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EDITORIAL MISSION:
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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AN EXOSKELETON THAT BENDS

While a real-life Iron Man suit may not yet be available, Lockheed Martin's FORTIS exoskeletons' ergonomic design moves naturally with the body, providing flexibility without hindrance. The unpowered, lightweight FORTIS developed for the U.S. Navy increases the operator's strength and endurance by transferring the weight of heavy loads from their body directly to the ground.

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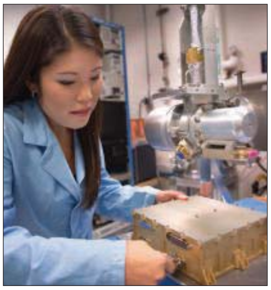
MICROTEK GETS SEAL OF APPROVAL

The U.S. Department of Defense's Defense Logistics Agency approved Microtek Laboratories' East Coast facility with Laboratory Suitability Status for MIL-PRF-55110, MIL-PRF-31032, and MIL-PRF-50884. With the approval, the lab can now perform all applicable Group A, Group B, and Group C conformance and reliability testing, as well as full qualification testing, for those specifications.

CRYOCOOLER CHILLS TO A BRISK -244° F



To maximize a satellite sensor's sensitivity, it must be chilled using cryogenic refrigerators known as cryocoolers. NASA's Orbiting Carbon Observatory-2 (OCO-2), launched in July 2014, used a high-efficiency cryocooler developed by Northrop Grumman to perform that task. It successfully cooled the satellite's infrared sensors to -244° F.

TOP 50 EMPLOYERS REPORT

In case you missed the most recent issue of *Electronic Design*, you can find our full annual report on electronic engineering's **Top 50 Employers** now online—with some big surprises at the top of the list. The comprehensive report includes a downloadable table listing the Top 50, an analysis of the trends that impacted the list in 2014, and profiles of some of those companies who lead this year's list.

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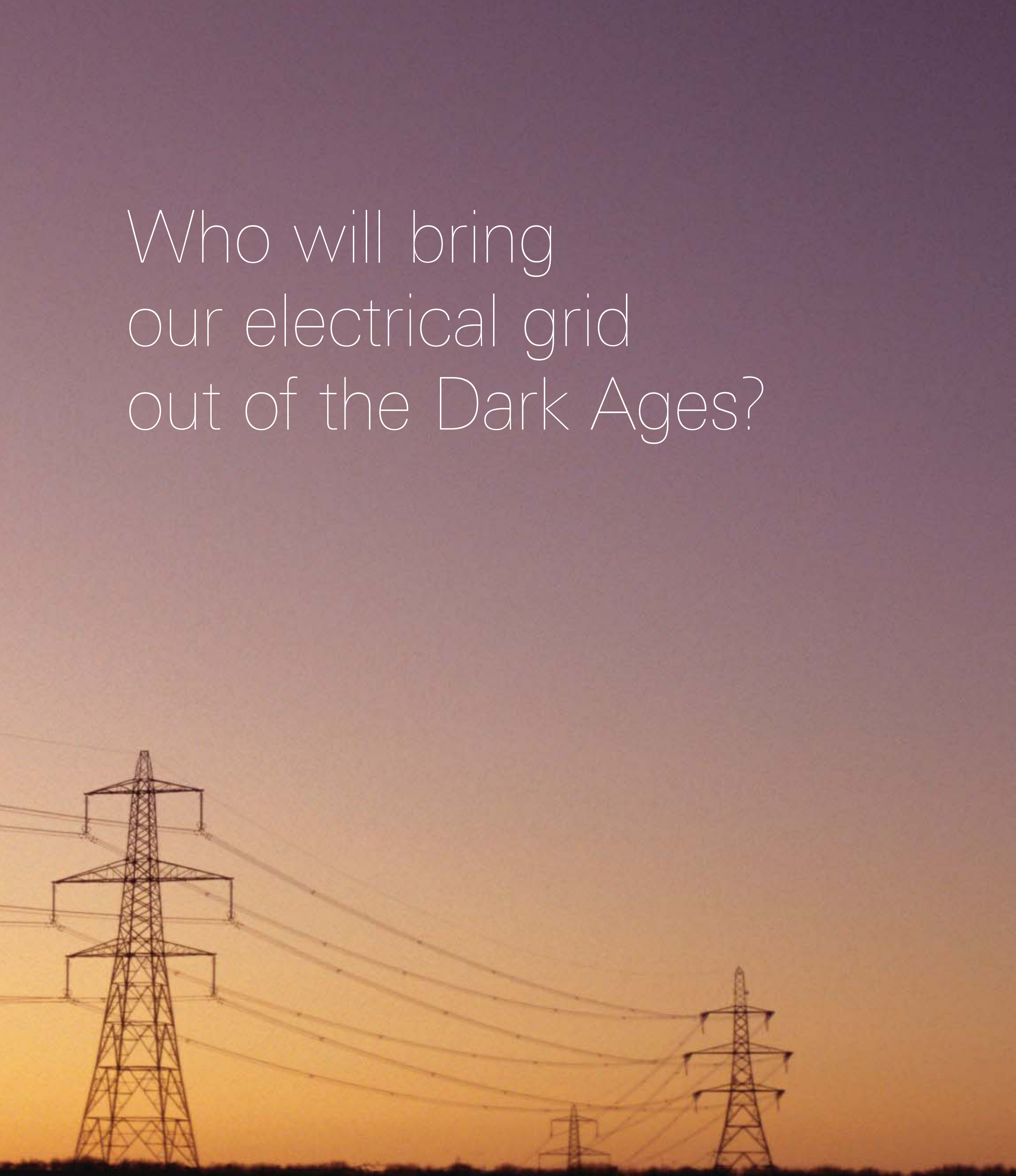

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Managing Heterogeneous Multicore Software Development

Sometimes, hardware hasn't been delivered yet, or it's otherwise difficult to obtain. Instruction-accurate (IA) simulators, or virtual platforms, allow developers to get their software running without having access to the hardware. Also, an IA simulator's debugging features may be more robust than those available in real hardware, even hardware with JTAG support. Virtual platforms are more than just an instruction set simulator (ISS) since they provide peripheral simulation as well.

Mentor Graphics designs its software development tools to handle a range of platforms from small, single-core microcontrollers to multicore system-on-chip (SoC) platforms. Symmetric multiprocessor (SMP) systems have had plenty of support, including hypervisors. They may run virtual machines (VMs) with a variety of operating systems (OSs), but the overall management comprises VMs. This is much different from a heterogeneous multicore system like Texas Instruments' latest OMAP5, which includes a mix of dual ARM Cortex-A15 and dual Cortex-M4 cores.

Developers have had to deal with the various OSs, middleware, and development tools when addressing heterogeneous multicore systems. Often, though, developers have had to provide the integration between the various components and tools. This is not easy, and using software components from different vendors makes it even harder.

Mentor has not even chosen a name for this overarching embedded development solution, which encompasses the company's wide range of software and services. Developers, then, can use high-level OSs like Mentor Embedded Linux and mix them with bare metal applications as well as the Nucleus real-time operating system (RTOS) running on different cores.

Part of the solution is the support for interprocess communication (IPC) and management such as VirtIO, the Multicore Communications API (MCAPI) from the Multicore Association, rpmsg, and remoteproc. This brings hypervisor support to heterogenous multicore, whereas the typical hypervisor is restricted to an SMP platform. Mentor Graphics' hypervisor shares this restriction, but the entire solution does not allow developers to use similar tools and application programming interfaces (APIs) across all the cores in platforms like TI's OMAP5.

The new tools start at system configuration and move through booting to IPC. They wind up with system visualization, which is a trace capability that lets programmers track task states across the mix of cores within the system. The boot support is an example of the integration details involved. Keep in mind that booting can be a complex process with multiple heterogeneous cores as well as VMs. Secure boot support is on the horizon. Hardware like the OMAP can handle it.

Tool vendors are going to need to address heterogeneous multicore environments as more and more appear. Integration and support are major issues and even more so in this environment. ed

News & Analysis

64-BIT ARM INCARNATION Employs Dynamic Code Optimization

NVidia often takes an interesting approach with its technology, and the firm's upcoming dual-core Tegra K1-64 is no different. It employs the Denver CPU architecture that implements ARM's ARMv8 64-bit architecture *(see "ARM Joins The 64-bit Club" on ElectronicDesign.com)*, but does so much differently than most other ARMv8 platforms.

NVidia has an ARMv8 ISA license rather than a Cortex-A57 core license. There are others that have taken this approach as well. This means that the resulting processor needs to match the ARMv8 ISA, but it can be implemented much differently than ARM's Cortex-A57 design.

Denver's code morphing approach is similar to that found in Transmeta processors available almost a decade ago *(see "Low-Power VLIW CPU Delivers Speedy x86 Upgrade" on ElectronicDesign.com)*. Code morphing is also known as dynamic code optimization. The technique is similar to Java's just-in-time (JIT) compilers. In both cases the object code is converted into microcode instructions that are cached. The conversion takes place once, and then the microcode can be executed repeatedly without additional overhead.

The Denver cores run their own microcode directly. ARMv8 instructions are converted to this microcode before being executed *(see the figure)*. An on-chip, 1K look-up table is used to check if a microcode sequence has already been generated by an Optimizer program and placed into the optimization cache.

The optimization cache is 128 Mbytes and it is stored in main memory. The cache is only accessible by the hardware and the Optimizer. The latter is also hidden from the system. It is written in microcode, so it does not have to use the conversion process that the ARMv8 instructions need. The Optimizer can run on either core when they are idle. It can also be interrupted. It handles management of the cache in addition to performing the optimized code conversion.

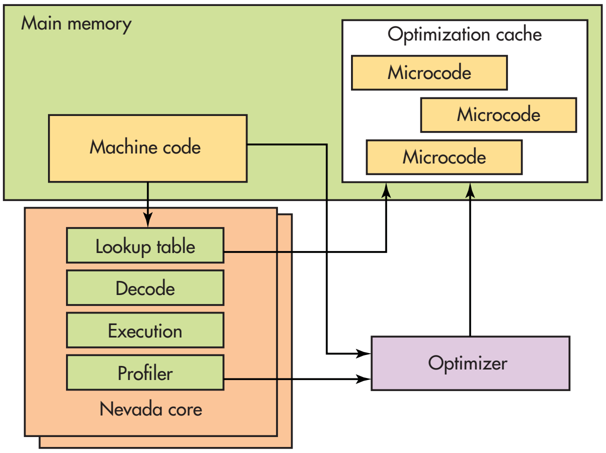
The code sequences in the cache are matched to the jump transitions of the ARMv8 instructions. This allows a block to be selected and run sequentially.

The reason for these gyrations is that the code generated by the decoder may be less efficient than what is generated by the Optimizer. It can take into account all the execution units available as well as timing and power details.

The Denver core can execute more than 7 ARMv8 instructions per cycle when using optimized code. The cache delivers a 32-byte "parcel" to the instruction scheduler every cycle. The parcel is actually a series of variable length instructions that will be passed onto the execution units.

The profiler provides information to the Optimizer program about what blocks to optimize and how to ensure the code is being executed. Frequently used blocks get more optimization.

The platform targets mobile devices that need to be very power-efficient. It also addresses applications that need the performance usually found in a 64-bit x86 platform. ■



NVidia's Denver architecture executes its own instruction after converting ARMv8 machine code to microcode. A 4-way look-up table also checks if optimized code is available in the 128 Mbyte optimization cache. This code will be used if it is available. An Optimizer program scans machine code and writes microcode blocks to the cache based on profile data from the core.

TAD KEELEY | SENIOR DIRECTOR, Analog & Power Product Marketing,
Renesas Electronics America

Pay Attention to These Power-Device Trends

Evolutionary advances in MOSFETs and IGBTs can arm trend-cognizant designers with the tools to develop performance-differentiating products.

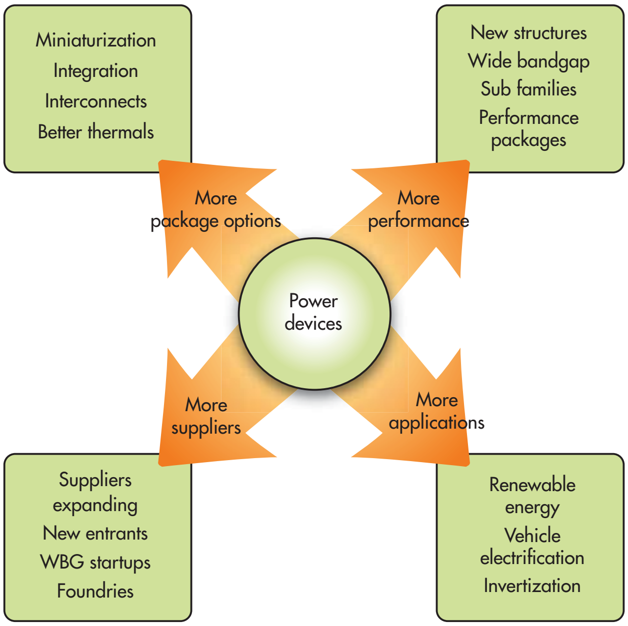
In the world of power technology, scores of new information on the lowest, highest, smallest, densest, etc., seemingly arrives daily, leaving engineers to scramble to keep up with the latest trends. It's those engineering teams carefully considering and selecting the latest power devices and related circuits that will likely reap the most significant performance gains. For designers starting new projects, this quick update will help in that effort—and may even influence the direction of future change.

For decades, breakthroughs in technology have reshaped the power-device landscape. And the beat goes on with the latest crop of innovative device structures, thinner wafers, higher cell densities, new materials, greater integration, and new packaging technologies *(see the figure)*.

Whether it's higher conductivity, faster switching, more robustness, or a combination thereof, progress is evident across most product categories. Compared to a just few years ago, systems engineers working on new designs have significantly better power devices at their fingertips. This, of course, spawns multiple benefits:

- **More performance:** In addition to the aforementioned performance enablers, stratification of power-device types into many sub-families has improved performance for narrowly targeted applications. These include MOSFETs with diodes optimized for several classes of reverse recovery time (t_{RR}), or IGBTs introduced with extended short-circuit withstand time (t_{SC}) options.
- **More packages:** Taking full advantage of better devices at a system level requires new packages for smaller size, higher switching speeds, less resistance, less inductance, more integration, better thermal performance, etc.
- **More applications:** Power-semiconductor content continues to expand as demand grows for greater energy efficiency in applications such as handheld devices, vehicle electrification, grid storage, renewable energy, and motor-drive "inverterization." Thus, there's a broad trend toward higher unit volumes. On top of that, devices that feed these specific applications will likely receive more development resources while rapidly advancing up the performance ladder.
- **More suppliers:** Despite recent consolidations, the power-device business overall continues to add suppliers. In particular, IGBTs and wide-bandgap (WBG) devices are available from both traditional and "startup" suppliers, creating a greater array of new part, performance, integration, and packaging options. As a result, the relationship between power-device OEMs and their customers has become more important than ever.

Digging deeper on the last bullet point, power-device performance and selection is inherently tied to a load, inductor, capacitor, or heat sink that's typically engineered on the system side. To ensure full capture of these device-level innovations at the system level, communication between power-device engineers and systems engineers is paramount. One sub-plot



In an era of "more of everything," power semiconductors take off in many directions. *(Source: Renesas Electronics America)* to it all, though, involves second-sourcing of discrete components—it's become more difficult due to increased optimization of power devices for specific uses, meaning greater complexity when trying to match performance across suppliers.

Taken together, power semiconductors currently reside in a dynamic era of "more of everything," particularly from the viewpoint of device users. What follows are some of the biggest movers and shakers.

