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

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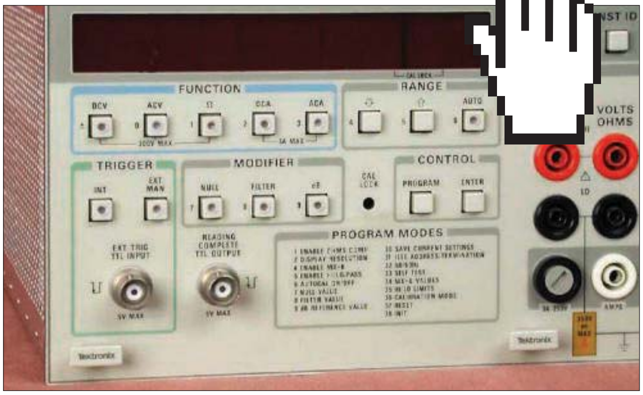

WHAT'S ALL THIS METER ACCURACY STUFF ANYHOW?

Bob Pease and Reginald Neale exchanged a series of letters back in 1989 addressing the age-old question of accuracy versus precision in their test equipment.

WHAT'S THE DIFFERENCE BETWEEN HAPTICS NOW AND THEN?

Great leaps are being taken in the understanding of human multi-sensory fusion, and engineering solutions can provide truly lifelike tactile response.

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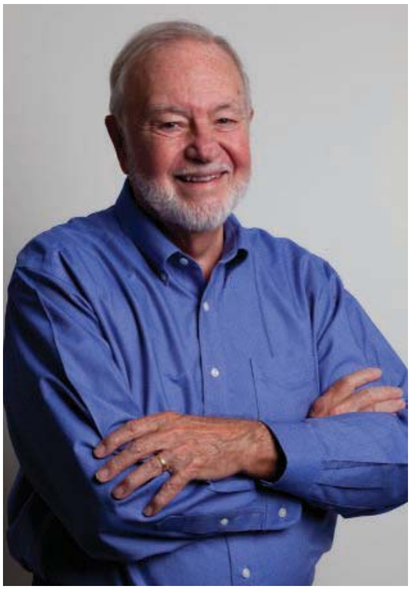

Is There Really A Shortage Of Engineers?

One of the things we keep hearing again and again is the refrain about the dire shortage of engineers. I think this so-called shortage is a myth. Where are the statistics to back it up? Is there a real hiring crisis or not? The real answer is probably yes and no.

Yes, there is a shortage of some critical engineering talent in some sectors. Analog/linear and RF/microwave design engineers are good examples. Programming talent is also in high demand. Yet companies create their own shortages by so narrowly defining job openings that there is little hope of ever finding just the right mix of education and specific experience.

However, the answer may be no for other engineering categories *(see "2013 Engineering Salary Survey: Pressure Up, Salaries Down," p. 26)*. Are there huge numbers of engineers out of work? Maybe some, but they may be engineers who are dated in their knowledge and skills. Do we really need all those H-1B visas to attract foreign engineers and programmers?

This purported shortage is creating another crisis in education. The general opinion is that we are not educating enough science, technology, engineering, and math (STEM) students to fill all those open and future positions *(see "What Should Colleges Be Teaching EEs?" at electronicdesign.com)*. As a result there is an enormous number of programs in high schools, community colleges, and universities to recruit students for STEM jobs. And the students are not responding. They generally hate the rigor and geekiness of engineering.

But what if we do start magically producing more STEM graduates? Fat chance that will happen, but if it does, will we be graduating students into a marketplace with few available jobs? That may be happening now given the continuing high unemployment rate. Who really knows?

Robert Charette, in his article "The STEM Crisis Is a Myth" in the September issue of *IEEE Spectrum*, says that there is no looming shortfall of STEM workers. He backs it up with some facts and figures. If this topic interests you, by all means take a look. I agree with his assessment, and you may too after reading it.

By my own barometer, there are some shortages in unique specialties of engineering, but not an overall shortage crisis. I do see a real shortage of skilled technology workers like manufacturing techs, machinists, repairmen, and installers. There are indeed jobs going unfilled simply because the youth of today just are not interested in such blue-collar jobs.

Our millennials (generation Y, ages roughly 15 to 29) are enamored of technology and are heavy users, but they have no interest in learning the math and science required to fill such jobs. Even the military rejects about 30% of applicants because of their poor math and science knowledge. How do we solve this problem?

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Analog Interface Designs
Don't Need High Power

The quest for power reduction in electronic circuits is one of the main drivers of circuit design innovation. Recently, the need to reduce power consumption has extended beyond the territory of battery-powered applications such as handheld devices and remote sensors to plug-in applications such as home entertainment to meet green label requirements and even cloud storage and processing due to the sheer amount of power used in these compute farms *(Fig. 1)*.

Furthermore, the use of ever more advanced process nodes, as described by Moore's Law, leads to chips with higher functionality (gate density) in the same area. More power per area unit is then generated inside the chip, despite the lower supply voltage. This excessive power is problematic unless it is properly dissipated, which requires expensive packages or heatsinks. The higher functionality of today's systems-on-chip (SoCs) is driving the integration in the SoC of the analog interfaces with the multitude of signal sources that exist in modern devices, such as the output of wireless radios, wireline transceivers, and sensors.

1. Compute farms and data centers drive circuit design innovation due to their need to reduce power consumption.

REDUCING POWER

Power consumption can be reduced in multiple ways. In the digital domain, power supply levels often are reduced in line with the evolution of technology. The well-known formula for dynamic power dissipation (P) shows quadratic gains when supply levels (V_{dd}) are reduced:

$$\overline{P} = a\frac{1}{2}CV_{dd}^{2}f_{clk}$$

Additionally, this formula highlights other strategies that yield immediate gains in terms of power dissipation: reduce the capacitance (C) being toggled (typically comprising gate capacitance plus any additional routing parasitic) and reduce the activity (a) of the circuit, through clocking strategies and, eventually, clock gating. The toggling rate (f_{clk}) can also be reduced in some cases, although it would have the unintended effect of reducing processing speed.

However, the analog interfaces are in the analog domain where static power components typically dominate power dissipation, limiting the potential gains that can be achieved through the equation above. Furthermore, analog performance requirements, especially linearity and noise, often limit the ability to reduce the supply levels and demand the use of power-hungry high-gain circuits.

In traditional analog circuits, power must be traded off for speed (bandwidth) and/or resolution (linearity), for example *(Fig. 2)*. Based on these tradeoffs, one could conclude that high-performance analog blocks cannot offer low power consumption and therefore limit the overall system power. All is not lost, though. This conclusion is contradicted by the sheer amount of scientific and development work dedicated to the subject of low-power analog circuit techniques.

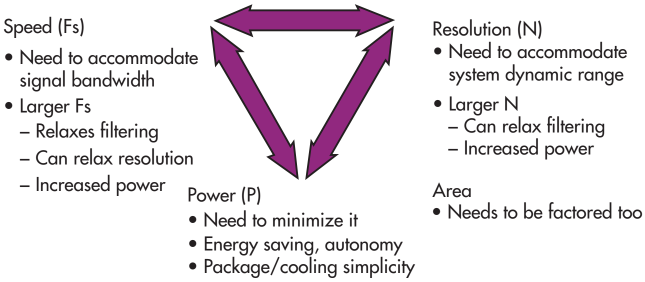
Many pure analog circuits have been implemented to save power and allow for low-supply-voltage operation by using techniques such as sub-threshold operation (a region below the transistors' normal operating region). These established techniques are effective in low-speed, medium-performance applications such as remote sensors and wristwatches.

For applications with higher speed or performance requirements, designers can take advantage of the abundance of digital transistors available in any modern process to significantly reduce the power (and area) of analog blocks at the expense of a (typically) modest area and power increase for the digital block.

For example, designers can minimize the tradeoffs between performance and power dissipation by transferring some of the complexity and performance requirements from the analog domain to the digital domain. This can be achieved by relying

on techniques such as digital compensation, digital calibration, and higher digital processing speed, leading to digitally enabled analog circuits.

Such techniques allow designs to attain high levels of accuracy with lower power dissipation. They are directly applicable to circuits that rely on matching, such as pipeline analog-to-digital converters (ADCs) and successive-approximation register (SAR) ADCs. They rely on digital calibration algorithms embedded in the same circuit that can analyze the "errors" and compensate for them autonomously, at power-up or during normal operation. By running this background calibration, the circuit also benefits from corrections to potential temperature or voltage drifts.

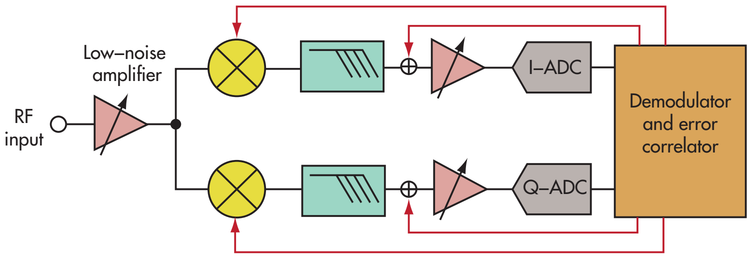


2. Designers need to make power, speed, and resolution tradeoffs in the analog domain.

MULTIPLE SITUATIONS

Digital calibration and compensation techniques can be used in a variety of situations in analog interface circuits like ADCs:

- Offset compensation: Circuit mismatches make offset unavoidable in analog circuits. The simplest way to improve matching is to increase the size of all devices, which directly penalizes power dissipation and area. Alternatively, measuring it can compensate for the offset—for example, by comparing the output voltage to 0 and then balancing the circuit by adding some adjustment voltage through a small digital-to-analog converter (DAC).
- Gain error compensation: Low gain accuracy across the operating range of an amplifier can adversely affect linearity. Closed loop gain requires high open loop gain, which is typically achieved at the expense of power dissipation. Gain calibration can compensate for gain inaccuracy, without requiring high open loop gain. It is achieved by injecting a small-scale signal (typically at noise level) that can be measured through correlation and then subtracted. Highest correlation is achieved when the gain is compensated. The algorithm's task is to find the coefficients that maximize the measured correlation.
- Mismatch between devices: Switched capacitor circuits such as ADCs rely heavily on the matching of capacitors to guarantee their accuracy. Relative matching is a function of device area. Capacitor matching errors can be calibrated by observing that the nominal value of each capacitor is equal to the sum of the remaining lower-order capacitors in the array. This comes naturally from the binary weighted nature of the capacitor array. The total capacitance is only dictated by the noise constraint, reducing the power spent in switching a large capacitor.



3. Radio receivers can use digitally assisted analog design techniques to compensate for analog circuit issues.

Digital calibration and compensation techniques are not confined to the analog block level. The analog block is embedded

in a complete system, including all of the digital signal processing stages, so the system can estimate the quality of the signal being processed across the complete signal chain. It can then determine the required adjustment parameters for the analog blocks across the complete analog signal processing chain. These techniques are very efficient for compensating for mismatches, phase deviations, and distortions *(Fig. 3)*.

Overall, these circuit techniques relax the performance requirements of the analog blocks, which can minimize both power consumption and area. They are particularly effective when the circuit is implemented in advanced process nodes and can take full advantage of the benefits of scaling.

In addition to the techniques that improve on established architectures, the analog blocks' power dissipation can be further reduced with simpler architectures while maintaining performance objectives. For example, when compared to a pipeline architecture, a SAR-based architecture is much simpler and does not rely on multiple stages (each containing large gain amplifiers) to achieve performance goals. Rather, the SAR-based architecture is a single-stage comparator, which is inherently very compact and low-power. The beauty of this architecture is that no power-hungry precision amplifier is required, as it employs only blocks that can be designed with no static consumption.

The drawback of SAR-based architectures is their limited speed. However, this limitation is overcome in advanced process nodes by taking advantage of the high speed of the process as well as the high processing power available to implement digital assisted algorithms that allow further power reduction.

CONCLUSION

Power consumption reduction is a huge requirement for ICs. As digital scaling requirements and the semiconductor roadmap push ICs to more advanced nodes, the analog blocks follow the same power reduction paradigm as the digital blocks in the same circuit, but not necessarily in the same manner. The move to smaller technologies encourages innovation in analog interface circuit design techniques that enable aggressive power and area reductions. ed

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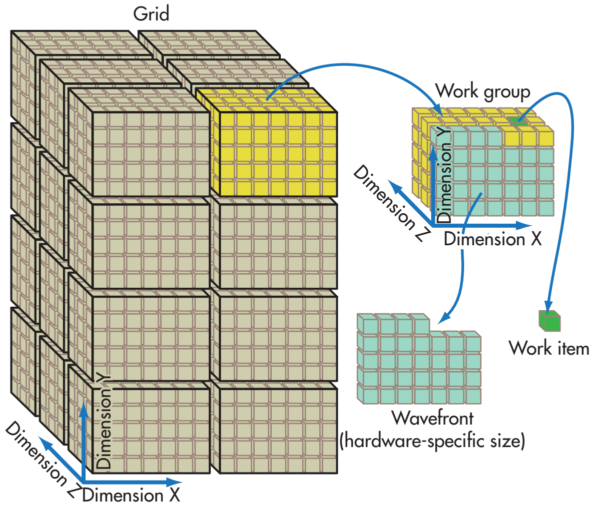
News & Analysis

HSA Gains HSAIL Support

AMD's Heterogeneous System Architecture (HSA) is the floorplan for its next generation of accelerated processing units (APUs), which combine the CPU and GPU into a common memory environment *(see "Unified CPU/GPU Memory Architecture Raises The Performance Bar" at electronicdesign.com)* via a cache-coherent shared virtual memory (CC-SVM). The original APU combined CPU and GPU cores but maintained distinct memory for each type of core.

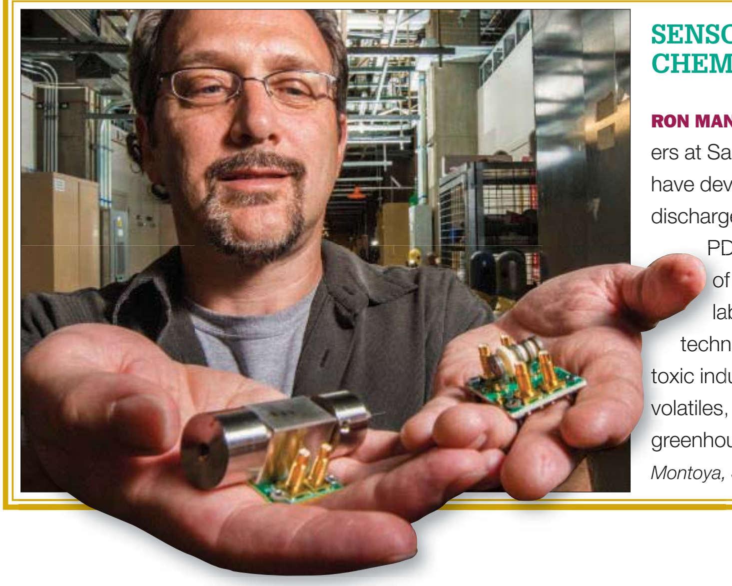
OpenCL 2.0 addresses CPU and GPU parallel processing environments *(see "OpenCL 2.0, OpenGL 4.4 Officially Released" at electronicdesign.com)*. Normally, the environment has a unique address space for the GPU. This model is also used for some FPGA-based OpenCL environments *(see "How To Put OpenCL Into An FPGA" at electronicdesign.com)*, but HSA is different because it has a unified memory environment. The Heterogeneous System Architecture Intermediate Language (HSAIL) and associated design environment were developed to take advantage of HSA. Frameworks like OpenCL can generate HSAIL that can run on a virtual machine that targets CPU/GPU cores.



1. HSAIL divides work into a grid, work group, and work items.

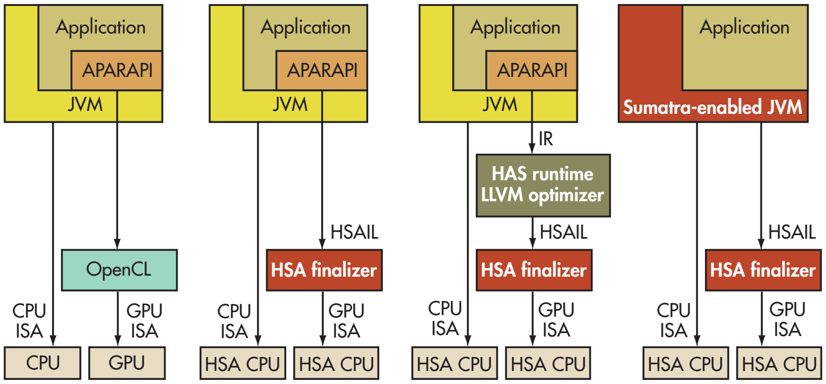
HSAIL divides work into a grid hierarchy *(Fig. 1)*. Like OpenCL, programmers define kernels that can be run in parallel on data. The big difference is that HSAIL essentially maps to an HSA-based virtual machine. The HSA finalizer is akin to the just-in-time (JIT) compilation for a Java virtual machine (JVM).

The HSAIL virtual machine consists of at least one host CPU and an HSA component. The Architected Queue Language (AQL) links the two. The host generates and enqueues AQL packets. The packets incorporate kernels that



SENSORS IMPROVE CHEMICAL DETECTION

RON MANGINELL AND other researchers at Sandia National Laboratories have developed miniature pulsed-discharge ionization detectors (mini-PDIDs) that broaden the scope of chemical targets that the labs' microanalytical detection technology can spot, including toxic industrial chemicals, biological volatiles, explosive compounds, and greenhouse gases. *(courtesy of Randy Montoya, Sandia)*



2. APARAPI allows Java to utilize parallel processing infrastructures like HSAIL. Project Sumatra will provide a more flexible parallel programming environment.

are executed by the HSA component. A kernel defines a multidimensional cube-shaped grid with a work-group item per grid point. Jobs are dispatched as work groups. They require all data to be available.

AMD would like HSA to be a standard so HSAIL is open, but for now it will take advantage only of AMD's HSA-based hardware. It may be wishful thinking that Intel would incorporate it, although an integrated CPU/GPU/memory environment has advantages and AMD and Intel have at least agreed upon the x86 instruction set. HSAIL could be applied to an ARM environment. It is interesting to note that ARM is one of the founding members of the HSA Foundation along with AMD, Samsung, Qualcomm, MediaTek, Imagination, and Texas Instruments.

Another aspect of HSAIL and HSA is Java support *(Fig. 2)*. APARAPI (A PARallel API) is one way for Java to support parallel programming environments. It typically maps to OpenCL, but it could target an HSAIL finalizer.

APARAPI eventually may be replaced by OpenJDK's Project Sumatra, which brings native parallel programming support to Java. Project Sumatra also could target HSAIL directly. Oracle and AMD are involved with Project Sumatra, so this combination may wind up in production. Support is targeted for Java 9.

Developers can leverage the HSA architecture using the BOLT library from AMD. The C++ template library inspired BOLT, which also has been targeted at OpenCL and C++AMP.

OpenCL and Project Sumatra will remain the primary programming environments for programmers, but

HSA can provide a better infrastructure. The unified memory architecture eliminates unnecessary copy operations since pointers can be shared between CPU and GPU cores. The approach also has a lower dispatch overhead.

For now, AMD's hardware will be driving HSAIL development and the software that runs on top of it. In the future, it could be much more. ed BILL WONG

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design FAQs

FREQUENTLY ASKED QUESTIONS

Managing Embedded Storage Using ECC-Enabled Flash Memory

William Wong
Embedded/Systems/Software Editor

Q: What options do developers have when it comes to embedded NAND flash storage?

A: There are three basic approaches to using embedded NAND flash storage: raw NAND flash memory, ECC-enabled (error correction code) NAND flash memory, and intelligent NAND flash memory with a built-in controller.

Q: What are the tradeoffs between these different approaches?

A: Raw NAND flash storage requires host-based software to perform all management, typically within a device driver. This includes error correction and functions such as wear-leveling and block management.

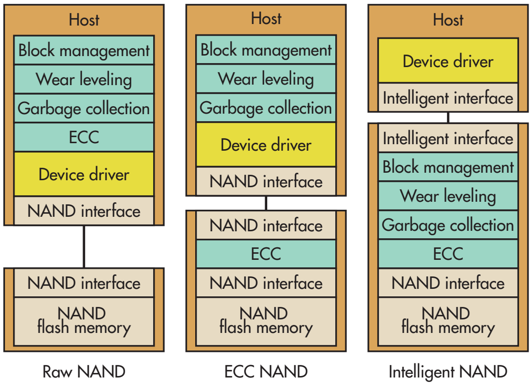
The host needs to have enough headroom to handle storage chores in addition to flash access. Error correction tends to incur a lot of the overhead. Hardware support reduces this overhead, but this type of hardware support is rare in microcontrollers.

NAND flash memory with built-in ECC incorporates just the error detection and correction hardware. The host must still handle details like block management and file system management. ECC-enabled NAND flash memory meshes allow the host to continue to handle most of the flash memory support.

Intelligent NAND has a built-in controller that offloads the entire flash management service from the host.

Q: Why not just utilize an intelligent NAND flash solution for all embedded applications?

A: Universal flash storage (UFS) incorporates a faster interface that is not available on all microcontrollers. It tends to be too fast for many 8-bit, 16-bit, and 32-bit microcontrollers.



Raw NAND and ECC-enabled flash put all or most of the controlling software on the host while an intelligent memory incorporates a controller that handles chores from block management to error correction to wear leveling.

Intelligent NAND flash solutions that employ slower interfaces can work, but with the additional cost of an embedded controller. Lower host overhead, higher bandwidth, and lower host software complexity offset the added cost.

On the other hand, many applications do not require the higher capacity, and putting the software on the host can reduce overall system costs. Speed and lower complexity are not always the top requirements.

Q: How do the ECC requirements change as the amount of NAND flash grows?

A: The probability of errors in NAND flash storage grows as the size of the memory array grows. Multi-level cell (MLC) NAND flash and triple-level cell (TLC) NAND flash both use a single cell to store more than a 0 or 1. MLC and TLC have shorter write lifetimes and are more susceptible to errors than single-level cell (SLC) NAND flash storage.

Single-bit ECC was common when NAND flash arrays were small, but multi-bit ECC was required to detect and correct errors in larger arrays. ECC computations typically have a high software overhead unless hardware acceleration is provided. Very large NAND arrays like those used on solid-state disk (SSD) drives are using different, adaptive rate error correction schemes such as low-density parity code (LDPC). This type of support is only found in controller-based schemes where hardware acceleration is used.

Q: So where does ECC-enabled NAND storage work best?

A: ECC-enabled NAND works best where capacities are smaller than SSDs but larger than a few hundred megabits. Chips of 1 Gbit or larger are now commonly available. This amount of storage is common in embedded microcontroller and microprocessor applications. The amount of storage is typically larger than any on-chip capacity.

Q: How hard is it to interface with ECC-enabled NAND flash storage?

A: ECC-enabled NAND flash storage uses the same interface as raw NAND flash with an additional indication of the validity of the data. This is obtained by reading an additional status byte after the transfer of a block's data using the ECC read status command. The ECC-enabled NAND flash storage provides a more reliable flash memory, but it is still possible for a block to contain bad data.

Q: Can a controller chip handle flash management chores?

A: Yes, there are flash storage controller chips that support 1-bit/512-byte memories. The latest 24-nm and 32-nm SLC NAND flash memories require 4-bit/512-byte or 8-bit/512-byte support. ECC-enabled NAND flash storage can handle these requirements.

Q: What is the difference between ECC-enabled and raw NAND performance?

A: ECC-enabled NAND flash has some timing overhead but is faster than a host using raw NAND flash storage when software overhead is considered.

Q: Will switching to ECC-enabled NAND flash from raw NAND require major changes in hardware?

A: No. ECC-enabled NAND flash is often pin-compatible with raw NAND. The interface is the same regardless, so board changes for a new chip are minimal.

Q: Will switching to ECC-enabled NAND flash from raw NAND require major changes to the software?

A: No. The basic software interface for ECC-enabled NAND flash is the same as with raw NAND. The interface commands are the same. The spare area for raw NAND and ECC-enabled NAND is the same so a host could generate the ECC in software, but that does not take advantage of the ECC hardware acceleration. The write process takes a little longer since the on-chip ECC hardware needs to generate and store the ECC support. If the host wants to track the number of error bits that have been corrected, then it simply emits a new status read command that returns the information.

Q: Are there other advantages to switching to ECC-enabled NAND flash?

A: Higher-density flash storage is now moving to finer lithographies. ECC-enabled NAND flash helps manage these larger-capacity chips. Intelligent NAND flash storage requires major changes to the hardware and software interface. ECC-enabled NAND flash has better longevity and better pricing compared to older technology. ECC-enabled NAND flash enables the use of higher-density chips without requiring a new controller. ■

EngineeringFeature

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2013 ENG SALA SURV

It's almost ironic. We're living in a time when engineering has never been more important. From communications devices in the hands of most people on the planet to the intelligence that is being embedded into manufactured goods at an unprecedented scale, engineering solutions have never been in higher demand.

Yet market dynamics are seemingly conspiring to undermine the ability of many engineers to make a decent living. Many engineers find themselves unemployed. Those who are employed are seeing their compensation erode even as they put in long hours.

Many factors are contributing to this somber situation. Globalization is placing downward pressure on wages. Advances increasingly seem to deliver incremental outcomes, rather than transformative ones. And there just isn't enough oxygen in the economy to fuel the kind of recovery that would really heat up the engineering job market.

So this year when we surveyed the experiences and views of nearly 3000 U.S. engineering professionals, we had to take a look at some very sobering realities. We hope that the resulting insights will be of value to you, even if it's only to let you know that you are not alone in your struggles—and that these are indeed pressure-packed times for the engineering profession.

EE UNEMPLOYMENT REMAINS HIGH

The unemployment rate for electrical and electronics engineers increased sharply in 2013. According to data from the U.S. Labor Department Bureau of Labor Statistics (BLS), engineering jobs in the first quarter of 2013 declined by 40,000 and the unemployment rate for engineers rose to 6.5%. The industry lost another 3000 jobs during the second quarter, although the unemployment rate dropped somewhat to 4.5% in Q2 for technical reasons.

By comparison, in both 2011 and 2012 the unemployment rate for EEs was just 3.4%. Last year there were 335,000 EEs counted in the workforce. At the midway point this year, the number was estimated at just 292,000.

The IEEE-USA sees the unemployment rate for engineers getting worse if the proposals to increase H-1B visas now making their way through Congress are successful. The organization has long opposed efforts to raise the H-1B cap.

INEERING RY EY: PRESSURE UP, SALARIES DOWN

Speaking before the House Judiciary Committee Subcommittee on Immigration and Border Security earlier this year, IEEE-USA representative Bruce Morrison testified in support of permanent employment-based visas for science, technology, engineering, and mathematics (STEM) professionals but criticized proposals to increase America's reliance on H-1B temporary visas.

"We hear all the time that this is a nation of immigrants," Morrison said. "No one has ever said this is a nation of guest workers."

