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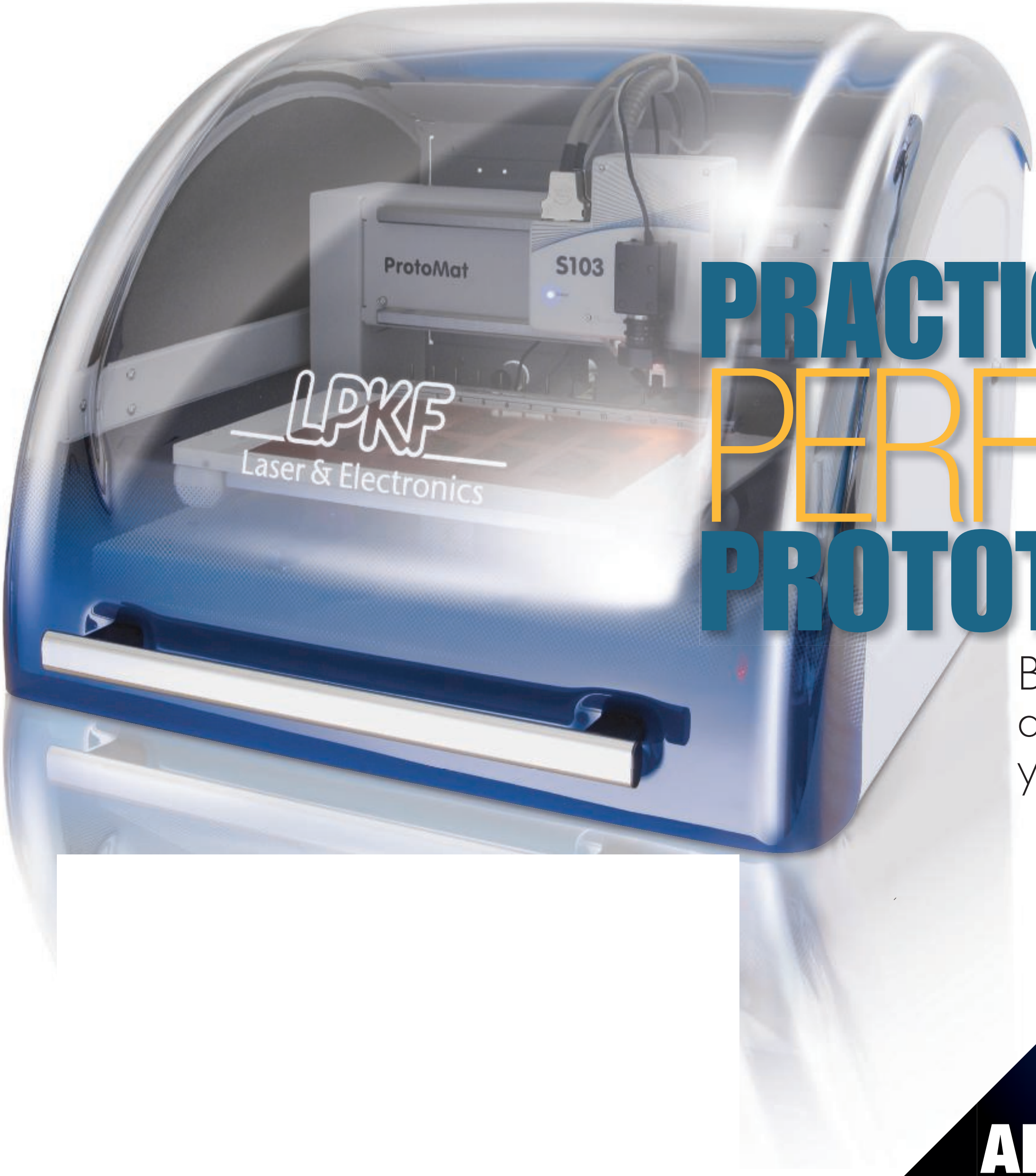

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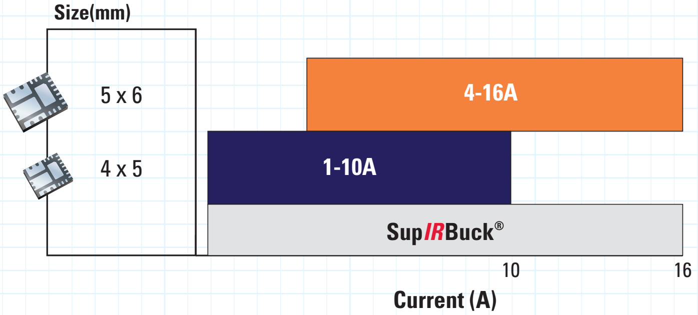

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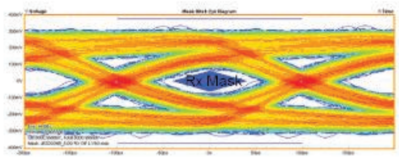

Columns

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

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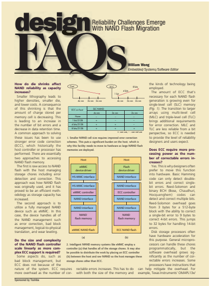
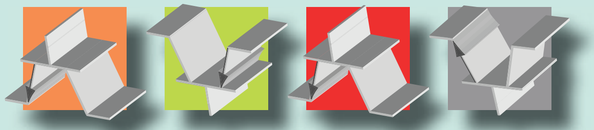
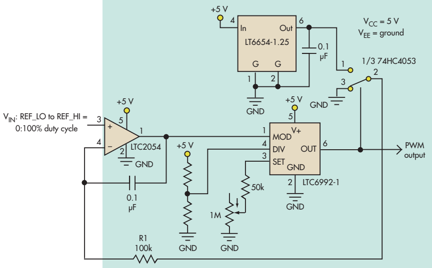
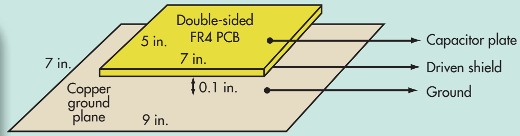




Ideas for Design



Electronic Design Products

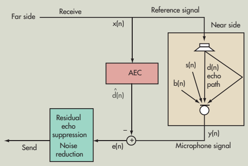


Product Features

On the Web @ electronicdesign.com

ON THE SAFE SIDE
THE ESSENTIALS OF AUTOMOTIVE HANDS-FREE COMMUNICATIONS

Phil Hetherington and Andrew Mohan | *QNX Software Systems Ltd.*

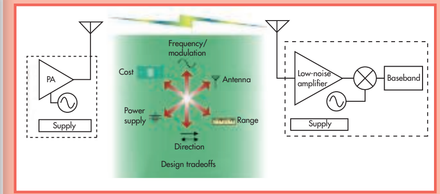


Designers need to be aware of key features that contribute to system performance before choosing a hands-free system for their automotive projects.

DESIGN SOLUTION
GETTING STARTED WITH A SHORT-RANGE RADIO DESIGN

Martin D. Stoehr | *Maxim Integrated*

The process of designing a short-range radio system can be complex and often involves many project tradeoffs. With a little insight, balancing these characteristics can make radio system design easier.



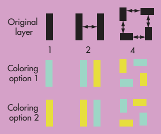
POINT OF VIEW
ANALOG'S ROLE KEEPS GROWING IN THE DIGITAL WORLD

David Robertson | *Analog Devices*

As the digital revolution races along, one may wonder whether analog signal processing is becoming obsolete or if it has been relegated to a "pad driver" function. In fact, several important industry trends are expanding the need for analog and mixed-signal circuits.

THE SILICON EDGE
MAKE THE LEAP FROM TEST CHIPS TO PRODUCTION DESIGNS AT 20 NM

Michael White | *Contributing Technical Expert*



As we start the transition from test chip evaluation to real production, it is perhaps a good time to reflect back on what we have learned about the IC design process for 20 nm.

ENGINEERING TV
A SMART HOME SOLUTION FROM STMICROELECTRONICS

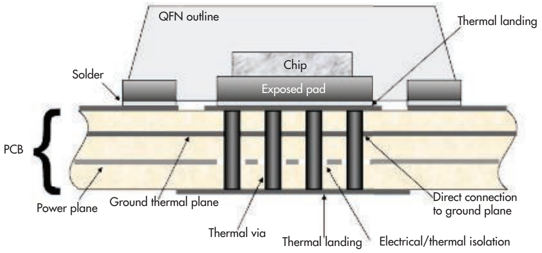
Joe Desposito | *Editor in Chief*

Luca Difalco of STMicroelectronics discusses a smart home solution that includes sensors, set-top box, software, and a relationship with IBM for storage in the cloud. See the video at *engineeringTV.com*.

DEMYSTIFYING PACKAGE DESIGN
ENHANCE THERMAL PERFORMANCE THROUGH DESIGN AND OPTIMIZATION

Darvin Edwards | *Contributing Technical Expert*

Two trends are resolving today's thermal issues: self-sensing electronics that throttle device performance and power consumption when they begin to overheat and expertise in the art of system design to optimize thermal performance.



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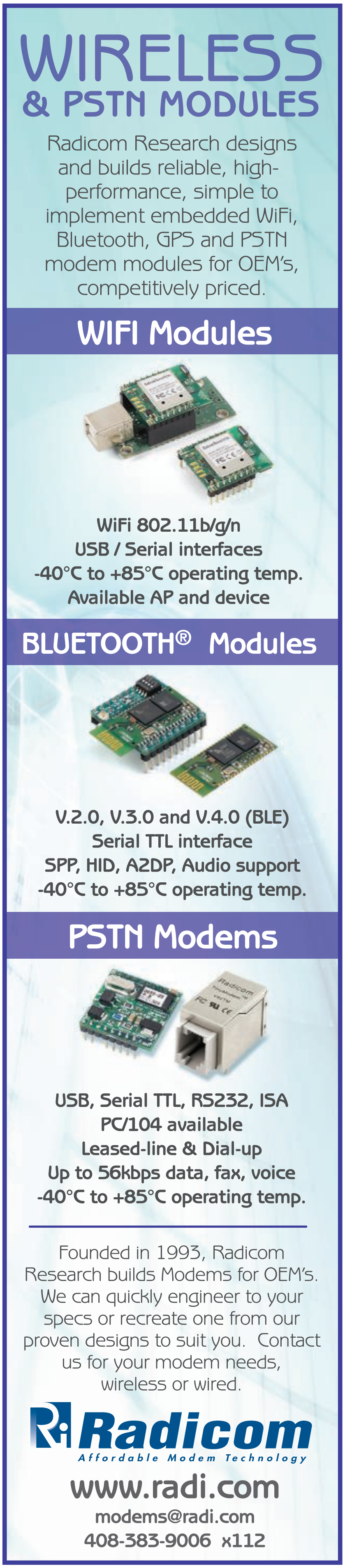
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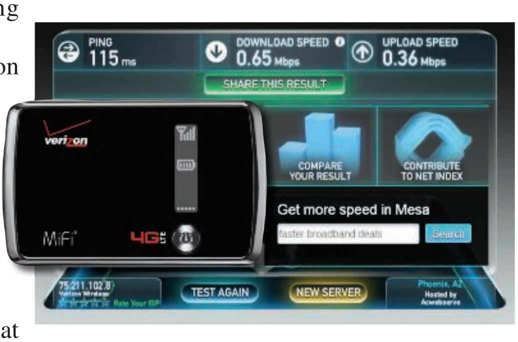
JOE DESPOSITO | EDITOR-IN-CHIEF joe.desposito@penton.com

CES Proves That 4G LTE Still Has A Long Way To Go

THERE'S PROBABLY NO better proving ground for 4G technologies than the International CES in Las Vegas. The show drew more than 150,000 in January, essentially bringing 4G to its knees.

I had brought a Verizon Jetpack 4G LTE mobile hotspot (MiFi 4510L) to the show, hoping to transfer some large video files while I was there. My first attempt to transfer a 500-Mbyte file came to naught when I noticed that only the violet LED on the device was blinking.



A speed test of upload and download speed confirmed that Verizon's 4G LTE hotspot was operating at 3G speeds during CES.

This meant that only 3G service was available. Throughout my entire stay at the show, I never saw the green light blink, indicating that Verizon's 4G LTE service was available.

One thing that surprised me at the show, as I spoke with executives from many high-tech companies, was their complete resignation to the fact that fast wireless service was not available. No one was particularly aggravated with the situation. It was more of a "what can you do?" attitude. This surprised me since I was really disappointed that my 4G hotspot wasn't working as it should.

I ran a speed test on speedtest.net and got just 0.65 Mbits/s for the download speed and 0.36 Mbits/s for the upload speed *(see the figure)*. That's excruciatingly slow. I don't know for sure if any other 4G systems were operational, such as WiMax from Sprint, but I assume that they too were struggling to accommodate the crowd. If anyone has a service other than Verizon's, I'd like to hear about your experience with 4G at CES.

GLOBAL LTE SUBSCRIBERS SET TO DOUBLE

A recent IHS iSuppli report said that global LTE subscribers will more than double in 2013, exceeding 100 million. By 2016, IHS says that LTE will claim more than 1 billion users, equivalent to a five-year compound annual growth rate of 139%.

This is excellent news for carriers, who can charge significantly more for 4G services than they did for 3G. And apparently, they have no obligation to actually provide the service if the traffic is too congested. That's a win-win for the carriers and a lose-lose for consumers under certain circumstances.

I paid $90 for the month for 10 Gbytes of mobile broadband data. I chose that plan due to my own plans to transfer a bunch of large video files over the network to our Engineering TV crew. But I hardly used any of it.

Would Verizon refund my money or extend my service since I couldn't use the LTE data service for a week? A call to customer care informed me that 4G isn't guaranteed in some areas, even though it looked solid on the map that Verizon provides on its Web site (search VZW Map at verizonwireless.com). Plus, the representative said, I called after my one-month plan had expired, so Verizon couldn't do anything for me. Very convenient.

I actually love Verizon's LTE—when it's working. After CES, I used the hotspot to connect to the Internet while on the railroad travelling home from my office in Manhattan. It worked perfectly, allowing me to view large attachments on e-mail and catch some of the video we shot at CES (see engineeringtv.com).

QUALCOMM'S PLAN FOR LTE AND BEYOND

Several months ago I listened to a talk by Matt Grob, CTO of Qualcomm, at MIT's Emerging Technology Conference. The gist of the talk concerned how to meet the growing network capacity needs of mobile users—1 billion by 2016, as noted above. He outlined a very aggressive plan to increase capacity by 1000 times! There were several facets to the plan, which he explained eloquently during his talk.

Part of the plan involved a great expansion of small-cell basestations. Particularly impressive was the fact that he posited a new paradigm, where small basestations inside of buildings would also provide coverage outside, instead of the other way around—that is, large outdoor basestations providing all of the coverage. You can view the video in its entirety at http://bit.ly/10S78BU. I sure hope the plan is successful. ed

FRANK SCHIRRMEISTER | CONTRIBUTING EDITOR franks@cadence.com

Hybrid Execution And Software-Driven Verification Will Emerge In 2013

LAST YEAR, I predicted two things would happen in 2012. First, I suggested that the hybrid, combined use of TLM simulation and the various ways to execute RTL (including hardware-assisted verification) would find further adoption. Second, I thought that more TLM modeling would be used in the FPGA space in which both main vendors were providing virtual prototyping solutions for their new FPGAs containing dual ARM subsystems. So, what happened?

HYBRIDS IN 2012

For the hybrid, combined use of execution engines for TLM and RTL, I compared four different engines to execute hardware to enable software development as early as possible: TLM simulation, RTL simulation, acceleration/emulation, and FPGA-based prototyping. The major tradeoffs between these engines are early time of availability, speed, accuracy of hardware execution, and ability to debug hardware and software. I predicted that we would see more and more hybrid uses of TLM- and RTL-based techniques in 2012.

I got this one right. User interest is significant, sparking Synopsys announcements of hybrids of TLM and FPGA-based prototyping at DAC, Cadence presentations at ARM TechCon and other venues about hybrid TLM and acceleration/emulation usage, and Eve papers about how its products are used with TLM simulation. Synopsys contributed to further market consolidation in the hardware-assisted verification space by adding Eve's FPGA-based system to its two FPGA-based systems from the previous ChipIT and Synplicity acquisitions.

Hybrid use will increase even more in 2013, and not only between TLM and RTL but across all engines. We already have users happily hot-swapping RTL execution back and forth between the Cadence Palladium XP Verification Compute Platform and Incisive RTL simulation. Acceleration, the combination of RTL simulation and emulation, finds further adoption as users are scrambling for more cycles to execute to increase verification coverage.

Cadence made specific announcements in this area with in-circuit acceleration, which combines the best of acceleration and emulation. We also see users connecting FPGA-based prototypes containing the stable version of the hardware with the newer, still to be debugged portion in emulation. And even in the pure TLM space, users are adopting hybrids with swapping between instruction-accurate and cycle-accurate processor models to trade off between accuracy and execution speed.

IN THE FPGA SPACE

The second prediction has to do with TLM modeling in the FPGA space to enable early software development on the ARM-based dual-core subsystems for the complex FPGAs both big vendors provide. We certainly saw interest and adoption in some areas, especially around porting of operating systems and some driver bring-up. However, I had overlooked an adoption trend that in hindsight should have been obvious.

First of all, ramp-up of the FPGAs themselves is still starting up. But in addition, a fair portion of the first wave of adoption of these FPGAs is in projects that consolidate into one chip what was previously two separate chips that held the processor subsystem and the hardware extensions. As a result, not that much new software development was necessary for these projects. Still, with further adoption in 2013, TLM modeling will become more important here as well.

OTHER DEVELOPMENTS IN 2013?

It is time for software-driven verification to be adopted at a faster rate. Previously I had suggested that embedded software running on the embedded processor would become an important part of test benches for hardware. The emergence of hybrid execution as discussed above now enables a much more efficient set of choices to actually execute the embedded test software targeted for verification.

I've seen in customer projects a significant variety of combinations of processors executing the test software in conjunction with the hardware block to be verified, the design under test (DUT). Some users are developing verification scenarios even before RTL is available on pure TLM-based virtual platforms using a virtual DUT followed by combining instruction-accurate or cycle-accurate processor models on the host with the DUT in RTL to refine verification scenarios.

The same tests can then later be executed in pure RTL simulation—now the processor is executed in its RTL form—as well as by acceleration/emulation and FPGA-based prototyping to increase execution speed. The tests can even be executed on the actual silicon once it is back from production.

The processor that executes the tests may be a processor available in the system anyway, but more and more users are considering a dedicated separate processor for those tests, which if it is implemented in the actual silicon would look like a very advanced built-in self test (BIST) module. One use model for the setups described is to verify a DUT in hardware using C-based test benches as opposed to the e language or SystemVerilog. Another use model is to model the system environment with connections like USB, PCI, and MIPI for chip interfaces, which is effectively a form of virtualization of the system environment in which the chip resides.