25- TO 30-V MOSFETS

In terms of dominance within the industry, 25- to 30-V_{DS} MOSFETs used for dc-dc downconversion in computing applications rank right at the top. Four prominent trends highlight this arena:

- **Markedly improved silicon performance:** Just a few years ago, the drain-source resistance ($R_{DS(ON)}$) for the top-performing syncFETs were double that of today's equivalently packaged best devices (syncFETs were Fairchild's original designation for FETs with integral Schottky diodes). Similar improvements have occurred with high-side FETs. Such FETs are now occasionally developed on a switching-performance-focused process that's completely independent from the syncFET process.
- **The move to 3-by-3 DFN packages and asymmetric half-bridge dual MOSFETs:** These have replaced 5-by-6 dual flat no-lead (DFN) packages in many applications, much like when 5-by-6 DFNs replaced DPAKs just as a few short years ago. The move is consistent with the industry-wide trend of miniaturized integrated devices targeting applications demanding higher performance. These packaging transitions occurred within just three to four years.
- **More integration for greater performance gains:** To effectively reduce size, increase efficiencies, and push switching speeds to and beyond 1 MHz requires minimization of package resistance and related parasitic effect. That means greater emphasis on integration of FETs, drivers, and controllers. Integrated dc-dc converters can be partitioned in various ways. For example, asymmetric dual MOSFETs (two die in one package) come in 5-by-6, 3-by-3, or other sizes widely used in downconverters to 30 A and beyond. Or two MOSFETS plus drivers (three die in one package) can create "DrMOS" (driver-MOSFET, an Intel packaging standard) and similar multichip module devices in various packages, which handle up to 60 A at frequencies over 500 kHz. Further, two MOSFETs plus a driver and a controller (three or four die in one package) could form a point-of load (POL) device and run almost as high a current as the DrMOS type parts. Finally, monolithic components that combine the controller, driver, and high- and low-side MOSFETs in a single die can run to 15 A, with efficiencies near 90% from 100 mA to 15 A even when stepping down to 1 V from 12 V.
- **Further segmentation counter trend:** On the other hand, continued strong supplier support for the 25- to 30-V commodity zone may retard segmentation. For this segment, device performance significantly lags the cutting edge.

40- TO 250-V MOSFETS

Key trends in this sector include:

- **Many more available parts:** More suppliers now develop power devices for motor drives in 48- to 80-V systems, synchronous rectification for ac-dc SMPS, isolated dc-dc converters for telecom/datacom, class-D audio amps, and UPSs.
- **Much improved technology:** In terms of potential performance, the new SiC and GaN semiconductor technologies developed for this segment is far superior to conventional silicon. It increased efficiency and power density, thus minimizing paralleling and board-space requirements.
- **Optimized SSR devices:** Solid-state-relay (SSR) devices have been optimized for $R_{DS(ON)}$, switching, and diode recovery losses. Low-gate charge, low-output capacitance, and reduced body-diode recovery charge helped shrink losses in non-resonant switching circuits.

400-V+ MOSFETS

The over-arching trend here revolves around high-voltage super-junction devices:

- **Super-junction MOSFETs with wider voltage ranges:** From a traditional base of 600 V, these devices are now available to 1200 V.
- **Trench-based alternatives:** Using deep-trench for charge balancing instead of multilevel-epitaxial devices—at least below 650 V—provides Q_G and Q_{GD} (two different definitions of gate charge) advantages that lead to reduced switching losses, with still very low $R_{DS(ON)}$.
- **Thin SMD packaging:** Low z-height surface-mount devices (SMDs), as opposed to TO-263 or TO-252, reduce size and parasitic inductances.
- **Arrival of new varieties, like faster body diodes:** Parts with better t_{RR} (150 ns and lower) for hard-switched applications have become more prominent.
- **Wider application of super-junction MOSFETs:** These devices are now moving into consumer applications (e.g., LED lighting), ac-dc flybacks, and lower-power solar inverters for solar and battery chargers.

IGBTS

Insulated-gate bipolar transistors (IGBTs) have long maintained an amperes-per-dollar edge over MOSFETs, and that remains the case today. However, IGBTs are changing in many other ways:

- **Performance boost via tradeoffs:** Major recent improvements, and those on the horizon, have and will be realized thanks to the three-way tradeoff among conduction performance (as measured by $V_{CE(SAT)}$), switching performance (as measured by t_F), and ruggedness (as measured by t_{SC}). For example, 100-A IGBTs with 10-µs t_{SC} are now available with typical $V_{CE(SAT)} = 1.5$ V @ 50 A and $t_F = 80$ ns. Just a few years ago, such a performance level would have required a device with a much lower t_{SC}.
- **Availability of higher-current IGBT die:** Such die, rated to hundreds of amperes, can help lessen the need for paralleling IGBTs, which brings added design challenges.
- **Better monolithic reverse-conducting IGBT performance:** The spike in performance makes it possible to reach more applications like resonant converters and small motor drives.
- **Continued dominance of modules:** One speculated trend, for reasons of cost and design flexibility, was a gradual migration from module- to more discrete-based designs. It hasn't happened, though. However, the integration advantages of modules for performance, size, and design simplicity remain powerful traits. Hybrid modules with an IGBT matched to a silicon-carbide (SiC) diode have emerged to further address IGBT limitations. Even full SiC-based solutions can be found.
- **IGBTs and MOSFETs remain app-specific:** Despite significant performance improvements from both IGBTs (faster) and MOSFETs (lower $R_{DS(ON)}$), there's been little sign of traditional MOSFET applications moving to IGBTs or vice versa.

WBG DEVICES

Wide-bandgap trends show that the devices are making inroads, though it's been slow:

- **Dominant footing in some spots:** A common perception is that costs must decrease before there's any widespread adoption of WBG devices. However, when conditions are right, such as in the power-factor-correction (PFC) diode socket of high-end power supplies, WBG-device performance outweighs its higher cost when trying to meet stringent efficiency standards.
- **WBG switch adoption remains low:** To justify the use of higher-cost WBG devices, a system overhaul, including shrinking heat sinks, inductors, and capacitors, is needed to reduce cost and boost performance. This is even evident for applications such as renewable energy (or electric vehicles)—straight device performance directly translates into better end-product performance, yet WBG can't seem to make a dent.

- **Cost reductions will ultimately accelerate adoption:** It's a synergistic loop—greater adoption will drive down costs, which will drive greater adoption. Early inroads, such as 1200-V SiC MOSFETs into formerly pure IGBT territory (e.g., high-power solar inverters), will catalyze this loop.

PACKAGING TRENDS

Breakthroughs at the silicon level (or GaN or SiC) often necessitate better packages to take full advantage of the possible performance, as well as skirt the parasitic inductance and resistance limitations of traditional packages. Examples include leadless or minimal-lead SMD packages to replace TO-263s and TO-252s, the use of chip-scale packages for low z-height requirements, and embedded packaging to maximize thermal performance. Another example is the hole-less TO-247 package. These packages enable larger devices and offer increased power output compared to standard TO-247s.

Another growing trend is the deployment of wire-bonding alternatives. Straps and clips can often replace wire bonding to maximize performance. Clips even enable higher currents in new packages, allowing migration away from through-hole packages such as TO-247s. Also trending is a rapid increase in integration. Development of new modules and multi-chip packages has sharply risen across all power levels, particularly for very-low and very-high voltages.

Power devices are no longer just a mix of a few TO-247 and TO-263 devices. A complex interaction of device R&D, packaging advances, growing application, customer, and supplier base have quickened the pace of power-device evolution. Designers can adopt simple practices to take advantage of these developments:

- Check datasheet revision dates on power-device choices. If the part is more than three or four years old, significantly improved devices are probably available.
- Look beyond previously preferred suppliers for better alternative devices.
- Check for new package options. If better versions are available, but lack the right device rating, suppliers may offer the preferred silicon in the new package upon request.
- If the power devices are critical to performance, maintain a close relationship with suppliers for customized solutions.
- Change products, such as IGBTs instead of MOSFETs, or WBG instead of either, to create new opportunity. ed

Engineering Feature

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2014 ENGINEERING SALARY

Engineers like certainty. There is, after all, nothing probabilistic about Ohm's Law. However, even as career conditions show improvement following an intense recession and a less-than-vigorous recovery, engineers may have to learn to live with uncertainty.

Cash-rich corporations are less than eager to take on the fixed overhead that comes with rehiring—and thus continue to embrace offshore outsourcing. Downward pressure on wages and other compensation also continues in the form of H-1B visa workers. And it's anyone's guess on how extensively economic slowdowns in markets such as Europe and China will dampen growth prospects for U.S. companies going forward.

That said, the numbers in *Electronic Design*'s 12th Annual Salary & Opinion Survey should give engineers cause for optimism. According to this year's nearly 3000 survey participants, the profession stands in relatively good health. Most engineers feel reasonably compensated, satisfied with their current position, and sufficiently challenged by their work. They are less fearful about losing their jobs than beforehand, too.

As professional troubleshooters, though, engineers are also alert to potential bugs in the program. Their concerns include working conditions, shortsighted management, and inadequate support on the part of their employers for the continuous education that's essential in a fast-moving world. They also have strong opinions about outsourcing.

So it appears that engineers will simply have to learn to accept some degree of uncertainty in their lives—even as they attempt to rigorously eliminate it from the performance of their designs. The good news is that in a world fraught with risk, the engineering game offers much better odds than most.

EMPLOYMENT UPSWING

The employment picture for engineers definitely brightened in 2014. The second quarter of the year saw a net gain of 38,000 engineering jobs, and the unemployment rate dropped to 1.6%—its lowest since 2007. The number of employed engineers also returned to its 2013 average at the 300,000 level after dipping in the first quarter of the year. This is a pronounced improvement over 2013, when the unemployment rate for EEs crept back up to 4.8% after trending downward since its peak of 6.4% back in 2009.

According to data from the U.S. Labor Department Bureau of Labor Statistics (BLS), however, engineering jobs actually

Average Salaries By Engineering Title	Base Salary	Total Compensation
Software engineering manager	$157,611	$166,461
Vice president /VP of engineering	$124,306	$140,107
Technical director/director of engineering/R&D/engineering manager	$123,822	$137,400
Chief engineer/senior engineer/ lead engineer/principal engineer	$108,961	$117,674
Manufacturing/production manager	$109,350	$117,475
President/owner/CEO/other executive management	$102,735	$113,538
Group leader/project team leader/ project manager	$103,142	$111,284
Systems engineer/applications engineer	$102,637	$111,001
Software engineer	$103,570	$110,483
Department head/section head	$98,813	$109,542
Applications/systems engineering manager	$99,230	$109,150
Other (please specify)	$88,718	$95,945
Design engineer/project engineer/ R&D engineer	$87,030	$94,288
Test engineer	$85,316	$92,417
QC/evaluation/test manager	$80,600	$89,356
Manufacturing/production engineer	$80,075	$88,390
Consulting engineer/scientist	$79,645	$85,992
Member of technical staff	$75,576	$81,983

SURVEY: AN UNCERTAIN REBOUND?

Concerns persist despite improved career prospects in 2014

declined by 55,000 in the first quarter of 2014. This indicates that the drop of the unemployment rate to 2.1% in Q1 likely resulted from technical reasons such as a higher number of out-of-work engineers actively seeking employment.

The survey revealed other positive signs on the job front. Only 11% of respondents anticipate their company scaling back engineering staff in the coming year, while 31% expect their company to increase the number of engineering jobs in 2014. That's slightly higher than the 28% who said their company would add engineering personnel last year.

Also, more than half (52%) say a recruitment specialist or headhunter seeking engineering talent had approached them within the past year. This indicates that competition may be heating up for engineering skills and experience.

Some companies may be unprepared for this increasingly competitive market, especially if the recent hirer's market made them complacent about working conditions. "My organization is experiencing record growth, but neglected the needs of employees so badly that more people were leaving than they were able to hire," said one engineer. "Although changes have now been made to make employment more attractive here again, there is still a long way to go."

Attrition is also forcing employers to up their game when it comes to recruitment and retention. "Our workforce is aging, so we need to attract and hang on to new employees to take the place of those who are approaching retirement age," another engineer noted.

Nonetheless, while the job-market scales seem to be tipping in the favor of engineers, 70% of survey respondents said they don't believe their company is as focused on employee retention this year versus last year. "Even though the positions are hard to fill, my company is still opting to replace senior engineers with young ones at a lower pay," one respondent complained.

"This company doesn't care about their employees, which is evident by the constant turnover of staff," echoed another. "The only reason the five of us who are 50+ years old don't move on is the dearth of jobs for engineers our age."

SALARY SURGE

After taking a bit of a hit in 2013, average total engineering compensation rebounded slightly in 2014—especially for engineers with management responsibility. Base salaries grew about 1.3% overall, while bonuses generally remained flat. Employers were also slightly more generous this year with stock options and other non-salary compensation, which rose about 7%. All told, average total income for all engineers in 2014 came to $106,482, up from $105,028 in 2013.

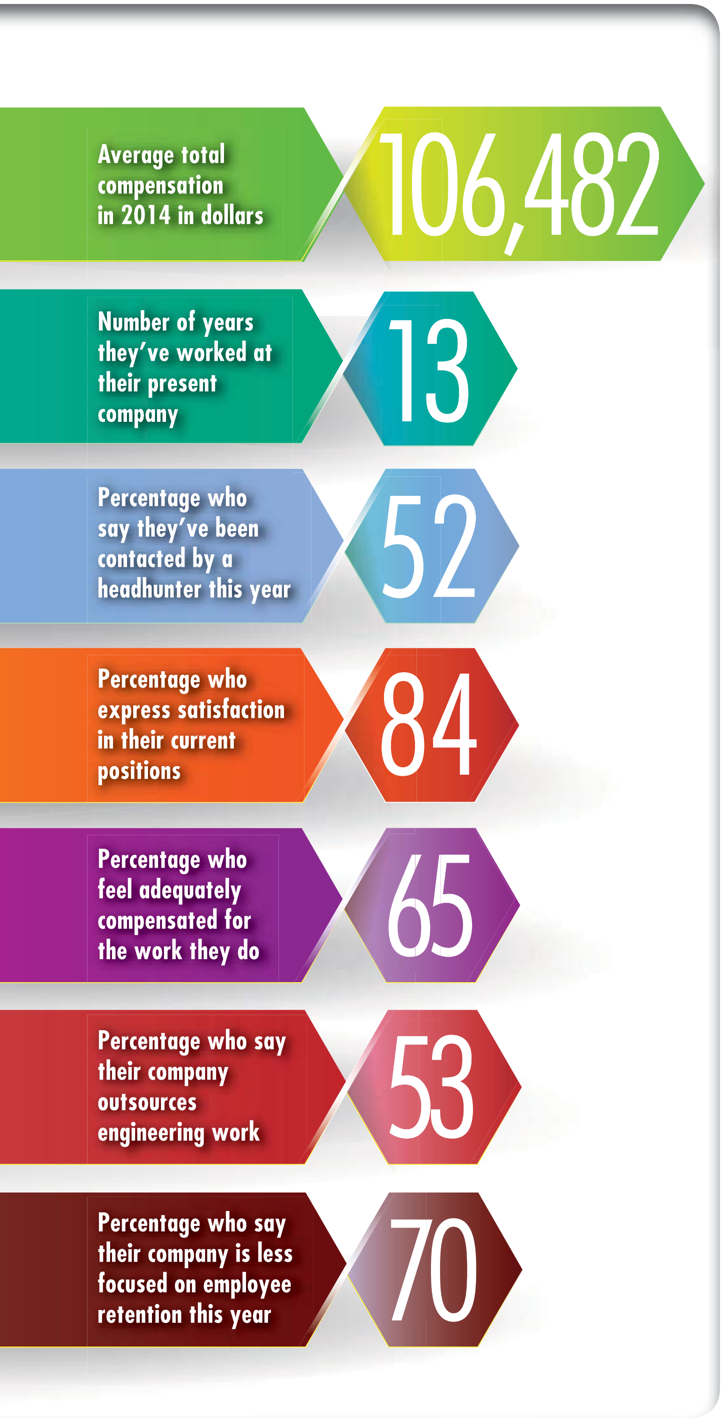
Many survey respondents said that their incremental pay raises come at a fairly steep price, though. Employers are restructuring compensation to make sure they get the outcomes they need from their engineering staffs. "There is a shift toward compensation based on goal-setting and achievements," observed one. "We are being offered a fixed salary plus performance-based incentives," said another. "The salary is about 60%, and the incentives are limited only by value addition."

Because of these productivity pressures, engineers are working as hard as ever for their money, averaging 55½-hour work weeks—typically 40 hours in the office plus additional time at home, on call, and/or at other locations. "You're expected to work 50+ hours per week with no extra pay, even if the project is on schedule," lamented one engineer. "It's just something you have to do if you want to advance to senior management."

Despite slight increases in salary overall, only 40% of engi-

neers believe their compensation is competitive with what other employers are paying for similar work, while 43% feel it's less competitive.

Respondents also don't think their salary gains are especially significant. "Salaries are not keeping up with inflation," complained one engineer. "There's not a lot of opportunity to move on to another position as companies prefer younger people with little experience. Companies know this and tend to use this fact against wage increases, advancement, and any other type of benefits."



Engineering salaries obviously vary considerably based on the type of work. Design & development engineers, for example, earned a base salary of $94,143 and total compensation of $102,248 this year. The job titles commanding the highest salaries were software engineering managers ($166,461), VPs of engineering ($140,107), technical directors ($137,400), and chief/principal engineers ($117,674).