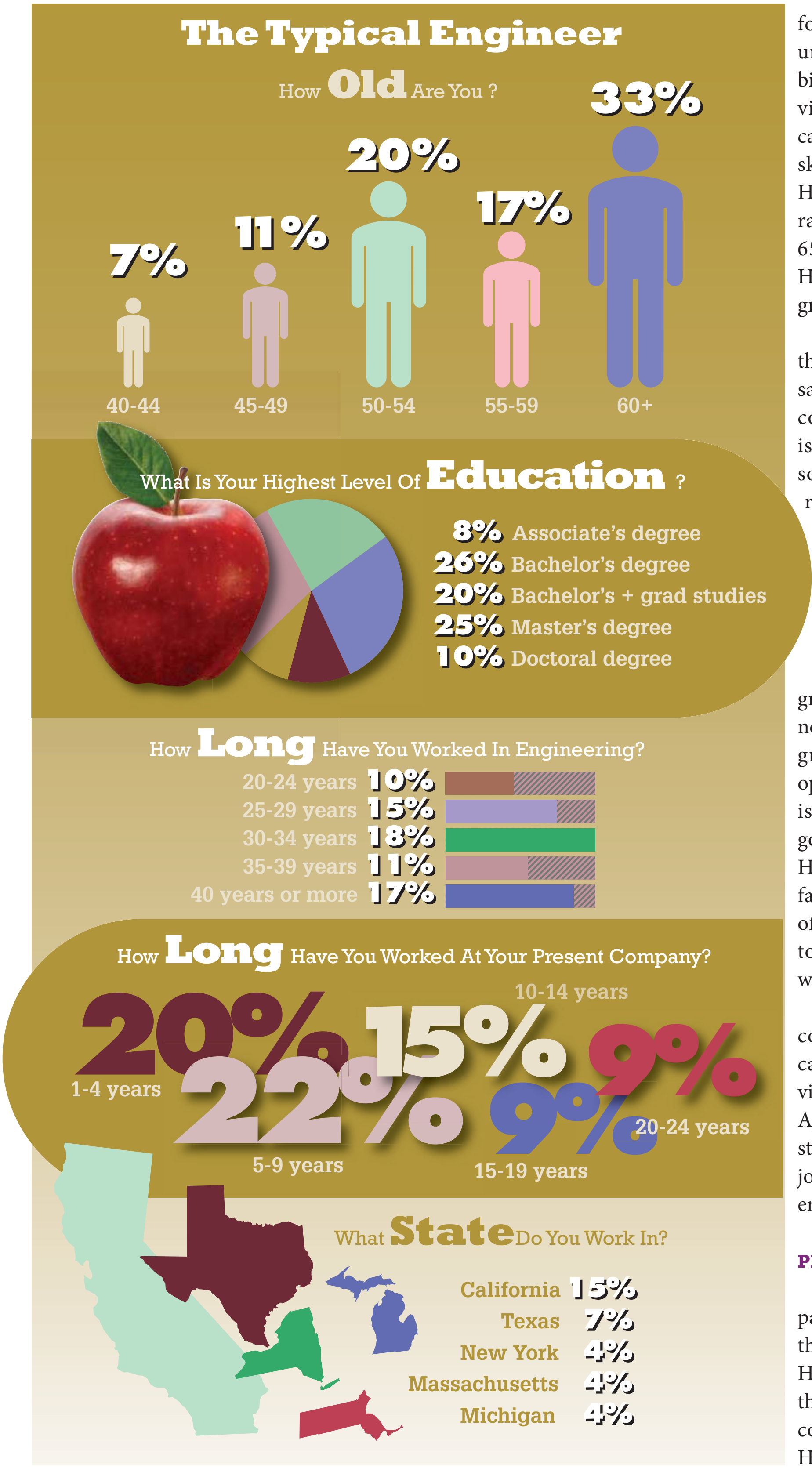
ALL EYES ON VISAS

Now that Congress has returned from its summer break, House Republican leaders are expected to resume work on their plan for high-skill immigration as part of a broader immigration strategy in part as a response to the plan adopted by the Senate in May. Backers of the Senate plan insist it has the potential to both increase the number of available H-1B visas for foreigners working in specialty occupations and shift the visa system to a more merit-based structure favoring STEM workers.

According to the BLS, five years from now nearly all of the 30 fastest-growing occupations will require quantitative skills and technical STEM knowledge. Supporters of the bipartisan legislation—including Google, Microsoft, IBM, Facebook, and other major tech companies—insist businesses cannot find the skills they require in the domestic labor market and need access to a bigger, global pool of STEM workers. Their hope is that companies will be able to attract more of the world's bright minds in engineering and technology by permitting these workers to stay in the U.S.

But others argue that there are plenty of engineers already in the U.S. who can do the job and that H-1B workers don't come with special skills, just lower wages. "Companies complain about 'no workers available' but are laying off experienced workers and replacing them with H-1B and offshore workers," one engineer lamented in a response to our survey. "The people who are hiring are paying entry-level wages or are demanding 60-hour workweeks."

There appears to be broad support in both chambers of Congress for increasing H-1B visas for the technology industry and for making STEM green cards available to



foreigners who graduate from U.S. universities. The Senate immigration bill would permit up to 180,000 H-1B visas and allow for unlimited green cards for U.S. STEM grads. The high-skill bill likely to be taken up in the House is the Skills Visa Act, which raises the H-1B cap to 155,000 from 65,000 and doubles the number of H-1B visas set aside for U.S. STEM grads to 40,000.

Lawmakers have chosen to advance the cause of skilled immigration at the same time as they grapple with more controversial immigration-related issues, so none of the visa reforms sought by the tech industry will be resolved unless the House and Senate can settle their differences over what to do about the more than 11 million undocumented aliens already in the U.S.

Still, the IEEE-USA believes it would be better to have an immigration policy based on "green cards, not guest workers" because those with green cards hold their own visa, as opposed to H-1B workers whose visa is held by the company. Numerous government studies have found that H-1B fraud and abuse is rampant. In fact, the IEEE-USA cited an analysis of government data that showed the top 10 users of H-1B visas last year were offshore outsourcers.

"This is another reason why our country should rely more on green cards for skilled workers, not H-1B visas," said IEEE-USA president Marc Apter. "Green card holders are free to start their own companies and create jobs in the United States. H-1B holders are not."

PERCEPTIONS OF H-1B HIRING

About one in five survey participants say they work at an organization that hires engineers with temporary H-1B visas. Nearly a third (32%) of those working at such firms say their company is looking to employ more H-1B workers in the coming year.

"They'll work for less, tolerate bad treatment, and then leave after a few years," complained one survey participant. "They'll then be followed by another younger H-1B holder who'll pull the bar even lower. Every H-1B visa holder means one more American engineer out of work. The 2012 graduates from engineering programs at most colleges are still looking for jobs. And less than a quarter of the grads in this region, which is home to four universities, are finding jobs in their field."

Another wrote: "They have generally demonstrated their capability as competent engineers. However, they have often been hired as contractors on a per-project or per-task basis. While this type of limited employment is a boon for employers, it is anathema for anyone currently in or looking for full-time continuing employment."

Interestingly, only 41% of those surveyed agree that hiring H-1B visa workers threatens opportunities for U.S. engineers. Fewer than 10% feel personally threatened by engineers with H-1B visas, although that number jumps to 17% for engineers who work at companies that hire H-1B visa workers.

"I believe my skills and expertise keep me in a secure position," explained one engineer. "Specialized work requires specialized skills, and you cannot readily obtain my level of experience and talent."

Other representative comments from survey participants included:

- "Many of the H-1B engineers I have worked with have looked to me for guidance and mentoring. These individuals have participated on our teams and contributed to our product improvements."
- "They have book smarts, but often do not have other sensibilities that make them a better engineer, such as a cultural understanding of customer needs and understanding how to make things work in a large organization. In general, they are used in narrowly focused areas of research or development."
- "American engineers still cannot be matched or beaten with respect to creativity, passion for product delivery, and their desire to make an impact on society with their hard work."

The bottom line, however, seems to be that the very phenomenon of the H-1B worker has a deleterious impact on the psyche of the American engineer. As one put it: "The stress of always being told that some low-income H-1B is standing in line for your job, along with the lack of respect from the organization and the long work hours, sometimes makes you feel the job's not worth it."

Average Salaries By Level Of Education	Base salary	Total compensation
Doctoral degree	$115,824	$127,144
Master's degree	$104,755	$113,550
Bachelor's plus graduate studies	$98,654	$107,488
Bachelor's degree	$93,524	$101,904
High school or less	$89,143	$96,260
Attended college	$77,000	$84,121
Associate's degree	$71,287	$77,290

WAGE STAGNATION

After three years of modest increases, engineering salaries have stalled. Base salaries and bonuses were off slightly in 2013, and employers were even more tightfisted with stock options (down 6%) and other sources of income (down 4%). All told, the average total income for engineers was $105,028 in 2013—down $1070, or 1% from 2012 levels.

"Engineering salaries in my company seem to have hit a ceiling," lamented one respondent. "Significant income potential beyond this seems like it's available only to managers, who are only modestly skilled."

As wages stagnate, engineers appear to be throttling back a bit on the hours they're willing to put into their jobs. Last year, engineers averaged a 53-hour workweek (41 hours in the office

Average Salaries By Years Of Engineering Experience	Base salary	Total compensation
30-34 years	$108,953	$117,574
25-29 years	$102,362	$111,076
40 years or more	$100,411	$109,625
20-24 years	$99,872	$108,461
35-39 years	$98,779	$107,696
15-19 years	$94,935	$104,080
10-14 years	$78,845	$87,677
Less than 1 year	$77,464	$82,653
5-9 years	$72,949	$80,592
1-4 years	$58,106	$63,516

Average Salaries By Size Of Company	Base salary	Total compensation
$5 billion - $9.9 billion	$120,457	$130,196
$10 billion or more	$115,705	$127,151
$500 million - $999.9 million	$114,434	$123,689
$1 billion - $4.9 billion	$108,381	$118,549
$100 million - $499.9 million	$105,899	$114,596
$25 million - $49.9 million	$103,863	$111,851
$50 million - $99.9 million	$99,860	$108,002
$5 million - $9 million	$98,756	$107,568
$10 million - $24.9 million	$91,975	$99,935
Less than $5 million	$78,395	$85,775

plus an additional 12 hours at home). This year, that number was closer to 49. Companies have cut the number of hours engineers spend moving between locations and on call this year, too.

Also, 40% of engineers believe their compensation is competitive with what other employers are paying for similar work, while 43% feel it's less competitive. "The only way to gain pay increases today is by changing employers," one respondent opined. "Staying with the same employer will only get you cost-of-living salary increases."

On average, design & development engineers earned a base salary of $96,155 this year and a total compensation of $104,072. The engineering job titles that commanded the most money this year were software engineering managers ($141,600), VPs of engineering ($133,051), technical directors ($127,475), group/team leaders ($116,169), and chief/principal engineers ($115,244).

Engineering managers, by the way, were not immune from the drop in income in 2013. On average, they earned $109,707 in base salary and $119,578 in total compensation—a nearly 5% dip in their paycheck.

Average Salaries By Type Of Design Work You Do	Base salary	Total compensation
ICs and semiconductors	$127,690	$142,531
Military products	$121,584	$129,689
Computer product design (supercomputers, mainframes, workstations, servers, PCs, notebooks/laptops, peripherals, boards, etc.)	$117,117	$128,135
Medical products	$111,649	$122,455
Software design/development/programming	$110,782	$119,365
Mobile equipment	$110,778	$119,153
Avionics, marine, or space	$110,588	$117,418
Materials handling equipment/services	$98,750	$111,550
Safety/security	$101,661	$111,191
Automotive products	$99,803	$107,162
Communications systems and equipment (local-area/wide-area networking products, wireless, cellular, RF and microwave, Bluetooth, etc.)	$93,408	$102,737
Test and measurement equipment	$92,476	$99,812
Consumer products	$91,092	$98,138
Industrial controls systems and equipment (including robotics)	$89,365	$97,968
Research & development	$87,369	$94,575
Components and subassemblies	$86,845	$93,755
Power design	$84,523	$92,189
Other (please specify)	$82,682	$91,079
Machine tool/automation	$74,952	$81,764
Packaging	$65,200	$76,875
Appliance	$65,000	$69,750

Average Salaries By Job Function	Base salary	Total compensation
Executive/operating management	$107,063	$120,598
Engineering management	$109,707	$119,578
Design & development engineering	$96,155	$104,072
Other engineering	$85,740	$92,725
Other	$82,066	$90,590

STAYING POSITIVE

Surprisingly, despite current wage stagnation, engineers are more likely than they have been in a while to agree that engineering offers the same opportunity for salary advancement that it did five years ago. This may be in part because 2008 was five years ago—and there's a sense that the global economy hit rock bottom then. But it's also because market forces continue to shift. As one respondent observed: "A skills shortage combined with Boomers exiting the job market has made recruitment of skilled labor difficult."

But not everyone has a rosy outlook about the future. "The economy has been shrinking, manufacturing has moved overseas, and many engineering jobs have moved overseas," remarked one engineer. "Companies are looking for the cheapest talent, so experience and knowledge do not seem to command the value they once did. There is an idea, pervasive in today's culture, that anybody can do any job. Perhaps this is because there is so much information easily available at the touch of a keyboard."

Geographic location also plays a big role in determining what engineers make. As in the past, the Pacific region is still on top with total incomes averaging $122,137, followed by the West South Central region ($114,251) and the New England states ($113,197).

The market segments also play a key role in compensation. Chip houses led the way in engineering pay again this year at $139,852, followed by software houses ($132,385), computer OEMs ($121,972), government/military contractors ($121,672), and medical electronics firms ($120,055).

GOTTA LOVE IT

Despite pay and job issues, engineers remain high on the profession. Nearly 90% say they would recommend engineering to a young person looking to choose a career. "Despite the salary stagnation I have experienced, engineering is still a very interesting and fulfilling profession," wrote one engineer. "My own son just graduated from engineering school last year and is now working as an aerospace engineer. He's loving it."

Average Salaries By Age	Base salary	Total compensation
50-54	$103,437	$112,353
55-59	$103,806	$111,974
45-49	$98,002	$107,926
60 or older	$96,596	$105,050
40-44	$94,464	$102,912
35-39	$82,848	$91,696
30-34	$68,597	$76,059
25-29	$67,811	$74,973
Under 25	$53,083	$58,377

Average Salaries By Size Of Company	Base salary	Total compensation
$5 billion - $9.9 billion	$120,457	$130,196
$10 billion or more	$115,705	$127,151
$500 million - $999.9 million	$114,434	$123,689
$1 billion - $4.9 billion	$108,381	$118,549
$100 million - $499.9 million	$105,899	$114,596
$25 million - $49.9 million	$103,863	$111,851
$50 million - $99.9 million	$99,860	$108,002
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$10 million - $24.9 million	$91,975	$99,935
Less than $5 million	$78,395	$85,775

Average Salaries By Geographic Region	Base salary	Total compensation
Pacific	$112,057	$122,137
West South Central	$104,770	$114,251
New England	$104,547	$113,197
South Atlantic	$101,539	$111,294
Mid-Atlantic	$99,629	$107,221
Mountain	$97,585	$106,178
East North Central	$92,736	$100,398
West North Central	$92,586	$99,255
East South Central	$85,500	$92,188

"I found it extremely rewarding and challenging," said another. "Owning a company, being its creative core, allows me to continue to learn and grow. Not too many other fields offer that type of independence. I have hired local college engineering students to encourage them to continue in this path."

Others are more sanguine. "There doesn't seem to be much room for advancement, and not as many positions are available today as there once were," said one engineer. "Salary expectations from new grads are over twice what is available."

Still, on the upside, nearly nine in 10 respondents say they enjoy their jobs, and an equally high number find their jobs at least somewhat challenging. Typical comments included:

- "Challenges faced by engineers in their professional tasks are far more interesting and rewarding (once solved) than in any other field."
- "It is still exciting and challenging. Most engineering-type personalities would be bored in any other field."
- "The challenges to fix real-life problems really get you going. There's great satisfaction that comes from solving issues and problems faced by folks in everyday life."

About two-thirds of the engineers surveyed say they feel adequately compensated for the work they do. As one clearly contented survey participant put it: "Name another profession where your employer buys all the cool toys and then pays you to 'play' with them. It is a profession where you can learn something new every hour of every day."

Not everyone is feeling the love, however. "Competition from less expensive foreign talent, and the tendency of professionals to retire later, make job openings a little more scarce," said one disgruntled engineer. "Additionally, many companies seem to have decided to adhere to five-years-ago salary offers, seem less willing to help employees develop more skills, and won't even discuss pay increases."

But just because engineers aren't thinking about going anywhere soon, it doesn't mean they couldn't be enticed if the right offer came along. "If given the option to take on more of a managerial or finance-style role within an engineering company, I would be interested," an industrial controls engineer declared. "Or if I could find an easier position in another capacity with the same pay, it would be tempting."

While only 7% of respondents say they're actively seeking a new position, one in four said they would follow up if they heard about an interesting opportunity somewhere else. Another third would listen to an offer if personally approached.

"There are literally hundreds of thousands of exciting, smart, useful products just waiting to be brought to creation out there with what is available today in off-the-shelf, economical, software and hardware," a respondent said. "And engineers are the folks that are going to make it happen."

Fewer than a third say they would ever consider leaving the profession. "We are in a more technologically advanced age than ever before," said one. "The drive for renewable energy, greater efficiency, greater portability means there are many opportunities and not enough engineers to fill the roles."

Most of the engineers we heard from who have considered leaving the profession pointed to the frustrations and stress. Here is one example of the venting our survey elicited:

"Engineers get a bad deal in most companies. They are forced to work under unrealistic deadlines without sharing in rewards that management does. If you want to stay in engineering as a career, you turn down management roles, which caps your promotion, salary, and bonus potential. On the other hand, if you take on management responsibility, you quickly lose touch with your engineering skills. Bottom line is that most engineering organizations are horribly understaffed, which makes the job very high-stress. I've had enough of that. Eventually, I formed my own consulting company and for the first time in 15 years I am not stressed out all the time, yet get to work in technology and management as I choose."

KEEPING CURRENT

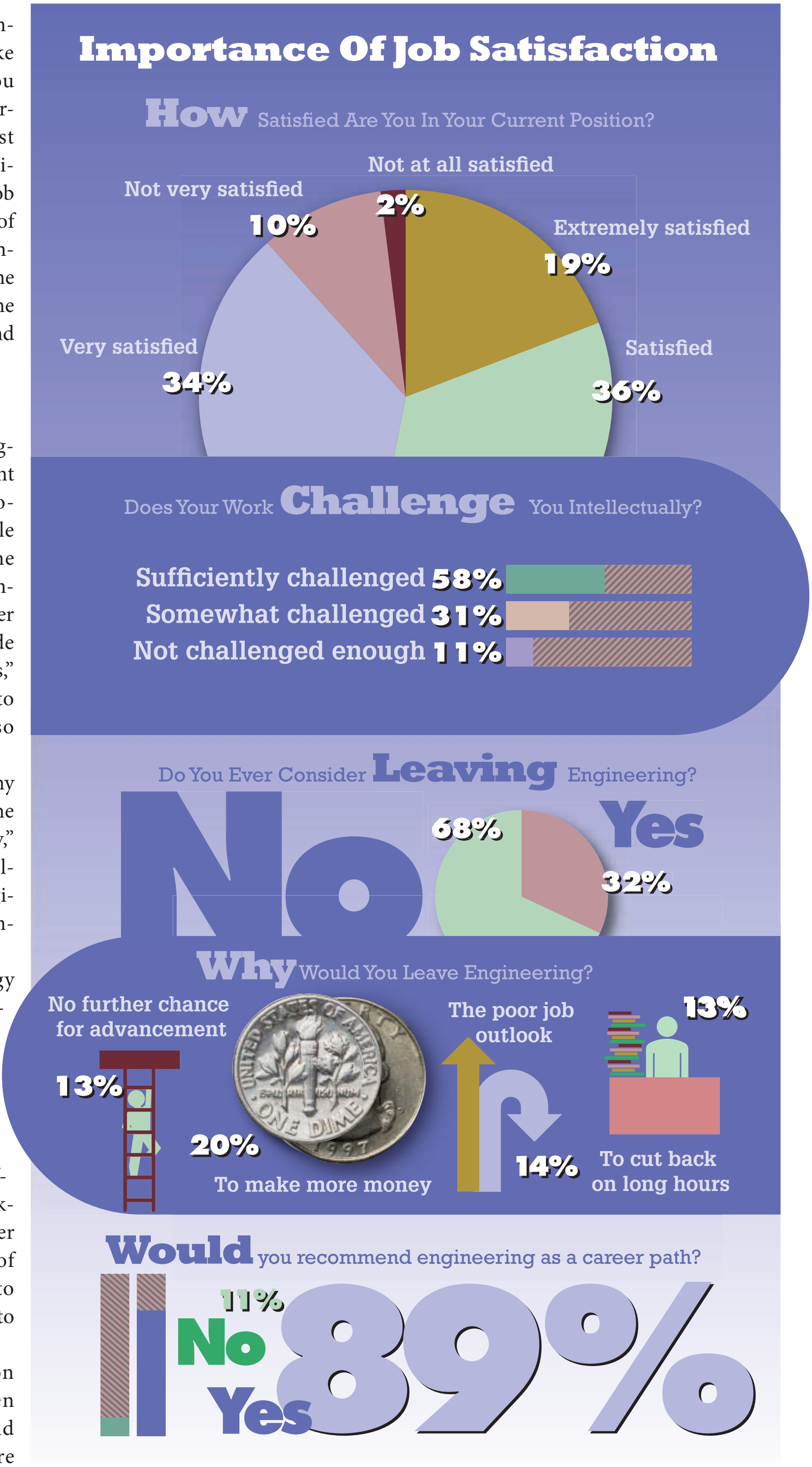
Most engineers still see their biggest challenge as remaining current with new and emerging technologies. Many find it nearly impossible to research and sift through all the information that's available while continuing to do the job at hand. "I cover a broad range of products for a wide range of applications and customers," said one engineer. "It can be easy to miss something when there are so many things to keep track of."

"I find myself trying to balance my own engineering interests against the engineering needs of my company," said another engineer. "Trying to filter out and focus on meaningful engineering developments… there's simply so much more going on."

In addition to reading technology journals like *Electronic Design*, engineers rely on white papers (67%), webcasts (60%), seminars (58%), textbooks (48%), trade shows (45%), and vendor-sponsored education (44%) to keep up to date.

"I try not to follow the flavor-of-the-month for design trends—sticking to basic principles," said another engineer. "Also, the complexity of system-on-chip devices can lead to information overload when trying to master new devices."

Unfortunately, engineers are on their own for the most part when it comes to keeping their skills and knowledge current. Barely half are



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WAYS ENGINEERS ARE EARNING THEIR BONUSES TODAY	
Personal performance	49%
Performance of company or division	48%
Profit sharing	23%
Patent awards	12%
Project milestone completion	10%
Certification/training	5%
Retention bonus	4%
Other	12%

SIGNING BONUSES/INCENTIVES FOR NEW ENGINEERING HIRES	
My company has never offered them	65%
We used to offer them, but don't anymore	15%
We stopped offering them, but have started to again	3%
We've always offered them	17%

TOP 10 PERKS IN 2013	
Health benefits	56%
401(k) match	49%
Time off	39%
Further education/training	20%
Pension plan	18%
Professional organization dues	15%
Company phone	15%
Stock options	13%
Tuition reimbursement	12%
Stock purchase plan	12%

reimbursed by their company for conferences (57%) and seminars (56%), while only about a third are reimbursed for engineering textbooks. "There's no budget for engineering education," complained one respondent. "And vendor-sponsored education is usually more of a sales pitch than real education."

Some positive indicators did pop up in our survey. Only 11% of survey respondents foresee their company scaling back engineering staff in the coming year, and 28% expect their company to increase the number of engineering jobs.

Nearly half the engineers we surveyed say their company is having difficulty finding qualified candidates to fill their open engineering positions. The jobs cited as the toughest to fill include analog designers, software engineers, systems engineers, and embedded systems designers. Perhaps it's not surprising then that nearly half the engineers we surveyed say a recruitment specialist or headhunter seeking engineering talent had approached them within the past year.

However, while engineers say their companies are struggling to find qualified candidates to fill open positions, an alarming 70% don't feel their company is as focused on employee retention this year as they were a year ago. "There is a constant apprehension that engineers are somehow expendable or that our work could be outsourced," said one engineer. "It seems like they don't care about retaining the knowledge gained through years of experience."

"With the overall financial crisis, retention is not a priority," said another. "Upper management relies on unemployment woes alone to keep sufficient staff. As a result, the best people end up going away."

Others noted that companies were beginning to wake up to the issue. "HR has been hearing the rumors of dissatisfaction and watched as the number of people leaving for other opportunities has increased," one engineer told us. "Now, after the fact, they are trying to stop the outgoing momentum."

WHITHER THE "RESHORING" BOOM?

One of the more interesting economic predictions in recent years has been that U.S. manufacturing is on the verge of a dramatic revival. As the theory goes, labor costs in China and other developing nations are on the rise. When you factor in the cost of international shipping and inventory, the cost advantages of manufacturing overseas are being diminished or even erased. Throw in the recent shale-gas boom here at home promising a new age of cheap natural gas and energy independence, and you've got a recipe for hundreds of thousands of new U.S. manufacturing jobs.

The debate over outsourcing and offshoring even took center stage in the 2012 Presidential race. As a result, there has been even greater focus on bringing manufacturing jobs back to America. Estimates suggest that many companies underestimate the real cost of offshoring by as much as 30% and fail to fully understand the risk to their supply chains.

"They still think that it's cheaper to manufacture overseas, while the real costs of doing so are ignored," railed one respondent to the survey.

Others believe outsourcing is baked into the political system. "There are just too many tax incentives for doing business overseas," said one engineer. "The U.S. tax system discourages domestic investment."

Another survey respondent put it this way: "A global company is positioned to take advantage of the best tax structures. In our industry, the medical device tax applies directly to a company's income, plus they get taxed on profit, which means there's double taxation. So I expect to see more offshore development, not less."

But while U.S. manufacturing has made a decent comeback in recent years, it appears that improvements in the sector—at least for now—are more the result of the overall bounce-back from the Great Recession than from any sort of long-term shift. Indeed, while U.S. exports—typically a reliable measure of manufacturing strength—have risen modestly since 2009, credit for the increase is generally given to a falling U.S. dollar, rather than a sustained structural improvement.

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What's more, energy represents a relatively small cost factor for many companies, so the notion that America's newfound glut of cheap natural gas will lead to a long-term manufacturing renaissance has as many skeptics as believers.

This year, 43% of the engineers in our survey say their company currently manufactures products outside the U.S., and only 11% say for certain that their company plans to transition some of its manufacturing back into the U.S. "Salaries for offshore manufacturing are approximately 20% of what they are in the U.S., so I don't see significant manufacturing returning unless cost of energy makes shipping prohibitive," explained one respondent.

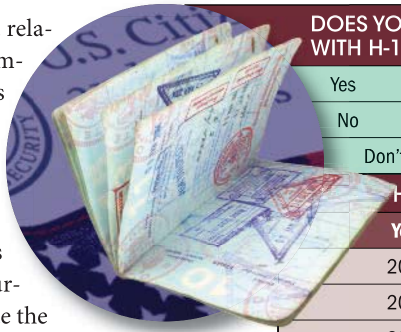
Many respondents say products are being specifically designed for offshore markets, globalization requires multiple locations worldwide, and companies are heavily invested in working with offshore contract manufacturers. "At this time, our primary markets are close to the outsourced locations where our products are being made, so shipping costs are lower than they would be shipping from the U.S.," said one engineer.

The chip sector poses a different set of challenges for bringing manufacturing back to U.S. shores. Taiwan, Japan, and South Korea are way ahead as the top consumers of semiconductor materials used to make microchips. According to an April report from the Semiconductor Industry Association, even China has now surpassed the U.S. in semiconductor manufacturing—and the number of plants for making microchips is expanding in China as it declines in the U.S. So, don't look for chip manufacturing to return to the U.S. anytime soon.

"We make highly specialized CMOS semiconductors products, and there are no affordable options in the U.S.," observed one respondent in the industry. Another survey respondent noted: "We are a fabless semiconductor company. New fabs that support our business just aren't being built in the U.S."

While it may be cheaper to make chips overseas, not everyone believes the cost of manufacturing should be the only consideration. "Semiconductor manufacturing is not workforce intensive, so it really should matter where the markets are," one respondent said. "Production should stay in the locations where products are consumed, including in the U.S. I see it as a fair practice to have it proportional to share of sales in each geographical area."

Companies that have transitioned some or all of their manufacturing back to the U.S. generally cite better control over quality and costs as the primary reason for the changeover. Some came to believe that certain sophisticated products are just better built in the U.S. Others discovered that offshoring introduced more problems, complications, and hidden costs than had been predicted. But many alluded to other hitches



DOES YOUR COMPANY CURRENTLY HIRE ENGINEERS WITH H-1B WORK VISAS?

Yes	19%
No	51%
Don't know	30%

H-1B VISA APPROVALS—FIVE-YEAR TREND

Year	Approved
2008	98,014
2009	80,283
2010	69,266
2011	99,591
2012	134,780

Initial petition requests that were approved; does not include renewals.
Source: U.S. Citizenship and Immigration Service

UNEMPLOYMENT RATE FOR EEs

Year	Approved
2009	6.4%
2010	5.4%
2011	3.4%
2012	3.4%
2013 Q1	6.5%
2013 Q2	4.5%

Source: U.S. Labor Department, Bureau of Labor Statistics

WHO'S HIRING ENGINEERS WITH H-1B TEMPORARY VISAS

By company size (Revenue)	
$1 billion or more	37%
$500 million - $999 million	27%
$100 million - $499 million	24%
$50 million - $99 million	19%
Less than $50 million	10%
By business and industry	
ICs and semiconductors	64%
Automotive electronics	30%
Computer systems/equipment	26%
Software	24%
Test and measurement equipment	24%
Communications systems/equipment	22%
Components and sub-assemblies	20%
Consumer electronics	19%
Research and development	18%
Medical electronics	17%
Avionics/marine/space	15%
Industrial controls systems/equipment	13%
Government/military	9%

0,03 REF. C11
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associated with offshoring, such as unanticipated transportation difficulties, language challenges, public relations concerns, stolen designs, supplier snags, public pressure, unstable political climates, and human rights issues.

"We do all our manufacturing in the U.S. now," said one engineer. "This was not a purposeful policy but happened because our Chinese manufacturers screwed up. For us, this turned out to be a really good move. What we now make in-house is far better and has enabled us to make a superior product that our customers love."

"We found it was important to have a balance of both domestic and offshore production capability to be responsive to customer needs and markets," said another. "Proximity to design and management allows for more efficiency and better cycle time when costs of manufacturing/assembly are reasonable."

