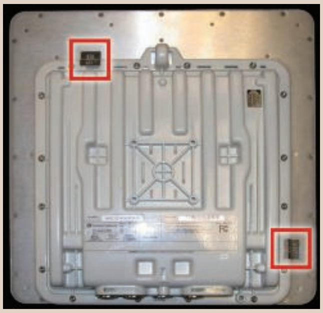
Products to be considered for UC APL certification require sponsorship by a DoD program. The UC APL certification also requires that the products receive Federal Information Processing Standards (FIPS) 140-2 Level 2 regulatory requirements for cryptographic algorithms. DoD organizations and many Federal agencies require FIPS 140-2 validation to secure sensitive data, voice, and video communications. Because PTP 600 systems are deployed by so many DoD groups, the Installation Information Infrastructure Modernization Program (I3MP) sponsored the PTP 600 and confirmed that it was worthy of APL consideration.

With I3MP's sponsorship, Cambium began multi-faceted testing efforts in 2009 and completed the process in 2011. Tests for all UC APL requirements were performed in Cambium's core development center, which is equipped and staffed for RF/microwave testing as well as network, intrusion, and vulnerability testing. FIPS 140 testing and validation was completed first, involving cryptographic algorithm evaluation via the National Institute for Standards and Technology (NIST) Cryptographic Algorithm Validation Program (CMVP), independent source code inspection by a NIST-certified test house, and extensive cryptographic self tests. **Table 1** shows the compliance levels validated during the FIPS 140 testing process.

After receiving I3MP sponsorship and FIPS 140-2 valida-

Table 2: FIPS 140-2 validated security standards for the PTP 600.

FIPS 140-2 validated security standards for the PTP 600			
Security standard	**Requirement**	**Operational environment**	**Validation description**
Secure hash standard (SHS)	SHA hashing functions conform to the secure hash algorithms as specified in FIPS 180-3	T1 C6414 DSP	Validation No. 1101
Digital signature algorithm (DSA)	DSA conforms to the digital signature algorithm as specified in FIPS 186-2 and FIPS 186-3	T1 C6414 DSP	Validation No. 399
Advanced encryption standard (AES) algorithm	AES conforms to the AES algorithm as specified in FIPS 197	VRTX 2	Validation No. 708 – wireless link encryption (Firmware) CFB128 (e only; 128, 192, 256)
		T1 C6414 DSP	Validation No. 1144 –TLS/ SNMP payload encryption (Firmware) ECB (e/d; 128, 192, 256) CBC (e/d; 128, 192, 256) CTR (ext only; 128, 192, 256
Keyed-hash message authentication code (HMAC)	Conforms to HMAC as specified in FIPS Publication 198	T1 C6414 DSP	Validation No. 700 (Firmware) HMAC-SHA1 (Key Sizes Ranges Tested: KS = BS) SHS Validation No.1101
Deterministic random bit generator (DRBG) Algorithm	Conforms to DRBG algorithm as specified in Special Publication 800-90, recommendation for random number generation using deterministic random bit generators	T1 C6414 DSP	Validation No. 21 (Firmware) CTR_DRBG: Prediction Resistance Tested: Not Enabled BlockCipher_Use_df: AES-128 AES Validation No.1144
Triple data encryption algorithm (DES)	Conforms to triple DES algorithm as specified in FIPS Publication 46-3, data encryption standard	T1 C6414 DSP	Validation No. 863 (Firmware) TCBC (e/d; KO 1,2) TCBCI (e/d; KO 1,2)



4. This PTP 600 integrated module shows the location of its anti-tamper labels.

tion for the PTP 600, Cambium received the Security Technical Implementation Guides (STIGs) which formed the DoD's Joint Interoperability Test Command (JITC) test specifications for UC APL certification. Thousands of STIG requirements had to be analyzed, tested, and certified as compliant with the DoD's strict IA and IO specifications.

By being validated to FIPS 140-2 Security Level 2 specifications,[1] operators are assured of the security of their information. Security Level 1 is the minimum requirement for UC APL certification. It requires that at least one Approved security function must be implemented in an Approved mode of operation but does not provide protection of Critical Security Parameters (CSPs) used or generated by the module. Level 1 allows the software components of a cryptographic module to be executed on a general-purpose computing system using an unevaluated operating system. No specific physical security mechanisms are required. FIPS 140-2 Security Level 2 enhances the physical security mechanisms of a Level 1 cryptographic module by adding the requirement for tamper evidence, including the use of tamper-evident coatings or seals, or for pick-resistant locks on removable module covers or doors. Tamper-evident coatings or seals are placed on a cryptographic module so that the coating or seal must be broken to attain physical access to the CSPs within the module.

Level 2 also requires role-based authentication in which a cryptographic module authenticates and verifies the authorization of an operator to assume a specific role and to perform a corresponding set of services. This protects against unauthorized execution, modification, and reading of cryptographic software.

Achieving FIPS 140-2 also requires testing and gaining approval for six key algorithms. Each algorithm must be subjected to thousands of cryptographic tests on the target platform. Test results for the PTP 600 system were submitted to InfoGard/NIST for validation, with details for those approved algorithms for the PTP 600 system shown in **Table 2**. In addition to the PTP 600 systems, Cambium's higher-frequency Ethernet-based PTP 800 Wireless Licensed Microwave solutions (**Fig. 2**) are also FIPS 140-2 validated.[2] The PTP 800 systems operate in frequency bands from 6 to 38 GHz, for applications where licensed exclusivity is

desired, can be deployed with full confidence that sensitive communications will be secure.

For additional protection, the PTP 600 systems meet key security validation requirements. The key-of-keys is stored as a 128/256-b Advanced Encryption Standard (AES) key and is read during the initialization procedure. The key of keys can be configured or erased only by a user with the security officer role.

The systems must also meet rigorous requirements for exposing any evidence of tampering. The cryptographic boundary of each wireless unit is the PTP 600's external casing. There are two product variants that have different casing arrangements. The integrated unit has an integrated RF antenna. A model with connectors is identical to the integrated version, except that the antenna is replaced by a metal plate with two N-type RF connectors for an external antenna.

Anti-tamper labels are installed on the metal cases to allow the modules to operate in a FIPS-approved mode of operation. Tamper-evident labels must go through rigorous testing at a NIST-approved lab before being declared fit for DoD purposes. Each PTP 600 radio is delivered with anti-tamper labels applied. A PTP 600 module with connectors (**Fig. 3**) has two labels wrapping around the enclosures edge, with one label on the top (horizontal) and one label on the left side (vertical). A PTP 600 integrated module has two labels on the underside of the enclosure (**Fig. 4**), with the top label (horizontal) and the side label (vertical).

Security Technical Implementation Guides (STIGs)[3] provide configuration standards for DoD IA and IA-enabled devices or systems. The guides contain technical guidance to secure information systems and software that might otherwise be vulnerable to malicious computer attack. In the first phase of meeting the STIG requirements, Cambium was required to provide specific responses to all STIG requirements. This procedure entailed in-house testing of STIG requirements to determine what, if any, PTP 600 enhancements would be needed to obtain UC APL certification. Based on the in-house analysis, Cambium added several software features, including the use of a secure network time protocol (NTP) to prevent an attacker from modifying a PTP 600's perception of time; and Remote Authentication Dial-In User Service (RADIUS), to remotely authenticate users and their levels of access based on an organization's network policies; and control user accounts via configurable password rules.

After the required enhancements were made, STIG testing was conducted by the DoD's JITC (www.jitc.fhu.disa.mil/) with a Cambium engineer on premises at the JITC lab. The process involved two weeks of IA testing which included extensive network intrusion, penetration, and vulnerability scanning. Another week of Ethernet, T1, and VoIP network testing was conducted to comply with interoperability requirements.

Following the two-year testing, development, and certification process, the PTP 600 Series backhaul solutions received UC APL certification, allowing all DoD agencies to purchase and operate UC-certified systems over a DoD network. The listing can be confirmed at https://aplits.disa.mil/processAPList.do/. The certification is especially crucial for the thousands of strategic and tactical communications vital to DoD and Federal agencies worldwide, including for battlefield communications; training and simulation networks; backhaul from telemetry and land mobile radios (LMRs); border patrol; sensor and security backhaul; ship-to-ship and ship-to-shore communications; satellite local-area-network (LAN) extensions; LTE and WiMAX backhaul; law enforcement; and test range communications. In addition to UC APL certification, PTP 600 radios have also passed MIL-STD 461 testing for electromagnetic interference, qualifying them for use on US Navy ships. **DE**

References

1. FIPS 140-2 validation can be confirmed at http://csrc.nist.gov/groups/STM/cmvp/documents/140-1/140val-all.htm#1515.
2. FIPS 140-2 certification status can be confirmed at http://csrc.nist.gov/groups/STM/cmvp/inprocess.html.
3. More information on STIGs is available at http://iase.disa.mil/stigs/index.html.

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Miniature Amplifiers Drive Signals To 6 GHz

These compact surface-mount monolithic amplifiers can be used for a variety of signal adjustments, from controlling noise to boosting levels, at frequencies to 6 GHz.

Signal-level adjustments are often necessary over some portion of an operating bandwidth. The addition of attenuation or amplification to a circuit can typically control signals that may be too high or too low in level, respectively. For signals through 6 GHz, at least, a series of monolithic-microwave-integrated-circuit (MMIC) amplifiers from Mini-Circuits (www.minicircuits.com) can help with signal gain adjustments. Based on indium-gallium-phosphide (InGaP) heterojunction-bipolar-transistor (HBT) active devices, these RoHS-compliant monolithic amplifiers are usable from 10 MHz to 6 GHz. Each amplifier is bonded to a multilayer low-temperature-cofired-ceramic (LTCC) substrate for thermal stability and hermetically sealed under a controlled nitrogen atmosphere. These monolithic amplifiers are housed with gold-plated covers and eutectic gold-tin (AuSn) solder in packages measuring only 3 x 3 x 1.14 mm.

The compact MMIC amplifiers **(see figure)** are available for operating voltages from +3 to +6 VDC and designed for operating temperatures from −55 to +105°C. As an example, model CMA-62+ operates from 10 MHz to 6 GHz with more than 16-dB small-signal gain at the lower frequencies, dropping somewhat at higher frequencies. The gain is typically 16.6 dB at 50 MHz, 15.4 dB at 2 GHz, and 13.7 dB at 6 GHz, with associated noise figures of typically 4.8, 5.4, and 5.7 dB at those three frequencies. The gain flatness is typically within ±0.6 dB from 0.05 to 3.0 GHz and ±0.1 dB from 0.7 to 2.6 GHz. The broadband amplifier exhibits typical reverse isolation of 21.9 dB at 2 GHz.

Model CMA-62+ provides output power at 1-dB compression of typically +19.9 dBm at 50 MHz, +19.2 dBm at 2 GHz, and +11.9 dBm at 6 GHz. The output third-order intercept point (IP3) is typically +39.0 dBm at 10 MHz, +33.4 dBm at 2 GHz, and +23.2 dBm at 6 GHz. The amplifier exhibits input return loss of 16.5 dB at 50 MHz, 14.7 dB at 2 GHz, and 13.9 dB at 6 GHz, with output return-loss performance levels of 14.1, 14.0, and 14.0 dB, respectively, at those three frequencies. In fact, the input and output return loss typically ranges from 10 to 23 dB for frequencies as high as 7 GHz, even without additional impedance-matching components. Model CMA-62+ is an efficient gain block, typically drawing only 82 mA from a +5-VDC supply.

These compact InGaP HBT MMIC amplifiers are usable for small-signal applications through 6 GHz and are supplied in nitrogen-filled, hermetic packages measuring only 3 x 3 x 1.14 mm.

For applications that may require more gain across that same frequency range, MMIC amplifier model CMA-63+ is also usable from 0.01 to 6.00 GHz, with typical gain of 21.9 dB at 50 MHz, 20.3 dB at 2 GHz, and 14.4 dB at 6 GHz. It maintains gain flatness within ±1.5 dB from 0.05 to 3.00 GHz and ±1.2 dB from 0.7 to 2.6 GHz. It delivers typical output power at 1-dB compression of +18.7 dBm at 50 MHz, +18.4 dBm at 2 GHz, and +11.7 dBm at 6 GHz, with output IP3 levels of typically +34.6 dBm at 50 MHz, +32.0 dBm at 2 GHz, and +25.3 dBm at 6 GHz. The rugged amplifier boasts reverse isolation of typically 23.7 dB at 2 GHz. Model CMA-63+ offers noise figures of 3.7 dB at 50 MHz, 3.9 dB at 2 GHz, and 4.6 dB at 6 GHz, and typically draws 69 mA current from a +5-VDC supply.

Where linearity and noise figure may be issues, MMIC HBT amplifier model CMA-545+ is usable from 50 MHz to 6 GHz, with low noise figures of 1.3 dB at 50 MHz, 1.2 dB at 2 GHz, and 2.5 dB at 6 GHz. It provides typical gain of 26.2 dB at 50 MHz, 14.8 dB at 2 GHz, and 6.6 dB at 6 GHz, with typical gain flatness within ±1.5 dB from 0.05 to 3.00 GHz and ±1.2 dB from 0.7 to 2.6 GHz. Model CMA-545+ achieves typical output power at 1-dB compression of +19.9 dBm at 50 MHz, +20.0 dBm at 2 GHz, and +21.0 dBm at 6 GHz, with typical output IP3 levels of +32.0 dBm at 50 MHz, +37.1 dBm at 2 GHz, and +36.6 dBm at 6 GHz. This lower-noise amplifier draws just 80 mA current from a +3-VDC supply.

These compact amplifiers are matched to 50 Ω input and output impedance and do not require additional matching components even with their broad frequency ranges. A great deal of care has been put into achieving high reliability with the InGaP HBT process and in maintaining that reliability through proper packaging. The amplifiers feature excellent electrostatic-discharge (ESD) protection, having been tested to Class 1C requirements for the human body model (HBM). The amplifiers meet the applicable requirements of MIL-STD-202, MIL-STD-750, and MIL-STD-883 for hermeticity, acceleration, vibration, mechanical shock, and temperature cycling. **DE**

Mini-Circuits, Inc., P.O. Box 350166, Brooklyn, NY 11235-0003; (718) 934-4500, FAX: (71) 332-4661, www.minicircuits.com.

