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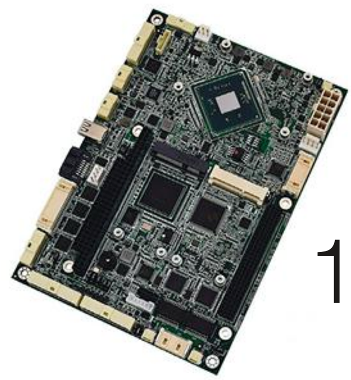

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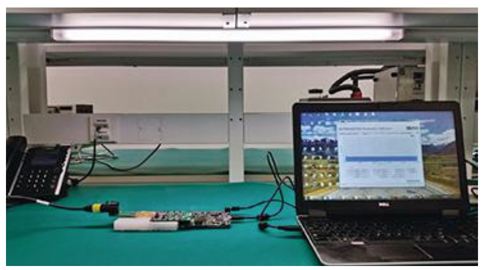

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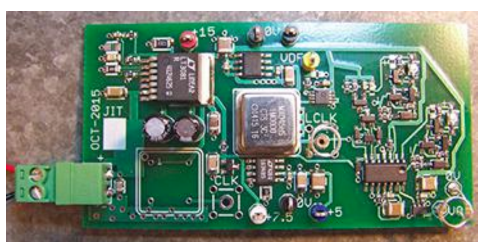

EDITORIAL MISSION:
To provide the most current, accurate, and in-depth technical coverage of the key emerging technologies that engineers need to design tomorrow's products today.

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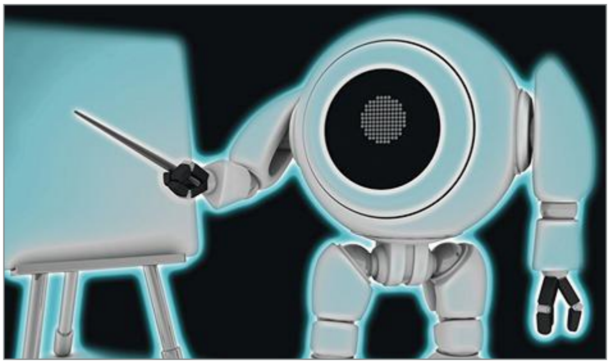
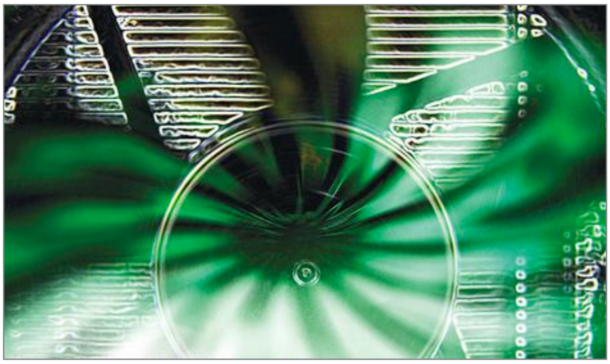


Learning Machine Learning

Machine learning is a hot topic for developers, but where can one learn about how to use the technology? Here, we'll take a more detailed look at some of the online resources available to you, and include links to websites with much more information about machine-learning classes, frameworks, and resources.

http://www.electronicdesign.com/industrial-automation/learning-machine-learning



Choosing a Cooling Fan in Five Easy Steps

Determining the type and size of a cooling fan for your electronic design can be tricky. Following these steps can help simplify that process.

http://www.electronicdesign.com/analog/how-choose-cooling-fan-five-easy-steps

The Lowdown on Z-Wave's S2 Security Support

Z-Wave was a popular wireless technology even before the Internet of Things (IoT) became a buzzword. Technology Editor Bill Wong talks with Sigma Designs' Raoul Wijgergangs about the latest version of Z-Wave, which includes the Security 2 (S2) framework.

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The Spread of Swarming Drones

Swarms of robot drones can perform some interesting feats. Most implementations are for research, but we are moving closer to useful deployments.

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Is China Already Out-Engineering the U.S.?

Chinese researchers are celebrating being the first to teleport an object to Earth's orbit, having essentially communicated information utilizing quantum mechanics.

For at least a decade, much of the West has been casting a wary eye to the East, concerned about its growing technical leadership among reports of China producing legions of college-educated engineers and physicists. While we nurture our science, technology, education, and math (STEM) programs to entice more of the younger generations to consider professions like engineering, China reportedly has a population eager to go into those professions—and in greater numbers than any of which we could dream. Now, it seems that this focus and investment into science (in addition, of course, to infrastructure and many other areas of development) has paid off: China has reported that it successfully teleported an object to Earth's orbit.

This "object" isn't something like a candy bar, but rather a photon—that little particle that represents electromagnetic radiation. It's also the elementary particle that is the basic unit comprising all light. This accomplishment, then, obviously requires some explanation regarding how the photon was transported and how they can tell it was transported.

In terms of the first question, according to the BBC, "This is achieved through quantum entanglement, a process where two particles react as one with no physical connection between them." With one photon on Earth in the Gobi desert, the researchers were able to transmit the information from it to another photon in a satellite currently orbiting 500 km above the Earth. They key to this process was quantum entanglement, whereby a pair of particles can react as if they are one unit even though they have no physical connection.

The satellite, named Micius, travels in a sun-synchronous orbit. This sensitive photon receiver passes over the same point on Earth at the same time every day. As it travels, it can distinguish the quantum states of single photons that are fired from the ground.

According to the *MIT Technology Review,* "To perform the experiment, the Chinese team created entangled pairs of photons on the ground at a rate of about 4,000 per second. They then beamed one of these photons to the satellite, which passed overhead every day at midnight. They kept the other photon on the ground. Finally, they measured the photons on the ground and in orbit to confirm that entanglement was taking place, and that they were able to teleport photons in this way. Over 32 days, they sent millions of photons and found positive results in 911 cases."

At this point, it is hard to foresee exactly what will come of this achievement. Although quantum optics labs worldwide have accomplished teleportation, this is a true "first." As such, it has potential for long-range communications, networking, quantum computing, and more. At this point, it is hard to predict its ramifications in terms of engineering and science leadership and globalization. One thing is clear: Those that invest in research and innovation will lead. And in today's economy, such leadership takes place on a global stage. It will be quite interesting to see the next teleportation first. As a sci-fi geek, I'm hoping to see a real object get teleported in my lifetime. ed

News

ARM, STILL TARGETING REGULAR Remote Updates, Pays $15 Million for Simulity

In the last 16 years, ARM has built a stronghold of low power chips for smartphones, cars, and sensors. But now it wants to make connecting and updating wireless devices more flexible for customers.

The company has paid around $15 million for Simulity, a supplier of embedded operating systems and SIM cards for Internet of Things devices, according to an announcement from private equity firm Foresight, which owned the Gwynedd, Pa.-based business.

Like the tiny silicon strips that slide into phones, Simulity's embedded SIM cards authorize that devices can access cellular networks. But unlike traditional SIM cards, they can be soldered directly into circuit boards that do everything from monitoring factory equipment and tracking shipping containers, and companies can update their network credentials over the air.

Simulity also offers standard software for conveying those wireless updates. It would be unfeasible to manually swap out the SIM cards in thousands or millions of devices with lifespans ranging from five years to twenty years. ARM plans to pair Simulity's technology with its tiny microcontrollers and secure wireless chips, which are already darlings of the Internet of Things market.

Vincent Korstanje, vice president of marketing for ARM's systems and software group, said in an email that "in the next two decades traditional SIM technology cannot deliver the scale or flexibility required" to manage not only millions but billions of connected devices.

"OEMs, cellular network operators and IoT service providers know that to be able to rollout IoT devices at scale they need the flexibility to remotely manage the network credentials of devices after they have been deployed," he added. Simulity's technology helps with that.

The deal also gives ARM thicker armor against hackers and other digital threats. In recent years, the Cambridge, UK-based firm has taken more responsibility for the embedded security that protects chips based on ARM's blueprints, which are used in almost every smartphone in the world as well as tiny microcontrollers that send instructions to everything from windshield wipers to thermostats.

Since ARM's founding in 1991, more than 100 billion chips based on the company's designs have been sold. Masayoshi Son, chief executive of Softbank, which bought ARM last year for $32 billion, has harshly criticized the current state of ARM's security. But he also believes that four out of every five chips sold in the next 20 years will capture, process, and transmit data about their surroundings using ARM chips.

ARM takes security seriously, but how much impact the company will have remains to be seen. In the last two years, ARM has hardwired security into its smallest crumb-sized chips, introduced a secure operating system, and debuted cloud software for remotely monitoring the firmware in devices.

Simon Segars, ARM's chief executive, recently said that the closest we have to a solution for embedded security is sending out regular remote updates to devices. It is the only way to stay ahead of hackers trying to break into any one of billions of chips inside traffic lights, power plants, and factory sensors.

The deal also moves ARM further into the business of low power connectivity. In February, it acquired two companies, Mistbase and NextG-Com, whose software stacks span the physical, second, and third layers of narrowband-IoT, which is based on 4G technology but only chews through a fraction of the power used. ■

SILICON LABS TARGETS Internet of Things Decades from Now

ALL THE COMPONENTS already exist for billions of tiny computers to be worn on our wrists, embedded in traffic lights, and scattered around factories. But Tyson Tuttle, the chief executive of Silicon Labs, predicts it will take "multiple decades" to take full advantage of the Internet of Things.

"The jet engine was invented in 1937 but it took 50 years for airplane networks to be deployed where we could jump on airplanes to get anywhere," Tuttle said in an hour-long keynote at the recent Design Automation Conference in Austin, Texas.

Tuttle, who assumed the chief executive role in 2012, offered a peek inside Silicon Labs' strategy over the last seven years. The company has increasingly moved its business toward connecting everything from factory equipment to home appliances, taking $314.6 million from its Internet of Things business last year, up from $209 million in 2014.

Silicon Labs is resting its future on chips that impart sensors and connectivity to "old school devices" like tennis rackets that analyze strokes or commercial drills whose torque can be calibrated from a smartphone to simplify delicate tasks like screwing down solar panels. Tuttle predicted that the largest markets would be industrial and medical devices.

"But how do you make this easy? How do you make complex software and hardware simple, so that an industrial company in Milwaukee can easily design products, not the RF and level-register," said Tuttle. The plan is for Silicon Labs to integrate "everyone else's devices, instead of the other way around."

Executing on that plan starts with SoC platforms that are cheap enough to be manufactured in large volumes. Tuttle envisions that these IoT SoCs will contain power management, sensors and interfaces, embedded memory, mixed-signal blocks, secure processors, and radios that support standards from Bluetooth to Thread.

"You can't design a product today without it being connected," he added.

Shrinking and squeezing these components onto the same slabs of silicon has been the heart of Silicon Labs' success over the last two decades. Silicon Labs, founded in 1996, made its name in tightly integrated RF synthesizers and transceivers. Tuttle was hired as a chip architect for the company in 1997.

That strategy also extends into the software stacks that let chips communicate wirelessly and development tools like Simplicity Studio, which helps developers to optimize chips for applications from smart lighting to asset tracking. The role of Silicon Labs is to make it easier for companies to profit from the data harvested from embedded devices, Tuttle said.

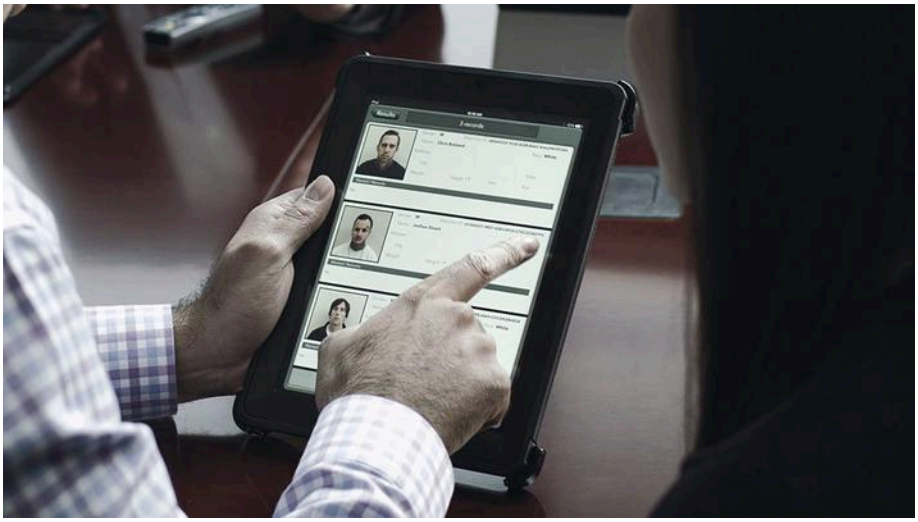
Tuttle has backstopped that strategy with small acquisitions. In 2012, Silicon Labs spent $72 million on Ember's wireless sensor network chips for the 2.4 gigahertz band. In 2015, it paid $61 million for Bluegiga Technologies to expand its war chest of Bluetooth and Wi-Fi modules and later acquired Telegesis, a supplier of ZigBee modules, for $20 million.

The acquisitions have also added new dimensions to Silicon Labs' software stack, which helps reduce the time spent connecting devices to each other and the cloud. When it acquired Zentri last year, for instance, it acquired a Wi-Fi software stack for applications like smart meters and household devices, making it easier to update the devices remotely.

This year, Silicon Labs introduced new boards under the brand Mighty Gecko, which contain specialized software that enables a single chip to efficiently swap between wireless protocols using little more than a smartphone and Bluetooth connection. Hundreds of devices can be configured to join a ZigBee or Thread network.

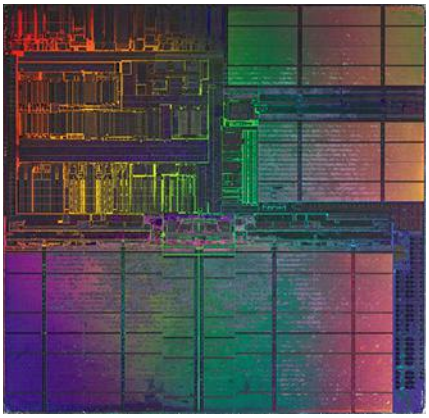
Today, half the engineers at Silicon Labs are writing software to help developers with these types of tasks, Tuttle said. Last year, it also bought Micrium with an eye toward customizing and optimizing its real-time operating systems, so that developers could avoid using a host processor to run the RTOS on Silicon Labs' chips.

"The silicon is really the heart of the system," said Tuttle. "But it's not just about the chip." ■



MACHINE LEARNING Offers Helping Hand to Edit Chips

TASKED WITH SQUEEZING billions of transistors onto fingernail-sized slabs of silicon, chip designers are asking whether machine learning can help.



In the view of electronic design automation firms, machine learning tools could chisel rough edges off complex chips, improving productivity, optimizing tradeoffs like power consumption and timing, and testing that chips are ready for manufacturing.

Though chip design is still a deeply creative process, engineers need tools that abstract the massive number of variables in modern chips. Using statistics, the software generates models fitted to simulations that replicate how physical chips will work. The tools would seem to be prime candidates for machine learning, which can be trained to find hidden insights in data without explicit programming.

But these teachable tools are still rare, said Elyse Rosenbaum, a professor of electrical and computer engineering at the University of Illinois Urbana-Champaign, in a telephone interview. Most machine learning tools that do exist are used to confirm that chips match specifications and will be manufactured without flaws.

Rosenbaum, who helps lead the Center for Advancing Electronics with Machine Learning (CAEML), said that most EDA applications will require humans for the training side of the equation. That contrasts from image recognition and cancer detection programs, which excel with unsupervised forms of machine learning.

Designing chips creates lots of data – and sometimes more than engineers know what to do with. "We need to stop providing chip makers with more data," Ting Ku said on a panel at the Design Automation Conference last month in Austin, Texas. "We need tools to make some decisions."

Ku, senior director of engineer for Nvidia, said that the company is already using machine learning to provide insights into manufacturing variations that could affect its graphics chips. And these variations are growing more unpredictable with the shift toward smaller process nodes like 10 nanometers.

But this is still virgin ground for an industry that only a few years ago signed onto big data analytics. "We can smell machine learning problems, but we can't just take a course in it," said Jeff Dyck, vice president of technical operations at Solido Design Automation. "We cannot back designs on guesses, we need higher levels of confidence."

Solido's tools are representative of how the industry is dipping its toes into machine learning. The firm recently released new characterization tools, which after being trained on circuit simulations can make faster predictions than other tools about how, for instance, standard cells and memory will react to higher-than-normal voltages.

Amit Gupta, Solido's chief executive, said in an email that the software "automatically determines and runs specific simulations, that is used as the training data to build the machine learning models in real time. The models then predict results with brute force accuracy. We find that building design-specific models per run is effective."

Solido claims that its other tools can verify memory, analog, and other circuits against statistical process variation faster than conventional software. Solido, which recently started a program called ML Labs to build special tools for customers, says that more than 40 companies use the variation-aware design tools to cut power consumption and die size.

Lots of other possibilities exist, though. Dave Kelf, vice president of marketing for OneSpin Solutions, said in an interview that the company is looking to apply machine learning to formal verification, which uses statistics to locate errors missed by simulations. Manish Pandey, Synopsys' chief architect for new technologies, has floated the same concept.

Eric Hall, chief technology officer at consulting firm E3 Data Science and a former master engineer for Broadcom, said that software trained by humans could also be useful for estimating logic gate power and timing in chips, as well as testing reliability and nonlinear responses.

Plunify, a Singapore-based software start-up, has targeted a new pattern recognition tool at FPGAs. The tool, called Kabuto, locates inelegant code that hurts performance or causes timing issues like pipelining. When the final version is released, it will suggest RTL fixes that chip architects can apply automatically.

Software that learns to design chips from scratch will not come out anytime soon or at all, experts said. In the short term, the EDA industry is targeting tools that act like editors making grammatical and spelling changes to the first draft of a novel, optimizing interconnects and other circuits much faster than traditional software.

The usefulness of convolutional neural networks – which have been used to classify images, make financial decisions, and play intuitive board games like Go – is still under debate. It might not fit electronic design automation at all, said Paul Franzon, a professor of electrical and computer engineering at North Carolina State University.