"In general, the cost advantage of foreign work does not justify the costs and risks of using foreign work," a survey respondent explained. "We set up somebody to build a part and we've just created a resource for our existing domestic competitors—and may have even created a foreign company to compete with us. Frankly, we would rather purchase and own a foreign manufacturer."

Others cited improving conditions at home. "U.S. commercial real estate is now attractive and so the cost of doing business here makes better sense, both financially as well as for maintaining quality control," said one engineer.

Some survey respondents saw the opportunity to grab government contracts. "There is a lot of discussion on developing domestic manufacturing to be able to bid for government projects," said an engineer involved in federal contracting. "That plus quality problems with products sourced from overseas are forcing us to reconsider our strategy."

A number of survey respondents also alluded to the intrinsic value of "Made in America" as a product attribute:

- "It is more attractive to consumers to know that the products they buy from us are manufactured here in the U.S."
- "Many customers participate in the Buy American Act, so we have begun assembling some products in the U.S. to meet our customer needs."
- "Our customers are demanding that we have an American footprint with manufacturing in case of a disaster or political issue outside the U.S. We are setting up our first-ever manufacturing facility in the USA this year."
- "I want to hire my neighbors—plain and simple."

While there's little evidence to suggest a major shift in manufacturing back to the U.S., there are signs that the tide may indeed be turning. Motorola, for example, is building the Moto X smart phone in the U.S. with a combined bill of materials (BOM) and manufacturing cost in the same range as market-leading products made offshore. The total BOM of the Moto X amounts to $214. When the $12 manufacturing expense is added in, the cost to produce the Moto X increases to $226.

DO YOU PERSONALLY FEEL THREATENED BY ENGINEERS WITH H-1B VISAS?	
All engineers	
Yes	9%
No	91%
Engineers who work at companies that currently employ H-1B visa workers	
Yes	17%
No	83%
IF YES, WILL YOUR COMPANY BE LOOKING TO HIRE MORE ENGINEERS WITH H-1B VISAS IN THE COMING YEAR?	
Yes	32%
No	14%
Don't know	54%
GENERALLY SPEAKING, DO YOU THINK HIRING ENGINEERS WITH H-1B VISAS THREATENS EMPLOYMENT OPPORTUNITIES FOR U.S. ENGINEERS?	
Yes	41%
No	24%
Don't know	35%

At this cost level, the Moto X comes roughly in the middle of the combined BOM and manufacturing costs of the leading smart-phone models, Apple's iPhone 5 and Samsung's Galaxy S4. While the manufacturing expense of the Moto X is $3.50 to $4 more than these phones, the total cost to make Motorola's smart phone is only 9% more than the iPhone 5 and about 5% less than the Galaxy S4.

"With the Moto X, Motorola is reaping the public relations and customization upsides of producing a smart phone in the United States, while maintaining competitive hardware costs," said Andrew Rassweiler, senior director, cost benchmarking services at IHS Inc., a global market information and analytics company. "In spite of its 'Made in the USA' label, overall costs are still competitive with similar smart phones."

OFFSHORING: MANAGEMENT VS. LABOR?

Outsourcing has been a way of life for decades in the electronics industry. But the conflict over this practice is getting more intense as engineering professionals feel increasingly threatened by management practices—while managers are under more pressure than ever to wrest every possible point of profit out of their lines of business.

According to this year's survey, most engineers (52%) say their company outsources engineering work—a number that has held pretty steady over the last several years. Also, 58% say the work is being outsourced to other locations in the U.S. The biggest offshore locations for outsourcing are China and the Pacific Rim (33%), India (25%), and Europe (20%).

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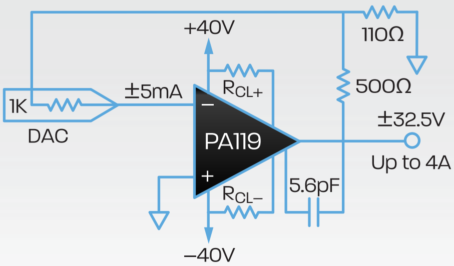

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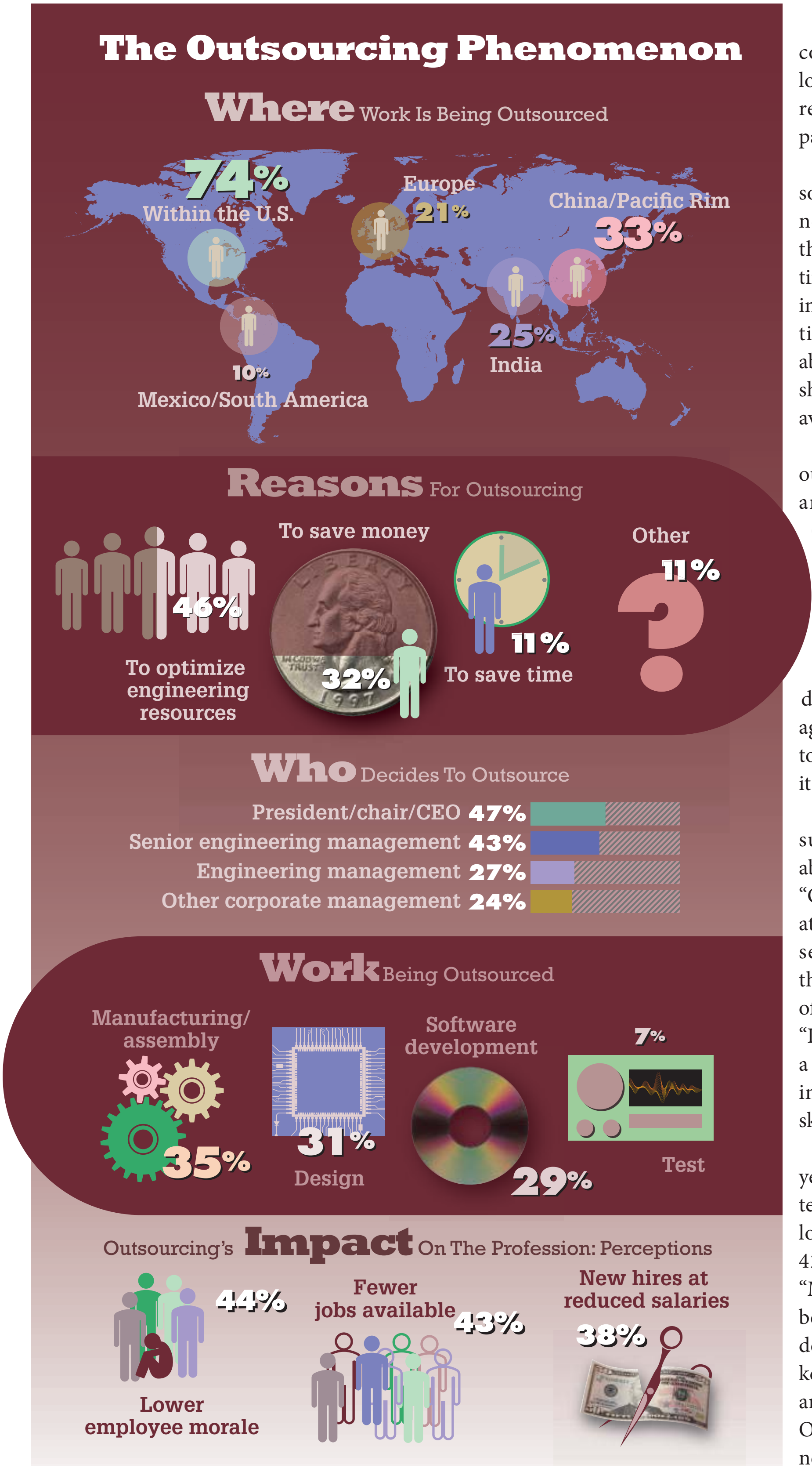

"As much as I hate it, most big companies are outsourcing work to low-cost countries," commented one respondent. "I can't blame my company for doing the same."

The reasons cited most for outsourcing include the need to use engineering resources better (46%) and the desire to save money (32%) and time (11%). Other reasons mentioned include the need to leverage capabilities or expertise that weren't available in-house, the needs to deliver on short-term projects, and the desire to avoid adding to the full-time staff.

The types of design work being outsourced most are manufacturing and assembly (35%), design work (31%), and software development (29%). "We have had a very hard time finding available qualified FPGA designers in the U.S. (especially in our area), but there is a wealth of very talented FPGA designers in Pakistan," said one manager. "We have not laid off anyone due to outsourcing. Instead, we have used it to augment our existing capacity."

One in four of the engineers we surveyed expressed some concern about losing their job to outsourcing. "Outsourcing has always happened at some level and it is needed, but it seems that many companies think that if some of it is good, then more of it will be better," said one engineer. "It reduces the value of engineering to a commodity. It drains the in-house intelligence by not replacing highly skilled engineers."

On the other hand, 36% of this year's respondents said they were not terribly concerned with the threat of losing their job to outsourcing, and 42% expressed no concerns at all. "My view is that outsourcing should be welcomed," said one such respondent. "It is cynical to have a free market for the sale of products we design and not for the engineering of them. Outsourcing forces the good engineers to become even better."

Average Salaries By Engineering Title	Base Salary	Total Compensation
Software engineering manager	$127,000	$141,600
Vice president/VP of engineering	$120,170	$133,051
Technical director/director of engineering/R&D/engineering manager	$117,254	$127,475
Group leader/project team leader/project manager	$108,267	$116,169
Chief engineer/senior engineer/lead engineer/principal engineer	$107,298	$115,244
President/owner/CEO/other executive management	$98,304	$109,653
Applications/systems engineering manager	$96,931	$109,283
Department head/section head	$98,807	$108,968
Software engineer	$100,302	$108,667
Systems engineer/applications engineer	$96,040	$104,422
Manufacturing/production manager	$88,364	$96,964
Design engineer/project engineer/R&D engineer	$89,898	$96,615
Other (please specify)	$85,585	$93,649
Manufacturing/production engineer	$86,097	$92,897
Consulting engineer/scientist	$82,948	$89,455
Member of technical staff	$80,091	$87,069
Test engineer	$77,670	$85,082
QC/evaluation/test manager	$70,818	$75,318

Outsourcing remains one of the most divisive issues in engineering, with strong feelings on both sides of the argument. For many, outsourcing is today's reality and engineers simply need to find ways to deal with it. "It is the world we live in," said one engineer. "In general, unions have driven employment costs so high that companies will save money in any category possible in order to survive and prosper, and engineering is just one of those categories."

Indeed, many respondents believe that outsourcing, if it's directed well with appropriately set expectations, has its place.

"It allows a company to accelerate their strengths while allowing an outside company to handle the less critical functions," said one engineer. "Engineers can then focus on being creative, finding new ways to improve a product design or utilize an all-new design. This has a direct benefit to the company as we are then seen as the go-to people for new ideas and new concepts."

"Within my department, it would be hard to staff all the engineers required for everything we do," admitted another. "Outsourcing is necessary to stay competitive and keep overhead down and profits up."

"Outsourcing has its pluses and minuses. It's clear that outsourcing is being used more to reduce the cost of operations than to compensate for the purported lack of availability of engineers. For instance, unless the laws of economics have been repealed, a shortage of engineers should result in an increase in wages," one respondent said.

"Additionally, engineers would be receiving more opportunities to get their skills updated by their employers. Instead, wages are mostly stagnant and employers say that older engineers do not have the required skills, so they are 'forced' to look for engineers with the required skills—who just happen to work for lower costs—and do not bother to support the retraining of their existing engineers," the respondent continued.

Many engineers believe outsourcing hurts company morale. "Relying on outsourcing to complete multiple projects in their entirety can diminish the morale of full-time employees who desire to work on those projects," said one respondent. "Outsourcing can also lead to reduced product quality when the outsourced engineering team does not follow the same quality metrics of the company hiring them."

Some blamed poor management as the reason why companies are forced to outsource. "Outsourcing is a strategy used to cover up poor management decisions in the past, something that is a quick fix in the short term, but a looming disaster in the future," said one engineer. "Employees observing this will be less concerned about the well-being of the company they work for. This lowers morale and the quality of their workmanship—even in management and office work, never mind technical staff."

"This is something large corporations do to cut costs, but they get what they pay for," said another engineer. "Foreign engineers are often just as competent, but some things get lost in translation. Engineering jobs could see declines similar to those in manufacturing due to outsourcing. Certainly sala-

Average Salaries By Industry	Base salary	Total compensation
ICs and semiconductors	$125,458	$139,852
Software	$122,568	$132,385
Computer systems/boards/peripherals/software	$110,473	$121,972
Government/military	$114,173	$121,676
Medical electronics	$109,651	$120,055
Avionics/marine/space	$102,320	$108,458
Automotive electronics	$99,975	$107,297
Communications systems/equipment	$93,341	$103,659
Consumer electronics	$94,197	$102,289
Test and measurement equipment	$94,991	$101,946
Other (please specify)	$91,665	$100,586
Components and subassemblies	$91,613	$99,519
Industrial controls systems/equipment	$87,330	$95,659
Research & development	$87,516	$95,063
Contract design or manufacturing	$80,267	$86,341
Consultant	$72,789	$79,571

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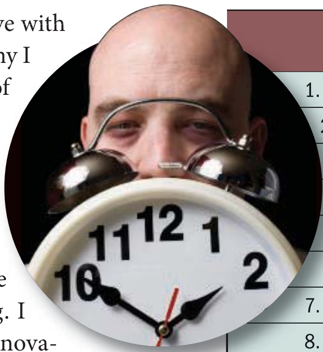
ries have been lowered to stay competitive with countries like India. But the small company I work for can't afford the hassle and time of outsourcing my job functions."



Many respondents see outsourcing as overrated in terms of cost savings and underrated relative to risk. "Outsourcing has not been as successful as advertised," said one engineer. "Innovation is more important than the cost of engineering. I have not seen that outsourcing fosters innovation. The effect of outsourcing at the company I contract to has been a loss of loyalty. Some of the best engineers have left for other opportunities as a result of it."

Other naysayers pointed to the fact that in-house staffs were being forced to clean up the work that had been done by outsourced workers.

"I don't have a negative opinion of outsourcing in general, but I have not had a positive experience with the results it has produced at my company," said another engineer. "The turnover rate of outsourced employees is tremendous and this leads to very few 'senior' engineers. A lot of the U.S. engineers' time is wasted trying to sort through design and documentation errors that came from the outsourced team."

Many survey respondents pointed to the challenges that are associated with trying to manage outsourced talent. "Engineering isn't like math or data crunching where there is only one answer," said one engineer. "To effectively manage a design, the designer and all supporting staff needs to be where the project is. Further, in my experience, outsourced work requires micromanaging to ensure that standards are being maintained. I am not in favor of outsourcing. By sending creativity elsewhere we risk losing our ability to be competitive. In effect, we are training our future competitors."

TOP 10 PROFESSIONAL ISSUES THAT KEEP YOU UP AT NIGHT
1. Staying current with new and emerging technologies
2. Looming project deadlines
3. Product reliability issues
4. Concerns about the general health of the economy
5. Product quality issues
6. Price/performance issues
7. Concerns about job security*
8. Concerns about financial health of your company
9. Specifying the right products/vendor for my designs*
10. Age discrimination

** New this year to the Top 10*

THE 10 MOST PRESSING PROBLEMS AT WORK	
1	Insufficient people resources to get the job done
2	Finding the optimal components for my designs
3	Insufficient funding for my design projects
4	Time-to-market pressures
5	Having to compromise my design approaches
6	Inability to adequately test product designs
7	Shrinking product life cycles
8	Competitive market pressures
9	Lack of design management direction
10	Politics at work

THE FACTORS THAT INFLUENCE JOB SATISFACTION	
1	The challenges that accompany the design of new products
2	Researching potential design solutions
3	Opportunity to design products that can benefit society
4	The compensation you receive for the work you do
5	The recognition you get from others for the work you do
6	Working in team situations with peers
7	Working independently of others
8	The pressures associated with solving design problems

Others expressed similar fears that outsourcing could have the effect of creating competitors in other countries. "I believe it is dangerously wrong to outsource engineering," said one engineer. "It grows competitors outside the country and undermines the future of engineering and science in the U.S."

Some believe that outsourcing more often than not results in poorer product quality.

"There are times when it makes sense, but most companies are only doing it to save money and aren't looking at the quality of the product they are getting," said one engineer. "Often they end up spending more money in support issues than they saved in the design process."

While many engineers object to the offshoring of engineering jobs, outsourcing work to U.S. contractors bothers them less. "Outsourcing within the U.S. is fine. That's a form of independent professional engineering," said one engineer. "Outsourcing outside of the U.S. hurts the American economy and serves to depress wages and opportunities for engineers here at home. It would be interesting to see how international 'insourcing' of engineering work could be achieved by firms outside the U.S."

"Outsourcing within the local area is best, keeping it within the USA is next best, and I am totally opposed to outsourcing outside the USA," said another engineer.

MORE PROS AND CONS

Many engineers suggested that a certain amount of outsourcing was okay as long as it freed them up to be more creative and make the best use of their time. "I think there's an appropriate use for outsourcing, particularly if you need to keep your core technology people focused on where they can add the most value," said one engineer.

"We have to outsource on occasion for some tasks and all the time for other tasks," noted one engineer. "Ideally, we'd have all of the resources in-house so we wouldn't have to outsource, but given the ebb and flow of the projects/dollars we win from our customers, it could be difficult to sustain a higher headcount. But we're growing our group so business is good now."

Still others suggested that there were certain situations where it has its place and can be used wisely to benefit the company. "Outsourcing can simply be smarter engineering," said one respondent. "Most technical resources are not needed on a full-time basis, so this makes good business sense and allows the in-sourcing company staff the opportunity to remain challenged with a diversity of tasks rather than react to a short-term goal and then coast until the next short-term task."

"It depends how it is done," said another. "We outsource so that we don't have to hire and then lay off six months down the road. It's to ensure that our staff is doing interesting things while

HOW YOU CONTINUE TO STAY SMART	
Engineering/technology publications	74%
White papers	67%
Webcasts	60%
Seminars	58%
Engineering textbooks	48%
Trade shows/conferences	45%
Vendor-sponsored education	44%
E-books	33%
Association-sponsored meetings	28%
In-house educational programs	21%
User group meetings/meet-ups	21%
Online discussion forums	19%
Online college courses	18%
In-classroom college courses	11%
Social media platforms used for business	
LinkedIn	52%
YouTube	17%
Facebook	16%
Google+	12%
Company's own social media sites	11%
Blogs	9%
Twitter	6%
Other	4%
None of these	35%
Mobile devices used for business	
Android-based smart phones	29%
iPhones	21%
iPads	12%
Android-based tablet	9%
BlackBerry	8%
Other tablet/reader	6%
None of these	36%

TOP RETIREMENT PLANS OFFERED BY OEMS	
401(k) match	56%
Pension programs	23%
Profit sharing	9%
Stock options	3%
% OF OEM COMPANIES THAT FUND RETIREMENT PLANS	
Yes	70%
No	30%

providing the best job security that we can. If it's done for the bottom line without regard to staffing, I'm not in favor of it."

Even companies that don't outsource have the potential to feel its effects. "It is not affecting my company directly because we do not outsource, but it is affecting our industry indirectly as more and more companies outside the U.S. are coming online that can produce products in competition to ours at lower manufacturing and regulatory costs," said one engineer. "This is compounded by the extensive intellectual property theft occurring that allows those who have not invested in their own research and development to unfairly compete against companies (and countries) that do."

Many of the engineers we surveyed suggested that outsourcing restricts opportunities for younger engineers. "I am not worried for my generation," said one. "However, I believe the impact on the current or recent graduates is more significant. They are competing with a much larger pool of engineers who are willing to work for lower wages."

"Outsourcing is moving many entry-level engineering positions out of the companies and making it difficult to train the next generation of senior engineers," said another.

"It's bad for the profession and future engineers," one engineer noted. "With the lack of good jobs and increased competition for those jobs that are available it's easy to see why students don't want to put forth the effort for any STEM job, especially engineering. Within 100 miles of where I work, hundreds of engineering jobs have disappeared within the past year. I'd put the unemployment/underemployment rate among engineers in the area at around 30% or higher. I know several people who have just given up on jobs in their area and have taken jobs selling insurance, cars, or even working in retail because of the lack of opportunity for engineers beyond the entry level."

Many expressed a real concern over the potential loss of intellectual property as one of the more dangerous side effects of outsourcing. "Outsourcing looks good on paper," said one engineer. "In operation it is inefficient and provides lower-quality design work. In the end, it is often self-defeating as foreign competitors are not above theft of IP and business."

"Using sources around the world theoretically allows 24-7 project progress and often at a lower total cost," said another. "However, it can increase the risk of technical IP loss and lower motivation of local employees. It also requires a system adept at transferring 'tribal knowledge' quickly and thoroughly."

"Companies are giving their entire intellectual property away for free—a dumb idea for short-term return," said another engineer. "Driven by MBA types looking at spreadsheets, the analogy I see is cutting down the peach trees after the harvest and selling them as firewood to avoid the cost of pruning, spraying fungicides, fertilizer. Pretty stupid."

"It's simple economics," another engineer noted. "In the long run, companies will figure out what they should outsource and what they should not. It's scary to see core technology shared with Chinese contractors, and our engineers are not happy with it in general."

But many could see the benefits of outsourcing to running their small businesses. "It is an essential part of business for a small company," said one engineer. "Without outsourcing it would be impossible for us to handle workload peaks efficiently and effectively."

"For a small company like ours, hiring someone or the capital expenditure involved is not feasible in the short term," said another engineer. "Once volume increases, or a new product is launched successfully, then bringing some outsourced processes and jobs in-house becomes more of an option. For my company, outsourcing allows us to grow. For the engineering profession, it allows small firms that specialize in a specific task (software programming, testing, etc.) to build a service for many companies. As long as 'cost' is not the only determining factor, outsourcing (not necessarily international) can be a very good thing."

Many expressed the belief that outsourcing should be considered only as a last resort. "Where there is the ability to promote internal staff, this should be done," one engineer explained. "Where outsourcing is used to fill positions, companies lose the good will of their employees. I can't see how this is good for business in the long term. Too often I see outsourcing used as an easy solution when it is, in fact, the most expensive path to take."

Some were downright philosophical on the subject of outsourcing. "I don't see outsourcing as the evil that most do," said one respondent. "I have worked at high levels in large global companies, and while we expanded greatly in Asia, we also had lots of experienced positions in the U.S. and Europe. In addition, there were always positions that were occupied by 'deadwood' and could be removed without impact. So from my perspective the overall pressures to outsource just made companies stronger by making better decisions on staffing levels and being more critical of retaining the highest talent and not accepting mediocrity.

"Further, I feel that for a sustainable global economy, there has to be a path to raise up a billion or so people out of poverty," this engineer continued. "That may mean some adjustments for those of us accustomed to excess. I have worked side by side with engineers in China, for example, and they are very intelligent, very hardworking, very eager, yet are living a quality of life much below that in the west. Yet those engineers are the lucky ones. There is so much more poverty. So if a balance of design here, design there plus balance on manufacturing is what it takes to do net good, I'm not concerned that we are harming U.S. jobs. In the long run this will all be for everyone's benefit."

SUMMARY

Engineers have to keep their expectations in check when it comes to their earning power. Also, the U.S. engineering market faces significant uncertainty as the economics of globalization and the vagaries of domestic policy remain turbulent.

Yet engineering itself is sure to remain a central activity of American and international commerce for the foreseeable future. Ultimately, engineers become engineers because that's who they are. So while they may have to suffer the slings and arrows of some outrageous fortune today, they can take solace in the fact that they are also playing a unique role in building the world's tomorrow. ed

LOU FRENZEL | Communications Editor
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Understanding The Small-Cell And HetNet Movement

Consumers want more from their wireless providers, but the current infrastructure can't handle the growing traffic. So, expect small cells and HetNets to shoulder some of that burden.

Small cells are miniature cellular basestations with limited power and range. They complement larger macro basestations, which are the most common cell sites, to permit greater subscriber capacity and faster data speeds. Small cells are a growing trend that will have their greatest impact in 2014 and beyond.

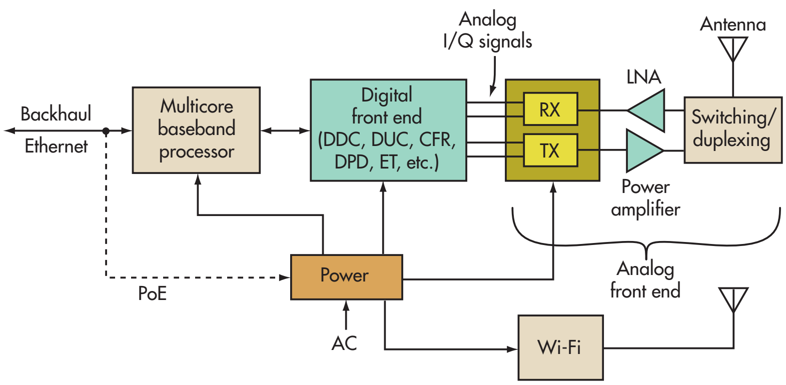
BACKGROUND

A huge network of cell sites called macro basestations handles cell-phone traffic. With their high power, tall towers with multiple antenna arrays, long range, and backup power sources, macro basestations cover most of the U.S. except for some very rural and geographically challenged areas. There are nearly 300,000 such basestations in the U.S. Finding and securing suitable locations for basestations is getting increasingly difficult, though. The solution is the small cell.

In addition, the success of the smart phone and the growing subscriber demand for more and faster service are pushing cellular carriers to expand and upgrade their basestation deployments. The carriers responded by upgrading their systems with 4G Long Term Evolution (LTE), which offers significantly faster download speeds demanded by the major increase in video consumption. LTE is still being installed with full coverage not expected for several more years. One clear solution is the LTE small cell.

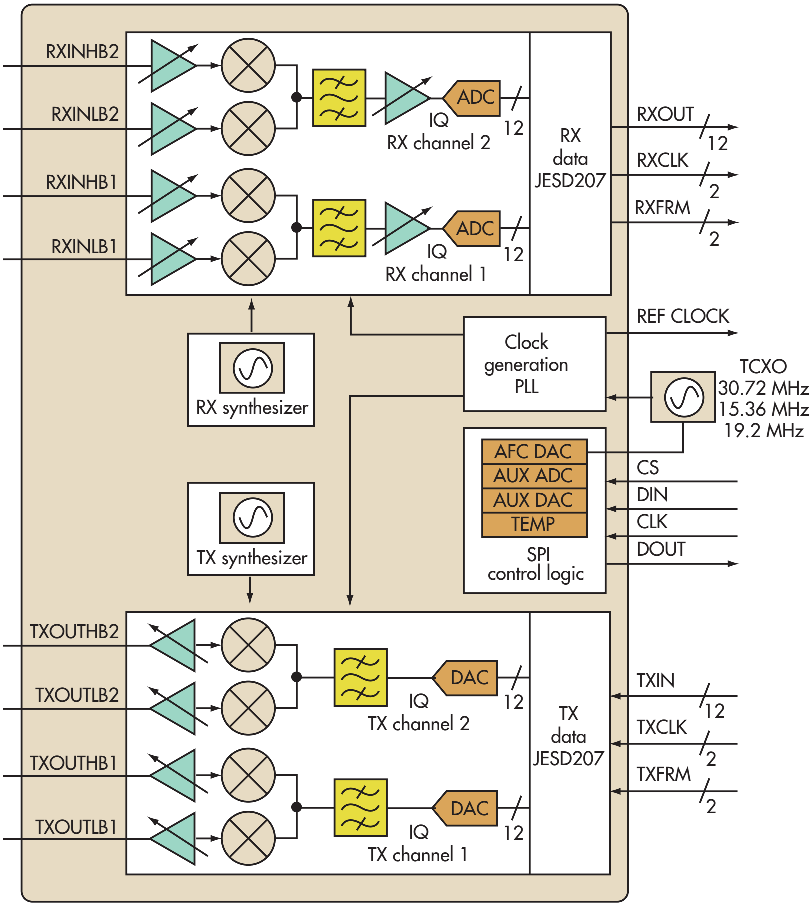
While the adoption of LTE will boost capacity and speed, limits are being reached. The orthogonal frequency-division multiplexing (OFDM) of LTE along with advanced modulation methods and multiple-input multiple-output (MIMO) have pushed the spectral efficiency (bits/Hz/Hz) of the cellular system to the Shannon limit. LTE-Advanced will improve speeds by providing more bandwidth through carrier aggregation. The ultimate limit is the spectrum available to the carrier. Again, small cells can provide an interim solution until more spectrum is freed up.

Another major issue for cell phones is indoor performance. More than 80% of all cell-phone calls occur in homes, offices, shopping malls, hotels, and other indoor venues. Indoor performance is significantly poorer than outdoor performance since the radio signals are seriously attenuated, distorted, and redirected by walls, ceilings, floors, furniture, and other obstacles. Indoor situations limit the range of the radio and greatly curtail data speeds. LTE is helpful in overcoming this problem, but the real solution is the small cell.