JACK BROWNE / TECHNICAL CONTRIBUTOR

GaN Devices Power Broadband Amplifiers

This family of coaxial GaN-based power amplifiers includes models with high gain and generous output levels, spanning the frequency range from 2 to 18 GHz.

This line of compact GaN-based solid-state power amplifiers covers frequencies from 2 to 18 GHz with output levels to 40 W, making them suitable replacements for TWTAs in aerospace and defense applications.

Broadband microwave amplification is vital to a large number of defense-related systems, including in communications, direction-finding (DF), radar, and electronic-warfare (EW) systems. Although large traveling-wave-tube amplifiers (TWTAs) have often been used to boost signal levels in these systems, wide-bandgap transistor technologies such as gallium nitride (GaN) have been gaining in power and frequency in recent years, making possible true TWTA-replacement amplifiers based on solid-state devices. CTT, Inc. (www.cttinc.com) has developed a line of durable GaN-based amplifiers capable of pulsed and continuous-wave (CW) power levels to 40 W at the frequencies most commonly used in defense systems, from 2 to 18 GHz **(see figure)**.

The broadband amplifiers draw upon CTT's long experience in microwave-integrated-circuit (MIC) thin-film technology for high reliability, even within the rigorous environments faced by aerospace/defense electronic systems. They are designed for operating temperatures from –55 to +85°C and also incorporate automatic thermal-shut-down circuitry to protect against overheating. Units are available for full coverage of the 2-to-18-GHz frequency range or portions thereof. The table offers a sampling of some standard available models. In addition, custom designs are available upon request.

For example, model AGM/060-4343 is designed for use from 2 to 6 GHz. It delivers +43 dBm typical saturated output power across that band, even at the band edges, in pulsed or CW operation. It boosts input signals with 43-dB minimum gain while achieving ±2.5 dB gain flatness across the 4-GHz operating bandwidth. Its maximum noise figure is 6 dB and maximum VSWR is 2.0:1. The amplifier's GaN devices draw 1820 mA current from a +30-VDC supply under small-signal conditions and 4200 mA current from a +30-VDC supply when operating at saturated output-power levels.

When more gain is needed for that same 2-to-6-GHz bandwidth, the firm also offers the model AGM/060-4646 GaN amplifier, with 46 dB minimum gain and ±2.5 dB gain flatness from 2 to 6 GHz. This amplifier also provides greater output power, with +46-dBm typical saturated output power across the operating band and +45.5-dBm minimum saturated output power at the band edges. It has a maximum noise figure of 6 dB and maximum input/output VSWR of 2.0:1. The AGM/060-4646 draws 3420 mA current from a +30-VDC supply under small-signal conditions and 770 mA current from the same supply when operating at saturated output-power levels.

For truly broadband applications, the model AGX/0218-3946 GaN power amplifier boasts 46-dB minimum gain with ±3.0-dB gain flatness from 2 to 18 GHz. It generates +39-dBm typical saturated output power across that frequency range with +38-dBm minimum saturated output power at the band edges. It exhibits 8-dB maximum noise figure from 2 to 18 GHz with maximum input/output VSWR of 2.20:1. It consumes 1350 mA from a +32-VDC supply at small-signal conditions and 3100 mA from a +32-VDC supply when providing full saturated output-power levels.

The highest-gain unit in the GaN PA line is model AGM/180-4458, with 58-dB minimum gain and ±2.5 dB gain flatness from 6 to 18 GHz. It has a maximum noise figure of 7 dB across that frequency range, with maximum input/output VSWR of 2.0:1, and provides +44-dBm typical saturated output power and +43-dBm minimum saturated output power at the band edges. This amplifier consumes 4100 mA current from a +32-VDC supply under small-signal conditions and 8600 mA current from the same voltage supply when operating at saturated output-power levels. **DE**

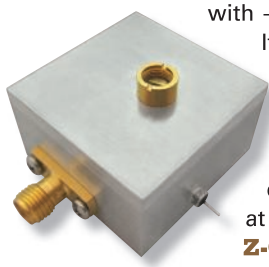
CTT's GaN power amplifiers at a glance.

Model	Frequency range (GHz)	Typical gain (dB)	Typical saturated output power (dBm)
AGM/060-4343	2 to 6	43	+43
AGM/060-4356	2 to 6	56	+43
AGM/060-4646	2 to 6	46	+46
AGX/0218-3946	2 to 18	46	+39
AGM/180-3940	6 to 18	40	+39
AGM/180-4250	6 to 18	50	+42
AGM/180-4458	6 to 18	58	+44
AGW/105-4250	8.5 to 10.5	50	+42
AGW/105-4550	8.5 to 10.5	50	+45

CTT, Inc., 241 East Java Dr., Sunnyvale, CA 94089; (408) 541-0794, FAX: (408) 541-0596; www.cttinc.com.

DRO Delivers Stable 10 GHz

Model DRO10000A is an extremely stable, low-noise dielectric resonator oscillator (DRO) available with output frequencies from 8 to 12 GHz. The 10-GHz model features a voltage tuning range of 0 to 12 VDC for ±3 MHz tuning range for precise tuning and use in phase-locked-loop (PLL) frequency synthesizers. This 10-GHz DRO exhibits low phase noise of –105 dBc/Hz offset 10 kHz from the carrier with –25-dBc typical harmonic suppression. It has low 100-mW power consumption and provides output power of 0 dBm that is flat within ± 3 dB. The DROs are available in surface-mount housings or metal packages with coaxial connectors, and are designed for use at temperatures from –40 to +85°C.



Z-Communications

14118 Stowe Dr., Ste. B, Poway, CA 92064; (858) 621-2700, FAX: (858) 486-1927, www.zcomm.com.

SDLVA Scans 700 To 1300 MHz

Model SDLVA-0R71R3-75-CD-3 is a successive-detection logarithmic video amplifier (SDLVA) with a greater than 75-dB dynamic range from 700 to 1300 MHz. It has a minimum logging range of –70 to +5 dBm, bringing ±0.8-dB typical logarithmic linearity from -60 to 0 dBm and typically ±1.2 dB typical logarithmic linearity for input signals across a power range from –65 to +5 dBm. It achieves tangential sensitivity of typically –70 dBm with a 15-ns typical log-video output rise time and 40-ns maximum output settling time. The amplifier provides a limited intermediate-frequency (IF) output of typically +5 dBm and has an output video log slope of nominally 40 mV/dB. Propagation delays are typically only 7 ns. The compact SDLVA measures 3.75 x 1.50 x 0.50 in. It draws 200 mA current from supplies of +12 to +15 VDC and 190 mA current from negative supplies of –12 to –15 VDC.

Planar Monolithic Industries, Inc.

7311F Grove Rd., Frederick, MD 21704; (301) 662-5019, FAX: (301) 662-1731, e-mail: sales@pmi-rf.com, www.pmi-rf.com.

LED Light Is Explosion Proof

For hazardous or hostile environments, model EPL-MB-161M-100 is an explosion-proof light-emitting-diode (LED) light that provides 10,000 lumens illumination. It features a frame constructed of nonsparking aluminum and a Class 1, Division 1 approved 150-W round LED lamp head mounted within a square frame aluminum pedestal base. It is light in weight and includes an additional aluminum bracket with four magnetic feet—each with 200-lb gripping power—for mounting the lamp and bracket to almost any ferrous metallic surface. The EPL-MB-161M-100 explosion-proof lamp can be used as a standard pedestal light or a temporary mounted light for illuminating larger areas. The 16-in. LED lamp is adjustable; it can be moved through vertical adjustment within its bracket by loosening two thumbscrews on either side of the lamp head and positioning it as needed.

Larson Electronics LLC

9419 E. US Highway 175, Kemp, TX 75143; (800) 369-671, (903) 498-3363, FAX: (903) 498-3364, www.larsonelectronics.com.

Module Guides FMCW Ranging

Model SSP-24303-42-D1 is a low-cost, K-band frequency-modulated-continuous-wave (FMCW) ranging and directional sensor module. It has a center frequency set at 24.125 GHz with ±150-MHz FM bandwidth and nominal output power of +3 dBm. The sensor module operates from a single +5-VDC supply and typically draws 250 mA current; it requires a voltage swing of 0 to +15 VDC for tuning. The module contains an in-phase/quadrature (I/Q) mixer to provide moving-target-indication (MTI) information. The standard unit, which is designed for operating temperatures from –40 to +85°C and equipped with WR-42 waveguide with UG595/U flange interface, measures 1.00 x 0.85 x 1.00 in. and weighs 2 oz. Over the temperature range, it has –0.8 MHz/°C frequency stability and –0.03 dB/°C amplitude stability.

SAGE Millimeter, Inc.

3043 Kashiwa St., Torrance, CA 90505; (424)-757-0168; FAX: (424)-757-0188, www.sagemillimeter.com.

Power Module Drives 14.40 to 15.35 GHz

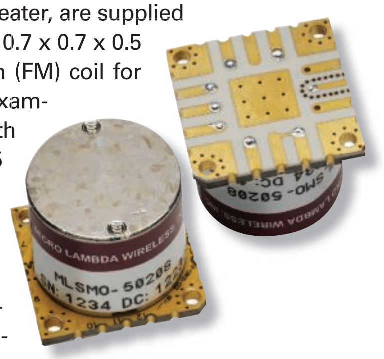
Model M1228 is a rugged Ku-band microwave power module (MPM) that delivers at least 70-W linear output power from 14.40 to 15.35 GHz. It is lighter and more efficient than traditional traveling-wave-tube amplifiers (TWTAs) and operates on a +28-VDC supply while consuming 350 W prime power. The MPM, which measures just 7.0 x 7.5 x 2.6 in. in its ruggedized housing, weighs only 6 lbs. It is designed for environments from –54 to +85° and compliant with MIL-STD-461 requirements. The MPM is primarily intended for airborne data link communication systems and can be optionally reconfigured for custom mechanical designs, including a forced-air heat exchanger.

L-3 Electron Devices

960 Industrial Rd., San Carlos, CA 94070; (650) 591-8411, FAX: (650) 508-1956, www.l-3com.com/edd.

YIG Oscillators Span 2 To 13 GHz

The MLSMO-Series of permanent-magnet YIG-tuned oscillators feature models with wide tuning ranges from 2 to 13 GHz with low phase noise and low spurious noise. The oscillators, which do not require a heater, are supplied in circular surface-mount housings measuring 0.7 x 0.7 x 0.5 in. All models include a frequency-modulation (FM) coil for use in phase-lock-loop (PLL) oscillators. As an example, model MLSMO-50306 tunes 3 to 6 GHz with +8-dBm minimum output power. It offers –15 dBc minimum harmonics; –70 dBc minimum spurious output levels; and phase noise of better than –103 dBc/Hz offset 10 kHz from the carrier and better than –128 dBc/Hz offset 100 kHz from the carrier. It has typical main coil tuning sensitivity of 9.7 MHz/mA with typical tuning linearity of ±6 MHz. The typical FM coil tuning sensitivity is 300 kHz/mA for a typical FM 3-dB bandwidth of 1 MHz. The YIG oscillators are built for operating temperatures from 0 to +65°C.



Micro Lambda Wireless, Inc.

46515 Landing Pkwy., Fremont, CA 94538; (510) 770-9221, FAX: (510) 770-9213, www.microlambdawireless.com.

ADVERTISERS' INDEX

MEMS Oscillators Lock Down Timing

Silicon microelectromechanical-systems (MEMS) technology is capable of impressive frequency-generation capabilities, even when compared to mature technologies such as quartz-crystal oscillators. The SiT8920 MEMS oscillator is available in 33 standard fixed frequencies between 7.3728 and 48 MHz and is suitable for applications requiring extremely high reliability. It features frequency stability as good as ±25 ppm and an aging rate of ±1.5 ppm. The MEMS oscillator achieves low acceleration (G) sensitivity of 0.1 ppg/G with typical root-mean-square (RMS) phase jitter of only 0.7 ps. It has 2.5 ns typical rise/fall time, 5 ms startup time, and 150 ns enable/disable time. The MEMS oscillator is lead-free and RoHS and REACH compliant, It is built for operating temperatures from –55 to +125°C.

SiTime Corp.

990 Almanor Ave., Sunnyvale, CA 94085; (408) 328-4400, www.sitime.com.

Stable DRO Delivers 10 GHz

Model DRO100 is a surface-mount dielectric resonator oscillator (DRO) with extremely low phase noise at 10 GHz. It provides a voltage tuning range of +1 to +15 VDC for phase-lock-loop (PLL) frequency synthesizer applications and has tuning sensitivity of typically 3 MHz/V. The compact microwave oscillator delivers at least +7 dBm output power into 50 Ω. The typical phase noise is -81 dBc/Hz offset 1 kHz from the 10-GHz carrier, –111 dBc/Hz offset 10 kHz from the same carrier, –137 dBc/Hz offset 100 kHz from the carrier, and –158 dBc/Hz offset 1 MHz from the carrier. Typical harmonic suppression is –20 dBc. The stable oscillator, which exhibits tuning port capacitance of typically 90 pF, exhibits jitter of a mere 35 fs.

Synergy Microwave Corp.

201 McLean Blvd., Paterson, NJ 07504; (973) 881-8800, FAX: (973) 881-8361, e-mail: sales@synergymwave.com, www.synergymwave.com.

VICTORIA FRAZA KICKHAM | DISTRIBUTION EDITOR victoria.kickham@penton.com

LOCAL FLAVOR SPELLS SUCCESS IN SOUTH AMERICA

Brazil remains the prime target as distributors expand in South America, using acquisitions and enhanced Web features to grow their customer base.

Heilind Electronics' 2012 purchase of Brazilian distributor Kotek Eletro Electronica gave the interconnect specialist immediate access to hundreds of new customers and entry into a growing economy that company leaders say is a key part of their global growth strategy, which began in earnest in 2011.

Kotek's 10-year history serving customers throughout Brazil meant immediate insight on navigating the country's complex regulatory and tax environment, ensuring a profitable business model from the start, says Brandon Clountz, Heilind's South regional manager, covering the southern United States, Mexico, and South America. That kind of insight can mean the difference between success and failure in a region where knowledge of local rules, regulations, and business culture is at a premium.

"Listening very carefully to our customers and supplier partners over the past several years was foundational in developing our strategic expansion plans, including our entrance into Brazil," says Clountz, pointing to an underlying message that the company's service model, interconnect focus, and commitment to inventory in North America would fill a void in the Brazilian marketplace and will play a key role if it is to be successful. "[Brazil] is a tight-knit market. You really need a localized, incorporated company to do business there. Kotek gave us that. Their team has expertise in importing product and building that into their cost model. We needed somebody that had a formula in place that was built along [Brazil's] taxation laws."

