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12 Wireless Options for IoT/M2M

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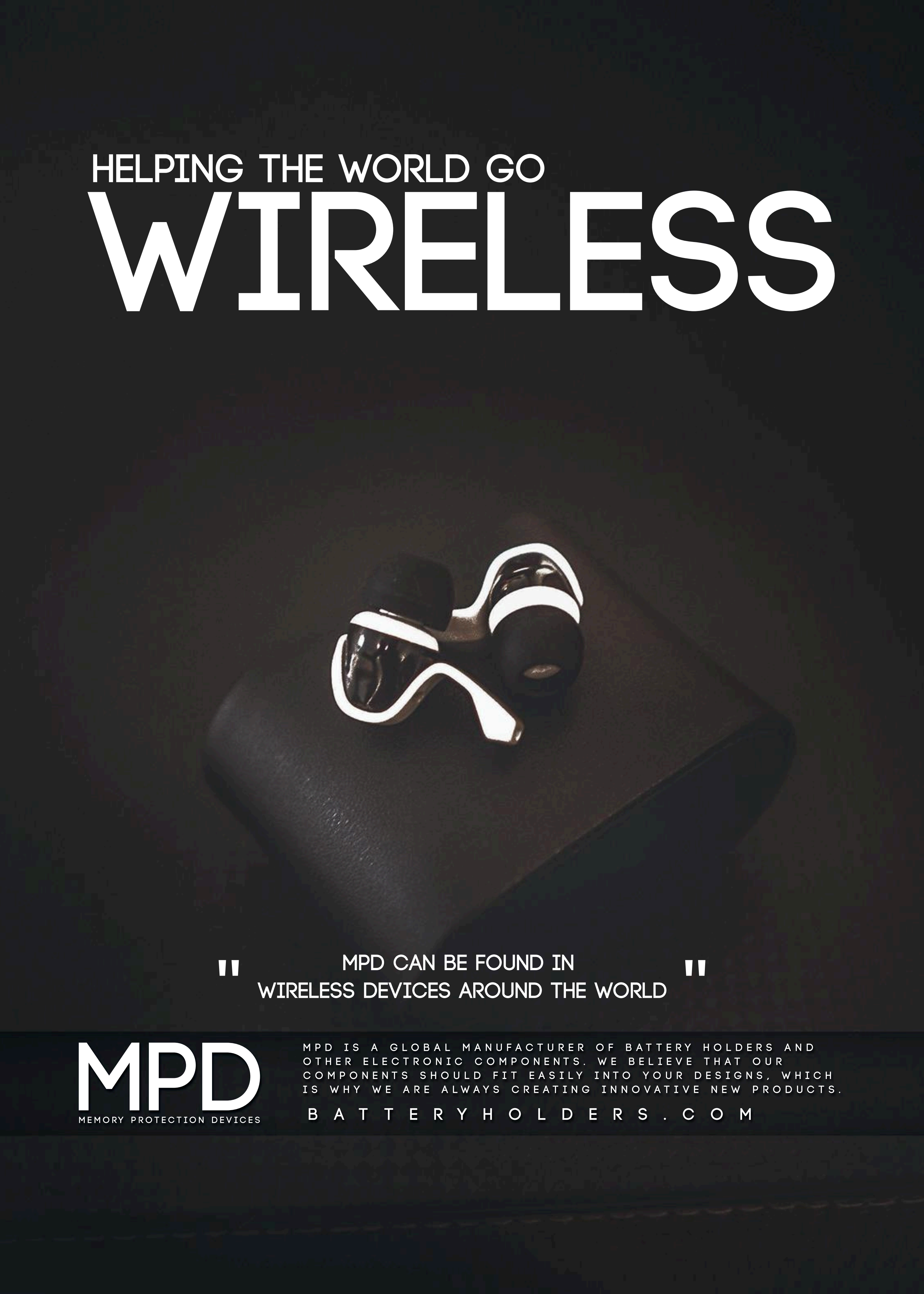
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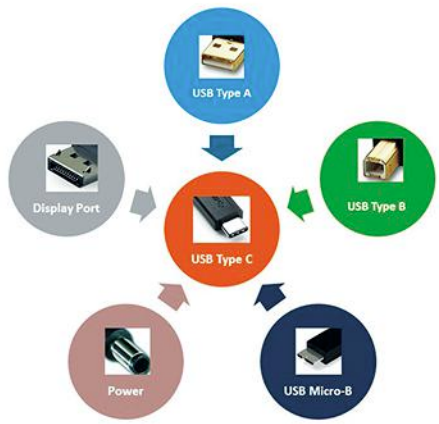

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To provide the most current, accurate, and in-depth technical coverage of the key emerging technologies that engineers need to design tomorrow's products today.

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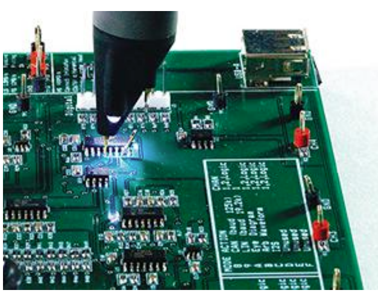
7 THINGS THEY DON'T TEACH YOU IN EE SCHOOL

http://electronicdesign.com/blog/7-critical-things-they-don-t-teach-you-ee-school

Where do most electrical engineers acquire the core knowledge that makes them successful in their career? In his latest blog, Lou Frenzel posits that that most job knowledge and skills were not picked up in school, and specifically outlines seven critical subjects that should be taught there—but aren't.

11 MYTHS ABOUT OSCILLOSCOPE PROBES

http://electronicdesign.com/test-measurement/11-myths-about-oscilloscope-probes



Just about everyone who has ever operated an oscilloscope has used an oscilloscope probe at one time or another. Some have had good experiences, while others had unfavorable ones—possibly as a result of their own actions. This article eliminates some of the myths and half-truths about oscilloscope probes so that their users may obtain more favorable results.

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3-IN-1 ARBITRARY WAVEFORM GENERATOR JOINS IoT FRAY

http://electronicdesign.com/blog/3-1-arbitrary-waveform-generator-joins-iot-fray

The Tektronix AWG4000 Series launched at this year's IMS Show is the first 3-in-1 arbitrary waveform generator—answering the needs of the company's customers whose biggest concern is integrating wireless. The "3-in-1" refers to basic, advanced, and digital modes that allow it to address signal-generation needs from radar and wireless to embedded systems and research.

AUGMENTED VS. VIRTUAL REALITY

http://electronicdesign.com/displays/what-s-difference-between-augmented-and-virtual-reality

What's the difference between augmented reality (AR) and virtual reality (VR) technologies? Actually the answer is relatively simple. AR lets you see the outside world while adding to what you see while VR masks the outside world presenting its own version exclusively. Here, we look at devices and applications ranging from Google Glass to Microsoft HoloLens and more, and where they fall in the "reality" spectrum. (Pictured at right, the Vuze VR camera.)

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Editorial

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Large-Scale Energy Storage Disrupting the Electrical Industry

The latest developments in energy storage promise a greener future for the electrical industry. With more effective and reliable interaction between renewable resources and the grid, greenhouse gas emissions can be reduced. Several studies have been conducted by both the private and public sectors to analyze the impact of such technology on the electrical grid. For example, a study released by Texas utility Oncor Electric Delivery Co. highlighted the many benefits of this technology for the grid:

- Energy storage placement is flexible in that it can be placed in many locations in the grid.
- A storage battery placed on the distribution system (substation or feeder) can be used to prevent distribution outages.
- Distributed deployment of storage can shift power consumption away from costly peak-load periods, reducing peak-load growth on distribution feeders and, therefore, deferring some of the ongoing distribution-system investment needs.
- It can help prevent generation- or demand-side capacity investment.

More research will take place this year following the announcement that Saft (a company involved in the design, development, and manufacture of high-tech batteries used in transport, industry, and defense) has been awarded a megawatt-scale Li-ion (lithium-ion) battery energy-storage contract by Fortum, the Finnish energy company.

A Saft Intensium Max containerized battery system, with a nominal output of 2 MW and 1 MWh, will be installed at Fortum's Suomenoja power plant in Finland as part of the electricity storage pilot project in the Nordic countries. The objective of this pilot project is to research the suitability and optimum usage of batteries used for storing electricity to maintain a power balance in the electricity system.

In addition, the research will explore new opportunities offered by large-scale electricity storage and by the flexible intermediate storage of electricity. The capacity of this power plant will be offered to the national grid company Fingrid to maintain a continuous power balance in the electricity system.

"Li-ion batteries provide good cycle life and great energy density. For this project specifically, Saft will use lithium nickel cobalt aluminum Li-ion batteries (commonly named NAC Li-ion)," said Saft's grid product and marketing manager, Michael Lippert, in a phone interview. Besides highlighting the benefits of Li-ion batteries, he also pointed out the importance of the outcomes of this pilot project because it will help to find out how large-scale energy storage benefits the grid and how Li-ion batteries perform at such high scale.

As the number of energy storage projects increases globally, it is worth mentioning one of the American finalists for the 2015 Project of the Year Awards announced by Renewable Energy World: The Grand Ridge Energy Storage Project at Invenergy's Beech Ridge Energy Center. The Grand Ridge Energy Storage Project is a 31.5-MW lithium-ion battery system in operation located in Marseilles, Ill. The project has had great success helping grid operator PJM balance the supply and demand using BYD's proprietary lithium-ion iron-phosphate battery chemistry.

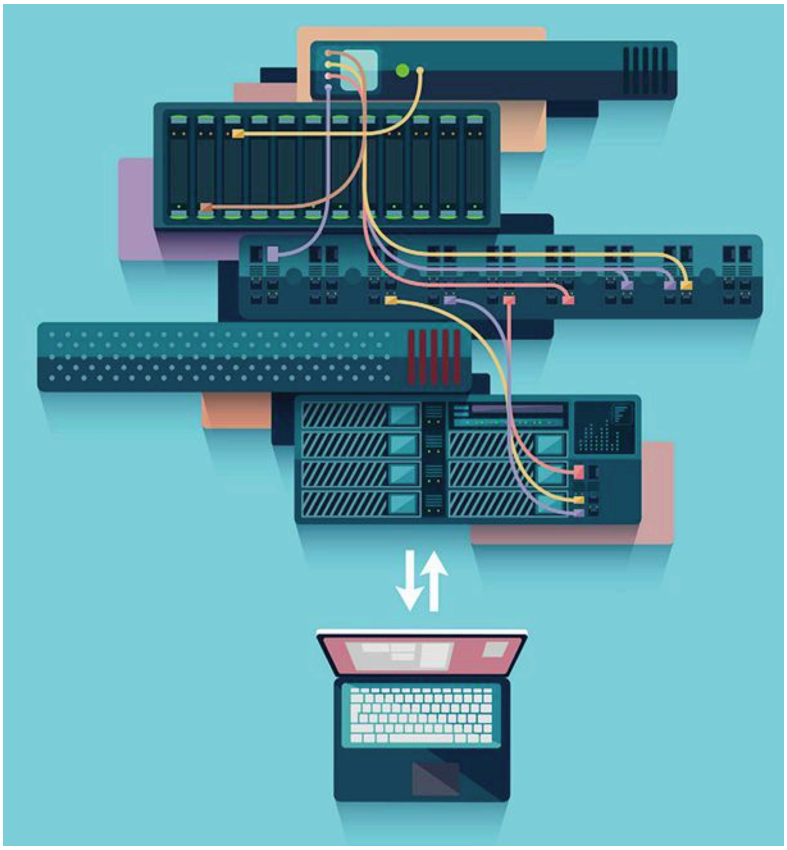
According to market-research firm IHS, the energy storage market is set to "explode" to an annual installation size of 6 gigawatts (GW) in 2017 and over 40 GW by 2022—from an initial base of only 0.34 GW installed in 2012 and 2013. Energy companies are investing in energy storage because it can help them meet future energy needs and at the same time encourage the use of renewable sources reducing greenhouse gas emissions.

News

SEEKING AN INTERCONNECT for Desperate Data Centers

In the semiconductor industry, the time between new generations of chips is stretching out. The task of etching smaller transistors onto silicon has grown vastly more difficult, while shrinking transistors near atomic limits has introduced problems with keeping them cool. The manufacturing costs have also stopped falling.

Now, internet giants like Google and Facebook—which are shoveling millions of chips into their data centers—are looking for ways around the industry's slowing pace. They have taken to adding special chips that better handle certain aspects of computing, like those related to artificial intelligence. That shift has seen standard chips combined with everything from graphics processors to more exotic chips that mimic the human brain.



(Image courtesy of Rogotaine, Thinkstock)

As companies buy more of these accelerator chips, an alliance of seven chipmakers is trying to ensure that they can all coexist. The goal is to create a special kind of interconnect that can seamlessly share data between processors, accelerators, and memory caches.

Companies working on the project are all trying to build more profitable data center businesses: Advanced Micro Devices, ARM, Huawei, IBM, Mellanox, Qualcomm Technologies, and Xilinx. They will pursue a cache-coherent fabric to ensure everyone's chips can share the same memory—without stepping on any toes to access that data.

The project, known as the Cache-Coherent Interconnect for Accelerators (CCIX), is significant because it will bridge some of the major set instruction architectures—the part of the processor visible to programmers—in the industry. That includes IBM's Power architecture as well as ARM and x86 designs.

The new interconnect will primarily help to increase the speed at which information moves within data centers. Today's computers are sharing data with accelerators and memory using interconnects not designed for high bandwidth, low latency applications. That creates a bottleneck for software that learns to find patterns in large datasets, manage wireless networks in the cloud, or provide internet services like search.

To help mitigate that problem, software engineers are usually forced into some heavy lifting. They depend on extremely complex programming to stitch together different chip architectures in the same system. For data center operators, another option to just buy chips from a small set of manufacturers.

Not everyone thinks that last option is healthy for the industry. The "one-size-fits-all architecture approach to data center workloads does not deliver the required performance and efficiency," said Lakshmi Mandyam, director of server systems at ARM.

Ultimately, the new project is aiming to replace PCI Express (PCIe) interconnect upon which most data centers depend. PCIe is the connective tissue that links accelerators with the processors from ARM, x86, or Power. Engineers have applied that formula for more than a decade, but PCIe was not designed for the fast and efficient transfers between accelerators and processors.

In the last year, the practice of using accelerators to improve efficiency has spread all over the technology industry. Last month, for instance, Google revealed its own custom chips that would run machine learning in its search engine and other services.

Facebook has opened the architecture behind its Big Sur graphics chips, while China's Baidu and Microsoft have been experimenting with FGPA chips that increase the speed of cloud services. Nvidia's latest architecture for graphics processing units, Pascal, was designed specifically for machine learning.

Some companies have already tackled the interconnect problem. IBM has developed the Cache-Coherent Accelerator Processor Interconnect, or CAPI, but it is only supported by IBM and a handful of partners. Nvidia has invested in its own technology called NVLink, which provides faster connections between its graphics chips and IBM's Power chips.

Having an interface between different chip architectures could give data center operators a wider range of options for buying chips. It could also open the door to greater competition and enable operators to update existing equipment, rather than adding more servers or investing in complex programming.

From that perspective, Intel's exclusion from the new project speaks volumes, according to industry analysts. The world's largest server chipmaker, Intel has its own alternative to the PCIe standard called the QuickPath Interconnect. Intel is running that technology in server chips that combines its CPUs with FPGA accelerators.