Engineering managers did especially well in 2014, averaging $121,921 in base salary and $133,132 in total compensation—an increase of about 11%—after seeing their pay dip 5% in 2013. Operating management also saw a bump in their paychecks (by about 10%) for an average of $119,740 in base salary and $133,230 after bonuses and other pay perks.

GUARDED OPTIMISM

Although wages have languished in recent years, engineers remain generally optimistic about their profession. "Engineers are always in demand," said one survey respondent. "I know many well-paid engineers that have left my company for even better pay."

"Financially, engineering is a ticket to a comfortable middle-class lifestyle, which is more than a new grad would be likely to get in the arts, education, or most other major areas of study," noted another.

A third respondent offered this perspective: "There are many engineering niches, each of which requires intense specialization. The general term 'Electrical Engineer' can refer to a person working on anything from chip lithography to high-power motor controls. With the number of these niches increasing every year, our field shows no signs of slowing down."

But not everyone paints such a rosy outlook about the future. One respondent's perspective was typical: "Due to the poor economy, fewer engineers are advancing. The large number of foreign-born engineering students graduating and wishing to remain in the U.S. is keeping salaries from rising. The rise of China's economy in the world marketplace and the increase in the number of their own engineers is also putting a downward pressure on jobs and salaries."

Perspectives also tend to vary by region because, simply put, compensation varies geographically. As we've seen in pre-

ENGINEERING BY THE numbers

vious surveys, engineers on the West Coast top all wage earners with total incomes this year averaging $126,269 (up 3.4%). They're followed by New England at $115,893 (up 2.4%) and the West South Central region—comprising Texas, Arkansas, Oklahoma, and Louisiana—at $115,473 (up 1.1%).

The type of firm also plays a substantial role in determining engineers' compensation. Chip houses led the way in engineering pay again this year at $145,831—followed by software houses ($123,414), computer OEMs ($122,297), government/military contractors ($116,377), and medical electronics firms ($109,483).

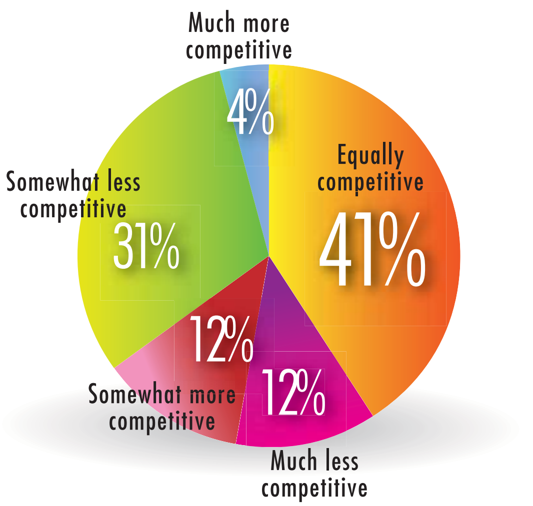
An engineer's level of education is another big factor. Engineers with bachelor's degrees earned less than the average ($100,948), while those who'd tacked on graduate studies had incomes 8% higher at $109,063. Engineers with master's degrees earned $115,424 in 2014, and those with doctorates averaged $122,831. Those differentials may not seem that great on an annual basis, given the high cost of a post-bachelor's education. But over the course of a career, the increased income can add up substantially.

MORE A CALLING THAN A JOB?

Few jobs are as fun, challenging, and satisfying as engineering. And few offer such a wide range of opportunities. That's why, like last year, about 90% of our survey respondents said they would recommend engineering as a career path to a young person looking to choose a profession.

"Engineering can be immensely rewarding, especially if you enjoy discovering how things work and how to make them better," wrote one engineer. "Whether it is process development, product development, or software development, the ability to turn your vision into a real-world system is awe-inspiring."

HOW YOUR COMPENSATION COMPARES TO WHAT OTHER COMPANIES ARE PAYING



Average Salaries By Level Of Education	Base salary	Total compensation
Doctoral degree	$111,894	$122,831
Masters degree	$106,024	$115,424
Bachelors plus graduate studies	$100,313	$109,063
Bachelors degree	$93,049	$100,948
High school or less	$87,545	$96,265
Attended college	$81,157	$89,458
Associates degree	$75,269	$83,001

Average Salaries By Type Of Design Work You Do	Base salary	Total compensation
ICs and semiconductors	$125,939	$140,410
Computer product design (supercomputers, mainframes, workstations, servers, PCs, notebooks/laptops, peripherals, boards, etc.)	$116,452	$126,940
Military products	$111,395	$117,744
Software design/development/programming	$106,945	$115,211
Medical products	$105,397	$114,684
Mobile equipment	$102,769	$112,769
Avionics, marine, or space	$104,701	$111,380
Automotive products	$100,621	$109,199
Communications systems and equipment (local-area/wide-area networking products, wireless, cellular, RF and microwave, Bluetooth, etc.)	$97,398	$106,976
Research & development	$95,429	$104,317
Other (please specify)	$94,178	$103,831
Safety/security	$95,313	$103,035
Test and measurement equipment	$94,066	$101,325
Components and subassemblies	$92,409	$101,287
Power design	$91,215	$100,614
Materials handling equipment/services	$91,563	$99,979
Packaging	$92,833	$98,033
Industrial controls systems and equipment (including robotics)	$86,595	$95,198
Consumer products	$85,812	$94,233
Machine tool/automation	$77,941	$84,386
Appliance	$65,833	$71,633

Average Salaries By Job Function	Base salary	Total compensation
Executive/operating management	$119,740	$133,230
Engineering management	$121,921	$133,132
Design & development engineering	$94,143	$102,248
Other engineering	$88,206	$95,509

Average Salaries By Industry	Base salary	Total compensation
ICs and semiconductors	$130,634	$145,831
Software	$111,500	$123,414
Computer systems/boards/ peripherals/software	$111,889	$122,297
Government/Military	$110,598	$116,377
Medical electronics	$100,611	$109,484
Avionics/marine/space	$101,909	$108,664
Communications systems/ equipment	$97,603	$106,794
Automotive electronics	$97,940	$106,540
Test and measurement equipment	$98,189	$105,274
Other (please specify)	$92,586	$102,117
Research & development	$91,632	$101,063
Components and subassemblies	$90,304	$99,954
Industrial controls systems/equip-ment	$90,400	$99,289
Consumer electronics	$87,401	$96,306
Consultant	$85,372	$92,465
Contract design or manufacturing	$83,045	$88,506

Another one put it this way: "If you have an inquisitive mind and good work ethic, engineering is a field that continues to advance by leaps and bounds. This relentless change challenges you to never stop learning. Plus, by getting involved in engineering societies such as IEEE, you can directly influence the standards and guidelines that future engineers will use to accomplish their designs. This can be deeply rewarding."

One respondent finds it particularly enjoyable to participate in the development of new, young engineering talent. "I recently hired a BSME right out of school at $60k," he explained. "This is the second one in the last three years. Our facility is small enough that I can work with and develop these new hires so they can move on to other opportunities within our parent company."

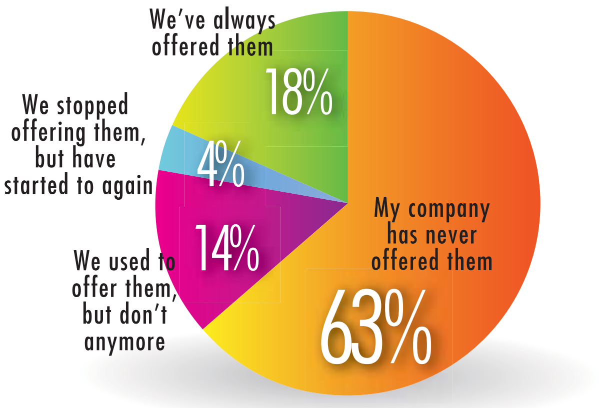
But not everyone shares the same enthusiasm. "I don't believe there are as many opportunities in engineering for someone starting out as there were 20 years ago," opined one respondent. "Also, management doesn't seem to appreciate the contribution that engineers make to a company's bottom line. We are seen merely as a commodity that can be discarded when no longer needed for a project."

That respondent was far from alone. "In today's business environment, engineers are not respected—and company management does not have a good understanding of the development process," wrote one such respondent. "Projects are often under-resourced, which sets up engineering teams for failure and frustration."

Despite the presence of these voices, nearly 9 in 10 respondents say they enjoy their jobs—and an equally high number find their jobs at least somewhat challenging. "Engineering continues to provide intellectual challenge, a good income, and a path to progress into management for those with business acumen and interest," asserted one of many respondents holding this point of view.

And, although respondents generally acknowledge the downward pressures on compensation, nearly two-thirds nonetheless believe that they are at least adequately compen-

SIGNING BONUSES/INCENTIVES FOR NEW ENGINEERING HIRES



Average Salaries By Years Of Engineering Experience	Base salary	Total compensation
30-34 years	$108,137	$117,214
25-29 years	$106,136	$116,004
35-39 years	$105,664	$114,974
20-24 years	$101,106	$110,937
40 years or more	$93,217	$101,520
15-19 years	$92,483	$100,040
10-14 years	$90,015	$98,758
5-9 years	$73,156	$80,604
Less than 1 year	$69,318	$76,790
1-4 years	$69,139	$76,176

Average Salaries By Size Of Company	Base salary	Total compensation
$5 billion - $9.9 billion	$120,859	$130,614
$1 billion - $4.9 billion	$115,363	$126,851
$10 billion or more	$115,019	$125,062
$5 - $9 million	$109,997	$119,671
$500 - $999.9 million	$109,432	$118,758
$100 - $499.9 million	$107,722	$117,471
$50 - $99.9 million	$100,033	$106,500
$25 - $49.9 million	$95,898	$104,515
$10 million - $24.9 million	$90,219	$97,445
Less than $5 million	$78,292	$85,980

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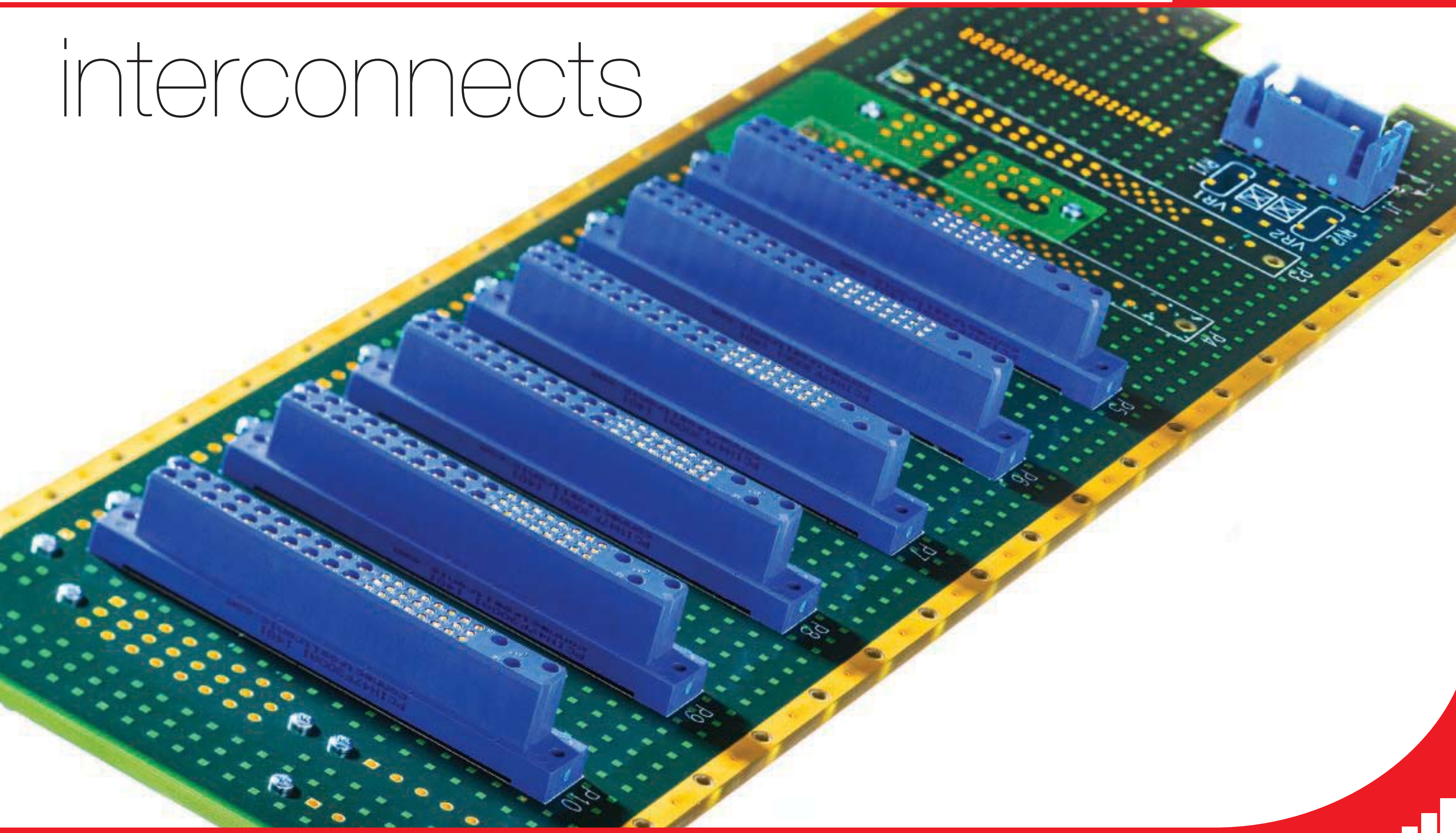

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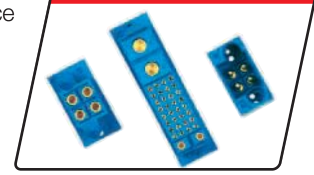

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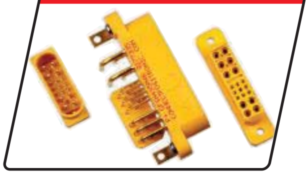

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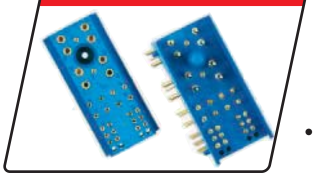

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sated for their work. "Although sometimes it feels like it's lost some luster, engineering is still a high-paying field in which a person has a lot of options," said one such respondent.

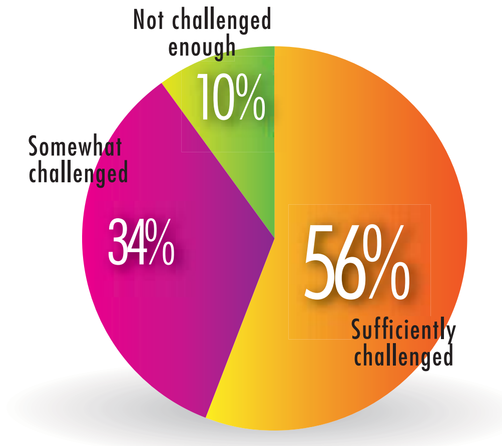
Among the remaining third who believe they're underpaid, the consensus is that they would need about a 21% increase in compensation to be brought up to fair market value. "The amount of schooling, keeping up with the latest developments, and stress outweigh the pay and satisfaction," wrote one particularly disgruntled respondent.

Whether due to job satisfaction or skepticism about conditions being better elsewhere, fewer than 10% of survey respondents say they're actively seeking a new position. More than one in four, on the other hand, said they would definitely follow up if they heard about an interesting opportunity elsewhere, and another third said they'd listen if personally approached with an offer.

One engineer explained his approach to career management this way: "As an engineer, you are in charge of your career. You need to sacrifice and learn to work closely with different people. And you must continually learn about new elements of the industry and how they can impact your career."

The challenges and sacrifices associated with a career in engineering prompted 37% of survey respondents to admit to considering leaving the profession altogether. Top reasons for making a switch included the desire to try something different (33%); to pursue other interests or opportunities (31%); to do something they perceived as more fulfilling or satisfying (27%); to make more money (24%); to do something less stressful (23%); or to start a business of their own (21%). Still, these amounted to sentiments rather than actions.