Business leaders agree that Brazil's complex import/export and tax structure is a challenge to doing business in the country, pointing to how quickly those rules can change, in particular. And although all the major large distributors do business in the region, many go to market as exporters, serving the region from locations elsewhere in Latin America or the United States.

Those with local offices and warehouses have done so largely by acquisition or by pursuing value-added strategies that help ease the financial burden of importing products—services such as repair, refurbishment, and recycling; supply chain management; testing; system configuration; and more. Avnet Electronics Marketing, a prime example, has been expanding steadily in Brazil. Last year, it added to its service business with another technology integration center in the region that serves its embedded business customers as well as original equipment manufacturers and others.

Despite the challenges of doing business in South America, distributors remain especially focused on the opportunities of the Brazilian marketplace. Heilind's recent move to grow in the region is a pointed example, but others are finding new reasons to enhance their presence there as well. Clountz points to the country's growing middle class and the resulting need for the infrastructure and technological comforts to support it. He says he expects Brazil to provide a steady source of growth for Heilind now and down the road.

"There really is an unmet demand in those markets for our value proposition," says Mouser's VP of sales and service for the Americas, Steve Newland.

A RETURN TO GROWTH

Growth in the Brazilian economy slowed last year, but local officials say the country is poised for more growth in 2013, with government leaders promising late in 2012 to take action that will ensure more sustainable growth going forward. Growth slowed to around 1% last year, following nearly 3% expansion in 2011, when the country surpassed the United Kingdom to become the sixth largest economy in the world.

Heilind wanted a piece of that action and put South America at the top of its aggressive global expansion strategy. In addition to Brazil, the company has expanded in China recently, looking to bring its interconnect expertise to a worldwide audience. The company is projecting healthy growth in Brazil this year, buoyed by the addition of new connector products to a previously limited line card in the region, an expanded sales force, and larger warehouse space.

"If you stock the product, the customers are going to come," says Clountz, adding that Brazilian customers are no different than those that Heilind serves elsewhere in the world with their need for good service and reliable delivery. "We serve second-, third-, and fourth-tier customers really well. They look for service and inventory at a relatively competitive price. They need inventory, and we have the ability to do that for them."

Clountz says local customers are also looking for advice on design and sourcing options. "That allows us, as a specialist, to utilize and harness the technical support we have to make those recommendations," he adds.

Kotek-Heilind sells to a wide range of customers in Brazil, including industrial, consumer, electronics, telecommunications, and the automotive industry, all of which are new to Heilind and local to the Brazilian economy.

"Prior to the past year, the Brazilian economy had been exploding, Clountz says. "If they can continue to add jobs and rework some of their tax laws, we expect solid growth in this market for the next five to 10 years. We are very enthusiastic about Brazil."

THE WEB'S THE ANSWER

In evaluating the competitive landscape, Clountz puts it at 50-50: 50% local distribution, 50% traditional competition that Heilind comes up against in North America and elsewhere. Online strategies are winning big with Brazilian customers, as large catalog houses like Digi-Key and Mouser Electronics continue to invest heavily in their Web sites to reach customers around the world.

Mouser, in particular, has a steady focus on Brazil with its Portuguese-language customer service program. The distributor has a team of native Portuguese speakers, all Brazilian, who work out of the United States to support its Brazilian customers. The program complements the distributor's Portuguese-language Web site.

Although South America represents a small portion of Mouser's business, it is a fast-growing segment, says Steve Newland, vice president of sales and service for the Americas.

"There really is an unmet demand in those markets for our value proposition," says Newland, pointing to Mouser's focus on getting design engineers the newest and widest variety of products in no-minimum order quantities. "That message really resounds with that group as it does in other regions."

Mouser serves South American customers from branches in Mexico and the U.S., but is investigating opening branches in Argentina and Brazil as well. Newland says most customers in the region come to Mouser via the Web, however, so the current local-language Web site and complementary Portuguese-language customer service aspects of the business model continue to make sense. Going forward, Newland and U.S.-based Latin American sales manager Mauro Salomao say they expect the Web to continue to drive growth, especially as electronics-related business increases in the region.

"The globalization of the economy is bringing new projects into the territory," says Salomao, a native Brazilian who has worked with Latin American customers for 20 years.

But how much of that new business will turn into design opportunity? The design engineering market in South America is smaller than it is in Europe and Asia, Newland says, although he points to large pockets of opportunity in Brazil. The design engineering community remains Mouser's focus, so the company continues to follow that business wherever it grows.

"The driver for us is new design and development in the region. Brazil is a multi-national economy, so there's a lot of design activity that goes on there, but there's an equal amount that goes on outside of Brazil as well," says Newland.

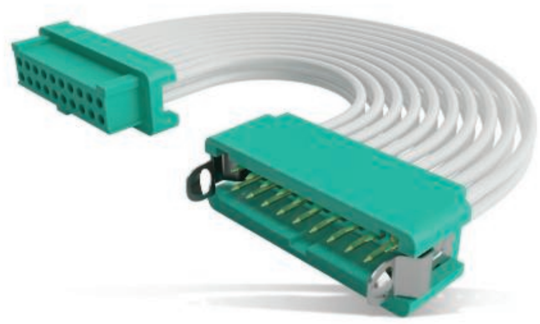
"There is opportunity there," he adds. "It's a little harder to get at than other regions of the world, but we're not afraid of it. You need to get in there, target the market, and get to know it to succeed. And all told, we have quite a bit of resources focused on that part of the world."

DISTRIBUTORS PROMOTE SPACE-SAVING CONNECTORS

Interconnect products get smarter and smaller for wide-ranging applications.

Component manufacturers are turning out smaller and smaller connector solutions in response to growing demand in a broad array of applications, including lighting, medical devices, robotics, and gaming equipment. Compact size and durability are making headlines as distributors introduced some of the newest products early in 2013.

In January, Mouser Electronics announced it was the first to stock Harwin's G125 Gecko connectors, which provide a low-profile, dual-row cable-to-board and board-to-board interconnect solution, ideally suited for stacking and cable mating in areas where printed-circuit board (PCB) real estate is at a premium *(see the figure)*. The connectors are designed to offer high performance in a miniature package, with pin spacing of 1.25 mm and up to 50 contacts per connector, offering a space savings of 35% over other high-performance connector solutions. They also are designed for extreme conditions, operating in a wide temperature range and under extreme vibration.



Harwin's G125 Gecko connectors provide a low-profile, dual-row cable-to-board and board-to-board interconnect solution, ideally suited for stacking and cable mating in areas where PCB real estate is at a premium.

In another nod to space savings, Digi-Key is promoting 3M's line of 2-mm pitch ribbon cable-to-PCB interconnects, consisting of an IDC-style (insulation displacement connector) cable mount socket (158 series) and a shrouded PCB header in multiple configurations (159 series). Each series is available in multiple tiered offerings with a wide range of competitive options. Ribbon cable sockets and their mating headers are prevalent in a wide range of applications, including industrial production equipment, communications, military, aerospace, computer, and datacom.

Heilind Electronics has announced the availability of the DF62 series of slim in-line connectors from Hirose. Representing the company's newest addition to its wire-to-wire family of connectors, the small and durable DF62 series is ideal for tighter, more compact spaces and is virtually tangle free. The series features a locking structure that gives the user two lock completion indicators—a tactile click and a visual check of the socket lock through the plug slit. Advanced engineering and design have reduced the diagonal diameter of the connector by 50%. These connectors are ideally suited for servo amp, LED lighting, portable medical device, motion control and robotic arms, and gaming equipment applications.

Among TTI's newest interconnect offerings, Molex's Mini50 unsealed, wire-to-board connection system offers customers reduced package sizes compared to conventional 0.64-mm connection systems. Mini50 connectors reduce overall harness weight and costs by allowing wire-harness customers to crimp and process smaller wire gauges versus traditional 0.64-mm terminal systems. Mini50 surface-mount (SMT) headers are being developed to allow customers to maximize valuable PCB area by removing pass-through features on the circuit board. Module and PCB designers will be able to locate SMT components beneath the Mini50 headers on the opposite side of the PCB. The headers will be designed to mate to the existing, industry-recognized Mini50 receptacles.

AUTOMOTIVE, ENERGY MARKETS DRIVE GROWTH IN INDUSTRIAL AUTOMATION

NEWARK ELEMENT14'S RICHARD Halliday says he expects the distributor's industrial automation business to outpace its core business growth this year, as design engineers and production customers keep busy in North America. Halliday is director of product marketing for Newark element14, and he credits much of the opportunity to the company's focus on both the design and production sides of the manufacturing economy.

"We have the board-level components and then we have the products used at the other end of the design lifecycle," he says. "We would expect some solid, high single-digit growth."

Halliday isn't alone in his outlook. Other large distributors specializing in industrial automation reported optimism as 2013 began, pointing to growth in energy and automotive markets in particular. Allied Electronics' Mark Simon says he's hopeful the growth Allied saw early in the year is a harbinger of more to come in 2013. He notes that Allied saw some growth in January and that early indicators pointed to growth in February, the final month of the distributor's fiscal year. The good start came as welcome news amidst continuing concerns about the so-called "fiscal cliff" here at home.

"There have been a number of companies that have lost government incentives going into this year, so there's that caution," says Simon, Allied's vice president of sales. "But looking at the year 2013 as a whole, we're hoping we can produce 3% to 4% growth as a business."

Indeed, supply chain companies are betting on facility upgrades, new projects, and customers' thirst for product and process innovation to drive that growth this year.

AUTO, ENERGY MARKETS BODE WELL

Halliday points to aerospace and automotive markets as good opportunities for factory automation projects this year, especially as original equipment manufacturers (OEMs) and contract manufacturers (CMs) look to upgrade and enhance existing production lines.

"One of the things we are seeing is there is a bit of a move to get a little bit more manufacturing occurring in the United Sates, so that presents certain opportunities," Halliday explains, pointing to CMs, in particular, which are building new facilities or moving some back to the United States. Both situations create opportunities for supplying the newest technologies to streamline the production process.

On the process side of the business, Halliday points to the oil and gas markets. Those customers are increasingly looking for new technologies such as high-performance sensors, creating an opportunity he says he expects will continue throughout the year. Simon concurs about the energy market, pointing to recently released projects in certain regions that spell opportunity for Allied in 2013.

"Energy is very good," Simon says. "It did start to flatten at the end of July, when we started to see some big customers [have] cancellations, but it didn't last long. I've had some reports from Houston and Oklahoma that there are some projects that are starting to release again, so that's a positive."

Simon says the biggest slowdown is among military and defense customers as they struggle to deal with federal budget reductions. Although some projects are going forward, he says the uncertainty surrounding which ones will be funded is a key concern.

On the positive side, product advances are helping drive business as customers look for new technologies to streamline processes and save costs. For example, Simon says demand for wireless products continues to grow, particularly because of their ability to reduce installation and maintenance costs in production environments. Wireless solutions are easier to deploy and to repurpose if the customer needs to make a change, he says.

"If you've got a production line and you've got to reconfigure it, wireless makes it so much easier to do that," notes Simon. "There are still a lot of upgrades going through that are still wired, but there's a lot of development by the manufacturers and a big appetite for wireless [solutions]."

SACHIN GUPTA | CYPRESS SEMICONDUCTOR sgup@cypress.com

ONE POWERFUL ISSUE

DESIGN TOUCHSCREEN-BASED HANDHELD SYSTEMS FOR LOW POWER CONSUMPTON

Keep an eye on how your system operates in four key modes—active power, sleep, deep sleep, and hibernate—to improve power efficiency.

LOW-POWER OPERATION IS one of the major design aspects of any touchscreen device. Power efficiency helps to extend battery life, satisfying a primary design constraint for increased operating life. Power-efficient design also helps reduce the battery size and, hence, the end system's size and weight, which are also important specifications. In addition, power efficiency reduces the overhead required to manage thermal dissipation because the generation of heat is reduced at the source by optimizing the power consumed.

Designers can stretch the operating battery life of handheld devices through judicious management of the operational states. Touchscreens, which are now nearly ubiquitous, make a good example. The operating conditions for a portable device, with the variety of applications it can support, generally can vary from intensely busy to nearly idle in a moment's time. By utilizing knowledge of how a device is being used, the power consumed by the touchscreen can be more efficiently managed.

Most embedded systems incorporate several subsystems. In a smart phone, these include the touchscreen interface, wireless module, and battery charging. Total system power consumption is the cumulative power consumption of all these different blocks in the system. Most of these blocks have independent controllers that communicate with the host processor. Thus, each block is more or less an independent entity in terms of system design and must be optimized to minimize the overall power consumption of the system. In particular, carelessly designed touchscreens can cause the system's battery to drain very quickly.

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POWER CONSUMPTION BASICS

There are two major components of power consumption in a CMOS circuit: dynamic power consumption and static power consumption. Dynamic power consumption is due to the switching outputs from logic high to low and vice versa. Overall power consumption can be managed by controlling either dynamic or static power or both.

In CMOS-based designs, circuits dissipate power by charging and discharging load capacitances. Considering the internal architecture of a touchscreen controller, load capacitance is nothing but the gate capacitance of the next stage or the bus capacitance.

Power is dissipated across a PMOS transistor when the load capacitor is being charged and across an NMOS when the load capacitor is being discharged. Instantaneous power dissipation across an NMOS transistor in a CMOS inverter *(Fig. 1)* is given by:

$$P_{PMOSi} = i_L(V_{DD} - V_O) \quad [1]$$

After substituting the value of i_L:

$$P_{PMOSi} = C_L(V_{DD} - V_O)dV_O/dt \quad [2]$$

Total power dissipation across the PMOS to switch the output from low to high can be determined by integrating power dissipation across the PMOS to charge the load capacitor from 0 V to V_{DD}:

$$\text{PMOS power consumption, } P_{PMOS} = ½C_LV_{DD}^2 \quad [3]$$

Similarly, to switch the output from high to low, total power dissipation across the NMOS is:

$$\text{NMOS power consumption, } P_{NMOS} = ½C_LV_{DD}^2 \quad [4]$$

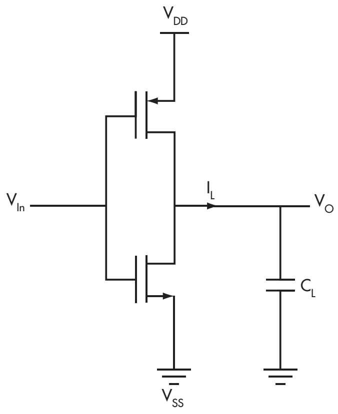
For one complete switching cycle, the power dissipation is:

$$P_{Total} = P_{NMOS} + P_{PMOS} = C_LV_{DD}^2 \quad [5]$$

Defining the average power in terms of switching frequency (f):

$$P = fC_LV_{DD}^2 \quad [6]$$

Several factors influence static power consumption, including sub-threshold conditions and tunneling current. Tunneling current becomes dominant when the transistor is scaled



1. In a basic CMOS inverter, power is dissipated across a PMOS transistor when the load capacitor is being charged and across an NMOS when the load capacitor is being discharged.

down for compact chip design, because reduced dimensions result in a reduction in oxide thickness.

