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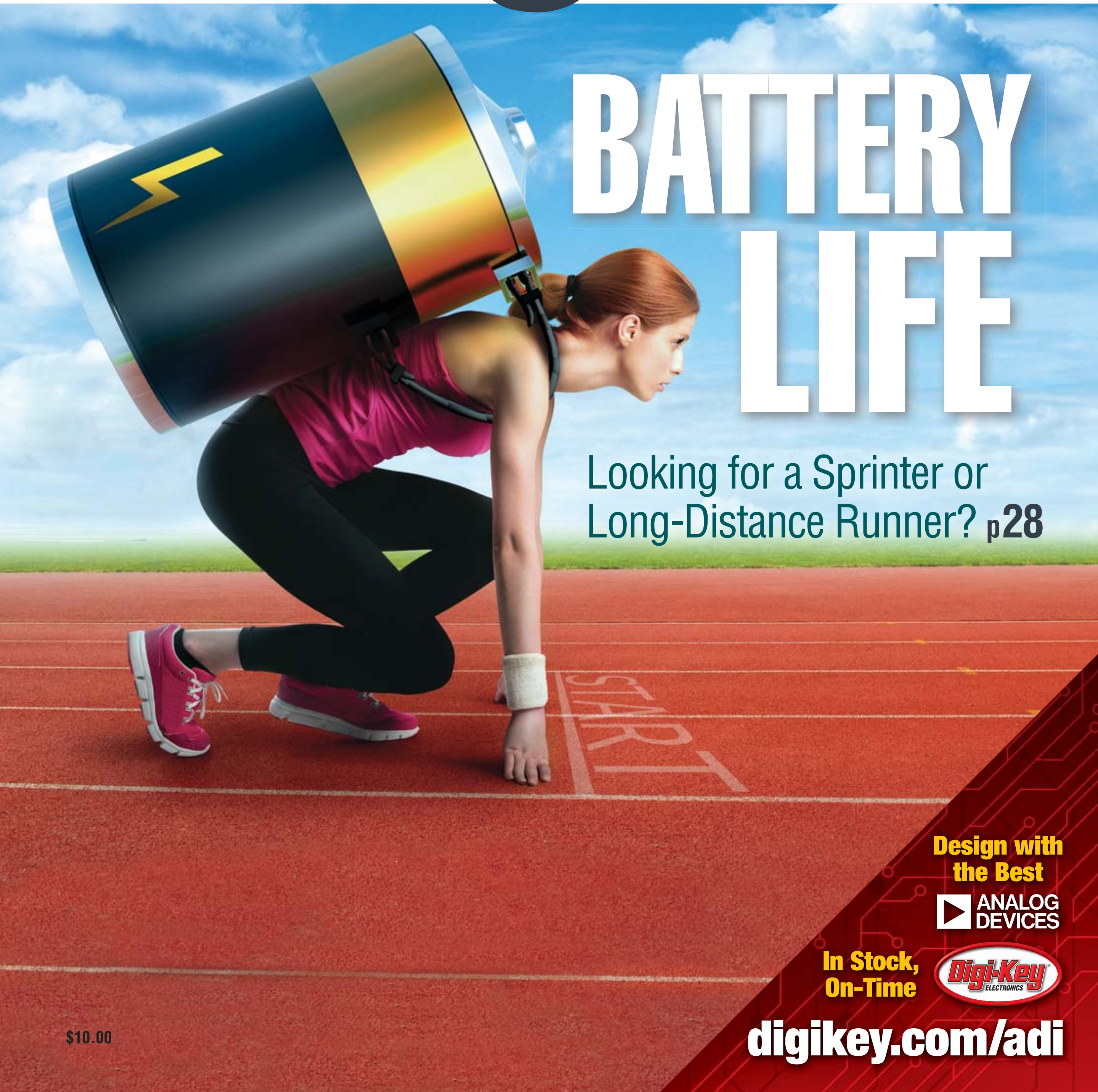