1. A small cell comprises a multicore baseband digital processor connected to the analog RF front end, which includes the transmitter and receiver. Backhaul is usually via Ethernet.

As it turns out, public and private Wi-Fi hotspots and access points fit the basic definition of a small cell. They can connect to a user smart phone, tablet, or laptop and provide access to video and other information and media demanded by the user. You don't have to use the cellular network



2. The Maxim Integrated MAX2580 RF transceiver features two full radios to implement 2x2 MIMO.

to download video or access other big data applications if a Wi-Fi hotspot is nearby. Most cellular small cells will include a Wi-Fi access point.

Groups of physically small cells can be installed anywhere, indoors or out. They can sit on a desk or be mounted on a wall, roof, lamppost, or light pole. The small cells fill in the gaps in coverage and provide service where macrocell coverage is poor.

There will be from five to 25 small cells per macro cell in most networks. Networks of small cells overlay, or as some say underlay, the macro network to provide an overall boost not only in data speeds but also subscriber capacity. The general customer performance is greatly improved with more reliable connections and significantly higher download speeds.

Distributed antenna systems (DASs) also are part of the small-cell trend. They use fiber-optic cable from a macro basestation to an array of antennas spread over a wide area to extend the reach and improve connection reliability. DASs are used in large buildings, airports, convention centers, and other large public venues. They could potentially be used to extend the range of small cells as well. Collections of macro basestations, small cells, Wi-Fi hotspots, and DASs are known as heterogeneous networks, or HetNets.

All small cells use the existing licensed spectrum assigned to the carrier's networks. The limited spectrum is shared by frequency reuse and spatial diversity. Frequency reuse refers to the use of the same band by multiple cell sites. Spatial diversity means these sites are spaced from one another so coverage areas do not overlap. Power levels are controlled to eliminate or minimize interference with adjacent cells and with those on the same frequency.

SMALL CELLS DEFINED

There are several different sizes and versions of small cells. They vary in the number of users they can handle, their power, and their range. In virtually all cases, they include the essential 3G technologies of the carrier, LTE and Wi-Fi. They also have a power source and a backhaul connection to the cellular network *(see the table)*.

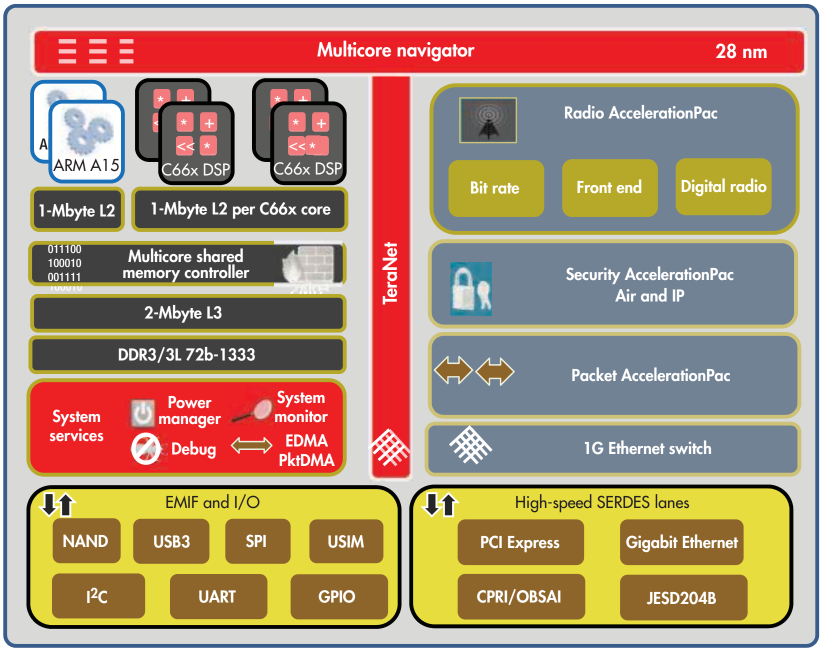
The smallest is the femtocell, which is a single-box basestation used by the consumer to improve local cellular service. Femtos have been around for years, and millions have been installed by most large carriers. Backhaul is by way of the customer's high-speed Internet connection via a cable TV or DSL telecom provider. There are also enterprise femtos that handle more users and provide a significant boost in indoor accessibility.

There are progressively larger small cells such as the picocell, microcell, and metrocell, each with increasing capacity, power, and range. Virtually all handle legacy 3G, LTE, and Wi-Fi. Many future small cells will also feature LTE-Advanced.

INSIDE THE SMALL CELL

A small cell is still a cellular basestation but boiled down to only a few key chips and circuits. Thanks to super-fast multicore processors, a single IC easily can handle most 3G and LTE baseband operations. This baseband IC is then connected to the RF circuitry, making up the radio transceiver *(Fig. 1)*.

The RF transceiver called the analog front end consists of the receiver (RX) and transmitter (TX). The receiver gets its signal from the antenna and amplifies it in a low-noise amplifier (LNA) and sends the signal to I/Q mixers forming a demodulator that recovers the signal. The signals are passed to analog-to-digital converters (ADCs) that create the input to the digital front-end processor.



3. The Texas Instruments TCI6630K2L is a small-cell baseband processor with two ARM CPUs and four C66x DSPs plus accelerators, the digital front-end components, and multiple interfaces including a Gigabit Ethernet switch.

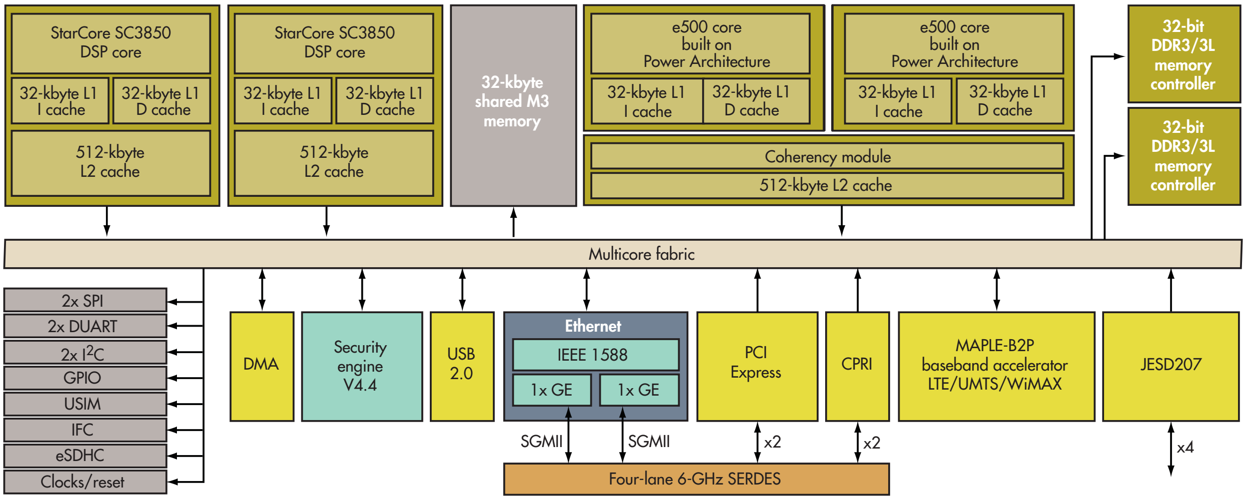
Between the RF front end and the baseband processor is additional circuitry that performs decimation, digital upconversion (DUC), and digital downconversion (DDC). Other digital processing includes crest factor reduction (CFR), digital predistortion (DPD), and envelope tracking (ET). DPD and ET are used for linearization of the RF power amplifiers to improve efficiency *(see "Envelope Tracking Improves Mobile Handset Performance" at electronicdesign.com)*. All this circuitry may be in a separate ASIC or FPGA, or it may be included in the baseband chip or front-end RF circuitry.

The baseband processor creates the digital I/Q signals for the transmitter. These signals go to digital-to-analog converters (DACs) in the analog front end that produce the equivalent analog signals. These signals then are sent to I/Q mixers that form a modulator. The modulator output is sent to one or more power amplifiers and then to the antenna.

The baseband processor has multiple-standard CPUs and DSPs. It also handles all the modulation, demodulation, and other processes involved with the various cellular standards. The I/O to the backhaul is typically by Ethernet. Power comes from a Power over Ethernet (PoE) connection if available or by some other source.

Maxim Integrated's MAX2580 single-chip analog front end includes the I/Q modulator and demodulator as well as their fractional-N frequency synthesizers for channel selection *(Fig. 2)*. The multiple circuits support 2x2 MIMO. The synthesizers cover all LTE bands 1 to 41 and provide for bandwidth selection from 1.4 MHz to 20 MHz. The ADCs and DACs are included on chip. The digital interfaces to the baseband processor are JESD207.

The receiver section includes the LNAs, though additional external LNAs could be added if necessary. The transmitter output amplifiers provide 0 dBm. If more power is needed, external



4. Freescale's BSC9132 multicore baseband processor supports LTE-FDD/TDD, HSPA+, and WCDMA standards for up to 64 simultaneous LTE users. It can handle up to 150 Mbits/s downlink and 75 Mbits/s uplink in a 20-MHz channel.

power amplifiers can be added. Maxim makes a wide range of other RF circuits including the MAX2550-MAX2553 3G femtocell transceivers for CDMA systems.

Texas Instruments' similar AFE7500 RF front-end chip has two separate transmit and receive streams to support 2x2 MIMO. It also includes all of the ADCs and DACs. A separate single-path receiver accommodates the feedback from the antenna needed by the DPD linearization circuits. The interface to the baseband processor is the JESD204B.

TI also has a full line of multcore processors to support the basestation needs. The KeyStone line includes a mix of ARM A15 RISC processors as well as TI's well-known C66x DSPs. The TCI6630K2L features two ARM cores and four C66x DSPs *(Fig. 3)*. It also has multiple accelerators to speed up operations, minimize the number of cores, and reduce power consumption. Further, it includes the digital front-end circuits like DUC/DDC/DPD/CFR. Multiple interfaces include JESD240B, PCI Express, SPI, USB, and a Gigabit Ethernet switch.

Freescale makes a full line of wireless infrastructure processors, including the QorIQ Qonverge BSC9131 for home and small business femto cells for up to 16 users, the BSC9132 for enterprise femtocells or picocells with up to 100 users, the B4420 for larger metrocell and microcells, and the B4860 for macrocells. All support LTE-FDD, TD-LTE, and LTE-Advanced as well as WCDMA and HSPA 3G standards. The BSC9132 comprises two Power Architecture e500 RISC cores and two StarCore SC3850 DSPs plus the MAPLE B2P baseband accelerators *(Fig. 4)*. Multiple I/Os permit connection to a variety of RF chips including the MAX2580.

Finally, most small cells will include Wi-Fi and possibly GPS. Power will come from PoE plus a mix of dc-dc converters and regulators. The RF power amplifiers and the baseband processor system-on-chip (SoC) consume most of the power.

MORE ON SMALL CELLS

As consumers demand more video and other data on their mobile devices, carriers will rely on small cells to support the huge volumes of traffic. For more about these solutions, go to **electronicdesign.com** and see:

- Understanding Small-Cell Unification's Vital Role In LTE And 4G
- Interview: Freescale's Tareq Bustami
- An Introduction To LTE-Advanced: The Real 4G

TIMING AND SYNCHRONIZATION

A key requirement of all LTE basestations, macro or small-cell, is timing and synchronization of all the radios in the net-

5. The Ceragon FibeAir IP-20C is typical of the small-cell backhaul units available. It is available in standard licensed band frequencies from 6 to 42 GHz. Typical data rate is 1 Gbit/s in a single channel. It uses 2048 quadrature amplitude modulation (QAM) and can implement 4x4 MIMO in line-of-sight situations.

work. Timing and synchronization are essential to meet the specifications of the Third Generation Partnership Project (3GPP), the organization establishing the LTE standards. Timing and synchronization are implemented by delivering a formatted clock signal to the radio circuits of the basestation. These signals are then used to create the phase and frequency components of the LTE modulation. Timing and synchronization are also essential for proper handoff and backhaul coordination.

Several timing and synchronization methods have been developed including synchronous Ethernet (SyncE) or G.8262 by the ITU and the IEEE's Precision Time Protocol (PTP) 1588-2008. Both are used, but PTP 1588-2008 seems to be preferred. PTP can be delivered with a grandmaster clock in the form of a timestamp over the packet network. An alternative, Network Time Protocol (NTP), is designed to synchronize clock to some time reference over a variable latency data network.

The timing requirements for implementing LTE in the network are severe. The typical clock precision required is 16 parts per billion (ppb) in the transport network and 50 ppb in the air interface. For TDD and Advanced versions of LTE, the phase requirements are also critical. In addition, the method of backhaul will vary with different types of small cells. Many will use microwave. Others will use fiber. In residential femtos, DSL or cable TV provide the backhaul. Different timing schemes are needed to optimize the performance.

The LTE-Advanced small cells to come will have strict timing and synchronization requirements to implement the key features of enhanced inter-cell interference coordination (eICIC) and coordinated multipoint transmission/reception (CoMP). These interference management technologies are required for self-organizing networks (SON).

WI-FI OFFLOAD

The concept of Wi-Fi offload is simple. It is the formal use of available hotspots and access points to carry the high-speed data, relieving the cellular network of that burden. Since all smart phones have Wi-Fi, it is possible to create a system that automatically selects Wi-Fi for a fast download if a hotspot is nearby. While subscribers could voluntarily access the data with Wi-Fi, they may not be aware of a useable hotspot.

By offloading the cellular system, that network can handle more users with high-speed data needs that cannot be addressed with Wi-Fi. Today, users can automatically offload the network themselves by actively seeking an available hotspot to avoid the cost of using the cellular network. Otherwise, an automatic carrier-driven approach can be implemented to make the offload work seamlessly when users access high-volume downloads.

While the ultimate solution to volume is to roll out a small-cell underlay to increase capacity and coverage, Wi-Fi offers an immediate solution to the demand for faster downloads. Since high-speed traffic like video is growing faster than the carriers can implement a full small-cell system, Wi-Fi offers a fast and inexpensive way to deal with the problem. To make this work, several things must happen.

First, cellular operators will have to partner with existing Wi-Fi providers in their coverage areas. Alternately, the cellular operators will need to build out their own Wi-Fi networks. Many have already constructed their own Wi-Fi networks to ensure the desired coverage. Wi-Fi networks are significantly less expensive to install than cellular basestations, including small cells. And, they are usually faster than most 4G networks. These cellular operator Wi-Fi networks are called carrier-grade networks.

Second, some mechanism is needed to initiate an automatic selection of Wi-Fi versus cellular networks when a subscriber attempts to access some source of video or other big data. A subscriber's smart phone or tablet will seek out the available networks and then select the best option, mostly favoring Wi-Fi if it is available. Up to 50% of cellular data traffic will eventually be offloaded to Wi-Fi, giving carriers time to roll out more small cells, expand their LTE networks, or add new spectrum while minimizing capital expenditures.

The mechanism for this selection is now available in the form of the Wi-Fi Alliance's Hotspot 2.0 and the IEEE 802.11u standard. First, 802.11u is a relatively recent enhancement to the 802.11 wireless local-area network (WLAN) standards. It enables Wi-Fi to work with other networks including cellular networks. The enhancement essentially automates the connection between a smart phone, tablet, or laptop to different Wi-Fi networks. It replaces the process of discovering nearby hotspots, entering passwords, authenticating, and connecting.

Next, Hotspot 2.0 is an addition to the basic standard that uses 802.11u to automate access point discovery, registration, provisioning, and connection. This not only enables roaming between hotspots, it also provides a mechanism to link to cellular networks to perform automated handoff between the cellular network and available Wi-Fi hotspots.

Virtually all 3G/4G small cells will also include carrier-grade Wi-Fi either in the same enclosure or in an adjacent box. Furthermore, the newer cell-phone models will incorporate Hotspot 2.0/802.11u to make the offload option function. Cellular operators see the offload strategy as a way to buy time until more wireless spectrum is available or as funds are available to acquire it.

BACKHAUL

Backhaul is the name of the connection of a cell site to the core network. Most macro basestations in the U.S. use fiber-optic cable. Some carriers in hard-to-reach areas use a microwave link. Fiber is preferred, of course, as it is fast and reliable. But it is costly to install since it requires access to property, digging in the ground, or permission to use power poles.

Microwave is simply line-of-sight (LOS) point-and-shoot wireless. It is not as fast, but that limitation is gradually going away with the new systems. With most microwave links, data capacity up to 1 Gbit/s is usually available.

Small-cell backhaul will most likely be a mix of fiber and wireless. If fiber is available and affordable, it will be used. Otherwise, a wireless link will be the backhaul of choice. Small-cell backhaul also will be tricky sometimes.

With small cells on lampposts, sides of buildings, and other odd locations, fiber or even ac power may be hard to come by. A wireless link may be the only choice, and even that could be a challenge in large cities with tall buildings and other structures blocking most paths back to the core network. Multiple-hop links may be used in some instances.

The most popular wireless backhaul frequencies are 6, 11, 18, and 23 GHz. These frequencies require a license to use, and equipment is generally expensive. However, other potential bands are the 60-GHz band and 70/80-GHz E-band. The 80-GHz band requires a license, but the 60-GHz band does not. The 60-GHz band (57-64 GHz) is an industrial-scientific-medical (ISM) band that is open to any service.

The millimeter-wave bands above 30 GHz offer lots of bandwidth to support higher data rates, but their range is severely limited by the physics of their short wavelength. With high-gain directional antennas and higher power, though, ranges can extend to several kilometers. Just recently the Federal Communications Commission modified the Part 15 rules and regulations to permit higher power and antenna gains in the 60-GHz band to make it more useful for small-cell backhaul *(Fig. 5)*.

SELF-ORGANIZING NETWORKS

Self-organizing networks (SONs) are a software solution to managing a HetNet. While the interaction between macrocells is usually managed manually, with multiple small cells, such a manual task is overwhelming. With SON, the HetNet will essentially manage itself. SON can automate configuration and dynamically optimize the network based on the traffic loads.

SONs can be categorized by their three basic functions: self-configuration, self-optimization, and self-healing. Self-configuration adjusts the small-cell frequency, power level, and interfaces automatically as the device joins the system. It works with the automatic neighbor relations (ANR) software that builds and maintains a list of all cells in the network and the location and physical characteristics of each *(see "Test ANR Functionality On Your LTE Devices" at electronicdesign.com)*. If any new cell is added, the configuration is automatic and the list is updated. The same occurs if a cell is removed.

Self-optimization refers to the ability of the network to adapt itself to surrounding conditions and optimize its performance based on coverage, capacity, handover between cells, and interference. Two key functions are load balancing and interference mitigation. Load balancing is dividing the traffic between the cells so no one cell becomes too overloaded if adjacent cells are within range and have

LICENSED SMALL CELLS

	Femto	Pico	Micro/metro	Macro
Indoor/outdoor	Indoor	Indoor or outdoor	Outdoor	Outdoor
Number of users	4 to 16	32 to 100	200	200 to 1000+
Maximum output power	20 to 100 mW	250 mW	2 to 10 W	40 to 100 W
Maximum cell radius	10 to 50 m	200 m	2 km	10 to 40 km
Bandwidth	10 MHz	20 MHz	20, 40 MHz	60 to 75 MHz
Technology	3G/4G/Wi-Fi	3G/4G/Wi-Fi	3G/4G/Wi-Fi	3G/4G
MIMO	2x2	2x2	4x4	4x4
Backhaul	DSL, cable, fiber	Microwave, mm	Fiber, microwave	Fiber, microwave

available capacity. Load balancing occurs automatically. This ability also helps balance the backhaul traffic load.

Interference management is essential in a HetNet since the small cells are generally closely spaced and could potentially interfere with one another. SON software uses the cells to measure the characteristics of nearby cells to determine if interference is a possibility. It then makes adjustments dynamically to change frequency or power level as necessary to minimize interference.

Self-healing refers to a SON's ability to adjust to changing conditions such as cell failure. SON technology is a key part of HetNets, and the LTE standard supports it. Tests have shown that SON can monitor and update a network within milliseconds in some cases and dynamically adapt. Overall throughput can be improved by 10% to 45% in many cases.

DISTRIBUTED ANTENNA SYSTEMS

DASs also are a key part of the HetNet movement. A DAS isn't exactly a small cell, but it similarly improves coverage and performance in a given region. A DAS expands the coverage on a given basestation by distributing the signal over a wider area using a network of antennas. It is useful for improving coverage in multi-floor office buildings, stadiums, hotels, malls, airports, and subways, as well as tunnels and roadways. It can be used indoors or outdoors, although indoor coverage is more common.

A DAS connects to an existing macro basestation either directly or by a wireless link. It then distributes this service over fiber-optic cable or coax cable or some combination. Typically the unit connected to the basestation involves a repeater that amplifies the signal and sends it to various regions in the coverage area by way of a fiber-optic cable. In some cases no amplification is used. The RF signals are simply transported over the fiber.

The fiber connects to distribution boxes that convert the signals for coax cable distribution to an array of antennas. These antennas must be separated from one another by several wavelengths to be effective. The array divides the transmitted power among the antennas. While the signal at each antenna is smaller, it typically is a better signal than what might be an even smaller signal directly from the basestation. A DAS eliminates dead zones caused by the huge attenuation with distance and through walls, ceilings, and other obstructions. It provides a more direct line-of-sight connection to the cell phone or other user device.

A DAS may be passive or active. Passive systems are simplest and use a mix of filters, splitters, and couplers to distribute the signals. Active systems use amplifiers and repeaters to boost signal levels. The facility owner usually owns the DAS instead of the cellular carrier, like other small cells. A distribution agreement with the carrier is necessary. DAS may be carrier-specific or generic to handle any 2G/3G/4G signals. Some DASs work with Wi-Fi as well.

SUMMARY

Only a few small-cell networks are around now, but many are expected in the future. The major carriers will undergo many trials and tests as they attempt to solve the many challenges of placing and provisioning small cells. The larger rollout of small cells will begin in 2014 and continue thereafter.

Small cells not only will improve smart-phone and tablet operations but also will accelerate mobile cloud applications and machine-to-machine (M2M) services. Then 5G systems will emerge, including a small-cell solution. ed

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Freescale's Ritu Favre
Discusses Today's RF Technologies

Radio-frequency (RF) technology isn't just a niche in electronics. It's the basis for the massive use of wireless we see today. Freescale Semiconductor is a leader in RF power transistors, amplifiers, and other RF circuits. Ritu Favre, VP of Freescale's RF division, discusses the RF business, products, and markets.

ED: Tell us something about Freescale's RF Division. What is the scope of the products?

RF: For over 20 years, Freescale has been the leader in defining "what's next" in RF. In the 1990s when bipolar was the industry standard, Freescale was the first to introduce laterally diffused metal-oxide semiconductors (LDMOS), and that enabled multi-generational improvement in power amplifier (PA) performance. In the 2000s when discrete ceramics were the industry standard, Freescale was the first to launch radio-frequency integrated circuits (RFICs) and plastic packaging, thereby enabling compact, easy-to-design PAs.

Today, with a significant market share lead in RF power amplifiers, Freescale is successfully leveraging our technology position to grow revenue outside of cellular infrastructure in areas such as millimeter-wave monolithic integrated circuits (MMICs), RF industrial, RF military & aerospace, and land mobile markets.

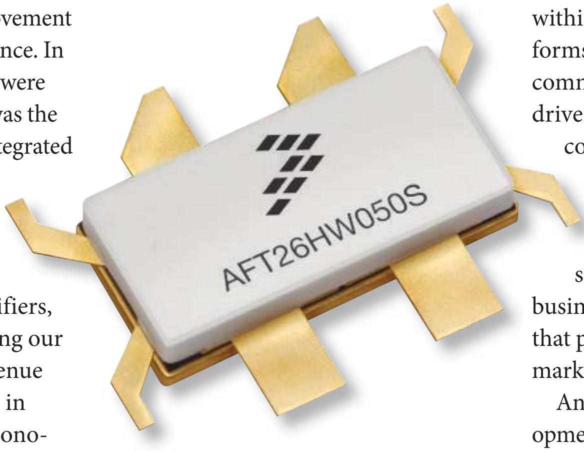
ED: What products make up the greatest percentage of the business?

RF: Today our largest revenue stream is from RF cellular markets (basestation PAs).

ED: What key factors are driving your RF business right now?

RF: Cellular networks are continuing to transform from voice-centric to data-centric in nature, and the accompanying explosion in mobile data usage has led to expansion and upgrades of cellular networks. In turn, this has created a healthy demand for our products and led to growth in our businesses.

Our announcement earlier this year that we are entering the RF military & aerospace markets has also been very well received, and we are getting significant pull there. Our overall industrial offerings also continue to gain traction, and we are performing very nicely in these areas.



The newest Freescale Airfast LDMOS transistors are designed specifically for TD-LTE basestations at the 2.3/2.6-GHz frequency bands. These transistors span a broad range of power points, from 50 W to 200 W. The AFT26HW050S/GS targets metrocell basestation applications in the 2496- to 2690-MHz band. In an asymmetrical Doherty configuration, it delivers 47.4 dBm of peak power.

ED: Are you developing any products for the automotive/telematics/connected car market?

RF: Freescale is a major supplier of semiconductors to the automotive industry. Our sister business groups within Freescale are developing platforms and solutions for inter-vehicle communications and for advanced driver assistance including radar-based communications.

Freescale has a broad portfolio of automotive microcontrollers, integrated circuits, and sensor solutions. Specifically in the RF business, there are sections of our group that participate in the connected car market.

An example of this would be the development of high-definition FM (HDFM) and radio data system-traffic message channel (RDS-TMC), where traditional radio stations can now broadcast traffic information through FM transmitters. We lead the pack in FM RF power transistors. Additionally, as part of our emerging market product team, we are working on other RF automotive applications such as plasma ignition.

ED: Is the LDMOS power transistor business still solid given the big interest in gallium nitride (GaN)?
RF: Freescale's objective to remain a market leader can only be fulfilled if we are able to provide the right solutions at the right price across the market segments we serve. To enable this, our technology investments span LDMOS, GaN, gallium arsenide (GaAs), and other technologies. Today, the cellular infrastructure market is by and large still an LDMOS-dominant market.

So, yes, our LDMOS outlook is quite strong as we look forward. There are niche applications where wide band gap provides differentiation, and we are investing in these areas. For example, at S band there are performance-to-cost ratios that must be considered, and at C and especially X band, the performance benefits of GaN make it attractive.

ED: Are you doing anything with GaN?
RF: We are developing GaN products for markets that can derive the most benefit from the advantages that GaN has to offer, such as higher Ft, broadband, and power density. This year we announced our initial offerings for cellular infrastructure and broadband land mobile applications. In addition to that, we are investing in GaN development at C and X band, where GaN provides significant performance benefits.

ED: What is the status of the Doherty amplifier business?
RF: Doherty remains the workhorse of high-power RF PAs. Although alternative architectures are always being developed, I do not expect Doherty's status as a critical technology to change in the near future.

ED: What is the future for GaAs RF circuits?
RF: The future for GaAs is very bright, especially in lower-power applications. We expect GaAs to receive a further boost through femtocell markets, both consumer and enterprise varieties. Additionally, using this technology platform we have developed application-specific products such as ADAM, which is a solution that can dramatically reduce production variation in Doherty amplifiers.

ED: Does Freescale have RF circuits for the cellular market?
RF: Yes, Freescale invests heavily in RF power circuits to help reduce our customers' cycle times and increase performance and time-to-market. We have expanded our single-stage reference circuit design offerings to include full PA lineups, which allow customers to finalize their designs much quicker.

ED: What's happening with the ZigBee business these days?
RF: Freescale continues to offer ZigBee solutions in smart energy, home automation, and other short-range connectivity applications. The RF business I manage is focused on higher-power solutions, such as the ones mentioned.

ED: Do you have RF design tools or reference designs that help engineers design?
RF: Absolutely. A very large portion of our investments is in areas that help our customers' designers reduce the complexity and cycle time of their designs. For example, our FET2 and MET models for RF high-power transistors and RFICs are nonlinear models that simulate electrical phenomena and account for dynamic self-heating. They were specifically developed to model high-power RF transistors and RF ICs. Freescale's RF models are generally recognized as market leading and enable our customers' circuit designers to predict prototype performance more accurately.

As mentioned above, we also invest heavily in reference designs. As one example of this, we have launched a "130 ways to get smarter" campaign based on our 130 reference designs in the RF industrial space. We will continue to produce more and more of them, as they are a key enabler for us and ease our customers' design process significantly.

ED: What do you see as the "next big thing" in RF?
RF: We understand that true differentiation is needed to maintain and grow cellular market share, and we will continue to focus there. As an example, we believe that

Freescale's latest Airfast RF products are best-in-class at multiple frequency bands and power levels *(see the figure)*. However, for the "next big thing" we are making very significant investments in our industrial and MMIC businesses, and we see a bright future for these application areas.

ED: What challenges have you overcome to get to where you are today?