"For most problems you want another model, not a classification," said Franzon, who oversees CAEML along with Rosenbaum and Madhavan Swaminathan of Georgia Tech, in a recent interview. "You can distinguish a Persian cat from one sitting on a fence, but that is not a concept that fits many EDA problems."

To learn how machine learning fits into chip design is the mission of CAEML, which launched last year with National Science Foundation support. It has partnered with chip suppliers like Samsung and Qualcomm, software firms Cadence and Synopsys, and server companies like Hewlett Packard Enterprise.

CAEML projects include the use of machine learning to reuse intellectual property, optimize power delivery networks, model high-speed links, and create modular algorithms to speed up verification. Another will test deep learning software for checking that chip layouts match specifications.

Sorin Dobre, senior technology director and manager for Qualcomm, who has designed digital chips from 180nm to 7nm, said that such tools could not only make life easier for senior engineers but also make chip design more accessible to those without decades of experience.

Dobre also said that machine learning could maximize how companies manage massive amounts of design data. IC Manage is already on that route with software that analyzes tape outs to predict bugs in new chips. The Campbell, Calif.-based firm already sells software for accelerating EDA tools, which lets companies cut back on servers for handling their data.

Few experts doubt that machine learning is part of the industry's future, keeping engineers from getting bogged down in the complexity of multicores and system-on-chips. "In the longer term, we hope to push good design into software, so that it moves with creativity on the human side," Franzon said. ■

TAKING THE PULSE of China's Semiconductor Industry

THE LATEST CHINESE industrial policy, Made in China 2025, came out two years ago with an emphasis on semiconductors, fanning the nation's ambition to become a global superpower in microchips.

But semiconductor experts at the Design Automation Conference in Austin wanted to dispel misconceptions about how China wields a $150 billion investment fund – called the "Big Fund" inside China – to assist chip suppliers in competing with foreign rivals and manufacturing memory and computer chips locally.

Shaogun Wei, a professor of electrical engineering at Tsinghua University, trotted out statistics in a presentation to ground China's fast-growing industry. He wanted filter out the "noise" surrounding China, which has been accused of propping up the industry, requiring companies to buy local chips, and stealing intellectual property.

Last year, Chinese manufacturers consumed 27% of the world's chips but exported two-thirds of those inside smartphones, televisions, and other gadgets. The nation's chip makers only account for 7.3% of the $338 billion global market, while China's largest fab SMIC is two process nodes behind rival foundries like TSMC.

"China is on the lower end of the value chain," Wei said.

A panel of four executives from China also aimed to clarify the state of the industry, which is feeling growing pains. In the panel, "Growing IC Design and Ecosystem in China," they said that most funding came from private equity firms and provincial governments, which sometimes only send part of the money that companies were promised.

New companies have been piling up. There are around 1,300 fabless suppliers in China, up from 500 in 2011, according to the Chinese Semiconductor Industry Association. The industry is top-heavy, with 90% employing fewer than a hundred people and half earning less than 10 million RMB – around $1.5 million – per year.

The surge in start-ups could also be related to China's engineering culture, the panelists said. "Every Chinese engineer wants to become a C.E.O. in China," said Xianing Qi, the chief executive of Hangzhou's C-Sky Microsystems, whose CPU cores have been shipped in over 500 million chips.

Last year, only around 13% of China's fabless suppliers accounted for 81% of the entire fabless industry, which generated 164.4 billion RMB or around $24.1 billion in revenue. Last year, the fabless industry grew 24.1% in China, Wei said.

The smaller firms often lack the technological chops to take full advantage of government funding and handle the intense scrutiny that comes with it. "We need to build up our muscles before we can use the money in the right way," said Steve Yang, chief executive of Huada Empyrean, an electronic design automation firm. ■

MAURIZIO DI PAOLO EMILIO | Contributing Editor

MEMS Sensors Help Safeguard Passengers

Beyond typical applications like airbags and advanced driver-assistance systems, inertial MEMS gyroscopes and accelerometers can enable a range of automotive control solutions to provide greater efficiency.

Microelectromechanical-systems (MEMS) technology uses micro fabrication techniques to combine microelectronics capabilities with the mechanical properties of microsensors. Increasingly, MEMS gyroscopes and accelerometers are used in a large number of devices for both consumer and industrial applications.

Active suspensions, for example, require four extremely stable and accurate sensors mounted on the wheels in order to achieve a greater degree of ride quality and car handling, thus allowing for better traction and control. Another application is to prevent passengers on the front seat from being thrown out of the passenger compartment in case of an accident.

The benefits of these MEMS approaches include high efficiency, small size, and low cost. Automobile MEMS sensors play a key role, solving safety challenges in an extremely accurate and stable design. In fact, electronic safety systems based on MEMS technology can ensure compliance with functional safety standards, enabling designers to more efficiently achieve their goals. Demand is stronger than ever for enhanced safety and security in the automotive industry, which is propelling growth and development in the MEMS market.

MEMS accelerometers and gyroscopes both are benefiting from this growth. Accelerometers measure accelerations in one, two, or three orthogonal axes. They're typically used to calculate inclination or orientation with respect to gravity acceleration, as well as to measure vibrations and shocks. To select the right accelerometer for particular application, designers must consider different project variables, including sensor structure, resonance, reliability, stability, bandwidth, and energy consumption, together with cost.

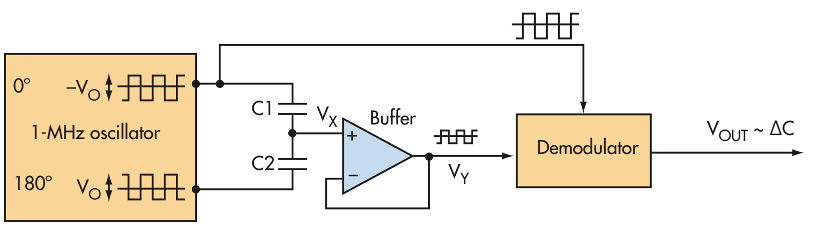
In contrast, MEMS gyroscopes provide a simple way to measure angular velocity (or rotation motion) in easy-to-install packages on the printed-circuit board (PCB). They're a popular choice for feedback systems as a sensitive element for motion control.

MORE ON MEMS ACCELEROMETERS

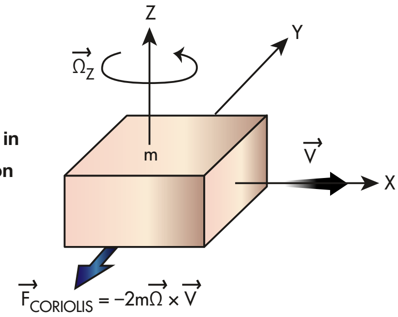
Most accelerometer sensors are of the silicon variety. These devices generally break down into two fundamental types—they're based on either a capacitive or thermal approach.

Depending on the application, use of a MEMS thermal accelerometer can be advantageous for a number of reasons. For example, the capacitive approach may be more suitable for detecting a car accident and/or activating the airbag. In contrast, the thermal approach is best suited for electronic stability control (ESC), as it's based on the principle of the convection of heated gas molecules inside a sealed cavity.

Through very accurate sensors, it's possible to detect variations in the temperature profile resulting from small variations of acceleration (or inclination). Capacitive MEMS, on the other hand, exploit the piezoelectric effect through microscopic crystalline structures urged by accelerating forces. This, in turn, causes electrical stress. They are intrinsically broadband transducers (> 5 kHz), with a mechanical resonance frequency of near 2 kHz for low g devices. A typical way to detect temp-profile variations is to measure the variation of capacities, where the capacitors can operate both as sensors and actuators *(Fig. 1)*.



1. Shown is an electrical diagram for measuring variations in capacity from a MEMS sensor. Detection is based on capacity variation when the geometry of a capacitor is about to change.



2. MEMS gyroscopes use the Coriolis effect to measure angular velocity. When a mass (m) is moving in the direction of V and an angular rotation Ω is applied, the mass will experience a force in the direction of the arrow ($F_{CORIOLOS}$) due to Coriolis's strength.

Capacitive accelerometers require a two-die solution (one for the sensor element and the other for the application-specific integrated circuit, or ASIC) to measure inclination in high-vibration environments. In most cases, the sensor element requires a much larger geometry than the ASIC. For its part, a MEMS thermal sensor integrates the sensor and electronics into a single monolithic IC, which results in a much smaller device and thus simplifies the assembly process.

MEMS GYROSCOPES

Most available MEMS gyroscopes are based on a diapason configuration with two masses, which oscillate continuously in opposite directions. When an angular force is applied, the Coriolis's strength on each mass also acts in opposite directions. The resulting variation in capacity is proportional to the angular velocity (Ω). That velocity is converted to an output voltage for analog or digital gyroscopes *(Fig. 2)*.

In terms of noise, MEMS gyroscopes contribute to angular velocity. This intrinsic noise represents the variation of the gyro's output signal when it's in a state of static inertia (i.e., without rotation) and in conditions of environmental immunity (or without vibrations or bumps).

The most common parameters for describing such noise behavior are rate noise density (RND) and angular random walk (ARW). The RND factor typically uses a unit of degrees/sec /√Hz and provides a simple mode to predict total noise based on the gyroscope frequency response. The ARW factor, on the other hand, typically uses grading units/√hour , and is often more useful when analyzing the impact of noise on angle estimation for specific time periods.

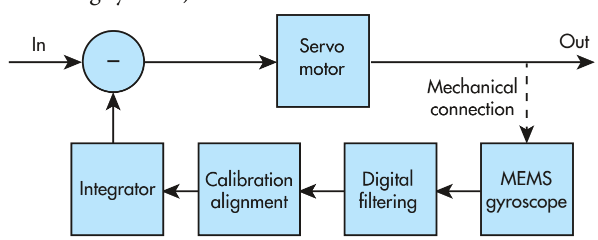
WHAT'S NEXT?

As the automotive industry continues to undergo a massive transformation, new features like advanced safety and driver-assistance systems continue to evolve. The various sensors already available, such as pressure and temperature, will still be used in vehicles. Yet other types of sensors will certainly be implemented in autonomous driving to support safety functions.

In addition, advances in science and engineering will lead to new materials and processing methods. They will enable the design and manufacturing of film for next-generation MEMS technologies and sensors targeted at automobile applications like advanced driver-assistance systems (ADAS).

Inside the cabin, for example, automotive companies are designing MEMS microphone solutions to offer new voice-control functions with noise-to-noise ratios in the range of 60 to 70 dB. Such microphones offer a high signal-to-noise ratio (SNR) and good sensitivity with a surface-mount assembly processes. Moreover, they offer less variation in sensitivity over temperature, with significant advantages in terms of performance, reliability, and manufacturability for a multitude of safety applications in the automotive industry.

In addition, a gyroscope can be used to activate the electronic-stability-control (ESC) braking system to prevent accidents when the car is, for example, traveling along a narrow curve *(Fig. 3)*. A gyroscope also can be used to activate an airbag when there's a tilting condition or frontal accident. In machines, including those of the automotive variety, it can be used to measure orientation to keep the direction of movement on a digital map when the GPS signal is lost (dead-reckoning systems).



3. Within feedback systems, the MEMS sensor performs the feedback task and, therefore, the control response is associated.

NOISE VS. MOTION CONTROL

Clearly, MEMS gyroscopes and accelerometers already help to make automobiles more secure—their massive presence in vehicle control systems significantly enhances driving stability. A MEMS device also forms the core of a system that in most cases requires noise filtering, adaptive learning algorithms, and the ability to reset any imbalance of the effects due to temperature variations and vibrations.

Keep in mind, though, that the noise of MEMS systems can have a direct influence on the key performance criteria in motion-control systems. Thus, it should be carefully considered in the design process.

Also keep in mind that a new MEMS market is emerging: nanoelectromechanical systems (NEMS). Due to their sensitivity, these nanometric devices are able to get very small sensors to detect stress and vibration at the atomic level.

Nanotechnologies promise to improve the performance of existing automotive technologies, improving engine efficiency and fuel consumption. These devices increase the computational ability of microelectronics and mechanics with sensing and control capabilities, providing a high level of functional integration and low-power operation. ed

BILL SCHWEBER | Jaffa Engineering

Optical Fiber
Powers MRI-Compatible Cardiac Catheter

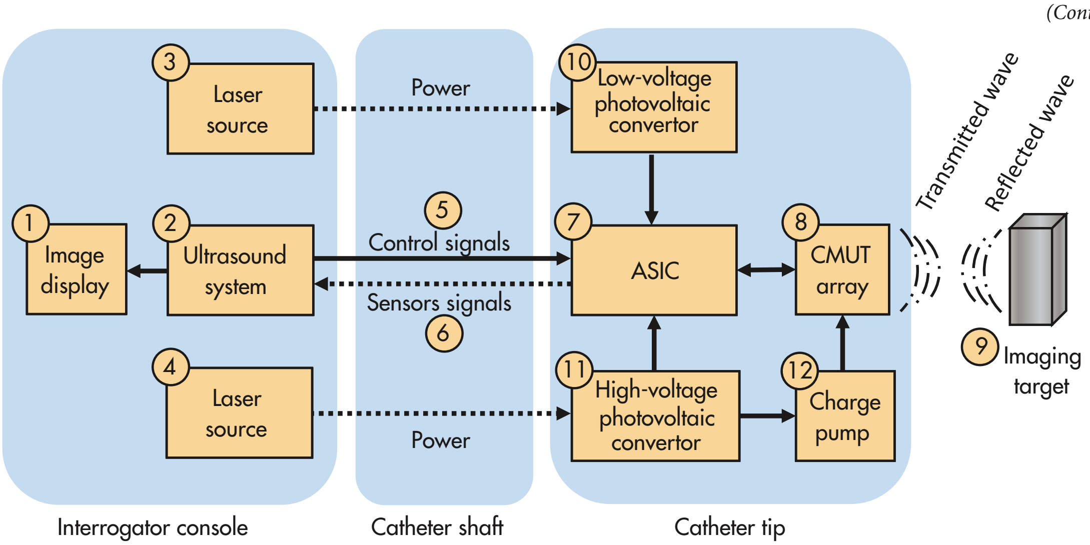
By replacing a cardiac catheter's wire leads with optical fiber for power and control, this prototype takes a major step toward demonstrating how this approach can work in making difficult measurements in an MRI setting.

Optical fibers are very good for conveying data, but generally impractical for transferring useful amounts of power. Nonetheless, a joint team from Royal Philips NV (Eindhoven, Netherlands) and Erasmus Medical Center (Rotterdam, Netherlands) and Rasmussen Medical Center (Rotterdam, Netherlands) developed a benchtop-prototype cardiac catheter that uses multiple optical fibers to deliver power to a cardiac catheter.

This novel approach, explained in the lengthy, detailed paper "Electrifying catheters with light," from the Optical Society of America, targets eliminating two problems associated with a catheter's wire leads when the patient is being assessed with an MRI machine: localized heating due to wires resonating with the magnetic field (a rise of more than 70°C within 30 seconds), and image degradation due to metallic wire interference. As an added benefit, an optical link also provides galvanic isolation.

The proof-of-concept design *(Fig. 1)* presently uses three optical fibers plus a wire pair; the next planned phase will try to eliminate those remaining wires. One fiber carries a higher-power light which will convert to a high voltage (about 44 V) for eventual use by the scanner's transducer. The second carries power for use at the lower voltage for the

(Continued on page 46)



1. This block diagram of the optoelectrical ultrasound imaging system shows electrical connections as solid arrows and the optical connections as dashed arrows. *(Source: Optical Society of America)*

WILLIAM WONG | Technical Editor

LoRaWAN Is Made for IoT

LoRa is a low-power wide area network (LPWAN) specification intended for wireless batteries operated for IoT applications. We take a look at the technology, challenges, and its adoption.

The LoRa Alliance's LoRaWAN (Long Range Wide Area Network) is a Low Power Wide Area Network (LPWAN) made for the Internet of Things (IoT). It is designed for long-range, low-power operation with sensors and controls that work off of batteries or energy-harvesting devices. It has applications in transportation and logistics, smart buildings, smart cities, and agriculture. For example, Vinduino is an open-source, LoRaWAN-based solution for wineries that want to track the soil moisture in their vineyards. It also incorporates an Arduino board and is programmed using Python. LoRa was originally developed by Semtech.

The recent LoRa conference in Philadelphia was host to gateway and hardware vendors as well as service providers like Comcast that announced its machineQ LoRa service. It was able to cover most of the city with only three gateways.

LoRa's two-key encryption security system works well for multi-tenant services like machineQ. One key is used to encrypt and authenticate exchanges with the network infrastructure. The other is for communication with the data service. This allows Comcast to have access to the infrastructure communication, but not the application data that is encrypted using the other key.

LoRa is not a speed demon. Even at short range it tops out at 50 kbits/s. It scales down to 292 bits/s but with a range that is measured in kilometers as well as being able to penetrate barriers like walls that would stop or significantly attenuate other wireless protocols like Wi-Fi or cellular. This makes LoRa a good choice in buildings or for in-ground sensors like PNI Sensors' PlacePod magnetic sensor for parking space management that is embedded in the floor.

LoRa gateways like Multi-Tech Systems' Linux-based, MultiConnect Conduit *(Fig. 1)* work with any LoRa device. The gateway actually has a pair of mCard slots and there is an mCard that supports LoRa. Multi-Tech's mDot modules come in a number of plug-in and solderable form factors.

1. Multi-Tech Systems' MultiConnect Conduit supports a pair of plug-in modules such as a LoRa wireless module.

The Sodaq ExpLoRer *(Fig. 2)* is an example of a typical LoRa device development platform. It is based on Microchip's RN2903 LoRa transceiver module and the board also hosts the SAMD21 ARM Cortex-M0 microcontroller. The board has a PCB antenna, Bluetooth 4.2 support and a temperature sensor.

LoRa uses unlicensed spectrum. The bands differ by country but in North America it uses the 915 Mhz band providing 64 upstream and eight downstream channels. Chirped-FM modulation and high receiver sensitivity help with reception over long distances or through materials. LoRa has broadcast-based firmware over-the-air (FOTA) update support that is slow, because of the network's speed, but reliable because multiple, RAID-like packets are sent with sufficient redundancy that dropping some will still result in a successful update.