HOW INTELLECTUALLY CHALLENGED YOU ARE AT WORK



RUNNING IN PLACE

Staying current with new and emerging technologies remains a central challenge for engineers. Many find it nearly impossible to research and sift through the vast array of available information while focusing on the job at hand. "Since I work on a wide variety of products, I need to support a wide variety of technol-

Average Salaries By Age	Base salary	Total compensation
60 or older	$92,398	$100,566
50-54	$110,904	$121,695
55-59	$104,744	$113,302
45-49	$100,380	$109,273
40-44	$94,386	$103,595
35-39	$85,542	$93,901
30-34	$80,689	$88,517
25-29	$68,400	$75,533
Average Salaries By Geographic Region	**Base salary**	**Total compensation**
Pacific	$115,003	$126,269
New England	$105,900	$115,893
West South Central	$105,792	$115,473
Mid-Atlantic	$99,881	$108,409
South Atlantic	$98,255	$107,124
East South Central	$98,767	$106,058
East North Central	$91,831	$99,542
Mountain	$90,938	$99,180
West North Central	$90,065	$97,584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ogies," said one engineer. "Determining which ones to pursue ahead of time can be difficult, if not impossible."

To stay "current," engineers distill information from a variety of sources. In addition to reading technology journals like *Electronic Design*, engineers rely on white papers (65%), webcasts (62%), seminars (58%), textbooks (46%), trade shows and conferences (44%), and vendor-sponsored education (43%) to help them stay up-to-date.

"With the flood of information out there, it's a challenge every day to decide what to trash and what to skim through," said one respondent. "If I tried to take in all the information that comes my way, I wouldn't be able to accomplish anything."

Unfortunately, when it comes to keeping their skills and knowledge current, engineers increasingly find themselves on their own. Only about half say their company reimburses them for conferences and seminars (55%), while only 44% say they get money back from their employers for college tuition. Barely a third are reimbursed for engineering textbooks.

"Managers talk a lot about how they want you to keep current—but when you ask them to give you time off and pay for a two-day training seminar, they act like you just killed their dog," joked one respondent.

THE OUTSOURCING ISSUE

As companies look more aggressively for ways to control costs and avoid fixed overhead, outsourcing remains as prevalent as ever throughout the engineering world. According to this year's survey, a majority (53%) of engineers say their company outsources engineering work—a number that continues to inch up each year. The most-outsourced types of work include software development (49%), manufacturing and assembly (47%), and design (41%).

More than half of survey respondents (57%) say the work is being outsourced to contractors within the U.S. Primary offshore locations for outsourcing include China and the Pacific Rim (37%), India (29%), and Europe (19%).

"If the talent can't be found locally, then companies must look elsewhere," said one survey respondent sympathetic to the practice. "I am with a small company, so outsourcing is sometimes necessary to get the job done. Plus engineers cost a lot to a company, so there has to be a business justification for their salary."

Another respondent agreed: "There are times when the expertise needed to realize some key feature of a new product is not in house. In those cases, it's necessary to outsource that part of the design. Then our engineers can complete the rest of the work successfully."

About half (48%) of survey respondents, however, claimed that the main

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- Type of work being outsourced
- Where work is being outsourced
- Primary reasons your company outsources
- Level of concern over losing your job to outsourcing
- Types of continuing education costs companies are willing to reimburse to engineers

motivation for outsourcing is cost savings—rather than a lack of locally available talent. "Large companies outsource the most, because they're run by accountants and lawyers," one engineer griped. "If they can save five cents by outsourcing, they will."

Other reasons for outsourcing were a lack of in-house capabilities (40%); the need to put existing engineering resources to better use (34%); and the need to save time (32%).

"At our company, we've worked pretty hard to keep the design work in-house, but sometimes we have to use outsourcing to accelerate implementation," one respondent explained. "We are not saving that much money."

"Outsourcing is better when we need an unusual design solution and it would take too much time to do the R&D ourselves," said a like-minded colleague.

About one in four of survey respondents expressed some level of concern with the prospect of losing their job to outsourcing. However, 35% said they weren't terribly concerned with the threat of losing their job to outsourcing, and an additional 42% expressed no concerns at all.

"Outsourcing is a mixed blessing that allows engineers to harness the entrepreneurial spirit at the cost of stable jobs in traditional settings," one respondent observed. "But for my company, it has really helped fill in the gaps."

Several respondents offered a variety of caveats about viewing outsourcing as some kind of operational panacea. "I've heard outsourcing nightmares where the results were so bad that the money saved was irrelevant," said one respondent. "Outsourcing only works if someone very competent manages it," said another, adding that such management potentially offered lucrative work for engineers with the right skills. Others cited potential long-term issues with excessive reliance on outsourcing, such as a loss of vital in-house capabilities and the potential loss of competitive differentiated intellectual property.

In another vein, several respondents noted that the propensity of many companies to outsource offshore is likely to diminish with an evolving global economy. "At this point, we are starting to see many functions that were once sent offshore returning to the U.S. as economies in the countries that were once favored destinations continue to develop," noted one respondent. "The result is that the cost differentials have become less attractive, and it may even be cheaper now to perform them here at home."

WHERE ARE THE GOOD U.S.-PRODUCED ENGINEERS?

One reason U.S. companies may have to outsource—and turn to H-1B visa workers—is a lack of qualified engineers produced from the country's educational system. According to this year's survey, most (52%) engineers say their organization is struggling to find qualified candidates for open engineering positions. "Truly skilled, diverse, and practical engineers, as we need for our work, are hard to find—and it seems to be getting harder," said one.

As we've seen in past surveys, the jobs that continue to be toughest to fill in 2014 are those that require specialties in analog technology (36%), software (35%), systems engineering (33%), embedded technology (32%), RF design (29%), and power design (26%).

Is there a problem with domestically educated engineers? Two-thirds of survey respondents say they've recently hired American engineering graduates. But respondents split equally over whether today's engineering students are entering the workforce with sufficient knowledge and skill.

Some suggest that a four-year education isn't enough for the intense challenges posed by today's complex technologies. They also feel that large-scale changes must be made in the way students are prepared for engineering careers, especially when other countries have adopted seemingly more effective training models.

"Electronic engineering is too specialized for a general four-year degree," declared one veteran EE. "I think a much better model would be a two-year general electronics foundation, followed by specialized two-to-three-year education in some particular field such as embedded, digital, or analog technology."

Others agreed, but noted that astronomically high college and university tuitions make such an education financially unfeasible for the typical American engineering student. "It may be true that the skills the industry needs can't be crammed into a four-year engineering degree," remarked one engineer. "But given the costs, students can't afford anything more than that."

Respondents cited many other issues that may be undermining an American university's ability to produce the types of entry-level engineers needed to deliver innovative solutions to market on-time and on-budget. Some suggested that a purely technical education simply doesn't prepare young people to thrive in the modern workplace, since "people skills" and an understanding of how tech-centric business function are also necessary for success in the real world.

Others pointed the finger at a university system that places excessive pressure on faculty to bring in research funding and publish noteworthy results—at the expense of a genuine commitment to teach and nurture the next generation of American engineers.

A number of respondents expressed skepticism about academia altogether. Nearly 60% of those surveyed saw too much emphasis being spent on theoretical knowledge in schools. "Academic institutions tend to focus on technical theory," said one of these skeptics. "But, in practice, engineers need a set of specific skills and experiences that will empower them to discover solutions to complex real-world problems."

"A lot of the coursework is firmly theoretical, and any practical information is mentioned often in passing," said another. "There also isn't enough hands-on training or exposure to different software programs. Oddly enough, spelling seems to be an issue, too."

Another critic noted that, because of the time it takes to develop course curricula, university courses typically lag far behind the state of the industry—and therefore tend to be terribly out-of-date. "As the engineering manager of a large corporation who has attended numerous job fairs looking for interns and junior engineers, I can tell you the pickings are pretty slim," he wrote. "Whatever they're teaching these students, it's not what we need."

Three out of four engineers surveyed believe today's engineering students don't get enough hands-on experience in school labs. "New graduates need more hands-on work," remarked one engineer. "I wish education would focus on the basics more, more general problem-solving and less 'hard core' technical material. When you enter the workforce, that's when you really learn what you will need to know. I have seen many new engineers with horrible problem-solving skills, and who are terrible in the lab. I have never had to solve a root-locus problem in my professional career, but I have had to sit at a soldering bench on many occasions!"

When asked how much training engineering graduates need to do their jobs independently once they've been hired, 44% said it requires nine to 12 months or more. "Universities have not been graduating students with skills as good as they used to, protested one engineer. "I believe that good grades are easier to come by and students aren't being required to learn as much as they used to. Qualified candidates are more difficult to find."

Many respondents expressed the belief that engineering graduates should spend time as interns to gain the hands-on experience necessary to be of value on a project team. In fact, 72% believe internships should be a mandatory component of every engineer's education. "During an internship, a student gains real-world skills that cannot be taught in the university setting," said one engineer. "Internships and co-ops played a huge role in me being hired at my current company. If I didn't have that experience, I would have never been considered."

"Students need real world experience," agreed another engineer. "Too many professors have been in academia for so long that they're out of touch. Also, engineers are expected to build things, but school laboratories are artificial. A lot of engineers come out of school without ever building, testing, or troubleshooting real applications."

Some pointed out that—in addition to providing valuable hands-on experience—internships can also help students decide if engineering is the right track for them. "Classroom work and 'for pay' work are very different," one respondent noted. "I've encountered many folks who no longer want to be engineers and would have changed fields before entering the industry if they'd had intern experience first. I've also encountered interns who reported at the end of the internship that they were glad to see real engineering work life and decided to look for something else before launching into it for a living."

But not everyone is in favor of making internships mandatory. "Although very important, if they were mandatory, then the industry would abuse it by requiring students to work for no, or very little, compensation," said one engineer. "Internships should be paid positions, though obviously not at full engineering salaries.

Some respondents with a negative opinion about the quality of U.S. engineering graduates suggested that the problems faced by younger engineering candidates transcend shortcomings in academic formal curricula or a failure to engage in adequate pre-employment internships. One, for example, observed that while the next generation of engineers excels at writing software, they haven't grown up with the hands-on experiences older engineers had with hardware. "Hobbies for hardware-oriented EEs are almost non-existent," said this nostalgic respondent. "Heathkit, for example, has been gone for years."

The other half of the survey's respondents had starkly constrasting viewpoints. They expressed that today's engineering degree programs are as good and challenging as ever, and those who make it through are skilled, well-prepared, and highly motivated. "I think U.S. colleges and universities have excellent faculty and some of the finest engineering programs," said one representative of this contingent. "Those who are able to afford to complete an education are well-prepared for the engineering employment we and other companies offer."

Many expressed similar sentiments. "We generally find talented new grads for most engineering disciplines we hire," said one. "We expect them to be well-grounded in the basics and assume we will train them in the specifics of our systems."

"The U.S. graduates plenty of talented engineers," asserted still another. "There is no STEM [science, technology, engineering, and math] shortage, only a shortage of good entry-level jobs where these new graduates can get their careers off the ground." According to this respondent, outsourcing has led companies to retain only senior-level specialist engineers or project managers. Jobs that allow entry-level engineers to learn in their early years are disappearing.

At the same time, he added, large companies like Apple, Intel, Microsoft, and others are pushing for more H-1B visas to bring in low-paid engineers from overseas. The decision to pursue a strategy of procuring low-cost labor rather than invest in young American students creates the very shortfall that these employers bemoan. "Our engineers graduate with excellent skills and are just as entrepreneurial as foreign-born engineers," he asserted in his survey response. "The only difference is that they expect fair compensation."

A number of survey respondents expressed that the mission of engineering schools is to teach students how to "think like an engineer" and how to work collaboratively with others, rather than produce individuals with the exact skills needed by a particular employer. These respondents took the position that those skills can only be gained on the job.

One respondent went another route: "Education does not create engineers. Education creates individuals who know how to study and solve problems. Engineers are grown out of those people who learn how to solve real-world problems and create designs for real-world equipment that does what is needed to solve a problem."

About half the respondents to this year's survey say their company has a relationship with a local college or university for internships that eventually leads to hires; 80% believe this approach enables them to hire engineers with the skills they're seeking. However, only four out of 10 say their firm fosters STEM education by sponsoring events or offering mentoring.

IS ENGINEER PRODUCTION ABROAD ANY BETTER?

Do apparent shortcomings with the U.S. education system mean that other countries are superior in producing good engineers? Not according to this year's survey respondents. While 70% work for companies that have hired engineers who were born and raised outside the U.S., only 21% believe that engineering programs worldwide better prepare engineers for real-world job duties and responsibilities.

"American engineers are the most creative, focused, and hard-working in the world—and I have worked with engineers from every continent," declared one respondent. "New engineers from abroad tend to want step-by-step instructions on how to create physical designs of integrated circuits," said another. "Some do not learn to think for themselves or think outside the box when given new design challenges."

Many expressed the view that while many foreign engineers possess adequate theoretical skills, they graduate with even fewer practical engineering skills than American students. "Foreign-trained engineers are well-grounded in math and physics principles, but do not generally get very much practical experience or training," observed one engineer. Another said: "From what I've seen, foreign engineering education involves mostly memorizing test answers, rather than any practical design experience."

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THE GENDER DIVIDE

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Women remain underrepresented in engineering—and the situation isn't improving

Like past surveys, relatively few female voices were heard in this year's Salary & Opinion Survey. Only about 3% of our 3000 responses came from women. So, to get a better understanding of some of the issues facing women in the field, *Electronic Design* teamed up with IEEE Women In Engineering—the professional association's wing dedicated to promoting women engineers and scientists—on research that paralleled our annual salary survey.

For this project, we solicited responses from nearly 400 women involved in design engineering, engineering management, and executive management at OEMs. These women shared their insights on general industry subjects as well as issues specific to women in engineering.

Engineering, of course, remains a male-dominated profession. The Congressional Joint Economic Committee recently reported that only about 14% of the engineers currently working in the U.S. are female. While that's a significant improvement from the early 1980s—when women made up a mere 6% of the engineering workforce—it still indicates that a serious gender divide exists in the field.

What's more, the profession's gender disparity may be getting worse, not better. According to the U.S. Census Bureau, the percentage of women holding STEM jobs is on the decline—mainly because their share of computer occupations dropped to 27% after reaching a high of 34% in 1990. "We have seen an increase in women employed in STEM occupations, but they are still underrepresented in engineering and computer

occupations that make up more than 80% of STEM employment," said Liana Christin Landivar, a sociologist in the Census Bureau's Industry and Occupation Statistics Branch.

Women make up 51% of the U.S. population and 47% of the workforce, so it's clear that some issue or issues are preventing their proportionate representation in one of the working world's more lucrative professions.

Because the number of women participating in our main Salary Survey was so small, it probably does not offer a statistically significant insight into the compensation disparities between men and women. That said, for the sample on hand, income between the sexes differed by about 10% ($106,869 in total compensation for men vs. $97,357 for women).

However, this disparity isn't based on a direct comparison of women and men holding the same positions or in the same situations. For example, the sample of women who participated in the Electronic Design survey were, on average, much younger (45 years of age vs. 53 for the men) and had nine fewer years of engineering experience than the men we heard from (18 years for women vs. 27 years for men).

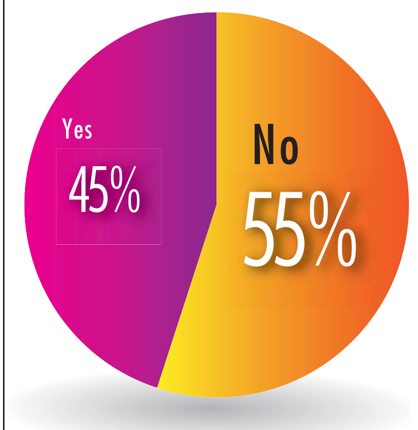
On the other hand, when we looked at the 400 participants in the separate survey of women conducted with IEEE, we found that they had much higher levels of education than the average participant in our main survey. For example, 42% hold a master's degree (compared to just 30% in our main survey)—while 23% have a doctorate (compared to 9% in our main survey).

So rather than focus on issues related to compensation, we decided to use data from both surveys to compare how men and women engineers differ in their views about the profession generally and their jobs specifically. We also asked women to open up about their experiences working in a male-dominated occupation, as well as offer advice to young women who might consider entering the field.

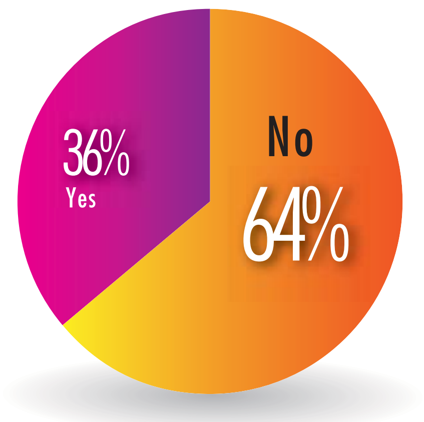
DOES IT START IN SCHOOL?