Intel's data center business has been growing rapidly as the company attempts to transition out of personal computers, which have been on the decline for years. The data center business posted revenue of $4 billion in the first quarter of 2016, up 9% from the first quarter last year. That was nearly 30% of the company's $13.7 billion in revenue during the first quarter.

The CCIX project is one attempt at putting up a fight against Intel. Qualcomm, the biggest maker of mobile phone chips, has developed a server variant of its Snapdragon processor to rival Intel, which has undercut some of Qualcomm's mobile business. Like Intel, the chipmaker is experiencing some growing pains, working through a major restructuring that will cut up to 15% of the workforce.

(continued on p. 14)

BLUETOOTH TRIES WORKING Smarter, Not Harder

SVENN-TORE LARSEN IS trying to build a business on Bluetooth. But the company where he serves as CEO, Nordic Semiconductor, is not using the familiar wireless standard that has found its place in everything from smartphones to headphones.

Instead, the company is betting on Bluetooth Smart, a relatively newer version (about half the age of standard Bluetooth) that consumes significantly less power from batteries inside things like wearables and tiny sensors. In 2015, around 57% of the company's $193 million in revenue came from sales of Bluetooth Smart chips, up from 37% of Nordic's business in 2014.

"We are positioned for a great market opportunity," Larsen said during the conference call for Nordic's first quarter earnings in April, citing the growing demand for Bluetooth Smart in household devices and wearables. He told investors that over the next few years Bluetooth Smart would account for an increasing part of the business, which includes other low-power wireless chips based on standards like ANT and sub-GHz radio.

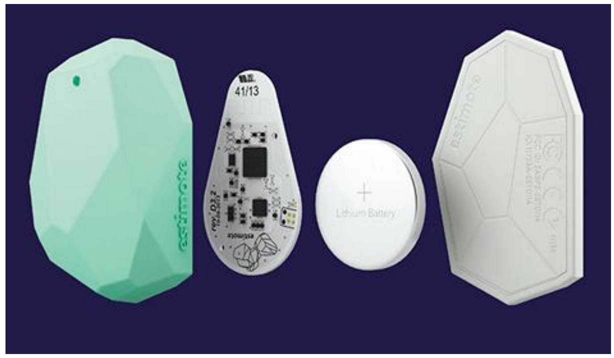
Nordic's efforts are not that unusual. The company is part of a stampede of companies that are fusing processors with low-power wireless components inside integrated chips or SoCs. The industry anticipates that sensors and other devices in buildings and factories will have to operate on incredibly low power to conserve battery power—or allow them to harvest energy from their surroundings. But that is only possible with extremely low-power networks.

ABI Research, a technology research firm, estimates that Bluetooth Smart will be inside around 27% of all Bluetooth products by 2021. Their previous research has estimated that around 20 billion Bluetooth chips will be sold between 2014 and 2019. The Bluetooth Special Interests Group, which maintains the standard, predicts that more than 90% of smartphones with Bluetooth will support the low-power version by 2018.

"While there remain significant opportunities for Bluetooth smartphone accessories and connected home devices, there will be increasing traction toward connecting to everyday household objects," says Andrew Zignani, industry analyst at ABI Research. "Improvements in energy efficiency and range, and reductions in size, will be contributing factors accelerating shipment growth."

First developed around a decade ago, Bluetooth Smart was known as Wibree before merging with the main Bluetooth specification in 2010. Over the last few years, the Bluetooth SIG has updated the standard to play into Smart's strengths. Later this year, the standard will gain significant increases in range and speed, without consuming any additional power. The new version will also include mesh networking, allowing Bluetooth devices to connect in networks covering entire buildings.

Earlier this year, the Bluetooth SIG introduced a new architecture that would help developers build gateways to relay data to the cloud and back. Arduino recently built Smart into its latest Primo development board, so that it could "communicate with other internet-connected nodes without requiring the resources of a complex and expensive gateway such as a Wi-Fi router or smartphone."



Bluetooth Smart beacon built by Krakow, Poland-based startup Estimote. *(Image courtesy of Estimote)*

Major chipmakers are racing to incorporate Bluetooth Smart into their products. Some companies—wireless veterans like Mediatek and Internet of Things crusaders like Texas Instruments and Marvell—are devoting internal resources to low-power chips. Others are turning to mergers and acquisitions to avoid missing the boat for things like wearables and sensors.

In 2014, Qualcomm bought Cambridge Silicon Radio, a company that helped introduce mesh networking with Bluetooth Smart, in the second-largest deal in the company's history. Not long after that, Silicon Labs jumped at the opportunity to buy Bluegiga Technologies, which developed Bluetooth Smart modules for industrial equipment and smart household devices.

More recently, Cypress Semiconductors made a huge step into the low-power wireless market, buying Broadcom's wireless Internet of Things business for $550 million. Under the terms of the deal, Broadcom will shed its Wi-Fi, Bluetooth, and ZigBee products and intellectual property. Cypress plans to combine the new wireless chips with its low-power programmable chips and microcontrollers.

Only tracing how Bluetooth chips have changed hands, however, undercuts the wide net that chipmakers are casting into wireless. Last year, Silicon Labs also acquired Telegesis, which designs mesh networking modules based on ZigBee and Thread protocols. Bluetooth is also clashing with other parvenus like Z-Wave and a low-power version of Wi-Fi called HaLow.

The migration into low-power wireless standards is helping to create new kinds of devices, ones that could gather the huge amounts of data necessary to automate homes and businesses. Many startups are trying to make sensors and other devices self-sufficient by harvesting tiny bits of energy—like wireless radiation—from their surroundings. Instead of using batteries, the sensors can save that energy to collect and transmit data.

Bluetooth Smart has also created an opening for new consumer experiences. Large companies including Google and Apple are playing around with beacons, or tiny Bluetooth transmitters. Apps installed on your smartphone listen for signals radiated by the beacons, which can be embedded in anything from grocery store shelves to movie posters. When your smartphone gets within range, you can receive a coupon for a bag of chips, find show times for the movie advertised on the poster, and even make payments to things like parking meters.

Google and Apple both have open platforms for developing beacons, called Eddystone and iBeacon, respectively. Google has released several application programming interfaces that help developers detect nearby beacons and business owners manage the data gathered by beacons on the cloud.

"OEMs can also utilize Bluetooth's throughput advantage versus 802.15.4 [standards like ZigBee and Thread] and lower power consumption versus Wi-Fi in order to create new and unique use cases that separate them from competing connectivity solutions," Zignani said. ■

WIRELESS CHIP TACKLES Multiple Low-Power Standards

FOR YEARS, wireless chipmakers like Qualcomm and Silicon Labs have known that linking sensors in an electrical turbine, factory assembly line, or smart household device would require networks that span large areas and consume little power from the sensors' batteries.

Word has spread quickly. Now that industrial companies are trying to seed factories with remote sensors and consumer companies including Google's Nest are promoting smart thermometers and other devices, low-power wireless networks are crawling out of the woodwork. The options are so numerous that the industry has begun clamoring for a standard in a sea of standards.

Imec, the microelectronics research center, recently unveiled a new radio chip that supports over five low-power wireless standards, enabling it to connect devices that might have been isolated on a single type of network. It was developed along with the Holst Centre, a research laboratory in the Netherlands for sensors and flexible electronics.

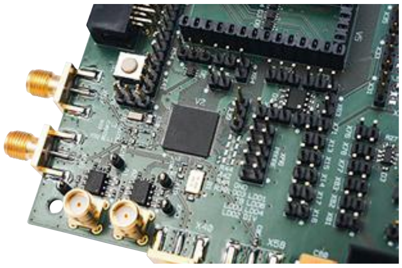
The new chip supports several standards for low-power wide-area networks, including the popular LoRa and SigFox protocols. It also supports IEEE 802.15.4 standards, such as ZigBee and the Thread protocol, which Nest has used to connect its thermostats and security cameras.

The chip is also compatible with certain cellular networks, which under normal circumstances chew through too much power and bandwidth for things like sensors. The 3G Partnership Project, the organization that maintains cellular standards, is in the process of defining one such protocol known as Narrowband-IoT, a low-power network that shares the airwaves with LTE and 3G signals.

The chip is a highly-integrated system that channels spectrum bands between 780MHz to 930MHz. Operating in the industrial, scientific, medical (ISM) and short-range devices (SRD) bands, it covers a frequency range that has been reserved for applications other than telecommunications.

The new chip was introduced as low-power wide-area networks are increasingly being used to connect smart meters and remote sensors inside factories, buildings, and city infrastructure. In certain cases, they are even being used for monitoring the environment—even tracking volcano activity in Japan.

"It is clear that protocols such as NB-IoT, SigFox, and LoRA are here to stay for the coming years," said Kathleen Philips, the program director for perceptive



The new multi-standard chip. *(Image courtesy of Imec)*

systems at Imec, who revealed the chip at the laboratory's technology forum in Belgium.

What remains unclear is what wireless standards will still be around in the future. The vast arrays of sensors packed inside factories and buildings are still in the early stages of development, so most companies have not rallied behind a single networking protocol. Imec's radio chip attempts to avoid the debate by working with multiple standards, making sensor networks easier to manage. ■

(continued from p. 11)

ARM, which expects to start challenging Intel in server chips, is known for its mobile chip designs used by Qualcomm, but has also been contributing its designs to AMD Opteron server chips and graphics accelerators. Huawei, which operates a fabless semiconductor business HiSilicon, also depends on ARM designs.

"There is no doubt that the computing industry will laud their efforts as the only sensible path to provide an alternative to an all-Intel computing world," wrote Karl Freund, a senior analyst with Moor Insights and Strategy, in a recent *Forbes* article about the project's impact.

The group, which only has a one-page website with little information, has yet to release any technical or financial details about the project. Freund is predicting the fruits of the partnership will not ripen until around 2019 or 2020. ■

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LOU FRENZEL | Contributing Editor

12 Wireless Options for IoT/M2M: DIVERSITY OR

A plethora of standards populate the wireless-communications field, all offering unique twists to fit specific connection needs.

The Internet of Things (IoT) is a massive collection of sensors, actuators, and/or devices either connected to one another or to some master control or monitoring point via the internet. Multiple communications links are used to make the connection.

However, the device itself usually connects to the system by radio. This wireless connection is the critical or weakest link in the system. Therefore, it's essential that you select a wireless method that matches the device and its surrounding environment. Literally dozens of wireless technologies and standards are available to choose from—this article guides you through the most likely wireless candidates for new designs.

A typical IoT connection scenario involves the device linking to a gateway via wireless *(see figure)*. The gateway is the interface to the internet via a common broadband cable or DSL modem, and then on to the internet service provider for connection to the internet. In an alternative scenario, otherwise known as M2M, the device connection goes through a cellular carrier and then to another carrier or on to the internet.

A number of design factors must be scrutinized when selecting a wireless technology:

- *Data rate of the device:* Streaming video, measuring temperature every minute, or something in between.
- *Range or distance to the gateway:* A few feet within a room or over a mile in a rural area.
- *The environment:* Hazardous surroundings in a factory, outdoors, noise from electrical equipment or EMI, etc.
- *Need for encryption or authentication:* What is the demand for data security?
- *Power consumption:* Battery life; energy efficiency; possible need for an ac mains connection.
- *Capacity:* Number of connected devices.
- Quality of service and reliability.
- *Network topology:* Star, mesh, or other.
- *Simplex or duplex:* One-way vs. two-way communications.
- *Suitable and available spectrum:* Licensed or unlicensed.
- Available ICs, modules, and equipment.
- *Cost:* Design, manufacturing, or internet access service expense.
- *Development platform:* Is an OS needed? What other software is required?
- *Internet access:* Cellular, DSL, cable, satellite.
- Licensing conditions of standards available.

2G/3G CELLULAR

Yes, cellular networks can be used for IoT applications. Generally known as machine-to-machine (M2M), many of its use cases are nonetheless similar to IoT. Multiple vendors offer cell-

DILEMMA?

phone modules to embed into other products, and most of the major cellular carriers provide M2M connection services over standard licensed spectrum. Though 2G technology like GSM/GPRS/EDGE is popular, some carriers already have plans to phase-out 2G capability.

However, most networks still support 3G technologies like WCDMA and cdma2000 with data rates up to several megabits per second. Range is the distance to a cell site, and can be up to several kilometers. Cellular connectivity is clearly an option, although more expensive than some alternatives like the low-power wide-area-network (LPWAN) technologies described later.

802.15.4

This is the popular wireless standard developed by the Institute of Electrical and Electronic Engineers (IEEE). Targeting short-range, low- to medium-data-rate and low-power-consumption use cases, it's the basis for several other standards listed later. Its main operating spectrum is the 2.4-GHz industrial, scientific, and medical (ISM) license-free band. The 902- to 928-MHz and 868-MHz bands are in play, too.

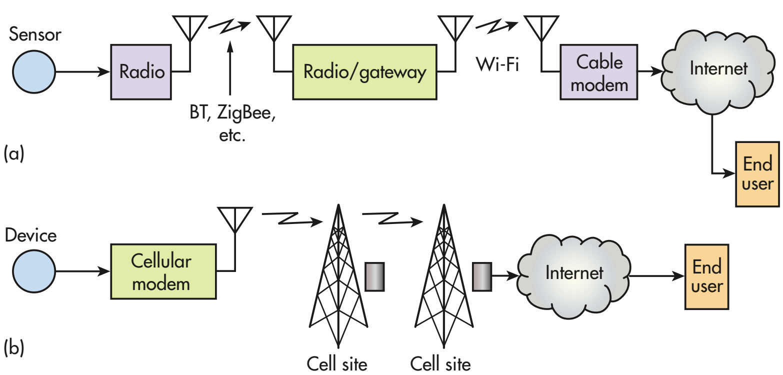
Modulation is direct sequence spread spectrum (DSSS) with differential binary phase-shfit keying (BPSK) or offset quadrature phase-shift keying (QPSK). Operating at a 1 mW (0 dBm), it offers a data rate of 250 kb/s in the 2.4-GHz band. Range is 10 to 100 meters using a point-to-point or star topology. Access is carrier sense multiple access with carrier avoidance (CSMA/CA) for up to 2^{16} nodes; more nodes are possible with 6LoWPAN *(see "6LoWPAN Addresses Nodes," p. 19)*. It employs AES-128 encryption for security purposes.

The 802.15.4 standard provides the PHY and MAC networking layers with a packet-based protocol. Other standards use this as the basis for adding more layers, providing enhanced networking features and capabilities.

BLUETOOTH

Perhaps the most widely used short-range wireless technology is Bluetooth (BT), which operates in the 2.4-GHz ISM band. Several different versions offer multiple data rates, power levels, and range potentials. The basic operating principle is frequency-hopping spread spectrum (FHSS) with different modulation methods. Gaussian frequency-shift keying (GFSK) is the main modulation method, providing a 1-Mb/s data rate. Data rates of 2.1 or 3 Mb/s can be achieved using higher modulation rates. Power levels to 100 mW boost its range up to 100 meters.

The newest version of Bluetooth is BT Smart or version 4.1. Also called Bluetooth Low Energy (BLE), the configuration uses shortened packets, a maximum rate of 1 Mb/s, and GFSK modulation. Its primary benefit is super-low power consumption. Transmit power is 10 mW, and its range can extend up to 100 meters. Multiple software profiles are available for different uses, and an interoperability certification is in effect to ensure full compatibility.



The diagram shows typical wireless-connection scenarios for the IoT (a) and M2M (b).