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FEATURES

COLUMNS & DEPARTMENTS

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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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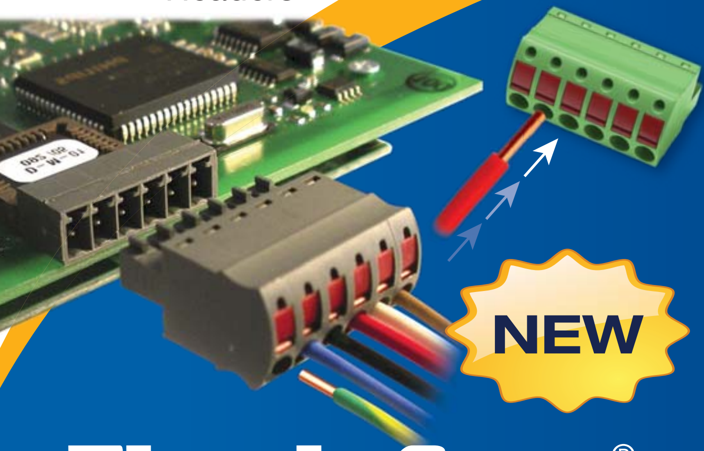

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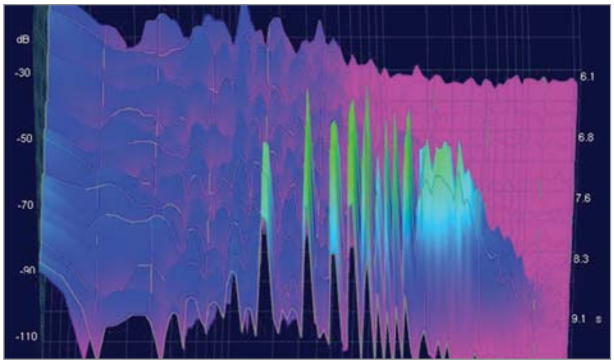

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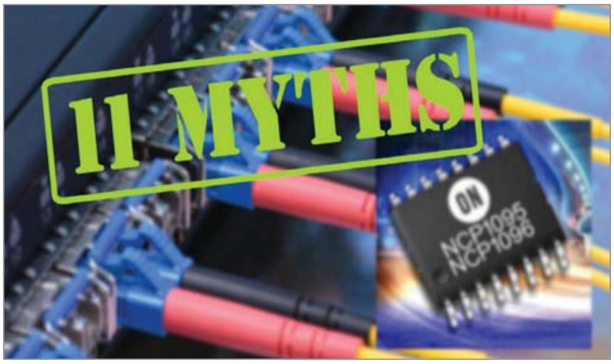

11 Myths About PoE

Power over Ethernet (PoE), which allows deployment of devices without requiring a separate power supply, is often a misunderstood technology.

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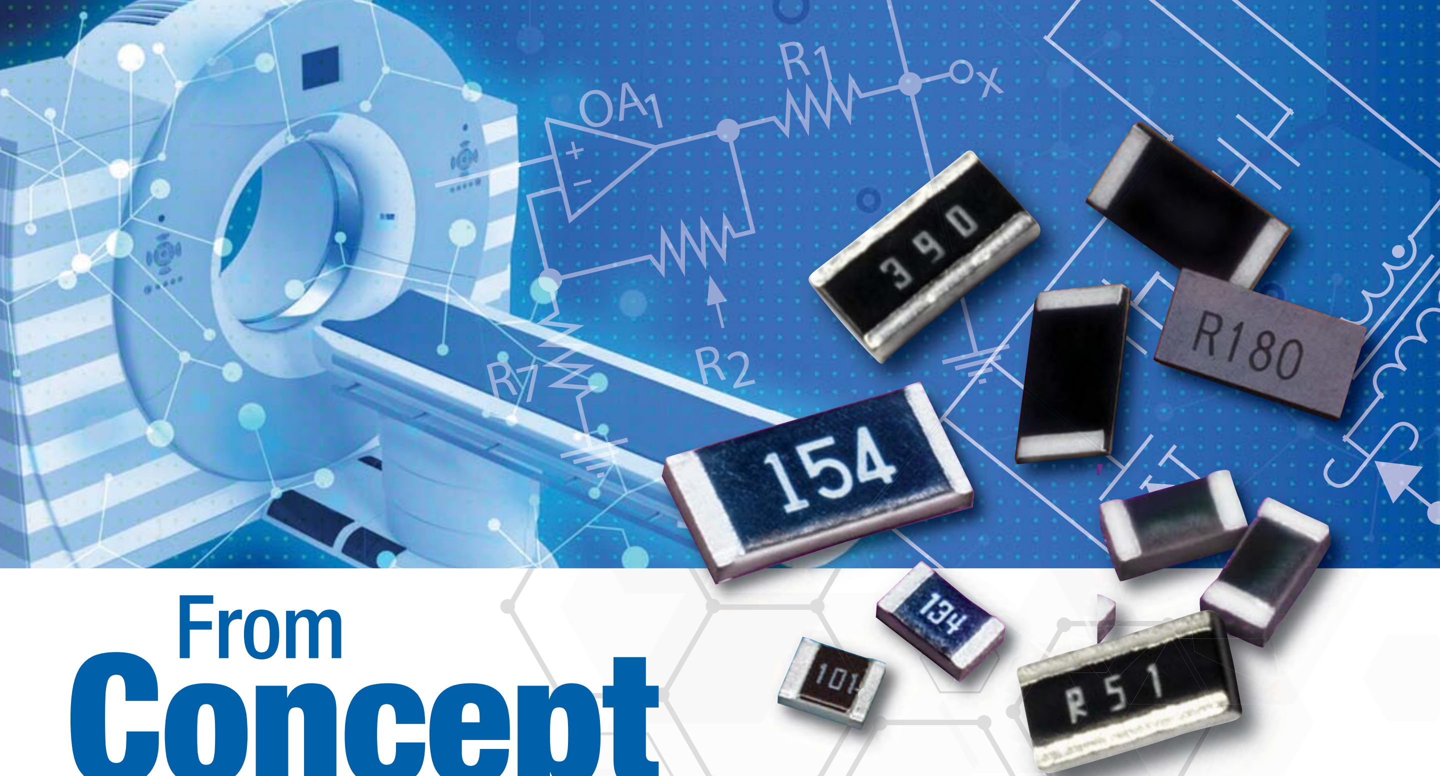