Handheld mobile devices integrate several component blocks such as the LCD driver, touchscreen controller, power management, and communications link. In touchscreen-based phones, the touchscreen controller can be a power sink if it isn't designed for efficient power. An appropriate touchscreen controller must be selected and configured so it consumes minimal power.

TOUCHSCREEN CONTROLLERS

Most simple microcontrollers essentially have two power modes: active and sleep. A touchscreen controller, however, isn't so simple. (For example, it incorporates an analog front end for capacitance measurement.) Touchscreen controllers, then, often offer more granular handling of power consumption, which typically takes the form of additional power. Common power modes for touchscreen controllers include:

- **Active power:** The CPU and other resources on the chip are up and running. Static and dynamic power consumption both contribute to the total power consumption in this mode, which is the most commonly used mode for most of the controllers and processors in the industry. (Even here, however, the CPU can power down some clocks and resources in touchscreen controllers, based on system requirements. This makes the touchscreen controller more sophisticated than basic controllers. Nevertheless, this mode requires more power than any other. It sets a baseline for the design of the battery system.)
- **Sleep:** This is another familiar power mode for most controllers. Primarily, it involves the CPU going to sleep (i.e., its clock is disconnected). The only contribution by the CPU toward the total power consumption is static power consumption, since there is no clocking.
- **Deep sleep:** In this mode, the system clock is disabled, so none of the high-frequency resources (CPU registers, SRAM, etc.) is available. However, their previous state is retained. Because the high-frequency clock is disabled, a lot of power that would have been consumed due to switching is conserved. Deep sleep modes generally provide an option to keep running a low-frequency clock that can be used to drive some low frequency-resources such as a timer. Additionally, this mode allows the designer to employ communication protocol blocks such as an I^2C slave that do not require any clock generated by the device itself. The usual way to enter this mode is to disable the main system clock while keeping the blocks powered up. The only battery drain in this mode comes from the static power consumption of all the blocks on the chip.
- **Hibernate:** In this mode, all the clocks are switched off and power is removed from all chip resources in the chip, except for those used as a wakeup source when triggered by an external event. As almost everything is powered down in this mode, it yields the lowest power.

Average current consumption for the system is:

$$\sum_{i=0}^{\max\ \#\ \text{of power modes}-1} \text{Current consumption in mode i} \times \text{time in mode i} \quad [7]$$

TOUCHSCREEN SENSOR CONTROLLER OPTIONS

Controllers provide for following a logical series of states for device operation *(Fig. 2)*. Generally, the amount of time the system remains in active and various low-power modes depends on the application. Certain applications may need to have the controller running all the time, and others may require it to run only occasionally. System designers must consider power consumption in the specific mode in which their system must spend most of its time to ensure that their designs are power-efficient.

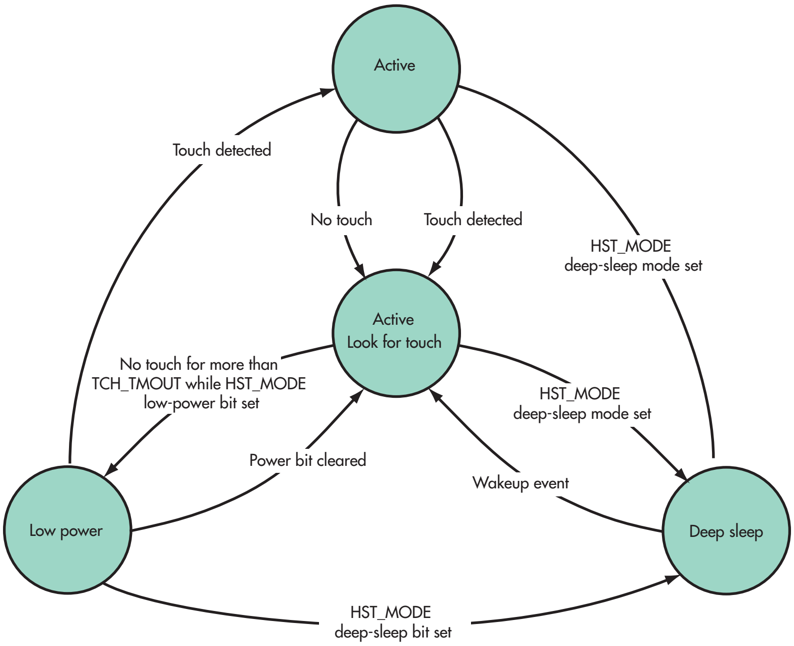
In some applications, it could prove beneficial for the system to run at a higher speed so it can complete its job and get into the low-power mode faster. For other applications, the CPU can run at a slower speed that keeps active power consumption low without entering low-power mode. Here, the system designer has to analyze the best case for the application considering the current at different operating speeds; the time it takes to come out of low power mode; current consumption in low-power mode; and the frequency with which the system needs to switch between active and sleep modes.

Touchscreen controller programming can help reduce total system power consumption in four ways: reducing the time during which the system needs to remain in active mode; increasing the signal-to-noise ratio (SNR) by choosing the right operating voltage; taking advantage of greater CPU power; and allowing system designers to select the time the controller needs to remain in a particular power mode.

SNR is one of the most important parameters in defining touchscreen reliability. Noise from a display or charger can drastically impact touchscreen performance, including an increased risk of false touches. The higher the SNR of a device is, the better the touchscreen performance is in noisy environments.

To ensure there are no false triggers, samples need to be filtered if SNR is poor. Higher transmit voltage helps in achieving better SNR. So, empowered by high SNR, touchscreens with higher transmit voltage need fewer samples to be filtered, resulting in less time needed to process these samples to achieve the same accuracy as would otherwise be required over longer times with a lower SNR. The controller, therefore, needs to remain in the active mode for less time to achieve a particular refresh rate. The Cypress TrueTouch Gen4 controller, for example, has 10-V transmit to provide a high SNR.

Even though the voltage at which the touchscreen panel is driven is greater, the improve-



2. State diagrams, such as this one for the Cypress TrueTouch Gen4 controller, aid designers in programming power states.

ment in SNR improves performance in terms of reducing false touches in the presence of noise, while shortening the filtering cycle to use less power.

When it comes to the CPU, more measurement precision is better. That higher precision made possible by a better SNR makes it practical to use a controller with a 32-bit ARM M-Cortex core, providing faster throughput (e.g., a 60-Hz refresh rate for two-finger touch, while keeping active power to 2 mW).

Enabling system designers to select the time the controller needs to remain in a particular power mode is one of the most important aspects of touchscreen system design. The system designer should be able to select an optimal refresh rate based on the kind of application running on the mobile device and the user's battery life preferences. Real-time updatable register-configurable resources in the controller, for example, give system designers better control over power modes and the durations in which a system remains in any particular mode.

An important factor in improving the overall power consumption in handheld devices is to increase processing speed so the time the controller requires to remain in active mode decreases. Additionally, putting the controller in low-power modes for longer periods of time helps reduce the average power consumption.

In particular, a touch panel's refresh rate determines the length of time in which the controller remains in active and low-power modes. Also, refresh rate requirements are different for different applications; i.e., a gaming application will need a higher refresh rate than an application used for making phone calls. Based on the application, the designer must ensure that the refresh rate is controlled dynamically to achieve higher battery life. A touchscreen controller that can deliver low active power in the presence of multiple touches with a fast refresh rate is the best choice for system designers looking to maximize the battery life of their handheld devices. ed

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DESIGN NOTES

65V, 500mA Step-Down Converter Fits Easily into Automotive and Industrial Applications

Design Note 512

Charlie Zhao

Introduction

The trend in automobiles and industrial systems is to replace mechanical functions with electronics, thus multiplying the number of microcontrollers, signal processors, sensors and other electronic devices throughout. The issue is that 24V truck electrical systems and industrial equipment use relatively high voltages for motors and solenoids while the microcontrollers and other electronics require much lower voltages. As a result, there is a clear need for compact, high efficiency step-down converters that can produce very low voltages from the high input voltages.

65V Input, 500mA DC/DC Converter with an Adjustable Output Down to 800mV

The LTC®3630 is a versatile Burst Mode® synchronous step-down DC/DC converter that includes three pin-selectable preset output voltages. Alternatively, the output can be set via feedback resistors down to 800mV. An adjustable output or input current limit from 50mA to 500mA can be set via a single resistor. The hysteretic nature of this topology provides inherent short-circuit protection. Higher output currents are possible by paralleling multiple LTC3630s together and connecting the FBO of the master device to the VFB pin of a slave device. An adjustable soft-start is included. A precision RUN pin threshold voltage can be used for an undervoltage lockout function.

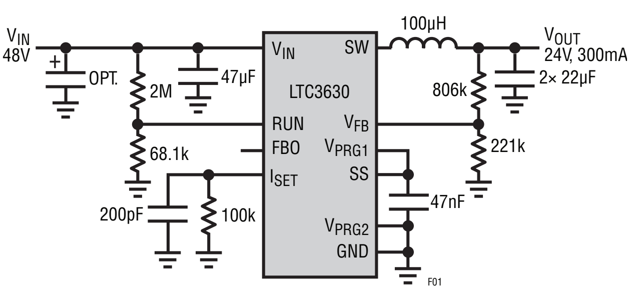

Figure 1. High Efficiency 24V Regulator with Undervoltage Lockout and 300mA Current Limit

24V Regulator with 300mA Output Current Limit and Input Undervoltage Lockout

Figure 1 shows a 48V to 24V application that showcases several of the LTC3630's features, including the undervoltage lockout and output current limit. Operational efficiencies are shown in Figure 2.

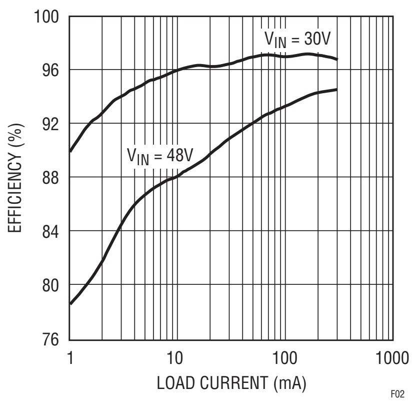

Figure 2. Efficiency of Circuit in Figure 1

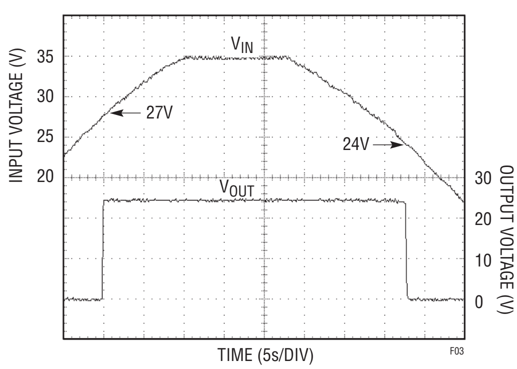

Figure 3. Input Voltage Sweep vs Output Voltage Showing Undervoltage Lockout Threshold Levels

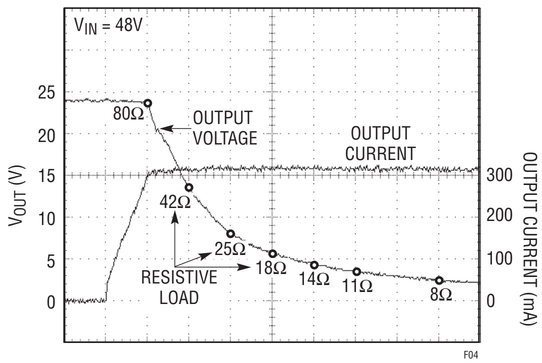

Figure 4. Resistive Load Sweep vs Output Current vs Output Voltage with Output Current Limit Set to 300mA

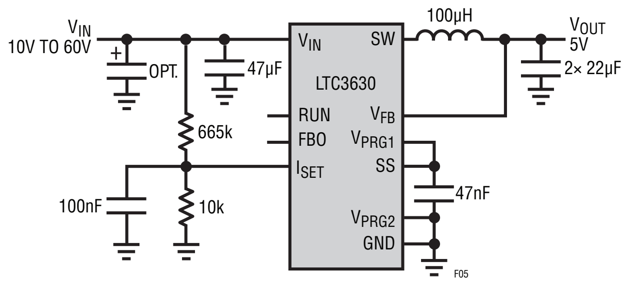

Figure 5. 5V Regulator with 55mA Input Current Limit

The RUN pin is programmed for V_{IN} undervoltage lockout threshold levels of 27V rising and 24V falling. Figure 3 shows V_{OUT} vs V_{IN}. This feature assures that V_{OUT} is in regulation only when sufficient input voltage is available.

The 24V output voltage can be programmed using the 800mV 1% reference or one of the preset voltages. This circuit uses the 5V preset option along with feedback resistors to program the output voltage. This increases circuit noise immunity and allows lower value feedback resistors to be used.

Although the LTC3630 can supply up to 500mA of output current, the circuit in Figure 1 is programmed for a maximum of 300mA. An internally generated 5µA bias out of the I_{SET} pin produces a voltage across an I_{SET} resistor, which determines the maximum output current. Figure 4 shows the output voltage as a resistive load is varied from approximately 100Ω down to 8Ω while maintaining the output current near the programmed value of 300mA. In addition, the hysteretic topology used in this DC/DC converter provides inherent short-circuit protection.