The minority status of women in engineering becomes evident to them while still in school. On average, women estimate there were 13.5% fewer woman engineering students on graduation day than when they first entered college. While some suggested that the rigors of an engineering education were partly to blame for the drop-off, others cited the paucity

ARE WOMEN IN ENGINEERING AFFORDED THE SAME OPPORTUNITIES FOR CAREER ADVANCEMENT IN **ENGINEERING** POSITIONS AS MEN?



ARE WOMEN IN ENGINEERING AFFORDED THE SAME OPPORTUNITIES FOR CAREER ADVANCEMENT IN **MANAGEMENT** POSITIONS AS MEN?



of mentors for women among the faculty and staff as a major contributing factor.

“The lack of mentorship—especially from women faculty members—was clearly one reason for the dropouts,” commented one survey participant. “The support of women faculty toward women students is non-existent. There are not many women faculty members at universities to begin with, and the majority of them are not supportive to students at all. They do not put their weight in at the admission committee when it comes to admitting more women students to the engineering programs. As a matter of fact, most male and women faculty members do not care about gender bias and gender equality issues at all.”

“Harassment of female students was rampant,” reflected another woman engineer. “It is much improved now. Also, in my college years, it was still an accepted practice for women to take care of the home and children in addition to any studies or outside work. The pressures of all of the responsibilities overwhelmed some.”

Despite the relatively high average salaries in engineering, fewer than a third (29%) of the women surveyed believe women engineers fare better than those in other professions when it comes to achieving equal pay for equal work. About 47% say the opportunities are roughly the same, while one in four say the chances of receiving compensation on par with men is worse in the engineering field than other professions.

“I think that at certain levels, an engineer is an engineer, and the salary will be the same between men and women,” said one survey respondent. “However, I think that the opportunities for advancement for women are lower, which then causes lower salaries.”

This was a common complaint among women: “I get the sense that women in engineering are paid the same as men in the same role, but that women tend to end up in roles that are paid less on average, like QA or tech support.”

“Women in general ask for less, so men are used to giving them less,” opined another. “When in that early discussion with recruiters, women usually do not know what their male peers receive as offers. I used to be shocked to discover that my male coworkers who weren’t as smart or productive as I was made more. Now I’m used to it, and I see how they receive more mentoring and guidance from their managers, who are almost all men.”

Some women cited work/home balance issues as the reason for the disparity. "Many of the women that I have worked with have had children and, as a result, spend less time at work and require more time off to take care of their children," said one respondent. "I believe this affects their salary. At one company I worked for, a manager even said to me that if he were hiring, he would not select a women because most of them require extra time off to take care of children. This is a man who had a stay-at-home wife and children. Unfortunately, even if a woman does not have children, she would be viewed the same as women with children and have less opportunity to move up."

"At my previous job, I was making 20-25% less than my male counterparts with the same title," one engineer related. "I performed better, accomplished more, but was paid less—and was expected not to complain."

Despite these issues, about half of the women surveyed say they are either extremely happy or very happy in their current positions—closely matching the results for men. Digging deeper, 63% of female engineers say they feel sufficiently challenged intellectually with the projects they work on, compared to just 56% of men.

But, despite that satisfaction, 42% of women engineers say they've considered ditching the profession altogether to pursue something else, compared to just over a third of the men we heard from. In fact, 15% of women say they're already looking for a new job, compared to only 9% of the men surveyed.

One reason may be that most women (55%) don't believe they have the same opportunities for career advancement in engineering positions as men. "Women tend to promote themselves less than men, even though they are just as capable," noted one women engineer. "In my experience, the engineers who are the most vocal about their accomplishments are advanced to higher levels than those who quietly do brilliant work."

"It's an unconscious bias," claimed another survey participant. "Women do not brag about their achievements or come forward with clear ambition for management positions. Plus, many men don't believe it's possible to have both a family and a management career."

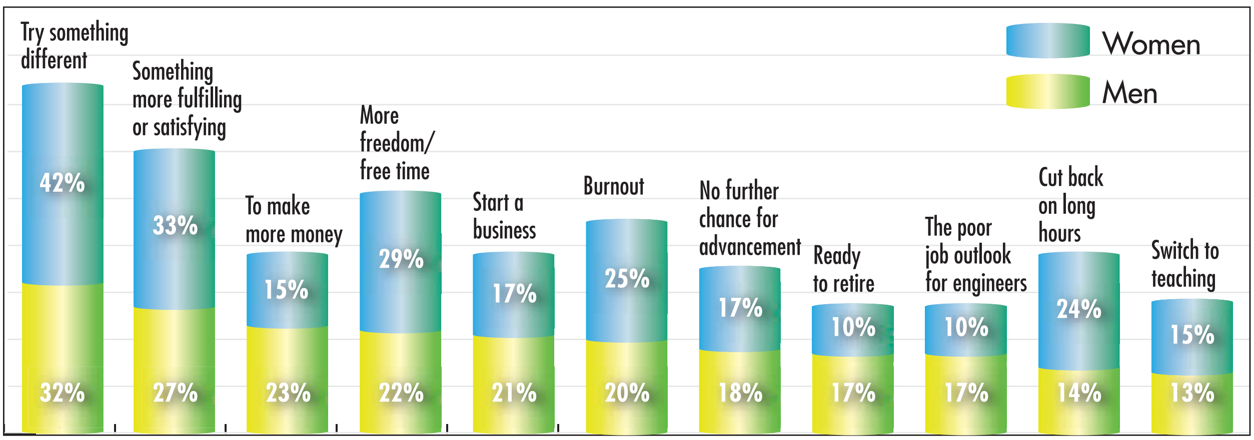
HOW DO WOMEN IN ENGINEERING FARE VS. WOMEN IN OTHER PROFESSIONS WHEN IT COMES TO EQUAL PAY FOR EQUAL WORK?

Another woman engineer put it this way: "There is a constant assumption that women engineers must face on a daily basis: that they're not engineers ('You're the admin, right?') or that they're not really engineers ('You're just the tester, right?'). Their voices are not heard in meetings, they're not acknowledged in leadership reviews, and they're discouraged from working on projects that could advance their careers. These micro-aggressions accumulate into reduced career outlook."

"We are not recognized for what we do," summarized another. "Peers, supervisors, and managers get the credit. What we do is forgotten or downplayed. Also, opportunities to be seen are given to male engineers by male engineers first."

The women we surveyed indicated that things get even worse for them if they do get into management. Nearly two-thirds (64%) of the female engineering managers we surveyed

NEARLY 1 IN 4 WOMEN HAVE CONSIDERED LEAVING THE ENGINEERING PROFESSION TO SPEND MORE TIME WITH FAMILY. OTHER REASONS ENGINEERS HAVE FOR LEAVING THE PROFESSION INCLUDE:



say they aren't afforded the same career advancement opportunities as men. "We are considered emotional and not able to make the tough decisions that men do," claimed one woman in a management position. "Women are still seen as emotional and needy, so they're not considered for some critical positions at companies," another agreed. "I've been told by management those exact words in previous jobs."

A smaller number of women described somewhat different experiences. "I think women who treat themselves like people rather than women advance the same as men," said one survey participant. "I've never seen myself as 'the woman in the room,' just 'a person in the room,' and I share my ideas and thoughts accordingly—and I have accelerated quickly at my company."

Ironically, however, this same survey participant also said that her compensation was only in the "21st percentile," while the male engineers who come to her for guidance are in the "90th percentile"—and was thus strongly inclined to leave her job. "It's very demoralizing, and it's too bad for the company that they haven't fixed it."

"Women in engineering have had to contend with men from the start," wrote another woman. "Be it in classrooms or on the job. You learn to live in their world and it helps when it comes to things like putting yourself out there for a raise or promotion."

Some are more philosophical: "As in anything with life, if you are a go-getter and want to advance in your career you will, but if you are timid and don't afford yourself appropriate connections you will not get the same opportunities."

One reason women have very different experiences is that their companies maintain very different policies when it comes to gender issues. "In my division at IBM, there are an unusually high percentage of managers and engineers who are women compared to other corporations with which I've interacted," wrote one respondent. "IBM has made a concerted effort to advance women in technical roles. Also many of the women in our organization are the best in the world in their fields."

Some companies are making special efforts to address gender disparities, which may account for one interesting statistic from our research: 67% of them told us they'd been contacted by a headhunter or recruitment specialist within the past year, while only 54% of men could make that claim.

"I've always been lucky enough to encounter men who are more than thrilled at finding a woman engineer who can do as good, if not better, a job than her male counterparts," chimed in another. "These men typically afford women the same opportunities for advancement."

And, while it's important not to make unfounded generalizations about behavior and gender, it does appear that women do approach their jobs differently than men. Women, for example, use social media more extensively for their work than men. This gives some credence to the belief that women tend to be more collaborative than their male counterparts.

ADVICE TO THE NEXT GENERATION

Despite the challenges women engineers face, 93% still say they would recommend engineering as a career path to young girls and boys alike. "Engineering has been a satisfying and personally rewarding career for me," said one. "I do believe that women often have obstacles that men don't as engineers, but if they are willing to negotiate those obstacles, it can be a fulfilling career."

"Engineering is an exciting field where you can make a difference," said another respondent. "There are opportunities for both men and women, but I would caution women that they need to be willing to work hard and be prepared to promote their own accomplishments if they want to be noticed and recognized for their skills."

"It is a good career, challenging, and pays well," said another. "Women do well in engineering, but the glass ceiling is low. This still is a field dominated by men, and it is difficult to fit in."

Some respondents suggested that the bigger issue for young people was a general understanding of what the engineering profession was all about. "It's something that I believe more people would enjoy if they had had exposure to it at an early age," observed one engineer. "The U.S. education system does not prepare high school students for careers. Exposure to engineering is minimal to nonexistent before college and that's unfortunate."

Some women suggested that they would only recommend engineering to young boys. "When I meet someone new and shake their hand, there is zero chance that their first comment won't be about my gender," complained one women engineer. "After ten years in the field, it is as sexist as when I first started. I'm tired of having to fight to be seen as an engineer. I wouldn't recommend this field to young women because I think they can get further in other fields that don't have the perception obstacle. Why fight if you can go somewhere better?"

Others shared similar sentiments: "I believe the only women who will continue in engineering with the current work environment are those who desperately love the work itself," one female respondent opined. "Why deal with others minimizing your accomplishments and with constant, blatant discrimination when you can work in a profession where women are more welcome? Why go through difficult engineering courses and social hostility to get paid what someone without an undergraduate education gets paid? Medicine has a large pay gap for women, but women are more socially accepted. My friends that switched to become doctors found it an easier thing, purely

INTERVIEW With Nita Patel

IEEE Women In Engineering Committee Chair

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Why have so few women taken up engineering as a career?

I think there's a component of awareness and stereotypes involved. Awareness in that many people don't know what an engineer does or what it means to be an engineer. There are stereotypes and misconceptions about engineering. Also, there are stereotypes about the capabilities required. I think there's a stereotype and bias that implies that girls are not capable of pursuing a STEM field. Yes, STEM can be hard, but so are many other fields of study and women are successful in them (*e.g.*, doctors and lawyers).

In your view, what are some of the aspects of engineering that make it a particularly good career path for women?

I think it's a great career choice because there is an incredible amount of flexibility and many opportunities. An engineering/technical background provides many opportunities in terms of type of industry (defense, medical, commercial, space...), type of career (full-time, part-time, independent, team-based...), and level of contribution (individual, team lead, executive...). The analytical and logical skills that you learn through a STEM degree can be applied to many different industries. Also, most engineering careers are project-based, so there is great flexibility in the hours you can set.

What are the biggest challenges women in engineering face?

I think people are aware of and control overt biases. There are still some subtle biases floating around. The perception that engineering is a man's field is still prevalent, so this can be discouraging and prolongs the bias.

Given some of these challenges, would you recommend engineering as a career path for women?

Absolutely, I do not think the challenges are overwhelming. I think the career is very rewarding. Women have a lot to contribute in this field.

What career advice do you have for women currently working in engineering?

Challenge yourself and ask for larger leadership roles. I think it's important to get more women into higher-visibility management roles. I also think women should keep learning. Technology is ever-changing, so we must work to remain technically current and think about expanding our horizons by continually developing professional skills.

What advice do you have for women students who are considering the profession?

Go for it. You will find the technology exciting and the skills you learn will help you throughout your life. ■

because of social reasons. It isn't supposed to be an easy career track, but compared to engineering it was easier for them. Life is short and love of work is not always enough to override all of the pitfalls of being a woman in engineering. But I'm still in it because I love the work."

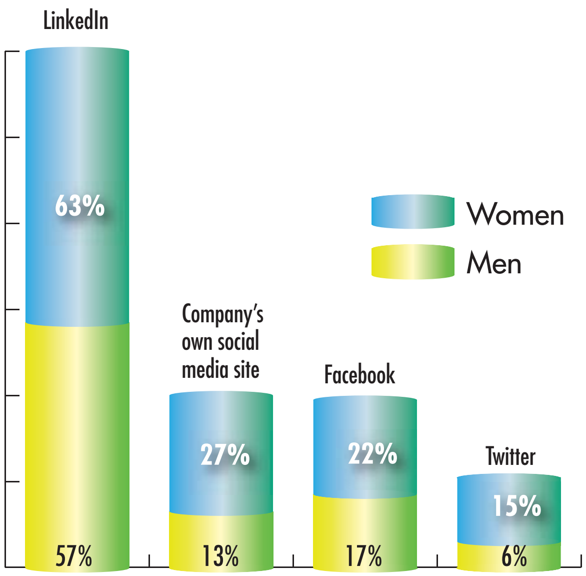
Young girls need extra reassurance and role models, according to some women. "Young women need more encouragement than men to go into a field that's already dominated by men," said one respondent. "I'm happy to mentor the men who have made that choice already, but young women need to see that there's a place for them here, too."

Others homed in on what they saw as a special opportunity for women. "There are not enough women in the field, and a social stigma exists for girls to pursue math and science in school," said one engineer. "Girls are often not expected to do well in math and science, and a lot of them seem to subsequently believe that they should not even try. I think women should want to succeed for themselves despite pushback or stereotypes."

These comments and others highlight the fact that, even in 2014, the engineering field still suffers from issues that have plagued it for decades. Our research may even serve as a cautionary note to men in the profession who are unaware of attitudes and behaviors that unfairly undermine the ability of women to succeed in the field, despite their technical competence.

The study also shows the importance of groups like IEEE Women In Engineering, which can shed light on gender issues in the profession and take a position of advocacy for women. Future studies may show some progress in a profession that—perhaps even more than most others—could theoretically recognize and reward empirically evident technical abilities without any regard whatsoever for gender. ed

WOMEN ENGINEERS ARE MORE ACTIVE USERS OF SOCIAL MEDIA FOR BUSINESS



Salary Survey

continued from p. 35

Some survey participants suggested that cultural issues are what really make things tougher for foreign-trained engineers. "American graduates fit in easier with the company culture," said one. "There is no language barrier. Also, foreign graduates need more structure when they get started. But many are already set in their ways by the time they arrive, so even years later they cannot fit in with company culture."

Another engineer put it this way: "Even if engineering programs abroad offer better skills and knowledge preparation, they provide very little notion about American society, markets, and the business of engineering in the U.S. Only the truly exceptional engineers—who would do well no matter where they were born or educated—are any better than those raised in the U.S. The culture here supports kids to learn the types of skills that make a good engineer. That culture does not exist in China or India, although it does seem to exist in Eastern Europe."

Others have gone through different experiences. "I am a U.S. citizen who went to school abroad. The program was more practically based and less theoretical. There was a large hands-on component. All the classes were taught in the engineering department and were geared toward engineering. We did not have Liberal Arts requirements. It was very focused and intense. We were in class for 32 hours per week. Our exams covered the entire year, not just one semester."

Another engineer said: "Engineering students abroad have to do more with less, do not have the resources, and thus really have to do engineering to overcome shortcomings on resources. Do you think Apple could have made a production iPhone without the help of Chinese engineers who showed them how to cut corners in order to meet production and cost goals?"

ECONOMIC PESSIMISM

The survey also asked engineers what they thought about the general outlook for the U.S. economy. Responses were not too enthusiastic. Less than half (43%) were at least somewhat positive about where things were headed. By contrast, 31% held a negative view and 26% were neutral.