With further adoption of TLM-based design in all areas including FPGAs, more effective hybrid connections between the TLM and RTL execution engines, and a push in software-driven verification, 2013 promises to be an exciting year. ed

FRANK SCHIRRMEISTER, senior director of product marketing at Cadence responsible for the System Design Suite, has an MSEE from the Technical University of Berlin.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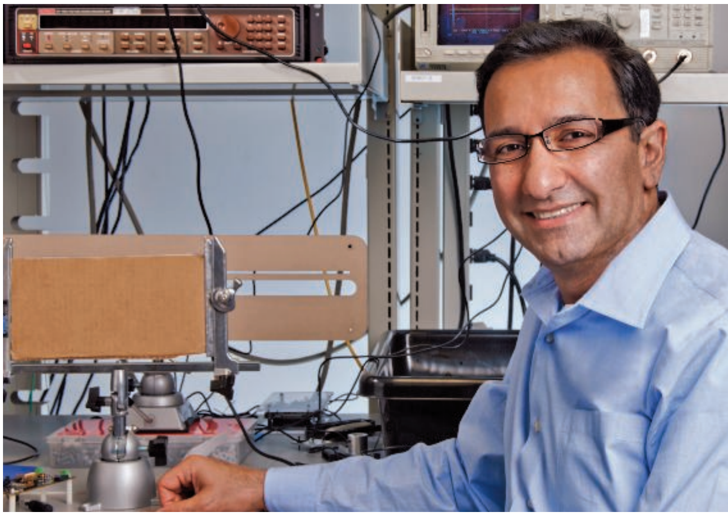
JOE DESPOSITO | EDITOR IN CHIEF joe.desposito@penton.com

Texas Instruments CTO Ahmad Bahai Charts Analog's Integrated Path

Texas Instruments CTO Ahmad Bahai discusses trends in analog for 2013 and beyond with Joe Desposito.



Ahmad Bahai is chief technology officer of analog business for Texas Instruments and director of Kilby Labs and TI Silicon Valley Labs. He co-invented multi-carrier spread spectrum theory, which is used in many modern communication systems such as 4G and power-line communications. He received his MS from Imperial College, University of London, and PhD from the University of California at Berkeley, both in electrical engineering. He holds 26 patents on systems and circuits as well.

JD: The trend toward integrating more analog functions on a single chip is gaining momentum. Will this trend come to some kind of an end?

AB: The answer really depends on what kind of analog integration you're referring to and the purpose. Different road maps and dynamics exist depending on the situation.

If you're talking about monolithic integration, that's one thing, and it has its own dynamics. If you're talking about SIP (system-in-package), package-level, or module-level integration, that's a different story. And again, the answer depends on the purpose of the integration.

In some cases, we are incentivized or encouraged to integrate for ease of use. Texas Instruments offers many integrated products along that line. In other cases, integration is performance-driven. For example, a designer may need an integrated power amplifier with matching circuits to avoid RF noise. Sometimes integration is cost-driven, which is mainly for high-volume applications.

Another aspect of integration is development time and cost. An SoC (system-on-chip) development containing high-performance analog blocks needs a large multi-disciplined team and in some cases multiple iterations in a process that is not necessarily well-modeled or tuned for analog.

In contrast, a SIP approach, where the functions are directed to a digital or analog chip on an optimized process and perhaps to a MEMS (microelectromechanical-systems) sensor element, minimizes both cost and risk. It is also easier to bring out a family of products given the multi-element flexibility

On ease of use, we see demand for more integration, mainly to reduce time-to-market. Our customers, who are not really IC designers, would like to see a more integrated solution for a broad range of applications, bringing together passives, multiple drivers, and data converters.

In many cases, this does not necessarily mean monolithic integration. It's module integration where the packaging has the look and feel of a monolithic solution. We see this gaining momentum.

More companies would like to have what I call kind of a "plug-and-play" solution. This can really reduce the headaches and need for expertise in analog board designs. And that's very exciting for us, too, because we feel that it gives us a chance to offer more of a solution than just the component and build up more momentum working with customers over the long run.

For performance-driven applications, integration should be applied more selectively. If you look at communications infrastructure, for example, such as high-end, big basestations, you see that designers still want high-performance devices, and sometimes integration and performance are a careful tradeoff. They want gigasample analog-to-digital converters (ADCs), high-performance amplifiers, and, of course, very low-noise amplifiers and such, and that will continue.

When it comes to slightly larger volume pico or small basestations, integration makes a lot of sense. Performance is, of course, important, but it doesn't have to be at the level of big basestations that require standalone high-performance devices.

That's why we have a range of products in development that integrate the entire front end of basestations, but mainly target the smaller basestations. These products will address everything after the low-noise amplifier (LNA), all the way to the data converter and, in fact, we have the back-end DSP for all modem functionality.

So, all you need are two chips after the LNA to design the whole basestation plus power management. That's integration driven by performance. Depending on the level of performance, you'll find different levels of integration.

The last category, cost-driven integration, is really for high-volume applications, such as mobile. In essence, this category is dominated by applications with very fast time-to-market and is very form factor-sensitive like mobile consumer products. This is where integration has a totally different angle.

In some cases, the applications are dominated by digital chip requirements. In other cases, applications are dominated by the fact that there are only a few major customers who are interested in having the fewest number of ICs in the final product so they can design products more quickly. Time-to-market cycles are faster because, as you know, things get really outdated in the mobile market very quickly.

This category is building up momentum. You can see IC designers integrating many dc-dc and LDO (low-dropout) converters in a single chip, and that trend is going to continue. PMICs (power-management ICs) are becoming more and more complex. In fact, PMICs at this point are quite complicated considering that they have battery management, lots of LDOs, switched mode dc-dc converters, battery monitoring, and, in some cases, chargers.

All this on one chip—a giant analog power management chip. In a cost-driven chip, performance is often compromised to realize all functions on a relatively low-cost process that has few special analog layers.

All of these integration roadmaps are happening, but depending on the category, they have different paths and momentum. For cost-driven integration, we see the biggest push. The performance-driven is not as strong. And in the broad market, we see a definite incentive for engineers to have an easy-to-use module. But of course, as I said, some of the broad markets use package-driven or SIP-driven integration. This is not affordable in high-volume mobile markets, but in some broad markets it's highly justified.

JD: TI has developed integrated chips, but is this trend accelerating? Do general-purpose chips have a future? Or will every analog chip become part of a solution for a particular market?

AB: At TI, we have strong programs in place for medical, audio, automotive, and other markets, but especially automotive. Automotive is very hot for all semiconductor companies.

In analog and mixed signal, and to some extent in digital, you really need to have a portfolio of high-performance IP blocks and ICs to build up an application-specific standard product (ASSP) presence. One of the unique strengths of TI is that we have more than 40,000 analog products, and that gives us huge leverage to put products together to address a specific need for a specific market.

So, you need high-performance IP blocks to have a strong ASSP presence in any automotive, medical, or high-performance audio market. And I don't think we can bypass developing high-performance standard linear products. We still need high-performance amplifiers and data converters and clocks and such to address some of these larger chips.

So, no, high-performance standalone products are not going away. They will always be there. From a business and marketing standpoint, though, there are markets and applications that are really at the highest end of performance. They still demand standalone, standard linear, high-performance analog blocks sometimes.

In some cases, the volume is not large enough to justify integration. But when we deal with a large volume market like mobile, we don't hesitate to invest in integration because if you are successful in that market, it's going to be hundreds of millions of dollars.

Let's consider medical. You need performance for MRIs and imaging like in the real-time X-ray machines that some of our customers build. It's a good business for TI. But the volume is not so huge that it justifies constant integration. Add to this the fact that performance is still at a premium. We cannot compromise performance for cost when it comes to real-time X-rays and a catheter into a brain, for example. So, in those cases, standalone high-performance analog will dominate for as far as I can see.

It makes sense from a technical viewpoint and from a business viewpoint. These machines are in hospitals, not in a doctor's office, so the volume doesn't justify too much integration. We need to continue to build up high-performance standalone products and also ASSPs. There are markets that really need performance at the premium price without too much integration. ed

For more, see "Texas Instruments CTO Ahmad Bahai Charts The Path Of Analog Technology" at electronicdesign.com.

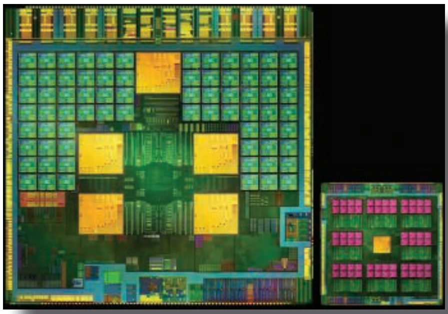
TechView

QUAD CORTEX-A15 + 72-CORE GEFORCE GPU = TEGRA 4

Nvidia's Tegra 4 system-on-chip (SoC) can be paired with the company's Icera i500 processor to deliver a high-performance 4G LTE voice and data platform *(Fig. 1)*. The Tegra 4's five Cortex-A15 cores offer more than twice the performance of the Tegra 3, which is based on the Cortex-A9. Also, its 72 GPU cores boost multimedia processing by a factor of six compared to the Tegra 3. The Icera i500 processor ships with LTE UE Category 3 with 100-Mbit/s downlink support.

Four of the Cortex-A15 cores provide the high-performance support while the fifth core is designed for low-power operation. Like the Tegra 3, the Tegra 4 uses one core or four cores at a time. The video support can handle 4K ultra-high-def video. The 72-core GeForce GPU can do more than just boost gaming and display performance. It also could reduce the time to deliver high dynamic range (HDR) image support, which tends to be computationally heavy.

Nvidia implemented the chip using 28-nm HPL high-K metal gate technology, which provides low-power operation while allowing the cores to run at 1.9 GHz. The 80-mm^2 chip is only slightly larger than the Tegra 3. It supports LP-DDR3 via a dual channel, 32-bit memory interface.



1. Nvidia's Tegra 4 SoC (left) and Icera i500 4G LTE processor (right) target mobile and gaming applications. The Tegra 4 has five Cortex-A15 cores plus 72 GPU cores.

2. The Shield gaming platform is based on the Tegra 4. It supports 1080p gaming.

The Tegra 4 also powers Nvidia's Shield open gaming platform *(Fig. 2)*. Using 802.11n technology, the Android system links to wireless displays. Its own 5-in. multitouch display boasts 1280- by 720-pixel resolution with 294-dpi density. It includes an HDMI port and microSD slot. And, it runs for five to 10 hours when playing games and 20 hours when playing HD video.

The Tegra 3 had a lot of company in the Cortex-A9 space, like Texas Instruments' quad-core OMAP 4470 and Freescale's i.MX6 series, but it still gained a good bit of traction in the mobile device space. The Tegra 4 is the natural upgrade. It's faster and uses less power than its predecessor, so its success is ensured. The Shield's success may take a little longer. It's a neat idea and well executed, though, and several major game publishers already support it. **BILL WONG**

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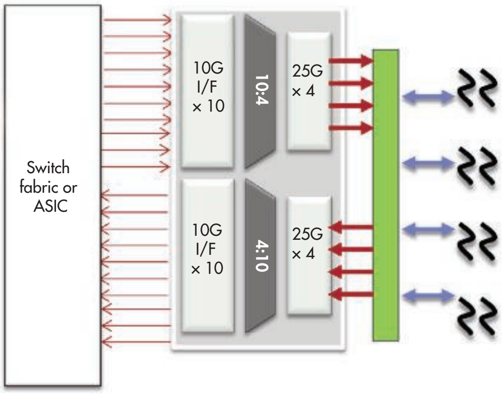
SERDES GEARBOX PHY SIMPLIFIES 100-GBIT/S CONNECTIVITY

The AVSP-1104 joins the Avago Technologies Vortex Gearbox family of physical-layer (PHY) transceivers. This flexible, programmable interface can be configured multiple ways to match data streams into and out of data center equipment like routers, switches, and blade servers using 100-Gbit/s Ethernet or Optical Transport Network (OTN).

The AVSP-1104's full duplex 10:4 or 4:10 gearbox mode is useful when connecting an ASIC or FPGA to a backplane or cable *(see the figure)*. The IC can convert four lanes of 25 Gbits/s or 28 Gbits/s to 10 lanes of 10 Gbits/s or vice versa. In another mode, the device can serve as a 10:10 repeater or retimer. The



The Avago Technologies AVSP-1104 programmable gearbox PHY is designed for use with 100-Gbit/s Ethernet or OTN optical modules, backplanes, or copper cables. Its 10:4 and 4:10 modes switch between 25 Gbits/s or 28 Gbits/s and 10 Gbits/s.

IC can be used to drive optical modules, backplanes, or copper cables.

The device offers programmable Tx/Rx equalization of all serializers-deserializers (SERDES) using Avago's proprietary decision feedback equalization (DFE) and long-reach performance that can withstand up to 32-dB channel loss. It also has a bit error rate (BER) of 1 × 10^{-20} and includes diagnostic software for remote debugging. It complies with IEEE CAUI and Common Electrical Interface (CEI) standards CEI-11G-SR, CEI 28G-VSR, and CEI 25G-LR. And, it boasts low power consumption and low latency.

The AVSP-1104 is made with 28-nm CMOS and comes in a 320-pin flip-chip ball-grid array (fcBGA) package. Samples are available now. Production is slated for March 2013. **LOUIS E. FRENZEL**

AVAGO TECHNOLOGIES

www.avagotech.com/asics/vortex

MEDICAL AFEs FOLLOW TREND TOWARD APPLICATION SPECIALIZATION

Today's analog front ends (AFEs) often simplify the entire system design process. The tradeoff is that they usually are tightly focused on some particular narrow application. Case in point: Texas Instruments' AFE44xx family integrates front-end and timing control functionality for medical photometry.

Photometry is used in pulse oximeters, blood glucose meters, and photo plethysmograph-based (PPG) heart rate monitors. The AFEs combine transmitter and receiver circuits in a single device and draw less than 1-mA quiescent current.

The AFE4490 targets clinical applications, and the AFE4400 suits home health care. In both, the receive path comprises a programmable transimpedance amplifier (TIA), ambient-light cancellation circuitry, and analog-to-digital converter (ADC) signal chain components. On the transmit side, the AFEs incorporate the LED driver and a programmable 8-bit current source. An integrated timing controller module eliminates the need to program that functionality into system software.

In addition to transmit and receive functionality, the AFE4400 includes diagnostics to detect open or short conditions of the LED and photosensor, LED current profile feedback, and cable-on or cable-off detection. The AFE4490 is more sophisticated.

The AFE4490 costs $7.95 and the AFE4400 is priced at $2.95, both in quantities of 1000. They both come in 6- by 6-mm quad flat no-lead (QFN) packages. **DON TUITE**

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design FAQs

Reliability Challenges Emerge With NAND Flash Migration

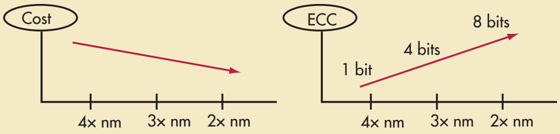
William Wong
Embedded/Systems/Software Editor

How do die shrinks affect NAND reliability as capacity increases?

Smaller lithography leads to higher densities, smaller die, and lower costs. A consequence of this shrinking is that the amount of charge stored per memory cell is decreasing. This is leading to an increase in the number of bit errors and a decrease in data retention time. A common approach to solving these issues has been to use stronger error code correction (ECC), which historically the host controller or processor has performed. There are essentially two approaches to accessing NAND flash memory.

The first is raw access to NAND flash with the host managing storage chores including error detection and correction. This approach was how NAND flash was originally used, and it has proved to be an efficient methodology as storage capacity has increased.

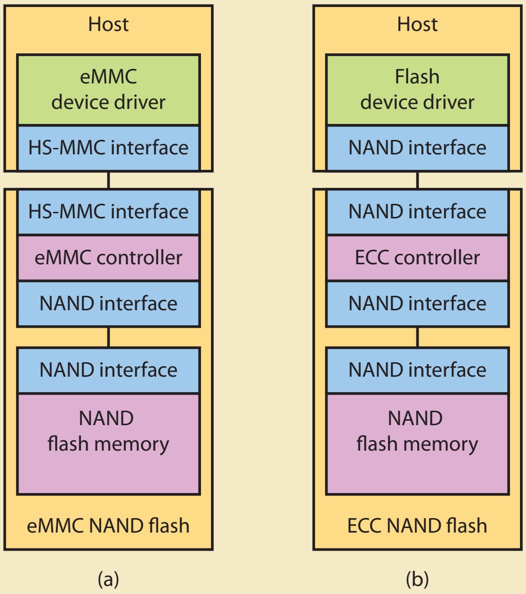
The second approach is to utilize a fully managed NAND device such as eMMC. In this case, the device handles all of the NAND management such as error correction, bad block management, logical-to-physical translation, and wear leveling.



ECC on host	SLC NAND		
	4x nm	3x nm	2x nm
None	–	–	–
1 bit/512B	+	–	–
4 bits/512B	+	+	–
8 bits/512B	+	+	+

+: can use, – : can not use

1. Smaller NAND cell size requires improved error correction schemes. This puts a significant burden on the host, which is why this facility needs to move to hardware as large NAND flash memories are deployed.



2. Intelligent NAND memory systems like eMMC employ a controller (a) that handles all of the storage chores. It may also be possible to distribute the work by placing an ECC controller (b) between the host and raw NAND so the host manages these storage chores other than ECC.

Do the size and complexity of the NAND flash controller scale linearly as more complex ECC support is required?

Some aspects do, such as bad block management, but ECC does not because of the nature of the system. ECC requires more overhead as the number of correctable errors increases. This has to do with both the size of the memory and the kinds of technology being employed.

The amount of ECC that's necessary for each NAND flash generation is growing even for single-level cell (SLC) memory *(Fig. 1)*. The transition to larger arrays using multi-level cell (MLC) and triple-level cell (TLC) brings additional requirements for error correction. MLC and TLC are less reliable from a bit perspective, so ECC is needed to provide the level of reliability designers and users expect.

Does ECC require more processing power as the number of correctable errors increases?

Yes. This is why designers often prefer to move this function into hardware. Basic Hamming code can only detect double-bit errors and correct single-bit errors. Reed-Solomon and binary BCH (Bose, Chaudhuri, Hocquenghem) codes can detect and correct multiple bits. Reed-Solomon overhead goes from 3 bytes for a 512-byte block with the ability to correct a single-bit error to 9 bytes to correct 4-bit errors. This jumps to 32 bytes for handling 14-bit errors.

Disk storage processors often have hardware acceleration for this purpose. General microprocessors can handle these chores programmatically, but the software overhead grows significantly as the number of correctable errors increases. Some processors have instructions that can help mitigate the overhead. For example, Texas Instruments' OMAPL13x/

C674x microprocessors have a built-in ECC engine that handles 1-bit and 4-bit ECC. In general, conventional microprocessors lack support to match full hardware-based, multi-bit ECC.

Is it necessary to transition to flash systems like eMMC to offload the host?

Not necessarily. It is possible to provide transparent ECC support with a raw NAND flash interface *(Fig. 2)*. In this case, the intelligent ECC controller that sits between the host and the raw flash appears as raw flash to the host processor that continues to handle storage management chores and may even employ minimal error correction capabilities. The ECC controller provides error correction support, providing the host with essentially an error-free storage subsystem. The host continues to handle features such as bad block remapping and logical-to-physical translation.

The approach supports new and legacy applications that employ a conventional NAND flash interface typically without changing the host software. This may include error correction support, but it will effectively be unnecessary since the storage subsystem will be providing error-free data storage. Of course, the host will be given data with a detectable error if there is a hard, uncorrectable error that even the memory controller cannot handle.

Should new designs employ fully managed NAND solutions like eMMC or SATA or stick with raw NAND interfaces with built-in ECC?

This is a more difficult question to answer because there are more issues than simply the hardware. The type of software and its capabilities must be considered along with the capabilities of the host processor, which may dictate what is more efficient or cost effective.

The ability to utilize NAND flash with a built-in ECC controller simply expands the possibilities for new designs without being restricted by the ECC capability of the host system, which would be the case if raw NAND flash was utilized. This is especially true as storage moves past SLC NAND.

There will still be tradeoffs to consider when utilizing MLC and TLC NAND flash. Their lower cost per bit and higher capacity are a goal that designers will want to incorporate when possible. ■

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

TAP NEW TECHNOLOGIES TO PRODUCE PRACTICALLY PERFECT PROTOTYPES

Don't worry if you need to deliver polished prototypes quickly to meet looming time-to-market deadlines. Dev kits, 3D printers, and other tools can provide immediate help.