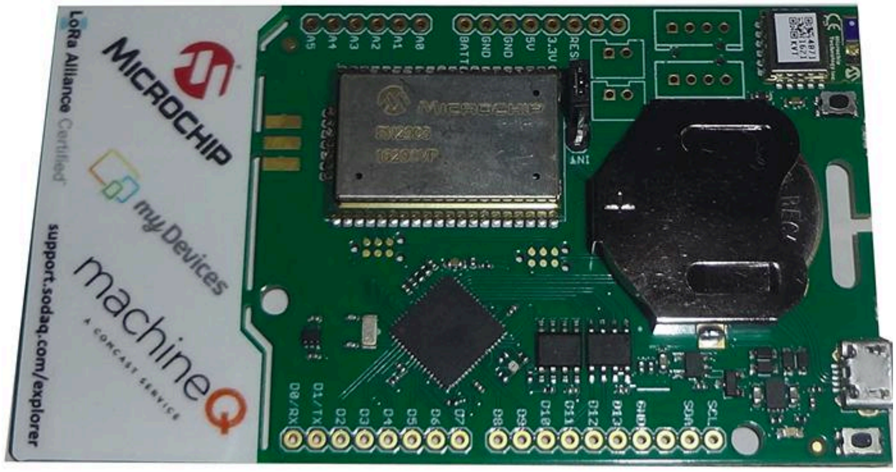
Software overhead on the device and gateway is minimal because of how the protocol works. There is no mesh networking and devices simply transmit and receive packets. Multiple gateways can provide overlapping coverage and they simply forward packets, along with meta information, to a LoRa server. A server is responsible for handling any redundancy. For example, it may receive the same packet from a device through two gateways. The server will discard one and send any response through the best gateway based on the meta data that includes details like the strength of the connection.

LoRa Server is an open-source implementation that handles deduplication. It supports ABP (activation by personalization) and OTAA (over-the-air activation).

Anyone can set up one or more LoRa gateways. Service providers like Comcast allow companies to deploy devices without having to build a WAN infrastructure. Typically end users will have their own gateway for applications like agriculture where service provider coverage is not available.

LoRa has garnered quite a bit of support that is reflected in the number of gateways available as well as the number of modules and chips supporting developers. Users and vendors have a number of options like self-hosting and services like Comcast's machineQ to choose from. The Things Network is an organization that ties LoRa gateways together that devices can share for free.

LoRa fills a gap between LANs like Bluetooth, Zigbee, and Wi-Fi and wide area networks like cellular. The latter requires the use of a service provider and the coverage is not adjustable by the user eliminating it as an option for some applications. ed



2. The Sodaq ExpLoRer combines Microchip's RN2903 LoRa transceiver module with its SAMD21 Arm Cortex-M0 microcontroller.

WILLIAM WONG | Embedded/Systems/Software Editor

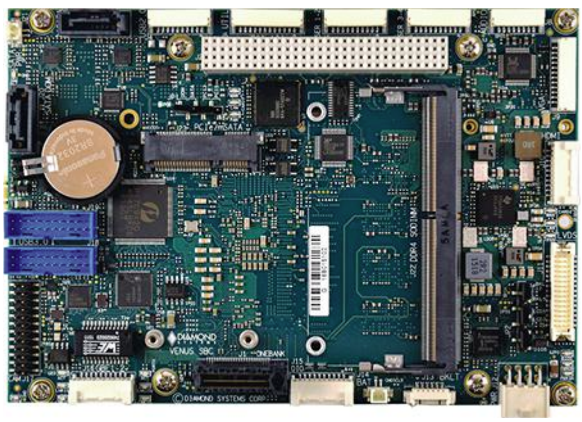
How Are EMBEDDED MOTHERBOARDS CHANGING?

We check out new features like multiple Mini-PCI Express sockets and M.2 flash memory to see what options designers now have available.

Embedded motherboard designs change slowly when it comes to peripheral interfaces. ISA-based interfaces like PC/104-Plus *(see "Will ISA Survive?")* remain because it supports legacy boards and it is easy to design peripheral boards, but the interface for the future is PCI Express (PCIe). While there are a host of PCIe daughter board options, the Mini-PCIe form factor offers a compact expansion option for embedded motherboards *(see "PCI Express Mini Card Tackles Compact Embedded Expansion")*.

A single Mini-PCIe socket has been commonly found on embedded motherboards for some time, but the number of sockets is increasing as developers are finding more ways to embed peripherals via Mini-PCIe modules. These can often replace the peripherals on legacy boards that take up significantly more space and use more power. The x1 PCIe interface provides sufficient bandwidth for high-speed peripherals, and the multifunction socket can often support interface like SATA in the form of mSATA modules.

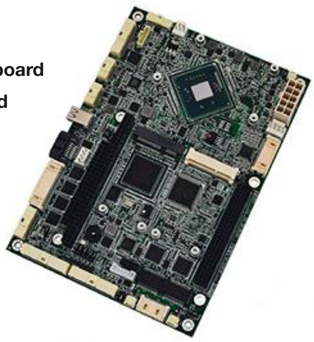
Diamond Systems' Venus *(Fig. 1)* motherboard supports Intel's "Skylake" 6th generation Core i7/i5 U series processor. It includes a pair of Mini-PCIe sockets, one of which supports mSATA modules. The single-board computer (SBC) also has PCI-104 and OneBank socket for stackable expansion boards. The OnBank has four x1 PCI Express ports and two USB ports. As with a typical SBC, the Venus includes networking support with a pair of Gigabit Ethernet ports, additional SATA ports, multiple video graphic outputs, and audio support. It has 16 digital ports but lacks analog support that can be easily added using the expansion sockets.



1. Shown is Diamond Systems' Venus, which includes a pair of Mini-PCIe sockets—one of which supports mSATA modules. It also has PCI-104 and OneBank stackable socket that has four x1 PCI Express ports and two USB ports.

2. Versalogic's Viper has two Mini-PCIe sockets along with PC/104-Plus expansion.

VersaLogic's Viper *(Fig. 2)* is an EBX SBC that hosts Intel's Bay Trail Atom processors. It has similar expansion and peripherals as the Venus, although it has PC/104-Plus that includes ISA and PCI sockets. There is a pair of Mini-PCIe sockets with mSATA support. The SBC also has two Gigabit Ethernet ports, plus USB 3.0 support, as well as an 8-channel, 12-bit ADC and 4-channel, 12-bit DAC. The two Mini-PCIe sockets can augment these interfaces or add functionality, such as GPS or wireless networking support.



3. WinSystems' EPX-C414 motherboard has a pair of Mini-PCIe sockets and PC/104-Plus expansion.

4. SuperMicro's X10SDV-12C-TL-N4F has a Mini-PCIe and M.2 socket.

The WinSystems EPX-C414 *(Fig. 3)* is similar to the Viper with a Bay Trail processor and two Mini-PCIe sockets. It has 48 digital I/O ports, dual-gigabit Ethernet, and USB 2.0 ports and four serial ports. There is a CFast socket, as well as mSATA support on the Mini-PCIe sockets.

The other expansion port that is becoming more common is the M.2 socket; typically used for storage, it also can support peripherals *(see "What's the Difference Between M.2 Modules?")*. It can have up to a x4 PCI Express interface that supports NVMe or a SATA interface *(see "What's The Difference Between SATA And NVMe?")*. NVMe has the speed advantage, and M.2 modules are available in higher capacities than Mini-PCIe modules, because the M.2 modules can be larger.

Super Microcomputer (SuperMicro) has a number of embedded motherboards that have an M.2 socket as well as a Mini-PCIe socket. The X10SDV-12C-TLN4F *(Fig. 4)* can run a 12-core Intel Xeon, and it sports a Mini-PCIe and x4 PCIe M.2 socket, along with two 10 Gbit Ethernet ports and two 1 Gbit Ethernet ports.

M.2 has higher capacity storage solutions compared to Mini-PCIe, but there are currently no M.2 modules that match the more rugged specifications of many Mini-PCIe modules. Developers that require high capacities may have to resort to SATA drives that will take up more space.

Motherboards with even more Mini-PCIe and M.2 sockets are becoming available. This allows developers to take advantage of the larger number of PCIe ports available on new systems. This can allow designers to create more compact and flexible systems without the need for daughterboard expansion. ed

STEVEN XIE | Analog Devices Inc.

TIPS AND TRICKS for Addressing Fixed-Frequency Spurs in ADC Signal Chains

Design solutions and calculation methods presented in this article will help root out the spur issues that plague high-resolution, precision ADC circuits.

Today's successive-approximation-register (SAR) analog-to-digital converters (ADCs) and sigma-delta ADCs are known for their high resolution and low noise. Nevertheless, achieving signal-to-noise (SNR) performance specified in the datasheet can be difficult. An even greater challenge is optimizing ADC spurious-free dynamic range (SFDR) by establishing a reliable noise floor without incurring spurs in the system signal chain. Such spurs are often caused by improper circuitry surrounding the ADC, or can result from external interference, especially in harsh operating environments.

This article will describe techniques for identifying the root causes of spur issues in high-resolution, precision ADC applications, and offer solutions to solve them while improving end-system EMC capability and reliability. Use cases include spurs caused by dc-dc power-supply radiation, ac-ac adapter noise, analog input cable noise, and room lighting.

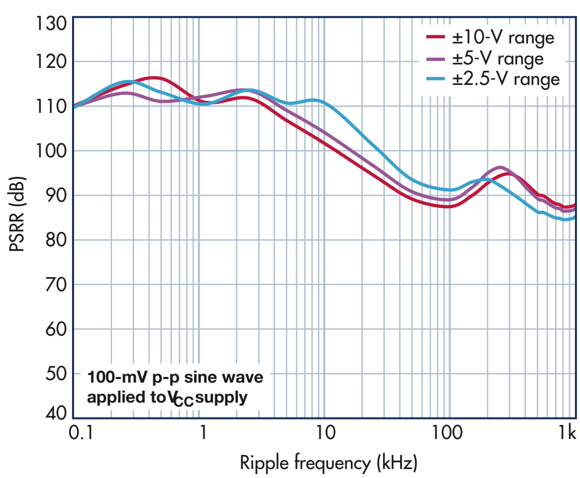
SPURS AND SFDR

It's common knowledge that spurious-free dynamic range (SFDR) represents the smallest power signal that can be distinguished from a large interfering signal. For current high-resolution, precision ADCs, the SFDR is typically dominated by the dynamic range between a fundamental frequency and the second or third harmonic of the fundamental frequency of interest. However, certain spurs can limit the performance due to other aspects of the system.

The spurs can be categorized as input-frequency-dependent spurs and fixed-frequency spurs. Input-frequency-dependent spurs are related to harmonic or nonlinearity performance. This article will focus on the fixed-frequency spurs caused by power supplies, external references, digital interfacing, external interference, and more. Based on the application, these types of spurs can either be reduced or avoided entirely to help achieve maximum signal-chain performance.

SPUR ISSUES CAUSED BY ON-BOARD DC-DC POWER-SUPPLY NOISE

Typically, LDOs are the suggested solution for generating low-noise power-supply rails for precision ADCs in precision measurement systems because of the dc-dc switching regula-



1. AD7616 PSRR vs. ripple frequency.

tor's higher ripple noise. The fixed-frequency or pulse-width-modulated switching regulators provide switching ripple that's usually at a fixed frequency ranging from tens of kilohertz to a couple of megahertz. The noise at the fixed frequency can feed into the ADC conversion codes via the ADC's power-supply rejection-ratio (PSRR) mechanism.

Some designers may use dc-dc switching regulators for precision ADC applications due to limited budget or board space. They have to limit the ripple noise or use ADCs with high PSRR to make sure that the ripple noise is below the ADC noise floor in order to achieve signal-chain performance. Otherwise, there could be spurs at the switching frequency in the ADC's output spectrum, which may degrade signal-chain dynamic range.

The AD7616 is a 16-bit data-acquisition system (DAS) that supports dual-simultaneous sampling of 16 channels for power line monitoring. It has a very high PSRR and is effective at rejecting/attenuating the switching ripple. For example, a dc-dc switching power supply with 100-mV p-p ripple noise at 100 kHz is used for the AD7616, which has a VCC of 5 V with ±10-V input range.

The digital code noise caused by the ripple noise is:

$$\frac{|100\text{ mV p–p}}{10^{\frac{88\text{ dB}}{20}}} = 3.98\ \mu\text{V}\ \textit{or}\ 0.013\text{ LSB}$$

The level of ripple showing up in the ADC output *(Fig. 1)* is low for a 16-bit converter. ADCs exhibiting high PSRR performance make it possible to use switching regulators in precision measurement systems.

SPUR ISSUES CAUSED BY DC-DC POWER-SUPPLY RADIATION

Using a high-PSRR ADC does not ensure that switching regulators will not cause problems in precision measurement systems. The ripple noise from switching regulators could feed into the ADC's digital codes through other ways.

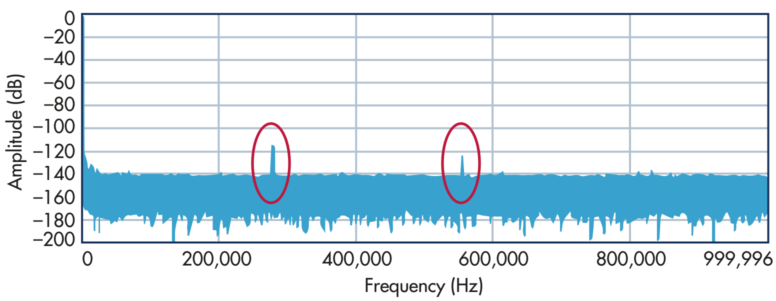
To illustrate, the AD4003 is a low-noise, low-power, 18-bit, 2-Msample/s SAR ADC. During EVAL-AD4003FMCZ evaluation board ac performance testing, a spur at a level of about –115 dBFS was found at around 277.5 kHz; the spur and its second harmonic appeared as shown in *Figure 2*.

First, it was confirmed that the AD4003 power supplies were not causing the spurs. Then, tests were performed to determine if the spurs were coming from the analog input:

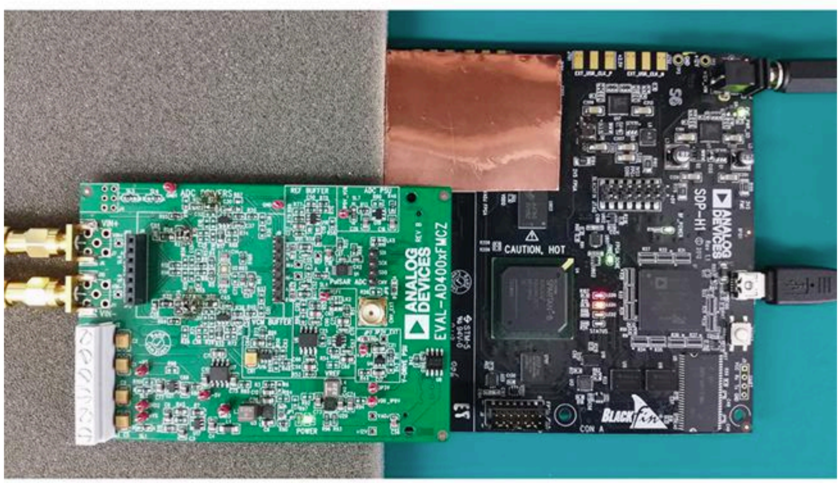
- The spurs decreased when the differential analog-input conditioning circuitry was removed.
- The spurs decreased when a narrow bandwidth RC filter (e.g., 1 kΩ, 10 nF) was inserted at the front end of the AD4003 buffer amplifier (ADA4807-1).

These results show that the noise causing the spurs may pass through the conditioning circuitry and into the AD4003's analog inputs. Next, the sensor output was disconnected and the conditioning circuitry removed, leaving only the $V_{REF}/2$ CM voltage input at the noninverting input of the ADA4807-1. However, the spurs remained and at a similar level.

It was then suspected that the interference source was located around the EVAL-AD4003FMCZ signal chain. To prove this, a copper-foil shield was placed at various locations on the EVAL-AD4003FMCZ board and the controller SDP-H1 board. It was determined that when the copper-foil shield was placed over the dc-to-dc power supplies on the SDP-H1 board *(Fig. 3)*, the spurs would disappear. The spur frequency of 277.5 kHz matches the programmed switching frequency of the ADP2323 regulator. *Figure 4* shows the 3.3 V VADJ_FMC switching frequency power as captured by the EVAL-AD7616SDZ GUI FFT.



2. Spur issue as seen on an EVAL-AD4003FMCZ eval board.

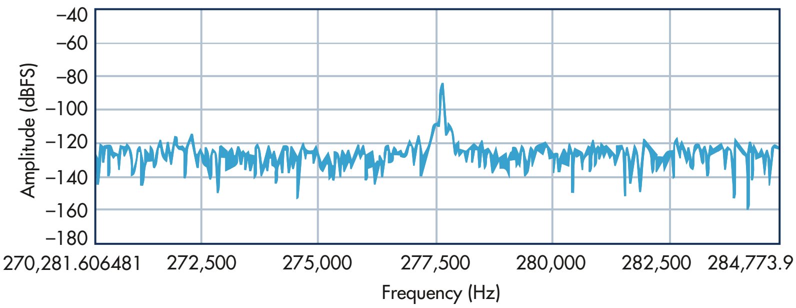


3. VADJ_FMC inductor L5 covered by copper-foil shield.

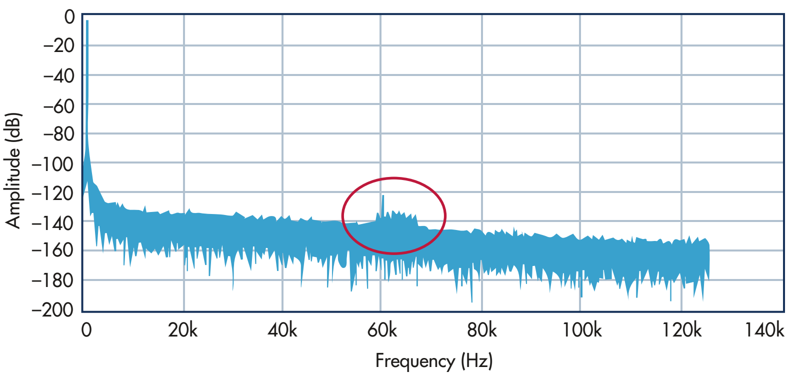
The conclusion was reached that the dc-dc switching frequency interference was being emitted by the 8.2-µH inductor (L5). The interference was being injected into the signal chain at the input of buffer amplifier ADA4807-1, where it then went into the AD4003 ADC's analog input.