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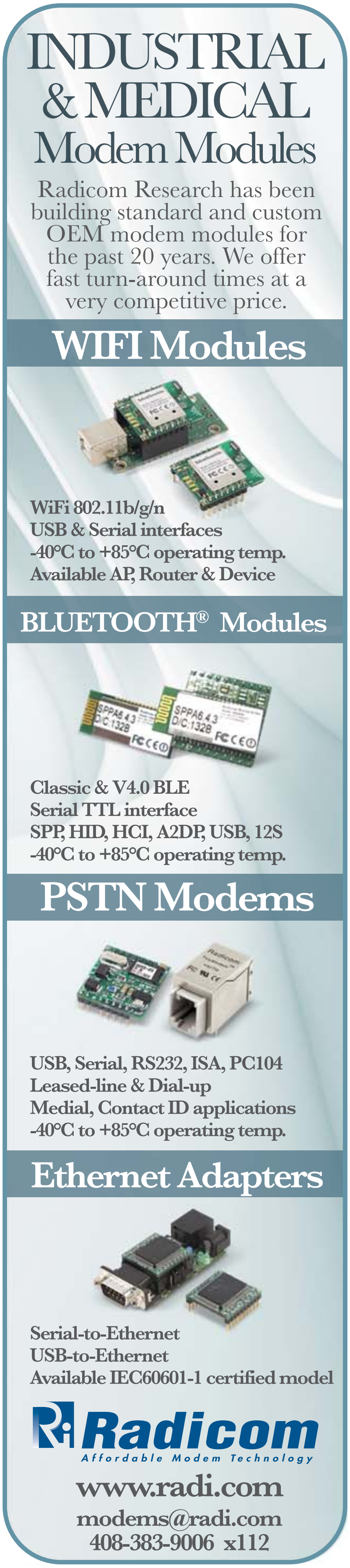