Design cycles keep getting shorter. Developers are using a host of technologies to meet these new deadlines. Everything from slick development kits to complete reference designs can cut days or months from a schedule.

Prototypes often need to meet more demanding requirements as well, especially where mobile consumer electronics are concerned. It's hard to imagine how a solution works if it's strewn across a workbench with wires and probes attached.

The challenge for creating something closer to an end product is often mechanical. Soldering irons rarely touch circuit boards these days, and boards are no longer simple rectangles. Sometimes fast-turnaround outsourcing is the answer. Sometimes it's in-house creation of boards and other mechanicals.

The rise of desktop solutions in printed-circuit board (PCB) creation and 3D printing enable small design teams and even individual designers to perform this kind of work themselves. The resulting solution often may be almost identical to the final product. More importantly, these solutions enable designers to quickly create new variations. Rarely is the first version of a prototype the same as the final product. Several iterations often are required.

Designs can change because of the way designers see the software, hardware, and mechanicals come together. Circuit boards may be redesigned for better system construction or information presentation. Software may be able to take advantage of more input if additional buttons can be included.

In the past, longer design cycles allowed this feedback to occur. Short design cycles mean this type of change needs to be completed more quickly. Sending something out to make each change is time consuming and can be costly. The ability to do the job locally can cut costs even if the additional tools are expensive.

A single designer can be a jack-of-all-trades and deal with everything from software to board and case design. But typically, a small design team brings the necessary expertise to bear.

MAKING THE MECHANICALS

Designers often concentrate on their area of expertise and overlook other aspects of the design, counting on someone else to turn out the final product. Because of the construction methods, final production traditionally was outsourced or required a significant in-house production facility.

Low-cost 3D printers like the Lulzbot AO-101 *(Fig. 1)* and the Makerbot Replicator 2x *(Fig. 2)* have changed the production process. These devices cost less than a couple thousand dollars, and they fit on the desktop. They're also easy to use.

3D printing isn't new, but 3D printers tended to be larger, expensive devices requiring expertise to get good results. Those machines are still invaluable in their application areas, allowing the creation of objects from a variety of materials including metals. Low-cost 3D printers, though, tend to utilize ABS or PLA plastic.

Some available 3D printing methodologies lend themselves better to different materials such as metals. Low-cost 3D printers like those from Lulzbot and Makerbot utilize plastic extrusion heads that build up layers of material.

The plastic used by these 3D printers comes in filament spools. The filament is fed into the extrusion head, which is heated, and a tiny bead is deposited at the end of the head. The head moves horizontally like an inkjet printhead, but it can move along all three axes. The head is raised slightly after it completes printing the current layer.

Objects created by 3D printers are usually limited in size by the volume that the nozzle can traverse. More expensive printers typically support larger-volume objects. Low-cost 3D printers like the AO-101 employ a single nozzle, so most objects are built using a single color and type of plastic. The plastic tends to be available in a variety of colors.

Some systems employ a dual extrusion head that allows printing with two different materials. It could be used for two different colors, or one of the materials might be used as a support for complex objects.

3D printers cannot simply print an object floating in the air. The object must sit on the build platform and be stable while the rest of it is built. Many object designs account for this placement. Sometimes, though, an object cannot be freestanding or it may have very limited support capacity, making accurate printing impossible.

The object design is often modified to include additional supports that would be removed when printing completes but before the object is used. These supports could be made of the same substance as the object, or they might be an additional substance that may be removed in a variety of ways, such as mechanical removal (i.e., breaking off a part) or dissolving in a solvent that could include water. Of course, the main substance of the object should not be destroyed in the process.

A single-head system can build up supports using different materials, but these materials need to be changed. A dual-head system can handle two materials, which is often sufficient for even very complex designs.

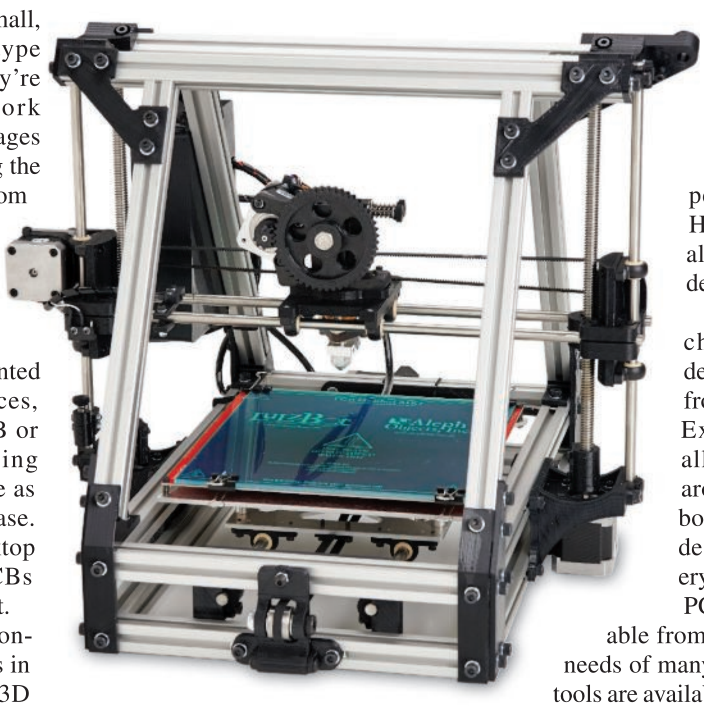
Another alternative to some complex designs is the creation of multiple objects that fit together. This may be a requirement for the overall design or it may be something that is introduced because of the complexity of the object.

The design of an object and its supports can have some effect on the accuracy of reproduction. Generally, though, the printer's capability sets the mark of quality.

Makerbot and Lulzbot have a layer thickness of 0.1 mm with nozzle diameters on the order of 0.25 mm to 0.4 mm. The build volume for the AO-101 is 200 by 190 by 100 mm. The Replicator 2x build volume is 285 by 153 by 155 mm.

The ability to print fine detail means these printers can create smooth surfaces that don't require post-production work. They also can handle small parts like gears and snap-fit connections.

LPKF's desktop ProtoMat S103 creates custom PCBs by grinding off unwanted copper from the board instead of doing the job chemically. It can create multilayer boards a layer at a time.



1. The Lulzbot AO-101 open-frame 3D printer fits on a desktop.

3D printers, large and small, often are used for prototype work. But sometimes, they're used for production work where the printer's advantages can be employed, including the creation of complex or custom parts. They also can be used for on-demand parts creation.

DESKTOP PCB CREATION

Inside those new 3D printed cases for electronic devices, there likely will be a PCB or two. Creating and revising these circuit boards can be as daunting as creating the case. As it turns out, some desktop solutions for creating PCBs don't require a chemical vat.

LPKF Laser and Electronics' ProtoMat family works in the opposite mode of the 3D printers. While 3D printers build up a new object in layers, the ProtoMat S103 is essentially a milling machine that starts with a PCB with a solid copper layer that is then ground away *(see the opening figure)*.

The ProtoMat's vacuum table holds down a blank circuit board. The milling head is moved so it can grind down the copper, which is vacuumed away. A two-sided board is created by manually flipping the board over and then doing the same thing to the other side. The system is accurate enough to handle multilayer boards, though they must be laminated together. An optical camera-based alignment system uses fiducials on the circuit board.

The approach is especially effective for PCBs related to radio technology including the creation of an on-board antenna because of its precision. The unit can take off part of a copper layer, not just all the copper from a designated area.

Likewise, copper just happens to be the component removed to make a PCB. The ProtoMat is a general milling machine that can work with almost any kind of material including plastics. If you don't have a 3D printer handy, it might be easier to take a stock case and cut it to fit.

PROTOTYPE PRODUCTION

Desktop PCB machines like the ProtoMat are an order of magnitude more expensive than the 3D plastic printers, so designers may have to turn to outside sources for PCBs. Designers have been doing that almost since the electronics industry began, but the turnaround time has shrunk. Likewise, the world has turned to surface-mount technology, pushing the soldering iron into the corner of unused tools for prototypers.

Anyone who thinks a PCB is just a PCB hasn't looked at the technology in a while. PCB technology has always included a wide range of options, from the number of layers to the dielectric spacing. Surface mount, RF designs, and the European Union's Restrictions on Hazardous Substances (RoHS) all combine to make new PCB design a challenge.

The Internet has radically changed the way PCBs are delivered. The ordering process from vendors like Sunstone and ExpressPCB is streamlined, allowing extremely fast turnaround. Developers specify the board requirements, upload the design files, and wait for delivery of the final product.

PCB design applications available from most PCB vendors meet the needs of many developers. More advanced tools are available from third parties that support a range of data formats so developers can choose the tool that meets their requirements.

Also known as check for manufacturability (CFM), the design rules check (DRC) normally associated with PCB tools is just the starting point for ensuring developers get the kind of results they intend. Design for manufacturing (DFM), which is where cutting-edge prototypers are, typically is part of an overall product cost management (PCM) system. PCM also includes methodologies such as design for procurement, design for assembly, and cost targeting.

Incorporating these design methodologies into the design cycle is important as developers deliver prototypes that are closer to final products. It also means that the move from prototypes to production becomes faster as well.

Designers should consider the type of support their tools have for these methodologies. Bare-bones PCB tools often lack this kind of support, while high-end products provide extensive support for these processes as well as integration with other enterprise-level management tools.

PCB assembly services often can be tied together with PCB creation. Sunstone works with Screaming Circuits to provide this type of service. The process is obviously more involved because parts delivery or acquisition is added to the mix in addition to placement details and other specifications required for assembly, but the results can be a working system.

Again, the Internet has streamlined the configuration and order process for simple projects. More involved projects tend to require more personal intervention, but they also tend to be more ambitious and more costly.

POLISHED DEV KITS AND REFERENCE DESIGNS

Functional cases and PCBs are of little use if there isn't an application, which is where software and hardware designers

contribute to the product. Starting from scratch is a possibility, but these days a project is likely to start from a development kit or a reference design.

The improvements in development kits have been remarkable. What used to be a bare board with a chip and some patch area is now a complete kit that often includes a substantial amount of development and diagnostic software. Open-source software and open hardware design have driven these improvements as vendors compete to get their components adopted for new projects.

The Eclipse integrated development environment (IDE) is the basis for many different toolsets. Individual IDEs are likely to have substantial customization over the base Eclipse IDE with features such as multicore debugging, system configuration, and others that highlight the underlying hardware.

The amount of software and its quality continues to increase. For example, Texas Instruments released its TI-RTOS for its development kits along with the Eclipse-based Code Composer Studio. Freescale provides the MQX RTOS for many of its platforms. It is integrated with Freescale's CodeWarrior IDE, which also is based on Eclipse.

Many more IDEs and operating systems are available with various development kits. Developers rarely start with a bare board or chip. Demo applications and other middleware including a TCP/IP stack or a motor control library often can make a developer's job easier.

Of course, most development kits come with their own board support packages (BSPs), but this may not always be the case when moving to custom or semi-custom hardware. There are a number of places to turn when looking for most custom configurations. For example, real-time operating system (RTOS) vendors like TimeSys build custom BSPs plus software development kit (SDKs) and IDEs based on user selections on their Web site configuration tools.

The open-source Yacto project provides similar support. Many commercial vendors support and utilize Yacto's software and tools within their own offerings. It supports a range of architectures including ARM, PPC, MIPS, x86, and x86-64. It also includes the core system component recipes from the OpenEmbedded Project, which is a Linux framework. It supports a wide range of frameworks such as GTK+, Qt, and Windows as well.

Those new to the Yacto project can give it a whirl using the Yacto Project Build Appliance. It allows system creation using a non-Linux platform. The software, design recipes, and other information are kept in Git repositories that are available via the Internet, providing developers with the latest software and source code. Using these shared resources is one way to get a prototype up and running since developers can take advantage of available tools and applications.

Reference designs have also improved significantly. If you're going to be designing a tablet, you can get reference design kits from a number of vendors. These kits typically have some level of expandability, so designers can customize the system. They come with the operating system and all device drivers so developers can concentrate on their application.

Reference designs typically provide a 90% solution or better. Hardware can be turned into product quickly, and software incorporates most of the underlying support from the operating system on up.

The Bug Labs BUGbase isn't really a reference design, but it's often a great alternative to a less modular reference design for mobile applications *(see "Build With A Bug" at electronicdesign.com)*. It's possible to plug up to four modules into a BUGbase with an Arm Cortex-A8 inside. The modules can be anything from an LCD touchscreen to a digital camera. Some wireless support is built in with cellular found in a module.

Bug Labs delivers open-source hardware, so it's possible to turn a design into a custom product. Small runs could even be built on the BUGbase.

Module platforms often are used by prototypers that are more interested in adding their software to the mix. The open-source Raspberry Pi and Arduino series are two popular platforms. Arduino started with Atmel's 8-bit AVR processor, and a C IDE and training environment was built around it. Also, 32-bit Arduino platforms with the same form factor were built to handle Arduino "shields" like Digilent's chipKIT MAX32 based on Microchip's 32-bit MIPS microcontroller.

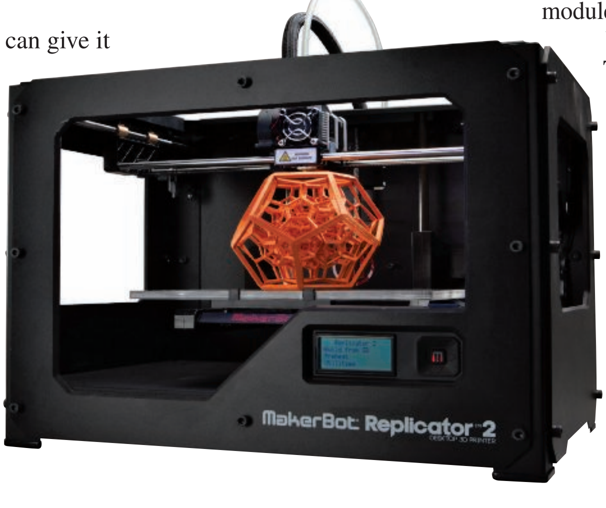
Modules offer prototype developers a way to build custom carrier boards that are usually less difficult to design. These boards are paired with a processor or system module that does the heavy lifting. The carrier provides connectors, power, and possibly some custom peripheral interfaces.

Modules like Opal Kelly's XEM6310 series pack in an FPGA and a SuperSpeed USB 3.0 interface. FPGA software design is still a challenge, but this alleviates the hardware design issues.

Gumstix offers a compact module suitable for mobile applications. In fact, Gumstix modules are used by some vendors providing display reference designs so developers can choose from a range of processor and peripheral options. The latest module has a dual-core Arm Cortex-A9.

Want to use the latest NVidia Tegra 4 with four Arm Cortex-A15 cores? Odds are a module will be the fastest way for most designers to get it into play.

Larger modules tend to come in standard form factors. COM Express and Qseven are two standards that have a variety of modules available from numer-



2. Makerbot's Replicator 2x can utilize a dual extrusion head, constructing objects using two different kinds of plastic.

ous vendors. They have different form factors, with more compact versions supporting mobile applications.

PROTOTYPING STUDIO

Smart-phone app development often is a software-only chore, but even smart-phone apps often need additional hardware. Sometimes it's plugged into the headphone jack or the USB connector found on many devices. The application isn't complete without that hardware.

The 3D printers already mentioned are sometimes an option for creating some of this hardware, but often a more robust workshop is required to turn an idea into a prototype. Many companies and individuals have the tools and expertise to do this, though designers often need to turn to outside sources for help or tools.

The TechShop is one of those spots where developers can gain access to tools and expertise that aren't common in the typical home or in most companies. TechShops can be found in a few major U.S. cities like Menlo Park in California and Detroit, Michigan.

Members have access to all the tools at the facility. If you're looking for a common tool, TechShop will have several available so there's no waiting. When it comes to larger items like the DETflowjet water jet, which can cut precisely through 6 inches of almost any material from metal to fabric, there may be only one available so it's a simple matter of scheduling time to get the job done *(Fig. 3)*.

3. TechShops members have access to a wide range of tools in electronics labs as well as metal and wood shops. Lead dream consultant Shawn Simone is using the DETflowjet water jet, which can cut precisely through 6 inches of almost any material.

4. Square's simple credit card reader is the type of hardware that can be easily prototyped with the right facilities like TechShop.

TechShop staff also provides training since safe operation is important and not everyone will be familiar with every tool. Likewise, TechShop is a good place to find a collaborator who might be able to handle unfamiliar work or generate an object or device when you lack the time or expertise.

TechShop isn't restricted to mechanical work, though it tends to be a significant portion of its toolset. Electronics and software are part of the mix as well. Square's iPhone credit card reader came out of a TechShop *(Fig. 4)*. Quite a number of other projects have evolved from prototypes to final products through the TechShop.

Of course, prototypes can be useful in funding new projects, and developers have been turning to Kickstarter to get funds. Venture capitalists are still an option, but Kickstarter offers a way to work directly with the customer.

A project on Kickstarter can have different types of supporters. Each supporter pledges a certain amount of money backed up by a credit card. A project goes forward if it receives some minimal amount of support that, in theory, provides the capital to complete the project. Supporters typically receive something in return. For example, Ouya's supporters get a game console and controller.

Different levels of support can provide supporters with different results. Ouya supporters who signed up for a more costly level got early delivery of a development platform with development software. Ouya already has delivered the NVidia Tegra 3-based development tools to those supporters.

INTERNET COLLABORATION

The Internet has had a major impact in shrinking the design cycle and raising the importance of prototype creation as early as possible. 3D desktop printers are affordable, and remote access to them is as common as getting a PCB generated by a third party.

Many companies are still physically located in one spot, but it's now possible to create virtual companies distributed across the globe. Collaboration tools are more effective, and video conferencing can provide face-to-face interaction.

3D printers can provide a way to distribute designs to various locations. Even delivery of PCBs and final boards can be used to support a disperse group of developers. Remote programming and debugging are possibilities if a particular device is unique or difficult to replicate at different locations.

Tools like 3D printers can be combined with customized reference designs to turn ideas into reality. These days, products can be produced for a lot less money, and the tools sit on the desktop. ed

LOUIS E. FRENZEL | COMMUNICATIONS EDITOR lou.frenzel@penton.com

AN INTRODUCTION TO LTE-ADVANCED: THE REAL 4G

The next generation of cellular technology is emerging faster than expected.

Long-Term Evolution (LTE) is being adopted around the world as the primary cell-phone communications service. Multiple 2G and 3G cellular radio methods are being phased out as carriers build their new LTE networks. It will be years before this expansion is complete, and older radio technologies like GSM and CDMA will coexist with LTE for a while *(see “The Evolution Of LTE,” p. 34)*.

LTE is probably the most complex wireless system that has ever been developed. It incorporates features that could not have been economically implemented as recently as a decade ago. Today, with large-scale ICs, LTE can be easily accommodated in basestations and in battery-powered handsets alike. The complexity is a function of the advanced wireless methods used as well as the many options and features that can be implemented.

In the meantime, the next phase of the LTE standards as put forth by the Third Generation Partnership Project (3GPP) is ready to be deployed.[1] Called LTE-Advanced (LTE-A), this significant upgrade to the LTE standard will provide more speed and greater reliability. While LTE-A is still being developed, some LTE-A service could begin late in 2013.

FREQUENCY & BANDWIDTH

LTE operates in some of the existing cellular bands as well as newer bands. Specific bands have been designated for LTE *(see the table)*. Different carriers use different bands depending upon the country of operation and the nature of their spectrum holdings. Most LTE phones use two of these bands, and they aren’t the same from carrier to carrier. For instance, Verizon’s iPhone 5 uses different bands than AT&T’s iPhone 5.