LoRa

LoRa (long range), a technology created by Semtech, has typical operating frequencies of 915 MHz for the U.S., 868 MHz for Europe, and 433 MHz for Asia. The LoRa physical layer (PHY) uses a unique form of FM chirp spread spectrum along with forward error correction (FEC). This spread-spectrum modulation permits multiple radios to use the same band if each radio employs a different chirp and data rate. Typical range is 2 to 5 km, and up to 15 km is possible depending on the location and antenna characteristics.

LTE Cat 0/1

LTE stands for Long Term Evolution, the current fourth-generation cellular technology. The standard, which is the creation of the 3GPP and ITU, is widely implemented in the U.S. and around the world. It's perhaps best known for its high-speed capability of up to 300-Mb/s downlink using higher-level QAM and MIMO.

LTE Cat 0 and Cat 1 are reduced-function versions of LTE designed for low power and low speed to match the needs of M2M. M2M applications, also called machine-type communications (MTC), use the existing cellular network in licensed spectrum rather than short-range wireless and the internet.

The standard LTE network is overkill for most basic monitoring and control uses. LTE Cat 0 and Cat 1 are simplified versions that can provide solutions for M2M applications with maximum data rates of 1 Mb/s and 10 Mb/s, respectively. Cat 0 and Cat 1 use the existing LTE bandwidths with orthogonal frequency-division multiple-access (OFDMA) modulation. This long-range solution is capable of kilometers of distance.

NB-IoT

A relatively recent variation of using LTE for IoT is NarrowBand IoT. Instead of using the full 10- or 20-MHz bandwidth of standard LTE, NB-IoT uses a 180-kHz-wide resource block of 12 15-kHz LTE subcarriers. Data rates will be in the 100-kb/s to 1-Mb/s range.

This more simplified standard provides very low power consumption for connected devices. Furthermore, it can be deployed in any LTE network as a software overlay. A resource block of NB-IoT fits nicely inside a standard LTE channel or within a guard band. It also fits into a standard GSM channel as carriers re-farm their older 2G spectrum. Modulation is OFDMA downlink and SC-FDMA uplink. NB-IoT offers another competitive long-range solution.

WEIGHTLESS

Weightless is a family of open wireless-technology standards targeting Internet of Things applications. Three different versions of this standard address different segments of the LPWAN marketplace.

The simplest version is Weightless-N for low-cost applications. This version targets simplex or one-way uses such as sensor monitoring. It operates in the sub-1-gigabit license-free ISM. Modulation is differential BPSK using a frequency-hopping technique to minimize interference. A key feature is its 128-bit AES encryption with full authentication. With low data rates and narrow channels, a range up to 5 km is possible. Up to 10 years of battery life is also possible, thanks to the standard's low power consumption.

If higher performance with two-way communication is needed, Weightless-P might be the best option. It uses a combination of frequency-division multiple access (FDMA) and time-division multiple access (TDMA) to manage access to multiple 12.5-kHz-wide channels. Data rates can range from a low of 200 bits/s to 100 kb/s using GMSK and offset QPSK modulation. Typical maximum range is about 2 km. Both AES-128/256 encryption and authentication are utilized for security measures.

The third version, Weightless-W, is designed to operate in the TV white spaces. White spaces are those 6-MHz-wide channels previously used by TV stations in the 470- to 790-MHz space. It is possible to achieve data rates from 1 kb/s to 10 Mb/s, depending on the link budget. A range of 5 km or more is possible in non-line-of-sight situations. Use of TV white spaces requires the base stations to reference a master database of TV bands and wireless microphone frequencies and subsequently choose an unused band to avoid interference. Weightless is a royalty-free IP that helps minimize cost.

SIGFOX

SIGFOX is a wireless technology as well as a network service. The name derives from a French company that offers wireless technology and a local LPWAN for longer-range IoT or M2M applications. It operates in the 868- and 902-MHz ISM bands, but consumes very little bandwidth or power.

SIGFOX radios, which exploit a technique called ultra-narrowband (UNB) modulation, only transmit short messages at low data rates occasionally. Messages can be up to 12 bytes long, and a node can send up to 140 messages per day. Because of the narrow bandwidth and short messages, in addition to its 162-dB link budget, long range up to several kilometers is possible. Networks with forwarding base stations have been established in Western Europe and the San Francisco area.

WIRELESS TECHNOLOGIES AT A GLANCE

Technology	Frequency	Data rate	Range	Power	Cost
2G/3G	Cellular bands	10 Mb/s	Several km	High	High
802.15.4	2.4 GHz	250 kb/s	100 m	Low	Low
Bluetooth	2.4 GHz	1, 2.1, 3 Mb/s	100 m	Low	Low
LoRa	< 1 GHz	<50 kb/s	2-5 km	Low	Medium
LTE Cat 0/1	Cellular bands	1-10 Mb/s	Several km	Medium	High
NB-IoT	Cellular bands	0.1-1 Mb/s	Several km	Medium	High
SIGFOX	<1 GHz	Very low	Several km	Low	Medium
Weightless	<1 GHz	0.1-24 Mb/s	Several km	Low	Low
Wi-Fi (11f/h)	2.4, 5, <1 GHz	0.1-1 Mb/s	Several km	Medium	Low
WirelessHART	2.4 GHz	250 kb/s	100 m	Medium	Medium
ZigBee	2.4 GHz	250 kb/s	100 m	Low	Medium
Z-Wave	908.42 MHz	40 kb/s	30 m	Low	Medium

Wi-Fi

Wi-Fi is employed in many IoT use cases, most commonly as the link from the gateway to the router with the connection to the internet. However, it does find a place in the main wireless link, which requires high speed and medium range. A good example is video monitoring in the home or in a commercial/industrial setting for security.

Most versions of Wi-Fi operate in the 2.4-GHz unlicensed band and have a range of up to 100 meters depending on the environment. The popular 802.11n can handle speeds to 300 Mb/s, while the more recent 802.11ac, which operates in the 5-GHz ISM band, reaches speeds in excess of 1.3 Gb/s.

A new IoT-friendly version of Wi-Fi called HaLow is coming soon. Designated 802.11ah, it uses the 902- to 928-MHz license-free band in the U.S. and similar bands just below 1 GHz in other countries. This is good news, as low power can be used over these lower frequencies, thus 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.

Modulation for 11ah is OFDM using 24 subcarriers in a 1-MHz channel and 52 subcarriers in the larger bandwidths. It can be BPSK, QPSK, or QAM, providing for a wide range of data rates. Rates of 100 kb/s to several megabits per second will suffice in most cases—the real goal was low power. The Wi-Fi Alliance says it will implement an 802.11ah testing and certification program by 2018.

Another new Wi-Fi standard targeting IoT applications is 802.11af. It's designed to use TV white spaces or 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 to ensure there's no interference to local TV signals. The base station queries a database to see what channels are available locally for data transmission. Modulation is OFDM using BPSK, QPSK, or QAM. Data rate per 6-MHz channel maxes out at about 24 Mb/s, though even longer ranges are expected at the lower VHF TV frequencies.

WirelessHART

This wireless version of the widely used Highway Addressable Remote Transducer (HART) industrial networking technology is used in process monitoring and control, sensor networks, building automation, and transportation. WirelessHART is the property of Linear Technology's Dust Networks and must be licensed to be used. Based on the popular IEEE 802.15.4 standard, it has the designation of 802.15.4e.

WirelessHART adds a time-synchronized mesh protocol to the basic standard. In addition to the mesh topology, it can adopt a star configuration. It uses TDMA for access for up to 2^{16} nodes with time-slotted channel hopping.

6LoWPAN ADDRESSES NODES

THE INTERNET ENGINEERING Task Force's (IETF) 6LoWPAN is shorthand for Internet Protocol 6 (IPv6) over Low Power Wireless Personal Area Networks. The standard allows IPv6 to give IoT nodes a standard IP address. It's designed to be used with other wireless standards.

Originally aimed at 802.15.4, the standard also has been adopted by Bluetooth Smart and low-power HaLow Wi-Fi. Specifically, 6LoWPAN defines ways to use encapsulation and header compression techniques to fit IPv6 packets into the frames of other protocols.

ZIGBEE

ZigBee is one of the great choices for IoT. It's been around for many years and is highly developed with continuing updates and enhancements, and certified interoperability. The technology is based on the IEEE 802.15.4 standard, but adds extra layers to the protocol.

Though ZigBee typically operates in the 2.4-GHz ISM band, it can also be used in the 902- to 928- and 868-MHz bands. Data rate is 250 kb/s in the 2.4-GHz band. It can be used in a point-to-point, star, or mesh configuration with up to 2^{16} nodes. As with others, security is via AES-128 encryption. One main advantage of ZigBee is the availability of pre-developed application profiles of software for specific applications, including IoT. End products must be licensed.

Z-WAVE

Z-Wave is a single-source proprietary wireless technology of Sigma Designs. Both chips and modules are available for this technology, which is found mostly in home-area networks for lighting control, security, and thermostat operation.

Z-Wave operates in the ISM band frequency of 908.42 MHz. It uses efficient GFSK and implements data rates of 9,600 bits/s or 40 kb/s; up to 100 kb/s is possible in some applications. Typical power level is 1 mW (0 dBm) and its maximum range is about 30 meters, depending on the environment. It can be used for point-to-point links or in a star configuration with up to 232 nodes. For security measures, it incorporates AES-128 encryption. This technology must be licensed for use in commercial products.

SUMMARY

The *table* offers a quick synopsis and comparison of the technologies covered in this article. As you might expect, it's unlikely that any standard will dominate given the huge diversity of IoT and M2M applications. There's literally a best-match for every occasion.

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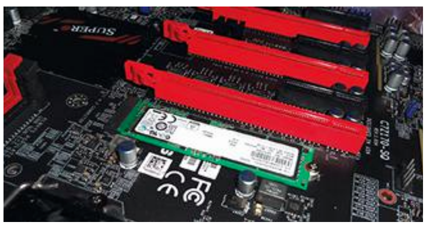
PCI EXPRESS Is Handling More than Just Peripherals

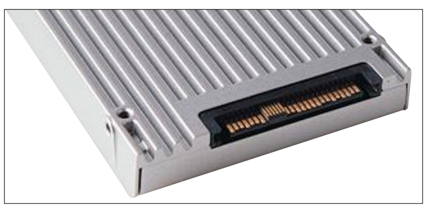
Style checkers and static analysis tools are one way to improve code quality. We examine some of the alternatives in this space.

PCI Express (PCIe) Gen 3 is the mainstay for microprocessors. It scales by adding more lanes typically in an x1, x2, x4, x8, and x16 progression. Processor chips may use anywhere from one to more than a couple dozen lanes depending upon the bandwidth needed for a particular application.

The high-speed serial PCIe interface superceded the parallel PCI bus as the foremost peripheral interface, although even the PCI predecessor, ISA, is still in use. Access to peripherals such as Ethernet adapters remains a focus for PCIe, but it can also be utilized as multiple-node interconnect fabric as well as an access mechanism for solid-state storage also known as non-volatile memory express or NVMe.



1. Micron's M.2 NVMe module uses an x4 PCI Express interface.



2. The U.2 drive module supports a range of interfaces including an x4 PCI Express interface designed to handle NVMe storage modules.

NVMe is a storage protocol based on SCSI that is also the basis for SAS (Serial Attached SCSI). SAS uses the same electrical interface as SATA (Serial Advanced Technology Attachment) while NVMe runs on top of PCI Express. In general, they are similar in that commands and operations are queued to provide more efficient throughput between the storage device and the host. NVMe can handle other storage technologies, but for now it is primarily NAND flash memory including 3D NAND flash.

NVMe storage devices can be placed on the motherboard or attached in a variety of ways. An NVMe PCI Express card is one way to do it. Another is the M.2 NVMe module form factor like Micron's 512 Gbyte unit (*Fig. 1*) that uses 3D NAND and an x4 PCI Express interface. The M.2 sockets are becoming more common on motherboards and are ideal for embedded applications since they are more rugged, but also provide a way for developers to select the amount of storage needed for an application.

On the enterprise side, the U.2 drive module (*Fig. 2*) is becoming more popular. The connector actually supports a range of interfaces including an x4 PCI Express interface to handle NVMe as well as multichannel SAS and SATA. These modules are designed for hot-swap operation and are found on systems that may have a half dozen to hundreds of slots. These take advantage of the PCI Express switches that are available so one or more hosts can access the drives.

PCI Express fabrics have been used to link multiple hosts together as in Dolphin's PCI Express solutions. This consists of a PCI Express switch and PCI Express host adapters that can be cabled to the switch. A system is designed to run a version of Linbit's DRBD that replicates disk storage. Of course, the hosts could use a PCI Express interface to use NVMe storage as well.

PCI Express has also been used to link other devices together. For example, some GPGPUs can utilize their PCI Express interface to communicate with other systems linked by Ethernet supporting remote DMA (RDMA) using a protocol called GPUDirect. This configuration is useful in supercomputing clusters with GPGPUs located on different nodes within the system.

PCI Express can be used with a single-root complex host to interface with peripherals, but these days it can do much more. ed

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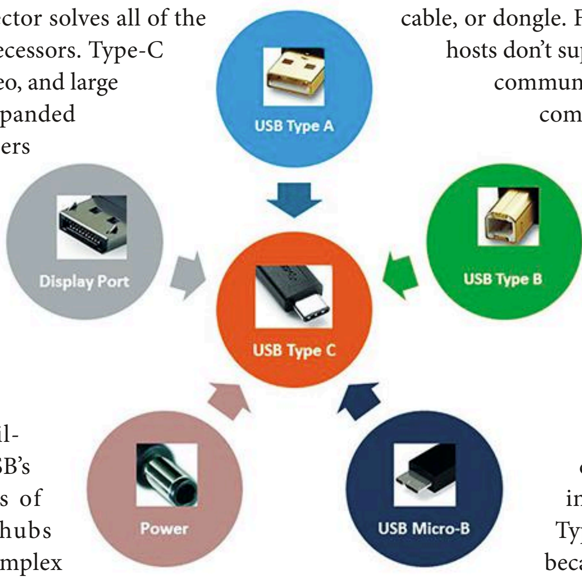
Add USB Type-C to Embedded Designs

Although USB Type-C technology provides a leap forward in convenience for end users, developers need to understand the complexities of Type-C when adding this USB innovation to their embedded designs.

Most commonly used electronic devices have some type of Universal Serial Bus (USB) port. These ports come in Micro, Mini, and Type-A connector formats and can support different USB standards such 2.0 or more recently, 3.1. USB Type-C is the next leap forward for these ports, featuring higher speeds and better power delivery. This more advanced connector solves all of the problems presented by its predecessors. Type-C can handle high-speed data, video, and large amounts of power. With the expanded capabilities of Type-C, consumers will only need to use Type-C cables to charge, stream video, or transfer data—tasks that took a variety of cables. Manufacturers will need to provide and develop Type-C ports on their devices to support different purposes.

Type-C technology's versatility comes at a cost, because USB's once-simple inner workings of cables, ports, dongles, and hubs have been replaced by more complex embedded components. A seemingly straightforward HDMI-to-Type-C cable is difficult to design due to the required embedded devices.

Two main complications arise when developing Type-C solutions. The first involves the ability to handle its wide range of power. The second is to avoid communication failures that can occur due to the increase in supported communication standards.



1. A USB Type-C receptacle port conforms other connections to one standard.

When two devices are connected, the USB Power Delivery (PD) protocol is initiated. The process involves a negotiation among the amount of power delivered and who will be the provider and consumer of that power. Since this communication requires detecting, reading, and processing analog and digital signals, it needs microcontroller functionality provided by an embedded MCU within the host port, cable, or dongle. Failures can occur when devices or hosts don't support each other and can't establish communication. They're detected and then communicated to the host and require further MCU functionality.