Input Current Limit

Another useful feature of the LTC3630 is shown in Figure 5. In this 5V circuit, the current limit is set by a resistive divider from V_{IN} to I_{SET}, which produces a voltage on the I_{SET} pin that tracks V_{IN}. This allows V_{IN} to control output current which determines input current.

An increased voltage on I_{SET} increases the converter's current limit. Figure 6 shows the steady-state input current vs input voltage and the available output current before the output voltage begins to drop out of regulation. For the values shown in Figure 5, the input current is limited to approximately 55mA over a 10V to 60V input voltage range.

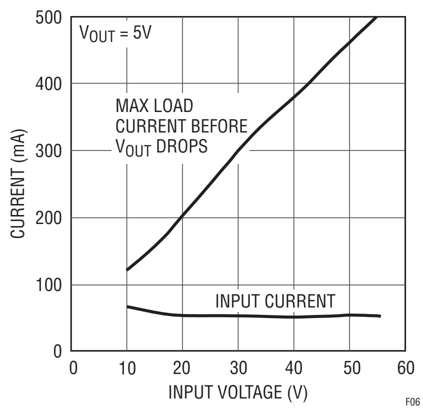

Figure 6. Input Voltage vs Load Current and Input Current with Input Current Limit Circuit Shown in Figure 5

Conclusion

The LTC3630 offers a mixture of features useful in high efficiency, high voltage applications. Its wide output voltage range, adjustable current capabilities and inherent short-circuit tolerant operation makes this DC/DC converter an easy fit in demanding applications.

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Ideas for Design

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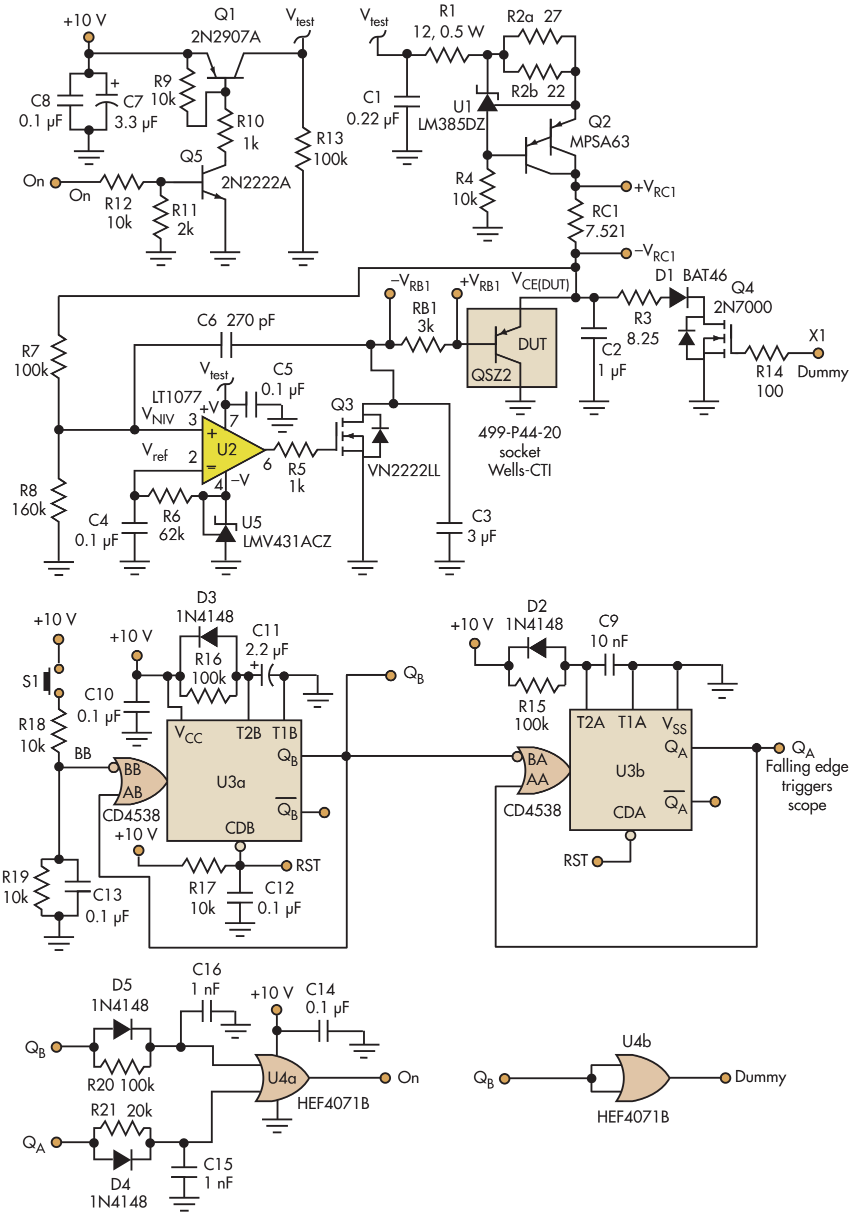
Test Setup Checks Transistors' h_{FE}s When Tight Control Is Important

THE SPREAD OF h_{FE} values in a batch of transistors may be wide enough to cause unreliable performance during mass production of a system. Consequently, bench evaluation of h_{FE} may be required during the system's development stage. Designers may have to screen samples over a spread of several years of date codes. Sometimes these measurements are made using pulsed collector current.



1. This test circuit provides the biasing conditions needed to evaluate a transistor's h_{FE} according to the manufacturer's criteria. In this example, the device under test is a QSZ2 (2SB1695), and the values chosen are specific to that device.

This idea describes how to make such measurements. For example, the QSZ2 transistor (2SB1695) specification states three biasing requirements on h_{FE}: $I_C = 0.1$ A, $V_{CE} = 2$ V, and $\Delta t_w = 1$ ms. The circuit in Figure 1 meets these requirements for h_{FE} measurement for a QSZ2 pnp transistor.

Zener U1 and its associated components form a current regulator that sources 0.1 A to the succeeding stage. During the test period (Δt_W in Figure 2), U2's feedback mechanism trims the base resistance of the device under test (DUT) while maintaining its V_{CE} at the required 2 V. This is expressed in Equation 1, in which R_{DSQ3} is automatically tuned against $I_{B(DUT)}$ and, therefore, h_{FE} and $V_{BE(DUT)}$ variations:

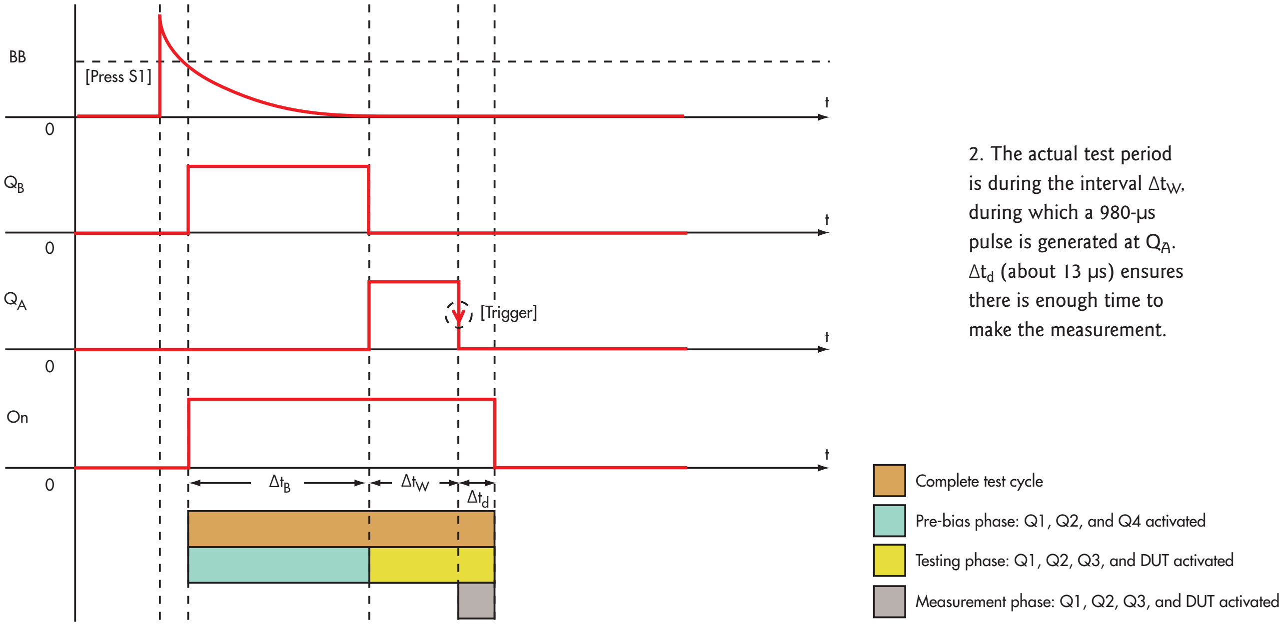
$$\begin{aligned} V_{CE(DUT)} &= V_{BE(DUT)} + V_{RB1} + V_{DSQ3} \\ &= 2\text{ V} \\ V_{BE(DUT)} &+ I_{B(DUT)}\left(R_{B1} + R_{DSQ3}\right) \\ &= 2\text{ V} \end{aligned} \quad (1)$$

Equation 2 then allows you to determine the value of the DUT's h_{FE} by monitoring V_{RB1}:

$$\frac{I_E}{I_B} = \left(h_{FE} + 1\right) \approx h_{FE} \text{ if } h_{FE} \gg 1$$

$$h_{FE} = \frac{0.1\text{ A}}{\dfrac{V_{RB1}}{3 \times 10^3}} = \frac{300}{V_{RB1}} \quad (2)$$

Basically, resistor RB1's value is set as large as possible to minimize the oscillation of $I_{B(DUT)}$ upon transition and to

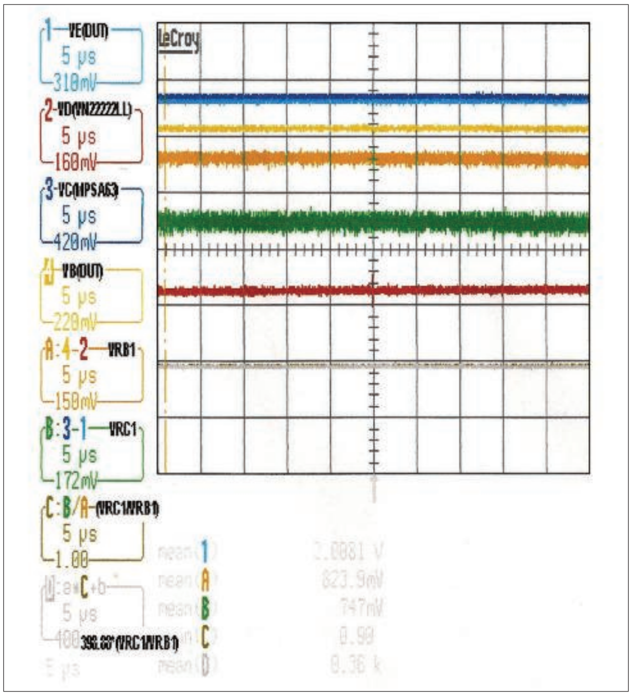


2. The actual test period is during the interval Δt_W, during which a 980-µs pulse is generated at Q_A. Δt_d (about 13 µs) ensures there is enough time to make the measurement.

maximize the signal level to ease V_{RB1} monitoring. The h_{FE} of a QSZ2 ranges from 270 to 680, so $I_{B(DUT)}$ falls between 147 µA and 370 µA.

Next, assume the worst-case $V_{BE(DUT)}$ variation of 0.5 V to 0.8 V. Then:

$$R_{B(min)} = \frac{\left(V_{CE(DUT)} - V_{BE(max)}\right)}{I_{B(max)}} = \frac{(2 - 0.8)}{370\ \mu A} = 3.243\ k\Omega \quad (3)$$



3. The falling edge of Q_A triggers an oscilloscope, which uses V_{RB1} (trace A) and V_{RC1} (trace B) to calculate h_{FE} (trace D).

$$R_{B(max)} = \frac{\left(V_{CE(DUT)} - V_{BE(min)}\right)}{I_{B(min)}} = \frac{(2 - 0.5)}{147\ \mu A} = 10.204\ k\Omega \quad (4)$$

Choose RB1 so that it is slightly below $R_{B(min)}$.

The circuitry around U3 forms two cascading one shots that, when triggered by S1, generate a 220-ms pulse ($\Delta t_B \approx R16 \times C11$) at the Q_B output. This is followed by a 980-µs pulse, Δt_W (determined by R15 and C9), at Q_A. The first pulse pre-biases and stabilizes the current source while the second one provides the needed test pulse for the DUT.

During Δ_{tB}, Q_4 is activated to sink the 0.1 A of U1, and R3 is selected so the effective voltage drop across R3, D1, and Q4 (and thus $V_{CE(DUT)}$) is slightly less than 2 V (about 1.7 V in this example). This forces U2's output and the DUT to stay "low" and "off," respectively.

At the end of Δt_B, Δt_W starts and Q4 is turned off, transferring the test current to the DUT. U2 then raises $V_{CE(DUT)}$ to 2 V and regulates it.

The high-to-low transition at the Q_A output after Δt_W triggers the measuring device (in our example an oscilloscope) *(Fig. 3)*. V_{RC1} and V_{RB1}, which correspond to I_C and I_B of the DUT, are recorded upon Q_A's trigger. R21 and C15 create Δt_d (about 13 µs), which ensures enough time to make the measurement before Q1 is gated "off."

For more, see "Anoop's Analysis" with the online version of this article at electronicdesign.com.

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Multiple Power Supplies Fortify High-Side Gate Control

FOR A RECENT design project, a robust power supply was needed to control the gates of high-side FETs. Optocouplers readily translate the logic signals up to the correct control voltages to drive the FETs. However, to ensure that the FETs turn on and off cleanly, the design required a solid –15 V relative to a wildly floating high-side rail.

A simple Zener diode and resistor, possibly with a FET buffer to ensure adequate current, might do the job under some conditions. In certain circumstances, though, the required gate drive would dip slightly below the lowest other supply rail in the system, which is in this case GND, since there are no negative supplies. At other times, it could be almost 100 V above all other supply voltages. Since the design in question was to be used in a production scheme, the solution had to stay away from proprietary, expensive, single-source parts.