Possible solutions to this spur issue caused by the dc-dc power converter are:

- Use a low-pass filter at the front end of the AD4003 ADC to attenuate the coupled dc-dc switching frequency interference to a level that meets the design target (that is, spur buried in noise floor) if the application bandwidth allows it.
- Use the new SDP-H1 board (BOM Rev 1.4), which uses a shielded inductor for L5. The radiated interference power is reduced, so the spurs captured in the AD4003 ADC's spectrum are much lower.
- The VADJ_FMC voltage level can be programmed by the EEPROM on the EVAL-AD4003FMCZ board. It was found that using a lower voltage level, such as 2.5 V for VADJ_FMC, caused the spurs to disappear, too.



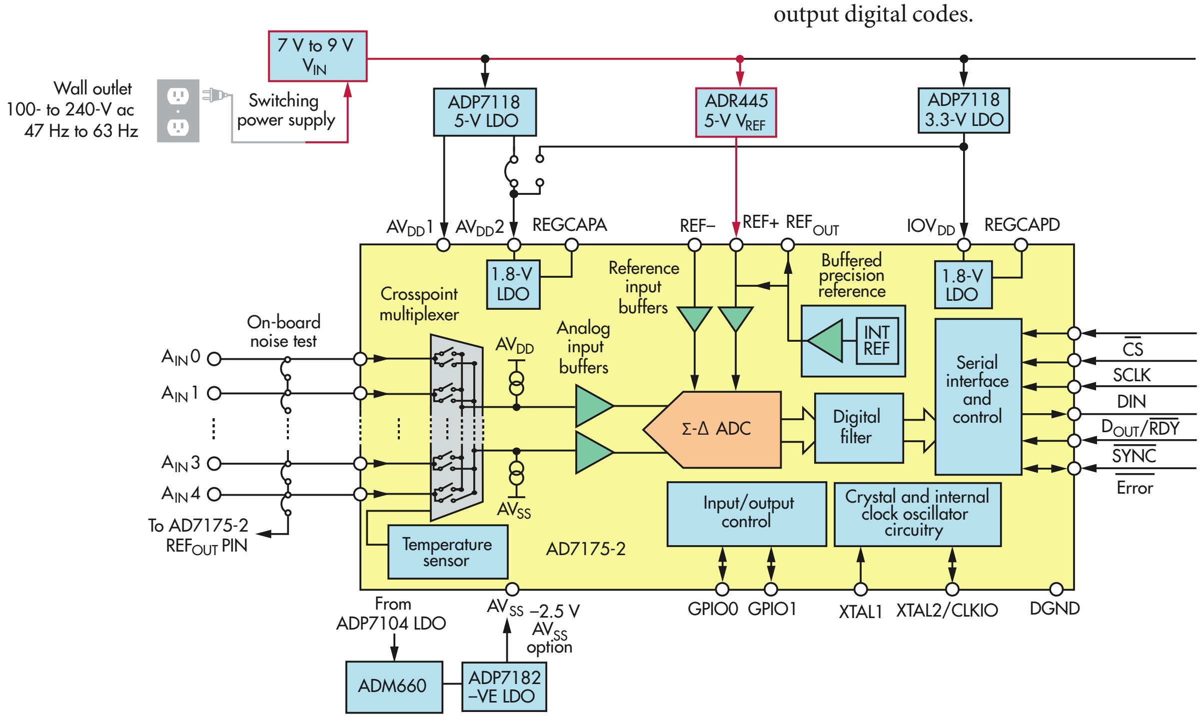
4. VADJ_FMC 3.3-V switching ripple captured by EVAL-AD7616SDZ GUI FFT.



5. Cluster of spurs as seen on the EVAL-AD7175-2SDZ evaluation board.

SPUR ISSUES CAUSED BY AC-DC ADAPTER NOISE COUPLING THROUGH EXTERNAL REFERENCE

ADCs quantize an analog signal into a digital code as referred to the ADCs' dc reference voltage level. Therefore, the noise on the dc reference input will directly feed into the ADC's output digital codes.



6. The spur issue was revealed using this EVAL-AD7175-2SDZ evaluation board.

The AD7175-2 is a low-noise, fast-settling, multiplexed, 2-/4-channel (fully/pseudo differential) Σ-Δ ADC for low-bandwidth inputs. During the EVAL-AD7175SDZ evaluation board's signal-chain test, a cluster of spurs around 60 kHz was captured *(Fig. 5)*.

The AD7175-2 ADC's power supplies and analog-conditioning circuitries were evaluated and found to be good. However, as shown in *Figure 6*, the AD7175-2's 5-V reference input is generated by the ADR445 reference supplied by 9-V dc from an ac-dc adapter that's external to the evaluation board. Next, a bench 9-V dc power module was substituted for the adapter. As a result, the cluster of spurs disappeared, leaving only a narrow spur at 60 kHz *(Fig. 7)*.

The 9-V output ac-dc adapter was tested with the EVAL-AD7616SDZ GUI FFT while supplying the EVAL-AD7175-2SDZ board with 320 mA of current output *(Fig. 8)*. The switching frequency power at the ADR445 reference's power pin is about –70 dBFS with an AD7616 ±10-V input range, which means 6.325 mV p-p or –64 dBFS at an AD7175-2 ±5-V input range:

$$20\text{ V} \times 10^{\frac{-70\text{ dB}}{20}} = 6.325\text{ mV p-p}$$

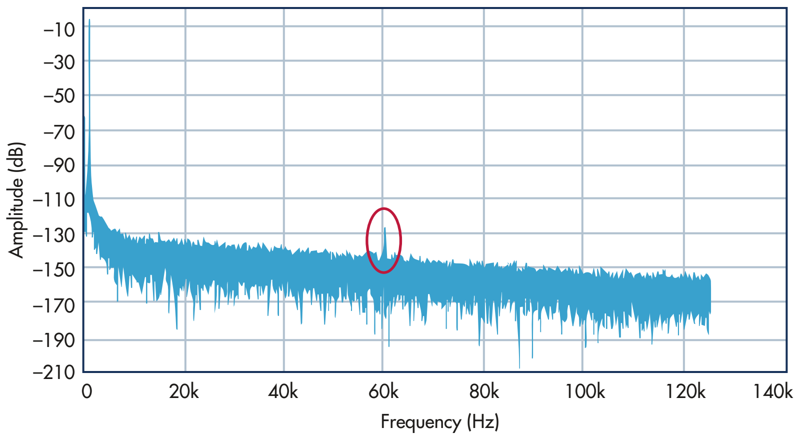
$$20 \times \log\left(\frac{6.325\text{ mV p-p}}{10\text{ V}}\right) = -64\text{ dBFS}$$

This power switching ripple noise feeds into the AD7175-2 ADC and shows up in the digital codes with some attenuation as stated below:

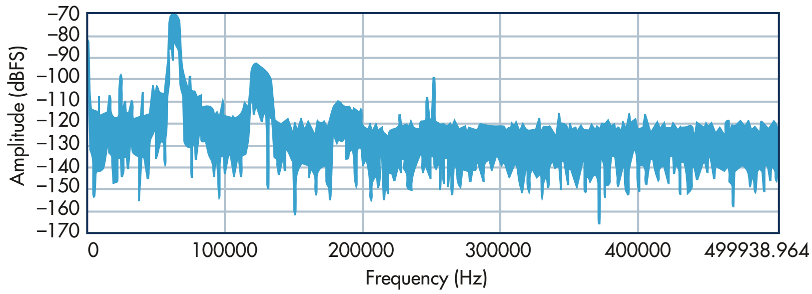
- The ADR445 reference's datasheet specifies a PSRR of 49 dB at 60 kHz.
- The ADR445 reference's output impedance is about 4.2 Ω at 60 kHz. It combines with the 4.8-µF reservoir caps, giving a further 18 dB of attention.
- In addition, the AD7175-2 ADC's digital filter sinc5 + sinc1 adds about –3 dB of attenuation at 60 kHz, when the output data rate is 256 ksamples/s.

$$-64\text{ dBFS} - 49\text{ dB} - 18\text{ dB} - 3\text{ dB} = -134\text{ dBFS}$$

This calculated –134-dBFS level is very close to the level of the captured –130-dBFS cluster of spurs (not including the highest narrow spur) shown in Fig. 5. This verifies that the cluster of spurs is caused by the ac-dc adapter's switching ripple feeding through the external reference ADR445. The remaining narrow spur will be resolved in the subsequent section.



7. The cluster of spurs removed on EVAL-AD7175-2SDZ evaluation board.



8. This 3.3-V VADJ_FMC switching ripple was captured by EVAL-AD7616SDZ GUI FFT.

SPUR ISSUES CAUSED BY INTERFERENCE INJECTED INTO SIGNAL CHAIN

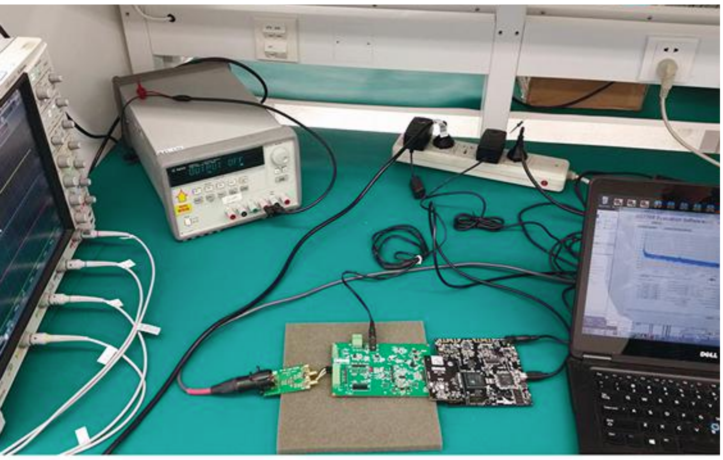
In the hardware system, there's generally a long signal chain from the input sensor to the input of the precision converters. This signal chain includes connecting cables, connectors, routing wires, scaling and conditioning circuitries, ADC drivers, and more. The potential is high for external interference to inject into the analog input signal chain and cause ADC spurs.

SPUR ISSUES CAUSED BY POWER CABLE INTERFERENCE INTO SIGNAL CHAIN

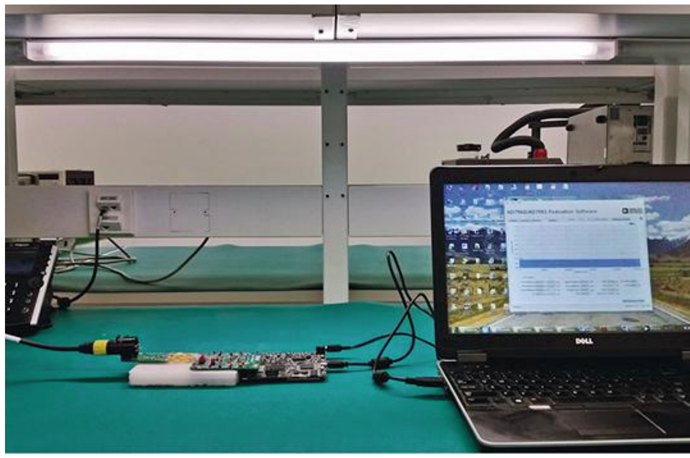
During the investigation of the remaining narrow spur on the EVAL-AD7175-2SDZ evaluation board's spectral output, a digital oscilloscope was observed operating on the test bench. As shown in *Figure 9*, the scope's 220-V ac power supply cable (the black one) was overlapping the EVAL-AD7175-2SDZ EVB's analog input cable (the gray one). When the oscilloscope was turned off or its power cable was physically moved away from the analog input cable, the narrow spur at 60 kHz disappeared, as shown in *Figure 10*.

In the system cabinet, care should be taken in routing the cables from the sensor to the DAQ board. It's a good practice to keep the low-level sensitive analog signals separated from the high-current power lines.

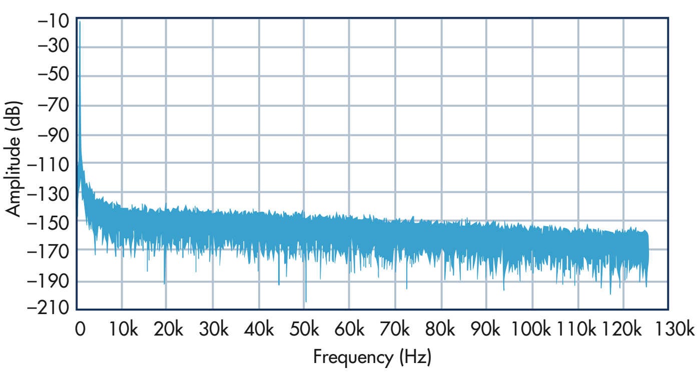
In the hardware system, there's generally a long signal chain from the input sensor to the input of the precision converters. This signal chain includes connecting cables, connectors, routing wires, scaling and conditioning circuitries, ADC drivers, and more. The potential is high for external interference to inject into the analog input signal chain and cause ADC spurs.



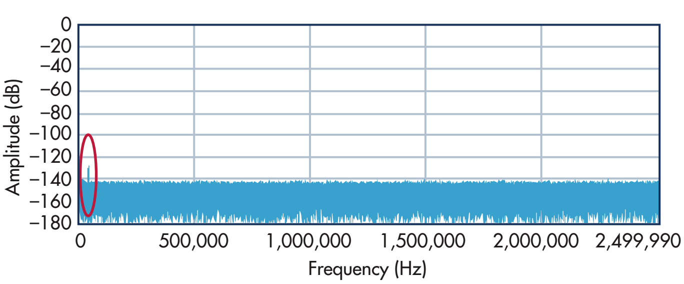
9. An oscilloscope power supply cable caused a spur.



12. Fluorescent lighting in proximity to the EVAL-AD7960FMCZ board.



10. All spurs were removed on the EVAL-AD7175-2SDZ evaluation board.



11. Spurs experienced on the EVAL-AD7960FMCZ were caused by fluorescent lighting radiation.

SPUR ISSUES CAUSED BY LAMP RADIATION

A spur appeared on the FFT spectrum while testing the EVAL-AD7960FMCZ evaluation board. As shown in *Figure 11*, the spur level was about –130 dB at 40 kHz.

The 40 kHz seemed to be unrelated to any of the signal frequencies that appear on the EVAL-AD7960FMCZ board and its controller board, SDP-H1. The next approach to finding the source of the spur was to clear the testbench in case there was something generating external interference. When the fluorescent light on the bench rack was turned off, the spur disappeared.

Furthermore, it was found that as the EVAL-AD7960FMCZ board was put closer to the light, the 40-kHz spur would get higher *(Fig. 12)*. An additional RC filter (such as 1 kΩ, 10 nF) was placed at the front of the buffer amplifier ADA4899-1 and the spur decreased about 10 dB. That meant that the fluorescent light was radiating disturbance into the signal-chain path at the front of the noninverting input of the buffer amplifier.

For systems that operate in a lighted environment, installing a shielding case over the front-end circuitry can help protect it from radiating interference and optimize signal-chain performance.

10 MHz Rubidium Frequency Standard

- ***5 MHz and 10 MHz outputs***
- ***Ultra-low phase noise (<–130 dBc/Hz at 10 Hz)***
- ***0.005 ppm aging over 20 years***
- ***Built-in distribution amplifier (up to 22 outputs)***
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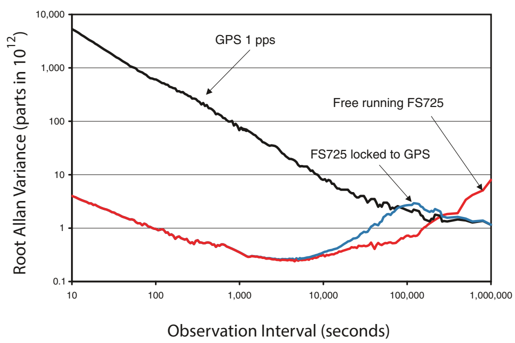
The FS725 Benchtop Rubidium Frequency Standard is ideal for metrology labs, R&D facilities, or anywhere a precision frequency standard is required.

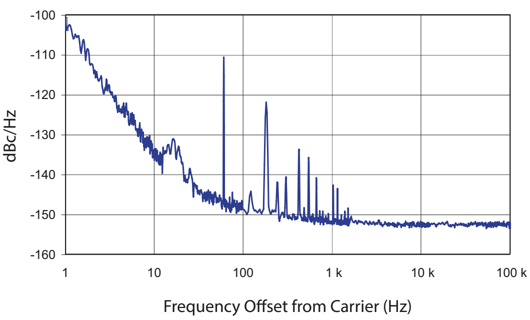
It has excellent aging characteristics, extremely low phase noise, and outstanding reliability. A 1 pps input is provided for phase-locking to GPS, providing Stratum 1 performance.

With a built-in 5 MHz and 10 MHz distribution amplifier, the FS725 is the ultimate laboratory frequency standard.