RF: To reach my current position, I had to overcome many barriers to being credible as a leader. I started in electrical engineering and was one of five women in my bachelor's classes. By my master's, I was the only woman.

Upon starting at Freescale, I started in manufacturing. I learned leadership skills working in the wafer fab and final manufacturing facilities. In order to progress in my career, I needed to move to a business role. I moved into business management and worked with a number of very intelligent RF engineers. Over time, I began to learn the technology and the challenges. Working closely with the team to gain credibility helped me to achieve the goals that I was looking to attain.

ED: What would you say to young girls considering a career in engineering or other STEM fields?

RF: I would say that always go for the hardest and most difficult types of math and science that you can do. Being an engineer is rewarding at so many levels and can lead to so many different types of careers. Math and science can also lead to medical degrees and other advanced degrees that enable entry into technology fields. The jobs are exciting and rewarding.

ED: What new skills do you see influencing the future of RF that new graduates should be cultivating?

RF: Communication skills are vital, such as being able to convey ideas clearly so others can understand them. Understand the person/audience you are talking to and ensure that you think through the best way to get your point across. Be an engineer for many years before making a shift into management. Become an expert in a particular field of engineering before branching out. Work hard, and let your career develop naturally. ed

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RITU FAVRE is senior vice president and RF general manager at Freescale. She has 25 years of experience in large corporations, covering all aspects of the value chain including the supply chain, technology, new product introduction, business operations, management, and developing strong customer relationships. She joined Freescale in 1988 and has served as the RF general manager since October 2010. She holds a bachelor's degree in electrical engineering and a master's degree in electrical engineering, semiconductor physics, from Arizona State University.


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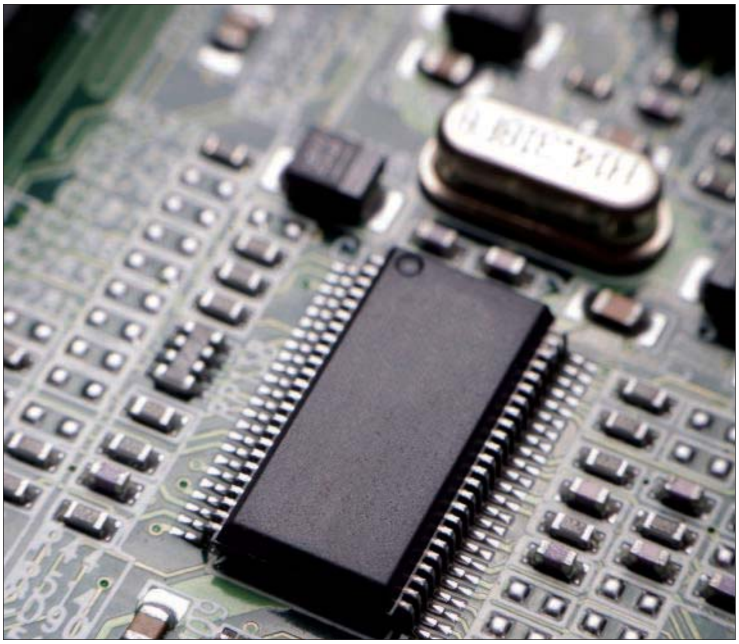

Smart Planning Ensures Successful Initiatives Against Counterfeiting

Independent distributors step up their game as OEMs and contract manufacturers respond to government regulations with tighter controls and stricter requirements for parts suppliers.

IF THERE'S ONE THING an engineer or procurement manager should do before buying from an independent distributor, it's a big chunk of homework. It's always been important to make sure you know your supplier. But some of the nation's largest independent distributors say the situation has risen to new heights in light of government regulations placing the onus on contractors for bad parts finding their way into the defense supply chain.

Passage of the National Defense Authorization Act (NDAA) nearly two years ago set in motion a new set of requirements for contractors supplying products and equipment to military and other high-reliability markets, making 2013 a year of change for both the independent and

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PERSPECTIVE

U.S. Anti-Counterfeit Regulations Drive Global Change

America's top trading partners are stepping up efforts to combat counterfeits in light of tightening U.S. regulations.

BY STEVE MARTIN | COMPONENTS DIRECT

MUCH HAS BEEN WRITTEN about efforts by the U.S. federal government to regulate the electronics supply chain to prevent the infiltration of counterfeit components. This increased scrutiny and regulation is especially true in military and other mission-critical industries.

The 2013 National Defense Authorization Act (NDAA) holds Department of Defense (DoD) contractors liable for counterfeit parts, implicitly encouraging buyers to source parts only from original manufacturers or franchised/authorized distributors. This regulation, and recent amendments to it, enlarges accountability not only with the government contractor, but also all the way up the supply chain to the original manufacturer, making direct traceability vital.

This direct traceability and accountability is especially critical given the increasingly global nature of the electronic components supply chain. For example, the growth of components bought by the U.S. military from non-U.S.-based manufacturers and distributors accounted for more than $2 billion of sales to the DoD from 2007 to 2011, according to research firm IHS iSuppli *(see the table)*.

Not only will the NDAA have ramifications for the global supply chain, but governments in countries where major buyers are located or where counterfeit components are rampant are

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Smart Planning

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authorized distributors that supply those companies with electronic components. Both have dealt with a flood of inquiries seeking that they have quality assurance and counterfeit mitigation plans in place, and many on the independent side have had to step up their sourcing, testing, and inspection capabilities. As original equipment manufacturers (OEMs) and contract manufacturers face financial liabilities should counterfeits find their way into their products, the trickle-down effect has put a spotlight on distributors—especially those that specialize in obsolete and hard-to-find parts.

"Obviously, money talks," says Paul Elefonte, executive vice president of diminishing manufacturing sources (DMS) for New York-based independent distributor Crestwood Technology Group, which supplies obsolete and end-of-life components to defense, aerospace, medical, and telecommunications customers. "The government finally put the onus on the contractor [by saying] 'if you deliver us product with counterfeit material or suspect counterfeit material, we won't foot the bill to rework or replace it.' This spawned an acceleration of the processes that we already had in place."

Those processes include strict sourcing arrangements and testing and inspection programs that combat the moving target that is counterfeit electronics. As detection methods improve, counterfeiters look for new ways to outsmart them, creating a continuing need for heightened detection capabilities. Such capabilities are the fee for entry to this increasingly competitive marketplace, and Elefonte and others say it's changing the independent distribution landscape. They anticipate fewer players in the game and changing roles as suppliers find their niche in what can only become an even tougher environment.

"Not all independent distributors are created equal," says Elefonte, pointing to the post-NDAA climate as a game-changer in the independent field. "That they're all the same has never been less true."

A THINNING HERD

Perhaps the greatest change will be a smaller field of independent competitors in the future. As the stakes increase, only the best are likely to win the lion's share of business, many distributors reason, leaving companies to find new roles to play in the supply chain. Brian Ellison, president of large independent distributor America II Electronics, points to what he calls a "natural progression"

"It's really about testing and the quality processes that you have in place," says Brian Ellison, president of independent distributor America II Electronics. "But it's also about vendor qualification processes that are very stringent, and it's about having those direct relationships and how you mitigate [counterfeit] through that."

in the franchised market years ago in which consolidation led to a smaller pool of distributors.

"We see the same thing happening in the independent channel," says Ellison, pointing to tougher requirements in defense circles that are having a trickle-down effect into commercial markets, making it increasingly difficult for companies to compete. "It will take some time for [this] to take hold, but the bar is being raised without a doubt."

Elefonte agrees, pointing to economic and political factors as key reasons for an anticipated "thinning of the herd." A difficult post-2008 economic climate and dwindling domestic defense budgets make it tougher for everyone to compete for new business, and the Senate Armed Services Committee hearings of 2011 and resulting NDAA requirements have only complicated matters, he explains.

"Really what we've seen [is that] independent distributors are going to have to make a choice," Elefonte says. "[They will have to] make the investment that top independent distributors have made in equipment, testing, and inspection [programs], or they'll have to stick to simply being a parts mover and moving the parts up the chain to [others] who do the testing and so forth.

"That's what I'm seeing—a thinning of the herd, and that there will really only be two places in this sector: you get the material and sell it up the chain or you can be one of the final gatekeepers, those who will remain on the [approved vendor list] of the big contractors."

MEETING NEW REQUIREMENTS

The U.S. Senate's late 2011 Armed Services Committee hearings on the problem of counterfeit electronics marked a turning point in the anti-counterfeit fight. Not only did the hearings address the large and growing problem of counterfeit components entering the defense supply chain, they also helped raise public awareness of the issue and spurred action in the contractor community. Distributors say the hearings caused many contractors who had been slow to develop anti-counterfeit policies to finally begin doing so, which signaled a key change for many component suppliers.

"There were some very responsible large enterprises—contractors—who were on the forefront and had been working on standards since the 2006 timeframe. There were other contractors that were laggards, so [the hearings] really drove the latter to get their policies moving and in place," explains Elefonte, also noting that suppliers that were aligned with the forward-thinking contractors had a leg up in the post-NDAA environment.

"In 2011, we were prepared," says Elefonte, pointing to Crestwood Technology's long-held focus on anti-counterfeit procedures. "When you looked under the rock, we were ready to go with the equipment, staff, and processes we'd been working on for years. A lot of the independent market had to flip a switch and try to play catch-up. For us it was continual refining and continuing with the path that we were on."

That path includes three key capabilities that customers should look for in an independent distributor: on-staff engineers and technical employees with special training and industry certification in counterfeit mitigation procedures, the most up-to-date test and inspection equipment available to verify parts authenticity, and their own approved supplier list. Such capabilities reinforce what Elefonte refers to as a "good in, good out" policy.

"We really take the attitude here that what we're purchasing is valid material. We're not trying to catch bad stuff," he says, adding that testing and inspection programs should be designed to reinforce good sourcing practices. "It's a shift in thinking, really; a zero defect and zero counterfeit [philosophy]."

America II's Ellison agrees.

"It's really about testing and the quality processes that you have in place," he says. "But it's also about vendor qualification processes that are very stringent, and it's about having those direct relationships and how you mitigate [counterfeit] through that."

NEW ROLES TO PLAY

The prediction that independents will take on new roles going forward is already taking shape. In a slightly different twist, America II Electronics is a pointed example of a company that's charting a new course in a changing business environment. The distributor has adopted what it calls a "blended distribution model," in which America II represents a handful of franchised distribution lines in addition to its business filling the need for obsolete and hard-to-find parts.

To date, America II buys direct from more than 400 manufacturers and has 14 authorized lines. The philosophy is aimed at building business with existing customers while also reaching out to new ones that may be skeptical about sourcing components from the independent market.

"In the past, we've been the shortage buy for our customers. That endears us to some, but scares some out of our realm," Ellison explains. "We've grown to just over 400 manufacturers that we buy direct from and now we're also taking on franchised and authorized lines. [Doing both] ensures that we have that channel into the component manufacturer."

It also helps build the necessary confidence required in the distributor-customer relationship, Ellison says.

"We've got the customers we've done business with for many years, and their confidence level is high," he says, pointing to potential customers, particularly in some industrial segments, who hesitate to buy from independents due to stringent sourcing requirements. "When we can offer the franchised piece, that's a positive for them. And as their confidence builds over time, we're able to expand our business."

The blended model doesn't reduce the need for testing, inspection, and other quality control measures, however. Ellison emphasizes the independent distributor's need to maintain tight control of the supply chain from the start as a way to ensure confidence throughout the channel.

"For us it's about controlling the supply chain to begin with, and then we have our in-house testing, so that allows us to mitigate a lot of the counterfeiting processes," Ellison explains. "There's so much to it. We're a part of IDEA [Independent Distributors of Electronics Association], which is a collective of independent distributors from around the world, and one of the main things we talk about is that counterfeiters are the enemy and how we can protect customers and suppliers. This is a global problem, and globally it's taken seriously." ■

Anti-Counterfeit Regulations

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also considering new steps they must take to continue doing business with the U.S. and keep counterfeits from entering their own sensitive supply chains.

THE EU'S SOLUTION

The NDAA is already having a major impact on the European Union. According to IHS iSuppli, 283 EU-based manufacturers and distributors have contracts with the U.S. DoD. These contracts provided more than $1 billion in revenue in 2012, accounting for more than 50% of the department's total revenue. The EU economy has much to lose if more stringent U.S. regulations start to hamper this trade.

The EU's initial response has been to adopt stricter inspection guidelines via an initiative called ChipCheck. Funded by the EU's Framework Programme for Research and Technological Development, a seven-year, €50 billion program to drive European competitiveness in global technology jobs, ChipCheck is a consortium of EU-based companies and research institutes formed to develop a new inspection system to detect counterfeit electronic components.

ChipCheck has become more of an advocacy group, launching webinars and YouTube information videos, but as yet lacks the regulatory backing that would give the project more muscle in the fight against counterfeits. And even where the EU has made regulatory headway, it is seeing those efforts circumvented by counterfeiters.

For instance, the EU's Restrictions on Hazardous Substances (RoHS) pro-

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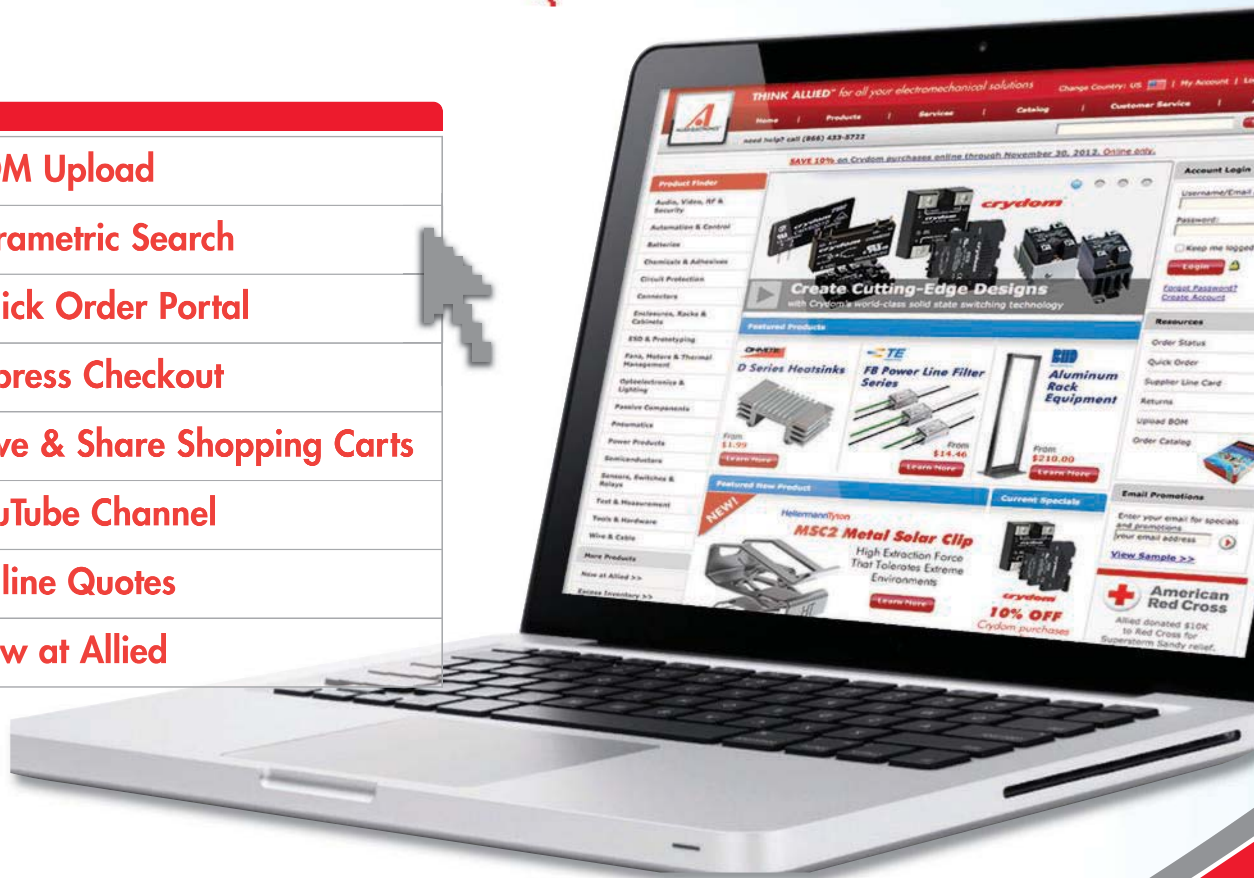

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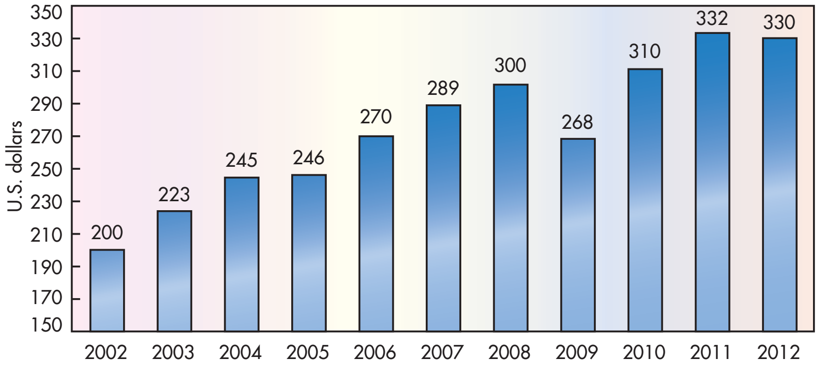
Connected Cars Drive Growth In Electronics

The automotive industry shines with opportunity for makers and sellers of electronic components as infotainment technology transforms the new-car market.



The global average of semiconductor content per motor vehicle sold has increased from $200 in 2002 to $330 in 2012. *(courtesy of IHS Inc., September 2013)*

THE TRANSFORMATIVE ROLE OF infotainment technology is opening new business doors for makers and distributors of automotive electronics, according to new research detailing today's demand for displays, apps, connectivity, and more in new cars and trucks.

Infotainment technology—which brings high-tech dashboard displays, Internet radio, and other connectivity solutions to automobiles—has "completely revolutionized cars and the automotive business as a whole," according to the Automotive Technology Portals and Services group from electronics industry researcher IHS Inc. The company points to the dramatically different look of new-car dashboards today compared to just 10 years ago, for example.

"In 2002, an owner of a new Ford Focus gazed down upon a proprietary dashboard that had no connectivity and that was adorned only with an AM/FM/CD music player," explains Ben Scott, technology solutions analyst for IHS Automotive. "In 2012, the proud owner of a new Focus beheld a dashboard rich with infotainment features, including multiple displays, a wealth of apps and services, and various means of connectivity. The major question that automakers need answered now is, 'What will the Focus dashboard of 2022 look like?'"

Other key changes to the automotive market in the last 10 years include rising demand for semiconductors and the consumer's demand for more bells and whistles. The average car in 2012 included roughly $330 worth of semiconductors, for example, up 65% from $200 in 2002 *(see the figure)*. Now, infotainment systems account for as much as 10% of the price of buying a new car. And in today's increasingly connected world, many cars now allow drivers to connect with the outside world via telematics, cellular technology, Wi-Fi, or Bluetooth.

Looking ahead, IHS says safety innovations, more connectivity, and the expanded availability of telematics are on the horizon. Collision warning systems are a key safety example. Not only are such systems becoming more widely available, IHS also points to their evolution from alert-only systems to include some form of autonomous emergency braking.

Looking at connectivity, car makers are spending more on R&D to enhance such systems as cars represent the third-fastest growing connected device behind smart phones and tablets, IHS says.

Telematics will likely experience fast growth as well because it is being driven by both consumers and original equipment makers (OEMs), says IHS. Consumers want more capabilities such as Internet radio and emergency/concierge services while OEMs see the potential to collect vehicle data via telematics.

"It's likely that in the developed regions, every car manufacturer will offer some type of connected service in its model lineup by 2015," IHS says.

Such changes are welcome throughout the electronics supply chain, as the global automotive infotainment market reached $34.6 billion in 2012, according to a separate report from IHS released in August. Panasonic remained the market's top supplier for the second straight year, posting automotive infotainment revenue of nearly $4 billion, 12% of global market revenue *(see the table)*. ■

TOP 10 AUTOMOTIVE INFOTAINMENT SUPPLIERS BY REVENUE IN U.S. DOLLARS

2012 rank	Company
1	Panasonic
2	Pioneer
3	Harman International
4	Continental
5	Alpine/Alps Electric
6	Denso
7	Fujitsu-Ten
8	Garmin
9	Kenwood
10	Bosch

Courtesy of IHS Inc., August 2013

Anti-Counterfeit Regulations
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hibits the use of many substances such as lead and cadmium in consumer electronics products. This has led some producers of components that include these substances to falsify markings and distribute these components through the gray market, prompting further response from the EU.

CANADA TAKES FIRST STEPS

Canada, the United States' largest trading partner and a leading provider of electronics, initially adopted a lukewarm stance to the counterfeit problem. When the U.S. Senate Committee expressed concern over counterfeits in military equipment, specifically the Lockheed Hercules transport plane, the Canadian military still purchased 17 of the planes.

"[At] this point in time, other than continuing to be vigilant, we don't have any particular concerns in this country," Julian Fantino, Canada's associate defense minister, told a Canadian Broadcasting Company reporter in June 2012. In the same CBC report, the head of an Ottawa laboratory that checks military and other electronic parts for counterfeits acknowledged that counterfeit military parts in Canada are a "billion-dollar problem," but said that Canadian industry was suffering from an "ostrich syndrome."

Fortunately, this attitude is changing. In March 2013, the Canadian Parliament proposed the "Combating Counterfeit Products Act." Endorsed by the Electro-Federation Canada industry group, the law calls for expanded powers to search, seize, and inspect electronic products crossing the Canadian border. As of August 2013, the law was still making its way through the Canadian Parliament.

PROMISING SIGNS FROM CHINA

China is a well-known market for electronic components, but the Chinese government has been less than transparent in its efforts to slow the counterfeit trade. As part of the NDAA debate in the Senate, China was singled out for obstructing U.S. lawmakers' efforts to investigate the sources for counterfeits supplied to the military, with the Chinese government going so far as to deny visas to Senate staffers hoping to travel to China to conduct their investigation.

Chinese laws are not strongly enforced, and additional pressure from the U.S. and other countries has not meaningfully affected the volume of counterfeits coming from that country. China is a prime example of the tension that exists in a nation when the informal economy, of which electronics counterfeiters are a part, represent such a large volume of revenue, and the government is reluctant to hinder that trade.

Fortunately in recent months, with subtle U.S. pressure, China has made some concessions. In July 2013, the country agreed to a joint operation with the United States to seize more than 243,000 counterfeit parts. China also is participating in high-level talks to reduce the quantity of counterfeits originating from within its borders.

These and other efforts have little chance of succeeding, however, if all countries involved in the highly globalized electronic components industry don't also create and enforce regulations aimed at halting counterfeits. There have been some movements towards global cooperation, such as the World Trade Organization and Interpol partnering with industry groups such as the International Electrotechnical Commission, to develop customs watch programs and increase border enforcement.

In the absence of binding global regulations, though, the onus is on individual countries, or possibly trading blocs such as in the EU, to ensure that effective legislation and regulations are properly implemented and followed. Only then can we achieve the global objective of reducing the number of counterfeit parts in the electronics supply chain and improving transparency across borders ■

REVENUE FROM SUPPLIERS TO THE U.S. GOVERNMENT, 2007-2011

Region	Number of companies affected	Revenue affected	% of overall revenue
European Union	283	$1,023,188,872	50.52%
Middle East	32	$951,248,650	46.97%
Asia-Pacific	38	$35,475,070	1.75%
South America	2	$9,693,771	0.48%
Caribbean	1	$3,211,084	0.16%
Central America	1	$2,190,856	0.11%
Africa	4	$148,074	0.01%
Eastern Bloc	1	$29,901	0.00%
Total	362	$2,025,186,278	100.00%

Courtesy of IHS iSuppli Research, April 2012

STEVE MARTIN is senior vice president of sales for Components Direct, an Avnet company.

He is responsible for all facets of the sales channel incorporated with both upstream supplier and downstream customer business at Components Direct. Most recently, he was in charge of running the western region for a leading independent distribution company, which provided fulfillment and supply-chain programs to EMS and OEM companies. He holds a bachelor's degree from Colorado State University.

ECIA Conference Features Leaders From Intel, PEI Genesis

THE ELECTRONIC COMPONENTS Industry Association will meet in Chicago later this month for its annual Executive Conference, where leaders from component manufacturing, distribution, and sales representative firms gather to network and get the latest industry news and analysis from experts inside and outside the electronics supply chain. Titled "Shift Happens," this year's meeting addresses the critical changes taking place in the electronics industry and how companies can turn those challenges into opportunities.

Industry experts speaking at the event include Steve Fisher of distributor PEI Genesis; Brad Whitworth of Cisco; Rick Dwyer of Intel; and Ed Smith, president of Avnet Electronics Marketing Americas.

Fisher will discuss "How to Grow a Niche Business without Losing Your Identity (or Your Soul)," for instance, and Dwyer's presentation will focus on "The Internet of Things." Other experts will address topics such as on-shoring, economic trends, market changes, venture capital, sales strategies, and global branding.

And in a nod to the increasingly important role of the Internet in today's electronics supply chain, the meeting will include a panel discussion featuring Web-savvy professionals from the media and the electronics industry who will discuss advances and solutions in digital marketing.

The 2013 Executive Conference will also feature an annual awards program designed to recognize members' achievements. The ECIA's highest honor, the Gail S. Carter Award, honors an industry leader for his or her significant contributions to the industry and active role in ECIA and civic affairs. A series of Distinguished Service Awards recognizes individual ECIA members for their contributions to the association.

The Electronics Choice Industry Awards (ECIAs) recognize excellence in marketing. Sponsored by ECIA and Penton's Design Engineering & Sourcing Group (which includes *Electronic Design*, *Global Purchasing*, and 13 other brands), the awards recognize members who have displayed exceptional branding and marketing campaigns in the last year. For more information on the conference, go to *www.eciaonline.org*. ■

2013 ECIA Executive Conference At-A-Glance

Sunday, October 27	
5 to 7 p.m.	Conference Registration
6 to 7 p.m.	Opening Reception
Monday, October 28	
7 a.m.	Conference Registration
7:30 to 8 a.m.	Continental Breakfast
8 to 8:15 a.m.	Welcome & Opening Remarks
8:15 to 9:15 a.m.	"From Shifting Markets to Future Success," Adam Hartung, Managing Partner, Spark Partners
9:15 to 10 a.m.	"Made in North America—Why It Makes Business Sense to Onshore," Alexander Fernandes, CEO, Avigilon
10 to 10:30 a.m.	Networking Break
10:30 to 11:15 a.m.	"Exploring the Trends Transforming Tomorrow," Jack Uldrich, Founder, the School of Unlearning
11:15 a.m. to noon	"Weapons of Mass Discussion To Boost Competitive Advantage," Frank Cutitta, Founder, the Center for Global Branding
Noon to 1 p.m.	Luncheon
1 to 1:45 p.m.	"Make Your Sales Team a Competitive Advantage in Shifting B2B World (Because Your Product, Price and Brand Will Not Be Enough)," Ryan Kubacki, President, Holden International
1:45 to 2:15 p.m.	ECIA Association Service Awards and Electronic Components Industry Awards
2:15 to 2:45 p.m.	Networking Break
2:45 to 3:30 p.m.	"The Internet of Things," Rick Dwyer, VP Sales & Marketing, GM Embedded Sales Group, Intel
3:30 to 4:15 p.m.	"Byte Me!" Brad Whitworth, Senior Communications Executive, Cisco
4:15 to 5:15 p.m.	"What Does the Internet Mean to You?" A Panel Discussion
5:15 p.m.	Closing Remarks & Announcements
6 to 7 p.m.	Evening Reception
Tuesday, October 29	
7:30 to 8 a.m.	Continental Breakfast
8 to 8:45 a.m.	"Beyond Venture Capital," Donna Kent, Tallwave
8:45 to 9:30 a.m.	"How to Grow a Niche Business Without Losing Your Identity (or Your Soul)," Steve Fisher, CEO, PEI Genesis
9:30 to 10 a.m.	Networking Break
10 to 10:45 a.m.	"Economic Outlook & Trends in 2014," Jack Ablin, Chief Investment Officer, BMO Private Bank
10:45 to 11:15 a.m.	"ECIA Update," CEO John Denslinger and special guest Tim Balz, FIRST team member
11:15 a.m. to noon	"Drivers Wanted," Ed Smith, President, Avnet Electronics Marketing Americas

All sessions take place at the InterContinental Chicago O'Hare. For more information visit www.eciaonline.org.