The design already included a switching supply to efficiently convert from an incoming supply at approximately 12 V, down to an internal logic supply at 4 V *(Fig. 1)*. The switch node of that supply, at the junction of U610 pin 3, L610, and D611, swings between the incoming 12-V rail and a diode drop below ground—approximately –0.5 V. This could provide the feed for a charge pump. However, the 4-V supply can't be lightly loaded, which would cause insufficient drive at this point to support a charge pump.

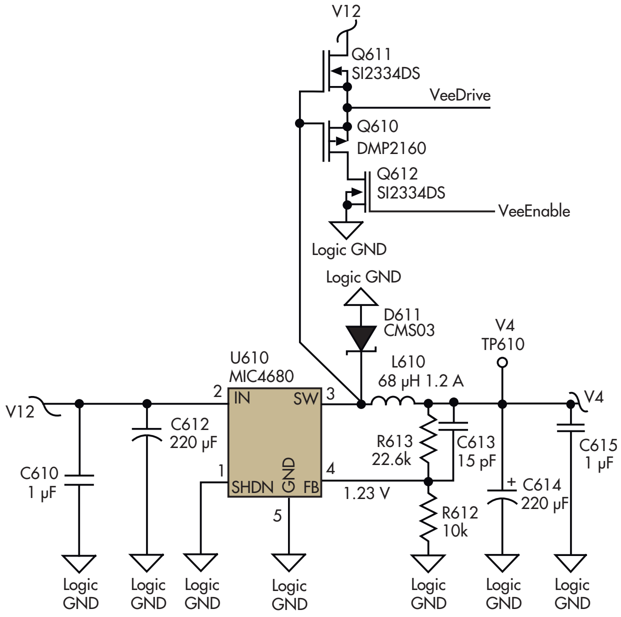
To guarantee a solid drive for the charge pump, power is derived directly from the 12-V supply and ground using transistors Q610 and Q611. Note that these aren't configured in a traditional inverter configuration, which could suffer from shoot-through when both are turned on simultaneously during the gate's voltage transition.

Instead, transistors Q610 and Q611 are simple source-followers. As the gate voltage rises more than about a volt above the present value of net VeeDrive shown in Figure 1 at the source terminals of Q610 and Q611, Q611 turns on, pulling up VeeDrive so it remains about 1 V below the gate voltage all the way up. On the falling edge at the switch node, the gate voltage falls, Q611 is turned solidly off, and Q610 begins to turn on as the gate voltage falls about 1 V below VeeDrive. Therefore, VeeDrive follows the gate voltage down to within about 1 V of Logic GND.

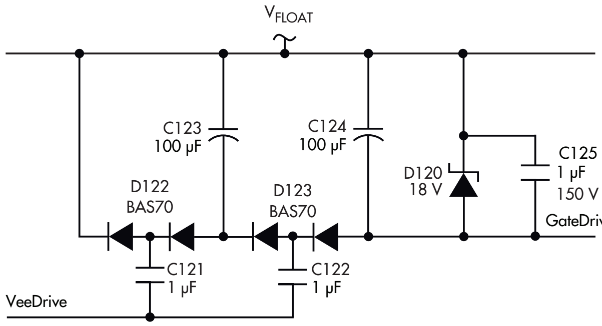
As a result, VeeDrive provides a sharp and muscular square-wave that swings between about 1 V and 11 V (relative to Logic GND), for a total of 10 V p-p. It's robust enough to drive several charge pumps, if the need arises for multiple supplies. In fact, this one square-wave provided all four supplies required by the design at hand.

Q612 is an optional component. Raising net VeeEnable, the gate drive to Q612, to a logic high voltage turns on Q612 and enables the charge pump action. Lowering VeeEnable back to Logic GND turns off Q612 and disables the low-side drive, allowing VeeDrive to settle to a steady state just below V12. This will save power during those times that don't require the GateDrive supply.

Figure 2 shows one of the four charge pumps using VeeDrive to provide a floating supply that follows a specific floating rail V_{FLOAT}. Because the gate drive must be at least 10 V below V_{FLOAT}, and some drops occur in the diodes, a two-stage



1. The 12-V downswitcher, which is already in the design, provides a square-wave to generate VeeDrive from V12 with about a 10-V swing.



2. The charge pump generates a robust supply that always tracks 15 V below V_{FLOAT}, even if that voltage is below ground. The voltage also can be placed above V_{FLOAT} by simply reversing the diodes and the polarized capacitors.

charge pump is employed. My actual design includes four copies of the charge pump shown in Figure 2 to produce GateDrive relative to each of four different floating supply rails. A single VeeDrive drives all four rails.

Starting with accumulators C123 and C124 discharged, when VeeDrive goes low (1 V), C121 charges up through C123 and the right half of dual diode D122 to approximately V_{FLOAT} – 1.5 V (after accounting for an approximate 0.5-V drop of the diode). When VeeDrive goes high (11 V), C121 discharges through the left half of D122 to V_{FLOAT} – 10.5 V (11 V – the 0.5-V drop in the diode). As cycling continues, charge continues to be drawn through C123, gradually charging up C123. In steady state, with no current being drawn off, C123 will charge up to 9 V, leaving its negative end at V_{FLOAT} – 9 V.

The second-stage charge pump, consisting of C122, D123, and C124, operates similarly to produce an additional 9-V offset. As a result, GateDrive is 18 V below V_{FLOAT}. In actual practice, of course, some current is being drawn off and there are more resistive drops, so the actual voltage settles close to 15 V. Should the voltage somehow exceed 18 V, Zener D120 clamps the voltage to no more than 18 V, which guarantees that the GateDrive's 20-V maximum limitation isn't surpassed. C125 helps to suppress switching noise caused by sudden loads on the supply during switching.

This arrangement can be readily adapted to many situations. If V_{FLOAT} can change, even fairly rapidly, the large size of accumulators C123 and C124 relative to flying capacitors C121 and C122 ensures that GateDrive maintains a fairly constant offset from V_{FLOAT}. This will hold true while the flying capacitors rapidly charge or discharge to the appropriate levels to continue the charge pump action.

Because the flying capacitors are ceramic (and thus unconcerned about polarity), GateDrive will remain 15 V below V_{FLOAT}, even if V_{FLOAT} should fall all the way to Logic GND or below. The flying capacitors must, however, have a sufficient voltage rating so that the highest value of V_{FLOAT} can occur in practice.

The output voltage at GateDrive is very consistent in practice and nicely matches the theoretical values after accounting for the various drops in the feed. There are several ways to adjust this voltage, though. Stages can be easily added to or removed from the charge pump to produce different multiples of the input voltage. If the input voltage is adjustable, finer granularity is possible.

It's easy to configure GateDrive when it must be above rather than below V_{FLOAT}. Simply flip the polarized accumulator capacitors to allow for the new state, and reverse the diodes. With those simple changes, the design will produce GateDrive at approximately V_{FLOAT} + 15 V.

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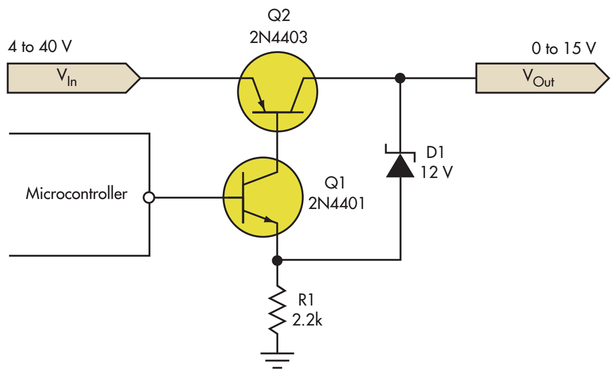
High-Side Switch Provides Overvoltage Protection With Only Four Components

ALTHOUGH MICROCONTROLLERS GENERALLY run at low voltages, such as 3.3 V, they often need to control loads running at higher voltages like 12 V. If switching the low side isn't an option, the microcontroller needs a way to control a high-side switch from its low-voltage output.

The circuit in the figure provides a simple solution. Besides using few components, it provides overvoltage protection as a bonus. As long as the input voltage stays below approximately 15 V, the output voltage will equal the input voltage (minus the tiny V_{CE} drop across transistor Q2).

Once the input voltage exceeds that limit, however, the circuit begins acting as a low-dropout regulator (LDO), limiting the output voltage to 15 V. This feature is useful if the input voltage occasionally exceeds the rated load voltage, but the load switch needs to remain efficient otherwise.

Transistor Q1 and resistor R1 form a current sink. The microcontroller's output voltage (V_{OH}) and Q1's base-emitter drop (V_{BE}) create a stable voltage across the resistor, producing a current of (V_{OH} – V_{BE})/R1, or about 1.2 mA for a 3.3-V microcontroller. Most of this current flows through Q2's base,



The microcontroller turns the load off by controlling a high-side switch formed by Q1 and Q2. The current-sink action of Q1 controls the load voltage.

which controls the load. This current drops to zero when the microcontroller output goes low, switching the load off.

Zener diode D1 provides an alternative path for R1's current. If the diode's breakdown current is V_Z, it will begin to conduct when the output voltage exceeds $V_Z + V_{OH} - V_{BE}$, or about 14.6 V for a 12-V diode and a 3.3-V microcontroller. Since the voltage across R1 is constant, the diode effectively "steals" current from the base of Q2, reducing the amount of current flowing into the load. This negative feedback causes the circuit to act like a voltage regulator.

To apply this circuit to your application, adjust R1 so Q2's base current equals the maximum load current (I_{MAX}) divided by Q2's gain (β), or $R1 = \beta \times (V_{OH} - V_{BE})/ I_{MAX}$. Be sure to select a transistor for Q2 that can dissipate the heat generated during an overvoltage event.

There is no straightforward way to calculate the exact output voltage, so the quickest approach is to try a few Zener diode voltages and pick the one that works. A good starting point is to pick Zener voltage V_Z to equal to the desired output voltage minus the microcontroller voltage. This is just an overvoltage protector, so great accuracy should not be necessary.

If the overvoltage protection isn't important, simply remove the Zener diode. The resulting load switch uses only three components and retains the advantage of driving Q2's base with an actual current source. Even if the input voltage changes, Q2's base current remains constant.

WILLIAM SWANSON graduated in 2005 with a BSEE from Cal Poly San Luis Obispo. He currently designs boards and writes firmware for an early stage startup company.

VISHWAS VAIDYA | TATA MOTORS vmv74342@tatamotors.com

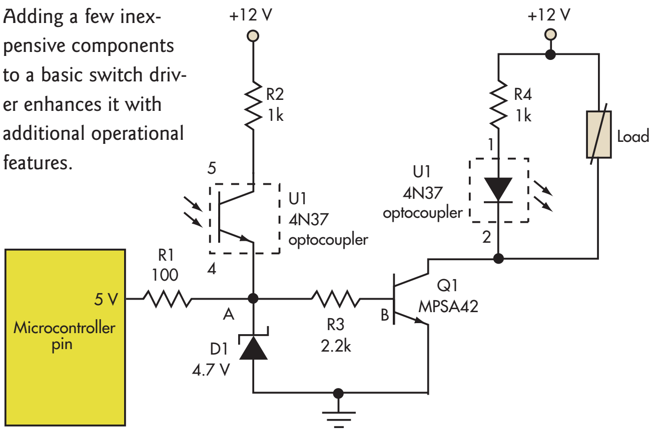
Add Short-Circuit Protection, Diagnostics To Automotive High-Side/Low-Side Driver

AUTOMOTIVE APPLICATIONS NEED "smarter" drivers for their switches, which handle loads ranging from a fraction of an ampere to several amperes. Not only are these smart chips costly, but many times, they also aren't available for the 24-V applications used in this application area. Further, they usually come in quads and pairs, so designers are paying for unused switches.

The simple circuit in the figure adds a few low-cost components to a "dumb driver" to make it a smart one, with added short-circuit protection and built-in diagnostics *(see the figure)*. Transistor Q1 is an inexpensive driver that can withstand a few hundred volts and drive a few hundred milliamps. The microcontroller output goes high to latch the transistor on via the phototransistor of optocoupler U1. It next configures the output pin into an input, while U1 keeps the transistor on by supplying its base current through R2.

U1 has its LED in the load circuit of Q1 for detecting the short circuit. Under short-circuit conditions, it is "starved" of current, turning off the phototransistor driving power-switch Q1's base and protecting it. The CPU input pin can sample the occurrence of the short circuit at its convenience as needed, such as every few seconds.

The voltage at point A changes from a few hundred millivolts during short circuit to 4.7 V during normal operation, providing a clear indication to the CPU's input port. For retry-based recovery from short circuit, the CPU may turn itself into an output again at its leisure for restoring the "on" status and recovering the switch from its "trip-off" condition. The CPU pin again now goes into input mode to sense if the external short is persisting. Depending on the application, a suitable retry regime can be worked out based on the end application.



Adding a few inexpensive components to a basic switch driver enhances it with additional operational features.

During normal operation, the CPU can easily turn off the switch by pulling the output low. The CPU can issue a logic low by turning the pin into output again whenever it needs to switch Q1 off during normal operation.

VISHWAS VAIDYA is an assistant general manager of the electronics division at Tata Motors Ltd. He is based in Pune, India. He holds a master's degree in control engineering from the Indian Institute of Technology, New Delhi, India.

SOL JACOBS | TADIRAN BATTERIES sjacobs@tadiranbat.com

Power Your Wireless Sensors For 40 Years

Battery replacement often is difficult or impossible in remote sensing systems. $LiSOCl_2$ batteries can extend the time between service calls to decades.

SHORT-RANGE WIRELESS SENSORS are experiencing rapid growth in a wide range of applications: RFID to GPS tracking, traditional automatic meter reading (AMR) plus advanced metering infrastructure (AMI), mesh networks, system control and data acquisition (SCADA), data loggers, measurement while drilling, oceanography, environmental systems, emergency/safety systems, military/aerospace systems, and more. Many of these applications rely on long-life lithium batteries with a potential lifespan of up to 40 years, especially in remote locations where battery replacement is difficult or impossible.

1. Bobbin-type lithium-thionyl-chloride ($LiSOCL_2$) chemistry is preferred for remote wireless sensors because of its high specific energy, high energy density, wide temperature range, and very low annual self-discharge rate.

However, actual battery life is often difficult to prove because it's not particularly easy to test primary lithium batteries for lifespan in conditions that accurately simulate in-field use. Therefore, design engineers must be extremely diligent in demanding verifiable information from battery manufacturers to avoid unscheduled battery replacements, which can incur 10 times the initial cost of the original battery *(see "Specifying A Primary Lithium Battery," p. 70)*.