Allan Variance vs. Time



FS725 Single Sideband Phase Noise



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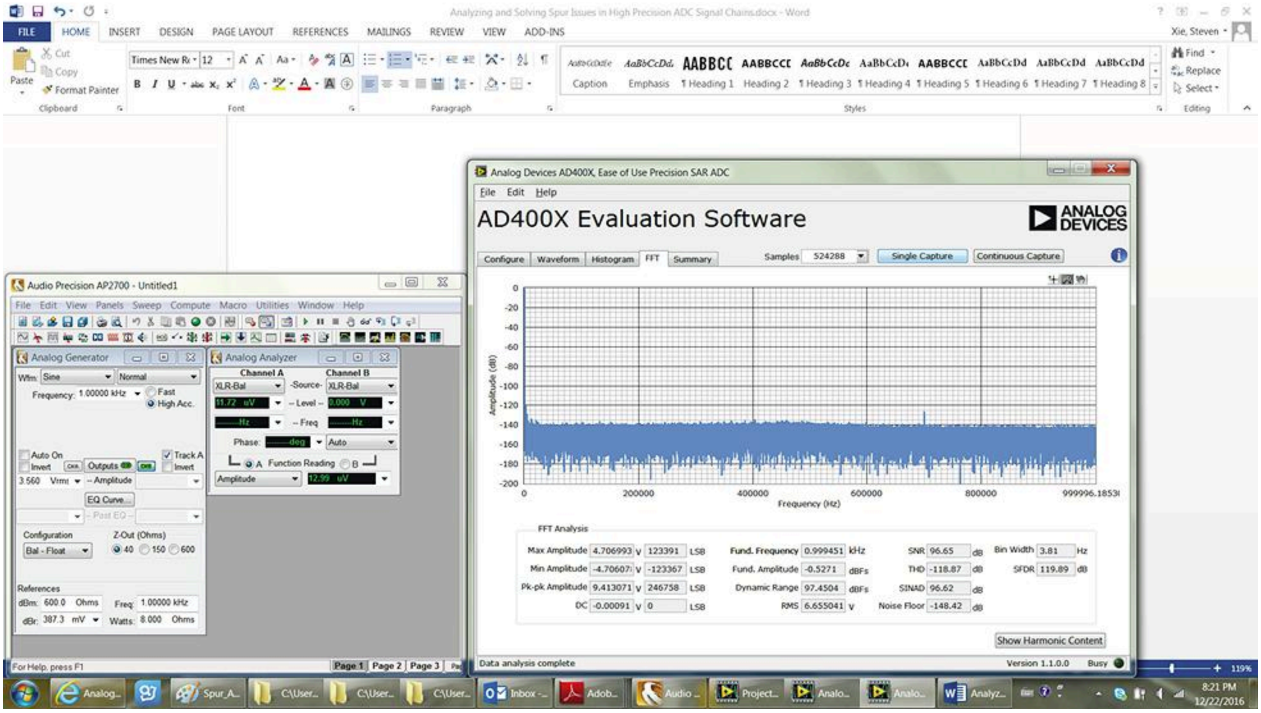
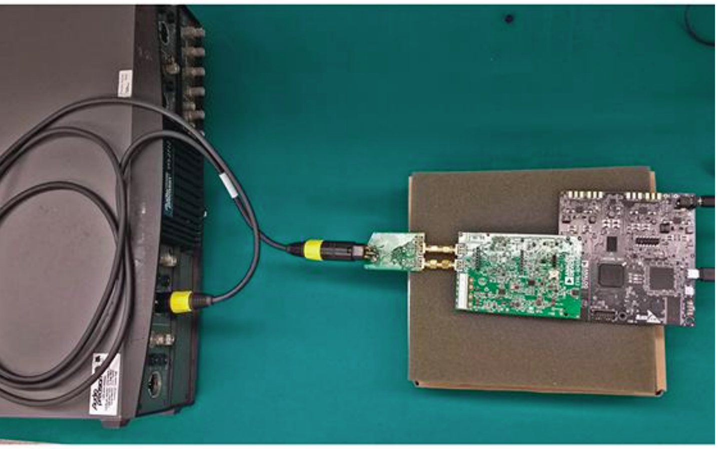


13. Spur on EVAL-AD4003FMCZ eval board caused by XLR cable.

SPUR ISSUES CAUSED BY A LONG ANALOG INPUT CABLE

During the evaluation of the EVAL-AD4003FMCZ board, an AP SY2712 signal generator was used to drive a low-noise and low-THD sine wave to the analog inputs through an XLR microphone cable (about 2 meters long). In this setup, a spur was apparent at a level of about –125 dB at 700 kHz *(Fig. 13)*.



14. AP driving the EVAL-AD4003FMCZ board through a long XLR cable.

Investigation of the spur revealed three ways to solve the problem:

- Bypass the 2-m-long XLR microphone cable and short the AP-balanced output XLR male connector to the interposer XLR female connector *(Fig. 14)*.
- Set the signal source SY2712's output impedance from Z-Out = 40 Ω to Z-Out = 600 Ω.
- The spur becomes smaller when a narrow bandwidth RC filter (such as 1 kΩ, 10 nF) is inserted in the signal chain at the front end of the AD4003's buffer amplifier, the ADA4807-1.

Finally, the conclusion was reached that the mismatch in the signal source's output impedance, and the long XLR cable, caused the high-frequency spur at 700 kHz.

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LOU FRENZEL | Contributing Editor

What's the Difference Between IEEE 802.11ah and 802.11af in the IoT?

Looking to gain a foothold in the Internet of Things, HaLow and White-Fi bring low-power and long-range potential to a wide array of applications.

The IEEE standard 802.11 usually defines what we all know as Wi-Fi. Multiple versions of this standard exist, but not all are designated as Wi-Fi despite their being a part of the family. Specifically, consider two relatively recent versions of the standard: 802.11af, now referred to as White-Fi, and 802.11ah, otherwise known as HaLow. Both versions, which are more suited to Internet of Things (IoT) applications, offer benefits beyond traditional Wi-Fi, including longer range and lower power consumption.

IoT REQUIREMENTS

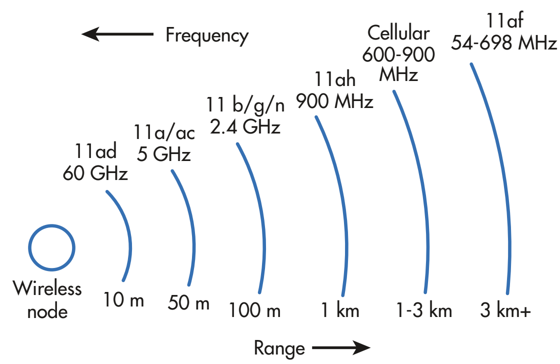
Most IoT applications involve sensors transmitting minimal data from remote locations over short distances. A core requirement is low power consumption—most applications are battery-operated, so long battery life is a must.

Another burgeoning need is longer range. Most IoT applications cover short range from 10 to say 100 meters. However, many others need to extend that range from 100 meters to many kilometers. Low data rates (less than 1 Mb/s) are typical.

Traditional wireless technologies such as Wi-Fi, Bluetooth, ZigBee, and others can easily handle the short-range applications, but their operating frequency limits that range. Power consumption may be an issue, too.

The distance traveled by a radio wave of a given power, antenna gain, and receiver sensitivity directly relates to the operating frequency. The physics of radio indicates that the range is inversely related to frequency. In other words, lower-frequency signals naturally travel farther than higher-frequency signals.

Most of the basic short-range technologies operate in the 2.4-GHz band, or 5 GHz. However, range can be extended with higher power up to the imposed FCC limits and by using gain antennas.



1. These are the approximate maximum ranges of 802.11 wireless technologies. Environment, obstacles, etc. can shorten or lengthen these ranges.

THE WI-FI OPTION

If your application requires high data rates and the expected range is less than 100 meters, a conventional Wi-Fi radio may be your best bet. Examples include video monitoring in the home or some commercial/industrial use requiring internet access and good security.

The widely used 802.11n standard can produce speeds to 300 Mb/s. The more recent 802.11ac operates in the 2.4- or 5-GHz bands and achieves speeds in excess of 1.3 Gb/s. The main limitations are a range of up to 100 meters, depending on the environment, and medium to high power consumption. Higher data rate needs can be met, though, with the 802.11ad WiGig option operating at 60 GHz. Range is typically less than 10 meters, but speeds can reach up to 7 Gb/s. Other choices are available if you need longer range and lower power consumption.

Figure 1 shows the estimated maximum ranges for the 802.11 standards.

If you're looking for a long-range, low-power wireless solution, lots of choices are available. The *table* lists the primary alternatives for building a low-power wide area network (LPWAN) with extended range. Space doesn't permit a comprehensive discussion of each, but more background information is available in the article "Long-Range IoT on the Road to Success" on *www.electronicdesign.com*.

MAIN FEATURES OF LPWAN TECHNOLOGIES

Technology	Frequency	Data rate max	Range	Power	Cost
Ingenu	2.4 GHz	624 kb/s	Many km	Low	Medium
LoRa	915 MHz	<50 kb/s	15 km	Low	Low
LTE-M	Cellular bands	1 Mb/s	Several km	Medium	High
NB-IoT	Cellular bands	250 kb/s	Several km	Medium	High
Sigfox	<1 GHz	100-1000 b/s	Several km	Low	Medium
Symphony	915 MHz	<50 kb/s	Up to 10 km	Low	Medium
Weightless	<1 GHz	0.1-24 Mb/s	Several km	Low	Low

The choices boil down into two groups: proprietary, nonstandard technologies and cellular. Cellular is an interesting choice, as it provides excellent range and reliable coverage with existing networks. The downsides for some applications are high cost and high power consumption. Proprietary technologies cover many use cases, so some evaluation is needed. Then again, the IEEE standards may simply be the answer.

HaLow (802.11AH)

This standard can use any industrial-scientific-medical (ISM) frequency spectrum below 1 GHz, but the primary targeted band is the 902- to 928-MHz license-free band in the U.S. Similar bands just below 1 GHz are found in other countries, such as 863-868 MHz in Europe, 717-723 MHz in Korea, 916-927 MHz in Japan, and 755-787 MHz in China. This is good news because low power can be used over these lower frequencies, enabling battery-operated equipment. While most Wi-Fi gear has a maximum range of 100 meters under ideal conditions, HaLow can reach up to a kilometer with the right antenna.

The real goal of 11ah is low power. The typical user station has a sleep mode to conserve battery charge. Short data packets and shortened contention access procedures minimize transmit time and power usage.

The standard supports a massive number of possible network stations (8191). A special station type is the relay access point, which helps all other stations pass along messages over longer distances at low power.

Support is also provided for up to four spatial data streams to further boost data rate. In addition, the antenna-sectorization feature partitions the coverage area.

The 802.11ah standard is blessed by the Wi-Fi Alliance (WFA), which gave it the trade name HaLow. The WFA says that it will implement one of its testing and certification programs for HaLow by 2018.

HaLow is a sophisticated technology that has yet to be widely adopted. Nevertheless, it's still worthy of consideration for new projects.

WHITE-FI (802.11AF)

White Fi, also known as Super Wi-Fi, is designed to use the TV white spaces (TVWS) or the unused TV channels from 54 to 698 MHz. These channels are ideal to support long-range and non-line-of-sight transmission. The standard employs cognitive-radio technology and geolocation database access to ensure that there's no interference to local TV signals or other services operating in this region (e.g., wireless microphones). The base station queries a database to see what channels are available locally for data transmission.

The 802.11af standard works with TV channels that have bandwidths of 6, 7, or 8 MHz. Modulation is OFDM using BPSK, QPSK, 16QAM, 64QAM, or 256QAM. A wide range of coding rates allow for optimization of the connection. The maximum data rate per 6-MHz channel is about 24 Mb/s. A typical mobile user station can have a transmit power of 100 mW, while a base station or access point has up to 4 W of power.

Range depends on the actual frequency. Several kilometers can be achieved at the higher frequencies. Even longer ranges of up to several miles are possible at the lower VHF TV frequencies.

This standard isn't part of the Wi-Fi Alliance family, unlike 802.11ah. Its main competition is the Weightless group of TVWS open standards and some proprietary designs. Few, if any, actual operating networks have been implemented.

TECHNOLOGIES LOOKING FOR ADOPTERS

Though both of these standards are viable options for new IoT applications, activity with them hasn't been visible. For low-speed, long-range, and low-power use cases, both technologies offer superior benefits. What's hindered their adoption is the fact that they joined the IoT movement late in the game, and the competition is fierce.

As you pursue new IoT or M2M projects, keep your mind open to 11ah and 11af as possible solutions. ed

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11 MYTHS About Digital Power

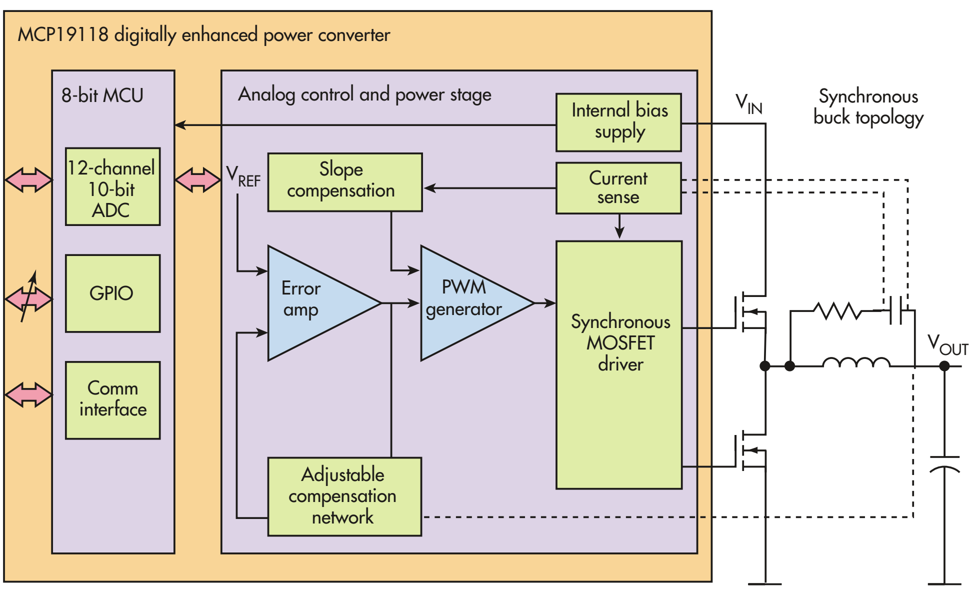
The second coming of power conversion or an unnecessary extravagance? We examine myths surrounding digital power conversion to better understand its challenges and benefits.

With the recent application of nano-photonic interference filter technology, XYZ color sensing is moving out of the realm of laboratory instrument into more mainstream applications, including in-situ spectral sensing and lighting. In this article, we tackle 11 of the most common misconceptions about XYZ and its applications.

More than ever, analog control chips include digital interfaces for external control, and digital microcontrollers incorporate analog components that allow for power-supply control *(Fig. 1)*. It's always been possible to add a microcontroller to a power supply, but today that microcontroller can have more influence on system operation than ever before. Or, alternatively, the whole control loop can be implemented in a digital signal controller.

1. Switch-mode power supplies are exclusively analog or digital.

Switch-mode power conversion is an inherently mixed-signal system. The pulse-width-modulation (PWM) signals are digital and the feedback signal is analog. What goes on between those two nodes is an analog-to-digital conversion with very precise timing. That conversion could happen after an amplifier-based control network decides when to switch, or it could happen at the feedback signal, allowing a digital algorithm to decide when to switch.



1. Shown here is the digital management of an analog control loop on the MCP19118.

DESIGN NOTES

Simple Power Backup Supply for a 3.3V Rail

Design Note 565

Victor Khasiev

Introduction

Data loss is a concern in telecom, industrial and automotive applications where embedded systems require a dependable supply of power. Sudden power interruptions can corrupt data during read and write operations performed by hard drives and flash memory. Designers often use batteries, capacitors and supercaps to store enough energy to support critical loads for a short time during a power interruption.

The LTC®3643 power backup supply allows designers to use a relatively inexpensive storage component: low cost electrolytic capacitors. In the backup or holdup supply presented here, the LTC3643 charges a storage capacitor to 40V when power is present, and discharges it to the critical load when power is interrupted. The load (output) voltage can be programmed to any voltage between 3V and 17V.

The LTC3643 easily fits backup solutions for 5V and 12V rails, but a 3.3V rail solution requires extra care. The minimum operating voltage of the LTC3643 is 3V, relatively close to the nominal 3.3V input voltage level. This is too tight when a blocking diode is used to decouple the backup voltage source from noncritical circuitry as shown in Figure 1a. If D1 is a Shottky diode, its forward voltage drop—as a function of load current and temperature—can reach 0.4V to 0.5V, enough to place the voltage at the LTC3643 V_{IN} pin below the 3V minimum. As a result, the backup supply circuit may not start up.

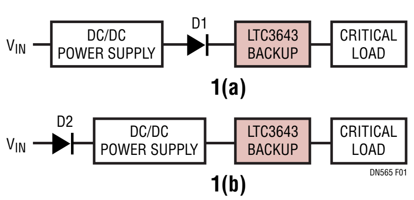


Figure 1(a) and (b). Location of the Blocking Diode in the Backup System Schematic

One possible solution is to move the diode to the input of the supplying DC/DC converter, D2, as shown in Figure 1b. Unfortunately, in this scenario, noncritical loads connected to the upstream DC/DC supply can draw power from the backup supply, leaving less energy for critical loads.

3.3V Backup Supply Operation

Figure 2 shows a solution to producing a 3.3V backup supply that reserves energy for critical loads using a blocking MOSFET. The blocking diode shown in Figure 1 is replaced by Q1, a low gate threshold voltage power P-channel MOSFET.

The key to operating the backup supply in a 3.3V environment is the addition of the series RA-CA circuit. At start-up, as the input voltage rises, the current through the capacitor CA is governed by the equation $I_C = C \cdot (dV/dt)$. This current generates a potential across RA, enough to enhance Q2, a low gate threshold voltage small signal N-channel MOSFET. As Q2 turns on, it pulls the gate of the Q1 to ground, providing an extremely low resistance path from the input voltage to the supply pins V_{IN} of LTC3643. Once 3.3V is applied to the converter, it starts up, pulling down both the gate of Q1 and the PFO pin, and it starts charging the storage capacitor.

As the 3.3V rail reaches steady state, the I_C current reduces to the point where the voltage across RA falls below the Q2 gate threshold level and Q2 turns off, no longer affecting the functionality of the backup converter. Also, the PFO pin grounds R3A, resetting the PFI pin power fail voltage level to the minimum 3V, to ensure that the converter remains operational when the input voltage source is disconnected.