Most of the bands are set up for frequency division duplexing (FDD), which uses two separate bands for uplink and downlink. The spacing between FDD channels in bands 1 through 28 varies considerably depending on carrier spectrum holdings. Bands 33 through 44 are used for time division duplexing (TDD), so the same frequencies are used for both uplink and downlink.

LTE is a broadband wireless technology that uses wide channels to achieve high data rates and accommodate lots of users. The standard is set up to permit bandwidths of 1.4, 3, 5, 10, 15, and 20 MHz. The carrier selects the bandwidth depending on spectrum holdings as well as the type of service to be offered. The 5- and 10-MHz widths are the most common. Some bandwidths cannot be used in different bands.

MODULATION

LTE uses the popular orthogonal frequency division multiplex (OFDM) modulation scheme. It provides the essential spectral efficiency to achieve high data rates but also permits multiple users to share a common channel. OFDM divides a given channel into many narrower subcarriers. The spacing is such that the subcarriers are orthogonal, so they won't interfere with one another despite the lack of guard bands between them. This comes about by having the subcarrier spacing equal to the reciprocal of symbol time. All subcarriers have a complete number of sine wave cycles that upon demodulation will sum to zero.

In LTE, the channel spacing is 15 kHz. The symbol period therefore is 1/15 kHz = 66.7 μs. The high-speed serial data to be transmitted is divided up into multiple slower streams, and each is used to modulate one of the subcarriers. For example, in a 5-MHz channel, up to 333 subcarriers could be used but the actual number is more like 300. A 20-MHz channel might use 1024 carriers. The modulation on each can be quadrature phase-shift keying (QPSK), 16-phase quadrature amplitude modulation (16QAM), or 64-state quadrature amplitude modulation (64QAM) depending on the speed needs.

OFDM uses frequency and time to spread the data, providing high speeds and greater signal reliability *(Fig. 1)*. For each subcarrier, the data is sent in sequential symbols where each symbol represents multiple bits (e.g., QPSK 2 bits, 16QAM 4 bits, and 64QAM 6 bits.) The basic data rate through a 15-kHz subcarrier channel is 15 kbits/s. With higher-level modulation, higher data rates are possible.

Data to be transmitted is allocated to one or more resource blocks (RBs). An RB is a segment of the OFDM spectrum that is 12 subcarriers wide for a total of 180 kHz. There are seven time segments per subcarrier for a duration of 0.5 ms. Data is then transmitted in packets or frames, and a standard frame contains 20 time slots of 0.5 ms each. An RB is the minimum basic building block of a transmission, and most transmissions require many RBs.

The only practical way to implement OFDM, though, is to do it in software. The fast Fourier transform (FFT) handles the basic process. The transmitter uses the inverse FFT, while the receiver uses the FFT. The algorithms are implemented in a digital signal processor (DSP), an FPGA, or an ASIC designed for the process. The usual techniques of scrambling and adding error-correcting codes are implemented as well.

OFDM was chosen for LTE primarily because of its reduced sensitivity to multipath effects. At the higher microwave frequencies, transmitted signals can take multiple paths to the receiver. The direct path is the best and preferred but multiple objects may reflect signals, creating new signals that reach the receiver somewhat later. Depending on the number of reflected signals,

BANDS ALLOCATED SPECIFICALLY FOR LTE

LTE band number	Uplink (MHz)	Downlink (MHz)
1	1920 to 1980	2110 to 2170
2	1850 to 1910	1930 to 1990
3	1710 to 1785	1805 to 1880
4	1710 to 1755	2110 to 2155
5	824 to 849	869 to 894
6	830 to 840	875 to 885
7	2500 to 2570	2620 to 2690
8	880 to 915	925 to 960
9	1749.9 to 1784.9	1844.9 to 1879.9
10	1710 to 1770	2110 to 2170
11	1427.9 to 1452.9	1475.9 to 1500.9
12	698 to 716	728 to 746
13	777 to 787	746 to 756
14	788 to 798	758 to 768
15	1900 to 1920	2600 to 2620
16	2010 to 2025	2585 to 2600
17	704 to 716	734 to 746
18	815 to 830	860 to 875
19	830 to 845	875 to 890
20	832 to 862	791 to 821
21	1447.9 to 1462.9	1495.9 to 1510.9
22	3410 to 3500	3510 to 3600
23	2000 to 2020	2180 to 2200
24	1625.9 to 1660.9	1525 to 1559
25	1850 to 1915	1930 to 1995
26	859 to 894	814 to 849
27	852 to 869	807 to 824
28	758 to 803	703 to 748
33	1900 to 1920	1900 to 1920
34	2010 to 2025	2010 to 2025
35	1850 to 1910	1850 to 1910
36	1930 to 1990	1930 to 1990
37	1910 to 1930	1910 to 1930
38	2570 to 2620	2570 to 2620
39	1880 to 1920	1880 to 1920
40	2300 to 2400	2300 to 2400
41	2496 to 2690	2496 to 2690
42	3400 to 3600	3400 to 3600
43	3600 to 3800	3600 to 3800
44	703 to 803	703 to 803

their strengths, their ranges, and other factors, the signals at the receiver may add up in a destructive way, creating fading or signal dropout.

The multipath effects occur when the signals reach the receiver all within the time for one symbol period. A symbol is a modulation state that is either an amplitude, a phase, or an amplitude-phase combination representing two or more bits. When the multipath effects lead the signals to arrive at the receiver spread over several symbol periods, inter-symbol interference (ISI) occurs, producing bit errors.

These issues can be overcome with error detecting and correcting codes, but these codes add to the complexity of the system. An equalizer at the receiver that collects all the received signals and delays them so they all add can also correct for this problem but only further complicates the process.

Spreading the signals in the form of multiple subcarriers over a wide bandwidth reduces these effects, especially if the symbol rate on each subcarrier is longer as it is in OFDM. If the multipath effects occur in less than one symbol period, no equalizer is needed. Time or frequency shifts such as those that are produced by the Doppler effect in a moving vehicle cause frequency variation of the subcarriers at the receiver. This shift in frequency results in the loss of orthogonality and subsequently bit errors.

LTE mitigates this problem by adding a cyclical prefix (CP) to each transmitted bit sequence. The CP is a portion of an OFDM symbol created during the DSP process that is copied and added back to the front of the symbol. This bit of redundancy allows the receiver to recover the symbol if the time dispersion is shorter than the cyclical prefix. OFDM then can be implemented without the complex equalization that can also correct for this problem.

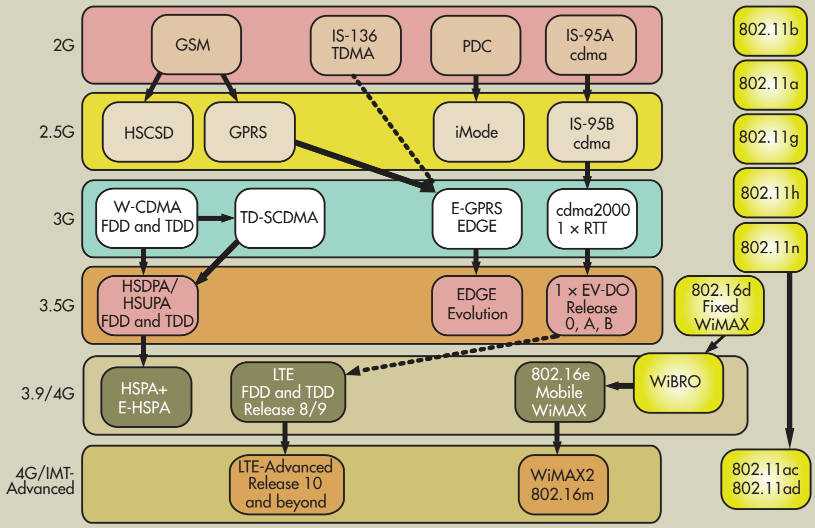
While LTE's downlink uses OFDM, the uplink uses a different modulation scheme known as single-carrier frequency-division multiplexing (SC-FDMA). OFDM signals have a high peak to average power ratio (PAPR), requiring a linear power amplifier with overall low efficiency. This is a poor quality for battery-operated handsets. While complex, SC-FDMA has a

THE EVOLUTION OF LTE

THE THIRD GENERATION Partnership Project (3GPP), the international organization that developed the widely used UMTS WCDMA/HSPA 3G standards, also developed Long-Term Evolution (LTE). Release 8 was completed in 2010, followed by release 9. Available now, release 10 defines the LTE-Advanced (LTE-A) standard.

Multiple cell-phone technologies designated by generations have led to LTE-A (see the figure). The first generation was analog (FM) technology, which is no longer available. The second generation (2G) brought digital technology with its benefits to the industry. Multiple incompatible 2G standards were developed. Only two, GSM and IS-95A CDMA, have survived.

The third generation (3G) standards were created next. Again, multiple standards were developed, notably WCDMA by the 3GPP and cdma2000 by Qualcomm. Both have survived and are still used today. The 3G standards were continually updated into what is known as 3.5G. WCDMA was upgraded to HSPA, and cdma2000 was expanded with 1xRTT EV-DO releases A and B. Both are still widely deployed.



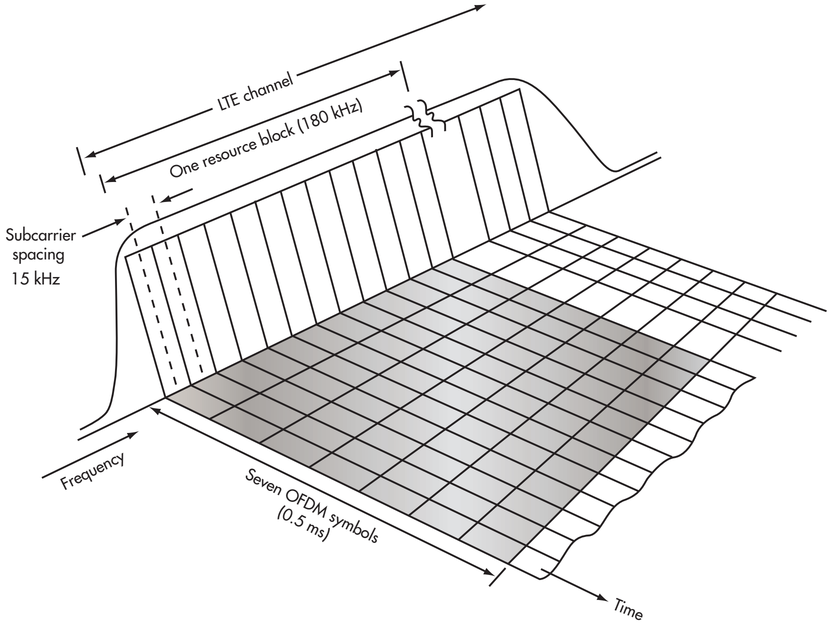
Cellular radio standards really left FM technologies behind in 1990 with 2G standards like GSM and IS-95A cdma. More than 20 years later, we're approaching true 4G with LTE-Advanced.

In fact, in many places around the world, carriers are still adding 3G or upgrading their 3G systems. In the U.S., AT&T and T-Mobile use GSM/WCDMA/HSPA while Verizon, Sprint, and MetroPCS use cdma2000/EV-DO. All of these carriers are building LTE networks.

LTE was created as an upgrade to the 3G standards. The cellular industry recognized its major benefits, and virtually every mobile carrier has embraced it as the next generation. All cellular operators are now on the path to implementing LTE. While 3GPP still defines LTE as a 3.9G technology, all of the current LTE networks are marketed at 4G. The real 4G as designated by 3GPP is LTE-A.

Currently, LTE is alive and functioning in many U.S. cellular companies and in others worldwide. The networks are not fully built out, and most of the older 2G and 3G systems are functioning in parallel. Since LTE coverage is not universal, most cell phones incorporate 2G and 3G systems for voice in areas where LTE is not yet deployed. LTE-A deployment is expected in 2014 and beyond.

LTE brings amazing new capabilities to the cellular business. First, it expands carrier capacity, meaning more subscribers can be added for a given spectrum assignment. Second, it provides the high data rates needed by growing new applications, mainly video downloads to smart phones and other Internet access. Third, it makes cellular connectivity more reliable. All of these needs are important to maintaining growth and profitability in the wireless business.



1. LTE transmits data by dividing it into slower parallel paths that modulate multiple subcarriers in the assigned channel. The data is transmitted in segments of one symbol per segment over each subcarrier.

lower PAPR and is better suited to portable implementation.[2, 3]

MIMO

LTE incorporates multiple-input multiple-output (MIMO), which uses two or more antennas and related receive and transmit circuitry to achieve higher speeds within a given channel. One common arrangement is 2x2 MIMO, where the first number indicates the number of transmit antennas and the second number is the number of receive antennas. Standard LTE can accommodate up to a 4x4 arrangement.

MIMO divides the serial data to be transmitted into separate data streams that are then transmitted simultaneously over the same channel. Since each signal path is different, with special processing they can be recognized and separated at the receiver. The result is an increase in the overall data rate by a factor related to the number of antennas. This technique also mitigates the multipath problem and adds to the signal reliability because of the diversity of reception.

The difficultly in implementing MIMO arises because of the small size of the handset and its limited space for antennas. Already, most smart phones include five antennas including those for all the different cellular bands plus Wi-Fi, Bluetooth, GPS, and perhaps near-field communications (NFC). Most phones probably won't feature more than two LTE MIMO antennas, and their inclusion will depend on whether or not they can be spaced far enough apart to preserve spatial diversity with sufficient isolation between them. Of course, it's easier to use more basestation antennas. A typical LTE arrangement appears to be 4x2 to provide optimal coverage with the space available.

DATA RATE

The data rate actually used or achieved with LTE depends on several features: channel bandwidth, modulation type, MIMO configuration, and the quality of the wireless path. In the worst-case situation, data rate could be only a few megahertz. But under good conditions, data rate can rise to more than 300 Mbits/s. On average, most practical LTE downlink rates range from 5 to 15 Mbits/s, which is faster than some fixed Internet access services using cable or DSL.

ACCESS

Access refers to using the same channel to accommodate more than one user. This is effectively a multiplexing method. Standard methods include frequency

2. The Agilent N7109A multi-channel LTE signal analyzer handles up to 8x8 MIMO channels.

division multiple access (FDMA), time division multiple access (TDMA), and code division multiple access (CDMA). GSM uses TDMA by dividing a single channel into multiple time slots. In 2G and 3G CDMA systems, code division uses unique coding for each user with a single bandwidth.

OFDM now offers OFDM Access (OFDMA), which uses some of the available subcarriers and time slots within those subcarriers for each user. The number of subcarriers and time slots used depends on multiple factors. In any case, it's usually possible to accommodate up to hundreds of users per channel bandwidth.

TD-LTE

Most LTE will be of the FDD variety at least in the United States, Europe, and parts of Asia. However, TD-LTE is being widely implemented in China and India because of the nature of their spectrum availability. TD-LTE conserves spectrum and provides for more users per megahertz. The LTE standards include a definition for TD-LTE. Some U.S. carriers will use TD-LTE including Clearwire and Sprint.

LTE-ADVANCED

LTE-A builds on the LTE OFDM/MIMO architecture to further increase data rate. It is defined in 3GPP releases 10 and 11. There are five major features: carrier aggregation, increased MIMO, coordinated multipoint transmission, heterogeneous network (HetNet) support, and relays.

Carrier aggregation combines up to five 20-MHz channels into one to increase data speed. These channels can be contiguous or non-contiguous as defined by the carrier's spectrum assignments. With maximum MIMO assignments, 64QAM, and 100-MHz bandwidth, a peak downlink data rate of 1 Gbit/s is possible.

LTE defines MIMO configurations up to 4x4. LTE-A extends that to 8x8 with support for two transmit antennas in the handset. Most LTE handsets use two receive antennas and one transmit antenna. These MIMO additions provide future data speed increases if adopted.

HetNet support refers to support for small cells in a larger overall heterogeneous network. The HetNet is an amalgamation of standard macrocell basestations plus microcells, metrocells, picocells, femtocells, and even Wi-Fi hotspots. This network increases coverage in a given area to improve connection reliability and increased data rates.

Coordinated multipoint transmission, also known as cooperative MIMO, is a set of techniques using different forms of MIMO and beamforming to improve the performance at cell edges. It uses coordinated scheduling and transmitters and antennas that aren't collocated to provide greater spatial diversity that can improve link reliability and data rate.

Relays use repeater stations to help coverage in selected areas, especially indoors where most calls are initiated. LTE-A defines another basestation type called a relay station. It's not a complete basestation but a type of small cell that will fit in the HetNet infrastructure and provide a way to boost data rates and improve a wireless link's dependability.

Some deployment of LTE-A is expected in late 2013 with increasing adoption in 2014 and beyond. LTE-A is forward and backward compatible with basic LTE, meaning LTE handsets will work on LTE-A networks and LTE-A handsets will work on standard LTE networks.

LTE-A DESIGN CHALLENGES

LTE solves many problems in providing high-speed wireless service. There is no better method, at least for now, but it does pose multiple serious design issues. The greatest problem is the necessity of having to use multiple bands that often are widely spaced from one another. As a result, multiple antennas, multiple power amplifiers, multiple filters, switching circuits, and, sometimes, complex impedance matching solutions are required. Each cellular operator specifies cell phones for its spectrum.

In addition, the power amplifiers (PAs) must be very linear if error vector magnitude (EVM) is to be within specifications for the various multi-level modulation methods used. Linear amplifiers are inefficient and consume the most power in the phone except for the touchscreen. The need to cover multiple bands necessitates the use of multiple PAs. Battery life in an LTE phone is typically shorter as a result. The need to include MIMO also means additional antennas and PAs.

Solutions to these problems lie in fewer yet more efficient PAs. Also, wider-bandwidth antennas solve the multiband problem. Companies like Ethertronics and SkyCross are designing tunable antennas as well to cover multiple bands with a single structure.

Another challenge is test. Several test companies have created systems to test LTE systems with MIMO, which can be a particularly complex process. One of the greatest challenges is testing the higher-level MIMO configurations. LTE-A permits up to 8x8 MIMO. Agilent's N7109A multi-channel MIMO analyzer is designed to work with the company's 89600 vector signal analyzer (VSA) and related Signal Studio software to test LTE-A in all its various configurations *(Fig. 2)*.

VOICE OVER LTE

LTE is a packet-based IP data network. It doesn't include a voice service yet, though one is planned. Today, if you're using an LTE smart phone, you're still using the existing 2G or 3G network for what is called circuit-switched voice service. Voice over LTE (VoLTE) eventually will be implemented. VoLTE is just Voice over Internet Protocol (VoIP) over LTE, and it will operate simply as a data application on the IP network.

While a VoLTE protocol has been defined, implementation requires major engineering decisions and network changes, mostly concerning maintaining voice connections for older non-LTE phones for some extended period. Particularly tricky are the changes that will allow LTE phone users to get voice service if they move into an area that doesn't have LTE.

When VoLTE is available, subscribers could initiate a call using the LTE system but drive out of the LTE coverage area. Systems must be able to hand that call off to a traditional voice network. The mechanism for this, network software called circuit-switched fallback (CSFB), is now available on most networks. Another issue is getting VoLTE into the handsets. VoLTE requires a separate chip in the phone, and few phones have such a capability today.

VoIP also requires a vocoder, a circuit that is essentially an analog-to-digital converter (ADC) to digitize the voice signal and a digital-to-analog converter (DAC) to convert the digital voice back into analog voice for the user. A vocoder also incorporates voice compression, a technique that effectively minimizes the number of bits used to represent voice. Voice then can be transmitted faster but at lower data rates so it doesn't occupy much bandwidth.