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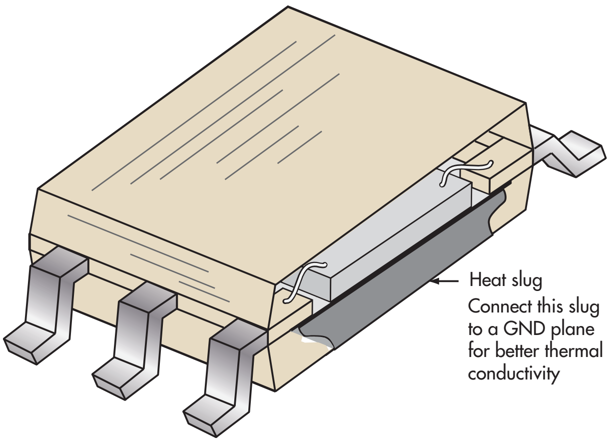
7 Critical Steps In Switching Power Supply Design

The design of switching power supplies requires significant attention to detail, from component placement and thermal analysis to careful testing for a wide range of operating conditions.

Switching power supplies are inevitable in today's designs. They're power-efficient and thermal-efficient, with various schemes available for every application. Switching regulators solve the power dissipation and efficiency problem by operating via pulse-width modulation (PWM).

There are multiple considerations when designing the switching power supply circuit, though, and price shouldn't be the only driver for the component selection. A complete understanding of all these elements will help you select the most cost-effective part for your design.



1. The heatpad underneath the 16PSOP package helps to release the heat to the PCB. (courtesy of Fairchild Semiconductor)

1. POWER OUTPUT

The voltage and nominal current required at the output of the switching dc-dc stage is the most obvious factor to consider in the design. Datasheets only tell part of the story. Don't take their stated output capabilities for granted! In fact, you might want to calculate the maximum output power you might need from the switching power circuit and make sure the device can provide it with some safety margin on top *(see "Choose The Right Switching Regulator," p. 76)*.

The same part number with different packaging will offer different thermal abilities, leading to different output capabilities. Different packages have different thermal resistance, and some packages are better at handling the thermal release than others. Space is important in the component package selection, but so is ease of manufacturing, overall airflow considerations, and board layout.

Compact design due to limited space or footprint requires a good evaluation that the thermal heat will be released correctly without affecting other equipment sections since this gradient my cause significant issues in ultra-low-noise circuits, high-performance systems, optical circuitry, and other applications.

Linear Technology's LT1170 comes in different packages, from the popular TO-220 to the DIP-8 and the 8-SOIC, 16-SOIC, and D2PAK-5 surface-mount versions. The SOIC-16 offers the poorest thermal performance with 150°C/W, while the D2PAK offers 25°C/W when 2.8 square inches of 1-oz copper is used in the layer. So, the power available from the LT1170 (as with any switching supply component) will depend on the package, but also configuration, components, layout, and heatsinking.

Get an evaluation board of your target switching regulator to evaluate its performance with your particular application. The switching frequency might be an issue, and testing this component with the rest of your system will tell you if you need additional filtering or heatsinks or if you need to use a different part.

2. INPUT CONDITIONS

Some systems are powered by a single power source with a definitive input voltage. But in other cases, that power input stage must withstand a wide range of opportunities, such as different battery voltages or a fluctuating power source. This gets more stringent in automotive applications, where the power supply components might have to tolerate cold cranking and load dump.

Some power sources such as batteries might degrade over time. Your switching power supply should be able to handle degradation to provide a stable output over a wide range of your system conditions. Therefore, it is important to understand your input range and operating conditions when designing your power supply.

For example, isolation is a good feature to have, but it isn't always necessary. If it was integrated in a previous stage, there might be an isolated ac-dc converter inside the same system, so the isolation was implemented in that circuit. Or, the system may be battery based and there is no need for isolation.

Isolated switching power supplies are more complex and expensive, but if they are necessary, then so be it. Note that ac line voltage without isolation might introduce safety and regulatory issues. Even in the case of dc-powered systems, ground loops will introduce profound headaches to the design team, and isolation is a good solution to resolve the unknown.

3. THERMAL AND HEATSINKING ISSUES

Usually the output power stated is based on the best heatsink provided to the component at the best temperature conditions. But the reality is that at the power required by the load in the target application, the temperature likely will be higher than the room. If your product goes inside some packaging, airflow will be limited. If your application happens to be deployed in the middle of a dessert, you need to make sure everything remains below the absolute maximums. Plan for adequate thermal strategies and possible heatsinking as necessary.

If an external heatsink is used, then it is better to evaluate the heat flow with your mechanical team. This also opens the discussion to find alternative heatsink ways, such as directly in the enclosure or another structural support. Some heatsinks require additional labor such as a thermal compound, insulator, or screw support, while some heatsinks are designed for automated mounting. A possible alternative is to use the same printed-circuit board (PCB) to release the heat.

Next, use the right footprint for your component. The Fairchild Semiconductor ML6554 buck regulator comes in a 16PSOP package that can be mistaken for a SOIC-16, but it does have a thermal pad underneath that has to be there for the component to release the heat to the PCB *(Fig. 1)*. This is how the component can handle the thermal requirements. If the thermal pad is not placed, the component will experience early shutdown due to thermal issues. Also notice that based on the ounces of copper on the layer (0.5, 1, 2, etc.), the heatsinking capability of the plane will differ, and wider area is required for thinner layers to achieve the same cooling effect.

Further consideration should be given to the component's operating temperature range. Electrolytic capacitors are limited in the low temperature range, and capacitance varies significantly in the extreme temperatures.

LM5116 RESULTS AT DIFFERENT TEMPERATURES

	-40°C	30°C	85°C
BOM footprint (mm^2)	473	549	1994
BOM cost ($)	$5.07	$5.91	$7.59
BOM count	23	25	24
Efficiency	88%	90%	92%

4. COMPONENT QUALITY

The quality of the components plays a significant role in the switching regulator performance. Other parameters have to be right in addition to the values. For example, inductors of the same inductance value might have different saturation. Inductor saturation is when the magnetic characteristic of the device is stressed in excess of its ability and the device doesn't behave as the inductor required.

Capacitors also vary their capacitance value as a function of temperature and frequency, so the correct type and quality are crucial for the correct operation. Similar capacitor values even from the same maker might have different features and prices. United Chemi-Con has a variety of electrolytic capacitors. Some are general purpose like the KMG series. Others such as the MZA series are low impedance. The MVH series offers higher ripple current. Other vendors offer a similar variety. Consequently, the capacitor value and type are not enough.

The source impedance is extremely important. Some inductance at the input of a switching regulator can help to decouple the current spikes from the switching power supply to the source. But in some cases, it can cause some ringing and spiking on the input voltage. Every dc-dc converter chip is designed to work with a specific combination of components with a range of acceptable values from a minimum to a maximum, so the datasheet must be scrutinized to validate any potential limitations. It is always good to perform all the calculations in spreadsheets and have a range (minimum and maximum) for all the component values.

On the other hand, a poor selection of components might jeopardize the product certification. Switching power supplies tend to be very noisy, to a point where electromagnetic interference (EMI) might be a concern. Using shielded inductors and high-quality capacitors might minimize the amount of noise present in the system. The capacitor's equivalent series resistance (ESR) plays a role in the circuit stability and performance. Some configurations might call for a specific ESR, so you don't always want low ESR. Pay particular attention to the input and output capacitance.

The input capacitors reduce the ripple voltage amplitude seen at the input of the converter to reduce the RMS ripple current to a level that bulk capacitors can handle. Ceramic capacitors have the extremely low ESR needed to reduce the ripple voltage amplitude. Therefore, it is important to place them close to the switching converter input. As the converter switches, it has to draw current pulses from the input source. An additional electrolytic or tantalum capacitor will help to provide enough energy to the load.

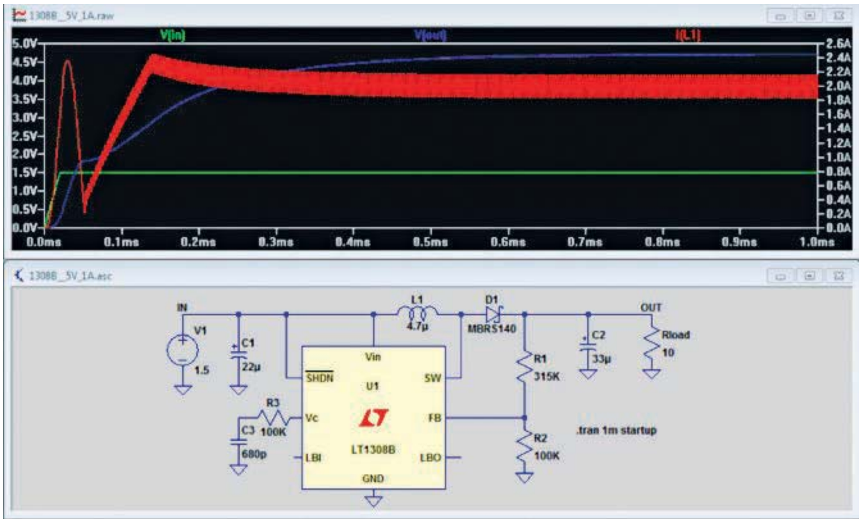
The output capacitor filters and minimizes any ripple at the output. This is a function of the capacitor's ESR, which also can affect the regulator loop stability. Good quality capacitors will have a specified ESR. General-purpose electrolytic capacitors only specify ESR at 120 Hz, but high-frequency capacitors will have the ESR guaranteed at a higher frequency like 20 kHz to 100 kHz. The ESR will increase at low operating temperatures, and the output ripple voltage will increase accordingly. The ESR of a typical aluminum electrolytic may increase as much as 40 times at –40°C, so evaluate the use of electrolytic in low-temperature applications thoroughly.

The ripple current that the output capacitor can handle also should be considered. This current increases the internal temperature inside the capacitor due to power losses, so neglecting to verify the capacitor's ripple current might have pyrotechnic consequences. Capacitors in parallel may be used to meet the ESR and RMS current handling requirements.

Some power supplies might require component certifications. Make sure you know what part needs to be tested and how it will be tested so your design is consistent with your targeted standard. If optocouplers are used for isolated converters, their design should consider light degradation over time, temperature limits, and common-mode potentials.

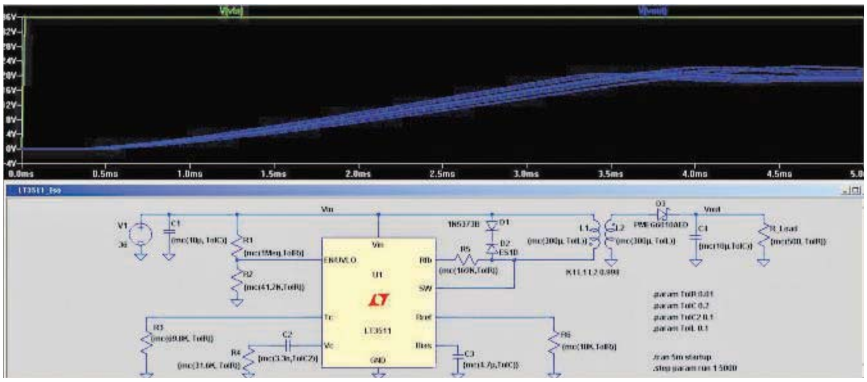
5. WORST-CASE SCENARIO

Running a simulation to verify that the design can handle the output current at the output voltage required in the time needed is always prudent *(Fig. 2)*. It is important to know how the component's variations perform over frequency, load, and temperature variations. Because of the dynamic nature of some switching regulators, their worst condition might not be in an extreme load, but rather somewhere in between. Testing your power supply for all the possible variations in your target circuit is important.



2. By simulating your switching circuit, the final voltage and loading conditions can be explored. Voltage and current waveforms can be reviewed to verify transients and ripples.

Prior to any implementation, simulate the correct operation over the entire operating temperature range. Simulations with Spice allow us to run Monte Carlo analysis or worst-case analysis to determine performance under different component tolerance variations *(Fig. 3)*. It can also be used to vary the load condition. Linear Technologies' LTSpice is a free version that works wonders. Texas Instruments (TI) offers TINA. And other vendors have a variety of tools to simplify simulation, selection, and component evaluation.



3. Worst-case simulations allow designers to explore which components might affect the design more significantly and identify other issues.

Designers can also use the Texas Instruments WEBENCH tool to select and size dc-dc components and configurations *(Fig. 4)*. Users can enter all the design requirements such as voltage input range, voltage out, and current out and temperature, and the software will select all

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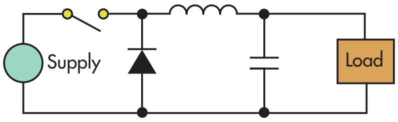
the components and show the circuit configuration. In most cases, it will offer a range of options such as footprint, number of components, and cost.

For each design, the software will show thermal analysis and efficiency plots. Users can run multiple temperature scenarios, which the WEBENCH software currently cannot run simultaneously. For example, for Vin_min = 8 V, Vin_max = 48 V, Vout= 5 V, and Iout = 7.5 A, the LM5116 shows different data at different operating temperatures *(see the table)*. So, don't take the first result for granted! Also, review all your circuit

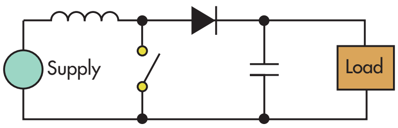
CHOOSE THE RIGHT SWITCHING REGULATOR

MANUFACTURERS SELL DIFFERENT types of switching regulators. The location of the storage elements in reference to the switching elements and their quantities generally determines the type of switching supply configuration, as can be seen in various architectures.

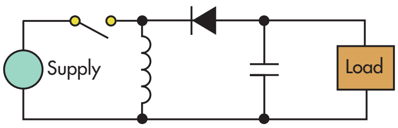
Also known as the step-down converter, the buck converter is the most commonly used switching converter *(Fig. 1)*. It's used to down-convert a dc voltage to a lower dc voltage of the same polarity. Although linear regulators can also perform this function, switching buck regulators can do it with higher efficiency. The boost converter, also known as the step-up converter, takes a dc input voltage and produces a dc output voltage that's higher in value than the input but of the same polarity *(Fig. 2)*. Linear regulators cannot provide this feature.



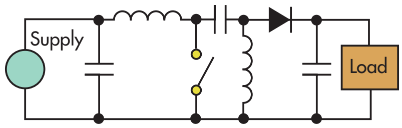
1. In the generic buck configuration, the switch controls the current flowing into the inductor. The inductor stores the energy for the load.



2. The generic boost configuration steps up the voltage since the inductor is placed prior to the switch.



3. The generic buck-boost configuration can output a voltage that is either greater or less than the input voltage magnitude, including negative voltages.



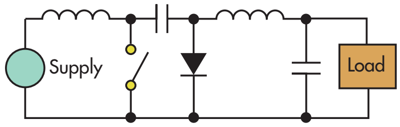
4. The generic SEPIC configuration also can provide voltages above or below the input. The duty cycle of the control switch controls this configuration.

The buck-boost or inverting regulator produces a dc voltage that's above, below, or opposite in polarity to the input *(Fig. 3)*. The negative output voltage can be larger or smaller than the input voltage. There usually is a limitation in the Vin – (–Vout) magnitude that the regulator can handle. Buck-boost can work with input voltages above and below the output.

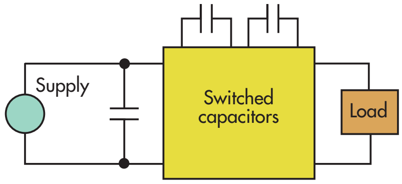
The single-ended primary-inductor converter (SEPIC) is similar to a traditional buck-boost converter *(Fig. 4)*. The voltage output can be greater than, less than, or equal to that at its input. The SEPIC also is capable of true shutdown. When the switch is turned off, its output drops to 0 V.

The CUK converter's output voltage can be greater than or less than the input voltage magnitude *(Fig. 5)*. It uses a capacitor as its main energy-storage component. By using inductors on the input and output, the CUK converter produces very little input and output current ripple. And, it has minimized electromagnetic interference (EMI) radiation.

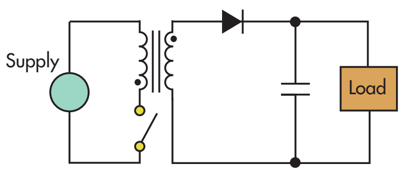
Also known as a charge pump, the switched capacitor regulator uses capacitors as energy storage elements to create a higher or lower voltage *(Fig. 6)*. It can generate arbitrary voltages, depending on the controller and circuit topology. Charge pumps can double, triple, halve, invert, or fractionally multiply or scale voltages such as x3/2, x4/3, and x2/3. Furthermore, the regulator can provide multiple outputs.



5. The generic CUK configuration can output a voltage that is either greater or less than the input voltage magnitude.



6. The generic switched capacitor converter uses capacitors as storage elements to generate other voltages.



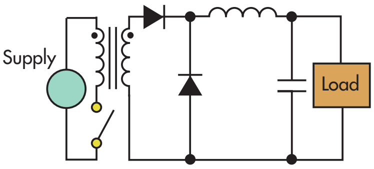
7. The generic flyback configuration is similar to a buck-boost converter with the inductor replaced by a transformer. The energy is temporarily stored in a magnetic field in the inductor air gap before it is transferred to the secondary side.

conditions from minimum temperature to high temperature. Before settling on a configuration, make sure it is the most adequate for the target application and environment. WEBENCH will always start with an easy temperature of 30°C as well. And, WEBENCH doesn't cover all the TI switching regulators, so review the component selection on the TI Web site and validate them individually.

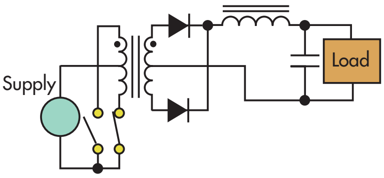
The flyback converter is the most versatile of all the topologies *(Fig. 7)*. It allows for one or more output voltages, some of which may be opposite in polarity. Additionally, it is very popular in battery-powered systems. It provides isolation as well.

The forward converter is a buck regulator that has a transformer inserted between the buck switch and the load *(Fig. 8)*. It provides both higher and lower voltage outputs as well as isolation. Additionally, it might be more energy efficient than a flyback converter.

The push-pull converter is a forward converter that has two primaries *(Fig. 9)*. It can generate multiple output voltages. Some of the voltages may be negative in polarity. It provides isolation as well. However, it requires very good matching of the switch transistors to prevent unequal ON times.



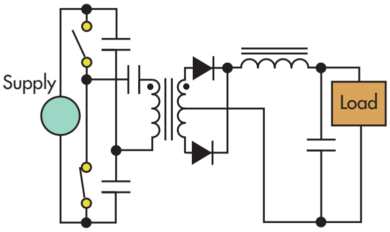
8. In the generic forward configuration, the energy is transferred directly between the primary and secondary sides.



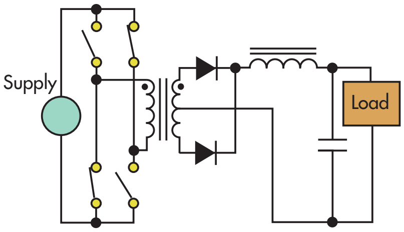
9. The pairs of switches (transistors) in a generic symmetrical push-pull circuit help to maintain a steadier input current and create less noise on the input line.

The half-bridge converter is usually operated directly from the ac line *(Fig. 10)*. The switch transistor drive circuitry must be isolated from the transistors, requiring the use of base drive transformers.

The full-bridge converter provides isolation from the ac line *(Fig. 11)*. The pulse-width modulation (PWM) control circuitry is referenced to the output ground, requiring a dedicated voltage rail to run the control circuits. The base drive voltages for the switch transistors have to be transformer-coupled because of the required isolation.



10. The primary-side capacitors in a generic half-bridge configuration are used to produce a constant half voltage at their junction, reducing the stress on the switches to only the input voltage.



11. Only the diagonal switches in the generic full-bridge configuration are switched ON simultaneously. This arrangement provides full input voltage across the primary winding of the transformer. The transformer's polarity reverses in each half cycle.

ANALOG DESIGNERS LEARN TO LOVE "PROGRAMMABLE"

THE STARTLING GROWTH sweeping through the power-management industry can be traced to concerns surrounding energy costs and the environment. Depending on how you define power management, Exar Corp. estimates that it's a market of some $15 billion for silicon devices. The specific part of the market served by Exar currently comes in at about $1 billion, including analog and mixed-signal devices—some of which have a large digital element.

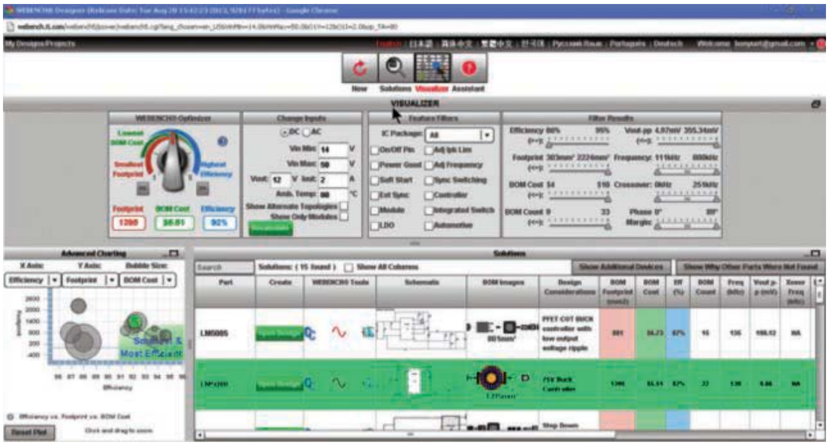
One of the most important recent developments has been the rise of programmable power controllers, which use digital technology. Naturally, analog designers were somewhat reluctant to embrace digital devices. However, the arguments in favor of digital power management have become so compelling that they're hard to ignore.

Consider designs that use FPGAs, DSPs, applications processors, media processors, or microcontrollers. These designs usually need several voltage rails: 5 V for analog, 3.3 V for digital, 1.5 to 2.5 V for memory, and one for the processor core or cores. Lots of components and board space is required to deliver these separate voltages via analog regulators. It ultimately adds complexity and is very restrictive during system design.

A programmable, digital power-management controller cuts both component count and manufacturing costs. For example, an Exar XRP77xx programmable switching controller can form the basis of a four-rail, flexible power-control circuit using just 33 components. The input voltage can range from 4.75 to 25 V with user-configurable outputs from 0.6 V to 5.5 V. Similar functionality delivered from an analog circuit would need more than four times as many components and therefore render the circuit less reliable. On top of that, it still would deliver inferior performance and features. However, functional integration is only part of the story.

For example, when using analog regulators, if any aspect of the power circuit needs to be changed, it will require a board redesign, more component inventory,

Many other vendors offer excellent lines of switching regulators, ultra-high efficiency, very low leakage, wider input range, low noise, multiple outputs, and even a combined linear regulation with the switching regulation. It is then pru-



4. Use the Texas Instruments WEBENCH tool to select and size some of your TI switching regulators.

POWER MANAGEMENT

and time to implement these changes. It's possible to eliminate these issues, though, with a programmable power-management controller (e.g., a software design tool with a simple GUI). That means quick adjustment of voltage rails, setting up precision power sequencing, implementing voltage and current monitoring, and programming conditional fault handling.

During system development, it's very easy to adapt the power system to accommodate changes. As a result, programmable power management can be a catalyst in significantly reducing time-to-market for new products. But it goes further than that.

There are cases where it's desirable to make small changes to equipment in the field to improve performance. Programmable power control facilitates this field serviceability. A simple firmware upgrade, delivered via an integrated I^2C interface on the power controller, can be used to increase a supply rail from 1.2 to 1.3 V, for example, to boost the performance of the part of the system it feeds. Many designers have learned that the nominal voltage-supply figure shown in a semiconductor data sheet is not always indicative of its highest-possible performance for a given application.

In addition to these advantages, programmable power controllers offer the opportunity to minimize system energy consumption under all load conditions. This is important because many systems often operate well below full load.

For example, a data center only approaches full-load operation during periods of maximum data throughput—perhaps just 10% of the time. Energy consumption must be minimized for the other 90%. Distributed power architectures using point-of-load converters and programmable controllers deliver that capability.

JAMES LOUGHEED, vice president for power management products at Exar Corp., holds an MBA and an electrical engineering degree from the University of Southern Queensland, Australia.

dent for designers to review all of the potential candidates for suitability, cost, and performance.

As with any component, switching power components have a derating factor over their temperature range. Use the worse condition to estimate the power output your device requires. Characterizing the power components in the frequency range can provide some answers about the EMI performance.

Run your simulations with the worst-case scenarios and then validate the components' tolerances to make sure that they will perform well in the temperature and tolerance range with a range of load variations. Simulation with different components might provide a broad range of alternatives, offer a better perspective for cost decisions, and open the opportunity to verify the component sizing.

6. PCB AREA, LAYOUT, AND FOOTPRINT

Some components can be heatsinks to the PCB. The area used for these components plays a role in the heat released. Also, consider the thickness of the copper layer and if there should be any additional thermal vias. Consider the vias' distribution as well. Make sure your manufacturing house can handle thermal vias in its production line if you are using them. Some libraries don't include the right footprint to handle more power, and they might require additional copper definitions in the PCB layout.

Use short and wide PCB tracks to decrease voltage drops and minimize inductance. The high-frequency switching makes good component layout imperative. Place the switching elements first and close to the energy-storing element. Minimize the input and output loops to reduce radiation and high-frequency resonance problems.

This strategy will minimize the current loops on the PCB that are the main culprit in electromagnetic radiation. Furthermore, take a look at the evaluation board and reference design to place the components. A solid ground plane and ground pour will help you spread the heat. It additionally will enhance power transfer.

7. PERFORMANCE TESTING

Following the design guidelines and formulas for component selection somewhat validates the design. The circuit simulation might answer a few other questions in terms of operations in borderline conditions. However, the important aspect is the implementation for final performance testing. The final power and EMI verification is possible only on a real board with your targeted application.

The Federal Communications Commission mandates testing in the United States. Since all switching power supplies emit some level of EMI, they are potential culprits for failure. Careful component placement, layout, product integration, and packaging might mitigate overall emissions, but that needs to be validated in the final product.

Some new switching regulators allow the switching frequency to be changed, which should be explored in the case of EMI violations. Some dc-dc regulators offer dithering, which constantly varies the switching frequency on the fly. Therefore, the energy is spread out over a wider range and the resulting magnitude of the emitted energy at each individual frequency is lower.

Some cases might require an additional snubber on the switching element to mitigate the noise at the expense of some additional power. Finally, the full temperature range testing and field operation should be performed to confirm the adequate performance of the switching power supply and the rest of the electronics associated with the product. ed

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David Bonyuet has been an electronic gadgeteer and hacker for more than 20 years. He has a PhD in communication engineering from the Technical University of California. For more, go to *http://electronicdesign.com/author/david-bonyuet*.

DESIGN NOTES

Active Bridge Rectifiers Reduce Heat Dissipation within PoE Security Cameras – Design Note 519

Ryan Huff

Introduction

Power over Ethernet (PoE) has been embraced by the video surveillance industry as a solution to an age-old problem: complicated cabling. For instance, a basic, traditional fixed-view security camera requires two cables: one for power (10W to 15W from a 24V AC or 12V DC), and a separate, coax cable for the video signal. With PoE, a single Ethernet cable carries both video data and power. Everything is simplified. Right?

Not quite. To meet compatibility with existing systems, camera manufacturers must produce PoE-enabled cameras that are also compatible with legacy power sources—they must accept PoE 37V to 57V DC from an RJ-45 jack or 24V AC, +12V DC, or –12V DC from an auxiliary power connector.

The Old Way Loses Power

Figure 1 shows the power architecture used by many PoE camera manufacturers to solve this problem. A full-bridge diode rectifier after the auxiliary (old-school) input produces positive DC power from either 24V AC, +12V DC or –12V DC. The resulting DC power and the PoE inputs are diode-ORed with the winning supply fed to a wide input voltage isolated switching power supply, which in turn powers the camera electronics.

This power architecture presents a few challenges. When the camera is powered from the auxiliary input, three diodes (circled in Figure 1) fall into the power path. In addition to the inefficiency of this design and possible heat problems from the power dissipated by the diodes, the three diodes lead to a significant voltage drop at the input to the switching power supply. With a 10W to 15W camera, these challenges are easily surmountable, but the latest security cameras have doubled this power consumption. Features like pan/tilt/zoom (PTZ) and camera lens heaters for outdoor operation have made this power architecture unsuitable for this new wave of cameras.