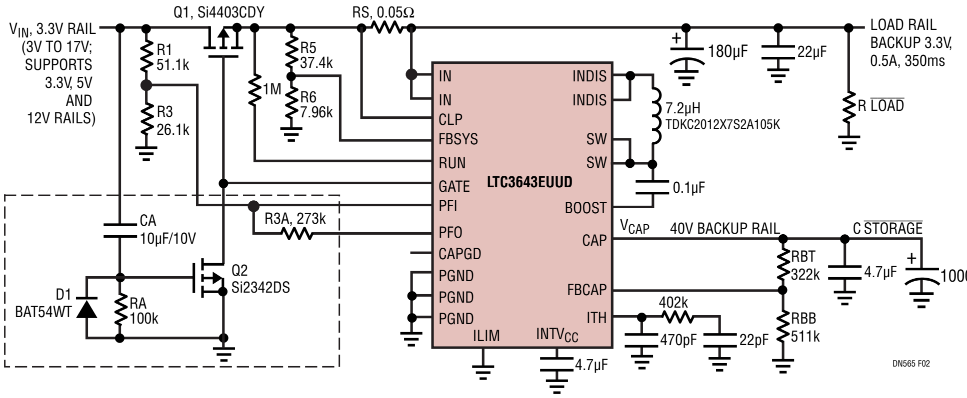
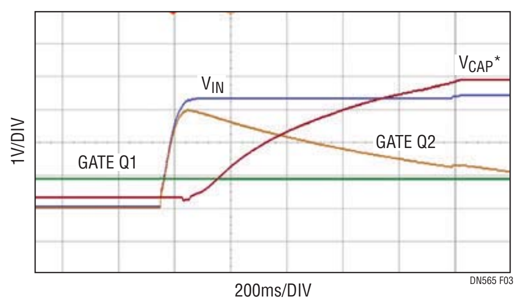


Figure 2. Enhanced Schematic of the LTC3643 Solution for a 3.3V Rail

Circuit Functionality

The waveforms in Figure 3 show results as the 3.3V rail starts up. As the input voltage rises, so does the gate of Q2, pulling the gate of Q1 low. Q1 remains enhanced, allowing the full 3.3V to reach the LTC3643, bypassing the Q1 body diode. Eventually the gate of Q2 voltage drops below the threshold level and Q2 turns off—by this time the LTC3643 is fully operational and takes control over the gate of Q1.

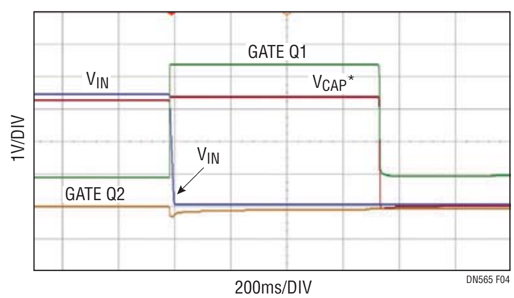


*V_{CAP} IS 10V/DIV; ALL OTHER VOLTAGES 1V/DIV

Figure 3. Waveforms of 3.3V Rail for Power-Up

The versatility of the LTC3643 is on display here: specifically its ability to limit the charging current of the boost converter used to charge the storage capacitor. In cases where total current must be minimized, such as when there are long lines or high impedance voltage sources. The boost current can be set relatively low to minimize the effect of charging current on the input voltage drop. This is particularly important for 3.3V rails. In Figure 2 the resistor, RS, 0.05Ω, sets a limit of 0.5A (10.5A load) for the boost converter charging current (maximum possible set limit is 2A); the rest is delivered to the load.

Figure 4 shows the waveforms when the 3.3V rail is lost. As the input voltage falls, the voltage at the gate of Q2 remains unchanged, close to ground, and Q2 remains off. In contrast, the voltage at the gate of Q1 rises sharply to 3.3V. This turns Q1 off, with the body diode of Q1 acting as a blocking diode, decoupling load from the input. At this point the backup supply takes over, with the LTC3643 supplying 3.3V to the critical load by discharging a storage capacitor.



*V_{CAP} IS 10V/DIV; ALL OTHER VOLTAGES 1V/DIV

Figure 4. Waveforms of 3.3V Rail for Power-Down

Conclusion

The circuit presented here enables the LTC3643 to be used as a backup supply solution for 3.3V rails. The LTC3643 simplifies backup supplies by employing low cost electrolytic capacitors as the energy storage component.

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Either way, power supply designs can be more flexible, more adjustable, and respond more intelligently to environmental conditions or external inputs. These features can be added regardless of whether the control loop itself is implemented in a digital or analog domain. Today, switch-mode power supplies can have as much digital logic as required an application.

2. Digital features require digital control loops.

The control method is just one of the features of the power-conversion system. A microcontroller can be added to any analog system to allow for additional supervision or management, power supplies included. Historically, a microcontroller's ability to affect an analog control loop has been very limited, due to the very limited dynamic configurability of dedicated analog control parts.

However, newer analog control devices more commonly contain digital interfaces, with more configuration or programmability than previous generation devices. Similarly, there are integrated power converter products with microcontrollers on chip, which allow new dimensions of dynamic configuration. With smart component selection, digital communication interfaces, sleep modes, frequency shifts, synchronization, soft-start, intelligent fault protection, or output voltage/current changes can all be intelligently implemented in a power-conversion system—added to either analog or digital control-loop implementations.

3. Digital power is less robust than analog power.

Robustness is a complicated system feature, and many things can be done to improve the robustness of either analog or digital power supplies. Depending on the implementation, analog power supplies could have faster hardware fault responses, with quick acting undervoltage and overvoltage comparators, and true cycle-by-cycle current limiting.

However, those things can also be implemented in a digitally controlled power supply, possibly with dedicated analog structures present in more advanced digital control chips. Digital controllers may include analog current limit comparators. In addition, digitally featured power supplies (even those using analog control loops) have several distinct advantages that can't really be mimicked in a true all-analog solution. Digital program code can provide customized fault or brown out responses, including customized soft start, soft shutdown, trickle charge, timeout or retry approaches that would be difficult (or impossible) to implement using analog controllers.

Furthermore, digital control loops or integrated on-chip feedback networks reduce reliance on external passive components, which often shift or degrade over time. Finally, digital interfaces provide diagnostic and reporting information that can be used to identify future problems, avoiding hard system outages.

Adding all of these features can create a more robust system than a simple dedicated analog solution. Regardless of the implementation, all power supplies require careful testing to ensure good product lifetimes. However, there are no fundamental reliability limitations to digital power systems that will lead them to perform poorly compared to their analog counterparts.

4. Digital power is more expensive.

While designers are under the impression that digitally controlled power supplies are more expensive than their analog counterparts, this isn't always the case. Digital supplies can be less expensive because they may be designed around less precise, and therefore less expensive, components. They may also require fewer total components, reducing both the cost and solution size.

Digital supplies can also save money in terms of the total cost of ownership. In applications with variable load conditions, designers are able to implement nonlinear and adaptive algorithms to deliver the highest possible efficiency for any given set of operating conditions. Another reason that digital supplies may cost less to operate is that they can account for component aging over the life of the supply, notify users if preventative maintenance is required, and avoid catastrophic component failures (also resulting in expensive, unexpected downtime).

5. Digital power is more efficient.

Oftentimes, digitally controlled power supplies offer more energy efficiency across widely varying load conditions. They may utilize adaptive algorithms and even modify the topology of the system in response to changing conditions using techniques such as phase shedding. Digitally controlled supplies can use nonlinear and predictive algorithms to improve dynamic response to transients.

Analog power supplies can be every bit as energy-efficient as digital power supplies at a given design point. The challenge for analog supplies, though, is to maximize the efficiency if conditions such as load current move away from the optimum operational point.

On the other hand, the power required to run a digital controller can exceed the power required for an analog controller. Digital controllers are usually a better fit for higher-power applications, where their energy use overhead is easily offset by the additional energy savings made possible by the more comprehensive control algorithms enabled by digital technology.

6. A digital controller's latency negatively impacts transient response.

A digitally compensated system faces two major latency concerns: the sampling effects and the computation time.

With any power conversion, the crossover frequency (transient response) will always trade off against the phase margin (stability). Digital systems are fundamentally similar, but digital control systems are sampled. A periodic sampling (once per cycle) adds a phase shift to the transfer function. This can't be easily compensated for; the digital system requires a lower crossover frequency to achieve the same phase margin (if using the same compensation method). On top of that, the processor needs to perform the ADC reading and difference calculations within one switching cycle, or there will be an additional period of latency from the calculation time.

However, these negatives can be overcome with advanced nonlinear control methods and feed-forward techniques—algorithms that would be difficult (or impossible) to implement in an analog control system. The drawback is the processing requirements, which creates a tradeoff between processing speed, switching frequency, algorithm complexity, and transient response. This needs to be designed for, but doesn't necessarily cause a reduction in transient response due to the digital control.

7. No load current is a problem.

Switching power supplies typically run in one of two modes: discontinuous conduction and continuous conduction. In discontinuous conduction operation, the inductor current falls to zero at the end of every PWM cycle. Continuous conduction operation maintains continuous current flow in the inductor.

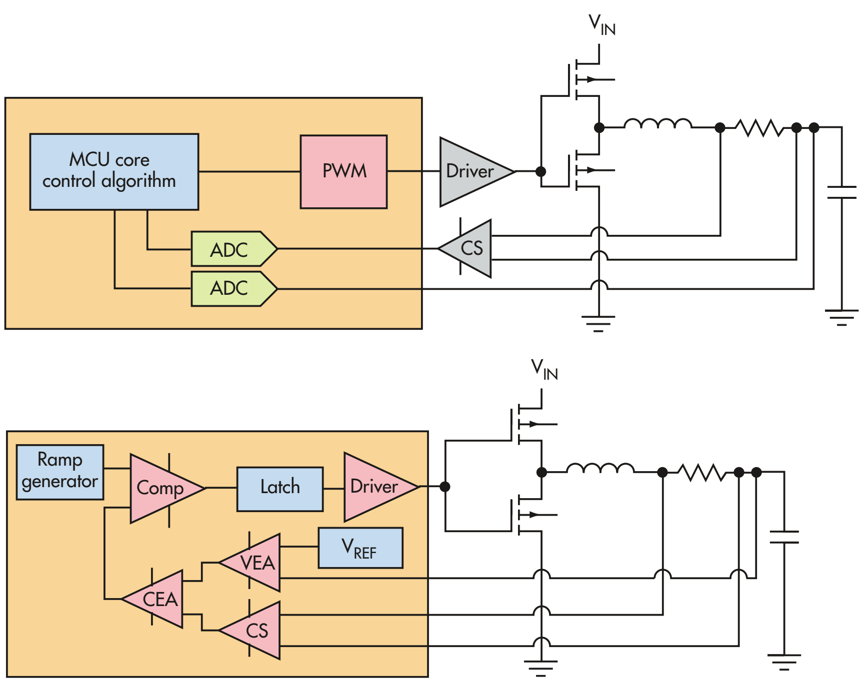
The advantage of continuous conduction is that the inductor current doesn't have to ramp up from zero on every PWM pulse, thus delivering more current each PWM cycle. The disadvantage is that the error amplifier/loop filter must have the right combination of poles and zeros to maintain stability. Unfortunately, if the current in a continuous conduction design does go to zero, it can make the control loop unstable.

To combat this, older designs often either specify a minimum current or guarantee a minimum current by placing a load resistor on the output (forced continuous conduction, or FCC). Fortunately, a number of power-supply controllers today can handle both continuous and discontinuous modes of operation (PWM and pulse frequency modulation, or PFM) with monitoring circuitry to determine when to switch from one mode to the other. So, while this was once a limitation due to the design of power-supply controllers, newer controllers automatically handle the mode switching and the limitation is little more than a footnote in history.

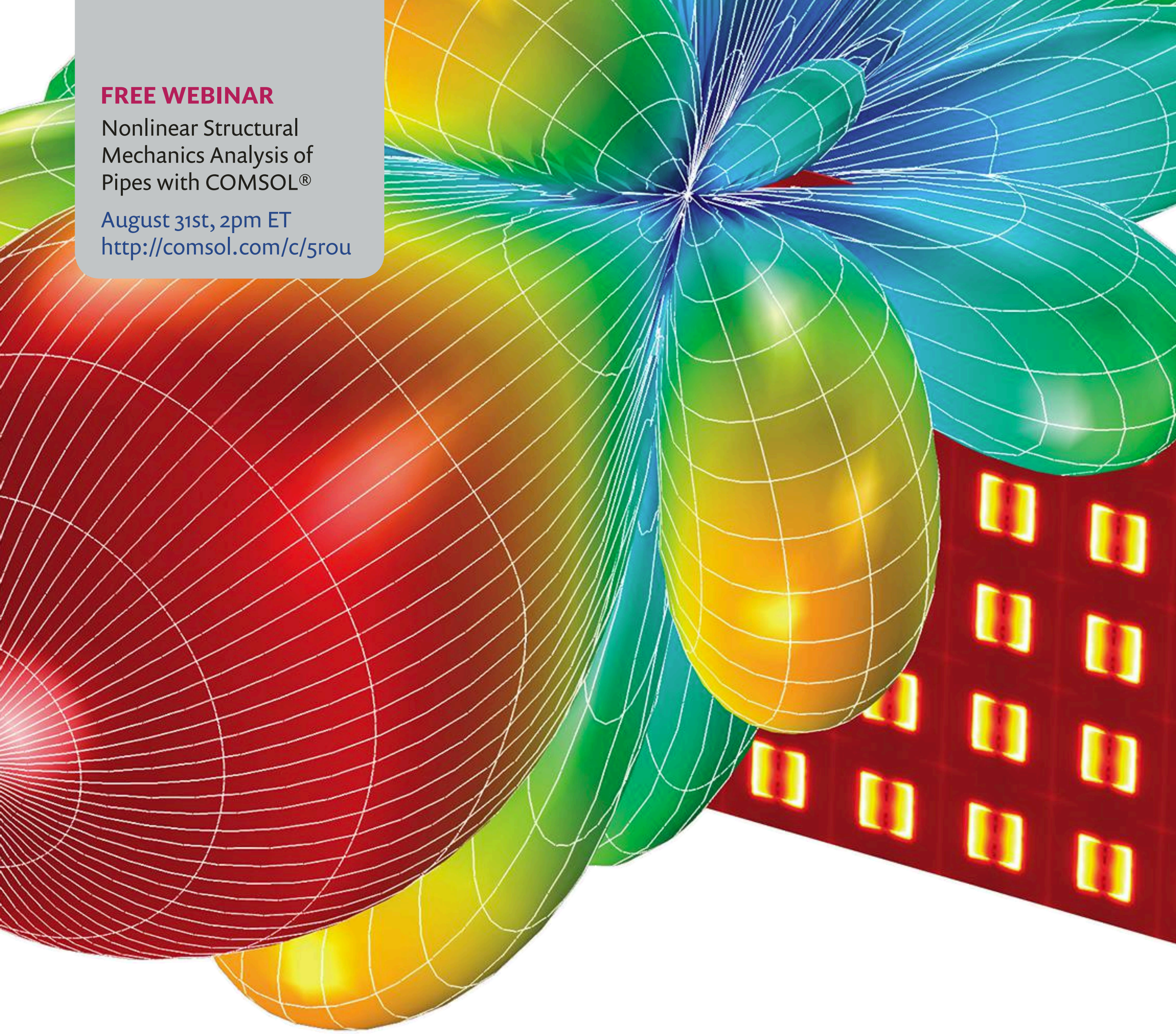
8. Digital power supplies are difficult to design.

Designing a digitally controlled power supply isn't necessarily more difficult than designing an analog supply; it's just different. The powertrain design is very similar in both cases *(for a hardware illustration, see Fig. 2)*. The control loop or compensator design is implemented in digital controller firmware rather than with analog circuitry.

The location of poles and zeros of the plant are used to define the compensator characteristics (same as an analog



2. The top diagram is the hardware required for a digital control loop in a switch-mode power supply; the bottom diagram shows the analog control loop equivalent.



> A few years ago, the prediction was that software-defined radio (SDR) would take over as the default design for radio receivers. While SDR offered several advantages, it suffered from one major drawback: It required a processor with 10X to 100X MIPS to receive frequency.

design). However, in the case of a digital compensator, software tools are often used to configure the optimum response for the control loop. For example, highly optimized software libraries, including common 2P2Z (type II) and 3P3Z (type III) compensator algorithms, for use on Microchip's family of dsPIC digital signal controllers, are available for free on the company's website. Designers don't need to write the software for those functions themselves. In addition, these algorithms are tuned for specific powertrains by providing coefficients that are derived by the design tools.

9. Digital power-supply design is easier than analog (because it's just software).

The fact that digital power supplies use software for the control algorithms doesn't discernibly simplify their design. Designers must still fully understand control systems and characterize the powertrain's frequency response to be able to properly configure the software-based compensator that's used. On the other hand, tweaking the operation of the supply to fine-tune results can be easier in software than it would be if hardware has to be modified to make the changes.

10. All you need is a DSP—digital power will replace everything else.

While many pundits push digital power as the silver bullet that solves all problems, it doesn't fit every application. For example, it doesn't make sense to put all of that processing power into a palm-sized MP3 player running on an internal lithium-ion cell, just to boost the supply voltage. On the other hand, platinum-level server power supplies need the capabilities of a digital power converter to efficiently generate the necessary power output and respond quickly to load changes.

For example, cell-phone towers have a high current requirement when the transmitter is on, but use much less power when it's off. The controller for the transmitter knows when it's going to turn on, so it alerts the power converter and coordinates a move up in the average current. Therefore, when the transmitter kicks on, the current is already there. That allows it to avoid a sag in the power while the loop filter responds, after the fact. This is one of the powerful features of digital power, and it justifies the additional complexity in the design.

On the other hand, a system with a relatively constant power requirement can use an analog system with its much simpler design, lower complexity, and lower cost. After all, it's pretty hard to beat the cost and simplicity of an ASIC-based regulator.

11. Software-defined power will take over.

A few years ago, the prediction was that software-defined radio (SDR) would take over as the default design for radio receivers. While SDR offered several advantages, it suffered from one major drawback: It required a processor with 10X to 100X MIPS to receive frequency. Even systems that used an analog mixer to translate the radio frequency (RF) down to a lower intermediate frequency (IF) would still require 10 to 100 MIPS, and demodulation would be all that the processor could handle. This is clearly not very cost-effective.

Now, when someone says that software-defined power (SDP) will take over, one shouldn't take it too seriously. There's nothing simpler and cheaper than a linear regulator. And, even if a processor with the necessary MIPS were available at the same price, you would still need the Linear 5-V regulator to bootstrap the power for the processor to get it started. SDP has a definite place in power, and really is the only thing that can do its job. However, it is not, nor will it ever be, a one-size-fits-all solution for power conversion.