LTE uses the Adaptive Multi-Rate (AMR) vocoder, which also is used in GSM systems and other 3GPP standards. It has a variable bit-rate capability from 1.8 to 12.2 kbits/s. Digitized voice is then assembled into AMR packets and then into IP packets that are scheduled into a transmission sequence. A call is allocated to some of the OFDMA subcarriers and to some of the time slots within the bit streams of each subcarrier.

All of the needed phone and network changes will take time, so VoLTE isn't widespread. Carrier MetroPCS has it now on its LTE network and Verizon has VoLTE in trials, as do most other major carriers. However, there will be very little VoLTE activity until 2014 and beyond.

WAITING FOR 5G

It will take a decade or more for LTE and especially LTE-A to dominate cellular coverage. Furthermore, new LTE releases are yet to come. In addition, some provisions of current LTE releases have yet to be implemented, such as self-organizing networks (SONs), which make networks easier to plan, configure, optimize, and manage.

With SON, all basestations would be self-configuring taking into account nearby basestations and using internal algorithms to heal, self-optimize, and adapt to new nearby stations and other conditions. The small-cell movement is definitely LTE-based, and extensive deployment with SON is yet to come. In addition, new higher-frequency spectrum such as 3550 to 3650 MHz will be found, making it possible to extend 4G well into the future.

In the meantime, research continues into the "next big thing," more specifically the fifth generation (5G) of cellular wireless. 5G may simply stay on the same path as 4G and LTE, using higher frequencies and wider bandwidths to achieve even higher data rates. With semiconductor technology still viable at ever-smaller IC feature sizes, operation well into the hundreds of gigahertz is possible.

Already, advanced millimeter wave (30 to 300 GHz) systems are functioning with advanced chipsets in short-range personal-area networks (PANs) for home video transfer (60 GHz), automotive radar (77 GHz), and cellular/hotspot backhaul (80 GHz). Some experts think the 28-GHz and 38-GHz spectrum segments offer good opportunities for cellular. Because of the higher frequencies, range is shorter, meaning more but smaller cell sites.

However, by using higher-gain antenna arrays and beamforming, coverage will be reliable and the available bandwidth will permit download data rates as high as 10 Gbits/s. It's something to look forward to. ed

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

ROHS 2 CREEPS UP ON THE INDUSTRY

As RoHS recast compliance rules take effect in Europe, concern lingers over companies' preparedness to meet the new requirements.

Gary Nevison and the folks in the element14 community are doing their part to educate the electronics community about new requirements of the RoHS Recast 2011/65/EU, an update to the European Restrictions on Hazardous Substances (RoHS), which took effect on January 2. Element14 has posted an updated e-book and several webinars detailing the new requirements on element14.com, and Nevison may soon be on the lecture circuit delivering that message to suppliers, customers, trade organizations, and others selling electronic components and finished products in Europe. Nevison is head of legislation and compliance for Premier Farnell, element14's parent company, and he says the requirements of the RoHS update are taking many in the industry by surprise.

"I think there are many areas of industry not aware of this," explains Nevison, pointing to new requirements for designating products with a CE mark, which means they conform to European standards, in particular.

The new requirements are part of a scheduled revision to the RoHS directive, known as the RoHS recast, which began in 2010. The new requirements update the original 2006 directive, which banned the use of six substances—lead (Pb), mercury (Hg), hexavalent chromium (Cr (VI)), cadmium (Cd), polybrominated biphenyl flame retardants (PBB), and polybrominated diphenyl ether flame retardants (PBDE)—in eight categories of electrical and electronic equipment. RoHS 2, as it is known, broadens the scope of the directive to include additional products and product categories and makes RoHS compliance a CE directive, placing more data collection work on companies throughout the supply chain.

Some industry watchers say RoHS 2 has fallen off of many companies' radar screens because it was a much bigger deal due to its newness in 2006. Quite simply, companies have been through it once, are largely familiar with the issue, and have procedures in place to address it. Further complicating the issue for American distributors is local legislation on counterfeit components and conflict minerals that is drawing more immediate attention. But Nevison and others caution against putting RoHS 2 on the back burner as environmental concerns become more acute worldwide and the regulatory climate heats up.

"Make no mistake about it, the authorities will be on this. They will come to check you for these technical files," Nevison says, pointing to the need for documentation that products comply with European Union directives. He adds that each European state retains the responsibility for enforcing the rules under RoHS 2. "These are the facts. It's getting more stringent rather than the other way around."

MORE PRODUCTS, MORE DOCUMENTATION

Identifying products with a CE mark, which stands for Conformité Européenne (or European Conformity), ensures that they comply with EU regulations. The CE Mark directive places more data collection work on distributors and importers as they seek to verify RoHS compliance, Nevison explains.

"The main impact on industry is the inclusion of RoHS as a CE directive," says Nevison. "[Companies] need to supply lots of new documentation. The CE Mark is the biggest challenge to us at this point in time."

In most cases, manufacturers are responsible for documentation and CE Mark designation, but in some instances the responsibility falls to the distributor or importer—especially when the distributor is selling the product under its own brand. The issue is further complicated because the CE Mark now applies to low-cost development boards, which is a sticking point for many manufacturers.

"I think some companies in all honesty didn't think they needed to comply, but in most cases they do," says Nevison, pointing to differing views over how development boards or kits are classified. "I think what deceives people is that these small, open PCBs don't look like a piece of finished equipment. But as soon as they're plugged into a PC to make them work, if you like, they are classed as finished equipment."

"I think some companies in all honesty didn't think they needed to comply, but in most cases they do," says Gary Nevison, head of legislation for Premier Farnell. "I think what deceives people is that these small, open PCBs don't look like a piece of finished equipment. But as soon as they're plugged into a PC to make them work, if you like, they are classed as finished equipment."

Development boards that were already on the market before January 2, 2013, do not need to be remarked. RoHS 2 applies to any development boards or kits placed on the market after that date. Nevison says many development kit suppliers are surprised to learn that their products are in scope.

The other key issue is the broadened scope of the directive itself. RoHS 2 includes products that depend on electric currents or electromagnetic fields for at least one of their functions. Previously, the directive applied only to products that depended on electric currents or electromagnetic fields to work properly. This widens the field of covered products.

Nevison points to two typical examples: a gas stove with an electric clock and a gasoline-powered lawnmower with an electric ignition, neither of which was covered under RoHS 1. These examples will be in scope as July 2019 under categories one and six of the directive, respectively.

"So it will capture some different products," he says. "And it's worth saying there are lots of exclusions this time. Those will be reviewed by July 2014, and they may even be extended."

RoHS 2 has a number of phase-in dates for new product categories as well. Medical devices and consumer monitoring and control equipment must be in compliance by July 2014, with in vitro diagnostics coming into scope in 2016 and industrial monitoring and control instruments in July 2017. What's more, RoHS 2 adds an eleventh category in July 2019 when all electrical and electronic equipment not captured in categories 1 to 10 comes into scope, unless specifically excluded.

Nevison emphasizes that revisions are ongoing, noting that the commission overseeing the RoHS directive plans to review more substances next year while also considering whether or not further exclusions should be granted.

Robin Gray, COO for the Electronic Components Industry Association, which represents manufacturers, distributors, and independent representatives in the electronics industry, says the modifications to the RoHS directive are part of a larger trend toward increased regulation worldwide. He points to pending RoHS legislation in China, new U.S. rules surrounding conflict minerals sourcing, varying state-level bans on certain chemicals in the U.S., and the simmering concern over the supply of rare earth minerals commonly used in electronics equipment.

"I think the industry's going to see more and more regulation—environmentally or otherwise," says Gray. "The other issue is that so much of electronics uses rare earth minerals, and the supply of that is relatively limited—and some very limited. If you're going to ban certain metals or certain chemicals, how viable are certain components for the long term? You've got to find new technologies, processes, or chemical formulas, or you've got to be willing to make a trade off. I think this is only going to become more of an issue."

BOOMING LED MARKET DELIVERS SAVINGS

LED technology remains a bright spot in the electronics supply chain, and distributors focused on delivering lighting solutions are reaping big benefits from new projects. Future Electronics' recent completion of a street lighting retrofit in Israel is a case in point.

The distributor partnered with supplier Bright LED to retrofit new street luminaires in Carmel Center in Haifa. The project marked the city's first step in converting to LEDs to save money and increase the efficiency of its more than 30,000 street lights. Some of those lights were converted to LEDs in the Carmel Center project. The project tested the feasibility of moving the city's entire network to LEDs, and now Bright LED and the city are in talks to move on to phase two.

Haifa officials say LED lighting fits perfectly with the city's desire to "go green" while reducing electricity and maintenance

costs. As municipalities around the world set similar goals, supply chain companies are betting on lighting as a key business driver. Future Electronics formed its Future Lighting Solutions group more than 10 years ago to capitalize on the growing popularity of LED technology and hasn't looked back.

"Now, energy efficiency is the focus. People are adopting [new] technology faster because of energy efficiency and the total cost perspective," says Future Electronics executive vice president Lindsley Ruth.

LIGHTING THE WAY

LEDs performed well in the market as 2012 came to a close, with continued strong demand expected in lighting as well as in other applications. A December report from IHS iSuppli pointed to the LED segment as a pillar of strength in an otherwise weak semiconductor market. The global semiconductor market was set to shrink 2% last year, IHS said, with a tentative rebound set for late in the first quarter of 2013.

"The one segment that seemed to have remained untouched this year was the robust light-emitting diode (LED) market, thanks to the LED lighting boom that has taken hold in many parts of the world," said IHS principal analyst Robbie Galoso.

Indeed, third-quarter LED sales for lighting manufacturer Philips grew more than 50% and represented nearly a quarter of the firm's total lighting sales as of last fall. Other LED lamp makers reported strong sales through the end of the year as well, with Cree, for one, posting 17% growth in its 2013 fiscal first quarter ended September 23.

But lighting isn't the only category in which LEDs are making headlines. Manufacturers were showcasing a range of new applications at the 2013 International CES in Las Vegas last month, adding more fuel to the LED fire. Advances in high-brightness LEDs are yielding new applications, particularly in home-based entertainment systems and appliances.

LED maker Luminus Devices offered a glimpse at the newest advances in projection displays, for instance, with a look at consumer LED projectors with features that rival the latest flat-panel TVs, with one key exception: the projectors can easily move around the house and turn any room into a 100-inch+ home theater, says Stephane Bellosguardo, director of global product marketing, display business group at Luminus.

"We have aggressively continued our R&D, product innovation, and advanced performance-based developments. These allow our customers to develop new product strategies around solid-state light sources and enable new and exciting consumer electronic appliances, not only in traditional business and education markets, but now in the much larger consumer markets," Bellosguardo says.

SMART PHONES AND APPS DOMINATE CONSUMER ELECTRONICS

Distributors serving the burgeoning consumer electronics market still have their eyes on the growing demand for smart phones and similar gadgets as consumers demand more from their mobile devices—and the real money is on apps and the technology needed to make mobile devices do even more.

A technology shift from hardware toward features and applications is driving much of the change in the smart-phone market, as the devices are increasingly used for non-communication functions, according to the Consumer Electronics Association. Attendees at last month's International CES in Las Vegas noted similar trends, pointing to growing demand for more features in everything from smart phones to tablet PCs.

"Tablet and smart-phone demand remains strong, particularly as price reductions attract new consumers," says Todd Traylor, vice president of global trading for N.F. Smith and Associates, an independent distributor based in Houston. "Beyond the expanding competition for tablets, 'phablets' [phone/tablet hybrids], and smart phones, [the International CES] reveals how the feature envelope is being pushed to both unify and expand users' mobile experiences."

And that comes down to the software and electronic components used to power the gadgets. On the components side, Traylor and others point to the growing use of sensors in consumer electronics.

"Devices like smart phones are making increasing use of sensors that allow the digitization of everyday things," according to IHS iSuppli. "Specific types of applications mentioned included infrared, near-field communications, and moisture sensors that tell users when their plants need to be watered."

"Notably, there are many examples at CES of increased capabilities for devices connecting via wireless sensors over the latest 802.11ac Wi-Fi standard and Bluetooth," Taylor says. "Perhaps the most prolific merging of sensors, power management, and wireless chips is the wireless charging that seems to be sweeping CES this year."

Others point to microelectromechanical systems (MEMS) as a key growth category. MEMS commonly serve as sensors in smart-phone applications, including gyroscopes, accelerometers, and pressure sensors. Global revenue for MEMS in consumer and mobile applications is expected to reach $3.2 billion this year, up more than 20% from $2.6 billion in 2012. Revenue will reach nearly $5 billion by 2016, IHS said.

Analysts expect similar growth in smart phones and apps. IHS predicts global smart-phone shipments will rise nearly 30% in 2013, a slowdown from the 35% growth seen last year and the more than 60% growth in 2011. However, 2013 marks the first year smart-phone shipments will represent more than 50% of cell-phone shipments worldwide.

Global smart-phone app store revenue also will more than double between 2012 and 2016 after more than doubling in 2011. IHS expects worldwide app store revenue to climb nearly 50% in 2013 to reach about $8 billion.


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FASTER JESD204B STANDARD PRESENTS VERIFICATION CHALLENGES

The new 12.5-Gbit/s interface for data converters lacks an official compliance test specification, but all is not lost as the standards document provides enough detail to develop PHY timing and protocol test procedures.

JESD204B IS A new 12.5-Gbit/s serial interface standard for high-speed, high-resolution data converters. Already, devices from converter manufacturers are beginning to make their way into the market, and the number of JESD204B-enabled products is expected to increase tremendously in the near future. The primary value of the JESD204B interface is a reliable increase in the data transfer bandwidth between a converter and a logic device such as an FPGA or ASIC.

As with any new interface, JESD204B brings new challenges. For system developers, the challenges are how to best implement JESD204B from a printed-circuit board (PCB) design standpoint and how to debug a system if something isn't initially working right. For component manufacturers, challenges involve testing new JESD204B devices. Testing not only ensures that specifications are being met in a relatively ideal environment, it also ensures successful JESD204B operation in end system environments.

FRANK FARRELLY is a product engineering manager at Analog Devices. He has been with the company for 19 years. He holds a BSEE from the University of Tennessee, Knoxville, and an MBA from the University of North Carolina, Greensboro.

CHRIS LOBERG is a senior technical marketing manager at Tektronix responsible for oscilloscopes in the Americas Region. He has held various positions with Tektronix during his more than 13 years with the company. He earned an MBA in marketing from San Jose State University, Calif.

A NATURAL EVOLUTION

Data converters are used in many applications ranging from audio and music to test instrumentation. The world of data converters is evolving. As the bit depth and sample rate go up, it is becoming more and more difficult to get data in and out.

A decade or two ago, with sample rates for high-speed converters limited to 100 Msamples/s and below, using transistor-transistor logic (TTL) or CMOS parallel data busses was sufficient. For example, a 12-bit converter with 12 pins dedicated to data could be implemented with reasonable setup and hold times with respect to the clock.

As speeds increased above 100 Msamples/s, setup and hold times for single-ended signals no longer could be maintained. To boost speeds, high-speed converters moved to differential signaling, but at the cost of increased pin counts. For example, a 12-bit converter now would need 24 pins dedicated to data.

To address the pin count issue, serial data interfaces were adopted. A converter data interface with 6x serialization now allows that same 12-bit converter to transfer data with just two differential I/Os (only four pins). Fast forwarding to today, data converters are now being developed using the JESD204B specification for the data interface.

The JEDEC standards organization has published two versions of the JESD204 high-speed serial digital interface specification. The first, JESD204 2006, brought the advantages of SERDES-based (serializer-deserializer) high-speed serial interfaces to data converters with a 3.125-Gbit/s maximum speed rating. It was revised in 2008 (JESD204A 2008), adding important enhancements including support for multiple data lanes and lane synchronization.

1. Jitter represents a potential point of confusion for JESD204B testing as terminology varies in the standards documents provided by OIF compared to terms used in standard Dual-Dirac jitter models from Tektronix (that now includes bounded uncorrelated jitter as shown) and other test equipment vendors. The table provides a handy translation of those terms.

Comprising about 65 members from 25 companies, the international JEDEC JC-16 Task Group (Project 150.01) developed the second version of the specification, JESD204B.[1] Its major enhancements included a higher maximum lane rate, support for deterministic latency through the interface, and support for harmonic frame clocking.

LACK OF AN OFFICIAL COMPLIANCE TEST SPECIFICATION

Unlike many other high-speed serial interface standards, JESD204B doesn't include an official compliance test specification. A test specification is doubly valuable because it lists the tests that must be performed to ensure compatibility as well as the procedures for doing those tests. Consistent procedures used by different manufacturers help ensure a common understanding of the specification and eliminate differences in assumptions.

The lack of an official compliance test specification does not mean all is lost, though. All of the information needed to develop a set of tests and procedures can be found in the JESD204B specification and the specifications it refers to. Individual chip manufacturers and system developers must pull together that information.

PHY TESTING

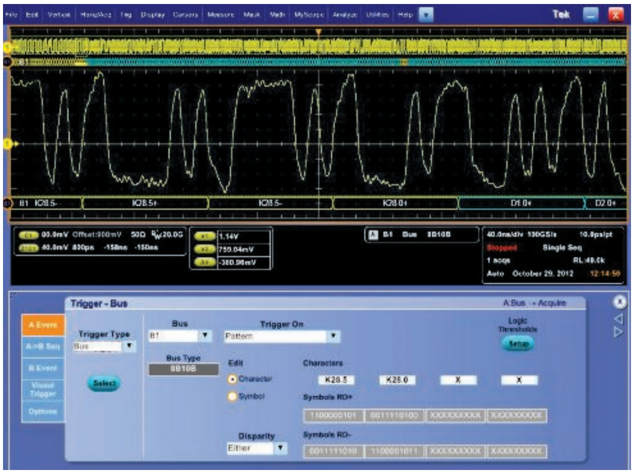
Physical-layer (PHY) tests are related to the individual data lane driver and receiver circuitry—in other words, the analog tests of a link. They do not include digital functionality or procedural tests. Working toward the development of a thorough list of PHY tests, a list of recommended SERDES PHY tests can be obtained from the OIF-CEI-02.02 specification, section 1.7.

The JESD204B specification closely follows those recommendations, but it does include a few modifications. For example, JESD204B does not specify random jitter as a standalone test item, including it under total jitter instead. Also, JESD204B specifies JSPAT, JTSPAT, and modified RPAT as recommended test patterns whereas OIF-CEI-02.0 specifies using the PRBS31 pattern.

Above and beyond the required PHY tests, additional PHY tests that aren't listed in OIF-CEI-02.0 or in the PHY section of the JESD204B specification could be performed. One can look to other SERDES compliance test specifications for examples and find tests such as intra-pair skew (for a Tx) and intra-pair skew tolerance (for an Rx).

These tests don't necessarily need to be added to the JESD204B specification, though. Additional PHY tests are not required to ensure JESD204B compatibility. But if a particular PHY test is failing, other PHY tests can be used to help gain insight as to why.

Once the list of tests is set, limits for those tests can be obtained from the JESD204B specification. Just keep in mind that there are three sets of limits, LV-OIF-11G-SR, LV-OIF-6G-SR, and LV-OIF-SxI5. A particular JESD204B device may support more than one set of limits. In that case, the component should be tested against all of the supported sets of limits.



2. Today's performance oscilloscopes are equipped to decode incoming waveforms to display 8b/10b data such as that used in JESD204B. This Tektronix oscilloscope is performing a serial decode of a JESD204B data lane at 6 Gbits/s at the beginning of the initial lane alignment sequence (ILAS).