USB Type-C makes life easier for end users by reducing cables and ensuring that devices work together. Because of its inherent complexity, Type-C can also pose design challenges.

WHAT IS USB TYPE-C?

Many types of USB ports and cables are available these days, including Mini, Micro, Type-A and Type-B. Such variety can be confusing because a mobile phone has a different port than a laptop, which has a different port than a digital camera.

USB Type-C condenses most connections to one standard, covering all devices and enhancing usability. This convergence of all USB ports and cables *(Fig. 1)* can also handle charging as well as video. Furthermore, USB Type-C supports multiple protocols and is backward-compatible with USB 2.0. Almost all accessories, including monitors, headphones, chargers, and keyboards,

Connectivity

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1–	Vbus	CC1	D+	D–	SBU1	Vbus	RX2–	RX2+	GND
GND	RX1+	RX1–	Vbus	SBU2	D–	D+	CC2	Vbus	TX2–	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

2. USB Type-C supports numerous receptacle ports.

A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1
GND	RX2+	RX2–	Vbus	SBU1	D–	D+	CC	Vbus	TX1–	TX1+	GND
GND	TX2+	TX2–	Vbus	Vconn			SBU2	Vbus	RX1–	RX1+	GND
B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12

3. USB Type-C has unique plug pinouts.

are able to use USB Type-C to communicate with computers, tablets, and smartphones.

USB Type-C port and cable layouts are shown in *Figures 2 and 3*. Flipping the plug doesn't cause any problems due to the symmetrical design of the signals in the receptacle port. The USB 3.1 SuperSpeed TX/RX, Vbus, GND, and other pins are connected correctly regardless of the orientation of the plug and receptacle. From a user standpoint, this approach is an upgrade from Type-A ports, as the Type-C cable can be inserted in either direction.

USB Type-C is versatile and user-friendly, but this ease of use increases the internal complexity for devices that employ the technology. It has increased power capability (delivering up to 100 W of power to charge a high-current device), but that creates issues for devices that don't require so much power. This is where the PD protocol is useful. PD ensures the appropriate range of power is delivered or sourced from any connected devices.

USB TYPE-C TERMINOLOGY

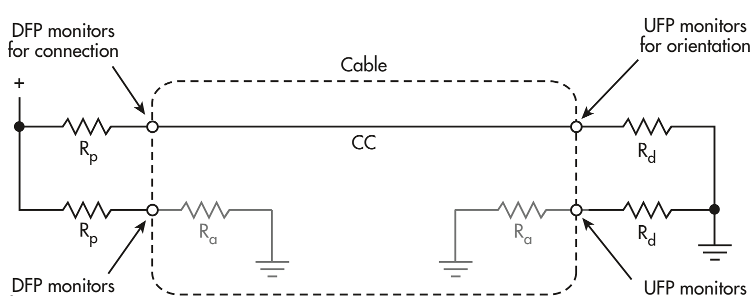
Before discussing USB Type-C, it's important to distinguish between the device, the host, the power supplier (source), and the power receiver (sink). The host isn't always the source; therefore, the terms can't be used interchangeably. Hosts initiate all communication and devices respond. Typically, the host is the downstream-facing port (DFP), and the device is the upstream-facing port (UFP). If two hosts are connected, they can act as a dual-role port (DRP) to switch between acting as a host and a device. For example, when a keyboard is connected to a laptop, the keyboard is the UFP and sink, while the laptop is the DFP and source.

POWER DELIVERY

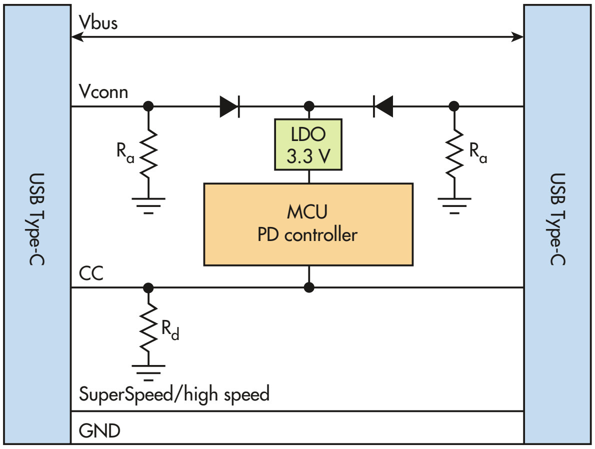
The initial power-delivery agreement between connected devices is executed through a series of resistors acting as voltage dividers on CC wires when a Type-C plug is inserted into the receptacle. *Figure 4* shows a typical USB Type-C channel line topology.

Since the CC line in the plug is either connected to CC1 or CC2 in the receptacle, the receptacle determines the orientation of the plug by simply measuring the voltages on both CC1 and CC2 lines. The different values of the pull-up resistors will communicate the amount of current the source is able to supply, and in turn establish what will ultimately be the UFP and the DFP.

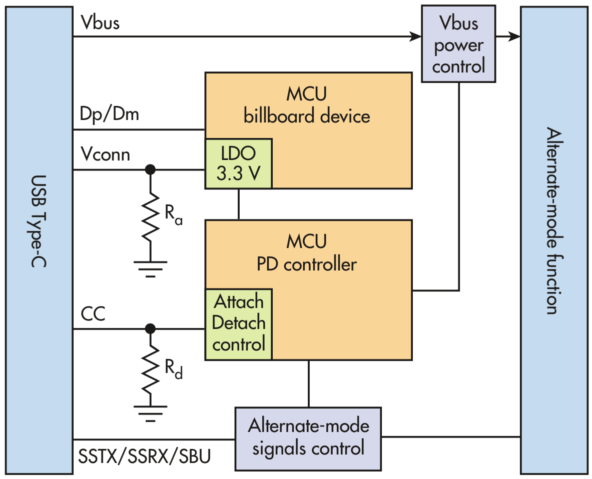
The power consumer doesn't have a way to indicate how much current it sinks through different pull-down resistor



4. A series of resistors act as voltage dividers on CC wires in a USB Type-C channel line topology.



5. Two Type-C devices can connect together using USB Type-C to Type-C cable.



6. USB Type-C alternate mode adapter cable is used to support legacy formats.

values. It has to dynamically adapt its load to match the maximum current available from the provider.

To read the voltage divider correctly, both devices need an analog processing unit, usually in the form of an accurate analog-to-digital converter (ADC) within an MCU. The ADC measures the voltage on the CC line continuously to monitor the connection between the plug and the receptacle. The MCU, known as the PD controller, handles the complete physical layer and upper layer protocol. It negotiates the power being delivered or received. For simple Type-C applications, the power negotiation stops with the resistors. For a more adaptable design, though, the devices can agree on a different setup by communicating over the CC line.

Once the plug orientation and initial power are decided, the devices use the CC line to communicate with each other. Using this line, the devices can agree on different levels of power and designate the sink or source, enabling real-time power-delivery adaptation. CC line communication is also used to announce which type of communication will be used. As previously stated, USB Type-C can communicate on the high-speed lines, USB 2.0, and other lines. The devices announce which of these lines can be used via the CC line. However, not all devices support all communication protocols.

FAILURE NOTIFICATION

A failure occurs if the two connected devices don't support one another. For example, a failure would occur if a monitor, which can only receive video from a host, is connected to a host that's unable to support or supply video data. If this happens, the host will remain unaware of the failure because communication can't be established.

In light of this scenario, the USB Type-C standard demands an embedded device on the monitor or device side to act as a failsafe known as a "Billboard" device. The Billboard device signals to the host through the USB 2.0 standard on the D+ and D- lines that communication cannot be established. The host can then notify the user that the two devices are incompatible. Billboard devices are typically MCUs, which may be the same as the PD controller.

TYPE-C CABLES AND ADAPTERS

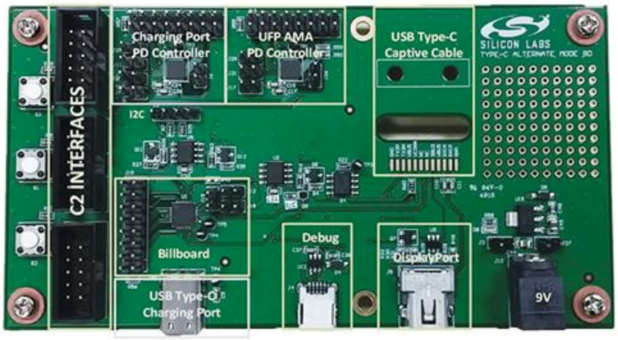
Users who wish to use older peripherals that don't support USB Type-C need to incorporate converting cables or dongles. There are multiple cases to account for, the first being the simple USB 2.0 to Type-C. Because USB 2.0 doesn't support higher speeds, and doesn't require more than 5 V or 3 A on Vbus, the cable can simply route D+/D-, Vbus, and GND to the connectors. A Type-C to Type-C cable, a dongle that converts USB 3.0/1 to Type-C, or one that requires more than 5 V or 3 A on Vbus, is more difficult to design.

In these cases, the dongle becomes part of the power negotiation between the two devices, requiring the cable or dongle to have an embedded PD controller. The PD controller is initially powered through Vbus set at 5 V or the Vconn line. It then negotiates with the host to set an agreed upon power level on the Vbus line.

Figure 5 shows an electronically marked cable assembly (EMCA) example for connecting two Type-C devices. The PD controller can be powered by Vconn 1 or Vconn 2. The EMCA will advertise its maximum power capabilities on the CC line, and the source will adapt to suit.

TYPE-C ADAPTER WITH ALTERNATE MODE

An alternate mode represents the functional extension of the Type-C interface. This mode makes it possible for DisplayPort, PCI Express, or other types of communications protocols to take advantage of the USB 3.1 SuperSpeed lines.



7. A purpose-built development board can simplify the task of adding USB Type-C functionality to embedded designs.

The alternate mode is entered when connecting the adapter to a compatible host.

A dongle that supports the alternate mode requires extra precautions and embedded devices. The dongle must inform the host if it was unable to enter the alternate mode to avoid a silent failure. It accomplishes this task through the Billboard device, and the USB Type-C PD standard mandates that any alternate-mode accessory implement a Billboard device.

Figure 6 shows a cable that converts a legacy video port into Type-C. If the Type-C device doesn't support the legacy video format, the PD controller will inform the Billboard device, and, in turn, inform the Type-C device of the failure.

DOCKING STATION OR HUB

A more complex example than display/Type-C to Type-C is a docking station or hub that must support charging many devices. The hub can be a combination of multiple Type-C or Type-A ports, HDMI, and PCIe. This hub requires multiple embedded devices to successfully support connected devices. Each port, depending on what device is connected, will need different amounts of power. To account for this, each port may require a PD device.

Any video ports, such as display, VGA, or HDMI, will need a Billboard device. In addition, the hub requires a device to control traffic to the host. This remains largely unchanged from the Type-A hubs, because you must prevent collisions on the lines and ensure that only one device is communicating to the host at one time. It's clear that the previously simple hub now requires a more complex and demanding design.

USB TYPE-C SOLUTIONS

All of this added design complexity needn't fall solely on developers. USB device suppliers like Silicon Labs provide development boards, PD libraries, Billboard source code, and example code aimed at dongles, docking stations, and device ports. Developers can greatly reduce USB Type-C development time and effort by using these tools when developing new Type-C devices.

Development boards *(Fig. 7)* are now available that implement a Vesa DisplayPort alternate-mode adapter with charging capability. Developing such a device increases the capability of a single Type-C port on a host by allowing power (charging) and video to come through one port.

The board shown in Fig. 7 features two PD controllers, one for each port, and a Billboard device to accompany the DisplayPort. The reference design handles switching to alternate mode, charging, informing the host of a failure, and ensuring correct power delivery to the display port and host.

Using a development board like this, along with supplied firmware, is less painful and faster than creating a new platform and writing firmware from scratch. With such development tools, manufacturers and suppliers can quickly deliver a Type-C solution with enhanced functionality.

CONCLUSION

USB Type-C is the standard of the future. The days of digging through a drawer looking for the correct conversion or cable ends are over. Going forward, choosing a cable will involve deciding whether the end is a plug or receptacle, and whether it can handle higher amounts of power. Smartphones, tablets, and laptops that have only Type-C ports are already on the market, and these pioneering devices represent just the start.

Type-C requires embedded devices and firmware to handle vast functionalities, which puts a strain on developers and manufacturers as they migrate their devices. Fortunately, embedded developers are able to turn to USB Type-C reference designs, libraries, firmware, and support teams that are dedicated to simplifying Type-C requirements for a wide array of applications. ed

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Delivering 3D Video for Virtual and Augmented Reality Applications

Why put a single camera on a servo when a half dozen with a compute engine provide a better result?

Remember when digital cameras were big, bulky, and expensive? Getting a single camera to provide wider visual coverage often entailed multiple servos. Getting one to provide a stable image while flying around attached to a plane or quadcopter was an even greater challenge. In fact, that is what Viooa's solution is designed for.

The Viooa (*Fig. 1a*) uses three image sensors to deliver a 360-deg. by 180-deg. image. That is an 8.5 Mpixel snapshot or 4K Ultra HD video. It uses on-board compute power to knit together the camera images into a single panoramic image. The module also has GPS support as well as gyroscopes and accelerometers to support digital image stabilization.

The Viooa Super Resolution (*Fig. 1b*) camera uses a 4K color camera with a fish-eye lens plus four monochrome cameras to generate 8K images. The monochrome cameras also support Viooa's Sense and Avoid software.

Both cameras are designed to mate with a number of UAVs, from the fixed with Quest to the DJI series of quadcopters like the Phantom and Inspire 1.

Viooa's solution is just one of many multiple-imager products. For example, the Vuze VR (*see "New Cameras and Apps Drive Augmented and Virtual Reality" on electronicdesign.com*) uses four pairs of image sensors to provide 360-deg. video for 3D virtual-reality videos. Each pair handles an overlapping quadrant and the pairs provide 3D imaging within the quadrant.

StereoLabs' ZED 2K Stereo Camera (*Fig. 2*) is designed for a single quadrant, but it can deliver 2.2K (4416 by 1242 pixels) video at 15 frames/s, 1080p at 30 frames/s, or 720p at 60 frames/s using 4 Mpixel sensors. The ZED SDK is a C++ library that can generate 3D point clouds using information from the camera. The ZED SDK works with Nvidia's Jetson TX1 (*see "Jetson TX1 Powers New Products at GTC 2016" on electronicdesign.com*) running NVidia's CUDA software. The camera is connected to the Jetson TX1 by a USB 3.0 cable. It allows the system to provide depth sensing from 1 m to 15 m. This information can then be used for object recognition and eventually obstacle avoidance as well as path planning.

1. Viooa (a) has three color image sensors while the Super Resolution model (b) has a single fish-eye color camera surrounded by four monochrome sensors for image stabilization.

2. StereoLabs' ZED 2K Stereo Camera provides high-definition 3D depth sensing when coupled with a compute engine like NVidia's Jetson TX1.

Some systems do post processing of video where a heftier compute server is available to knit together video and GPS information. Others, like the ZED and Jetson TX1, work in real time. Having enough heavy-duty compute power available for video processing means there may be headroom to handle other image processing chores such as obstacle and face recognition.

Multiple cameras have the advantage of covering a large area as well as providing 3D information. This may not eliminate the need for other sensors such as LIDAR for some applications, but these image sensors may be the only ones needed in many applications. ed

5 METHODS For Improving Data Center Efficiency

To support the growth of data consumption arising from voice, video, and data communications, data centers need to be added or expanded overloading the power grid. Therefore, data-center designers are working on greener designs with minimum power consumption.