CONCLUSION

Often, it's difficult to separate marketing fluff from hard information, particularly when the market is in flux, such as is the case with the current power market (no pun intended). Proponents for change typically extol the virtues of new technology, often forgetting to mention inherent challenges that come with it. The conservatives focus just on the challenges and argue "if it ain't broke don't fix it."

Of course, we don't live in either extreme. We typically have to design and work in the middle ground, take the new with the old, and find the right mix for our current design needs. That's why a company like Microchip has a portfolio of power solutions extends from traditional analog to digital power. Such firms realize that the world is not black and white; rather, it's a continuum, so they try to meet all customer needs.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LOU FRENZEL | Contributing Editor

Should We Bring Back Analog Computers?

Creation of a single-chip analog/hybrid computer reveals that special analog versions of computers could be used to solve complex problems.

Just recently, I received a note from Professor Yannis Tsividis of Columbia University, who happened to read a blog I wrote in 2007 on analog computers.

In that blog, I ended by saying that "I sometimes wonder if we shouldn't bring back a modern version of an analog computer." Professor Tsividis wanted to alert me to the fact that he and his colleagues had done just that. Indeed, they created a single-chip analog/hybrid computer. It's described in detail in an IEEE paper published last year.[1] This is positive proof that perhaps analog computers still have a place in computing.

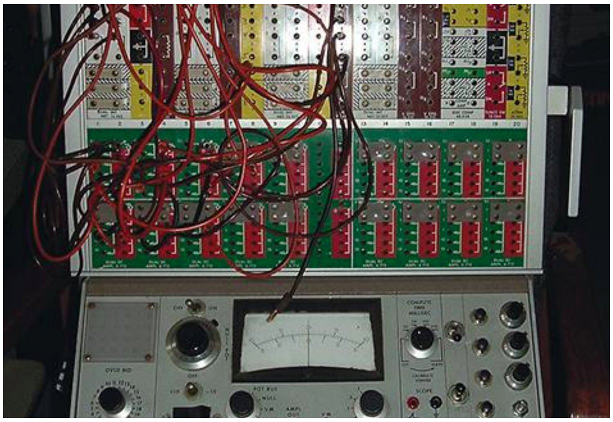
For those of you not familiar with analog computers, let me elucidate. Analog computers solve problems by representing variables and constants with voltage. These quantities are then manipulated by electronic circuits that perform math.

Analog computers are designed primarily to simulate physical systems. This is done by writing the math equations describing the processes and functions of the system. Analogs are particularly good at calculus, making differential equations almost trivial. Then a collection of computing circuits is assembled to perform the math. Voilà! A nearly instant solution. By playing with the variables, you can try out different conditions and scenarios.

EVOLUTION OF DIGITAL

Analog computers peaked back in the 1960s and 1970s. Though digital computers were highly developed by that time, they were still too slow for some math operations and especially for simulating large systems like aerospace hardware or complex chemical processing plants. They played a major role in the Apollo space program, simulating spacecraft dynamics and control systems.

Analog computers were always fast but were not always accurate. They suffered from op-amp drift and offset, component tolerances and variables, and other traditional analog-circuit maladies. Today, op amps and other components are better than ever, so a superior analog computer is very achievable. The main question is: "Would it be viable, given today's fast and cheap processors?" Probably not, but one could make the case for special versions to solve unique problems.



Professor Tsividis and his colleagues pretty much validated that approach by creating an analog/hybrid computing circuit on a single chip. Using 65-nm CMOS, the computer is capable of solving nonlinear differential equations up to the 4th order. Analog blocks like the op amps operate class AB and have digitally assisted calibration. Computational accuracy is in the 0.5% to 5% range, with solution times from less than a microsecond to several hundred microseconds.

The article[1] only describes a 4th-order computer, but today Tsividis and crew now have a 16th-order chip. With two of them on a board, they have a 32nd-order computer that interfaces with a laptop via a USB port. Such a system can solve some serious problems on a desktop—quite a change from the big analog/hybrid systems of the past that filled a room with a raised floor.

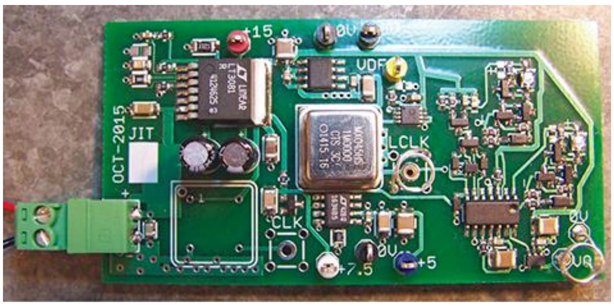
Generally speaking, analogs are still a good solution for some problems. Nevertheless, it doesn't seem likely we will ever see a commercial general-purpose analog computer again. But special computers could easily be built with modern circuits at reasonable cost. Congrats to Professor Tsividis and his group for proving that analogs still have a place.

REFERENCES:

1. N. Guo, Y. Huang, T. Mai, S. Patil, C. Cao, M. Seok, S. Sethumadhavan, and Y. Tsividis, "Energy-Efficient Hybrid Analog/Digital Approximate Computation in Continuous Time," *IEEE Journal of Solid-State Circuits*, vol. 51, no. 7, pp. 1514-1524, July 2016.

Test Technique Quantifies Jitter of Discrete-Comparator Design

By TIM DAVIS | Engineer, tdavismn@gmail.com



1. In the PCB of the circuit used to test the comparator with a low-jitter clock, the dual comparator is on the far right (one comparator is active, the second is "tied off" as a spare) and the CTS 1-MHz clock module is in the board center.

A COLLEAGUE ASKED for the measured jitter number on a single-supply comparator design based on the LM359 IC.[1] He wanted to know how the jitter performance of the discrete comparator compared to an IC comparator, which was used with an ultrasound application.

To set up the test, a special power-supply circuit was designed for the comparator as well as for a crystal-clock module with specified jitter. The power supply, clock, and comparator of the circuit *(Fig. 1)* were placed on a single printed-circuit board (PCB) with ground plane. The board used a special scope probe-tip test point with a fitted, spiral ground wire, into which the probe's ground-sleeve can fit. (This technique is often employed to reduce parasitic ringing and give a good return ground.) The rms jitter for this commercially available crystal-based clock module (CTS MXO45HS-3C-1M0000, 5 ps maximum) was better than the comparator could provide.

In the circuit *(Fig. 2)*, using R_{SET}, the main regulator (LT3081) can deliver +5 V to power either a basic clock, or +15 V to the level-shifted clock and comparator. The LT3081 was chosen as it is inherently stable with any type of load capacitance. Using this power configuration for flexibility, the non-level-shifted clock's jitter can be measured, or the jitter of the level-shifted clock and comparator can be measured. A 5-V reference (REF195) is biased in series with a 5-V shunt reference (LT1634B-5). The crystal clock's supply is powered with 5 V from the REF195.

The clock's output will swing between 5 and 10 V with respect to ground. The level-shifted clock is applied to the comparator's inverting terminal. The non-inverting comparator terminal is connected to +7.5 V, which is produced by placing another 2.5-V shunt reference (ADR5041B) in series with the 5-V shunt reference.

For test purposes, an instrumentation amplifier (AD8220) with unity gain is placed across the crystal clock's power-supply pins to measure the supply's stability during clock transitions. The integrated scope test points prevent significant overshoot and ringing on the high-speed edges of the signals from the level-shifted clock and comparator *(Fig. 3)*.

In order to develop a test method to determine the rms jitter, a Tektronix field applications engineer recommended the "TekScope Anywhere Waveform Analysis Application" to analyze voltage-versus-time data from long record-length captures. Data captures from a Tektronix MSO4034 (a 350-MHz, 2.5-Gsample/s scope) were in their .isf format and the collected file sizes were kept to less than 20 MB, to fit email-attachment memory limits and simplify working at different locations. Both the level-shifted clock and the output of the comparator had .isf files generated by the Tektronix scope.

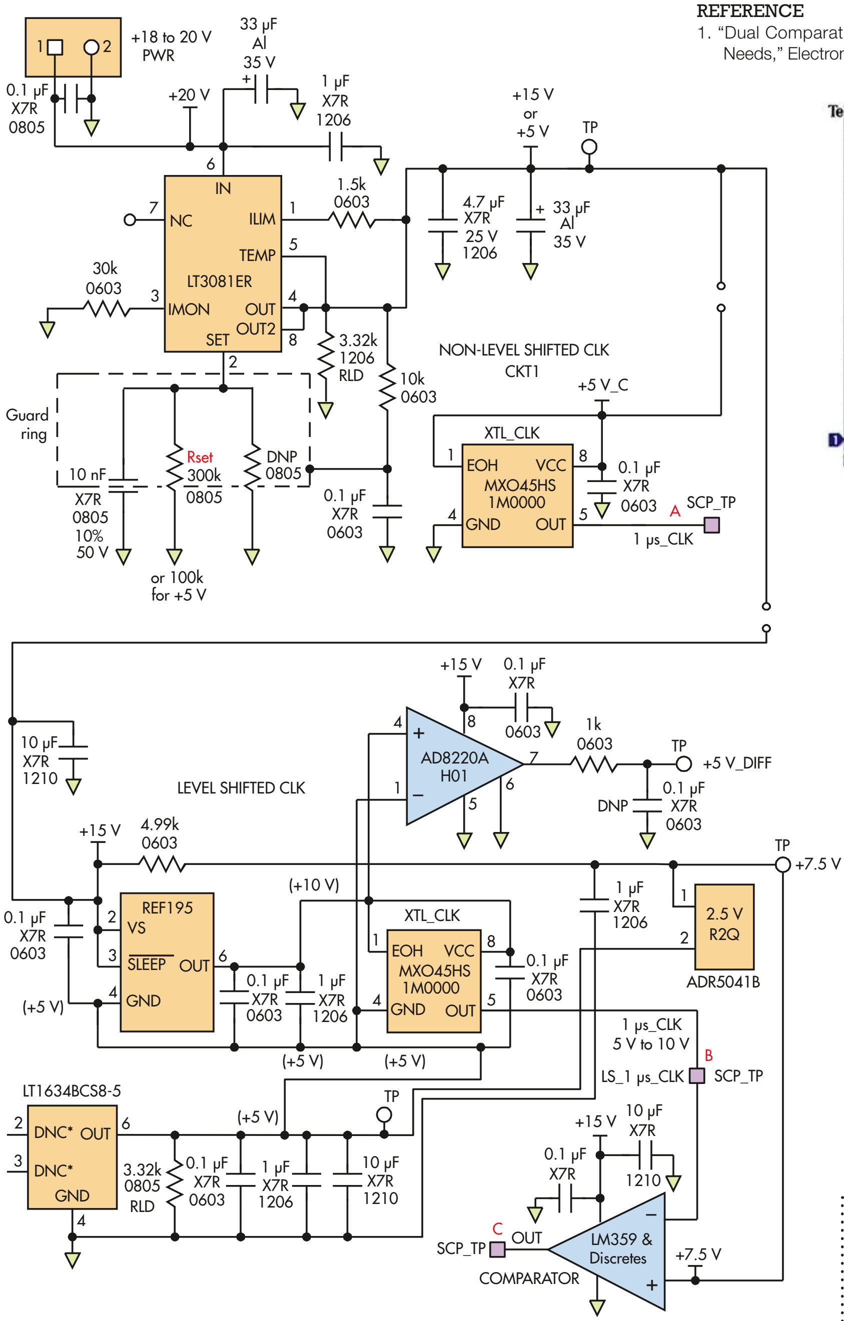
The signals were ac-coupled to ease scaling of the input-signal traces and make better use of the analog-to-digital converter's input range without clipping. The scope settings included a sample rate of 2.50 Gsamples/s, record length of 10 Mpoints, V (clock) of 700 mV/div, V (comparator) of 1.8 V/div, time base of 100 µs/div, and ac coupling on each channel. The trigger method involved Trigger-B sequence Trigger Follow by n events, with n = 1000 events. If just an edge trigger were used, the scope triggering would try to compensate for jitter at the trigger point. (The typical jitter specification for an MDO4000 series unit, probably similar to the MSO4000 series, is less than 10 ps rms for edge-type triggers). The chosen trigger method likely reduced the effect of the instrument's trigger jitter.

The Tektronix application was used to generate the data and plots from .isf files collected on the MSO scope, and the data was processed for standard deviation and peak-to-peak jitter. Based on the 3998 clock-period samples captured, a histogram was plotted and merged with the results from the application *(Fig. 4)*. The upper graph is the measured period versus time, and shows that a few spikes occurred in the data at random sampling times; these will produce "outliers" in a histogram (the second graph).

The measured jitter performance of the comparator—just 23-ps rms jitter at one standard deviation with a 1-MHz input clock—exceeded design expectations. It was determined using the following equation with time in picoseconds (the jitter performance of the scope is not included):

$$\text{comparator jitter rms} = \sqrt{27.1^2 - 14.4^2} \quad (1)$$

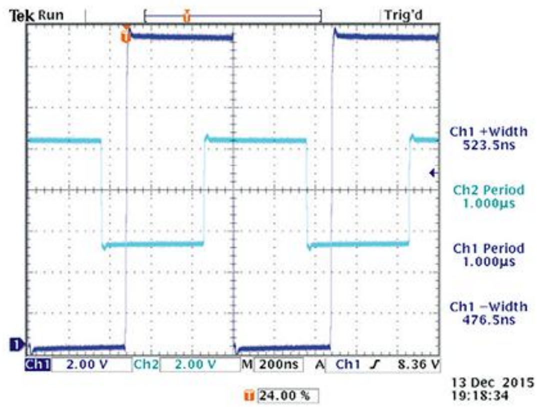
The conclusion was that it is feasible to build a simple test PCB and collect jitter data from a high-performance circuit, if a good digital scope such as the Tektronix unit is available. The jitter results showed this comparator could work with the colleague's ultrasound application.



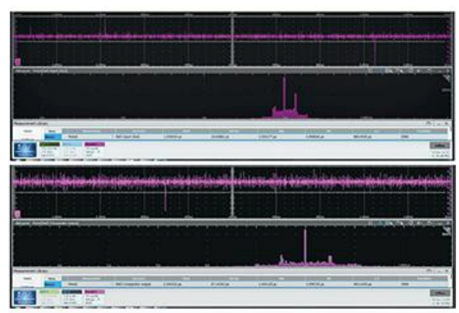
2. The LT3081 power supply is configurable for driving one of two possible circuits in the schematic diagram of the test board used to test comparator jitter.

REFERENCE

1. "Dual Comparators Match Precision Industrial, Instrumentation Application Needs," Electronic Design.



3. CH1 is the output of LM359 discrete comparator and CH2 is the input level-shifted clock; their baselines are coincident with each other.



4. Looking at the merged results of the Tektronix "TekScope Anywhere" application, the top graphic is the input clock along with its histogram (the standard deviation of the input clock is 14.4 ps), while the bottom graphic shows comparator output and its histogram (the standard deviation of the comparator output is 27.1 ps).

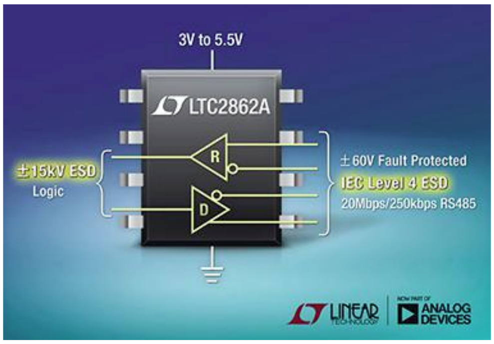
TIM DAVIS graduated with a BSEE from Iowa State University in Ames, Iowa. He has more than 28 years of experience in analog circuit design, power electronics, and IC design, including several patents for electronics in the medical industry.

3D Transponder Coils Boost Sensitivity for Automotive

THE B82453C*A* SERIES of 3D transponder coils is designed by TDK to provide a high sensitivity level for PEPS and other access systems. Measuring 11.5 × 12.5 × 3.6 mm, the series features six types of 3D transponder coils that offer sensitivity levels from 45 to 83 mV/µT and inductance values from 4.75 to 13.2 mH. Center frequency is at 125 kHz in all models. An optimized core geometry in the inductors boosts sensitivity levels to enable the wake-up function of PEPS in vehicles applications to be activated at greater distances.

The RoHS-compatible 3D transponder coils have a robust overmolded casing and the terminals of the windings are laser-welded, resulting in very high mechanical stability, as is demonstrated by the severe drop tests required for PEPS applications. Accordingly, the B82453C*A* series of 3D transponder coils are qualified to AEC-Q200.

TDK, *www.global.tdk.com*



Rugged RS485 Transceiver Meets IEC Level 4 ESD

LINEAR TECHNOLOGY'S NEW LTC2862A is an enhanced version of the LTC2862 ±60 V tolerant RS485/RS422 transceiver they released several years ago. Both of the half-duplex transceivers eliminate field failures without the need of external protection devices by protecting practical RS485 systems from installation cross-wiring faults, ground voltage faults or lightning induced surge voltages, and both devices operate from 3 V to 5.5 V while maintaining compliance with TIA/EIA-485-A. However, the LTC2862A raises its predecessor's ESD protection and noise immunity to improve robustness and signal integrity.

Providing protection and reliability for RS485/RS422 applications in industrial control, instrumentation networks and automotive electronics, the new product withstands ±40 kV HBM (IEC-61000-4-2 ESD Level 4: ±8 kV) on the transceiver pins without latchup or damage, while all other pins are protected to ±15 kV HBM. The device also guards against EFTs with IEC 610004-4 EFT Level 4: ±5 kV protection.

Two data rate options, the 20 Mbps LTC2862A-1 and the low EMI 250 kbps LTC2862A-2, offered in commercial, industrial, automotive, and military temperature grades, are available in SO-8 and DFN-8 packaging. Pricing starts at $2.35 each/1,000.

LINEAR TECHNOLOGY, *www.linear.com*

Sample Kit Offers Real-Time 360-Deg. Remote Monitoring

VIA TECHNOLOGIES' NEW VIA Mobile360 Surround View Sample Kit is now available for real-time commercial 360-deg. video vehicle monitoring, recording, and tracking applications. The kit combines a ruggedized in-vehicle system featuring an integrated 4G modem and GPS for remote wireless tracking and monitoring with four automotive-grade FOV-190 cameras, and a 7-in. automotive-grade 720P P-Cap touch monitor with VESA mount support.