One point of potential confusion with JESD204B PHY testing is jitter terminology. JESD204B and OIF-CEI-02.0 use different terminology from what the test equipment vendors use *(Fig. 1)*. Test equipment makers base their terminology on the industry standard Dual-Dirac jitter model. This difference in terminology is a point of potential problems in test procedures, as jitter is a quite tricky topic *(see the table)*.

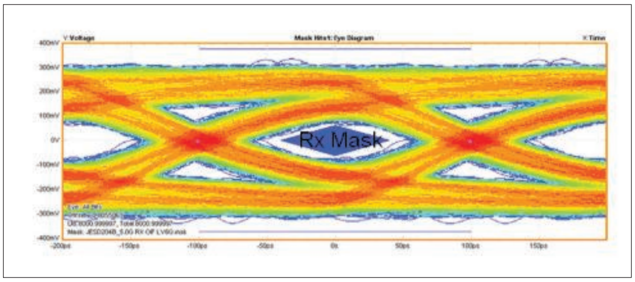
Another point of potential confusion with JESD204B PHY testing is the eye mask for data rates above 11.1 Gbits/s. The JESD204B specification says that for data rates greater than 11.1 Gbits/s, a normalized bit time of 11.1 Gbits/s should be used. So if you're running at 12.5 Gbits/s (with an 80-ps bit period), the bit period for 11.1 Gbits/s (90.9 ps) should be used.

The issue at hand here is that eye masks can be built by starting either at the edge of the user interface (UI) or from the center of the UI, and the JESD204B does not clearly state which reference point to start from. If the reference point is the center of the UI, then the eye mask is bigger than normal at 12.5 Gbits/s, making it harder for a Tx to pass but easier for an Rx to work. If the reference point is the edge of the UI, then the eye mask is smaller than normal at 12.5 Gbits/s, making it easier for a Tx to pass but hard for an Rx to work. Ultimately, until this question is resolved, you should test against each of the two mask options to ensure compatibility.

TIMING TESTING

Coming up with a thorough list of timing tests for JESD204B is not an easy task. There are at least a dozen timing diagrams throughout the specification and it's not immediately apparent which apply to the Tx, the channel, or the Rx. Also, some only apply to a particular subclass (0, 1, or 2). An official compliance test specification would be especially helpful here if it were to simply consolidate the timing specifications into a single table. Once time is taken to methodically go through the timing specifications, there is no confusion about them.

One nice thing about timing for system developers is that specifying timing for a JESD204B component turns out to be easier than is immediately apparent from the specification. For subclass 0 and 2, only Device Clock-to-SYNC~ timing must be specified. For subclass 1, only Device Clock-to-SYSREF timing must be specified.



3. The eye diagram at the end of an ISI PCB trace can be directly measured by an oscilloscope and compared against the JESD204B Rx mask to determine if there are unacceptable levels of insertion loss. Compare this nearly closed eye to the one in Figure 4.

PROTOCOL TESTING

As with the PHY tests, there is no official list of JESD204B protocol tests. Therefore, each user must scour through the specification and compile a list of functions to test. For example, the test sequences are one category of protocol tests.

For PHY testing, JESD204B transmitters must be able to output JSPAT and modified RPAT patterns. From a protocol standpoint, there's a need to validate that those patterns are correct. The same is true with JESD204B receivers and the JTSPAT pattern. Optionally, if they support PRBS patterns, those need to be validated as well.

Next, the short and long transport layer patterns are included to help system developers debug their systems by proving that the link is working correctly through the transport layer. From a component manufacturer standpoint, those transport layer patterns have to be validated for every mode of operation that the device supports, which, considering the number of link configuration variables, ends up being a lot of cases.

One question that comes up regarding protocol testing is how to do it at 12.5 Gbits/s. One solution is to use a high-speed oscilloscope with a serial data decoder. Many higher-end oscilloscopes now come with a dedicated trigger chip for triggering on 8b/10b data such as that used in JESD204B *(Fig. 2)*.

Another group of protocol tests can be built around the initial lane alignment sequence (ILAS). The ILAS as a whole is fairly complex, so breaking it down into its individual components can make protocol testing more meaningful. Some tests can be measured on a transmitter to validate its operation.

For example, is the multiframe length correct? Does each multiframe start with a /R/ control code and end with a /A/ control code? Is the /Q/ control code in the right location? Is the link configuration data correct and in the right location? Does the ILAS contain data? How many multiframes does the ILAS last? Is the ILAS the same on all lanes? Clearly, there is a lot of potential for protocol testing around the ILAS sequence.

JESD204B does not have a lot of handshaking, but what it does have can be tested. Depending on the subclass, a number of tests can be performed. Since the SYNC~ signal can be used for initial handshaking, error reporting, and link re-initialization, do the Tx and Rx components do their part accordingly? Does the Rx assert SYNC~ starting at the right time and for the right duration? Does the Tx react correctly based on the duration of SYNC~ assertion? Since the data sent over the link also plays a part in the handshaking (i.e., the ILAS), is it correct for its content and with respect to SYNC~ timing?

Next, some smaller digital functions need to be tested as a part of protocol including scrambling, 8b/10b encoding/decoding, skew and skew tolerance, control bits, tail bits, SYNC~ signal combining, frame alignment monitoring, and correction. All of these functions need to be validated.

Lastly, there is the error handling category of protocol tests. The specification includes a minimum set of errors that must be detected and reported: disparity errors, not-in-table errors, unexpected control character errors, and code group synchronization errors, but many more potential errors could be detected and reported. For each and every type that is detectable by a JESD204B component, there should be a protocol test.

These types of protocol tests can be a bit of a challenge to test and validate because a properly working link will never exercise them. They generally will require specialized test equipment. A bit error rate test (BERT) pattern generator can be used for many tests by creating a pattern that includes an error. Error cases can also be generated using an FPGA with code modified to specifically generate those errors.

EMPHASIS AND EQUALIZATION TESTING

The JESD204B specification covers very little about emphasis and equalization. There are a few comments like "pre-emphasis might be required" and "equalization might need to be implemented," from which one can determine that the specification allows them but does not give any additional guidance.

When using a converter with JESD204B that includes emphasis or equalization, how does one go about deter-

DESIGN NOTES

20V, 2.5A Monolithic Synchronous Buck SWITCHER+ with Input Current, Output Current and Temperature Sensing/Limiting Capabilities

Design Note 511

Tom Gross

Introduction

The LTC®3626 synchronous buck regulator with current and temperature monitoring is the first of Linear's SWITCHER+™ line of monolithic regulators. It is a high efficiency, monolithic synchronous step-down switching regulator capable of delivering a maximum output current of 2.5A from an input voltage ranging from 3.6V to 20V (circuit shown in Figure 1). The LTC3626 employs a unique controlled on-time/constant-frequency, current-mode architecture, making it ideal for low duty cycle applications and high frequency operation, while yielding fast response to load transients (see Figure 2). It also features mode setting, tracking and synchronization capabilities. The LTC3626's 3mm × 4mm package has such low thermal impedance that it can operate without an external heat sink even while delivering maximum power to the load.

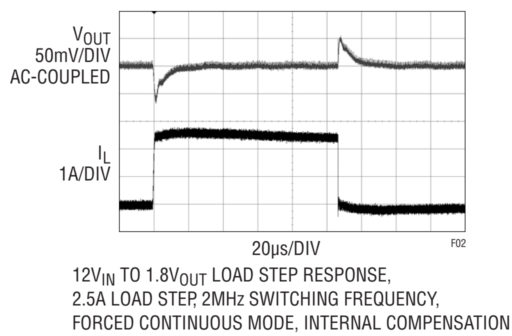


Figure 2. Load Step Response for Figure 1 Circuit

Beyond its impressive regulator capabilities, the LTC3626's current and temperature monitoring functions stand out. They offer both monitoring and control capabilities with minimal additional components.

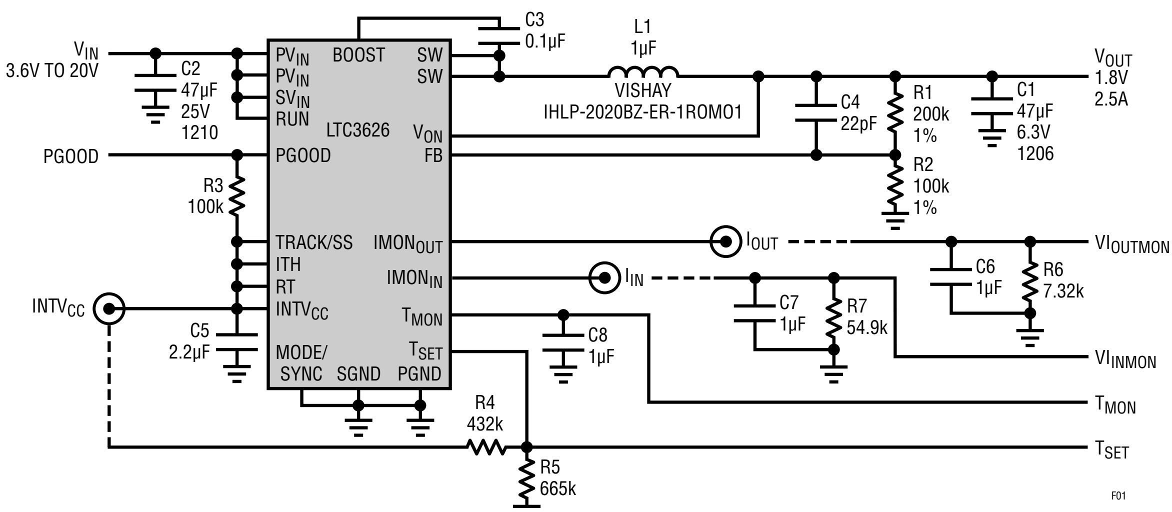


Figure 1. 20V Maximum Input, 2.5A, 2MHz Buck Regulator with Current and Temperature Monitoring

Output/Input Current Sensing

The LTC3626 senses the output current through the synchronous switch during the switch's on-time and generates a proportional current (scaled to 1/16000) at the $IMON_{OUT}$ pin. Figure 3 shows the accuracy of the $IMON_{OUT}$ output by comparing the measured output of the $IMON_{OUT}$ pin with calculated values. Error remains less than 1% over most of the output current range.

Likewise, this same sense current signal is combined with the buck regulator's duty cycle to produce a current proportional to the input current—again by 1/16000—at the $IMON_{IN}$ pin. A precision of better than 5% is achieved over a wide current range (see Figure 4).

Both current signals are connected to internal voltage amplifiers, referenced to 1.2V, that can shut down the part when tripped. So the input and output current limits are set by simply connecting a resistor to the $IMON_{IN}$ or $IMON_{OUT}$ pins, respectively, as shown in Figure 1. The relationship between the current limit and the resistor is:

$$I_{LIM} \simeq \frac{1.2V \bullet 16000}{R_{LIM}}$$

For example, a 10k resistor sets a current limit of approximately 2A.

This simple scheme allows both monitoring and active control of the input and output current limits—the latter can be implemented via external control circuitry, such as a DAC with a few passive components.

Temperature Sensing

The LTC3626 generates a voltage proportional to its own die temperature, which can be used to set a maximum temperature limit. The voltage at the temperature monitor pin (T_{MON}) is typically 1.5V at room temperature. To calculate the die temperature, T_J, multiply the T_{MON} voltage by the temperature monitor voltage-to-temperature conversion factor of 200°K/V, and subtract the 273°C offset. The LTC3626 also has a temperature limit comparator fed by the temperature limit set pin, T_{SET}, and the T_{MON} pin. Hence, by applying a voltage to the T_{SET} pin, a maximum temperature limit can be set according to the following:

$$V_{TSET} = \frac{T_J + 273}{200°K/V}$$

Choosing a maximum temperature limit of 125°C equates to an approximate 2V setting on the T_{SET} pin—the IC will shut down once the die temperature T_J reaches this limit.

Conclusion

The LTC3626 combines current and temperature monitoring capabilities with a high performance buck regulator in a compact package. A microprocessor or other external control logic can supervise conditions via easy-to-use input and output current and temperature monitor pins, and it can shut itself down by setting a threshold voltage on the temperature set limit pin.

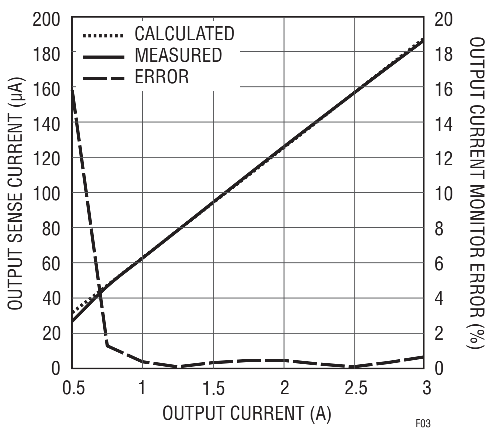


Figure 3. Output Current vs Output Current Monitor

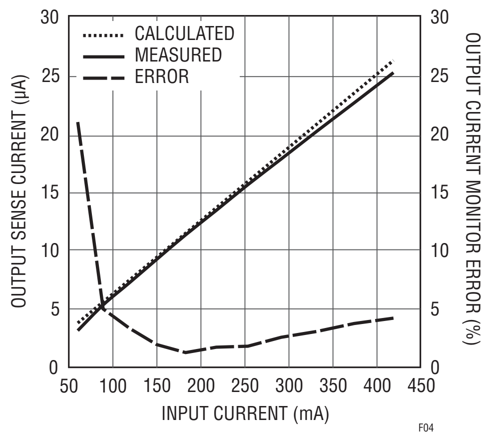


Figure 4. Input Current vs Input Current Monitor

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mining whether or not to turn it on and, if so, how much to turn it on? To answer that question, it is first best to understand the type of jitter called inter-symbol interference (ISI), which is the name for the variation in edge timing caused by the filtering effects of a transmission line.

Mathematically, ISI can be simply modeled as a low pass filter. When sending high-speed serial data down a transmission line, the filtering results in a distorted signal. Emphasis and equalization counteract the filtering effects of ISI to bring the frequency response at the end of the channel back to as close to flat over frequency as possible, resulting in a signal that isn't distorted by ISI.

With a basic understanding of emphasis and equalization and ISI, the next step is setting them. Many people first ask how long of a trace can be driven with and without emphasis and equalization. Real-world PCB designs have too many variables that can affect ISI to be able to specify the channel in terms of trace length.

Variables like trace width, trace length, vias versus no vias, dielectric material, connectors versus no connectors, trace material, corners, passive components, and distance to ground plane can all affect channel performance. So how can channel characteristics ever be correlated to emphasis/equalization?

The solution is to specify the channel in terms of insertion loss, which JESD204B describes as a measure of the power loss of a signal over frequency. Emphasis, equalization, and PCB channel can all be related in terms of insertion loss (and gain). Using a relevant frequency (JESD204B lists three-quarters baud rate) and an insertion loss limit (JESD204B lists –6 dB), the gain provided by emphasis and/or equalization can be selected to bring the frequency response at the selected frequency up above the loss limit. For example, a PCB channel with –12 dB of loss at 9 GHz would need +6 dB of emphasis and equalization gain to bring the total back up to –6 dB.

Alternately, converter manufacturers can provide a table of emphasis/equalization settings versus PCB insertion loss. This method can result in a better solution, as it does not depend on as many assumptions. To build such a table for a transmitter (and to emulate end system designs), a set of test evaluation boards can be built with varying trace lengths.

The eye diagram at the end of the PCB trace can be directly measured and compared against the JESD204B Rx mask. By trying various PCB trace lengths, one will result in the eye just barely passing the Rx mask. Since the insertion loss of that specific trace can be measured, the drive capability for a specific emphasis setting is known.

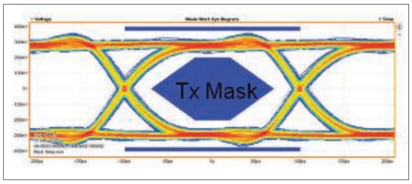
JITTER TERMINOLOGY

JESD204B jitter term	JESD204B jitter name	Test equipment jitter translation
T_UBHPJ	Transmit uncorrelated bounded high-probability jitter	BUJ (Pj and NPJ)
T_DCD	Transmit duty-cycle distortion	DCD
T_Tj	Transmit total jitter	TJ
R_SJ-hf	Receive sinusoidal jitter, high frequency	PJ >1/1667*BR
R_SJ-max	Receive sinusoidal jitter, maximum	PJ < 1/166,700*BR
R_BHPJ	Receive bounded high-probability jitter: correlated	DDJ
	Receive bounded high-probability jitter: uncorrelated	NPJ
R_Tj	Receive total jitter	TJ

Compare Figure 3 showing an eye diagram at the end of an ISI PCB to Figure 4, the eye diagram going into an ISI PCB. In this case, the data rate is 5 Gbits/s, the ISI PCB has 8 dB of insertion loss at 4 GHz, and emphasis is off.

Repeating this process versus emphasis settings will yield a table of emphasis settings versus insertion loss. A similar approach can be taken on a receiver with equalization. Start with a BERT generator outputting the maximum allowed total jitter (except for ISI jitter). Using the same set of ISI test boards with varying trace lengths, test with longer traces until the receiver starts to get errors that exceed the target bit error rate (1E-15). Measure the insertion loss of the PCB trace. Repeat for every equalizer setting.

In summary, if a JESD204B device manufacturer provides only emphasis/equalization gain, the first method can be used to pick settings. It's best if the manufacturer provides a table of settings versus channel insertion loss.



4. Eye diagram mask measurements enable you to compare insertion loss from different PCB trace lengths. See Figure 3 for a higher degree of insertion loss leading to a closed eye diagram compared to this eye going into an ISI PCB.

Should you use emphasis or equalization? From a frequency response correction standpoint, there's no clear reason to use one or the other. However, emphasis can generate a certain amount of gain with less power in most cases. If system power is important, that could be a reason to choose emphasis over equalization. Another advantage of choosing emphasis over equalization is that the effect on the signal can be directly measured with an oscilloscope.

Having both a JESD204B Tx with emphasis and an Rx with equalization can be common. How would you determine when to turn on both? Simply, if the insertion loss of the channel cannot be overcome by just emphasis or just equalization, then it's time to turn on both.

As for how much gain to set each of them to, one advantage of specifying response in terms of insertion loss (and gain) is that it's additive. For example, at the frequency of interest, a PCB trace with –20 dB of loss, a Tx with +6 dB of emphasis, and an Rx with +8 dB of equalization can be represented as –20 dB + 6 dB + 8 dB = –6 dB total.

EMULATING SYSTEM ENVIRONMENTS

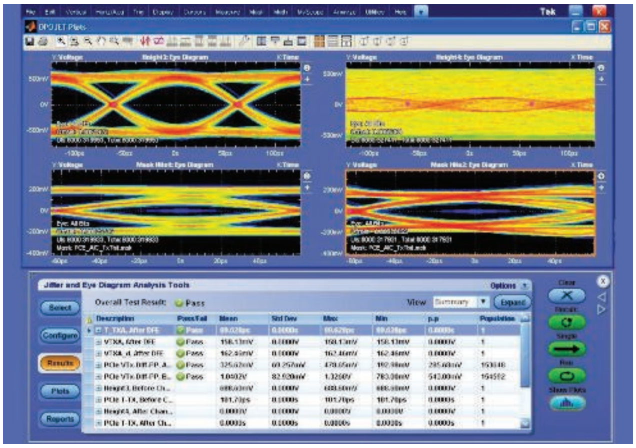
No end system design is free of noise and jitter. JESD204B fully specifies system jitter emulation, but it doesn't specify voltage noise. To emulate voltage noise in end system designs, component manufacturers can perform noise tolerance tests. One such test is power supply noise tolerance.