The data-center industry has become one of the world's largest consumers of electricity. Accordingly, Yole Développement recently published a report entitled "New Technologies and Architectures for Efficient Data Center," which examines several scenarios for the evolution of these centers' energy consumption.

And make no mistake: Evolution is a necessity. "In the actual scenario, with an average Power Usage Efficiency (PUE) of 1.8, worldwide data-center energy consumption will reach 507.9 TWh by 2020," explains Mattin Grao Txapartegy, a technology & market analyst at Yole.

With that in mind, here are five major tools that will help create more efficient data centers:

1. ENERGY-EFFICIENCY METRICS

To help understand the energy use of a data center, we must understand and communicate about energy through the same energy-efficiency metrics, such as Power Usage Effectiveness (PUE) and Data Center Infrastructure Efficiency (DCiE).

- Power Usage Effectiveness is an index defined by The Green Grid that measures how efficiently a computer data center uses energy—specifically, how much energy is used by the computing equipment. PUE is the ratio of total amount of energy used by a computer data-center facility to the energy delivered to computing equipment. PUE is determined on a scale from 1 to 4, with 1 being very efficient, and 4 being very inefficient. Anything else that isn't considered a computing device in a data center (lighting, cooling, etc.) falls into the category of facility energy consumption.

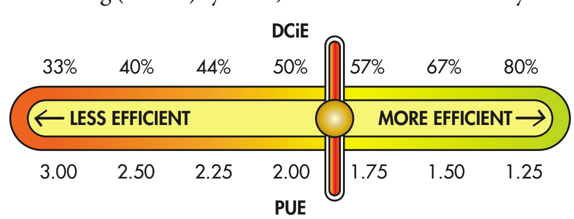
PUE = Total Facility Power [kW]/IT Equipment Power[kW]

Total Facility Power is the power measured at the utility meter; IT Equipment Energy represents the load of IT equipment.

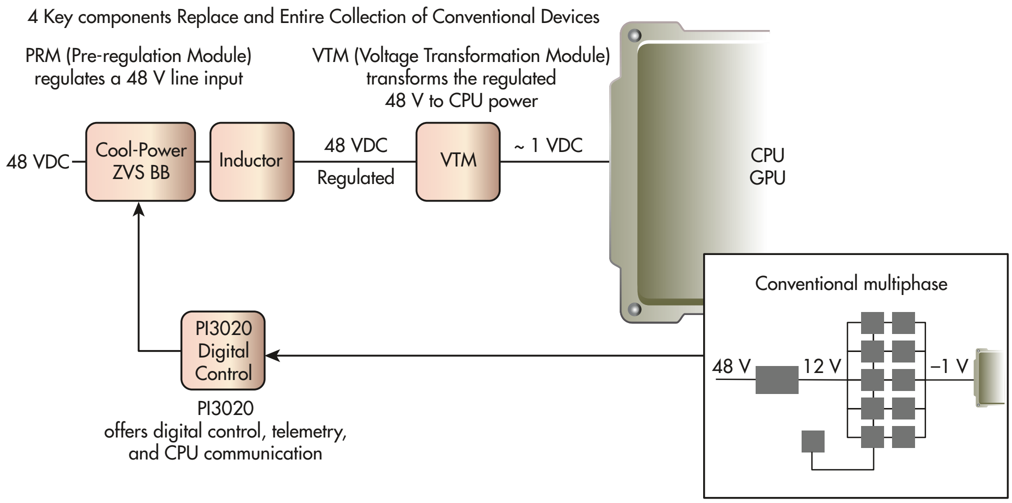
- Data Center Infrastructure Efficiency is the reciprocal of PUE. It is calculated as a percentage by taking the total power of the IT equipment, then dividing it by the total power into the data center multiplied by 100.

*DCiE = IT Equipment Power[kW]/Total Facility Power [kW] * 100%*

In reality, not all of the power entering the data center is used to operate the IT loads. There are losses in the power system that must not be ignored. In addition, power is consumed by the data-center support infrastructure. The support infrastructure elements include power transformers, uninterruptible power supply (UPS), generators, computer-room air conditioners (CRACs), remote transmission units (RTUs), ventilation, air-conditioning (HVAC) systems, and video-surveillance systems.



1. Typical values for DCiE (PUE) range from a very inefficient 33% (3.00) to a very efficient 90% (1.11). *(Courtesy of Spook)*



2. In applications that require telemetry and PMBus digital control (e.g., some CPU, GPU, ASIC, and DDR4 memory applications) Vicor's PI3020 Digital Control and Telemetry device may be used with a VTM/PRM pair *(Courtesy of Vicor)*

An ideal PUE value of 1.0 is difficult to reach *(Fig. 1)*. Uptime Institute's 2014 Data Center Industry Survey concluded that the average PUE value for its respondents' largest facilities is 1.7. The Green Grid recommends the use of annualized energy consumption figures in calculations, which allows facilities to avoid periods when their IT equipment is running at full capacity to avoid incorrect PUE values. According to The Green Grid, the most likely measurement point would be at the output of the computer-room power distribution units (PDUs).

2. POWER-CONVERSION ARCHITECTURES

Two-stage power conversion (48 V to 12 V to load) has been a very common architecture for powering CPUs and GPUs in data centers. Single-stage power conversion is another option (48 V to point of load). It reportedly eliminates one conversion loss and reduces distribution power loss by a factor of 16 in a rack implementation, compared with two-stage power conversion.

Google announced at the Open Compute Project (OCP) Summit that it has been using a 48-V to point-of-load (POL) design for the last several few years. It does not require special safety precautions; Google found that it was at least 30% more energy-efficient and more cost-effective than a two-stage power-conversion design. Since joining OCP, Google has been promoting single-stage power conversion (48 V to point of load) and working toward a rack standard that suppliers could use in the future. Here are two of the latest solutions in the market:

Vicor Corp. has been supporting the data-center infrastructure highlighted above by Google for some years already. Vicor's latest generation of 48-V direct-to-POL modules integrate the following: non-isolated buck-boost pre-regulator modules (PRMs; e.g., PI3751-00) and voltage-transformation modules (VTMs; e.g., VTM48KP020x095BA0; *Fig. 2*). Vicor's technology takes the regulation, isolation, and voltage-transformation functions of a typical dc-dc converter and separates them into individual elements. The PRM acts as high-efficiency step-up/step-down voltage regulation. In contrast, the VTM acts as a high-efficiency voltage transformation unit at the point of load while providing isolation from input to output.

In addition, STMicroelectronics has developed a digital power architecture that is fully isolated for direct power conversion from 48 V to any point of load. This three-chip solution is fully compliant with Intel's VR12.5 (Haswell and Broadwell), VR13 (Skylake), and DDR3/4 voltage-regulation specifications, as well as all field-programmable gate arrays (FPGAs) and application-specific integrated circuits (ASICs) for data-center applications.

3. POWER SUPPLY

An uninterruptible power supply (UPS) is a system that provides backup electricity to IT systems. It contains an energy storage system that supplies power to the load when utility power is unavailable. Traditionally, data centers draw power from the grid. Microsoft previously claimed that in a traditional 25-MW data center (approx. 25 MW), the UPS and battery-equipment room footprint accounts for 150,000 ft.[2].

Last year, the company donated a distributed UPS technology called Local Energy Storage (LES) to the Open Compute Project. LES offers an integrated power supply and battery that completely eliminates the facility UPS and moves that capability directly into the IT load. Moving the energy storage close to the server eliminates up to 9% of the losses associated with conventional UPS systems, resulting in an up-to-15% improvement in data-center PUE while shrinking the data-center footprint.

An example of such a power supply is the one just released by Artesyn Embedded Technologies. This 1600-W power supply (HS-OCS Series) is designed for hyperscale data centers, like those using the Open Compute Project specifications *(Fig. 3)*.

4. LIGHTING SYSTEMS

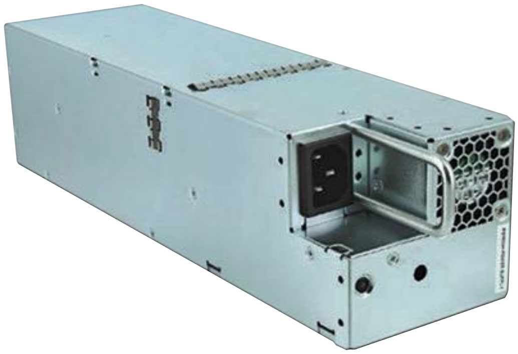
Light-emitting diodes (LEDs) are another tool that can help to improve the efficiency of a data center. They consume less energy, generate less heat, and are more durable when compared to traditional and halogen incandescent technologies.

The Telecommunication Infrastructure Association (TIA) Standard for Data Centers, ANSI/TIA-942-A, recommends that data-center operators implement LED lighting within their facilities. However, the focus is not solely on changing the lighting. There is now an LED-lighting-system solution that allows lighting use whenever and wherever it is needed.

For example, the OCP electrical specification (Data Center v1.0) used in the design of Facebook's innovative and energy-efficient data center uses LED lighting throughout the data-center interior. Each fixture has an occupancy sensor with local manual override and programmable alerts via flashing LEDs.

Ethernet LED-lighting technology is also known as Power over Ethernet (PoE). It can provide data centers with intelligent lighting capabilities that integrate sensors, which are able to detect motion, lighting, and energy metering. LED light fixtures can be powered by basic Ethernet cable rather than use an electrical powerline, because low-energy LED lighting is low voltage.

Data centers are starting to adopt this technology. For example, the Long Island, N.Y.-based data center mindSHIFT Technologies Inc. has installed PoE LED lighting across 40,000 square feet of data center and office space, where it hopes the technology will lead to 70% less energy consumption than ordinary LED-lighting systems. The company selected SmartCast PoE LED lighting, developed by Cree Inc., integrated with a Cisco network.



3. Artesyn HS-OCS Series offers up to 94% peak efficiency. Users can connect up to six of the power supplies in parallel with active load sharing from 35 to 100% of the full load. *(Courtesy of Artesyn Embedded Technologies)*

5. POWER SOFTWARE

Data-center virtualization can reduce cost, power, cooling, and hardware, resulting in greener data centers. In addition, a new tool for software-defined power promises to help achieve more efficient data-center infrastructure in terms of power. Dubbed Virtual Power Systems (VPS), it was recently selected as a 2016 TiE50 Top Start-up. VPS promises to aid in optimizing capacity utilization, controlling performance, and reducing TCO costs using a software-defined power called Intelligent Control of Energy (ICE).

VPS ICE intelligently and dynamically allocates power to racks, branch circuits, and IT nodes, with constant awareness of power-consumption needs across the data-center topology. CUI partnered with VPS to set a new standard for an efficient power infrastructure for data centers to create a larger software-defined power ecosystem, ultimately creating a more intelligent, more efficient data-center infrastructure. ed

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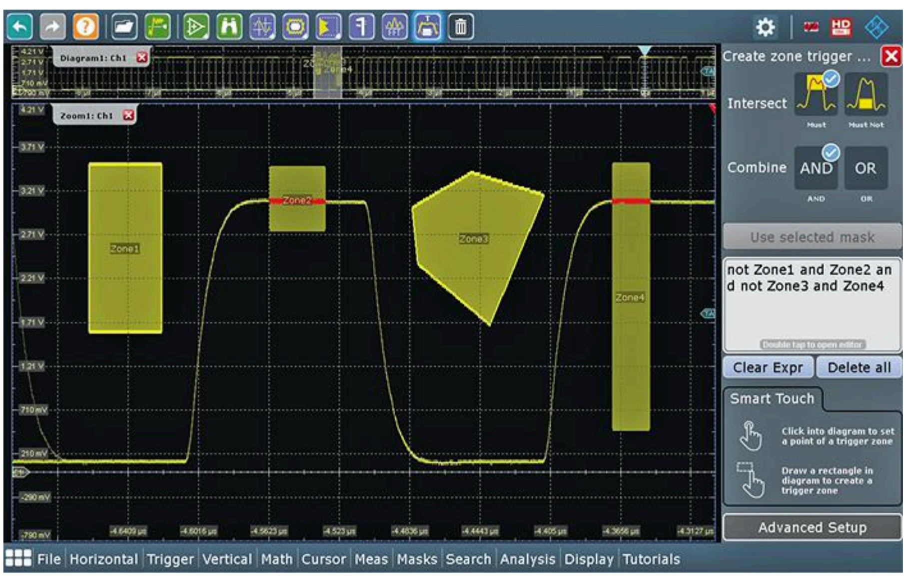
FIVE QUESTIONS About Oscilloscope Zone Triggering

Zone triggering is an oscilloscope technology that complements traditional scope triggering, helping to isolate events when hardware-based triggers fall short.

Oscilloscopes remain the ultimate authority for real-world troubleshooting and problem identification. The primary oscilloscope technology block that allows engineers to isolate specific events is the trigger. Oscilloscopes come equipped with standard hardware-based triggering capabilities for events such as edge, pulse width, pattern, and other parametric conditions.

While these traditional hardware-based triggers excel at isolating the rarest of events, sometimes they simply aren't sufficient. For example, a user may be able to graphically see an anomaly, but the available trigger options don't readily conform to isolate this event.

Graphical triggering, also known as zone triggering, complements traditional hardware-based triggering by giving oscilloscope users additional triggering flexibility. Engineers who want to make use of zone triggering and evaluate zone-triggering offerings across oscilloscope manufacturers will benefit from the following questions and answers.



1. Zone triggering complements traditional hardware-based scope triggering by allowing users to graphically draw one or more zones where a signal should or should not intersect. The oscilloscope only displays acquisitions that meet the zone conditions and discards other acquisitions. In this example, the R&S RTO2000 uses four zones to isolate a 0, 1, 0, 1 pattern.

DESIGN NOTES

Inverting Regulator Takes Inputs Up to 50V and Supports Outputs to 4A

Design Note 552

Victor Khasiev

Introduction

Positive-to-negative DC/DC conversion (inverting output) is widely used in LCD devices, OLED displays, audio amplifiers, industrial equipment, measurement tools, test systems, LED drivers and battery chargers. In all of these cases, the inverting converter must be compact, support high power and accommodate an extended input voltage range. The LTC®7149 satisfies all of these requirements. Its integrated 4A switches and wide 3.4V to 60V input voltage range exceed the requirements of the most demanding applications, including those in automotive environments.

Circuit Description and Functionality

Figure 1 shows a positive-to-negative converter based on the LTC7149. This solution delivers –10V at 2A from an input voltage of 12V—an automotive rail, for instance. The power train components were selected for a nominal 12V input, but with proper derating, the input voltage of this application can be as low as 4V or as high as 50V.

In automotive applications, the LTC7149's ability to handle high voltage inputs eliminates the need for costly voltage suppressors. The very low minimum input voltage keeps sensitive systems operational even during cold crank conditions. Guidelines for calculating voltage and current stress on the components around the LTC7149 are detailed in the LTC7149 data sheet. As an example, derating of the output current at input voltages below 12V is shown in Figure 2.