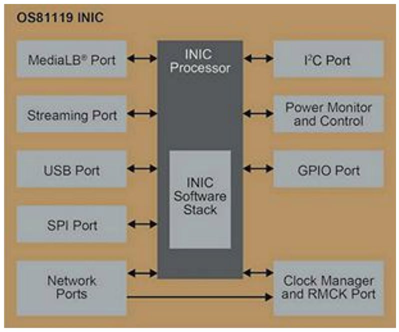
The system harnesses VIA Multi-Stitch Technology to combine the camera feeds on the fly and create an all-encompassing 360-deg. view that can be displayed locally or remotely. It also features VIA Mobile360 E-Track, a cloud portal that enables fleet owners to collect and organize vehicle and driver data for real-time vehicle tracking, event and data recording, and asset management.

Customization options are available to expand functionality through the integration of up to two additional FOV-190 or FOV-50 cameras, including Enhanced Surround View for boosting 360-deg. video capture and stitching capabilities on longer vehicles; Partial ADAS for the front/rear or right/left sides of the vehicle; and Computer Vision for extra E-Track capabilities like driver monitoring, cargo monitoring, and license plate recognition.

VIA TECHNOLOGIES, *www.viatech.com/en*

INIC Enables Automotive Daisy-Chain Communications

OS81119, THE LATEST MOST150 INIC from Microchip Technology enables the incorporation of MOST networks in a daisy-chain configuration on coaxial physical layer with the support of full-duplex communication, in addition to a ring topology. A single cable segment is sufficient to connect two adjacent devices in the daisy-chain network, reducing cables and connectors for the back channel on each connection, and eliminating the return wire connecting the last node to the first.



The interface controller helps simplify the network architecture of automotive in-vehicle infotainment systems by using integrated cPHY, oPHY, daisy-chain topologies or creative hybrid combinations. Current MOST150 systems users can migrate to new topologies or daisy-chain additional nodes with little hardware and software redesign. A USB 2.0 high-speed user interface is also included.

Used by automobile manufacturers and tier one suppliers for in-vehicle networking, MOST technology specifically targets infotainment and telematics applications such as smart antennas, head units, amplifiers, digital clusters, ADAS, information systems and infotainment systems. Offered in a QFN88 package, OS81119 MOST150 INICs are available now starting at $6.50 each/10,000.

MICROCHIP TECHNOLOGY, *www.microchip.com*

ATE Core Configurations Provide Core Infrastructure

NATIONAL INSTRUMENTS' NEW highly customizable ATE Core Configurations offer core mechanical, power and safety infrastructure to help accelerate the design and build of automated test systems in industries ranging from semiconductor and consumer electronics to aerospace and automotive.

The readily deployable core configurations help simplify the design, procurement, assembly, and deployment of smarter test systems with a shorter time to market by empowering test organizations with a platform for standardization. The 19" rack-based configurations are available in various rack-unit heights, and offer scalable power profiles to match the needs of most application and geography. Test organizations can benefit from highly integrated safety features such as thermal shutoff, EPO, optional UPS, and IEC 61010 certification. The units are also supported by NI's high-performance PXI instrumentation and test software portfolio.

The ATE Core Configurations can also include TestStand test management software and LabVIEW code module development software, API and example program support for PXI instruments, and over 13,000 instrument drivers for third-party box instruments.

NATIONAL INSTRUMENTS, *www.ni.com*

Functional Safety Tools Support Automotive MCUs

IAR SYSTEMS' functional safety edition of the IAR Embedded Workbench for Renesas' RH850 MCU Family is designed for safety-related software development. Featuring qualified tools, simplified validation and guaranteed support through the product life cycle, the tools offering is certified by TÜV SÜD according to the requirements of IEC 61508, automotive ISO 26262 and European railway EN 50128.

Certified editions of the C/C++ compiler and debugger toolchain are now also available for the RH850 automotive MCUs offering high performance balanced with low-power consumption over a scalable range of products supporting high reliability requirements. The certification validates the quality of the entire development processes, as well as the delivered software.

The new edition includes a functional safety certificate, a safety report from TÜV SÜD and a Safety Manual. With the certified tools comes a Functional Safety Support and Update Agreement with guaranteed support for the sold version for the longevity of the contract. Functional safety tools for ARM, and for the Renesas RX and the Renesas RL78 MCUs are also available.

IAR SYSTEMS, *www.iar.com*

WTB Connection System Combines IDC/ Press-Fit

THE 53-8702 SERIES off-the-shelf, high-reliability WTB connection system is designed by AVX for discrete 18-24 AWG wire-to-board terminations in automotive electronics applications exposed to harsh environmental hazards, including airbag, engine, and transmission control units. The series combines industry-proven IDC and press-fit or compliant pin technology in a single package to provide robust, double-ended, cold-welded and gas-tight WTB terminations that eliminate two-piece connector systems, enable problem-free conformal coating and remain effective throughout the life of a vehicle.

The connectors feature two phosphor bronze contacts per position, each of which exhibits superior fatigue resistance over extreme temperature and deflection ranges. Currently available in five positions, the series is rated for 6 - 10 Amps, 125 V, -40°C to +125°C operating temperature range, and single termination cycle.

The products are compatible with potting processes with no risk of ingress. Dual assembly methodologies allow for either pre-installation on a PCB, or pre-installation on a wiring harness. The 53-8702 Series WTB connectors are sampling now.

AVX CORP., *www.avx.com*

Secure LTE Automotive Modules Integrate CPU

THE TOBY-L4 series of automotive grade telematics modules from u-blox integrate LTE, UMTS and GSM connectivity with a powerful embedded processor, providing full gateway capabilities in a single device capable of delivering up to 300 Mbit/s data rates with carrier aggregation. The modules' 24.8 × 35.6 × 2.6 mm, 248-pin LGA format meets the size, weight and power limitations of in-car applications.

The modules support both voice and data in the form of LTE, UMTS/DC-HSPA+, GSM, SMS, and VoLTE and CSFB. With support for eCall (operating also at +95°C for at least 2 minutes) and ERA Glonass, the product meets all industry and carrier requirements. With 19000 DMIPS and hardware virtualization, the processor is powerful enough to safely support Linux/Yocto distribution, enabling software applications to run securely alongside a range of pre-integrated communications protocols on the same device.

The TOBY-L4 series, consisting of four automotive grade telematics modules, boast comprehensive band configurations, allowing the module to operate throughout North America, EMEA, APAC/Brazil, and China.

U-BLOX, *www.u-blox.com*

AEC Q101 Photocouplers Address Isolation

TOSHIBA (TAEC) HAS a new range of ten AEC Q101-qualified photocouplers designed to address isolation, interface, switching, and form factor requirements of automotive applications. The range includes the IC output TLX9304, TLX9378 and TLX9376, which are housed in low-profile SO6 packages and offer data rates of 1, 10 and 20 Mbps. Also supplied in SO6 packaging are the TLX9300 and TLX9185A transistor output and TLX9905 and TLX9906 PV output devices. The TLX9000 and TLX9291A offer transistor outputs as well, and are differentiated by their half-pitch SO4 packages. A high-voltage MOSFET between the TLX9175J SO6-packaged photorelay's output terminals is designed to meet automotive battery control needs.

The photocouplers can operate at temperatures from -40°C to 125°C (except TLX9175J: Topr -55°C to 105°C), suiting them to inverter control and IPM interface applications in conventional, EV and HEV applications. All of the new photocouplers have creepage distances of 5 mm and offer a minimum isolation voltage of 3,750 Vrms. The TLX9304, TLX9378 and TLX9376 integrate a GaAlAs infrared light emitting diode and high-gain, high-speed photodetectors.

TOSHIBA (TAEC), *www.toshiba.com/taec/*

Sensor Design Kit Simplifies Speed Measuring Designs

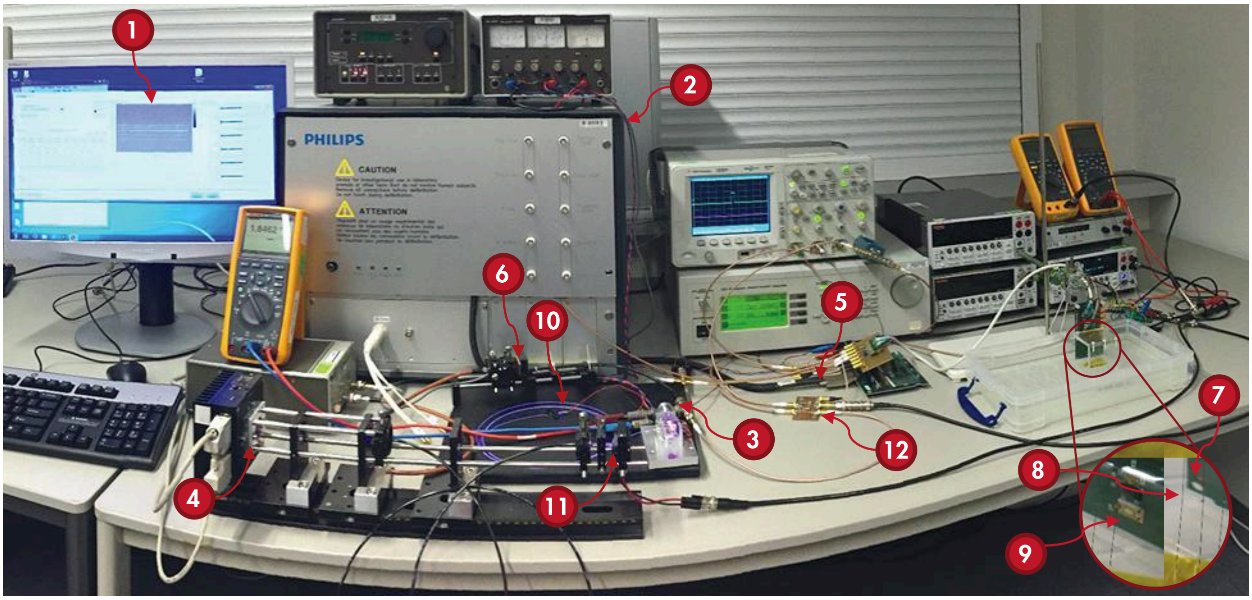
INFINEON TECHNOLOGIES' new TLE4922 Hall sensor, along with the Speed Sensor 2Go design kit that goes with it, are now available for producing reliable and fast measurement of speed. The sensor was developed for automotive applications such as speed detection of crankshafts and transmissions in two-wheelers and three-wheelers, as well as for industrial applications such as speed detection in production and building automation and for the control of electric drives.

The Hall sensor can be used for speed detection in wheel types, such as magnetic encoder wheels or ferromagnetic gear wheels. It withstands vibration and air gap jumps while providing precise speed detection across the magnetic field range of +/-400 mT.

Particularly suited for a TIM configuration, the sensor can replace passive VR sensors in the motor and on the wheels of two-wheelers and cars. Available in a 4-pin SSO package, it operates with a supply voltage of 4.5 V to 18 V from -40°C to 155°C, and its EMC and ESD robustness suit it for use in harsh environments. The "Speed Sensor 2Go" kit includes sensor, interface board, and a cable.

INFINEON TECHNOLOGIES, *www.infineon.com*

(Continued from page 14)



2. The labeled numbers in this photograph of the optoelectrical ultrasound imaging system match the items shown in the block diagram. *(Source: Optical Society of America)*

ASIC and electronics mounted at the catheter tip. The third sends the transducer data back to the console, after encoding by the ASIC (which also controls pulsing of the transducer).

The bidirectional ultrasonic unit is a capacitive micromachined ultrasonic transducer (CMUT) array consisting of 512 active cells, each with a diameter of 60 µm; total active area is 2 × 1 mm2. The CMUT echo output is digitized via a 14-bit analog-to-digital converter (ADC) with a 5-ns sampling time, ramp-compensated for tissue-distance attenuation via a time-gain compensation (TGC) amplifier (a standard technique), then averaged over 16 samples before being encoded by the ASIC.

DUAL SUBSYSTEMS

The two optical-power subsystems are very different and tailored to their load requirements. For the CMUT-power path, a high-power violet laser diode's output is coupled through a 1-mm diameter glass fiber to a 50-V LED comprised of 18 monolithic LEDs in series. A capacitor stores energy so that about 2.5 µJ will be available for the pulsing of the transducer array. A 16-kHz charge pump and inverter takes the 44-V output of the LED array and boosts it to –90 V needed by the transducer. The high-voltage laser receives 1.4 W of power; power efficiency from source to output of the optical/electrical conversion circuitry at the catheter tip is 13.4%.

The low-voltage subsystem powers the electronics and provides bias voltage to the VCSEL , which sources the optical signal needed for transmission of data back to the console. This path is powered by a 405-nm laser from a Blu-ray disk player, and is coupled via a lens and dichroic mirror into a 400-µm diameter glass fiber.

The receiving end doesn't use a conventional photodiode. Instead, it uses a blue LED in "reverse mode" to convert light into electrical power, which is then regulated by a 1.8-V shunt device. (The GaN blue LED is used as a photovoltaic convertor because its high bandgap of 2.8 eV provides a compact power source that can deliver directly up to 2.4 V.) Electrical power to the low-voltage laser is 595 mW, and end-to-end conversion efficiency is 36.8%.

The data-transfer laser operates at 850 nm, using amplitude modulation to transmit data from the CMUT, which has been encoded by the ASIC. The received optical signal is focused on a photodiode, and then goes to a 20-dB amplifier for subsequent demodulation and decoding.

Although this catheter *(Fig. 2)* isn't completely "wireless" and still requires a pair of wires to send control signals to the ASIC at the catheter tip, it represents a major step toward an all-optical design. The long-term goal is to use just a single laser source, and a single fiber. A laser source and fiber could be replaced by a beam splitter at the catheter tip, with the same fiber used as a return path using a dichroic mirror at both ends. The control signals would also be sent over that optical fiber, with some receiving logic integrated in the catheter tip.

Of course, space is extremely limited: the maximum available diameter at the catheter tip, which must house electronics, CMUT, electrooptical elements, mirror, and lenses, is just 3 mm.

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Charged Up
MARIA GUERRA | Technology Editor
maria.guerra@penton.com

The Race for Cobalt-Free Rechargeable Batteries

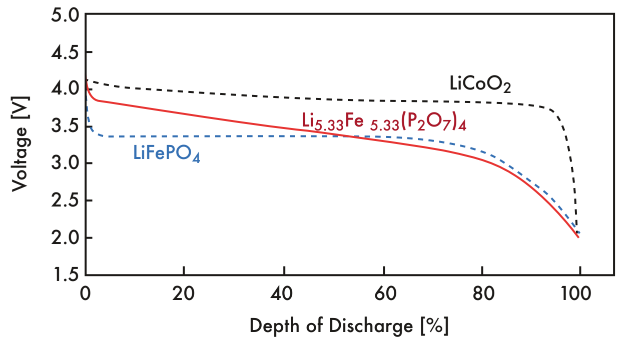
Fujitsu has developed a new high-voltage cobalt-free cathode material for lithium iron phosphate rechargeable batteries.

Based on concerns about insufficient supply and the rising cost of cobalt, Fujitsu Laboratories has been developing materials that use iron, which is abundant on Earth, as a constituent element in place of cobalt. They had successfully developed a cathode material for lithium iron phosphate rechargeable batteries capable of achieving high voltages that could only be achieved by cobalt-based materials in the past. More specifically, Fujitsu Laboratories has successfully synthesized lithium iron pyrophosphate ($Li_{5.33}Fe_{5.33}(P_2O_7)_4$); this phosphate-based material has a voltage of 3.8 V, comparable to that of existing cobalt-based materials *(Fig. 1)*.

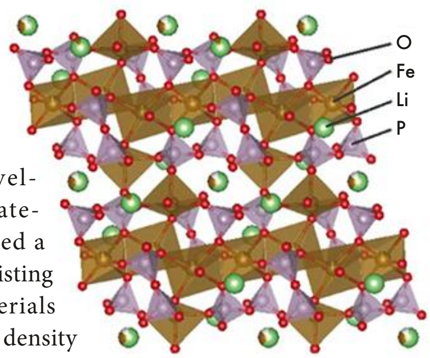
Previously, there was a problem with lithium-ion batteries using iron-based materials as they could not reach the energy density of those using cobalt-based materials. Accordingly, iron-based materials with voltage of 2.8 V to 3.5 V could not compete with cobalt-based materials whose voltage ranged from 3.75 V to 4.1 V. It is known that the voltage of cathode materials can change depending on the arrangement of atoms in the crystal structure, which created issues in the development of new iron-based materials with high voltage.

Fujitsu created advanced design of a new crystal structure *(Fig. 2)* that can maintain a high voltage state for longer periods. The voltage of cathode materials is significantly influenced by the coordination of elements such as iron and oxygen in the crystal. By analyzing the interrelationship between the crystal structure of a material and its electrochemical characteristics, it was discovered that a distorted arrangement of oxygen atoms around iron atoms is one of the critical factors for the high voltage.

Fujitsu Laboratories created a coin-shaped prototype battery and based on the results of its electrochemical properties evaluation, it was confirmed that it could achieve a voltage of 3.8 V, comparable to that of existing cobalt-based materials.



1. Curve of "Voltage vs. Depth of discharge" of a prototype coin battery using (Li5.33Fe5.33(P2O7)4) compare to previously developed materials. *(Courtesy of Fujitsu)*



2. Crystal structure of the new material. *(Courtesy of Fujitsu)*

The newly developed cathode material has not reached a voltage equal to existing cobalt-based materials in terms of energy density but Fujitsu Laboratories will work to design a crystal structure that can maintain a voltage on par with cobalt-based materials for longer periods. The electrode can also be used as a low-cost cathode material in safe, solid-state rechargeable batteries.

If a cathode material is developed with the same energy density as cobalt-based materials, this will enable the stable production of cathode materials by replacing the rare metal cobalt with abundant iron. Moreover, this is expected to contribute to the stable production of lithium-ion batteries. In the future, we will see more companies like Fujitsu Laboratories that will contribute to a more sustainable and comfortable society by developing next-generation high-energy-density rechargeable batteries that are safer, cheaper and environmentally friendly.

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