Noise is injected onto the components' various power supply domains. The amplitude of the noise is increased until the first compliance tests fails. (Often the first test to fail on a SERDES will be jitter.) This test is repeated over the frequency range at which PCB noise is typically present (a few hertz to around 100 MHz). A plot of maximum power supply noise tolerated versus frequency is generated.

The same test can be performed on all other pins. The end result of all this testing is typically a set of practical PCB design recommendations, such as "keep a particular supply domain separated" or "use a bypass capacitor on this pin" or "don't route any signals near this pin."

MAINTAIN SIGNAL INTEGRITY WHEN MEASURING

As with any high-speed serial test application, best practices apply to ensure accurate measurement results. Also, you must be sure that your instrumentation offers sufficient performance and signal integrity to deliver accurate measurement results. Considerations include:



5. By applying a model of the measurement channel to an acquired waveform, the effects of transmission line degradation can be removed or de-embedded for improved measurement accuracy. Tools like the Tektronix SDLA software shown here enable users to see the effects of model embedding and de-embedding.

- Dynamic range: In general, it's best to use the full range of your oscilloscope's analog-to-digital dynamic range without clipping the amplifier. Although clipping might be acceptable when looking at a clock signal, doing this will hide ISI issues when evaluating data signals. It also can affect the instrument's edge interpolation algorithm.
- Sample rate: Setting the oscilloscope to the highest sample rate provides the best timing resolution for the most accurate signal and jitter measurement. One exception would be if you're looking over longer time windows at lower timing accuracy.
- Capture window: Analyzing signals over a longer time window allows you to see low-frequency modulation effects like power supply coupling and spread-spectrum clocking. Increasing the capture window unfortunately increases the analysis processing time. On SERDES systems, there is often no need to look at modulation effects below the loop bandwidth of the CDR that are tracked and rejected.

- Test point access and de-embedding: Ensure that you employ a mechanism for keeping the probe as close to the Tx test point and as close to the Rx test point as possible. With high-speed signaling test, timing and amplitude measurements can seriously impact margin test results if the measurement process introduces unwanted signal discontinuity from long traces and/or fixturing from the actual Tx/Rx test points.

In some cases, the probe access point could be at a location where the signal is degraded due to the transmission line length. You then might have to de-embed the transmission line to see what the real signal is. De-embedding involves recreating a model (using a linear method with S parameters) of the measurement channel between the instrument and the targeted test point. This model can be applied to acquired waveform data in the oscilloscope to account for transmission line degradations *(Fig. 5)*.

By practicing good signal integrity in your measurement techniques, you'll be better equipped to evaluate and characterize high-speed technologies like JESD2024B.

SUMMARY

The JESD204B interface can reliably increase data transfer bandwidth between a converter and a logic device, and new devices using it are making their way to market. Unlike many other high-speed serial interface standards, JESD204B does not include an official compliance test specification, creating a number of challenges for system designers who must thoroughly test and debug their designs. Fortunately, the specification includes sufficient information to develop testing procedures, including PHY, timing, and protocol tests.

In addition to validating performance and compliance, testing can help determine the need for emphasis or equalization in a system design and help to identify unwanted sources of noise and jitter. Best practices for instrument selection, setup, and probing should be followed for consistent and accurate results. ed

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MARK THOREN | LINEAR TECHNOLOGY CORP. mthoren@linear.com

PWM-Based Analog Calculator Provides Four-Quadrant Multiplication, Division

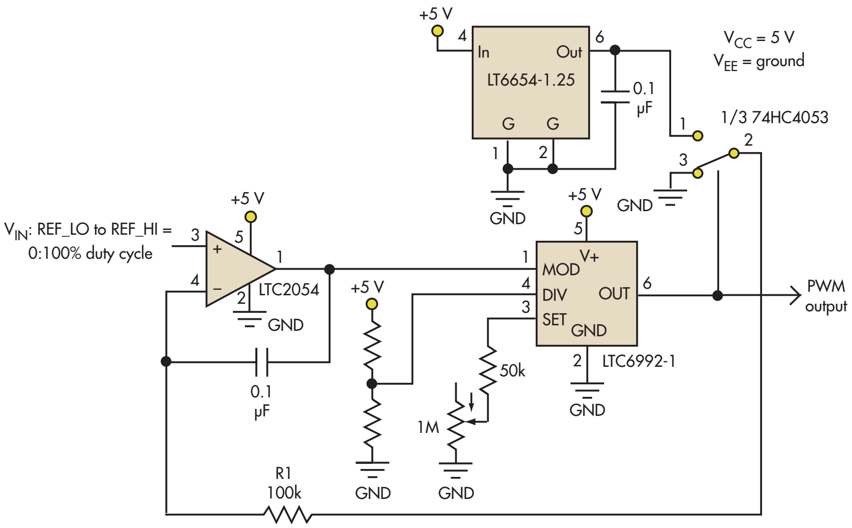
YOU CAN BUILD an analog calculator using a pulse-width modulator (PWM) to perform accurate four-quadrant multiplication and division. While this approach won't help you ace any math tests, it demonstrates some useful subcircuits that extend the functionality of the LTC6992 TimerBlox voltage-controlled PWM.

The LTC6992-1 translates a 0-1 V input at the MOD pin into an output with a 0% to 100% duty cycle at a frequency of 3.81 Hz to 1 MHz. A resistor at the SET pin and a resistor divider at the DIV pin control this frequency. In some applications, the LTC6992 will be in the feed-forward path of a closed-loop control system (as in a motor-speed controller), so its 1% typical linearity provides consistent overall loop performance.

Figure 1 shows a basic linearized PWM generator for applications where accurate PWM is required without an external feedback mechanism. This circuit easily achieves 0.1% PWM accuracy. The output of the LTC6992 controls one section of a 74HC4053 triple single-pole double-throw (SPDT) analog switch whose output is switched between ground and an LT6654-1.25 reference. An integrator compares this signal to the control input. The output duty cycle will settle on a value that equals the fraction of the 1.25-V reference that's present at the input. The term "fraction" implies that this circuit performs division, as the output PWM duty cycle is V_{In}/V_{Ref}.

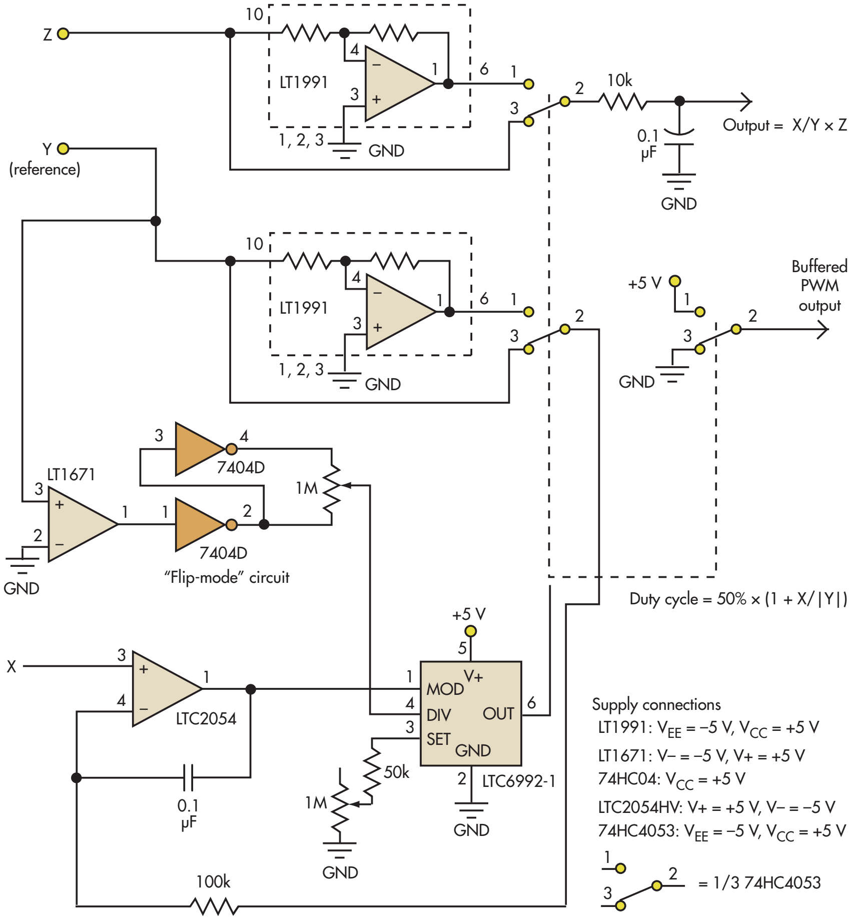
Figure 2 extends this concept, with X as the input (numerator) and Y as the reference (denominator). An LT1991 configured in a gain of –1 provides a precise negative copy of Y, extending operation to four quadrants (positive and negative X and Y), with duty cycle = 50% × [1 + (X/|Y|)].

As with any physical realization of division, a zero value for the denominator (Y) will produce an undefined output. A negative voltage applied to the Y input inverts the polarity of the feedback signal to the integrator, which requires another inversion

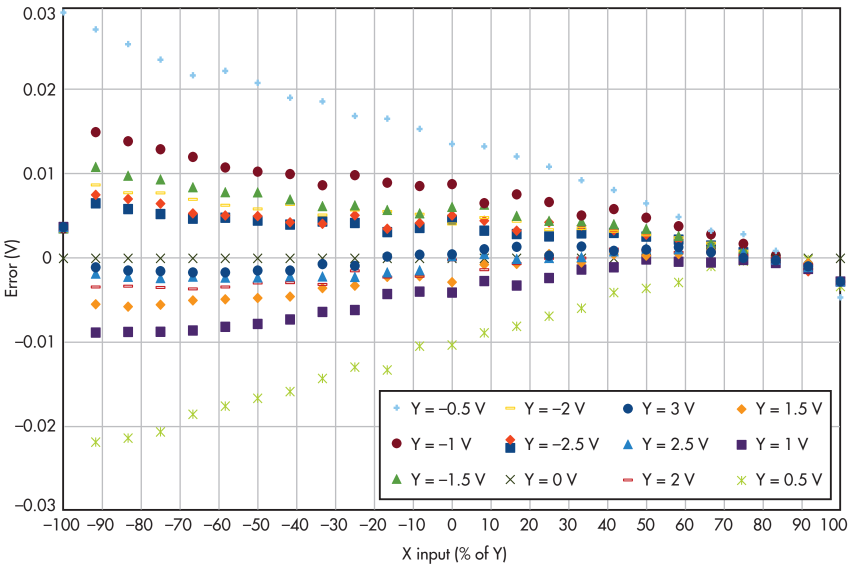


1. This basic linearized PWM generator, without an external feedback mechanism, can still provide accuracy of 0.1%.

DIVCODE PROGRAMMING					
DIVCODE	POL	N_{DIV}	Recommended f_{Out}	R1 (kΩ)	R2 (kΩ)
0	0	1	62.5 kHz to 1 MHz	Open	Short
1	0	4	15.63 to 250 kHz	976	102
2	0	16	3.906 to 62.5 kHz	976	182
3	0	64	976.6 Hz to 15.63 kHz	1000	280
4	0	256	244.1 Hz to 3.906 kHz	1000	392
5	0	1024	61.04 to 976.6 Hz	1000	523
6	0	4096	15.26 to 244.1 Hz	1000	681
7	0	16384	3.815 to 61.04 Hz	1000	887
8	1	16384	3.815 to 61.04 Hz	887	1000
9	1	4096	15.26 to 244.1 Hz	681	1000
10	1	1024	61.04 to 976.6 Hz	523	1000
11	1	256	244.1 Hz to 3.906 kHz	392	1000
12	1	64	976.6 Hz to 15.63 kHz	280	1000
13	1	16	3.906 to 62.5 kHz	182	976
14	1	4	15.63 to 250 kHz	102	976
15	1	1	62.5 kHz to 1 MHz	Short	Open



2. This enhancement to the circuit of Figure 1 extends the analog multiplication/division to all four analog signal quadrants.



3. This plot of absolute error shows better than 0.1% for large values of *Y*.

somewhere in the loop to ensure feedback is negative.

The DIV pin also can invert the PWM polarity (a 0- to 1-V input = 100% to 0% duty-cycle output), in addition to selecting one of eight N_{Div} values to set the frequency. The N_{Div} magnitudes are mirrored around $V_{CC}/2$, where swapping values in the resistor divider inverts the transfer function while maintaining the same divider value *(see the table)*.

An LT1671 comparator detects the polarity of the Y input and sets the polarity by switching the divider potentiometer's excitation accordingly, maintaining correct operation. Note that a 10-turn potentiometer works well for experimentation. You could replace it with a fixed resistor once you have selected the desired N_{Div}.

The "Z" input is multiplied by the X/Y quotient by supplying the inputs to another switch with Z and –Z. (Once again, an LT1991 provides precision inversion.) This is a "pulse width/pulse height" multiplier, also with four-quadrant operation.

Figure 3 shows the absolute error of the circuit at a 1.5-kHz frequency, sweeping X from –Y to +Y for values of Y from –3 V to +3 V, while holding Z constant at 5 V. Even with Y at 0.5 V (where error sources are more significant), the worst-case error is about 0.6% and rapidly improves with larger values of Y. Error sources include the 0.04% error of the LT1991, mismatch in switch resistance between its two positions compared with the resistance of the downstream filter's resistance, and the response of the LT1991 outputs to switching transients, whose effect will vary with PWM frequency.

MARK THOREN is the applications engineering manager for mixed-signal products at Linear Technology. He has a BS in agricultural/mechanical engineering and an MS in electrical engineering, both from the University of Maine.

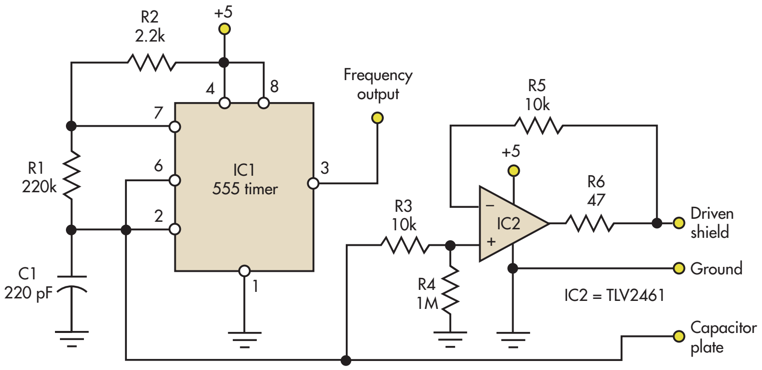
DEV GUALTIERI | TIKALON LLC, LEDGEWOOD, N.J. gualtieri@ieee.org

Driven Shield Enables Large-Area Capacitive Sensor

CAPACITIVE SENSORS ARE common in today's consumer electronics, since they are used in many touchscreen applications. Most of the circuits for such applications are designed for small-area capacitors and finger contact operation.

This circuit is designed for large-area touch plates that can be activated at a distance and hidden behind walls or inside other structures. It uses the "driven shield" concept that was popular in the early days of audio engineering, when high-impedance sound sources such as crystal microphones were used. Shielded cables are needed to connect these devices, but the cable capacitance limits the high-frequency response.

The solution to this problem is to go back to the physics of a capacitor to find a way to reduce the cable capacitance. Driving a conductor between the outer shield and the inner, signal conductor with the same voltage as the signal conductor largely eliminates the capacitance. NASA used this driven-shield idea in a large-area capacitive sensor two decades ago (John M. Vranish, et al., US Patent No. 5,116,679).



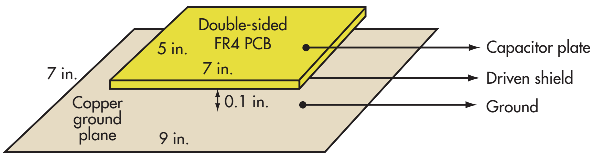
1. In this large-area capacitive sensor, C1 and any parallel capacitance set the frequency of the 555 astable multivibrator IC1, while IC2 buffers the voltage at the capacitor to drive the shield plate. (The pin-outs for IC1 are for the "N" package.)

The circuit in Figure 1 performs the main capacitance-sensing task, while leaving detection to a microcontroller. IC1 is a 555 timer wired as an astable multivibrator with as small a timing capacitance as possible. With the component values shown, the frequency is slightly above 10 kHz. IC2 buffers the voltage on this capacitor to drive a shield plate.

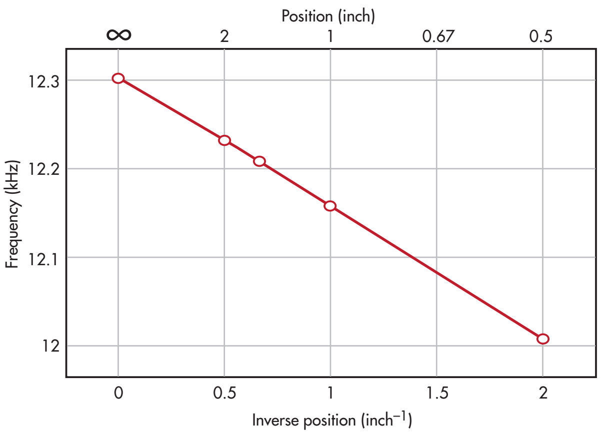
For IC2, resistors R3 and R4 decrease the buffered voltage by about 1%. This prevents oscillation that may occur because of the external capacitance. R6 is included since some operational amplifiers have difficulty driving a capacitive load. IC2 should have a high gain-bandwidth product to allow a faithful representation of the signal voltage without phase shift.

Figure 2 shows the construction of the sensing plate. These are the dimensions used in the author's tests, but quite a lot of variation is permissible. A practical implementation would be to build the circuitry onto an edge of the ground plane.

The frequency response decreases in a nearly linear fashion with respect to inverse position *(Fig. 3)*. In the author's test, hand contact reduced the frequency to 10.47 kHz. Hand contact through a 0.375-in. (10 mm) thick piece of plywood or gypsum wallboard resulted in a frequency change of 10%, which is easy to detect. Although frequency-detection ICs are available, a simpler, less expensive solution is to use a microcontroller to detect a change in signal period.



2. In the constructed sensor, a double-sided printed-circuit board (PCB) has one conductor as the signal plate and the other as the driven shield. The semi-infinite ground plane, which is slightly larger in area than the sensing or shield plates, can be another PCB or an aluminum plate.



3. The circuit response is a close-to-linear inverse-position relationship between hand position and the sensing plate.

DEV GUALTIERI received his PhD in solid-state science from Syracuse University in 1974. He now does various computer, electronic, and embedded systems projects at his consulting company, Tikalon LLC.

JOE FALCONE AND ANTHONY KALAIJAKIS | MOLEX INC. joe.falcone@molex.com, anthony.kalaijakis@molex.com

MEMS I/O Power Connectors Benefit Healthcare Devices

Tiny technologies enable compact and simple machines that medical personnel can use to administer care in the patient's own home.

SKYROCKETING GLOBAL HEALTHCARE costs, compounded by aging populations, are driving a surge in demand for portable medical diagnostic equipment and treatment in patients' homes as well as in underserved and remote regions.

A recent industry report[1] cites the proliferation of new equipment and markets serving patient home healthcare needs, including respiratory therapy, home infusion therapy, rehabilitation services, and monitoring of patients with chronic medical conditions *(Fig. 1)*.

In addition to projecting the home healthcare market to grow at an annual rate of 7.7% through 2016, the report notes that the most significant trend is the shift of treatment from hospitals to home to gain a cost advantage and reduce hospital expenditure.

The move from treatment to proactive monitoring is opening up opportunities for the home healthcare market as well, the report adds, as patients prefer home healthcare to hospitals for the convenience and cost-effectiveness it offers.