To illustrate the architecture's deficiencies, consider a 26W camera. For a 12V DC auxiliary input (assumed to

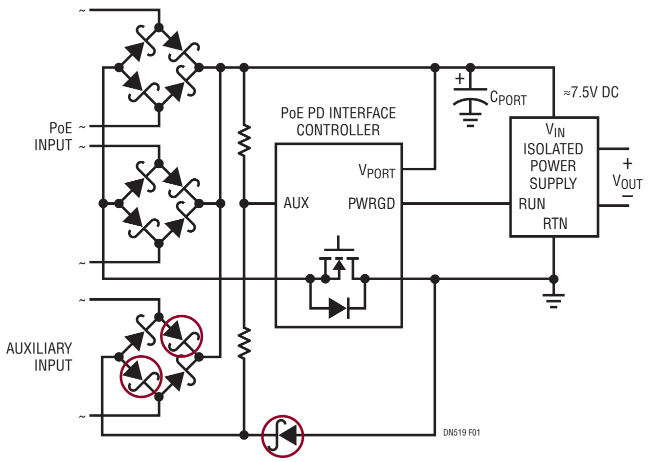

Figure 1. Auxiliary Input and PoE Power Architecture

actually be 9V DC due to use of unregulated wall warts/AC adapters) and three 0.5V drop Schottky diodes, the input voltage of the switching power supply is 7.5V (9V – 3 • 0.5V). The input current for this camera is approximately 3.5A (26W/7.5V). The resultant power dissipation of the three Schottky diodes in the power path is 5.2W (3.5A • 3 • 0.5V). This power dissipation leads to higher temperature within the camera, which is difficult, time consuming and expensive to mitigate.

Improve Performance with Ideal Diodes

Figure 2 shows a way to counter this shortcoming. Here, the two diodes of the full-bridge rectifier are replaced by ideal diodes, circled (black) in Figure 2. Ideal diodes are simply MOSFETs controlled to behave like regular diodes. The advantage of an ideal diode is that one can use MOSFETs with low channel resistance ($R_{DS(ON)}$), thus reducing the forward voltage drop (I_{DS} • $R_{DS(ON)}$) to much less than a Schottky diode drop. The LT®4320 ideal diode bridge controller enables the control of four MOSFETs in a full-bridge configuration. The third diode drop due to the diode-OR in Figure 1 is eliminated by the LT4275 LTPoE++™/PoE+/PoE PD controller. Its topology allows the use of a few small-signal diodes, circled together (red) in Figure 2, for auxiliary input sensing. These diodes are not in the power path as in the traditional architecture, so they do not contribute any additional voltage drop or heat issues.

Results

The power architecture shown in Figure 2 significantly reduces overall power losses when compared to that of Figure 1. To quantify, the LT4320 combined with low channel resistance MOSFETs results in a 20mV drop across each ideal diode bridge MOSFET. This produces an input at the isolated supply of 8.96V (9V – 2 • 20mV). The higher input voltage drops the required input current to only 2.9A (26W/8.96V) versus the original 3.5A.

The resulting power dissipation of the improved architecture is now a scant 116mW (2.9A • 2 • 20mV), versus 5.2W for the original architecture—a 45× reduction! Additionally, the lower input current further reduces power dissipation in the isolated power supply's power components (i.e., input filter inductor, power transformer and switching MOSFETs) due to the reduction of their I^2R power losses. A simple calculation puts this reduction at 31% (100% – $2.9A^2/3.5A^2$).

Conclusion

Adding the LT4320 and LT4275 to the auxiliary and PoE inputs of a PoE-enabled security camera recovers more than 5W (5.2W – 116mW) of power dissipation over traditional full-bridge/diode-OR designs. This reduction of power eases the thermal design time and complexity of PoE security cameras.

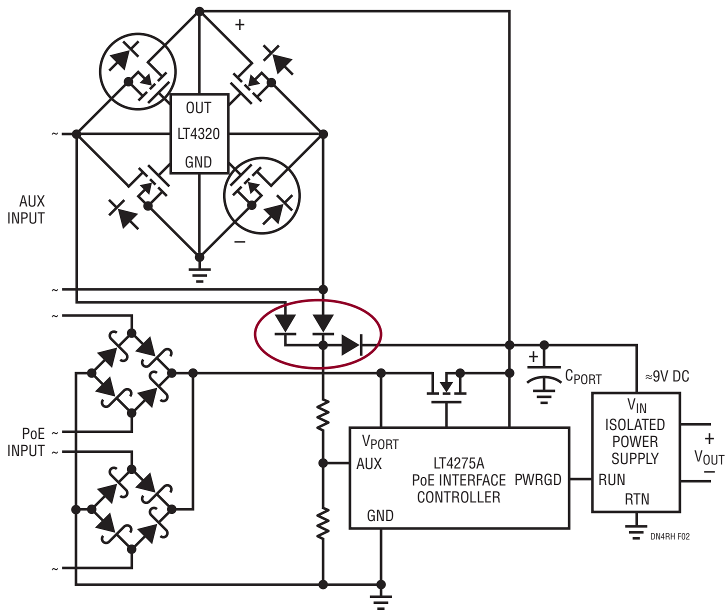

Figure 2. Improved Power Architecture with No Diode Drops in Power Path

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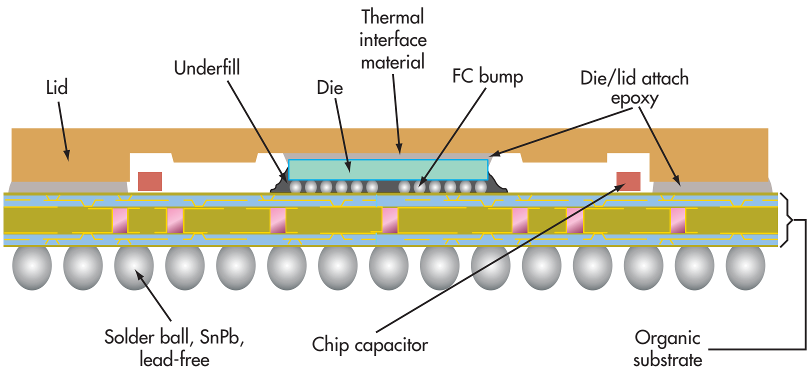
Repeating Failed History Fails Designs

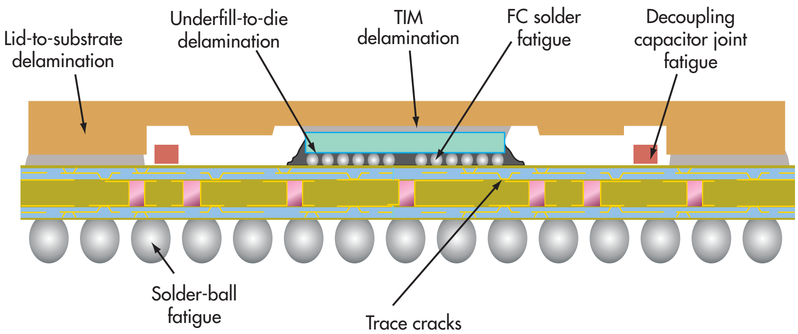
Knowing what failures are common and how to avoid them can go a long way toward eliminating problems in new designs, reducing the need for respins, improving time-to-market and reducing field return rates.

We've all heard that those who forget history are doomed to repeat it, and our schools work hard to teach students how to avoid those painful, misery-inducing historical mistakes. Similarly, if designers don't learn from past mistakes, those errors can return to haunt new products, resulting in degraded lifetimes, improper operation, and outright failures.

Design engineers must know as much as possible about such failure mechanisms and ways to avoid them. A few painful history lessons and horror stories are recounted below, along with the escape routes and tricks to avoid these deadly design snares.



1. The major attributes of an FC-BGA package include the die soldered to a substrate with solder bumps, an underfill material that reduces stresses on the bumps, a lid attached to the die and substrate through a thermal interface material, and solder balls attached to the package that form the electrical interconnect to the PCB.



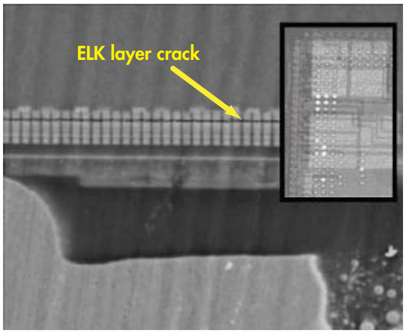
2. Failure mechanisms of the FC-BGA packages include oxide cracks under the die bumps, delamination between the underfill and die or substrate that results in solder fatigue and potential opens, delamination or cracking of the TIM that leads to overheating, cracking of traces on high-stress regions of the substrate, and solder-ball fatigue after the package has been soldered to the PCB.

FLIP-CHIP BGA FAILURE MECHANISMS

Flip-chip ball-grid array (FC-BGA) packages are very popular for high-performance ICs *(Fig. 1)*. They can provide great thermal dissipation through metal lids that conduct and spread heat into heatsinks attached to the package surface. They also can provide clean power and ground distribution and excellent signal propagation through appropriately applied power and ground planes and signal layers in the design. However, this package structure is prone to certain failure mechanisms if care is not taken *(Fig. 2)*.

The solder bumps that attach the chip to the substrate are usually made out of tin-lead (SnPb) or lead-free solder. These materials are soft and prone to creep, plastic deformation, and fatigue. If you've ever played with a solder or tin wire, you've probably noticed that you can indent the wire's surface with your fingernail. Yet this is the material that holds the chip with a coefficient of thermal expansion (CTE) of ~3 ppm/°C to a substrate with effective CTEs ranging from 12 to 17 ppm/°C.

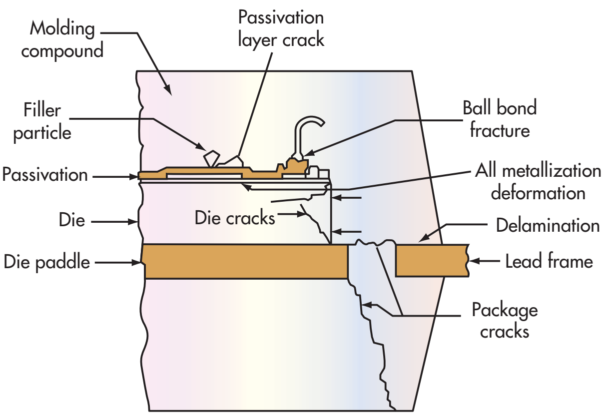
Exacerbating the situation, fragile, easily cracked oxides usually exist on chip surfaces, under the solder bumps.



3. Dielectric damage under bumps often shows up as white dots on SAM images, leading to the coined phase, "white bumps," to describe this failure mechanism.

Figure 3 shows a scanning acoustic microscope (SAM) image of a chip's surface that's been flipped onto a substrate. Inter-level dielectric (ILD) damage occurred at time zero when the chip and substrate cooled from reflow temperature to room temperature. These cracks show up as bright acoustic reflections in SAM images, hence the term "white bumps."[1, 2] Ways to avoid the problem include increasing the adhesive and cohesive strength of the stack, laying out the metal under the bumps to act like mechanical "rebar" to hold the die surface together, and even adding underfill to cure in place before the part fully cools from reflow to room temperature.

Thermal stresses can create delamination between the underfill-to-die and underfill-to-substrate interfaces. If this happens, the underfill loses its protective value and rapid fatigue failure of the solder bumps can occur. Materials with excellent adhesion strength minimize this risk, but interfacial contamination must also be controlled or eliminated throughout processing to avoid havoc along the adhered surfaces.



4. Common failure mechanisms in plastic packages include passivation damage on the die due to thermomechanical mismatch stresses and filler particles, oxide cracks under ball bonds, delamination that leads to lifted ball and stitch bonds, and mold compound cracks that propagate to the exterior of the package.

The thermal interface material (TIM) holding the lid to the die can lose adhesion during handling or thermal stresses. Again, a good understanding of the material adhesion and clean surfaces are required to minimize this failure. Choice of lid material, tuning the CTE to more closely match that of the package or substrate, can also be helpful to reduce stress. Fatigue in the bumps joining the chip to the substrate can risk opens during the product's lifetime. Appropriate choice of underfill material properties to reduce stresses through all thermal profiles is required to minimize this hazard.

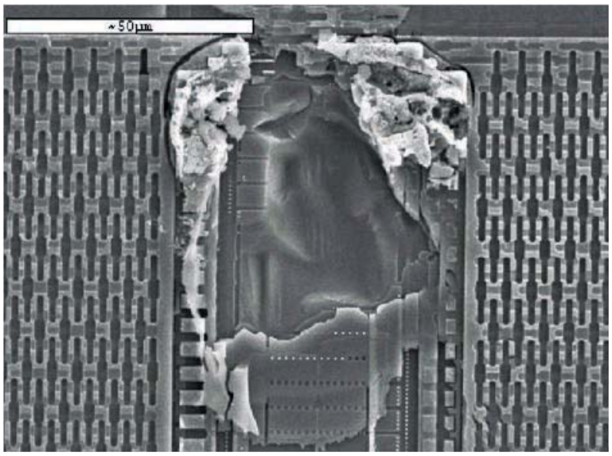
Solder fatigue in the balls that join the package to the printed-circuit board (PCB) is probably the biggest reliability concern. Choosing the appropriate low-fatigue solder alloys and appropriate die pad versus PCB land size reduces stresses that cause the damage, extending the initiation of failure far beyond expected product lifetimes.

Copper traces can become fatigued and cracked in high-stress regions such as under the die "shadow" or under the package ball locations. Wide PCB trace design in high-stress regions, trace shielding, "tear drop" trace connections to lands, and appropriate material choices for the underfill and substrate dielectrics reduce stresses on traces and can eliminate trace fatigue failures.

PLASTIC MOLDED PACKAGE FAILURE MECHANISMS

Figure 4 illustrates plastic molded package failure mechanisms. This image is as current today as when it was first drafted 25 years ago. Each new package generation, each change in process, and each change in material has to be re-optimized to eliminate these failures.

Gold or copper wire bonds are formed on pad surfaces by a machine that hammers a metallic ball onto the receiving die's bond pads. Ultrasonic energy is applied to the ball, scrubbing it on the surface and forming an intermetallic that melds it to



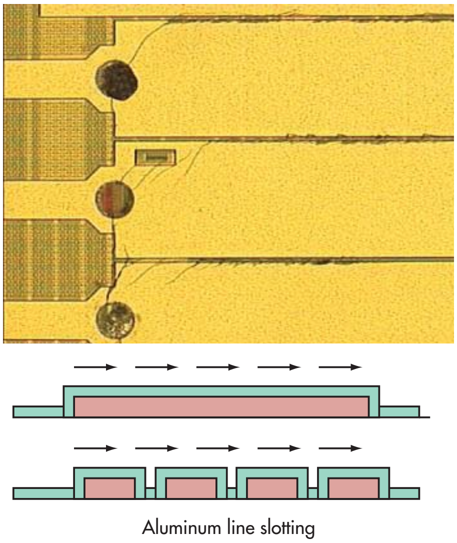
5. Over-bonded pads can result in dielectric cracking under the ball bond. This damage has been revealed by etching away the pad metallization.

the pad. Each bonding machine can create many balls per second.

The process is aggressive. With the ball metal being flattened, the aluminum interconnects under the ball are potentially extruded and the dielectrics under the ball can become cracked *(Fig. 5)*. Dielectric cracking, or cratering, is avoided by adjusting the ball bonding force, the ultrasonic energy, the thickness and composition of the underlying dielectrics, the thickness of the on-die metallization, and the wire composition and diameter. Design rules to construct stress-bearing structures with metal under the pads are also helpful to minimize dielectric cracking.

Packages can crack during reflow, so tests are run to determine package crack and delamination resistance during soldering conditions. Available environmental moisture permeates plastics during storage. In reflow, the absorbed moisture attempts to diffuse out of the device. Hydrostatic pressure can result, as well as weakened adhesive interfaces. If the combined hydrostatic and thermomechanical stresses overcome interfacial adhesions and material fracture toughness, delamination and bulk plastic cracks can occur.

Delamination gaps that intersect wire bonds are especially risky as they can lift ball bonds, leading to continuity fails. Additionally, delamination that breaks the bond between the die and pad can result in thermal degradation on devices requiring thermal conduction paths from the die through the pad and into the PCB. Designers can select mold compounds that enhance adhesion, can limit the die and pad size within a package to a combination that doesn't delaminate, or can provide locking features in the



6. Shear stresses in the package can cause this typical passivation crack signature over wide aluminum lines on the chip surface. Slotting the wide metal as diagrammed in the inset allows the passivation to contact rigid oxide under the easily deformed aluminum, reducing or eliminating the aluminum extrusion and corresponding passivation cracks.

lead-frame structures to minimize delamination. Changing the thicknesses of the layers can also reduce stresses.

Dry packing after assembly in moisture-impermeable dry bags also can stave off reflow damage. JEDEC J-STD-020c lists methods to measure and categorize each package's moisture sensitivity. Highly sensitive packages can't withstand much moisture exposure before reflow and must be used within a few hours after withdrawal from dry bags or must be baked prior to reflow to ensure no damage occurs during manufacturing. Less sensitive devices have longer floor lives before baking is needed. The least sensitive don't require baking or dry bagging.

Passivation layer cracks occur during temperature cycles when the mold compound contacting the die surface exerts enough stress to cause aluminum fatigue and extrusion. Figure 6 shows typical passivation cracks over wide aluminum. The cracks originate at the edge of aluminum lines and propagate across the metal surfaces. Sometimes, the edge cracks extend downwards into the underlying oxides, resulting in leakage, contamination ingress paths, and broken interconnect or polysilicon lines.

These stress-induced cracks occur preferentially over wide metal lines rather than narrow lines, so design methods to slot the metal lines have been developed to make wide lines behave like narrow lines. In effect, the chip layout designer engineers a mechanically robust super-structure on the die surface, enabling it to withstand the package stress.

Filler particles can induce a different type of passivation damage. They are used to tune multiple mold compound properties such as the expansion coefficient, the modulus, the thermal conductivity, and the melt viscosity. But if they are too large and have sharp points, they can be pulled against the die passivation during cure and thermal cycles, causing punctures that can drive leakage and inter-layer shorts.

Filler particle damage can be minimized most easily by reducing the diameter of the particles and by moving from irregularly shaped particles to rounded particles. Thickening the passivation can make it more robust, armor plating the die against this type of damage. ed

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1. Po-Jen Cheng, et al., "A Challenge of 45 nm Extreme Low-k Chip Using Cu Pillar Bumps as 1st Interconnection," Electronic Components and Technology Conference, May 2010, pp. 1618-1622.
2. H.Y. Lin, et al., "Nature of Package-Induced Deformation and the Risk of Fracture in Low-k Dielectric Stacks," ASME InterPACK Conference, July 6-8, 2011, pp. 351-356.

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SUKE JAWANDA AND SVEIN-EGIL NIELSEN | Bluetooth SIG, Bluetooth SIG Board and Nordic Semiconductor

Design With Bluetooth
For The Sports & Fitness Market

Bluetooth Smart is the go-to wireless solution for sports & fitness device manufacturers, offering many benefits and branding advantages.

There is an explosion underway of wearable sports and fitness sensor devices. You see them everywhere. Runners with Polar heart-rate sensors keep track of a target heart rate. Cyclists with sensors on their bike wheels measure speed and cadence. Even the executive down the hall wears his FitBit on his pocket to ensure his motion is monitored in real time. This proliferation is part of the Internet of Things (IoT), and Bluetooth technology is making it happen.

The globally recognized wireless standard makes it possible for everyday things to go wireless and connect to each other, to applications on Bluetooth Smart Ready hub devices like smart phones, laptops, and tablets, and, ultimately, to the cloud. According to ABI Research, the sports and fitness arena represents the bulk of this market—and Bluetooth is expected to lead it due to its ubiquity, performance, and low cost.

1. Smart phones can serve as hubs for collecting data from Bluetooth Smart sensors and other devices. The hubs can then process the data in an app or pass the data on to a PC or other device.

Bluetooth Smart sensors equipped with the low-energy feature of Bluetooth plus the ubiquity of Bluetooth Smart Ready hub devices, a rich base of suppliers, and low-cost chips combine to create a powerful trifecta for designing your sports or fitness device with Bluetooth.

According to IMS Research, more than 60 million sports, fitness, and health monitoring devices equipped with Bluetooth will ship between 2010 and 2015. Industry leaders like Adidas, HIOD Sports, Nike, Polar, and Wahoo Fitness are utilizing Bluetooth to connect everything for their sports and fitness monitoring solutions.

"Bluetooth technology is changing the way manufacturers look at connectivity and the potential of their products," said Mark Powell, executive director, Bluetooth SIG. "Increasingly, Bluetooth is being used to allow billions of diverse products from countless manufacturers to speak the same language. This results in unmatched convenience for the consumer, flexibility for the product manufacturers, and access for application developers."

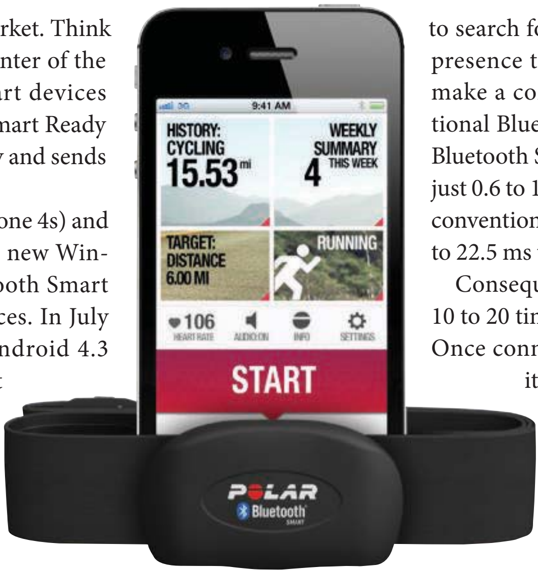
BLUETOOTH SMART AND SMART READY

The latest Bluetooth specification's ultra-low-power consumption presents a massive opportunity for companies to bring everyday products such as heart-rate monitors, toothbrushes, and running shoes into the connected world. Known as Bluetooth Smart, these devices are usually sensors sending information to an application running on a "hub" device like a smart phone, tablet, or PC.

These hubs, which receive information from power-efficient Bluetooth Smart products, are called Bluetooth Smart Ready. The unique capability of Smart Ready devices—the dual-mode Bluetooth radio (basic rate/enhanced data rate + low energy radio)—allows communication with traditional Bluetooth devices like headsets and wireless speakers, plus the newest generation of Bluetooth Smart devices.

Smart Ready devices also can be updated with new Bluetooth profiles after shipping from the factory. This allows them to connect to new Bluetooth Smart products and their associated apps as they come to market. Think of Smart Ready products as the center of the connected world. Bluetooth Smart devices securely feed data to apps on the Smart Ready hub, which in turn acts as a gateway and sends data to the cloud.

All new Apple iOS (since the iPhone 4s) and OS X (since Q4 2011) devices and new Windows 8 tablets and PCs are Bluetooth Smart Ready. So are BlackBerry 10 devices. In July 2013, Google announced that Android 4.3 natively supports Bluetooth Smart Ready as well. Traditional Bluetooth and new Bluetooth Smart devices now can connect to hundreds of millions of phones, tablets, and PCs without special dongles or extra hardware.



2. The Polar H7 heart-rate monitor straps to your upper arm and sends pulse data to a smart device like an iPhone or an iPod where an app processes the data and packages it for presentation.

WHY BLUETOOTH SMART?

It's important to understand that the power consumption of a dual-mode chip in a Bluetooth Smart Ready device when operating in basic rate/enhanced data rate (BR/EDR) mode is no different from previous versions of the technology. The device's low-energy capability saves some power, but the chips aren't ultra-low-power devices. The chip's functionality, size, cost, and compliance are close to the previous version.

In contrast, Bluetooth Smart devices are ultra-power-efficient. They employ a configurable connection interval that can be set from a few milliseconds to several seconds depending on the application. In addition, because it features a very rapid connection, Bluetooth Smart normally can be in a "not connected" state (saving power) where the two ends of a link are aware of each other, but only link up when absolutely necessary and then for as short a time as possible.

Bluetooth Smart chips operate for long periods (months or even years) from a coin cell battery such as a 3-V, 220-mAh CR2032. These devices support very low-duty-cycle operation. If you're looking for an interoperable 2.4-GHz radio technology for fully asynchronous transmission from a device sending low volumes of data (i.e., a few bytes) infrequently (for example, a few times per second to once every minute or more seldom), then Bluetooth Smart is the best choice.

Compact wireless sensors such as heart-rate monitors, cycle speed, and distance pods—in other words, many of the devices in the sports and fitness monitoring and tracking arena—are typical examples.

Bluetooth Smart products use some interesting tricks to reduce power consumption. The technology minimizes time on air by employing only three "advertising" channels to search for other devices or promote its own presence to devices that might be looking to make a connection. In comparison, conventional Bluetooth technology uses 32 channels. Bluetooth Smart devices need to switch "on" for just 0.6 to 1.2 ms to scan for other devices, while conventional Bluetooth technology requires up to 22.5 ms to scan 32 channels.

Consequently, Bluetooth Smart devices use 10 to 20 times less power to locate other radios. Once connected, the radio switches to one of its 37 data channels and then hops in a pseudorandom pattern using Bluetooth adaptive frequency hopping (AFH) technology. AFH ensures data traveling via Bluetooth securely gets from point A to point B even in chatty networking environments.

Also, Bluetooth Smart's raw data bandwidth of 1 Mbit/s allows information to be sent rapidly so the radio can quickly return to an ultra-low-power sleep state. A connection (i.e., scan for other devices, link, send data, authenticate, and terminate) takes just 3 ms. With conventional Bluetooth technology, a similar connection cycle is measured in hundreds of milliseconds. More time on air requires more energy from the battery.

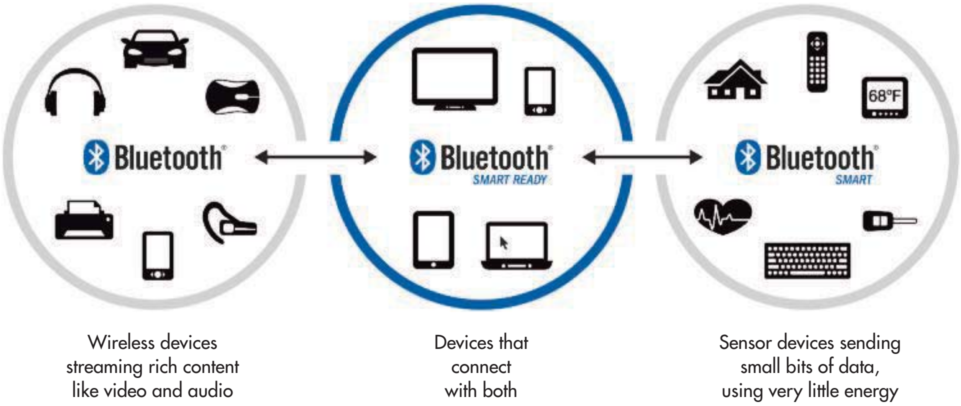
Bluetooth Smart also keeps a lid on peak power in two other ways: by employing more "relaxed" RF parameters than its big brother, and by sending very short packets. Shorter packets further minimize the time on air and keep the silicon cooler, eliminating the need for power-consuming recalibration and closed-loop architecture.

PROFILES FOR THE SPORTS & FITNESS MARKET

Product designers know the chip is just the first choice to make. Profiles are the special sauce of Bluetooth technology. In August 2012, the Bluetooth SIG introduced key profiles for the sports and fitness market. The new profiles, Running Speed and Cadence (S&C) and Cycling Speed and Cadence, extended capabilities for real-time running and cycling data monitoring. They also added critical functionality previously reserved for proprietary solutions.

Companies can now quickly implement Bluetooth Smart sensors in sports devices to instantaneously transmit data such as running cadence, stride length, total distance, or cycling speed, distance, and pedal cadence to Bluetooth Smart Ready devices like smart phones *(Fig. 2)*.

Historically, sports and fitness sensors capable of tracking speed and cadence relied on proprietary technology, severely limiting the potential number of devices they could connect



3. You can determine how to label and categorize your product based on the different Bluetooth "brands."

to. In contrast, the Running S&C and Cycling S&C profiles unlocked these sensors, allowing companies to build products that connect with tens of millions of Bluetooth Smart Ready devices already on the market and hundreds of millions on the way in the coming quarters.

More sports and fitness profiles are on the way with leading manufacturers like Polar and Intel, among many others, collaborating on standard profiles. Any company can join the Bluetooth SIG as an associate member and drive the creation of more profiles through working groups.

BLUETOOTH BRANDING

Additional design choices made possible by Bluetooth 4.0 provide great opportunity for the market, but change the landscape of compatibility between Bluetooth devices. To aid consumers in understanding the compatibility among devices, the Bluetooth SIG created Bluetooth Smart marks *(Fig. 3)*.

While the logos provide consumer guidance on device compatibility, earning that logo really makes the news. Bluetooth Smart Ready devices—hubs like phones, PCs, tablets, and TVs—must include the Bluetooth dual-mode radio described above and provide a means for consumers to update the software on each device.

MORE ON BLUETOOTH

Bluetooth is among the world's most popular wireless technologies, and it can be found in many of today's hottest commercial products. For more about the standard and its applications, go to **electronicdesign.com** and see:

- Bluetooth And Wi-Fi Rule The Airwaves
- Bluetooth's Background
- Build A Simple Wireless Bluetooth Stereo Audio System For The Outdoors
- How To Simplify Implementations For Bluetooth Smart Low-Energy Applications
- What's The Difference Between Bluetooth Low Energy And ANT?