$LiSOCL_2$ ENABLES 40-YEAR SERVICE

Bobbin-type lithium-thionyl-chloride ($LiSOCl_2$) chemistry is overwhelmingly preferred for remote wireless sensors because it offers the highest specific energy (energy per unit weight) and energy density (energy per unit volume) of all current battery chemistries *(Fig. 1)*. Lithium delivers high energy density due to its large electric potential, which exceeds other metals. It produces the higher 2.7- to 3.9-V dc voltages typical of lithium batteries.

2. $LiSOCL_2$ batteries have been utilized for decades in AMR applications, with some systems still operating on their original batteries after 28 years.

Lithium cells use a non-aqueous electrolyte, enabling certain $LiSOCl_2$ batteries to operate in extreme temperatures typically ranging from –55°C to 125°C. Certain cells are adaptable to the cold chain, down to –80°C. For example, Tadiran tested $LiSOCl_2$ cells in a cryogenic chamber and subjected them to progressively lower temperatures down to –100°C. These $LiSOCl_2$ cells continued to operate as necessary.

$LiSOCl_2$ chemistry is also renowned for long life. Formerly known as Hexagram, Aclara began using bobbin-type $LiSOCl_2$ batteries in 1984 to power meter transmitter units (MTUs) for automated meter reading systems used by water and gas utilities *(Fig. 2)*.

These older devices are being replaced by more technically advanced equipment, but the original batteries are still operating after 28 years in the field. This real-life example gives AMR/AMI equipment manufacturers the confidence to offer long-term performance contracts that increase the total return on investment (ROI) of an AMR/AMI network.

NOT ALL BATTERIES ARE EQUAL

While many battery manufacturers claim low annual self-discharge rates at ambient temperatures, such claims may be invalid depending on the construction method or specific design requirements. For example, testing on Tadiran batteries shows that these cells have an average self-discharge of approximately 0.7% per year, while other batteries using the same chemistry have 2.5% to 3% annual self-discharge.

The use of inferior raw materials or non-standard manufacturing techniques can lead to uneven battery performance. This includes batch-to-batch inconsis-

3. Tadiran's PulsesPlus batteries utilize a patented hybrid layer capacitor (HLC) to deliver the high current pulses required for advanced two-way communications.

4. Tadiran's TRR series batteries don't need an HLC but can deliver moderate current pulses without voltage or power delay.

tencies that raise the risk of anomalies in the field, even if initial performance characteristics seem identical. As a result, advanced manufacturing processes based on Six Sigma and statistical process control (SPC) methodologies are required to ensure consistent product quality.

When it comes to selecting the ideal battery, each application is unique in terms of a set of application-specific parameters:

- Overall energy consumption during sleep mode
- Energy consumption during active mode entailing the size, duration, and frequency of high current pulses, where applicable
- Battery self-discharge rate, which is sometimes higher than the actual sensor average-use rate
- Equipment cutoff voltage
- Length of storage periods
- Thermal environments

Experienced battery manufacturers know how to create a customer-specific energy-use profile along with sensitivity analyses. The end result is a mathematical model that accurately predicts battery-life expectancy.

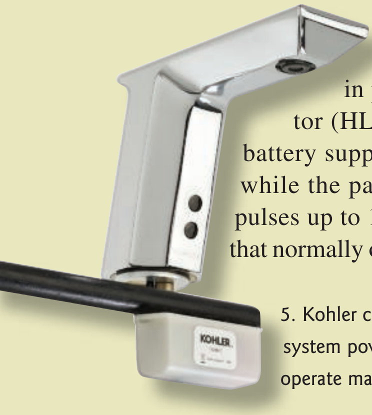
TWO-WAY REQUIREMENTS

Wireless sensors are increasingly providing "on demand" two-way RF communications, with the device operating in two modes. One is a dormant or sleep state where daily power consumption ranges from nil to a few microamps. The other is an active interrogation and transmission mode requiring high current pulses up to hundreds of milliamps for short-range RF communications to a few amps for certain GPRS protocols.

If a wireless sensor remains dormant for extended periods at elevated temperatures and is occasionally interrupted by a high current pulse, lower transient voltage could result during initial battery discharge, especially in low temperatures. This phenomenon, which is known as transient minimum voltage (TMV), is strongly related to the quality of the battery electrolyte or cathode.

One alternative is to combine supercapacitors with lithium cells, a solution that tends to fail prematurely due to relatively high self-discharge. A supercapacitor comprising dual 2.5-V capacitors also needs a balancing circuit to ensure acceptable service life. And, supercapacitors have a limited temperature range, disqualifying them for use in some applications.

To address the needs of advanced two-way communications, combine a standard bobbin-type $LiSOCl_2$ battery that works



in parallel with a hybrid layer capacitor (HLC). Tadiran's PulsesPlus $LiSOCl_2$ battery supplies long-term, low-current power while the patented HLC delivers high-current pulses up to 15 A to eliminate the voltage delay that normally occurs when a pulsed load is initially drawn *(Fig. 3)*. It allows users to program their devices to communicate low-battery status alerts. A 3.6-V system indicates when battery capacity is approximately 95% exhausted, while a 3.9-V system indicates when 90% capacity is gone.

5. Kohler commercial faucets utilize a hybrid energy system powered by $LiSOCl_2$ batteries with HLCs to operate maintenance-free for 30 years.

The HLC is a single unit that works in the 3.6-V to 3.9-V nominal range to avoid the balancing and current leakage problems associated with supercapacitors. It has been field proven to deliver high current pulses and a high safety margin.

Tadiran's TRR series $LiSOCl_2$ batteries are designed for moderate current pulse applications *(Fig. 4)*. These batter-

SPECIFYING A PRIMARY LITHIUM BATTERY

OPTIMIZING A BATTERY for long-term reliability involves the choice of chemistry, the cell design, the quality of the mechanical components, the purity of the raw materials, and the specific manufacturing processes employed. Any shortcut along the way can negatively impact battery service life.

Selecting the optimal power management solution begins with a battery comparison matrix that accounts for various application-specific parameters, including desired voltage, size and weight, expected service life, required temperature range, and cost. Special requirements also need to be considered, including high current pulses, high discharge rate, and minimum equipment shut-off voltage.

Challenging environmental requirements may also be factors. For example, many automatic meter reading (AMR) and advanced metering infrastructure (AMI) meters are designed for use in underground pits, and they should be encased in acrylic to help protect them from corrosion. Available board real estate and circuits assembly criteria also need to be considered. For instance, lithium-thionyl-chloride ($LiSOCl_2$) cells come in a wide variety of sizes and configurations, with through-hole soldering leads or with wire harnesses.

From a practical standpoint, it is essential to determine whether an $LiSOCl_2$ battery is indeed necessary. For example, if the sensor is easily accessible and replaceable or it is located near hard-wired ac power, a relatively inexpensive alkaline or rechargeable lithium battery may suffice.

If the application requires long life, low self-discharge, and a wide temperature range, then $LiSOCl_2$ chemistry is unsurpassed. A common example is the EZ-Pass electronic toll tag, an RFID application that is commonly exposed to extreme heat, vibration, and rapid temperature cycling, yet demands highly reliable long-term maintenance-free performance *(see the figure)*. For this particular application, $LiSOCl_2$ chemistry is the sole choice. $LiSOCl_2$ chemistry is also well suited for challenging applications, such as medical RFID tags that must withstand the prolonged heat autoclave sterilization, and data loggers that must operate continuously in the cold chain at –80°C.

EZ-Pass electronic toll tags are subject to extreme heat, vibration, and rapid temperature cycling while demanding highly reliable, long-term maintenance-free performance. $LiSOCl_2$ batteries can meet these specifications.

When specifying an $LiSOCl_2$ battery, be mindful that competing batteries using the exact same chemistry can exhibit very different self-discharge rates, which are largely governed by the chemical composition of the electrolyte. If the electrolyte is made from inferior materials with high levels of impurities, it could result in a higher self-discharge rate as well as greater impedance. An experienced battery manufacturer knows how to blend special additives into the electrolyte to reduce impedance.

Calculating expected service life based on nominal capacity can be highly misleading since the total volume of active ingredients is limited by the size of the cell. As a result, nominal capacity values typically do not vary substantially between competing brands. Instead of comparing nominal capacity, design engineers should compare the equivalent operating capacity (EOC) of competing brands to determine the estimated service life, considering the battery's self-discharge rate, its application current profile, and the environmental conditions.

Appearances can be deceiving, so it is also important to review raw material quality, manufacturing systems, and quality control procedures, as any production shortcut could severely impact battery service life.

As part of the vendor evaluation process, be sure to demand customer testimonials along with fully documented and verifiable performance test data, including discharge curves, battery pulses, low-temperature pulses, and repeatability, as well as safety tests for exposure to vibration, puncture, and short circuit.

$LiSOCl_2$ batteries are not created equal. Proper due diligence is required during the vendor evaluation process to ensure that the right battery is powering your wireless sensor, one that can deliver the energy that is necessary for decades of maintenance-free performance. ed ies don't require an HLC. Or, they can use a smaller HLC to deliver high capacity and high energy density without voltage or power delay. They virtually eliminate the voltage drop associated with a standard $LiSOCl_2$ battery when it faces an initial load, especially at cold temperatures or when the battery is nearing the end of its operating life.

APPLICATIONS

The Kohler Hybrid energy system is the first battery-powered, no-maintenance, water-saving solution designed to last 30 years *(Fig. 5)*. This commercial faucet uses Kohler Insight Technology to continuously analyze and log feedback from its environment, automatically recalibrating the factory default settings to eliminate false actuations caused by low lighting or highly reflective lighting, two challenging conditions that commonly plague battery-powered systems.

To maintain a 30-year life, the system employs a $LiSOCl_2$ battery with a patented hybrid layer capacitor. When the faucet opens, the capacitor collects and discharges small electrical charges. Additionally, the faucet is mercury-free, with no harmful chemicals or additives.

Powercast Corp. uses hybrid lithium batteries to power its WSN-1101 wall-mounted sensor, which measures indoor temperature and humidity *(Fig. 6)*. The WSN-1101 finds employment in HVAC, lighting control, energy management, industrial monitoring, and medical applications.

Designed for indoor use in temperatures ranging from –20°C to 50°C, the sensor can transmit data once per minute for more than 25 years to the Powercast WSG-101 wireless gateway, which interfaces with wired building automation systems (BAS) networks via industry-standard protocols.

The use of a long-life $LiSOCl_2$ battery enables Powercast to offer a highly cost-effective and reliable 25-year system that instantly converts buildings into smart buildings. It proves to be an ideal upgrade for older structures with concrete or cinder block walls that cannot be easily retrofitted for hard-wired solutions. ed

SOL JACOBS is the vice president and general manager of Tadiran Batteries. He has more than 25 years of experience in developing solutions for powering remote devices. He holds a BS in engineering and an MBA.

6. Powercast WSN-1101 battery-powered wireless sensors instantly convert buildings into smart buildings with remote monitoring of HVAC, lighting, and other building automation systems.

COMPONENTS

POWER SOURCES

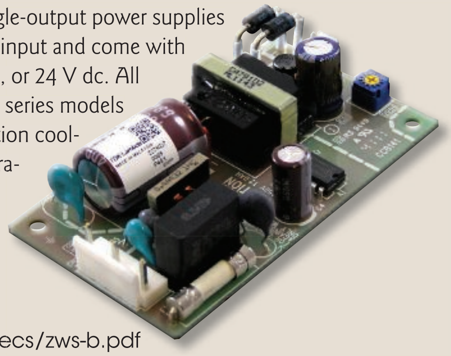
COMPACT 800-W AC-DC SUPPLIES EYE INDUSTRIAL POWER APPS

MicroPower Direct's MPU-800S ac-dc power supplies deliver 800 W of output power in U-channel packaging. Features include filtering to EN 55022 Class B, active power-factor correction to EN 61000-3-2 D, peak output power to 900 W, and I/O isolation of 3000 V ac. Models operate from a universal input of 90 to 264 V ac, which provides tightly regulated single outputs. Outputs are set to 12, 24, or 48 V dc, but are customizable (through the company) over a range of 2 to 60 V dc. Overload, overvoltage, overtemperature, and short-circuit protection is included. N+1 current share can be used to connect up to four units. Mean time between failure (per MIL HDBK 217F) is greater than 150 hours. Operating temperature ranges from 0°C to 70°C (ambient). Targeted applications include industrial power that demands high power density and robust performance at low cost.

MICROPOWER DIRECT
www.micropowerdirect.com

TWO-INCH-WIDE SWITCHING POWER SUPPLIES RANGE FROM 10 TO 30 W

Open-frame, high-density, high-efficiency power supplies recently unveiled by TDK-Lambda are merely two inches wide. Output power ratings for the ZWS10-30B series switchers are 10, 15, and 30 W. They consume less than 0.5 W under no-load conditions (0.2 W typical). In addition to the two-inch width, their profiles are one inch or less depending on the output rating. The 10-, 15-, and 30-W models are 2.89, 3.44, and 4.13 inches long, respectively. These single-output power supplies operate from a universal 85- to 265-V ac input and come with a choice of output voltage: 3.3, 5, 12, 15, or 24 V dc. All outputs are user-adjustable by ±10%. All series models can be operated at full load with convection cooling from –10°C to 50°C ambient temperature (up to 70°C with suitable derating). Applications include industrial, test and measurement, communications, and point-of-sale terminals/displays.



TDK-LAMBDA AMERICAS INC.
www.us.tdk-lambda.com/lp/ftp/specs/zws-b.pdf

DC-DC CONVERTER ENSURES STABLE, ELECTRICALLY ISOLATED SUPPLY

Targeting 24-V dc power-supply applications, Weidmuller's latest PRO-M Power Supplies dc-dc converter avoids critical earth loops and thus can generate a stable, low-distortion output voltage from an unregulated or distorted input voltage. The electrically isolated device features high resistance to shock and vibration and 91% efficiency. Its 60-mm width and ability to be mounted side by side without clearance requirements saves cabinet space. A status signal enables remote monitoring—an alarm output monitors the status of the 24-V output voltage, and an LED indicates dc OK status for the output voltage.