The circuit of Figure 1 uses external loop compensation. Connecting ITH to $INTV_{CC}$ allows internal compensation to be used, as shown in Figure 3. Tying the

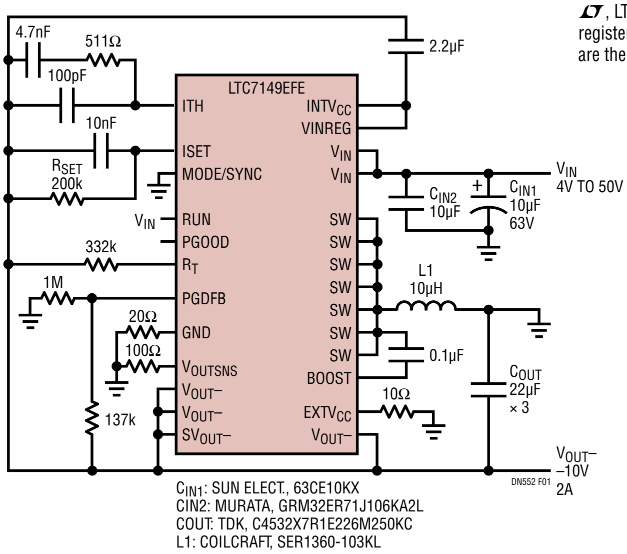


Figure 1. LTC7149, Positive-to-Negative Converter (V_{IN}: 4V – 50V, V_{OUT}: –10V at 2A)

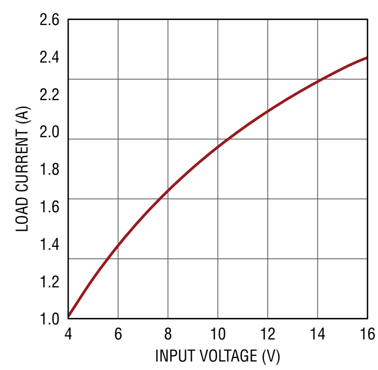


Figure 2. Output Current Derating vs Input Voltage for Figure 1

MODE/SYNC to GND activates Burst Mode® operation. Synchronization pulses referenced to GND can be applied to this pin if needed. Efficiency of this solution reaches 94%.

Voltage Controlled Variable Negative Output Circuit

A significant number of applications require on-the-fly changes to the negative bias, including LCD, OLED monitors and test equipment systems. The LTC7149 includes features to simplify this task.

Figure 3 shows a negative voltage source, where the negative output is controlled by a positive signal voltage. The positive control voltage, referenced to GND, is applied to the V_{OUTSNS} pin. In Figure 3, this is V_{CTRL}, in the range of 0V to 5V. The resulting negative output voltage V_{OUT^-} is determined by:

$$V_{OUT^-} = -50\mu A \bullet R_{SET} + V_{CTRL}$$

The lowpass filter R_F/C_F provides noise suppression. The V_{OUTSNS} pin cannot be left floating under any circumstances—some voltage potential must be present on this pin at all times. If this requirement cannot be met, for example during system testing, then resistor R_P should be installed.

Figure 4 shows V_{OUT^-} as a function of V_{CTRL}. Figure 5 illustrates the broad application potential of this approach as the V_{CTRL} voltage is shaped as a sine wave with a 2.5V amplitude.

Conclusion

The LTC7149 is a high efficiency 50V, 4A synchronous monolithic regulator for negative output power supplies. It combines wide input and output voltage ranges and integrated switching transistors, which simplify the converter design. The solutions and circuitry discussed in this design note can assist with the implementation of this regulator in automotive and industrial applications, display and monitor systems.

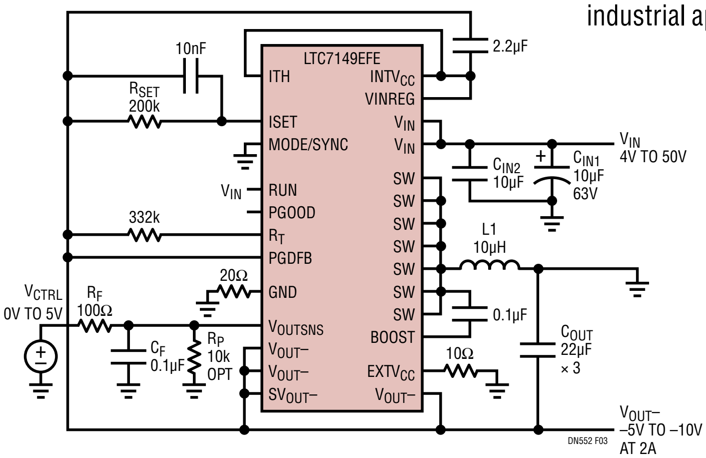


Figure 3. Positive-to-Negative Converter with Variable V_{OUT^-} from –5V to –10V

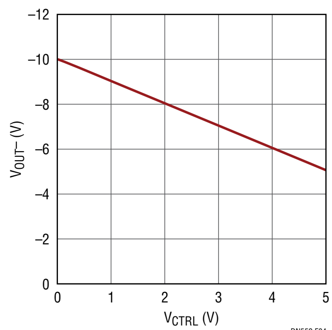


Figure 4. Variable Negative Output V_{OUT^-} as a Linear Function of V_{CTRL}

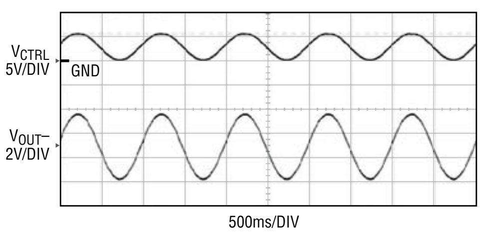


Figure 5. Variable Negative Output V_{OUT^-} Following the Sine Waveform on V_{CTRL}

Data Sheet Download

www.linear.com/LTC7149

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2. Recent innovations in zone triggering allow the technology to be used for math functions in addition to scope channels. In this example, the R&S RTO2000 has two single-ended passive probes connected to D- and D+ USB signals shown in the upper diagram. Zone triggering has been set to work on a math function that combines the two single-ended signals into a differential signal shown in the lower diagram.

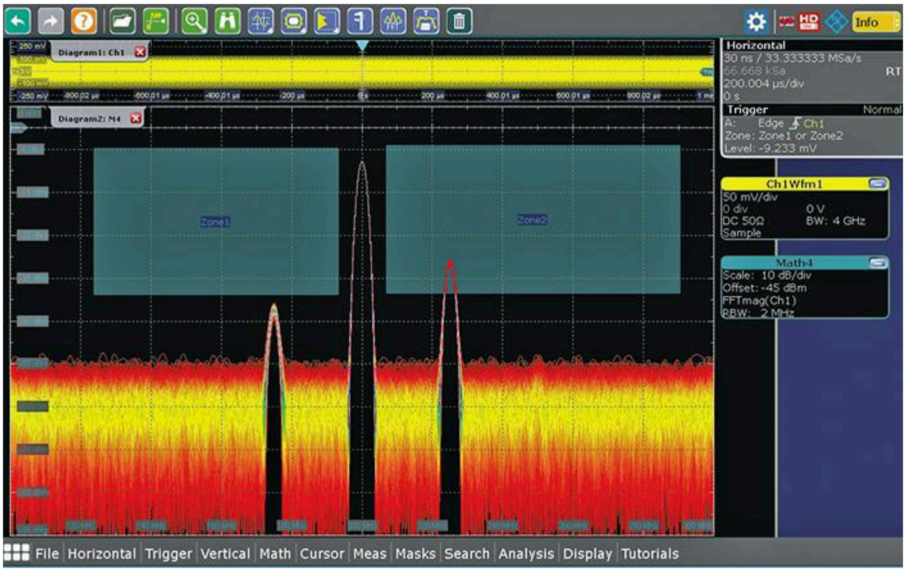
1. WHAT IS ZONE TRIGGERING?

By having a good understanding of zone-triggering technology, users can determine when it's effective and when it isn't a good choice. How does zone triggering work? Well, it's pretty simple. Users graphically draw one or more zones on the oscilloscope display *(Fig. 1)*. Each zone can be parametrized with a "must intersect" or a "must not intersect" condition.

With each new oscilloscope acquisition, the scope looks through the acquired record. If the acquisition matches the zone conditions set by the user, the scope displays the data. If the acquisition doesn't meet the zone condition, the scope discards the data. As a result, only acquisitions that meet user-specified zone conditions are displayed on the oscilloscope.

Zone triggering is typically set up as a second stage in a trigger and follows a traditional hardware-based trigger condition such as an edge trigger. This allows users to use a traditional trigger condition to narrow down event types, and then use the zone trigger to add greater specificity.

3. In this example, the user has set a zone trigger in the frequency domain on the R&S RTO2000. The oscilloscope will capture and display only acquisitions where the sidebands exceed a certain power level.



2. WHY USE IT?

Zone triggering allows the user to graphically specify conditions that must be met by a trigger. From a usability perspective, this often is simpler than determining how to accomplish the same goal using a traditional hardware-based trigger condition. More often, though, zone triggering allows users to isolate specific events that would be impossible to trigger on using traditional trigger selections. Zone triggering was invented to help engineers isolate events that slip by a traditional hardware-based trigger.

What are some examples? Double-data-rate (DDR) memory read and write cycles include wave shapes that vary slightly. Separating read versus write cycles is impossible to do using a traditional oscilloscope trigger, but very easy to do with zone triggering. The user simply draws a small square on the part of the waveform that varies between a read and a write cycle, and then is able to specify "must intersect" or "must not intersect" to have the scope only display the desired cycles.

Zone triggering can perform several functions. First, it displays acquisitions that have a non-monotonic edge. Second, it can be used to specify a sequential pattern of 1s and 0s by drawing a zone in each sequential clock period. Third, it's able to graphically isolate serial bus packets. For example, a user can draw a zone in an area where USB transmits data packets and only displays data packets.

3. WHAT SOURCES CAN BE USED WITH ZONE TRIGGERING?

Traditional oscilloscope hardware-based triggers operate exclusively on scope analog channels or digital channels. Since zone triggering is a post-acquisition algorithm, from a technical perspective, the technology can utilize a wider range of sources. Recent advances in zone triggering allow users to select math as a source. A user can specify a zone that operates on a math equation, or a fast Fourier transform (FFT). This advance provides unique capabilities not found in hardware-based triggering circuits, nor in earlier generations of zone-triggering technology.

For example, in the frequency domain, a user can use zone triggering to isolate all events where a sideband exceeds a specified power level. Or, in the time domain, where a user has connected a current probe and a voltage probe and multiplies to get power, the user can have the scope on display events where power is greater than a desired value. Adding math as a source for zone triggering makes zone triggering incredibly powerful, allowing it to be used as shown in *Figures 2 and 3*.

4. WHAT ARE THE TRADEOFFS?

Most technology innovation has tradeoffs, and zone triggering is not excluded. Remember that zone triggering is a post-processing technique. This results in two undesired consequences. The additional post-processing needs to slow down the overall update rate of the scope. It's not uncommon to see zone triggering reduce update rates by a factor of 100. This may cause the scope controls to feel more sluggish. More importantly, the additional processing requirements will result in increased blind time between scope acquisitions. This renders zone triggering effective only where signals are repetitive.

The amount of time required to perform the required zone-triggering processing will vary by vendor oscilloscope family and be heavily influenced by the amount of memory that's turned on, as well as the type and quantity of zone sources. In short, traditional hardware-based triggering is the only method to ensure capture of rare or non-repetitive events.

5. HOW TO EVALUATE ACROSS MANUFACTURERS?

If you're thinking about adding to an existing oscilloscope or evaluating zone-triggering capabilities on a new oscilloscope, several areas can be considered for comparison. The zone-triggering application typically is available on oscilloscopes that are several hundred megahertz in bandwidth or greater with sufficient processing capability.

Check with your manufacturer to see which of their scopes supports zone triggering. Almost all demo units for scopes that support zone triggering will have the option enabled for evaluation. For existing oscilloscopes where zone triggering is offered, vendors typically allow users to get a trial license.

One big difference users will find across oscilloscope-manufacturer zone-triggering applications is the sources on which the zones operate. All zone-triggering applications enable the user to specify an analog channel as a zone source. A smaller fraction of manufacturers allow zones to be applied to math functions. Math is commonly used for power analysis and for differential signals. Hence, zone triggering on math sources can be extremely valuable, as traditional hardware triggers can't trigger on math.

Does the zone-triggering application you're evaluating support zone triggering on FFTs? Oscilloscope hardware triggers operate on time-domain signals and can't be used in the frequency domain. Zone triggering is the only way for an oscilloscope to trigger in the frequency domain.

Another difference will be the amount of processing time that each manufacturer takes when zone triggering is enabled. While it's possible to measure update rate with a specific zone-triggering configuration, all scopes are slowed down with zone triggering enabled. Zone triggers can miss infrequent events. A hardware-based trigger is the only method to guarantee that the scope won't miss a trigger event. For this reason, impact on update-rate speed might not be significant as a comparison metric, unless it's at the point where controls are sluggish or viewing is significantly impaired due to slow update rate.

A number of other attributes will vary across oscilloscope vendors. Some vendors will allow users to exclusively draw rectangles as zone shapes, while others will let users draw arbitrary zone shapes. While rectangles are sufficient for a number of applications, the ability to create an arbitrary shape can help isolate events that require more precision.

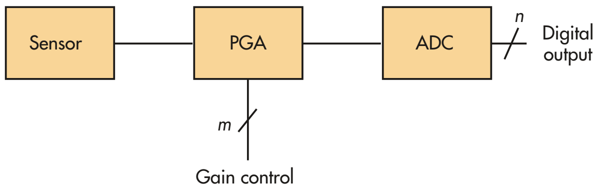
How easy is it to modify the zone size, shape, source, and type? Experiment by adding and removing zones on each scope that you're evaluating. Users tend to add and/or remove zones more frequently than they originally anticipate.

Zone triggering, an oscilloscope technology that complements traditional scope triggering, continues to grow in popularity. For users who haven't previously invested in zone-triggering applications, the technology is perpetually evolving, and can help isolate events where traditional hardware-based triggers fall short. Recent advances include the ability to apply zone conditions to math functions and FFT views. For repetitive signals, zone triggering makes an excellent complement as a second stage to traditional oscilloscope triggering technology. ed

Digitally Programmable Amplifier Meets Sensor Gain, Ranging Needs

CARLOS CASTRO-MIGUENS | Vigo University JOSÉ BENITO CASTRO-MIGUENS | Cesinel Company

MOST DATA-ACQUISITION SYSTEMS with wide dynamic range need a method of adjusting the input-signal level to the analog-to-digital converter (ADC) to ensure the maximum input signal will be fairly near to the ADC's full-scale input voltage (note that a typical ADC's full-scale input-voltage range is between 1 V and 10 V). At the same time, the gain applied to a sensor output may also need to be adjusted during run time, for example, to compensate the nonlinear output across the temperature range. To achieve this, a programmable gain amplifier (PGA) or a variable gain amplifier (VGA) is usually located between a sensor and its ADC (*Fig. 1*).