Many who expressed a positive outlook believed the recession was behind us. And, even though the recovery has been long and slow, they believe that things are likely to continue to grow slowly, but steadily.

"There is lots of interest in products that we are producing; capital expenditures are up, credit is available, and people are spending, hiring, and investing," commented one engineer.

"I think we're making our way back from the downturn," said an OEM business owner. "It's actually been good for one of the three companies I own, since it has meant that in the early

DESPITE RECENT HEALTHCARE REFORM, THE PERCENTAGE OF ENGINEERS THAT RECEIVE HEALTHCARE BENEFITS FROM THEIR COMPANY CONTINUES TO DROP				
2010	2011	2012	2013	2014
57%	63%	61%	56%	54%

stages of product development over the last three years, we've been able to be much more cost-efficient—because vendors are eager for work and not operating at full capacity. In a bustling economy, it's more difficult to attract the attention of vendors or have them work with you to keep costs contained."

"I believe that increasing interest in technology is spreading to the wider industrial community and that interest by the general population in the possibilities of IoT, 3D printing, and mobile devices is bringing more funding and innovation to the technology sector," another engineer commented.

Many of those who were less optimistic about the future cited corporate greed. "Companies are making record profits, but not sharing with their employees," observed one such respondent. "Sooner or later, that will implode."

A big majority blamed the current political environment, though. "For the economy to move forward and become stable, the proper incentives (such as a more sensible tax code) must be in place. The potential for growth and lasting recovery is there, but our lawmakers have not been actively working to drive the correct behavior and reward risk. At the moment, everyone is too cautious and risk-averse, due to the tenuous state of the economy."

"New technology is possible: the smart grid, the Internet of Things, electric cars, new medical devices," one engineer wrote. "If the government didn't declare a war on science, we would be doing more R&D to make new technology available to the world. Just fix the politics and the technology will flow."

MAKING THE MOST OF CHALLENGING TIMES

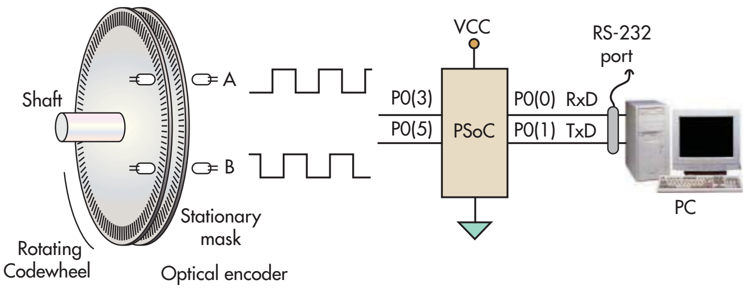
Life is not as easy for engineers in 2014 as it was in the go-go days of the tech boom. A dicey global economy, a risk- and cost-averse corporate culture, and the intensifying complexity of today's smart technologies all make life a little more difficult for engineers than they'd like.

But engineers have it better than most. Compensation continues to climb, and opportunities abound. The world's overall appetite for technology is strong—even if it's at a price and speed that tax the capacity of engineering teams.

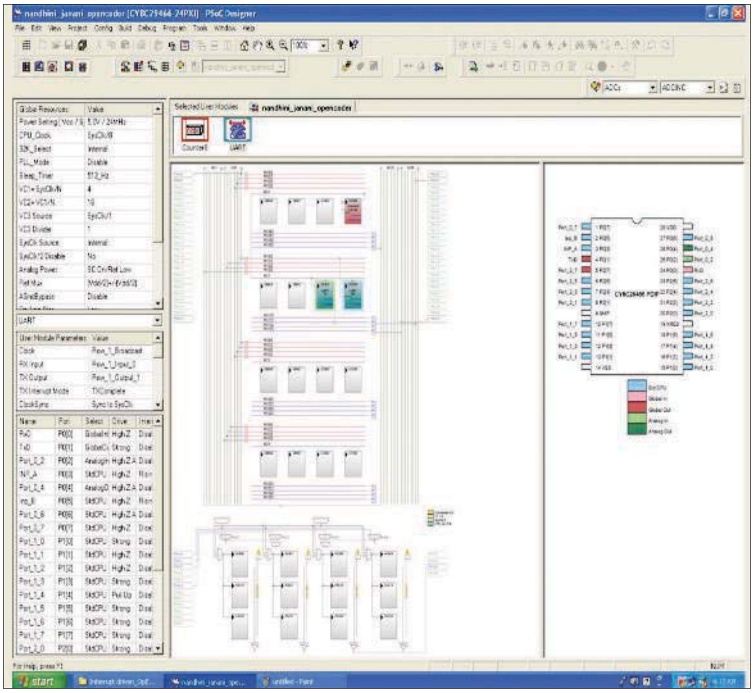
Perhaps most important, there is still something about being an engineer at this particular juncture of history that makes it unlike any other profession. As one survey respondent put it: "The teachers who told me 'Math and science are going to change your life' were right. With footprints on the moon and tire tracks on Mars, I know that the sky is no longer the limit." ed

Use PSoC GPIO And Interrupts To Resolve Optical Encoding Outputs

J. NANDHINI AND J. JANANI | SATHYABAMA UNIVERSITY, INDIA nandhinij1994@gmail.com, jananij1994@gmail.com



1. In an optical encoder (left), a pair of light-source/reflector/light sensor channels are used in quadrature to provide basic motion/direction information. Here, the outputs go to the interrupts and ISR of a PSoC device for decoding and then (optionally) to a PC for further use.



2. The PSoC 1 Designer Screen for the CY8C29466 DIP Package shows the blocks that are selected and how they are configured to implement increment/decrement counting via the interrupt service routine.

IN MANY APPLICATIONS, ACCURATELY sensing the position of an electrically controlled mechanical device such as a motor is critical. While many published designs require additional hardware components and thus increase cost, this approach uses the general-purpose input/output pin interrupt and interrupt service subroutine (GPIO ISR) of a Cypress PSoC to get the exact rotor position and direction while the motor is in motion via an optical encoder.

Optical encoders convert mechanical position into an electrical signal. They comprise a patterned disk, a light source, and photosensitive elements *(Fig. 1)*. The disk, which is mounted on the rotating shaft, has coded patterns of opaque and transparent sectors. As the disk rotates, these patterns interrupt the light emitted onto the photodetector, generating a digital square-pulse output.

A two-channel optical encoder pulse pair provides both the position and direction of the rotating motor, using a quadrature configuration. While the motor rotates clockwise, the rising edge of pulse A leads pulse B. During counter-clockwise rotation, the rising edge of pulse B leads pulse A. With these sequences, the read-out electronics can register the direction of the rotating motor. Incrementing and decrementing pulses A or B provides the exact positional information.

The PSoC input pin interrupt (the GPIO interrupt) supports neither state machines nor up/down counters. Instead, using the pin interrupt for the optical decoder, the two channels of optical encoder pulses A and B are connected to two inputs of the port_0, here port_0(3) and port_0(5) *(Fig. 2)*. For pulse decoding and sensing the direction of rotation and position of the motor, the "PSoCGPIO" interrupt is enabled.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The main advantage to this design is that when an interrupt occurs, the interrupt service routine (ISR) checks if it is due to clockwise rotation of motor movement (an incremented count) or counterclockwise rotation (a decremented count).

The GPIO ISR automatically determines the direction of the motor by incrementing and decrementing the counter to measure the rotor's direction and the motor's position. It decodes the quadrature signals through a simple software implementation in the PSoC designer tool without using any additional hardware, as the required tasks can be implemented easily within the PSoC and its architecture.

The GPIO interrupt service routine senses input pulses A and B going low and high, and high and low *(see the code listing available with the online version of this article at electronicdesign.com)*. Correspondingly, it increments the position with Position++ operator (B-high; A-low) or decrements the position with Position–– operator (A-high; B-low).

Thus, the GPIO interrupt handler registers the position and direction of the motor movement in a single interrupt sensing. The interrupt handler takes care of the exact position of the motor movement in both directions by updating a single data pointer "Position," incrementing the count in case of upward direction or decrementing the count while the motor moves down.

For a PC-compatible readout, a UART comprising TxD (Port_0_1) and RxD (Port_0_0) blocks is placed in the DCB12 and DCB13 digital blocks. The current "Position" data obtained through the interrupt handler is transmitted to the PC through UART blocks via the "Send Data" command. For the required baud-rate clock division, an 8-bit counter is placed in a DCB03 digital block. In this application, the UART rate is fixed at 115,200 baud.

No power supply is required for this design, since the PSoC CY8C29466 board gets its 5-V source via the USB port. The code listing provides the PSoC Editor program, including the GPIO ISR routine and UART protocol, which interfaces with the PC serial port.

J. NANDHINI AND J. JANANI are sisters in the third year of electronics and communication engineering at Sathyabamam University, Chennai, Tamil Nadu, India. Their area of interest is embedded designs.

DESIGN NOTES

55V High Efficiency Buck-Boost Power Manager and Multi-Chemistry Battery Charger

Design Note 531

Charlie Zhao

Introduction

Today, battery chargers are expected to easily support a variety of battery chemistries and accept a range of voltage inputs, including wide-ranging solar panels. It is increasingly common for input voltage ranges to span above and below the output battery voltage, requiring both step-down and step-up capability (buck-boost topology). The LTC4020 buck-boost power manager and multi-chemistry battery-charging controller can take wide-ranging 4.5V to 55V inputs and produce output voltages up to 55V. Its buck-boost DC/DC controller supports battery and system voltages above, below, or equal to the input voltage.

The charger is easily optimized for a variety of battery chemistries. For instance, it can follow a constant-current/constant-voltage (CC/CV) charge algorithm, with either C/10 or timed termination for lithium-based battery systems, a constant-current (CC) characteristic with timed termination, or an optimized 4-step, 3-stage lead-acid charge profile.

6.3A Charger for 25.2V Battery Float Voltage

Figure 1 shows a 15V to 55V input, 25.2V/6.3A buck-boost battery charger, featuring a high efficiency 4-switch (M2–M5) synchronous buck-boost DC/DC

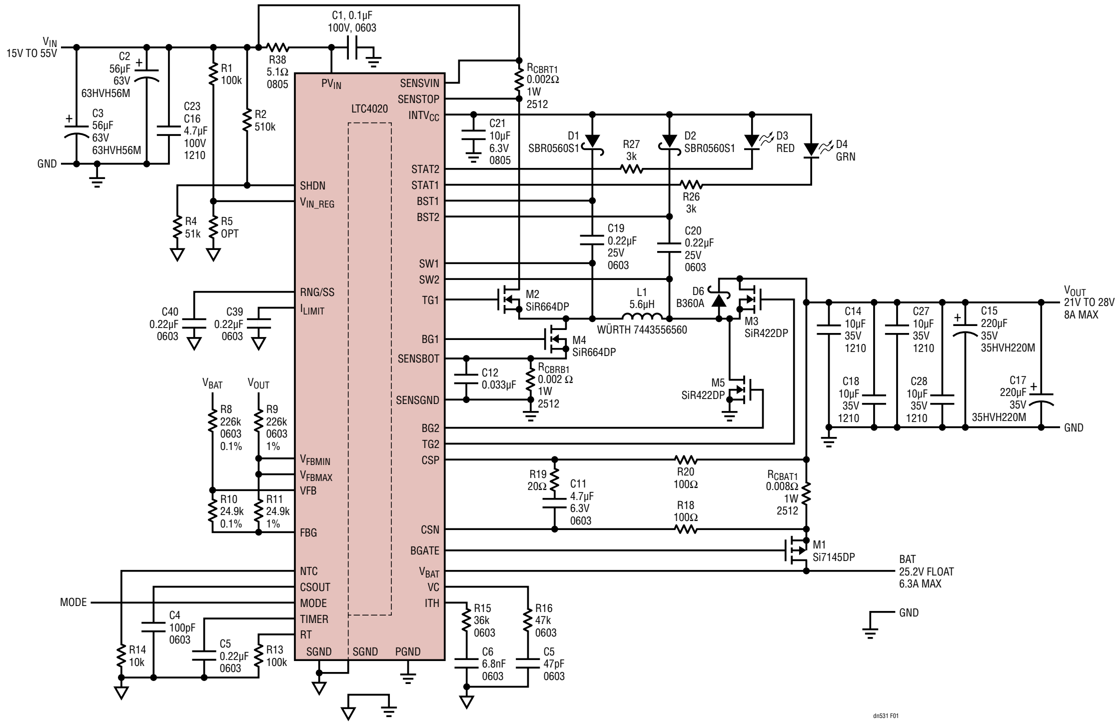

Figure 1. 15V to 55V Input, 25.2V/6.3A Buck-Boost Battery Charger

converter requiring only one inductor (L1). The proprietary average current mode architecture uses two sense resistors (R_{CBRT1} and R_{CBRB1}) to monitor the inductor current. In this buck-boost solution, when V_{IN} is higher than V_{OUT}, the converter operates in buck (step-down) mode; when V_{IN} is lower than V_{OUT}, the converter works at boost (step-up) mode. When V_{IN} is close to V_{OUT}, the converter operates in 4-switch buck-boost mode.

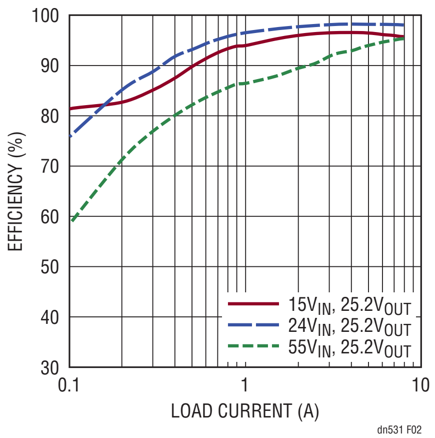

Figure 2. Efficiency vs Load Current I_{OUT} (V_{OUT} = 25.2V) of the Converter in Figure 1

The converter operates at a programmable constant switching frequency within the range of 50kHz to 500kHz, set with a resistor (R13 = 100k, 250kHz). The solution shown in Figure 1 can supply up to 8A to the system load (V_{OUT} = 25.2V). Figure 2 shows full load efficiency (I_{OUT} = 8A, V_{IN} = 24V) can reach above 98%.

The LTC4020 uses an external feedback resistor divider from the BAT pin to program battery voltages via the V_{FB} pin. The PowerPath™ FET (M1) is on during normal battery charging, forming a low impedance connection between the battery and the buck-boost converter output when possible. Battery charge current is monitored through a sense resistor (R_{CBAT1}). Maximum average battery charge current is easily programmed by selecting the value of R_{CBAT1}. Dynamic current limit adjustment is possible through the RNG/SS pin.

Instant-On and Ideal Diode Functions with PowerPath FET

For a heavily discharged battery, the LTC4020 can automatically configure the PowerPath FET (M1 in Figure 1) as a linear regulator, allowing the buck-boost converter output to rise above the battery voltage, while still providing charge current to the battery. This function is called PowerPath instant-on, when the PowerPath FET acts as a high impedance current source, providing charge current to the battery.

The LTC4020 automatically configures the PowerPath FET as an ideal diode when the battery charger is not in a charging cycle—namely, the buck-boost converter is operating exclusively for the system load. This allows the battery to remain disconnected from the converter output in normal operation. If, however, the system load current exceeds the buck-boost converter's capacity, additional power can be efficiently drawn from the battery through this ideal diode.

Additional Features

The LTC4020 supports timer-based charging algorithms—a capacitor from the TIMER pin to ground programs the end of the cycle time.

The LTC4020 features battery temperature monitoring and control. By connecting an NTC (negative temperature coefficient) thermistor to the NTC pin, and by placing the thermistor close to the battery pack (or other desired monitoring location), if the NTC pin voltage is out of range (above 1.35V or below 0.3V), the LTC4020 triggers an NTC fault and halts battery charging.

The LTC4020's V_{IN_REG} pin allows input voltage regulation. This pin can be used to program the peak power voltage for a solar panel, or help maintain a minimum voltage for other high impedance input supplies.

The LTC4020 has two open collector outputs, STAT1 and STAT2, to report charger status and fault conditions. These two pins are binary coded.

Conclusion

The LTC4020 is a versatile high voltage, high efficiency buck-boost power manager and multi-chemistry battery charger, supporting input voltages above, below or equal to the output battery or system voltages. Its low profile (0.75mm) thermally enhanced 38-pin 5mm × 7mm QFN package is suitable for portable industrial and medical equipment, solar-powered systems, military communications equipment, and 12V to 24V embedded automotive systems.