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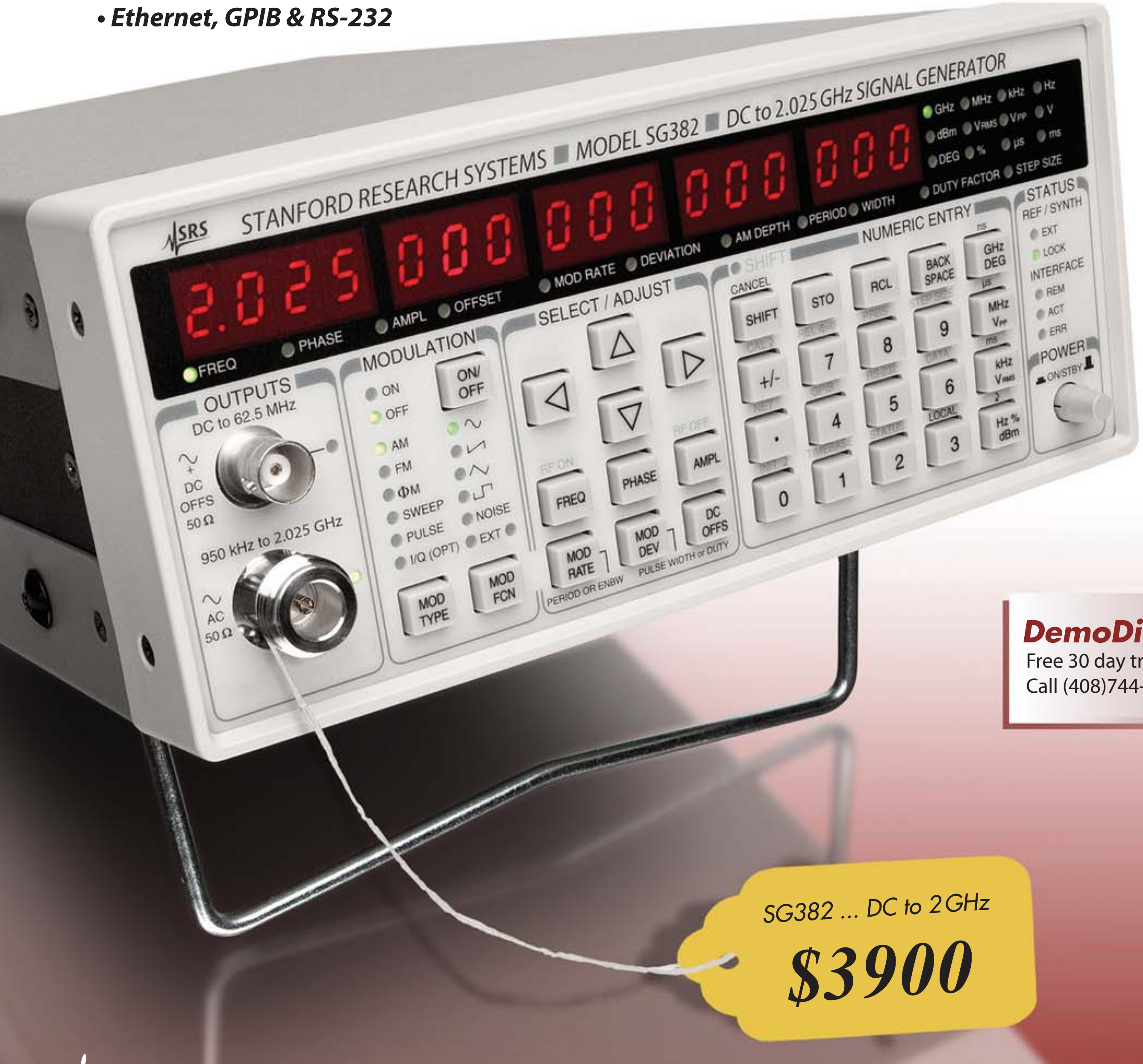
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Editorial

WILLIAM WONG | Senior Content Director
bill.wong@informa.com

OTA Updates: Boon, Bane, or Bust

Over-the-air (OTA) updates are key to IoT device support, but making changes in the field can be a challenge.

More companies are going to forced updates. For example, Microsoft Windows 10 users no longer have an option to refuse updates, only delay them. Enterprise users have more options, but updates generally get deployed often unbeknownst to users.

Over-the-air (OTA) updates are just a variant of this approach designed to keep IoT devices like Amazon's Echo Dot up to date. This can mean fixing bugs, improving security, or adding new features.

Many OTA services highlight secure updates as a key feature. And they are, but there's much more to deploying updates than guaranteeing that a particular update is valid. Managing updates is a complex task when dealing with hundreds to millions of devices. That's because many times it's rare that all devices in a collection will be identically configured or in the same state. This can affect deployment of an update.

An unfortunate consequence of a failed update is a "bricked" device. That's where a device no longer functions properly, if at all, and is equivalent to a brick. A recent Echo Dot update left many in a bricked state.

Likewise, updates can often degrade different performance aspects. A recent update for my Samsung Gear S3 watch resulted in reducing its normally good run time of almost two days to about two hours. This was due to an app update for tracking world time, which I never actively use, but one that can't be disabled or deleted.