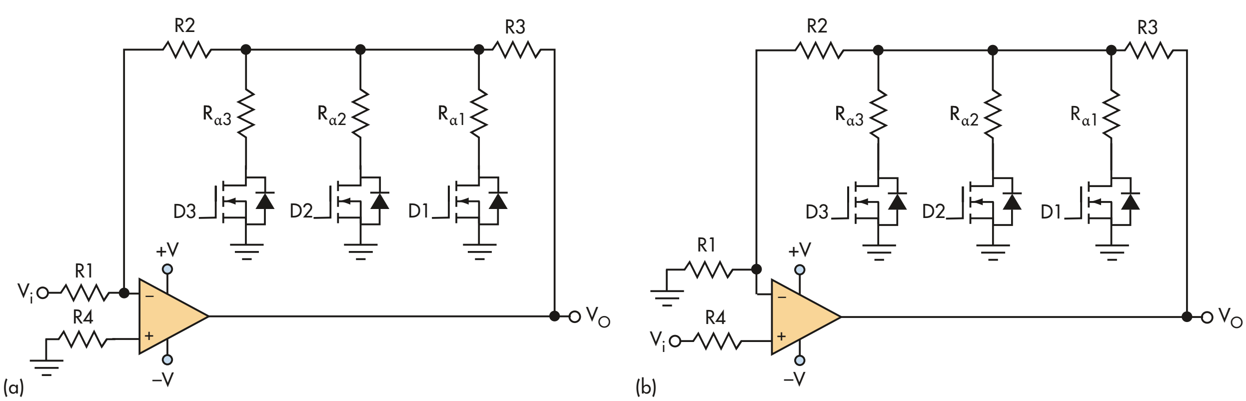
1. The function of the PGA in a data-acquisition system is to scale the sensor output span to match the input range of the ADC, for maximum resolution and minimum noise.

Both PGAs and VGAs usually allow for selection of fixed gains whose values are typically between 1 and 100. Some applications, such as sensing and/or controlling current flow, require applying specific gains to optimize both the sensor output-voltage range and the ADC's resolution. In these cases, the required gains can vary between 1 and 1500 or more, and its values don't fit to the selectable values in commercial PGAs or VGAs.

When choosing the topology of the amplifier circuit with a very high gain, it's convenient to bear in mind that in many cases, it's not advisable to use feedback resistors with a very high value (> 1 MΩ) due to the present noise. In addition, if it's necessary to implement an amplifier with a very precise gain, then the current by the resistances must be much greater than the op amp's offset current. This is only possible if the resistors don't have a very high value. On the other hand, it's always necessary (desirable) that the amplifier input resistance be reasonably high (not very small).

Figure 2 shows two amplifier circuits with eight digitally programmable gains that meet all of the above conditions. Although the number of gains that can be implemented with these circuits is equal to 2n, where n equals the number of MOSFETs, it's only possible to implement n independent gains. The values of the implemented gains in these circuits are easily adaptable to the needs of virtually any application that's considered.

Figure 2 shows two amplifier circuits with eight digitally programmable gains. The number of gains that can be imple-



2. The inverting amplifier circuit (a) and non-inverting amplifier circuit (b) each have eight programmable gains, set by three logic-level inputs (D1, D2, and D3), that control the MOSFET switches.

mented with these circuits is equal to 2n, where n is the number of MOSFETs used. The values of the implemented gains in these circuits are easily adaptable to the needs of the application.

Figure 2a represents an inverting amplifier circuit, while *Fig. 2b* is non-inverting. In both circuits, digital signals D1, D2, and D3 are used to select the gain of the amplifier. The MOSFETs used must be logic-level MOSFETs (or logic-level gate MOSFETs) with an $R_{DS(ON)}$ as low as possible (such as the 2N7002P with typical $R_{DS(ON)} = 1\ \Omega$ or the IRLML2502 with a typical $R_{DS(ON)} = 0.05\ \Omega$).

The independent gains that can be selected in the amplifier circuit of *Fig. 2a* are:

$$D_3\,D_2\,D_1 = 0\ 0\ 0 \rightarrow G_0 = \frac{v_0}{v_i} = \frac{-1}{R_1}\left[R_2 + R_3\right]$$

$$D_3\,D_2\,D_1 = 0\ 0\ 1 \rightarrow G_1 = \frac{v_0}{v_i} = \frac{-1}{R_1}\left[R_2 + R_3 + \frac{R_2 R_3}{R_{\alpha 1}}\right]$$

$$D_3\,D_2\,D_1 = 0\ 1\ 0 \rightarrow G_2 = \frac{v_0}{v_i} = \frac{-1}{R_1}\left[R_2 + R_3 + \frac{R_2 R_3}{R_{\alpha 2}}\right]$$

$$D_3\,D_2\,D_1 = 1\ 0\ 0 \rightarrow G_3 = \frac{v_0}{v_i} = \frac{-1}{R_1}\left[R_2 + R_3 + \frac{R_2 R_3}{R_{\alpha 3}}\right]$$

When two or more MOSFETs are used, the body diode of a MOSFET will start to conduct current if the input voltage (vi) becomes too large, thus distorting the amplifier's output voltage. To avoid this, the following condition must be satisfied:

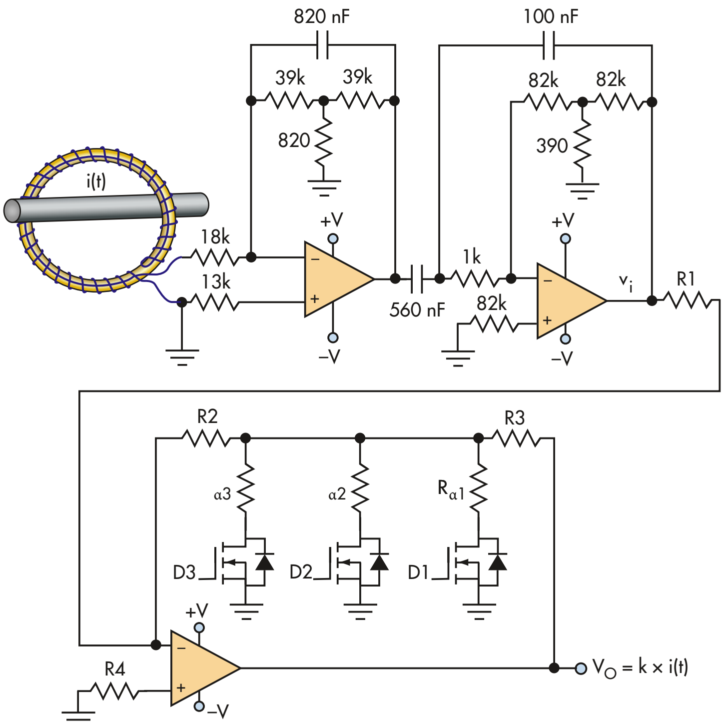
$$v_i \le \frac{R_1}{R_2} \cdot v_F$$

where v_F is the body-diode forward voltage of the MOSFET ($v_F > 0$).

When only one MOSFET is used, the input voltage must fulfill the following condition to avoid body-diode conduction:

$$v_i \le \frac{R_1}{R_2}\left(1 + \frac{R_\alpha}{R_{DS\ on}}\right) \cdot v_F$$

The independent gains that can be selected in the amplifier circuit of *Fig. 2b* are:



3. This practical current-measurement system uses a Rogowski coil as the sensor, with digitally selectable gain that can be set by the user or a system controller, to maximize use of the ADC's resolution.

$$D_3\,D_2\,D_1 = 0\,0\,0 \;\rightarrow\; G_0 = \frac{v_0}{v_i} = \frac{R_1+R_2+R_3}{R_1}$$

$$D_3\,D_2\,D_1 = 0\,0\,1 \;\rightarrow\; G_1 = \frac{v_0}{v_i} = \frac{R_3}{R_1}\left[1+\frac{R_1+R_2}{R_3\,PR_{\alpha 1}}\right]$$

$$D_3\,D_2\,D_1 = 0\,1\,0 \;\rightarrow\; G_2 = \frac{v_0}{v_i} = \frac{R_3}{R_1}\left[1+\frac{R_1+R_2}{R_3\,PR_{\alpha 2}}\right]$$

$$D_3\,D_2\,D_1 = 1\,0\,0 \;\rightarrow\; G_3 = \frac{v_0}{v_i} = \frac{R_3}{R_1}\left[1+\frac{R_1+R_2}{R_3\,PR_{\alpha 3}}\right]$$

In the circuit of *Fig. 2b*, when using two or more MOSFETs, the body diode will conduct current if the input voltage (v_i) takes too small negative values, distorting the output voltage of the amplifier. To avoid this, the following condition must be satisfied:

$$v_i \ge \frac{-v_F}{1+R_2/R_1}$$

When only one MOSFET is used, the input voltage must fulfill the following condition to avoid body-diode conduction:

$$v_i \ge -\left(\frac{1+R_\alpha/R_{DS-on}}{1+R_2/R_1}\right)\cdot v_F$$

Figure 3 shows a practical application of the circuit of *Fig. 2a*. In this example, a controllable-gain amplifier is used to amplify the output voltage (vi) of a circuit that integrates and filters the signal generated by a Rogowski coil. Assume the ADC that will sample the signal vo = k × i(t) has reference voltages of v_{REF+} = 2.5 V and v_{REF-} = –2.5 V, the Rogowski coil has a sensitivity constant of 30 µV/A, the integrator high-pass filter has a voltage gain of 1.2 (1.64 dB) at 50 Hz, and we want to measure ac currents in the following ranges: 1280, 320, 80, and 20 A_{RMS}.

The gains to select are: G0 = –38.363, G1 = –153.452, G2 = –613.808, and G3 = –2455.2. Many combinations of the resistances in the circuit shown in *Fig. 2a* can provide these gains. The following offers a simple and fast method to calculate the appropriate values of the resistors:

$R_{\alpha 3}$ = 300 × $R_{DS(ON)}$ = 300 × 1 Ω = 300 Ω, so we set the smallest value of the Rα resistors to ensure that the value of $R_{DS(ON)}$ doesn't have a significant influence on the amplifier gains.

$$R_2 = R_3 = 2 \times R_{\alpha 3} \times (G_3 - G_0)/G_0 = 37799.9 \cong 37.8\ k\Omega$$

$$R_1 = -4 \times R_{\alpha 3} \times (-1 + G_3/G_0)/G_0 = 1970.6 \cong 1.970\ k\Omega$$

$$R_{\alpha 1} = R_{\alpha 3} \times (G_3 - G_0)/(G_1 - G_0) = 6299.8 \cong 6.3\ k\Omega$$

$$R_{\alpha 2} = R_{\alpha 3} \times (G_3 - G_0)/(G_1 - G_0) = 1.260\ k\Omega$$

The gains obtained with the calculated values are (theoretical values are shown in square brackets):

$$D_3\ D_2\ D_1 = 0\ 0\ 0 \rightarrow G_0 \cong -38.3756\ \ [-38.363]$$

$$D_3\ D_2\ D_1 = 0\ 0\ 1 \rightarrow G_1 \cong -153.5025\ \ [-153.452]$$

$$D_3\ D_2\ D_1 = 0\ 1\ 0 \rightarrow G_2 \cong -614.01\ \ [-613.808]$$

$$D_3\ D_2\ D_1 = 1\ 0\ 0 \rightarrow G_3 \cong -2456\ \ [-2455.2]$$

In the case of using the amplifier circuit shown in *Fig. 2b*, the following method can be used to determine the appropriate values of resistors that provide gains G0 = 38'363, G1 = 153'452, G2 = 613'808 and G3 = 2455'2:Ω

$$R_{\alpha 3} = 300 \cdot R_{DS\text{-}on} = 300 \cdot 1\Omega = 300\ \Omega$$

$$R_2 = 2 \cdot R_{\alpha 3} \cdot (G_3 - G_0)/(1 + G_0) = 36840\ \Omega$$

$$R_3 = R_2$$

$$R_1 = 4 \cdot R_{\alpha 3}(G_3 - G_0)/(-1 + G_0^2) = 1972\ \Omega$$

$$R_{\alpha 1} = R_{\alpha 3} \cdot (G_3 - G_0)/(G_1 - G_0) = 6300\ \Omega$$

$$R_{\alpha 2} = R_{\alpha 3} \cdot (G_3 - G_0)/(G_2 - G_0) = 1260\ \Omega$$

CARLOS CASTRO-MIGUENS received his Electronic Engineering degree from Vigo University, Spain. He is currently employed as associate professor of the Electronics department at Vigo University. His primary interests are in power electronics (dynamic modeling and control of power converters, design of magnetic components for power converters) and design of embedded systems. He can be reached at cmiguens@uvigo.es.

JOSE B. CASTRO-MIGUENS received an Electrical & Electronic Engineering degree from UPCO University, Madrid, in 2003. He is currently employed (since 2003) by the Cesinel Company, working as design engineer on power electronics, instrumentation engineering, signal processing, and electric power control.

The gains obtained with the calculated values are (theoretical values are shown in square brackets):

$$D_3\,D_2\,D_1 = 0\;0\;0 \;\rightarrow\; G_0 = 38'3631\;\;[38'363]$$

$$D_3\,D_2\,D_1 = 0\;0\;1 \;\rightarrow\; G_1 = 153'4532\;\;[153'452]$$

$$D_3\,D_2\,D_1 = 0\;1\;0 \;\rightarrow\; G_2 = 613'8139\;\;[613'808]$$

$$D_3\,D_2\,D_1 = 1\;0\;0 \;\rightarrow\; G_3 = 2455'3\;\;[2455'2]$$

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10-bit PCIe High-Speed Digitizer Runs at 10 GS/s

THE U5310A10-BIT PCIE HIGH-SPEED DIGITIZER from Keysight Technologies features two channels with 10-bit resolution, simultaneous sampling at up to 5 GS/s and 10 GS/s in interleaved mode. With a dc up to 2.5 GHz bandwidth, the high speed digitizer provides on-board real-time averaging at full sampling rate and 4 GB memory. With a high dynamic range and 10-bit resolution across a 2.5 GHz bandwidth, the digitizer allows the capture of fast transients with high fidelity. The ADC card is designed for embedded OEM applications, such as medical research, analytical time-of-flight (MS-TOF), environmental monitoring (LiDAR), ultrasonic NDT, semiconductor testing, and DSTS.

A new low-distortion and low-noise LDNA front-end amplifier IC drives the ADC, and a new low-noise-dedicated QMCK clock IC with very low 25 fs jitter. This specific IC drives the two ADCs, minimizing jitter. Also, the TRAC trigger IC provides time precision of 15 ps RMS. This key component provides single-ended to differential outputs with a distortion from 10 to 15 dB lower than the distortion of the ADC. The U5310A PCIe high-speed digitizer, 2-channel, 10-bit, is available now.

KEYSIGHT TECHNOLOGIES

www.keysight.com

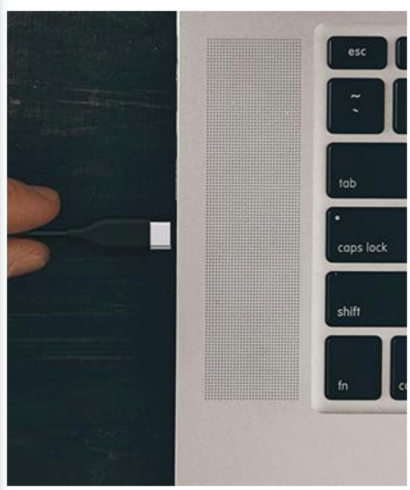
USB Type-C Reference Design Jump Starts Development

SILICON LABS' NEW COMPREHENSIVE REFERENCE DESIGN is focused on reducing the complexity associated with developing cables and cable adapters based on the USB Type-C specification. The reference design features ultra-low-power EFM8 MCUs, USB PD protocol stacks certified by the USB-IF, and USB Billboard Device source code. A complete solution for a USB Type-C to DisplayPort adapter is provided. Available to qualified developers at no charge, the reference design includes schematics, software libraries and stacks, source code, code examples, and access to Simplicity Studio development tools. The ultra-slim USB-C connector features reversible plug and cable orientation, enabling developers to design thinner and sleeker products. USB-C accommodates other interface specifications through USB Alternate Modes. For these reasons, USB-C is poised to become the connector standard of choice for mobile devices, PCs, docking stations, monitors and other consumer electronics products, with an estimated two billion USB-C-enabled devices deployed by 2019, according to IHS.