CONNECTORS PLAY A ROLE

As healthcare providers and patients navigate these transitions, leading electronics innovators are facing the technological challenges when equipment and devices traditionally used in doctor offices, clinics, and hospital settings move into patient homes.

Among those challenges, power management plays a vital role in terms of the ease of patient use, size, performance, and durability of these devices. So, engineers weighing system-level tradeoffs must make power management decisions as early as possible in the design cycle.

The power connector industry has stepped up with extremely small, low-profile connectors, pioneered in the smart-phone industry, to meet this growing need for improved portability and miniaturization in medical devices and equipment.

Combining electrical and mechanical components to produce a system of unprecedented miniature dimensions, microelectromechanical systems (MEMS) have emerged as an important technology of choice for the design of small, portable devices in a range of dynamic healthcare markets.

MEMS technology can be used in biomedical applications such as surgical tools, drug delivery, and biosensors, as well as in diagnostic and other in vitro applications. A compatible replacement for other larger connectors in existing designs, MEMS technology offers an ultra-low-profile solution and high performance in power connections. With a successful track record of real-world applications and customers, the MEMS micro-interconnect approach offers a powerful and viable tool for design engineers addressing demand for ever smaller micro-products to serve healthcare needs.

THE BENEFITS OF MEMS

MEMS I/O connectors are suitable for any market in which miniaturization plays a major role, including consumer, mobile, and medical applications. The technology has already made remarkable contributions to medicine in its efforts to improve patient care and safety, specifically during minimally invasive surgery, and for patients requiring frequent blood and urine testing and monitoring, as well as those receiving medications via sensored patches.

There are myriad benefits to using MEMS I/O technology in medical devices and equipment. Providing a reliable and flexible socketed interface, MEMS I/Os are more robust than many conventional connectors. Their "zero height" makes them ideal for drug delivery patches that electronically control precision dosing at set intervals. Consuming little power, they also improve the consistency of readings and require fewer battery changes in portable monitoring or other devices. In invasive procedures, MEMS I/Os can enable

ANTHONY J. KALAIJAKIS is the strategic medical marketing manager for Molex Inc. He has more than two decades of experience in the interconnect industry in various engineering, marketing, and sales positions.

JOE FALCONE is the group product manager with the Lisle Satellite team in Molex's Global Micro Products Division. He has 15 years experience in the interconnect industry in various sales, marketing, global business development, and product management roles. He holds a BSEE in electrical engineering and an MBA in finance/marketing.

1. Patient monitors are evolving from hospital bedside equipment to home healthcare and internetworked systems. Micro-interconnect I/O solutions and innovative capabilities align with the trend toward smaller, lighter, and integrated solutions for telehealth applications.

a smaller device footprint for a less painful experience for the patient as well.

MEMS I/O connectors have proven particularly innovative in medical battery connectors, camera modules, and sheet connector I/O applications, such as those found in sensors for small form factor, high-density ultrasound connectors *(Fig. 2)*. Ultrasound technology is an area of considerable patient need and a strong focus for leading health equipment manufacturers.

Size and other limitations make current ultrasound machines impractical for use in many regions of the world. Developing and emerging countries benefit with the influx of more MEMS-based micro-products, enabling a smaller, portable ultrasound footprint for use in remote regions.

The medical sensor market offers enormous application potential for MEMS, including refresher sensors, chemical sensors, flow sensors, and position sensors. Today, nearly 70% of chemical sensors in the U.S. market are oriented to healthcare. With the epidemic of obesity and incidence of diabetes on the rise, the low-profile format MEMS power connector is ideal for the mobile and portable glucose monitoring market. In home and institutional healthcare, any device or equipment problem can potentially place a patient at risk. Offering a stable, socketed "pull & lock" connection, MEMS I/O technology is ideal for handheld patient glucose and other disposable monitoring products.

A portable glucose monitoring device using a standard micro I/O to connect two boards results in a profile of approximately 0.7 mm. With MEMS technology, the same connector profile can be reduced to a mere 0.15 mm. An unprecedentedly miniscule layer, a MEMS connection appears visually as a flat surface, not unlike the depth of a diabetic strip. These power-packed miniature solutions meet healthcare demands and place reliable monitoring tools into patients' hands.

For high-impedance controlled cable solutions, MEMS I/O technology helps to mitigate these risks and can be used in conjunction with high-speed copper flex or any flexible substrate.

Some medical manufacturers use copper flex with tiny connections for actual monitoring. If a manufacturer is not using MEMS, it typically solders the jumper via anisotropic conductive film (ACF) bonding directly to the copper flex.

Initially used in mobile phones but applicable for medical devices, micro-camera modules are often directly soldered and permanently mounted on a jumper to the flexible cable printed-circuit board (PCB). Using this design concept, copper flex can become a costly jumper if the camera module is damaged and requires repair. More often than not, the "fix" is to disconnect and replace the entire flex cable.

However, MEMS I/O technology enables a micro-camera to be socketed directly onto the flex, without resulting in a higher profile, allowing easy disconnection and servicing without total replacement of the flex. In conjunction with a video-enabled camera or micro insulation displacement termination (IDT), a MEMS I/O can also be used to connect an HD video display to the main circuit board for streaming high-speed video in endoscopic and other invasive medical procedures.

2. MEMS I/O connectors have proven particularly innovative in medical battery connectors, camera modules, and sheet connector I/O applications, such as those found in sensors for small form factor, high-density ultrasound connectors.

Conventional endoscopes for diagnosing gastrointestinal colon cancer and other anomalies require patient sedation and enable viewing of only a portion of the small intestine. A MEMS-enabled endoscope allows a complete examination of the small intestine in a sedation-free procedure that enables digital images, a transmitter, and even a light source.

MEMS MANUFACTURING ADVANTAGES

A natural progression of the same processes used in semiconductor fabrication, MEMS fabrication entails the deposition of material layers onto which photolithography and etching produce the required circuitry and components such as power connectors. Standard power connectors designed for medical devices generally comprise molded plastic with stamped terminals and contacts, which produces a relatively large footprint overall.

Conversely, the technology behind MEMS basically comprises masking, catching, plating, printing, and laminating, producing a very low-profile contact sheet. A MEMS I/O system typically employs etching and drilling on extremely thin layers of sheet metal to create a sandwich-like insulated electrical connection. Sheets may be as thin as 150 µm (0.15 mm).

The advantage to MEMS is that the manufacturer can produce a significantly smaller, low-power consumption connector that delivers higher performance than larger competitive components. Additionally, the MEMS manufacturing process reduces time-to-market and the cost of producing a plastic injected mold and dye stamping terminals as are found in traditional connectors.

MEMS I/O technology integrates the high density and high-speed functionalities of high-speed connectors and cabling in micro-miniature products in a smaller form factor sheet connector that eliminates electromagnetic interference (EMI).

MEMS I/O connectors are rated for the same number of mating cycles as standard micro-miniature connectors, which typically rate at 15 to 30 mating-unmating cycles, but some models can range well into the thousands. Stringent testing shows that the MEMS I/O mating interface can withstand dropping and shock up to 6000 G with negligible impact.

By eliminating most of the traditional connector body without sacrificing performance or density, MEMS I/O technology represents an important paradigm shift for medical device designers and manufacturers. Not only does it drive down size and valuable space on the PCB, but by replacing permanent soldered PCB connections with a simple socketed mating interface, it also enables a level of design flexibility that heretofore could only be found in larger connectors and product designs.

Not surprisingly, the use of MEMS-enabled systems in medical equipment and devices has grown exponentially and is likely to continue this rapid growth trajectory. ed

REFERENCE

1. Home Healthcare Market Current Trends, Opportunities & Global Forecasts to 2016; *www.marketsandmarkets.com/Market-Reports/home-healthcare-equipment-market-696.html*

INTERCONNECTS

HARD METRIC CONNECTOR HANDLES SPEEDS BEYOND 20 GBITS/S

To meet next-generation data-processor requirements, ERNI developed a high-speed differential hard metric connector system that enables data rates of over 20 Gbits/s with quality crosstalk behavior. The ZDplus connector combines optimized signal routing with the press-fit termination of a female connector option, which helps improve layout on daughtercards. The connector offers 40 differential pairs per linear inch. Low-noise, dual-beam leaf contacts use one ground blade for every signal pair, with a 2.5-mm pitch from wafer to wafer. In-line ground arrangement at termination and the grounding shield help improve pre-alignment guide and polarizing features via four rigid blades in all modules. The ZDplus connector is backward-compatible with the company's ERmet ZD male connector. Three-pair and four-pair female versions are available.

ERNI ELECTRONICS

www.erni.com/ermet-zdplus-high-speed-connector/

MICRO-SIM CARD SOCKETS SIZED FOR MOBILE DEVICES

Molex's micro-SIM push-pull card, measuring 12 by 15 mm, is 52% smaller than its predecessor, the Mini-SIM card. It comes in 1.35-, 1.40-, and 1.45-mm heights and features a wide finger area on the shell for easy insertion and withdrawal. According to the company, it's the only micro-SIM tray version that doesn't require a tool for card extraction.

It also locks securely to prevent card fly-out, and advanced polarization features help prevent against improper card insertion. In addition, the card offers high contact normal-force of 0.30 N. Standard six-circuit and optional eight-circuit styles are available. All versions are ELV- and RoHS-certified. Applications include smart phones, tablet PCs, GPS watches, and others where space is at a premium.

MOLEX INC.

www.molex.com/link/micro-sim.html

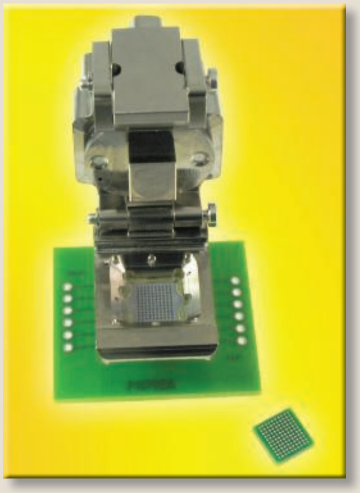
CONNECTOR MAINTAINS IP67 RATING WHEN UNMATED

Applications intended for medical and industrial environments can take advantage of the Series 770 NCC connectors thanks to their IP67 rating in unmated condition. The panel-mounted receptacle's internal sliding cap moves forward and seals the contact area when the plug is disconnected from the receptacle. According to developer Binder-USA, the connector's bayonet locking allows for quick, easy, and reliable mating and demating of the connector halves. Visual indicators on the plug and receptacle help align both connector halves during the mating process. The male cable connector can handle 2.5- to 8-mm diameter cables. Eight gold-plated contacts are rated at 175 V and 2 A per contact.

BINDER-USA

www.binder-usa.com

EXTREME-TEMP SOCKET MEETS BGA TESTING DEMANDS



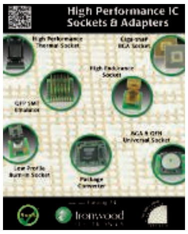
Ironwood Electronics' CBT-BGA 7010 ball-grid-array (BGA) socket addresses the high-performance requirements involved in testing BGA devices. The stamped spring pin contactor features 26-gram actuation force per ball and a cycle life of 500k insertions. A floating guide incorporated in the socket enables precise ball-to-pin alignment. Specs include 0.88-nH self-inductance, insertion loss of less than 1 dB at 15.7 GHz, and 0.097-pF capacitance. Each contactor has a 4-A current capacity at 80°C temperature rise. Operating temperature ranges from –55°C to 180°C. The CBT-BGA-7010 specifically tests 7.8- by 8-mm, 0.65-mm pitch, 110-position, 10- by 11-ball-array BGAs. It can be used for hand-test and quick device-screening applications with very stringent requirements. No soldering is involved when mounting on a printed-circuit board.

IRONWOOD ELECTRONICS

www.ironwoodelectronics.com

Catalog Literature Review

HIGH PERFORMANCE SOCKETS & ADAPTERS



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

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1335 Eagandale Court
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T: 800-404-0204
F: 952-229-8201

www.ironwoodelectronics.com

Ironwood Electronics

IR Expands PowlRaudio™ Family of Integrated Power Modules with the Introduction of 40V IR4311M and IR4312M

IR has announced the expansion of its PowlRaudio™ family of integrated power modules with the introduction of the IR4311M and IR4312M. The 40V IR4311M and IR4312M offer a compact, heatsink-free solution for low power Class D audio applications including tabletop audio systems, active speakers and musical instruments with integrated amplifiers.

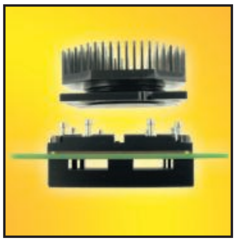
The combination of an advanced audio controller IC with MOSFETs fully optimized for audio performance results in improved efficiency, THD, and EMI, allowing the IR43xxM family to operate without a mechanical heatsink over a wide power supply range on either a single or split power supply. High voltage ratings and noise immunity ensure reliable operation over various environmental conditions.

Additional features common to the family include over-current protection, thermal shutdown, internal/external shutdown and floating differential input. The IR4312M also offers clip detection. Two reference designs, the IRAUDAMP15 and IRAUDAMP18, featuring the IR4311M and IR4312M respectively are also available.

More information is available on the **International Rectifier** website at
http://www.irf.com/whats-new/nr130108.html
For more information, contact Sian Cummins,
scummin1@irf.com, 310-252-7148.

Otter Computer, Inc.

High Performance - 10 GHz Socket Technology



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

Ironwood Electronics, Inc.
1335 Eagandale Court
Eagan, MN 55121
T: 800-404-0204 • F: 952-229-8201
Email: info@ironwoodelectronics.com
Web Site: www.ironwoodelectronics.com

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

When Will Self-Driving Cars Be Ready For You?

TOYOTA EXHIBITED A Lexus LS600 at the 2013 International CES in Las Vegas, January 8-11, along with other car vendors that were highlighting the latest electronics and automotive technology you can buy *(see the figure)*. This Lexus was different, though. The driver is optional, and it's a little more tricked out than your local dealer's LS600.

Toyota's autonomous car looks a bit like many other driverless research vehicles, with sensors decorating its exterior. Some of them like the laser tracking system are a bit expensive but provide very precise results. The car also has forward and side radars and high-definition color cameras. On-board computing power is substantial since it handles planning as well as sensor integration.

Toyota showed off its self-driving Lexus LS600 research vehicle (a) at the C2013 International CES in Las Vegas. It uses a 360° laser tracking system on the roof (b).

DRIVERLESS TECHNOLOGY

Google's driverless car has made it into the news quite a bit lately, though it's been a few years since the Defense Advanced Research Projects Agency's Grand Challenges *(see "Autonomous Vehicles Tackle The Urban Jungle" at electronicdesign.com)*. These research vehicles now can get from one point to another without major collisions, but they aren't ready to mix it up with their human-controlled counterparts yet.

Still, the latest driverless cars can do more than avoid buildings and other mobile vehicles. Pedestrian avoidance is good, and it's useful even in driver-controlled cars, providing an extra set of "eyes." But we won't see it in the mass market unless the technology can be made reliable and inexpensive.

Google got the first license for a driverless car in Nevada for driving research vehicles on public thoroughfares. Audi, which got the second license, demonstrated its driverless car at the Mandarin Oriental hotel in Las Vegas during CES. It was essentially a robotic valet. Press the Pickup button on the Audi smart-phone app, and the car shows up at the curb.

No external sensors were installed on the Audi itself, so it had fewer accoutrements than the Toyota research vehicle. Instead, it relied on a few blue sensors from a company called Sick in the parking lot and received information from the network. The driverless support was limited to the parking and pickup area, which was all that was necessary for the valet application, along with some intelligence.

DRIVERLESS LIABILITY

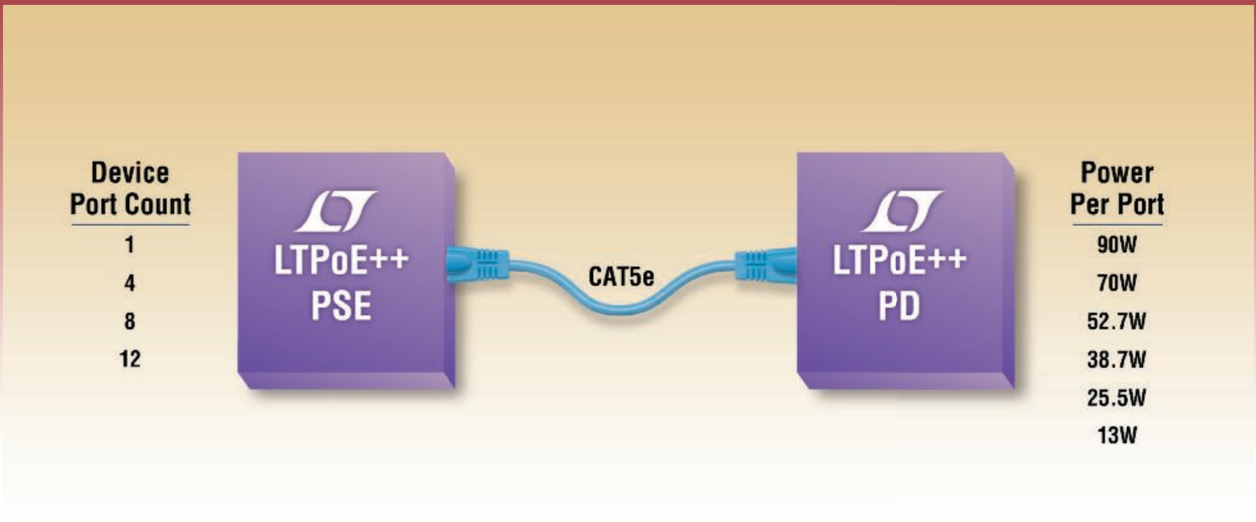
Of course, the real barrier to driverless cars will be liability insurance. I have no doubt we'll see driverless vehicles that meet or exceed the performance of human drivers, but insurance still is a major hurdle. Building a sufficiently safe and reliable driverless car is significantly more difficult than building a blender or medical monitor.

Everyday appliances are built with safety in mind. Of course, the standards that those devices must meet already exist. Mapping human standards for driving to a driverless car will take time. Unfortunately, it isn't as simple as making driverless cars meet human standards because these cars can't be held liable like people.

See what other engineers think about driverless cars on Engineering TV *(see "Engineering I/O: Are You Ready For Driverless Cars On the Road?" at engineeringtv.com)*. Most responses are very positive. Communications Editor Lou Frenzel, though, has some doubts *(see "Just Say No To The Driverless Car" at electronicdesign.com)*.

Driverless cars eventually will hit the streets. In the meantime, many of the technologies employed in these projects will be used in production vehicles and make driving safer. ed

End-to-End High Power PoE++



Efficient Power Delivery That Just Works!

Linear Technology's LTPoE++™ PSE and PD controllers provide a complete, low cost, end-to-end solution for up to 90W delivered power over a single CAT5e cable, without complicated LLDP software. Four available power levels (38.7W, 52.7W, 70W and 90W) allow you to optimize your design and guarantee interoperability with any LTPoE++, PoE+ (25.5W) and PoE (13W) device. Use of external MOSFETs, robust 100V IC design, and advanced power management features ensure maximum delivered power at any power level.

Features

- LTPoE++ High Power Standard
- Low BOM Cost
- Ultralow Heat Dissipation
- Robust Cable Discharge Protection
- Advanced Power Management Hardware
- Advanced Power Management Software

LTPoE++ Controllers

Part Number	Description
LTC4274A	1-Port PSE
LTC4266A	4-Port PSE
LTC4290A/ LTC4271	8-Port PSE
LTC4270A/ LTC4271	12-Port PSE
LT4275A	1-Port PD

Info & Free Samples

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