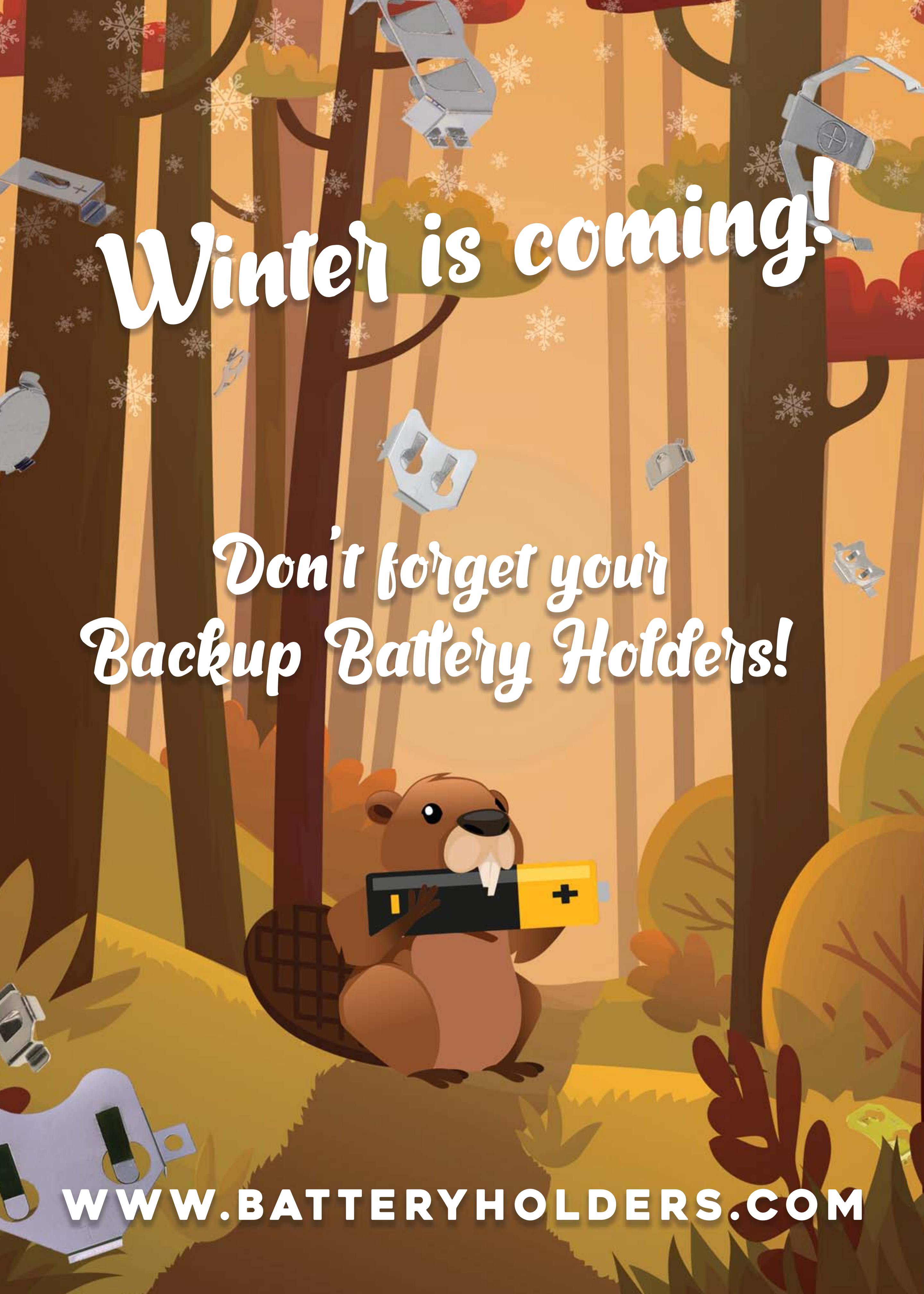
Testing of updates is a serious task and dealing with the plethora of states can be a challenge, especially when updates are done on a regular basis and in an incremental or differential fashion. The latter is common for IoT devices with low bandwidth communication methods, which reduces the amount of data to implement an update.

Designers also need to keep in mind that there are many ways to address these related issues, such as more advanced watchdog facilities and power-on self-test (POST) services. These can identify and address bad updates; therefore, a device may only be temporarily uncooperative rather than permanently bricked.

These issues are very important as the number of interconnected devices grows. New cars, let alone self-driving cars, have hundreds of devices that can be updated, many of which are critical to the vehicle's operation and the safety of the occupants. Liability for failure or degradation of these types of devices are more important than my watch, but effects can range from annoying to fatal.