This arrangement is less complicated than it may sound at first. In many cases, the device OEM includes the chip while the operating system that's powering the device natively takes care of enabling updateable profiles. Typically, the software update is transparent to users because it is implemented when they download the application that's associated with their new Bluetooth Smart device.

For instance, a consumer purchases a new-heart rate monitor and downloads the supporting app to a smart phone. The Bluetooth heart-rate data profile is also installed on the smart phone in the background, and the two devices work seamlessly together even though the heart-rate profile wasn't on the phone prior to installing the app.

This ability to update profiles on Smart Ready hubs is a game-changer for OEMs working with Bluetooth. It ensures that as new low-energy Bluetooth Smart sensors come to market, the Smart Ready hub devices consumers already own can be updated to be compatible, which frees OEMs to build products based on new profiles and still reach the huge install base of Smart Ready hubs.

REQUIREMENTS FOR QUALIFICATION

A Bluetooth Smart brand qualified product must incorporate Bluetooth Core Specification Version 4.0 (or higher) with GATT-based (Generic Attribute) architecture, feature a single-mode radio, and use the GATT-based architecture to enable particular device functionality.

A Bluetooth Smart Ready qualified product similarly must incorporate Bluetooth Core Specification Version 4.0 (or higher) with GATT-based architecture; feature a dual-mode radio (BR/EDR + Bluetooth low energy) where both radio modes may be activated, individually or simultaneously; and provide a means by which the end user can update functionality for a Bluetooth Smart device on the Bluetooth Smart Ready device. Manufacturers should also provide a way for third parties to create and distribute applications that receive data from Bluetooth Smart devices.

The SIG refers to hub devices using Bluetooth 4.0 as "Bluetooth Smart Ready" because they're "ready" to connect to the entire universe of Bluetooth devices in the market and because the updateable profiles can be made "ready" for new Bluetooth Smart devices as they are introduced.

Bluetooth Smart Ready products include the iPhone 5 and 4S, the iPad, the Motorola RAZR, the Samsung Galaxy, and all new hardware running Windows 8. Bluetooth Smart devices include the Polar H7 heart-rate monitor, the Wahoo Fitness Blue HC Cycling monitor, and the Casio G-Shock GB-6900 smart watch. All of the devices on the market can be found at *www.bluetooth.com/Pages/Bluetooth-Smart-Devices-List.aspx*.

PUTTING IT ALL TOGETHER

Beyond the sports and fitness market, the SIG sees this transformation playing out in other verticals like healthcare, the smart home, and industrial automation. Connected "things" are all part of the bigger movement toward the IoT, and Bluetooth will be an integral wireless technology to connect billions of power-sensitive sensors to Web services.

Bluetooth technology is multiplying at an amazing rate. ABI Research expects 2.5 billion Bluetooth enabled products to be shipped by the end of 2013, growing to approximately 5 billion per year by 2017. More than 9 billion Bluetooth products have been shipped since the inception of the technology, and this massive network of connected devices will triple by 2017. The new use cases made possible by Bluetooth Smart are accelerating this growth.

Understanding the market opportunity that's available now and ahead, the benefits, and the flexibility of Bluetooth and the clear path forward for the branding of Bluetooth devices should make the choice an obvious one for product designers of sports and fitness devices. Bluetooth technology makes perfect sense. ed

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Graphically Determine The Output Signal Level Of An RC Filter

GREGORY MIRSKY | ATLAS-MATERIALS TESTING COMPANY mirsky@usa.net

WHEN DESIGNING FILTERS, engineers very often need to know what the filtered value at the output will be. This is especially important for variable switching power supplies operating at different duty cycles. The analysis presented here discusses the calculation of the filtered output for RC filters, which are common in feedback circuits, current transformers, output devices, and other circuits. However, the analysis easily can be extended to other kinds of filters.

It's well known that for rectangular-pulse inputs the rms values of the unfiltered output parameters, like voltage and current, are proportional to the square root of a duty cycle. But the designer of a feedback filter for a switching power supply must consider that the filter output is not an rms value but rather proportional to the pulse's duty cycle. You can adjust the filter's parameters to obtain an rms value, but it would be valid only for one duty-cycle value.

The analysis employs several assumptions:

- The filter works in a continuous-conduction mode, which means the filter's time constant is much greater than the pulse's repetition rate (period).
- The filter capacitor's charge and discharge time constants are the same. That means the impedance sourcing signal to the filter is much lower than the filter resistance and the filter's load impedance is much higher than the filter's resistance, which you can easily obtain by using an operational amplifier as a decoupling component.
- The filter's voltage grows in exponential steps (charging and discharging) that become smaller as the output voltage approaches its limit value.
- The filter is loaded with an impedance that is so high that it can be ignored.

We did the analysis with MathCAD 15, and anyone with the appropriate license can reproduce the results.

The expressions for the nth values of the filtered voltage's maximum, Vh, and minimum, Vlow, are:

$$Vh_n = Vlow_n + \left(V_A - Vlow_n\right)\cdot\left(1 - e^{\frac{-\tau_1}{\tau}}\right) \quad (1)$$

$$Vlow_n = Vh_{n-1}\left[e^{\frac{-(T-\tau_1)}{\tau}}\right] \quad (2)$$

where τ is the filter's time constant and τ_1 is the pulse duration *(Fig. 1)*. For simplicity, define:

$$\alpha = e^{\frac{-(T-\tau_1)}{\tau}} \quad (3)$$

$$\beta = 1 - e^{\frac{-\tau_1}{\tau}} \quad (4)$$

$$\gamma = e^{\frac{-\tau_1}{\tau}} \quad (5)$$

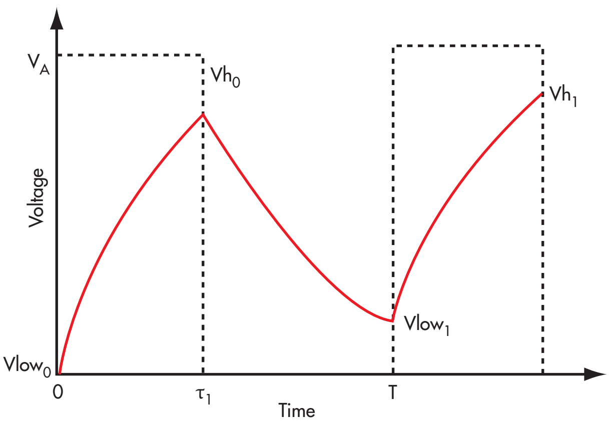
$$\tau_1 = DT \quad (6)$$

where D is the duty cycle of the input pulse train;

$$\tau = kT \quad (7)$$

where k is the number of periods for the filter time constant. So, Equations 1 and 2 become:

$$Vh_n = V_A\beta + Vlow_n\gamma \quad (8)$$



1. The plot of the input pulses (dashed lines) and filter output (solid lines) indicates the definition of the parameters used in the calculations.

$$Vlow_n = Vh_{(n-1)}\alpha \quad (9)$$

To derive the equation for the limit value of the filter output, you must use the recurrent equations for the low and high values and calculate the average, which is based on the initial parameters only. The equations for six high/low pairs are:

$$Vh_0 = V_A\beta$$
$$Vlow_0 = 0$$

$$Vh_1 = V_A\beta(\gamma\alpha + 1)$$
$$Vlow_1 = V_A\beta\alpha$$

$$Vh_2 = V_A\beta(\gamma^2\alpha^2 + \gamma\alpha + 1)$$
$$Vlow_2 = V_A\beta\alpha(\gamma\alpha + 1)$$

$$Vh_3 = V_A\beta(\gamma^3\alpha^3 + \gamma^2\alpha^2 + \gamma\alpha + 1)$$
$$Vlow_3 = V_A\beta\alpha(\gamma^2\alpha^2 + \gamma\alpha + 1)$$

$$Vh_4 = V_A\beta(\gamma^4\alpha^4 + \gamma^3\alpha^3 + \gamma^2\alpha^2 + \gamma\alpha + 1)$$
$$Vlow_4 = V_A\beta\alpha(\gamma^3\alpha^3 + \gamma^2\alpha^2 + \gamma\alpha + 1)$$

$$Vh_5 = V_A\beta(\gamma^5\alpha^5 + \gamma^4\alpha^4 + \gamma^3\alpha^3 + \gamma^2\alpha_2 + \gamma\alpha + 1)$$
$$Vlow_5 = V_A\beta\alpha(\gamma^4\alpha^4 + \gamma^3\alpha^3 + \gamma^2\alpha^2 + \gamma\alpha + 1)$$

Note from the above equations that:

$$Vlow_n = V_A\beta\alpha\left[\sum_{m=0}^{n-1}\left(\gamma^m\alpha^m\right)\right] \quad (10)$$

and:

$$Vh_n = V_A\beta\left[\sum_{m=0}^{n}\left(\gamma^m\alpha^m\right)\right] \quad (11)$$

The average for the output voltage is:

$$V_{limit_n} = Vlow_n + \left(\frac{Vh_n - Vlow_n}{2}\right) \quad (12)$$

You can calculate the limit for the normalized output voltage using MathCAD tools:

$$Limit = \frac{V_A + V_A e^{\frac{D-1}{k}} - V_A e^{-\frac{1}{k}} - V_A e^{-\frac{D}{k}}}{V_A\left(2e^{-\frac{1}{k}} - 2\right)} \quad (13)$$

or:

$$Limit = \frac{e^{-\frac{D}{k}} - e^{\frac{1}{k}(D-1)} + e^{-\frac{1}{k}} - 1}{2e^{-\frac{1}{k}} - 2} \quad (14)$$

(See the derivation of Equations 13 and 14 in "Normalized Output Voltage Limit Derivation," p. 91.)

Equation 14 is a transcendent equation with two variables, which is hard to solve symbolically. But you can find the limit value graphically by fixing the value of k and plotting the limit as a function of the duty cycle, D. If k = 100.0:

$$Limit(D) = \frac{e^{-D\frac{1}{k}} - e^{D\frac{1}{k}}e^{-\frac{1}{k}} + e^{-\frac{1}{k}} - 1}{2\left(e^{-\frac{1}{k}} - 1\right)} \quad (15)$$

A plot of this function shows that the limit of the normalized RC filter output is the duty cycle, D *(Fig. 2)*. To create an example, assign values to the variables in Figure 1:

$$V_A = 1\ V$$

$$D = 0.6$$

$$T = 20\ \mu s$$

$$\tau_1 = DT$$

$$k = 50$$

$$\tau = kT$$

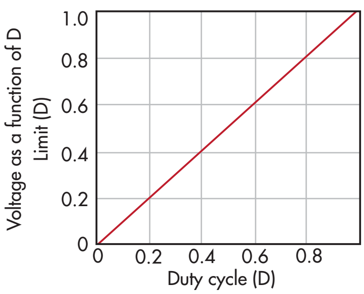
Then:

$$\alpha = e^{-(T - \tau 1)/\tau} = 0.992$$

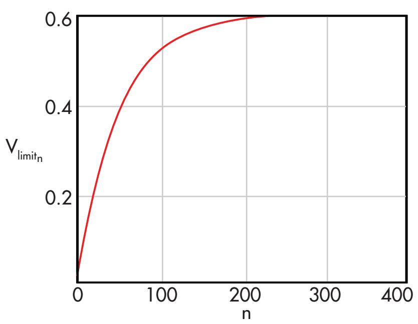
$$\beta = 1 - e^{-\tau 1/\tau} = 0.012$$

$$\tau = e^{-\tau 1/\tau} = 0.988$$

Then:



2. The normalized output voltage of the RC filter is the duty cycle value of the rectangular input pulses. The result does not depend on the value of k.



3. The limit value of the filtered voltage is equal to the input voltage's amplitude times the duty cycle.

$$\lim_{n\to\infty}\left[V_A\beta\alpha\left[\sum_{m=0}^{n-1}\left(\gamma^m\alpha^m\right)\right]+\frac{\left[V_A\beta\left[\sum_{m=0}^{n}\left(\gamma^m\alpha^m\right)\right]-V_A\beta\alpha\left[\sum_{m=0}^{n-1}\left(\gamma^m\alpha^m\right)\right]\right]}{2}\right]\rightarrow 0.5999984000183478787 9(V) \quad (16)$$

To plot the graph for the limit, assign n = 1…400. Then:

$$Vlow_n = V_A\beta\alpha\left[\sum_{m=0}^{n-1}\left(\gamma^m\alpha^m\right)\right] \quad (17)$$

$$Vh_n = V_A\beta\left[\sum_{m=0}^{n}\left(\gamma^m\alpha^m\right)\right] \quad (18)$$

$$V_{limit_n} = \left[Vlow_n + \left(\frac{Vh_n - Vlow_n}{2}\right)\right] \quad (19)$$

Figure 3 shows the resulting plot.

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NORMALIZED OUTPUT VOLTAGE LIMIT DERIVATION

Equation 12 can be interpreted as:

$$\lim_{n\to\infty}\left[V_A\beta\alpha\left[\sum_{m=0}^{n-1}\left(\gamma^m\alpha^m\right)\right]+\frac{\left[V_A\beta\left[\sum_{m=0}^{n}\left(\gamma^m\alpha^m\right)\right]-V_A\beta\alpha\left[\sum_{m=0}^{n-1}\left(\gamma^m\alpha^m\right)\right]\right]}{2}\right] \quad (1)$$

Its solution is:

$$\begin{cases} \text{signum}(V_A\beta,0)(\infty) \text{ if } \alpha = \dfrac{1}{\gamma} \\ \lim_{n\to\infty}\left[\dfrac{V_A\beta\left(\gamma\gamma^n\alpha\alpha^n - 1\right)}{2\gamma\alpha-2}+\dfrac{V_A\beta\alpha\left(\gamma^n\alpha^n-1\right)}{2\gamma\alpha-2}\right] \text{ if } \alpha \neq \dfrac{1}{\gamma} \end{cases} \quad (2)$$

Only the lower expression is of interest:

$$\lim_{n\to\infty}\left[\frac{V_A\beta\left(\gamma\gamma^n\alpha\alpha^n - 1\right)}{2\gamma\alpha-2}+\frac{V_A\beta\alpha\left(\gamma^n\alpha^n-1\right)}{2\gamma\alpha-2}\right] \quad (3)$$

Its solution is:

$$\begin{cases} 0 \text{ if } \alpha = \dfrac{1}{\gamma} \\ \dfrac{V_A\beta\left(\alpha-\alpha\infty+1\right)}{2\gamma\alpha-2} \text{ if } 1 < \gamma\alpha \\ \dfrac{V_A\beta\left(\alpha+1\right)}{2\gamma\alpha-2} \text{ if } \gamma|\alpha| < 1 \end{cases} \quad (4)$$

Again, only the lower expression is of interest:

$$-\left[\frac{V_A\left[1-e^{\frac{-DT}{kT}}\right]\left[e^{\frac{-(T-DT)}{kT}}+1\right]}{2\left(e^{\frac{-DT}{kT}}\right)\left(e^{\frac{-(T-DT)}{kT}}\right)-2}\right] \quad (5)$$

which can be converted into Equation 13.

Multiplexer With De-emphasis Characterizes 28.4-GHz Receivers

THE AGILENT Technologies M8061A multiplexer can test and characterize high-speed receivers used in the growing number of fast digital interfaces. The interfaces used in servers, storage systems, and data centers are getting faster as 40G, 100G, and other standards are being adopted.

These standards include IEEE 802.3ba/bj for 100-Gigabit Ethernet, Fibre Channel, CFP2, InfiniBand, OIF CEI, PCI Express, SATA, SAS, USB 3.0, DisplayPort, Thunderbolt, and others used in networks, backplanes, and active cables. Most of these standards use four 25.78125-Gbit/s channels or some similar speed.

The M8061A is designed to work with Agilent's N4903B jitter-bit error rate tester (J-BERT) with pattern generation up to 14.2 Gbits/s. It multiplexes two pulse signals from the N4903B into a single signal for the receiver under test. This allows double the rate from the J-BERT up to 28.4 Gbits/s.

A key feature of the M8061A is its optional de-emphasis capability. Most high-speed signal sources use some from of pre-emphasis to mitigate cable channel distortion. An optional four- or eight-tap de-emphasis circuit allows you to select the desired amount of de-emphasis to produce a solid opening in the eye pattern output. The test receiver output goes to an Agilent N4877A CDR and demultiplexer, then back to the J-BERT for loop back testing.

The M8061A offers four- to eight-tap de-emphasis capability up to 28.4 Gbits/s plus clock/2 jitter injection. The multiplexer is transparent to calibrated jitter injection from the J-BERT. Control is from the J-BERT via a USB port. Other specifications include 14-ps transitions from 20% to 80%, 1.2-V p-p outputs, <200-fs rms intrinsic jitter, interference superposition capability, and dc output coupling.

The M8061A is available now. The basic unit with the four-tap de-emphasis option costs $45,740. Add $9900 for the eight-tap option.

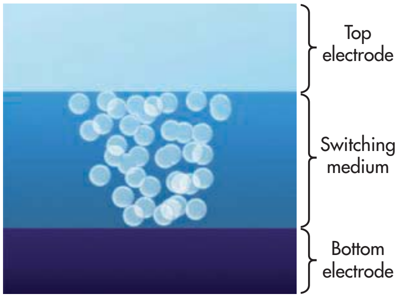
AGILENT TECHNOLOGIES
www.agilent.com/find/m8061a

LOU FRENZEL

Customize Differential Pressure Transmitters In A Snap

CROSSBAR'S RESISTIVE RAM (RRAM) joins magnetic and phase-change non-volatile memory technologies that are competing against the flash storage market. It will have lots of competition, but RRAM's features may put it ahead of the pack.

RRAM cells are easy to build using conventional CMOS processes. It also scales well, making it an interesting match to microcontroller and microprocessor on-chip system-on-chip (SoC) memory. Not all non-volatile storage technologies work well in this environment, and often designers stick to larger, less dense geometries to deliver the necessary cost and reliability characteristics for a product.



Memories with greater densities are desirable, but the cost of using these other approaches rises significantly.

The three-layer cell using current technology is 6 nm wide. Add 2-nm separation between cells for 10-nm cell spacing. The switching medium is amorphous silicon with tiny metal filaments. Metal ions migrate from one end of the filament to the other to change the cell's resistance during programming. The cell's resistance is measured to determine its logical value.

The RRAM approach can support multi-bit storage per cell like 2-bit multi-level cell (MLC) and 3-bit triple-level cell (TLC) flash memory. Unlike block-oriented NAND flash, RRAM is byte addressable, so it can be used as main memory rather than block storage.

RRAM has at least a 10-year retention and an endurance of more than 10,000 cycles. It is 20 times faster than NAND flash using the same geometries. It additionally has 20 times less power consumption and uses half the die size for the same NAND flash capacity. A 1-Tbyte RRAM chip should only be 200 mm^2. The technology is amenable to three-dimensional stacking, which is simpler than Samsung's new V-NAND.

CROSSBAR
www.crossbar-inc.com **BILL WONG**

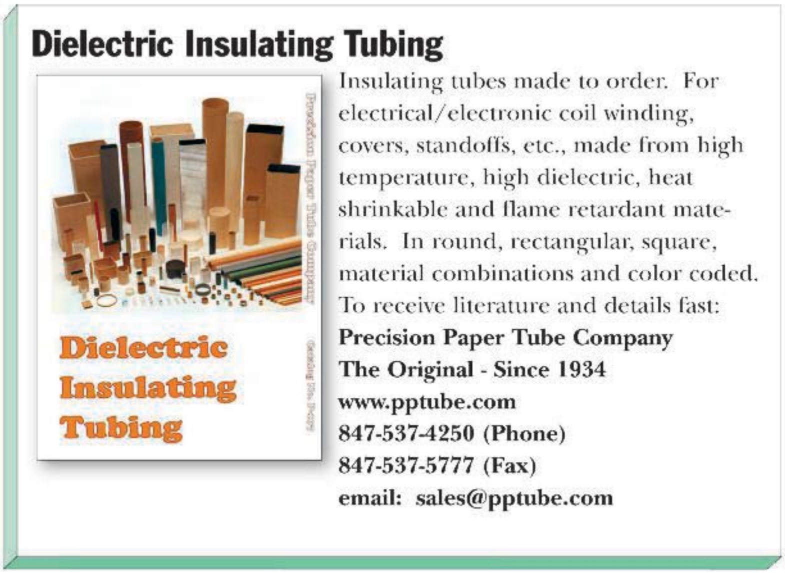
IR's IR3823 3A SupIRBuck® Integrated Voltage Regulator Delivers 97.5% Efficiency in an Ultra-Compact 3.5x3.5mm package

IR introduces the IR3823 SupIRBuck® integrated voltage regulator designed for space-constrained, energy efficient netcom, server and storage applications.

The IR3823 delivers up to 3A with superior efficiency in an ultra-compact 3.5x3.5mm package. Efficiencies in excess of 97.5% are obtainable for designs converting power from a 6V input to a 4.8V output. The extremely high initial efficiency allows switching at up to 1.5MHz from a 12V supply to enable a complete 3A power supply solution in less than 130mm². Featuring constant frequency and virtually jitter-free operation with synchronization capability, the new device is well suited to noise-sensitive applications, while the higher bandwidth reduces component count to shrink PCB footprint. A tri-level selectable soft-start feature is also offered for ease of sequencing.

The IR3823 features programmable switching frequency from 300kHz to 1.5MHz. Other key functions include thermally compensated over-current protection, output over-voltage protection and thermal shutdown.

More information is available on the **International Rectifier** website at
http://www.irf.com/whats-new/nr130808.html
For more information, contact Sian Cummins, **scummin1@irf.com, 310-252-7148.**



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Tracking Movement
Optically And Cheaply

Many machine sensors like accelerometers and gyroscopes have fallen in price because of the popularity of smart phones. Low-cost cameras and optical sensors have also benefited from smart phones with camera sensors for photography or video conferencing.

Almost a decade ago my daughter built a number of robotic science fair projects with a CMUcam that was developed at Carnegie Mellon University. It used an RGB camera. She turned that information into HSI (hue, saturation, intensity) to more readily track changes in the image. Back then the technology allowed results measured in seconds per frame.

I helped turn her Java code into assembler and put it on the CMUcam, replacing CMU's code. The resolution was still low but results were available in tens of frames per second.

Fast forward to the Pixy CMUcam 5, which also was developed at CMU and Charmed Labs as a low-cost sensor for robotics *(Fig. 1)*. The Omnivision OV9715 RGB camera is a supported automotive camera, so it will be available for a while. It can capture a 1280- by 800-pixel image, but the system uses a lower resolution so it can handle a higher frame rate.

The board has a 204-MHz NXP LPC4330 microcontroller. The micro has a Cortex-M0 and a Cortex-M4 core. The Cortex-M0 handles the camera reading and processing a frame at a time. It converts the RGB camera information so the Cortex-M4 can perform the frame analysis. The micro has 1 Mbyte of flash and 256 kbytes of RAM. It also has a high-speed quad-SPI (QSPI) that can handle high-speed serial flash memory.

The module exposes a USB, serial port, SPI, and I^2C interface. A 10-pin header is designed to link the system to an Arduino-compatible host. The USB interface is handy for PCs. The USB port can supply power. Two ports enable the LPC4330 to control positioning servos.

Kickstarter was used to launch the project. The module alone is $59. Different versions are available including one that comes with servos. The open-source software can be augmented. Eventually the system might include a Python interpreter, allowing even more image processing chores to be offloaded.

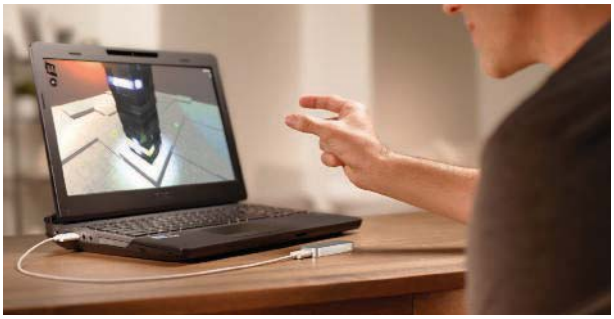
The software can capture the color of objects and recognize color codes (CC). A CC is two or more adjacent blobs of color. CCs can be tracked automatically and used to identify a particular type of object like a charging station or a goal.

1. The Pixy CMUcam 5's dual-core NXP microcontroller tracks multiple targets using hue and saturation information generated from an RGB camera chip.

ILLUMINATING FINGERS

Leap Motion's Controller also handles object recognition but is designed specifically to recognize hand and finger gestures for PC applications *(Fig. 2)*. It usually sits in front of a keyboard or display. The technology could be incorporated directly into something like a Mac or Windows laptop or a desktop display.

The Controller uses infrared emitters and a pair of cameras to recognize a user's fingers and hands. It handles gesture recognition and delivers the information via the USB connection. It can be tied into applications to handle 3D positioning and gestures like pinch/expand zooming. Scrolling now is possible with a swipe. ed



2. Leap Motion uses a pair of infrared sensors to detect finger motion above the sensor.

High Voltage ICs for Medical Ultrasound Applications

Supertex's family of high voltage analog switches/multiplexers, pulsers, high-speed MOSFET drivers, and discrete high voltage MOSFETs offer the best price/performance ratio available today. The feature-rich devices offer the highest channel density in the smallest packages. Integrated features such as bleed resistors in the ICs further reduce PCB density and overall cost.

High Voltage Analog Multiplexers / Switches

Features & Benefits

- Low harmonic distortion
- Low parasitic capacitance
- Wide RF bandwidth
- 8, 16, and 32 channel options

Transmit Pulsers & Continuous Wave Driver

Features & Benefits

- High density integration
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- Extremely low phase noise

MOSFET Drivers

Features & Benefits

- 6ns rise and fall time with 1000pF load
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- Dual and quad matched channels

T/R Switches

Features & Benefits

- No external supplies needed
- Fast switching speed
- Low insertion loss
- No control signals required

Front End Ultrasound Receiver

Features & Benefits

- Low power dynamic performance
- Extremely low noise operation, clear image
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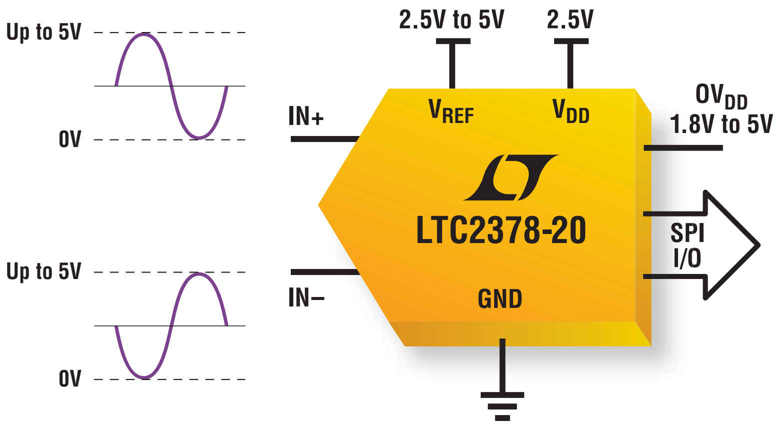
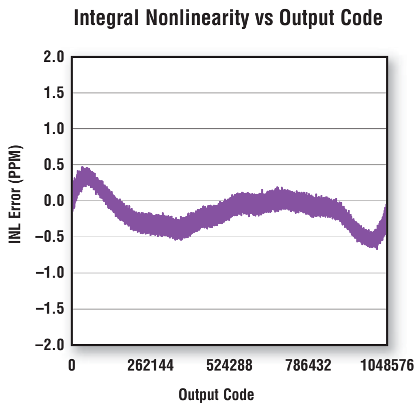
20-Bit 1Msps SAR ADC
0.5ppm INL





No Latency SAR ADC Achieves 104dB SNR

The LTC®2378-20 SAR ADC achieves 20 bits of resolution with outstanding 0.5ppm INL and 104dB SNR performance with no cycle latency and sample rates up to 1Msps. It offers uncompromised performance, low power dissipation and excellent temperature stability for high precision signal chains. The LTC2378-20 family includes pin-compatible 20-/18-/16-bit SAR ADCs from 250ksps up to 2Msps with serial SPI interface and explicit Busy and Chain pins that simplify digital timing.

Features

- 1Msps Throughput Rate
- ±0.5ppm INL (Typ), ±2ppm INL (Max)
- 104dB SNR (Typ) at f_{IN} = 2kHz
- –125dB THD (Typ) at f_{IN} = 2kHz
- Low Power: 21mW at 1Msps, 21μW at 1ksps
- Fully Differential Input Range ±V_{REF}
- V_{REF} Input Range from 2.5V to 5.1V
- Digital Gain Compression Eliminates Need for Negative Rails
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- 16-pin MSOP and 4mm x 3mm DFN Packages

Complete 20-/18-/16-Bit Pin-Compatible SAR ADC Family

	250ksps	500ksps	1Msps	1.6Msps	2Msps
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18-Bit 101dB SNR	2376-18	2377-18	2378-18	2379-18	
16-Bit 96dB SNR	2376-16	2377-16	2378-16		2380-16

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