Data Sheet Download

www.linear.com/LTC4020

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High-Side Load Driver Enhances Short-Circuit Protection

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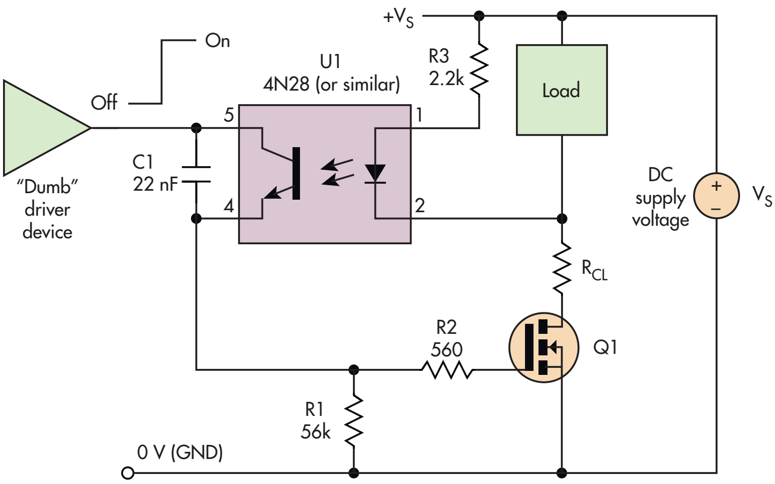
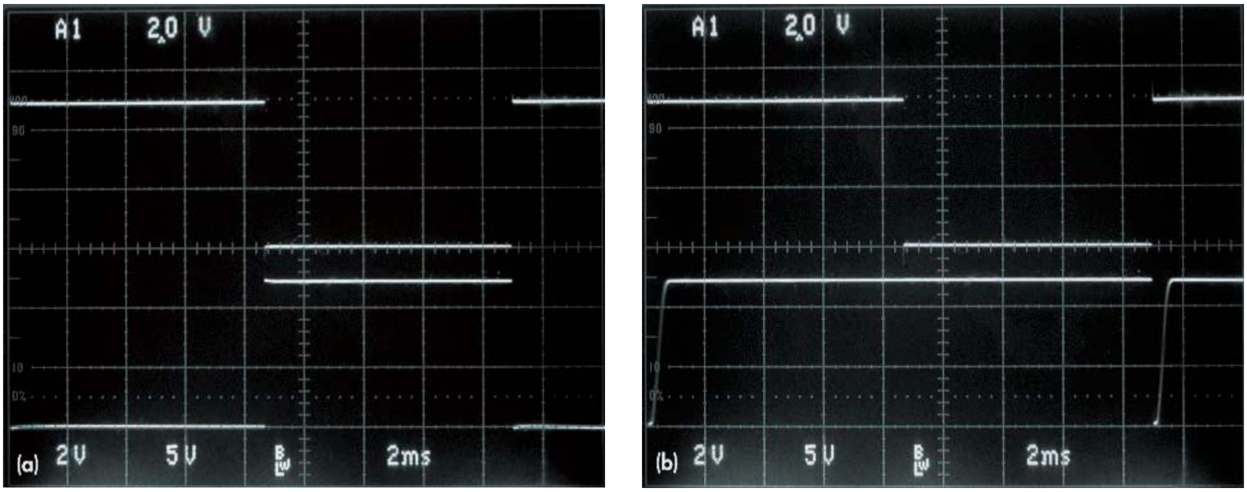
THIS CIRCUIT BUILDS on a previous idea in which the addition of an optocoupler to a microcontroller output converted a "dumb" high-side driver into a "smart" one with diagnostics and short-circuit protection.[1]

The circuit adapts this concept for cases where a microcontroller is either not required or inappropriate. It also adds short-circuit load protection to an even "dumber" driver such as the output of a simple logic gate *(Fig. 1)*. As a result, it too allows a "dumb" low-level device to control a high-power load operating at a much higher voltage without fear of destructive short-circuit conditions.

Assume that C1 is initially uncharged, the driver output is at 0 V, and N-channel MOSFET Q1 is off. When the driver output transitions from a low level to a high level,



1. The simple high-side driver can protect even a basic logic gate against load short circuits by controlling the optocoupler turn-on and turn-off periods.



2. Normal operation has a low level at Q1's drain terminal and the full supply voltage across the load (lower trace), due to a high level at the drive signal (upper trace) (a).When the load is shorted, the full voltage is impressed across the load for under a millisecond (b). Driver voltage is 2 V/div, Q1 drain is 5V/div, and the horizontal axis is 2 ms/div.

the pulse couples through C1 and R2 to the gate of Q1, turning it on. Without the feedback provided via optocoupler U1, capacitor C1 would rapidly charge via R1, Q1's gate voltage would fall to zero, and the MOSFET would turn off after about a millisecond. However, the presence of the optocoupler effectively allows the circuit to monitor the voltage across the load.

If the load is normal, the full supply voltage (+VS) appears across it when Q1 turns on, forward-biasing U1's photodiode via R3. This turns on U1's phototransistor, which shunts C1, pulling Q1's gate up to the high-level drive voltage. Since C1 is now effectively "clamped" by U1's phototransistor, it cannot charge up, so Q1 remains on and the load remains energized.

If the load is short-circuited at any time by a fault, though, U1's phototransistor turns off, C1 rapidly charges via R1, and Q1's gate voltage quickly falls to zero. The MOSFET now turns off, disrupting current flow to the faulty load, and remains off until the driver output is cycled low (to allow C1 to discharge) and then high again. The circuit will continue to "reset" to the off condition until the load fault is removed.

Resistor R2 provides current limiting to prevent Q1's gate-source capacitance damaging the driver's output at turn-on. It may also be necessary to prevent the MOSFET from oscillating. A value of a few hundred ohms is usually suitable.

Figure 2 shows the operation of a circuit built with a BUK455-60A MOSFET for Q1. Load-supply voltage $+V_S$ was 12 V, the load was 100 Ω, and the driving signal was a 60-Hz, 5-V square wave.

In normal operation *[Fig. 2(a)]*, a high level at the drive signal results in a low level at Q1's drain terminal (full supply voltage dropped across the load). In *Fig. 2(b)*, the load has been short-circuited.

When the driver signal goes high, the circuit output at Q1's drain terminal falls to zero only for a very brief time (less than a millisecond) and then immediately rises back up to +12 V. In other words, the full supply voltage only appears across the faulty load for less than a millisecond until the circuit "resets," causing the voltage across the load to drop to zero.

In the case of the faulty load, the C1/R1 time constant largely determines the duration of the brief "on" pulse. If this time constant is too short, the optocoupler will not have time to turn on properly to clamp C1 in the case of a normal load. But if the time constant is too long, a short-circuited load could cause the pulse current rating of Q1 to be exceeded during the brief "on" pulse, potentially damaging the MOSFET.

Using C1 of 22 nF and R1 of 56 kΩ worked well in the test circuit. An optional current-limiting resistor R_{CL} (usually a few ohms) in series with Q1's drain may be advisable to limit the maximum output current to a safe level.

REFERENCE

1. "Add Short-Circuit Protection, Diagnostics To Automotive High-Side/Low-Side Driver," Vishwas Vaidya, *Electronic Design*, March 7, 2013.

ANTHONY H. SMITH has been working as a consultant engineer for the past decade, designing products for the industrial, domestic, and automotive markets. He received a BSc (Honors) in electronics from Salford University, Greater Manchester. He also holds two patents.

VICTORIA FRAZA KICKHAM | DISTRIBUTION EDITOR

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War on Counterfeit

5 ways the fight against counterfeit components is evolving.

MOST ELECTRONICS INDUSTRY professionals agree that the industry is more vigilant and doing a better job of keeping counterfeit electronic components off the plant floor than it was just five or 10 years ago. But they also say that counterfeiters are getting better at their craft and that detection is becoming even harder—key reasons why suppliers can't weaken their resolve in the fight against counterfeit parts. A host of recent events, including newly released standards and a long-awaited update to the federal government's requirements for companies that supply equipment containing electronic components to the government, is keeping everyone in the channel on their toes.

"Overall, the supply chain is doing a better job of keeping this stuff out as much as they can—out of the end user's supply chains," says Mark Snider, president of ERAI, an association representing independent distributors of electronic components. "But it's only through diligence that they're making that happen."

Snider agrees that awareness of the counterfeit problem has risen dramatically in the last several years, and he points to recent government actions to highlight the problem as a key reason. New standards and regulations surrounding selling to defense organizations are at the heart of the issue, driving continued change on the counterfeit front. Here's a look at five ways the fight to keep counterfeit components out of the supply channel is evolving.

1. DFARS UPDATE

In May, the federal government issued an update to its rules for companies that sell equipment containing electronic components to the federal government. Known as the Defense Federal Acquisition Regulation Supplement (DFARS), the update addresses new requirements that arose from the National Defense Authorization Act for fiscal years 2012 and 2013 surrounding the detection and avoidance of counterfeit parts. Essentially, the update tells government contractors what they must do to detect and keep counterfeit parts

Continued on Page 54

Distributors Expand with New Connector Products

Avnet strengthens its global TE Connectivity offering and is certified for assembly of Deutsch connectors at its facility in Nogales, Mexico.

DISTRIBUTORS CONTINUED TO ENHANCE their connector lines this summer, and Avnet Electronics Marketing led the way with an expanded global agreement with TE Connectivity. Avnet EM now offers TE's Deutsch line of military connectors and is certified to assemble and maintain them for quick shipment *(see the figure)*.

The expanded agreement allows Avnet EM to supply TE connectors in sizes ranging from standard density to near-double-density D38999 styles. TE offers one of the largest

Avnet Electronics Marketing now offers TE Connectivity's Deutsch 369 connectors, an expansion to the distributor's TE Connectivity offering.

Continued on Page 58

out of the defense supply chain, and it has direct implications for suppliers of those components.

For the most part, the update reflects what the industry expected, so most companies have built their procedures around those expectations, says Kevin Sink, vice president of total quality for authorized distributor TTI Inc. Sink is a member of standard-setting organization SAE International's G19 Committee, which works to address prevention, detection, and electronics industry response to the counterfeit threat.

Sink points to the high activity level in preparation for the DFARS update and subsequent quiet period in recent months. Sink was scheduled to talk about the changes, as well as some of the new standards issued surrounding counterfeit avoidance and detection, at an industry meeting in late September.

"Now we have to figure out exactly what to do if it's different than we expected," he says of the DFARS update, noting that much of the work ahead for suppliers surrounds understanding the requirements and ensuring they have the right systems and procedures in place.

"Overall, the supply chain is doing a better job of keeping this stuff out as much as they can—out of the end user's supply chains."
–Mark Snider, President, ERAI

2. THE NEXT BIG ISSUE: SOFTWARE

Sink cautions that the DFARS update matches industry expectations "for the most part." A key difference is the federal government's definition of an electronic part, expanded to include "any embedded software or firmware."

"That caught everyone by surprise," Sink says, adding that detecting malicious code in software products—an issue for companies supplying products with programmable logic, for instance—had not been part of the discussion leading up to the DFARS update.

"There are no reported cases [of malicious or Trojan software] that we are aware of," Sink adds. "So unless it's occurring, and the government knows about it and hasn't told us—which is possible—then no one is really prepared to handle that part of it.

"I suspect we'll begin to have healthy debates around this issue in the next few months," he adds. "The issue of software will be an evolving one. It's challenging because it gets into issues that really are beyond counterfeiting."

3. MORE PLACES TO TURN FOR HELP

On a positive note, there is much more information available today to help companies throughout the supply channel navigate the regulations and guidelines surrounding counterfeit component detection, mitigation, and reporting.

"We now have several more standards in existence than before, so there is a lot more professional advice for companies to follow," Sink explains, pointing to the newest industry standard, AS6496, which is a guideline for authorized distributors of electronic components. This adds to other recent standards for original equipment manufacturers (OEMs) and independent distributors. The aerospace standard AS 5553, for OEMs, was released in 2009, and AS6081, for independent distributors, was issued in 2011.

AS6496 helps clarify the role of the authorized channel. "It gives customers a good understanding of the protections they get when they buy from the authorized channel—the authorized distributor in particular," Sink explains, noting that distributors complying with the standard must meet requirements regarding how they handle products, from whom they purchase them, and the level of manufacturer support they receive.

4. CLEARER BUSINESS SEGMENTATION

AS6496 also puts some teeth into the authorized model by creating a sharper distinction between authorized and independent business. This is a model many distributors are adopting, in which they handle a number of authorized and non-authorized product lines. The standard requires distributors to disclose to customers which lines they are authorized for and which ones they are not.

Sink says this helps create a clearer segregation between authorized and independent, or broker, business among the many independent distributors that do both types of business.

5. A SHARPER FOCUS ON SCRAP

By and large, companies are also taking a closer look at how they dispose of inventory they can't sell these days. This is especially true of distributors, Sink explains. Authorized distributors typically dispose of such inventory with third-party recyclers and, if they're not careful about the partners they deal with, those parts could fall into the wrong hands.

The reselling of products is how parts end up on the "gray market," a practice Sink says TTI has never participated in. Nonetheless, the path parts follow to get into the hands of counterfeiters is something everyone is taking a closer look at these days. The industry recommendation is that excess inventory should be destroyed so that it can't fall into the wrong hands and be misrepresented. To that end, Sink says many distributors are now having excess product ground up and melted down.

In the end, information is key. Sink was a keynote speaker at last month's SAE 2014 Aerospace Systems and Technology Conference in Cincinnati, Ohio. ERAI's annual meeting, scheduled for next April in San Diego, also will include detailed discussion of the DFARS update.

"We're going to be reaching out as much as we can to government to help," Snider explains, "making them available to answer questions and give people an update as to where we are."

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A Life-Saving Partnership

CSafe Global and electronics distributor Hughes-Peters deliver high-tech solutions for medical transport needs

MIKE TRAYLOR COUNTS CSafe Global and its AcuTemp product line as one of his most interesting accounts. As a sales representative for electronic components distributor Hughes-Peters based in Dayton, Ohio, Traylor sells interconnect, passive, and electromechanical (IP&E) products to a wide range of industrial customers throughout the Dayton area, but CSafe Global is his only customer that offers a specialty product for use in military medical applications.

CSafe Global makes temperature-controlled storage and transportation products for use in pharmaceutical, biomedical research, and disaster/conflict applications. In short, the company's products can be used to transport life-saving fluids and materials, protecting them from harsh environments and ensuring that they remain intact.

Traylor started working with CSafe several years ago, when the company introduced its AcuTemp AX56L mobile refrigerator/freezer, a thermal management active shipping device. The product has an ergonomic and rugged hard shell and is used to transport temperature-sensitive, life-saving vaccines and medical supplies to the point of need in any environment. Traylor says Hughes-Peters supported CSafe in its initial job to supply more than 1000 of the units to U.S. military operations in Afghanistan.

CSafe Global's AcuTemp AX56L mobile refrigerator/freezer is a thermal management active shipping device for transporting temperature-sensitive vaccines and medical supplies to the point of need in any environment. Distributor Hughes-Peters supported CSafe in its initial job to supply more than 1000 of the units to U.S. military operations in Afghanistan.

"The unit is really great, because it can run off of AC [power] but can also be powered by battery," Traylor says. "We sell a couple of larger batteries to keep the unit operable."

Traylor works with CSafe's engineers, quality managers, and purchasing staff on a variety of service and support issues, in addition to supplying the batteries to power the units.

"I think what's significant is that most of the products [CSafe makes] are geared toward life-sustaining types of things," Traylor explains, adding that the company has humanitarian goals at heart. "It's a pretty different company—it's people that care about people."

Hughes-Peters also supports CSafe's other products, many of which are larger items used for transporting pharmaceutical and biomedical materials. The distributor supplies CSafe with batteries, cable assemblies, and various other electronic components.

Traylor, again, emphasizes the human aspect of the account: "Their whole philosophy is to improve conditions for extended life."

Living Connected at ECIA's Executive Conference

Electronics distributors, manufacturers meet this month for industry conference featuring experts on all things "connected," including wearable technology, the Internet of Things, and more.

BY SARAH MANGIOLA | CONTRIBUTING EDITOR

The Electronic Components Industry Association (ECIA) will hold its annual Executive Conference at the Loews Chicago O'Hare Hotel in Chicago Oct. 26-28, giving industry professionals the opportunity to learn about the latest trends and prepare their businesses for the future.