No one said building IoT systems would be easy. However, if these devices are to provide the type of long-term functionality we desire, then all aspects related to OTA updates need to be addressed.

An update to the world clock app for the Samsung Gear S3 reduced runtime to about two hours.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News

BROADCOM ORDERED BY EU to Stop Enforcing Unfair Contracts

The European Union ordered Broadcom to stop demanding that some of its customers agree to allegedly anticompetitive contract terms, brightening the spotlight on its core chip business. The European Commission imposed the interim measures in October as part of an investigation into whether Broadcom wielded its dominance in the market for chips used in modems and television set-top boxes to discourage customers from going to rivals.

The commission said that Broadcom's business of selling chips used in television and broadband could lead to "serious and irreparable harm to competition." The agency accused the San Diego, Calif.-based company hammered out contracts with six main customers that hindered them from buying products from Broadcom's rivals. Other vendors could be forced out of business if the company's business conduct was not halted, the EU said.

The clampdown on Broadcom's conduct comes after the agency opened an investigation in June looking into whether it curbed competition in the market for chips used in modems and set-top boxes, where it holds more than 50% market share. Margrethe Vestager, the EU's competition chief, said the agency has "strong indications" that Broadcom is running afoul of local rules. She said the commission is aiming to protect competition while it finishes the investigation.

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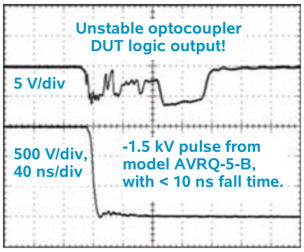

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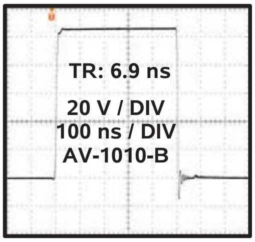

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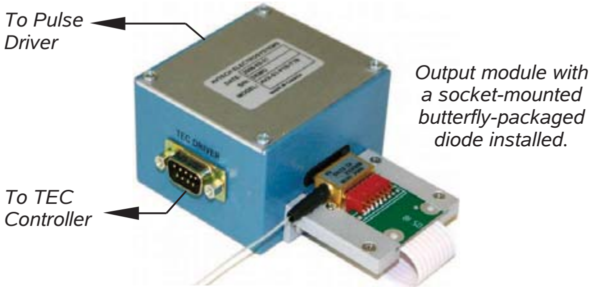
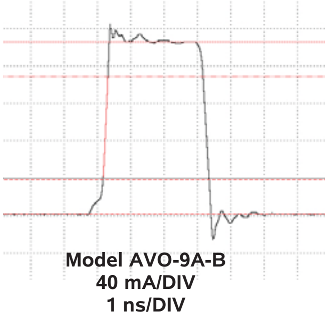

To Pulse Driver
Output module with a socket-mounted butterfly-packaged diode installed.
To TEC Controller



Each of the 19 models in the Avtech AVO-9 series of pulsed laser diode drivers includes a replaceable output module with an ultra-high-speed socket suitable for use with sub-nanosecond rise time pulses. Models with maximum currents of 0.1A to 10A are available with pulse widths from 400 ps to 1 us. GPIB, RS-232, and Ethernet control available.

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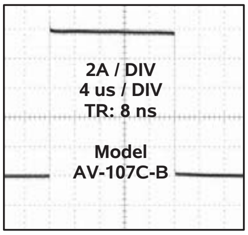

Series	I, V	PW	TR
AV-107	2 - 20 A, 60 V	0.2 - 200 us	10 - 30 ns
AV-106	5 - 100 A, 100 V	0.5 us - 1 ms	50 ns - 1 us
AV-108	12.5 - 200 A, 100V	2 us - 1 ms	5 - 15 us
AV-109	10 - 100 A, 5 V	10 us - 1 s	10 us
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"Broadcom's behavior is likely, in the absence of intervention, to create serious and irreversible harm to competition," Vestarger said in a statement. "We cannot let this happen, or else European customers and consumers would face higher prices and less choice and innovation." Broadcom, which also sells components to Apple, has been under fire in recent months from international regulators, which together are targeting most of its core chip product portfolio.

Broadcom is also facing a probe by the US Federal Trade Commission, which is reportedly trying to figure out whether it forced customers to buy Broadcom's Wi-Fi and Ethernet chips exclusively. The company is one of the largest players in the market for Wi-Fi ICs used in smartphones, routers, and gateways. It's also the global leader in chips used in networking switches sold by Cisco Systems, Arista Networks, and others to move data around data centers.