Silicon Labs' USB Type-C reference design deliverables (schematics, PD stack library, billboard device source code and sample code) are available now to qualified developers at no charge.

SILICON LABS

www.silabs.com



2-8 GHz Signal Generator Features -40 dBc Harmonics

VAUNIX TECHNOLOGY'S LATEST ADDITION to its family of LMS PC-driven signal generators, the LMS-802DX Lab Brick, has a power-control range of 80 dB, +10 to -70 dBm. The unit operates in the 2 to 8 GHz frequency range with a resolution of 100 Hz and a 100 microsecond switching time. When set to +10 dBm, the compact, one-pound signal generator exhibits typical harmonic performance of -40 dBc.

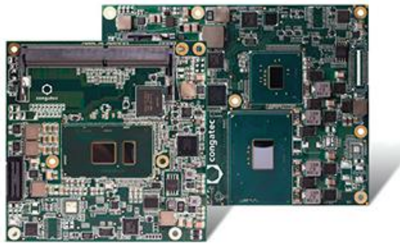
The Lab Brick offers the same advanced features as are typical of the LMS family of signal generators including phase-continuous linear-frequency sweeping, internal/external 10 MHz reference, and optional pulse modulation. Lab Brick signal generators are operated and powered through USB, and controlled with the included GUI, or through one of the company's APIs.

The ROHS-compliant units can be used with any PC or laptop with USB 2.0 port (or powered USB hub) and Windows. Lab Brick signal generators are provided with Lab Brick GUI software, 32 and 64 bit API DLL files, LabVIEW, and Linux-compatible drivers. The LMS-802DX Lab Brick unit retails at $3,249.

VAUNIX TECHNOLOGY

vaunix.com

COM Express Modules Integrate Celeron with DDR4 SO-DIMM



CONGATEC IS INCREASING the scalability of its COM Express modules with two new entry-level models based on the latest Intel 14nm microarchitecture. The Intel Celeron processor-based COM Express Basic and Compact modules combine dual-core CPU performance with features such as 4k multiscreen support, high-speed DDR4 RAM with increased bandwidth, and four USB 3.0 ports.

The COM Express Compact module conga-TC170 features the 2 GHz dual-core Intel Celeron Processor 3955U with a cTDP of 10 W to 15 W. The slightly larger conga-TS170 COM Express Basic modules are available with the Intel Celeron Processor G3900E with 2.4 GHz and 35 W TDP, or with the G3902E featuring 1.6 GHz and 25 W TDP. All modules support up to 32 GB of DDR4 dual channel memory. The Intel Gen9 HD Graphics 510 drives up to three independent displays with 4k @ 60 Hz via DisplayPort 1.2 and DMI 2.0. Hardware-accelerated encode and decode of HEVC, VP8, VP9, and VDENC video makes it now possible to stream HD video energy-efficiently in both directions. The computer modules support the COM Express Type 6 pinout including PCIe 3.0, USB 3.0 and 2.0, SATA 3, GbE, and low speed interfaces.

CONGATEC

www.congatec.com

Limit Switch Available with Integrated M12 Connector

MICROPRECISION ELECTRONICS IS EXTENDING the possibilities of its MP700 series of sealed limit switches in order to facilitate the connection of limit switches as sensing devices to industrial bus systems. The switches are now available with an M12 connector integrated directly into the housing. This option is implemented for 30 and 35 mm housing sizes, which reflects the 20 mm "EN" and 25 mm "US" mounting style.

A five-pin version is used in the MP740/60 metallic cases and a four-pin for the MP730/750 plastic cases. All cases are IP67 sealed. The electrical rating is adapted to the power specification of M12 connectors for 4 A up to 120 Vac and 3 A for 240 Vac. The MP700 limit switches come with a selection of actuator types consisting of pin and roller plungers, roller levers and others. The electrical switching module is a positive opening circuit with either slow- action or snap-action movements.

MICROPRECISION ELECTRONICS

http://www.microprecision.ch/

Software Tools Support Kinetis and LPC MCUs

VERSION 3.2 OF SOMNIUM'S DRT C/C++ embedded software development tools extend DRT's existing support for NXP Kinetis and other ARM-based MCUs to include support for NXP's LPC microcontrollers and software ecosystem. DRT is fully source-compatible with industry-standard GNU (including the latest C11 and C++14 dialects and C++ exception handling), while boasting better code generation and enhanced debug/trace features. New features in DRT 3.2 include automatic import and conversion for LPCXpresso projects, and additional features in DRT's advanced importer for CodeWarrior development tools to automatically convert legacy projects built with NXP's non-GNU Kinetis compiler. Advanced debug features include: live memory view (vital for debugging deeply embedded hard real time systems); fault diagnosis; trace; and using a small amount of on-chip RAM allows program trace to be gathered and viewed in a fully featured debug environment.

The IDE is built on the latest version of the industry standard Eclipse IDE. It is available on host environments such as Windows and Linux, with OSX support launching in Q2 2016.

SOMNIUM

http://somniumtech.com/

Low-Power Fanless Desktop Functions as Virtual CPE

LANNER'S NEXT-GENERATION desktop appliance, the FW-7526, features Intel Atom C2358/C2518 CPU, Intel QuickAssist Crypto Acceleration, 4 x RJ-45 GbE, 2 x SFP GbE, LAN bypass, Intel AES-NI, and up to 16 GB DDR3 memory. The hardware is driven by Intel Atom C2358 or C2518 CPU (dual-core or quad-core), suited for entry-level UTM, firewall, VPN, and virtual CPE in small-medium enterprise settings due to its low power consumption and steady performance. The platform is accompanied by Intel QuickAssist Crypto Acceleration technology for cryptographic boost. In addition, the processor is built in with Intel AES-NI.

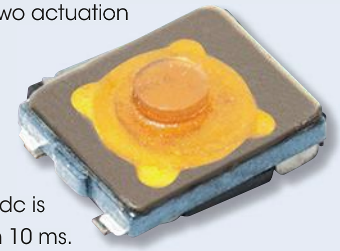
Functioning as a virtual CPE, the unit comes with four RJ-45 GbE ports and two SFP GbE ports for network connections. The device also features one pair of Lanner's Gen2 LAN bypass for network traffic reliability. I/O options include a mini-PCIe slot with SIM reader, mSATA storage socket, console, two USB ports, and support for nano-SIM card for wireless 3G/4G/LTE networking.

LANNER

www.lannerinc.com

Long-Life Double-Action Switches Offer Small Footprint

THE KXT2 SERIES DOUBLE-ACTION, top-actuated switches from C&K Components feature an ultra-miniature 3.7 x 3.0 x 1.05 mm footprint, an integrated actuator with 1.2 mm-diameter surface area, and extended 100,000-cyle lifespans. Suited for use in ultra-compact electronics such as wearable electronics, mobile phones, hearing aids, portable electronics, action/surveillance cameras, and personal healthcare monitoring systems, the series also offers two actuation forces, each with their own distinctive and stable tactile feeling.



The momentary action switches feature a dual-action SPDT-NO contact arrangement, and G-type SMT terminations designed to take up minimal board space (4.4 x 3.1 mm). Push-force one features a 100+/-40 gf operating force and 0.1 mm+/-0.05 mm travel, and push-force two features a 200+/-50 gf operating force and 0.2 mm +0.1/-0.05 mm travel. Maximum voltage is 12 Vdc and maximum current is 50 mA. Insulation resistance at 500 Vdc is 100 MΩ, contact resistance is less than 500 mΩ, and bounce time for the series is less than 10 ms. Operating temperature spans -40°C to 85°C.

C&K COMPONENTS

www.ck-components.com

Compact 60 V MOSFETs Offer High Efficiency

ALPHA AND OMEGA SEMICONDUCTOR has eight new products in the 60 V MOSFET family. Designed for synchronous rectification in flyback converters and used in quick chargers for smartphones and other portable devices, the products offer three levels of maximum on-resistance at 4.5 V gate drive voltage: 6.5, 8.5, and 13.5 mΩ, and they are available in three package types: SO-8, DFN5x6, and DFN3x3.

The entire 60 V product family is optimized for low on-resistance at a lower gate drive voltage. Switching losses are significantly dependent on the control scheme used in the charger circuit. AOS's proprietary AlphaSGT process boasts best-in-class on-resistance with very low parasitic capacitance, ensuring lower switching loss. The devices are also tuned to keep EMI suppression simpler and more reliable. All products in the family are available immediately in production quantities with a lead time of 12-14 weeks. Unit prices in 1,000-piece quantities are $0.79 for the AO4268, $0.58 for AO4262E, $0.48 for AO4264E, $0.79 for AON6268, $0.60 for AON6262E, $0.48 for AON6264E, $0.58 for AON7262E, and $0.48 for the AON7264E.

ALPHA & OMEGA SEMICONDUCTOR

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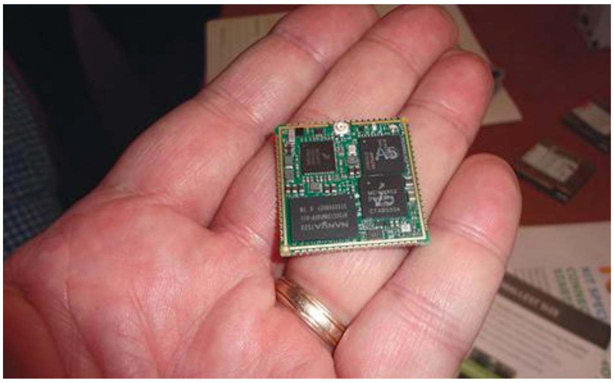
Tiny Modules Target IoT Applications

Small modules have been around for years, but ones featuring wireless support and built-in sensors have been gaining in popularity among designers for the Internet of Things.

The Internet of Things (IoT) often means tiny and mobile, and that makes designs challenging. One alternative is to use modules delivered by vendors like NXP, Digi International, and Intel. Small modules have been available for many years, but ones with wireless support and built-in sensors have recently become more popular.

1. NXP's SCM-i.MX 6SX incorporates a 1-GHz Cortex-A9 and an 227 MHz Cortex-M4 in a 13- by 13-mm Package on Package (PoP).

NXP's SCM-i.MX 6SX *(Fig. 1)* comes in a 13- by 13-mm Package on Package (PoP). It includes an i.MX 6SoloX apps processor with a Cortex-A9 and a Cortex-M4, up to 1 Gbytes of LPDDR2 memory, 4 Gbytes of eMMC flash memory, and a PF100 power management device, plus a collection of discrete components. The SCM-i.MX 6SX includes a gigabit Ethernet interface along with display and touch support. The 0.7-mm diagonal ball pitch array targets low-cost PCB boards. There is a larger V-Link variant that incorporates NXP's V-Link interface matched to off-the-shelf components for wireless support, including Wi-Fi, NFC, and Bluetooth.



2. Digi International's 29- by 29-mm CoreConnect i.MX6UL has a Cortex-A9 with Bluetooth 4.0 and 802.11a/b/g/n Wi-Fi support.

Digi International's 29-mm by 29-mm CoreConnect i.MX6UL *(Fig. 2)* has a 528 MHz Cortex-A7 with dual 10/100 Ethernet, Bluetooth 4.0, and 802.11a/b/g/n Wi-Fi support with on-board antenna. It comes in a 245-pad LGA (universal) or 76-pad (simple) castellated-edge VIA form factor. Versions are available with up to 2 Gbytes of NAND flash and 1 Gbyte of DDR3 DRAM. It uses NXP's PF3000 PMIC. A Cortex-M0+ handles system management, and there is a dedicated security controller that works with Digi's TrustFence Linux support.

Intel's Curie module is built around a 32-bit, x86 Quark *(see "How Many Quarks Does It Take To Make An IoT?" on electronicdesign.com)* and an ARC DSP sensor hub. The system has 384 Kbytes of flash an 80 Kbytes of SRAM. It also has Bluetooth LE support along with a 6-axis accelerometer/gyro.

The Curie also has General Vision's (formally CogniMem) NeuroMem's hardware pattern matching technology with 128 neurons *(see "Neural Net Chip Enables Recognition For Micros" on electronicdesign.com)*. The system allows applications to classify new patterns and report novelties or anomalies in real-time. Deep learning is being tackled by high-performance GPUs *(see "GPU Targets Deep Learning Applications" on electronicdesign.com)*, but this technology is found in a compact, low-power module.

Building a platform from scratch may be useful in special circumstances or for high-volume markets, but these modules can reduce time to market using the latest technology. They allow developers to concentrate on the application instead of packaging and PCB technology.

10 MHz Rubidium Frequency Standard

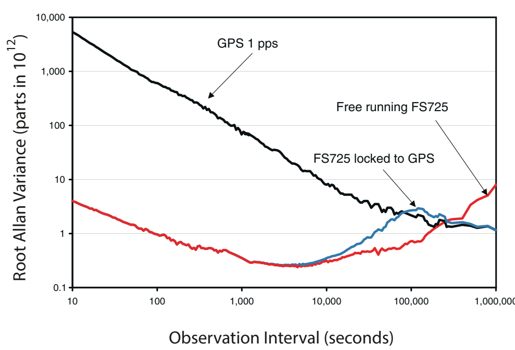
- ***5 MHz and 10 MHz outputs***
- ***Ultra-low phase noise (<–130 dBc/Hz at 10 Hz)***
- ***0.005 ppm aging over 20 years***
- ***Built-in distribution amplifier (up to 22 outputs)***
- ***1 pps input and output***

The FS725 Benchtop Rubidium Frequency Standard is ideal for metrology labs, R&D facilities, or anywhere a precision frequency standard is required.

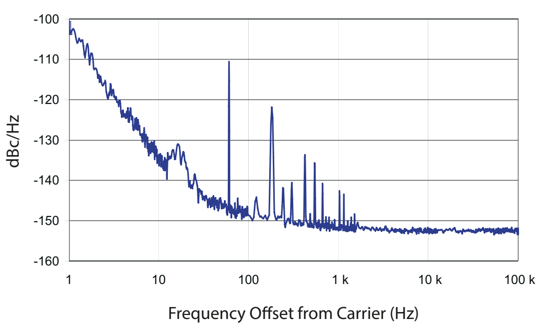
It has excellent aging characteristics, extremely low phase noise, and outstanding reliability. A 1 pps input is provided for phase-locking to GPS, providing Stratum 1 performance.

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



FS725 rear panel

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The LTC®4380 surge stopper shields downstream circuitry from destructive voltage and current surges. This comprehensive protection IC provides surge ride-through from transients above 100V in a compact footprint. An accurate output clamp is pin-selectable for 12V or 24V/28V systems, or can be flexibly adjusted using an input Zener, allowing the use of lower voltage rated, cost-effective downstream components. With device current consumption of just 8µA in normal operation and 6µA in shutdown mode, always-on battery powered applications benefit from prolonged battery life.

Features

- Withstands Surges Above 100V
- Low 8µA I_Q, 6µA in Shutdown
- 4V to 72V Operation
- Survives –60V Reverse Input
- Adjustable Clamp Voltage
- MOSFET Stress Accelerated Timer
- Low 0.1% Retry Duty Cycle
- –40°C to 125°C Operation
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LTC4380 Options

OPTION	GATE CLAMP	FAULT BEHAVIOR
-1	Internal 31.5V/ 50V to GND	Latchoff
-2	Internal 31.5V/ 50V to GND	Auto Retry
-3	Externally Adjustable	Latchoff
-4	Externally Adjustable	Auto Retry

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