ECIA Foundation Director Debbie Conyers weighed in on what this year's conference brings to the table: "The theme of this year's conference is Living Connected. Speakers will explore the industry impact and influence of the Internet of Things, the cloud, smart devices, and wearable technologies. And, aside from the industry, how they are changing our day-to-day lives."

Conference topics include opportunities and economics of the new technologies; big-data analysis; optimizing market share; implications of crowd

funding; and maximizing social platforms—how to use them to sell, hire, and connect to the next generation.

Among speakers at this year's conference are Chris Dancy, who will discuss "The Human Information System—BYOD, Wearable Computing, and Imperceptible Electronics." Dancy has 300 to 700 sensors, devices, applications, and services monitoring his body and surroundings non-stop. He plans to discuss how wearable technology can be used to people's advantage.

Dale Ford, vice president of industry research firm IHS Technology, will present "True Numbers for Everything Connected." As an electronics industry expert, Ford will discuss the increasing focus that has been placed on the cloud and the Internet of Things. He will focus on examples that enable an interdependent ecosystem such as advanced MEMS and image sensor technologies. Additionally, Janusz Bryzek, Ph.D., founder of TSensors Summit, will discuss how the demand for sensors will transform the industry during "Living Connected Through A Trillion Sensors." Sensor demand is predicted to enter the trillions in the next 10 years—an effect of the "abundance" theory he will address regarding how world problems can be solved in 20 years.

Joe Grand, president of Grand Idea Studios, will discuss "The Pitfalls and Perils of Poor Security." As a hacker, he will recount clever hacks and discuss the risks manufacturers are faced with when it comes to embedded system design. He will also go into how to make products more secure. "Pay it Forward—Developing Tomorrow's Leaders," with president of FIRST Donald E. Bossi, will address how living connected also applies to mentoring young people. FIRST focuses on young people's interest in science and technology by engaging them in mentor programs to build STEM (science, technology, engineering, and math) skills.

Rounding out the talks on the final morning will be Michael Knight, senior vice president of TTI Americas, and John Denslinger, president and CEO of ECIA. They will discuss the rebranding of ECIA and provide updates on the authorized electronic component inventory website, eciaauthorized.com.

Distributors Expand

Continued from Page 56

selections of small circular connectors designed for rugged durability and space and weight savings in military and aerospace markets. Furthermore, Avnet's value-added interconnect assembly operation in Nogales, Mexico, has been certified by TE and the U.S. Defense Logistics Agency to assemble and maintain TE's Deutsch connectors. This includes the MIL-DTL-26482 and MIL-DTL-83723 connectors, as well as the MIL-DTL-M39029 contacts.

"TE's Deutsch products are a great addition to Avnet's line and nicely round out TE's product offering with an industry-leading, high-reliability circular connector family for military and aerospace applications," said Tom McCartney, senior vice president, IP&E business development worldwide at Avnet. "For military customers looking to deliver a rugged solution that improves performance and saves space, these products can prove to be a great answer."

In other connector news, other distributors were promoting key products online over the summer. PEI-Genesis pointed to Amphenol's SCE2 Terrapin series of miniature push-pull connectors for use in harsh environments. The environmentally sealed connectors offer silent mating with high mating cycles and a lockable coupling ring to prevent connector breakaway. For use in radios, headsets, GPS units, computer systems, local-area network (LAN) switches and routers, and Gigabit Ethernet applications, the connectors feature brass shell material, black-silver shell plating, copper alloy contact material, and 1 μM of gold over nickel contact plating.

Heilind Electronics featured Molex's CLIK-Mate connectors, which are designed for applications that require higher pin-count connectors to carry more signal lines in less space. The system's unique tuning-fork terminal concept provides low insertion force and secure mating contact. Features and benefits include:

- Positive inner locks: Audible "click," low insertion force, and secure mating
- Tuning-fork style contact design: Secure contact and avoidance of terminal stubbing
- Flat area for pick-and-place: Easy, automatic board placement
- Reinforced metal solder tabs: Secure printed circuit-board (PCB) retention and solder joint strain relief
- Footprint compatibility: Drop-in replacement to various competitive versions

Powell Electronics featured Glenair's offering of circular and rectangular backshell connectors and accessories. The lineup includes simple wire bundle strain reliefs, backshells, dummy stowage receptacles and protective covers, advanced electromagnetic shielding and termination systems, extender backshells, pipe thread adapters, shorting caps, and cable sealing backshells. The selection includes virtually all AS85049 MIL-Spec accessories and includes backshells for every connector manufacturer's product, including Amphenol, Deutsch, and Cannon.

And, interconnect specialist Sager Electronics touted the Hirose HR41 circular waterproof connectors, which are IP68 rated, plastic-shelled connectors for advanced reliability and high-power use in harsh, outdoor environments. The series includes bayonet locking, cable-mount plugs, and panel-mount receptacles with the capacity to handle up to 20 A.


Erase Long Lead Times
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Dual-Display Signage System Enriches I/O, Network Connectivity

VIA'S ARTIGO A1300 is a quad-core system with connectivity and networking features designed for a range of dual-display signage, HMI, and other IoT applications. Fanless operation combined with rigorous reliability testing ensures reliability in space-constrained environments. Leveraging the 1.0 GHz VIA QuadCore E-Series and VIA VX11PH media system processors to provide rich multimedia capabilities for creating visual effects for single- and dual-screen signage displays, the system can play two 1080p videos or four 720p videos at the same time through its two HDMI ports. Other I/O ports include USB 3.0 (x2), Gigabit Ethernet, line-in/out audio, 12 Vdc-in power, USB 2.0 (x2), COM for RS232/422/485, and Digital I/O for 8-bit GPIO. The system includes support for WOL and PXE, and offers 802.11b/g/n USB and 3.75G HSP/UMTS mini-PCIe mobile broadband module options.

VIA TECHNOLOGIES INC.

www.viaembedded.com

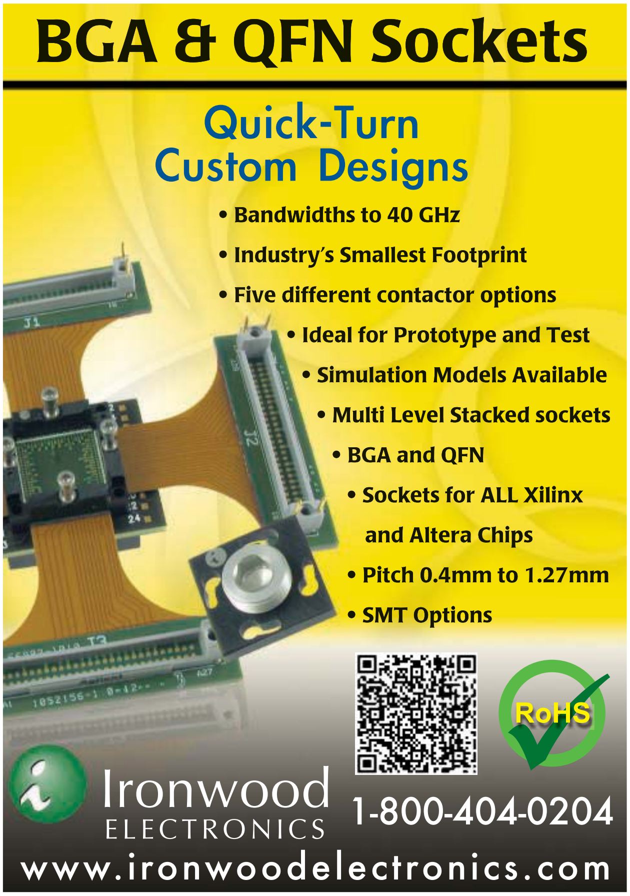
RJ45 Connectors Target Fire-Resistant Rail, Bus Data Cables

HARTING'S RJ Industrial EtherRail 4-pole RJ45 connector, with a wire diameter of up to 2 mm, will find homes in data cables used for fire protection. Specifically, it will suit the 4-core Ha-VIS 4xAWG22/7 EtherRail data cable for laying on and in rail vehicles and buses, and also the company's 4xAWG22/19 cable, which is mainly used as a linking connection between rail wagons, as well as installations within rail vehicles and buses.

Ha-VIS EtherRail cable design and construction, materials, and processing (irradiation cross-linking) meet the requirements of the EN 45545 European standard for rail applications. It also fulfills comprehensive fire tests in accordance with DIN5510, UL1685, and many other national and international requirements. In connection with the new Industrial EtherRail RJ45 connector, it's now possible to implement mechanical, highly robust RJ45 data cabling in trains, trams, and buses.

HARTING

www.harting.com



High-Contact-Density Data Connectors Meet Defense/Industrial Portable Needs

TT ELECTRONICS says its MIL-PP family of rugged, micro push-pull data connectors saves up to 35% in weight and space over previous devices, suiting them to harsh portable defense and industrial applications. Features include tactile blind-mateable key-keyway engagement, environmental sealing to IP68/69K, and various high-density insert arrangements for signal and data (USB, Ethernet, and RS-232 systems). Shell-to-shell

screening leverages "delta-clip" technology to improve electromagnetic-compatibility performance, thus minimizing any detectable electronic signature. Standard shell styles include cable plug, in-line cable receptacle, box receptacle, and low-profile recessed box receptacle. The connectors can be standalone or customized as a complete over-molded harness system. All come in aerospace-grade, aluminum-alloy housings that operate in temperatures ranging from –40 to +125°C.

TT ELECTRONICS PLC

www.ttelectronics.com

I/O Connector Transfers USB 3.1 Speed To 10 Gbps In Micro USB 2.0

THE NEW High-Speed Multi I/O Connector from TE transfers USB 3.1 signals in a Micro USB 2.0 form factor for slimmer mobile and wearable devices with increased functionality, higher speed and larger screens that require high-power battery consumption. Handling data from 5 Gbps for USB 3.0 up to 10 Gbps for USB 3.1 super speed, the connector features improved durability and EMI performance, with rapid charging from a 3 A battery charger and 2 A additional power over four optional additional pins. The device allows users to run high-speed data, video and power charging through one single connector and provides external video display connectivity including MyDP and MHL capability. The high-speed multi I/O connector receptacle is 7.52 mm wide, the same width as a standard Micro USB 2.0 receptacle, and comes with various pin position options such as 5+4 and 5+8. The multi I/O receptacle also offers backward compatibility with standard Micro USB 2.0 plugs.

TE CONNECTIVITY

www.te.com

K2 Ultracapacitor Series Adds High-Shock/Vibration-Resistant Cell

THE LATEST ultracapacitor cell from Maxwell Technologies, available through Richardson RFPD, increases the range of available specific power and stored energy in the 60-mm, cylindrical "K2" form factor. According to Maxwell, its DuraBlue Shock and Vibration technology, introduced in the new 2.85-V, 3400-F BCAP3400P285K04 cell, boosts vibration resistance by approximately 300% and shock immunity by 400% when compared with competitive devices. It features up to 18 kW/kg of specific power (typ.) and up to 4.00 Wh of stored energy (typ.). The ultracapacitor comes with threaded terminals or laser-weldable posts. Lifetime spans 10 years, or up to 1,000,000 duty cycles. Applications include automotive subsystems, wind-turbine pitch control, hybrid vehicles, rail, heavy industrial equipment, and UPS/telecom systems.

RICHARDSON RFPD INC.

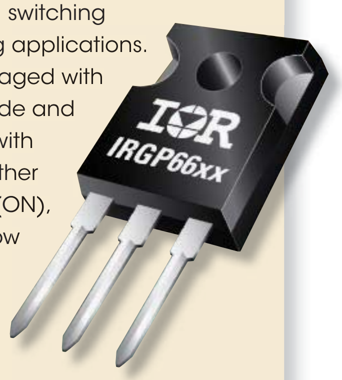
www.richardsonrfpd.com

MAXWELL TECHNOLOGIES

www.maxwell.com

Ultra-Fast 600-V Trench IGBTs Target Welding Apps

LEVERAGING TRENCH thin-wafer technology, International Rectifier's IR66xx series of 600-V trench-gate, field-stop insulated-gate bipolar transistors (IGBTs) deliver low conduction and switching losses optimized for welding applications. The devices come co-packaged with a soft-recovery low QRR diode and offer 8- to 30-kHz switching with a 5-μs short-circuit rating. Other features include a low VCE(ON), high switching frequency, low electromagnetic interference (EMI) to boost reliability, rugged transient performance, and positive temperature coefficient to facilitate paralleling. Maximum junction temperature is 175°C. An IGBT online selection tool can be accessed at http://mypower.irf.com/IGBT.



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Low-Power Rail-to-Rail Amps Boost Bandwidth Sixfold

EXAR NOW offers two single/dual op-amp families, each with different levels of supply current, which target applications ranging from industrial (e.g., smart meters, ultrasonic heat meters) to portable instrumentation (e.g., interactive whiteboards). The XR1008/XR2008 amps offer 75-MHz bandwidth while consuming a mere 505 μA. The lower-power XR1009/XR2009 devices deliver 35 MHz at 208 μA. Compared to other comparable amplifiers, the XR1008/XR2008 offer six times the bandwidth while the XR1009/XR2009 have three times the bandwidth, according to the company. All four devices support inputs that extend 300 mV beyond the negative supply voltage, as well as provide rail-to-rail outputs. Slew rates and input-voltage noise for the XR1008/XR2008 are specified at 50 V/μs and 12 nV/√Hz; for the XR1009/XR2009, specs are 27 V/μs and 21 nV/√Hz. They come housed in RoHS-compliant TSOT-5, MSOP-8, and SOIC-8 packages.

EXAR CORP.

www.exar.com

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Disney Supercomputer Renders *Big Hero 6*

Big Hero 6 (*BH6*) is a story about a boy, Hiro, and his super robot, Baymax. It is a very big robot (*Fig. 1*). But that is not this story.

This story is about a boy and his super computer. The boy in this case is Andy Hendrickson, chief technology officer at Walt Disney Animation Studios. He oversaw the creation of *BH6*, working with directors Don Hall and Chris Williams—both Disney Animation veterans—and turning vision into virtual reality.

1. Baymax and Hiro are the stars in Disney Animation's *Big Hero 6*.

THE RENDER FARM

Walt Disney Animation Studios' render farm is actually a cloud spread across four sites. It ranks about 75th compared to other supercomputers with over 55,000 Intel cores (*Fig. 2*). The system has 400 Tbytes of memory and sucks down 1.5 MW of power. That is actually a small amount of power compared to the system size.

The system is built around 1U COTS servers. It is linked via 10 Gigabit Ethernet links. All non-volatile storage is solid-state disks. The only thing moving in the system are the cooling fans.

The Disney archives are currently 4 Pbytes. The average movie consumes about 4 Tbytes of information.

Disney's in-house CODA job distribution system makes the system appear as a single virtual system. It handles a range of chores from rendering to asset management. The system typically performs 1 million render hours per day. This equates to about 400 jobs per day. The system is so automated that there is no overnight staff. (Of course, there is an app for that. This lets everyone check job status using an iPhone or Android phone.)

A director can interact with the system using dPIX, an internally created asset browsing system. It can show all the renderings done in the last 24 hours and allows progressive creative refinement. It can be used on a PC or in a darkened theater.

2. Walt Disney Animation Studios' supercomputer is about the 75th largest in the world with over 55,000 cores.

LIGHTING BY HYPERION

The big change with *BH6* is the use of Disney's new rendering system called Hyperion, which uses a new lighting system for Disney that supports global illumination. Directors can set up a scene similar to a physical environment by placing light sources and objects along with selecting materials with which the objects are covered.

Ray tracing tracks the light from the source. This is typical for rendering animated scenes, but Hyperion uses an energy-conserving transport approach that addresses subsurface scattering. This allows effects such as light through a translucent object.

The system is more complex, but it allows Hyperion to employ a single shader. This uses a bidirectional scattering distribution function. It also uses a streaming geometry rendering system, allowing more complex scenes to be rendered more quickly. The combination allows more complexity than what Disney previously had available, making it possible for Disney animators to build an extremely detailed version of "San Fransokyo," where *BH6* is set—an artistic challenge because it was three times as complex as any Disney film so far.

Hyperion took two years for Disney to build. It is now in production use on other animated films like *BH6*. Scalable quality is another thing Hyperion does well. Dial down the quality and the rendering time goes down as well. This is especially useful when a director needs to see what a scene will look like, but final-cut quality is not required. ed

The design specs have changed. The board needs to be smaller. And needs to be more powerful. But watch the EMI. Oh, and the deadline has been pulled in — the guy in the corner office is counting on this one for next quarter's revenue.

Your colleagues are sweating, but you remain cool. You are Incredible Shrinking Board Man. Here to save the day.

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