The European Commission in June said it planned to impose the interim measures instead of ordering Broadcom to overhaul its business once the investigation ends and the damage done. The commission said Broadcom has added contract provisions that grant rebates and other key benefits to customers as long as they only buy Broadcom products or meet minimum purchase requirements. That has made it much harder for other companies to compete, the EU said.

Broadcom has waved off the allegations. The commission is also looking into other questionable practices, such as product bundling and deliberately making it difficult for Broadcom's products to function with rival chips. The agency's conclusions could lead to hefty fines. The EU can impose fines up to 10% of the company's annual sales for violating antitrust rules. Broadcom forecasts sales of $22.5 billion in 2019 and chips account for almost 80% of its sales.

"Broadcom believes it complies with European competition rules and that the commission's concerns are without merit," the company said in a statement informing shareholders in June. "The interim measures, if adopted, will not preclude the continued sale by Broadcom of any products. Broadcom's contracts with these customers would remain in force, other than the provisions at issue, and it intends to continue to support these customers going forward."

Broadcom, which the Trump administration also stopped from buying rival Qualcomm last year, said it will follow the commission's orders, but plans to challenge the ruling in court. The company said the restrictions, which could last for up to three years, will not stop it from supplying chips to any of its affected customers. "Broadcom believes that this action will not have a material impact on its set-top box or broadband modem businesses," it said back in June. ■

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CUS150M	150W	O, E, B, F	2x4"	Class I / II
CUS200M	200W	O, E	3x5"	Class I
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* E = Enclosed, O = open frame, P = pcb mount, F internal fan, B conduction cooling

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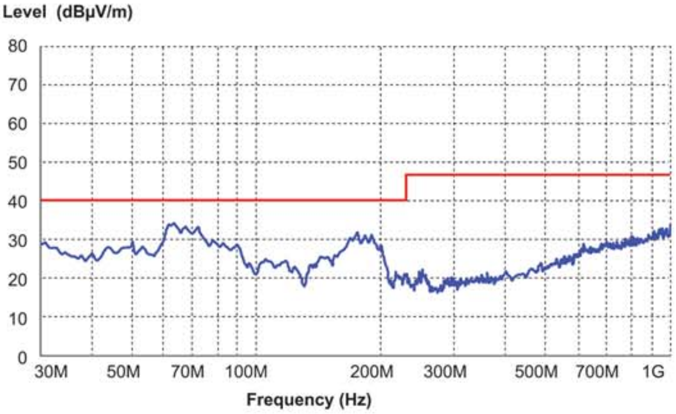

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FAQs

Safeguarding Machines with Hard Guards and Solenoid Locking Switches

What is the easiest way to protect a dangerous area on my machine?

Hard guarding is a very common approach to providing protection for both the visible and invisible hazardous areas of a machine. It can be made with a variety of materials including metal screening or clear plastic to allow visibility. The only limiting factor is that the material must be strong enough to contain the impact from any debris that could possibly be ejected during the manufacturing process or in the event of the potential breakage of any internal components. Fixed hard guarding is generally preferred due to its simplicity; however, since this prevents access to the machinery for maintenance, repairs, adjustments or product manipulation, other alternatives may need to be considered.

What if I need to access these areas?

Incorporation of a door or removable access panel can be added, so long as assurances can be made that the door or access panel is closed when the dangerous condition is present. Incorporating interlock switches is a common approach as they monitor the position of the guard. There are several different types of interlock switches available, including keyed safety switches, non-contact safety switches, and hinged safety switches. Standard switches provide one or two closed contacts when the door or panel is in place, thereby blocking the hazardous condition. Usually these are connected in series, forming a one- or two-looped safety circuit which is monitored by a safety relay or safety PLC. Typically these monitoring devices shut off the power, stopping the dangerous moving parts and preventing the start of the machine when the guard is opened or removed.

What if my machine takes a long time to stop?

Unfortunately, due to inertia some machines may continue to run after their power is disconnected. This can create a situation where it is possible to access the hazardous areas of the machine when they are still in a dangerous state. Examples of this include saws, fly wheel devices, and K presses. To eliminate this possibility, the guards must be placed at a sufficient distance to allow enough time for the process to stop completely before the operator is able to access it. This safety distance can be calculated based on the time it takes to open the guard, the response time of the safety relay, and an average hand speed constant.