WEIDMULLER
www.weidmuller.com

CHASSIS MOUNT ADDS VERSATILITY TO 25-W AC-DC SUPPLY

A series of ac-dc switching supplies developed by ConTech offers a flexible wrinkle to power design thanks to use of a chassis mount case. The CM25 series offers 25 W of fully regulated power. An easily accessible terminal block and output-voltage adjustment potentiometer build in the versatility for the switches' use in a wide range of applications. Available output voltages are 5, 12, 24, and 48 V dc, with efficiencies up to 83%. Universal input voltage ranges from 88 to 264 V ac. All models integrate short-circuit, overvoltage, and overload protection. The metal-cage chassis mount case is designed for free air-convection cooling. The series is rated for 3000-V ac isolation and is RoHS-compliant.

CONTECH (DIV. OF CALEX MFG.)
www.ConTech-us.com/pdf/CM25.pdf

HIGH-DENSITY AC-DCs OFFER UP TO 93.5% EFFICIENCY

Telecom, ITE, and industrial equipment are target applications for the 360-W CFM361S series of ac-dc power supplies that combine high power density with efficiency that tops out at 93.5%. The devices, developed by Power Sources Unlimited, come in single 12-, 24-, and 48-V output models with 5 V_{SB} (standby) at 500 mA and 12-V fan output at 300 mA. Universal input (with active power factor correction) ranges from 90 to 264 V ac, and operating temperature ranges from –20°C to 70°C (open frame) or –20°C to 85°C (enclosed). All devices also feature remote voltage sense and on/off remote control. The footprint for open-frame versions measures 3 by 5 by 1.6 in., while the optional U-frame/cover measures 3.4 by 5.4 by 1.7 in. All models are approved to UL/EN60950-1, EN55022 Class B standards and carry the CE Mark (LVD).

POWER SOURCES UNLIMITED INC.
www.psui.com/cincon/cfm361s.htm

PASSIVE COMPONENTS

WIREWOUND RESISTORS FLAUNT 12-kV SURGE WITHSTAND CAPABILITY

A series of axial-cemented wirewound resistors offers a customized high-voltage surge withstanding capability up to 12 kV—a first, according to developer Vishay Intertechnology. The maximum allowed surge-handling capacity depends on the resistor model and ohmic value. The Z300-C series Draloric devices feature non-flammable cement coatings and high-grade ceramic cores to boost safety in overload conditions. Power rating ranges from 1 to 6 W at an ambient temperature of 40°C and 0.9 to 5.4 W at 70°C. Resistance ranges from 0.15 Ω to 10 kΩ, with resistance tolerances of ±5% and ±10%.

VISHAY INTERTECHNOLOGY INC.

www.vishay.com

INTERCONNECTS

IPX7-RATED CRADLE CONNECTOR STAYS WATERPROOF

Yokowo says its new connector prevents the potentially damaging effects of liquid seepage into cradle connectors. The company's latest male side (cradle) connector, with an IPX7 rating, features a patent-pending design that reverses the direction of the pogo pins in the housing and incorporates a rubber strip. As a result, it becomes waterproof against liquids that would otherwise penetrate through the gaps in the typical moving-part construction of pogo pins. Rated currents range from 2 to 10 A, and contact resistance ranges from a minimum of 50 to 100 mΩ (adjustable according to customer requirements). Operating temperature ranges from –45°C to 80°C. Voltage is 12 V, and durability measures 20k to 100k. Applications include cradle or docking chargers, cell phones, tablet PCs, laptops, barcode readers, medical devices, and all handhelds such as GPS units.

YOKOWO AMERICA CORP.

www.yokowoconnector.com

CONNECTOR'S LOCKING MECHANISM FEATURES "AUDIBLE CLICK"

A narrow 1-mm-pitch, board-to-wire connector developed by Hirose Electric features a positive locking mechanism located at its center that provides a clear, tactile click sensation regardless of the number of repetitive cycles. The latch prevents both uneven locking commonly attributed to side locks and incomplete mating. The DF50 connector's distinct audible click, which confirms that the mating sequence is secure, can be beneficial when dealing with high-vibration and other critical applications. Its structure maintains a cable pull force of 10N minimum to prevent contacts from pulling loose during installation. Current rating is 1 A per pin, voltage rating is 100 V ac-dc, contact resistance measures 50 mΩ maximum at 20 mV (1 mA), and operating temperature ranges from –35°C to 85°C. The connector is designed with blade-type contacts attached to a thick housing wall that's resistant to cracking or deformation. Applications include LCDs, LCD TVs, PDPs, wireless local-area networks (WLANs), notebooks and laptops, and industrial control.

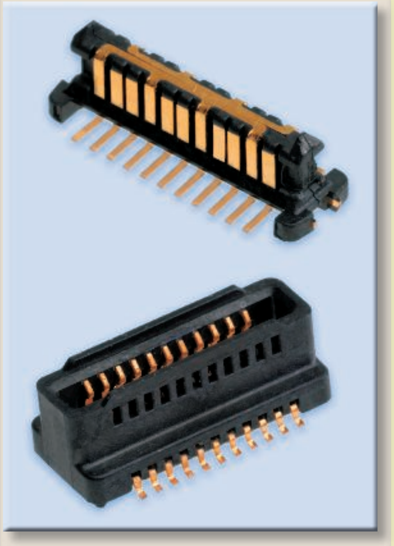
HIROSE ELECTRIC CO. LTD.

www.hiroseusa.com

INTERCONNECTS

LOW-PROFILE MEZZANINE CONNECTOR SUPPORTS 40-GBIT/S SPEEDS

Measuring a mere 4.00 to 10.00 mm, plus a 0.80-mm pitch, Molex's SpeedStack mezzanine connectors handle up to 40-Gbit/s data rates per differential pair. The devices come in circuit sizes of 22, 44, 60, 82, 104, and 120 with a range of six to 32 differential pairs, providing greater design flexibility. The 100-Ω version offers greater impedance control; an 85-Ω model (scheduled for release this June) will support PCI Express Generation 3.0 and Intel QuickPath Interconnect requirements for

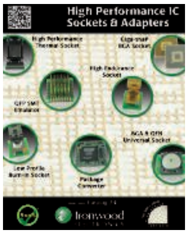


next-generation I/O and memory signaling. The connector's insert-molded wafer design includes a protective shrouded housing, which supports the terminal location and enhances electrical balance. Also, the narrowness of the housing allows for airflow and promotes system cooling. A common ground pin helps improve electrical performance and minimize crosstalk. The connectors will find homes in applications across a number of industries that contend with limited board space, such as telecommunications, military, medical, and consumer.

MOLEX INC.
www.molex.com/link/speedstack.html

Catalog Literature Review

HIGH PERFORMANCE SOCKETS & ADAPTERS



Includes 40 GHz bandwidth sockets for BGA and QFN, only slightly larger than IC with integral heatsink for medium power and optional heatsinking to over 100 watts. Up to 500k insertions. Adapters for prototype, test, package conversion, and more. Quick-Turn volume adapters are our specialty.

Ironwood Electronics
1335 Eagandale Court
Eagan, MN 55121
T: 800-404-0204
F: 952-229-8201

www.ironwoodelectronics.com

Ironwood Electronics

IR's Advanced Versatile SmartRectifier™ IC with SYNC Function Simplifies Design and Reduces Overall System Cost

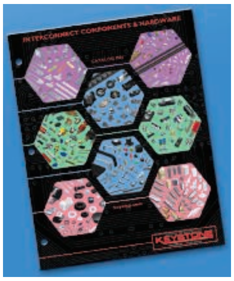
IR expands its family of SmartRectifier™ ICs with the introduction of the IR1169 high speed synchronous rectifier (SR) controller for flyback, forward and half-bridge converters used in AC-DC adapter, PC, server and Telecom SMPS applications.

The IR1169 features a SYNC function that turns off the SR MOSFET to prevent reverse current flow under continuous conduction mode (CCM) operation, thereby improving functionality and reliability. Unlike existing solutions, the advanced new device uses direct sensing with capacitor coupling to help simplify design and reduce overall system cost.

Featuring IR's proprietary 200V high-voltage IC technology, the IR1169 supports burst mode operation to deliver efficiency benefits even at light loads. Ruggedness and noise immunity are accomplished using an advanced blanking scheme and double-pulse suppression that allows reliable operation in fixed and variable frequency applications.
Other key features include maximum 500 kHz switching frequency, anti-bounce logic and UVLO protection, 4A peak turn-off gate drive current, micropower start-up and low quiescent current, 10.7V gate drive clamp, 50ns turn-off propagation delay and a wide Vcc operating range from 11V to 20V.

More information is available on the **International Rectifier** website at
http://www.irf.com/whats-new/nr130124.html
For more information, contact Sian Cummins,
scummin1@irf.com, 310-252-7148.

KEYSTONE'S M60 CATALOG - OVER 1,000 NEW PRODUCTS!



- Battery Clips, Contacts & Holders
- Fuse Clips and Holders
- Terminals and Test Points
- Spacers and Standoffs
- Panel Hardware
- Pins, Plugs, Jacks and Sockets
- PC Board & Multi-Purpose Hardware...MORE!

Keystone Electronics Corp.
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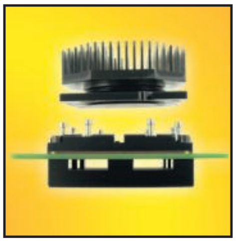
Request your copy www.keyelco.com

High Performance - 10 GHz Socket Technology



SG-BGA-8019 is constructed with high performance and low inductance elastomer. The temperature range is -40 C to +100 C. The pin inductance is 0.15 nH. Capacitance to ground is 0.10 pF. Current capacity is 2A per pin. This elastomer socket technology, applicable for BGA pitches from 0.3 to 1.27mm, allows these pitch BGA's to operate to over 10 GHz without significant contactor loss.

Ironwood Electronics, Inc.
1335 Eagandale Court
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T: 800-404-0204 • F: 952-229-8201
Email: info@ironwoodelectronics.com
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Otter Computer, Inc.

BILL WONG | EMBEDDED/SYSTEMS/SOFTWARE EDITOR bill.wong@penton.com

Low-Power Design Enables PoE Networking

POWER CONSUMPTION IS on everyone's specification checklist these days. Minimal power consumption means longer use between charges for smart phones, tablets, and laptops. It also means not having to liquid-cool thousands of cores in high-performance computing (HPC) systems. And, it means that devices can be wired and powered using different technologies like Power-over-Ethernet (PoE).

PoE has been around for more than a decade. It's well known in the network industry, but it has been primarily used for network devices like wireless access points and Voice over Internet Protocol (VoIP) telephones. It greatly simplifies wiring since deployment no longer requires a power outlet.

PoE requires a 48-V source that's typically found in the Ethernet hub or switch. It's possible to add a power injector inline with a connection, but that tends to be used as a stopgap measure or when only a single PoE device is needed.

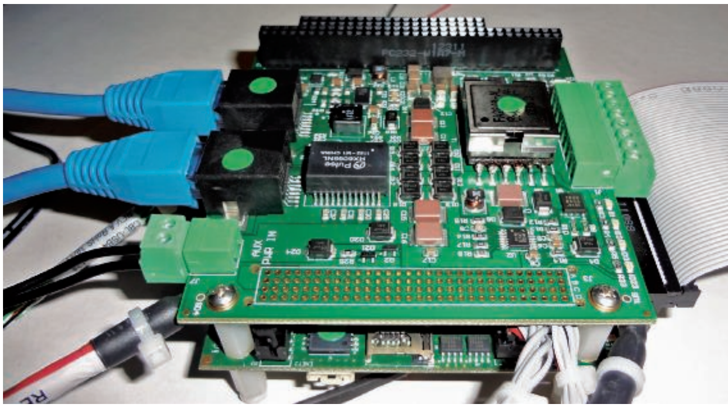
MANAGING POE

I've been working with Super Micro Computer's (aka Supermicro) SSE-G2252P Gigabit Ethernet *(Fig. 1)* intelligent non-blocking layer 2 switch *(see "Ethernet Switch Manages Power Over Ethernet Resources" at electronicdesign.com)*. It's a managed switch, and the PoE support is more extensive than most.

PoE started by delivering 15.4 W (the minimum is 44 V dc at 350 mA), but the standard has since been extended to deliver more power. The PoE Plus (PoE+) standard kicks up the limit to 25.5 W. The SSE-G2252P lets network managers specify the maximum amount of power per port. The switch has a maximum budget of 400 W.

I like the additional management that Supermicro put into the device. It supports scheduling and power distribution priority, which means my access points remain up even when I try to plug in too many PoE devices in the lab. It also has overload protection.

1. Super Micro Computer's SSE-G2252P layer 2, non-blocking Gigabit Ethernet switch provides more extensive managed PoE support than most other alternatives.



2. The WinSystems PPM-PS394 PoE node can power a PC/104-Plus stack.

DELIVERING POE SOLUTIONS

One of those devices in the lab is using the WinSystems PPM-PS394 *(Fig. 2)* to power a PC/104 Plus stack. The board fits into the stack and takes power from a pass-through PoE connection or dc source from 9 to 32 V. It can deliver up to 10 A at 5 V and 5 A at 3.3 V to the rest of the stack or other devices connected to it.

The rats nest in the photo is connected to the WinSystems PCM-VDX-2 PC/104 board hidden under the PPM-PS394. It runs a 1-GHz Vortex86DX processor, which is a 32-bit x86 system-on-chip (SoC) designed for low-power applications that easily runs on the minimum PoE setting.

The board has a pair of Ethernet ports. One will typically be connected to the PPM-PS394 pass-through. It also has the usual complement of serial I/O, parallel I/O, and four USB 2.0 ports. It's designed for headless operation, although it can accept the optional Volari XGI MiniPCI card with a VGA output.

I used the full peripheral complement, including booting from a Compact Flash card, and ran Linux. It also supports DOS and x86 real-time operating systems (RTOS) or most other 32-bit x86 operating systems.

The package uses about 7 W or half the base PoE budget. That means a PC/104 stack can be built up without busting the PoE switch. The system was plug-and-play all the way. Of course, the rats nest on the lab bench goes away once the hardware is placed inside a system for a target application.

The PoE board cannot drive all combinations of PC/104 hardware, but it can handle quite a few. Even the newer PXM-C388-S board with a 1.66-GHz Atom processor, on-board video, and SATA support only needs about 10 W.

There are some PoE switches for the home market, but this approach is more likely to find a home on the shop floor or in other industrial application areas where embedded devices are quite common. Best of all, PoE doesn't require a software change. ed