Another approach is to simply lock the guard or close the gate, allowing the machine enough time to safely wind down. This can be easily accomplished using solenoid locking keyed interlock switches. These switches use a solenoid mechanism to lock a door-mounted activation key into the switch, preventing the guard, gate, or door from being opened.

What type of locking functions are available?

Solenoid switches are available either “Normally Locked”, where the keys are locked into the switches automatically and the solenoid must be powered to remove them, or “Normally Unlocked”, which requires power to the solenoid to lock the keys into the switch.

How do I control a solenoid locking keyed safety switch?

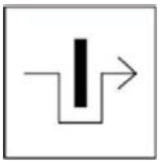
Typically, the power to the locking solenoid is controlled using a zero-speed device to sense that all the dangerous motion has stopped, or else a PLC or timer to ensure that enough time is provided for the machine to come to a complete stop.

What happens if I lose power?

Most Normally Locked solenoid locking switches include an “emergency override” which allows the locking actuator key to be removed manually in the event of a power failure. These are designed for emergency use only and usually require the use of a separate tool like an Allen wrench to open. If quick access to the override is required, some switches offer an optional hand-operated manual override, which can only be reset with a special tool.

What the difference between “Key Contacts” and “Locking Contacts”?

Many solenoid locking switches are available with multiple contacts that offer separate outputs indicating when the key has been properly inserted into the switch and if the key has been locked. Older generations of switches sometimes required the “key contacts” and “locking contacts” to be run in series to reach the highest safety levels. Newer switches feature a fail-safe locking design which integrates both functions into one contact indicating that the key is both in place and locked. There is a new symbol according to ISO 14119 used to designate these fail-safe contacts.



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What if I get trapped behind the guard?

One danger with locking a door or gate closed when guarding an area large enough to allow full body access (like a robotic manufacturing cell), is that it would be possible for the operator to be accidently locked inside in the hazardous area. Since the locking control and switch override would be outside of the cell, the operator would have no means of accessing them and, therefore, no means of escape.

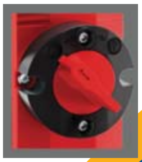
Some solenoid locking switches are available with optional emergency escape override accessible from the back of the switch. When mounted, the escape override extends through the guard, giving the operator access to unlock the switch from within the cell.

Can I use a keyed interlock switch as a latch?

Neither non-locking nor locking keyed interlock switches are designed to be used as physical stops for the doors or gates. This is especially true with larger heavy door and gate designs. Many switches offer separate hardware that can be used in conjunction with the switches, so as to support the weight and forces required to secure the gate. These units, typically referred to as "slide bolts" or "shock bolts", are equipped with a handle to allow the operator to open and close the gate by hand when unlocked.

Can I use these switches with an extruded aluminum rail guard?

Many solenoid locking switches are now vertically designed to make them much easier to mount on extruded aluminum rail systems, which are very popular for hard guarding applications. Some also feature a combination of plastic and metal in their construction components to make them both durable and cost-effective.



SACHIN GUPTA | Staff Product Marketing Engineer, Cypress Semiconductor

Good Wi-Fi Connectvity is Essential for IoT Product Success

Factors that make for effective Wi-Fi include ample range, high throughput, low packet error rate, and suitable coexistence—all of which can be enhanced via 802.11ac.

Internet of Things (IoT) momentum is bringing connectivity to devices we never thought would ever be connected. Now you can prepare your coffee without walking to your coffeemaker. You simply send a command to the maker using your phone. It even learns your preferences and prepares your coffee the way you like, every time.

The number of connected devices and users continues to increase rapidly. And that's great! But, for a sustainable IoT infrastructure, it's necessary that an IoT device performs well in every environment. An IoT device that can't connect to the local access point (AP) is useless. System designers need to understand various Wi-Fi parameters such as transmit power, receive sensitivity, coexistence, and throughput while designing an IoT product. This article covers some of the important aspects that are essential for a successful IoT product.

2.4 GHz IS A CROWD

Today, the most commonly used wireless technologies used in IoT devices are Wi-Fi and Bluetooth that utilize the 2.4-GHz spectrum. Not only is Wi-Fi implemented by IoT devices, but it's extensively used in every home for televisions, laptops, tablets, and mobile phones. The 2.4-GHz spectrum has become like a conference room where several people are all trying to have a conversation at the same time. For a conversation to be understood, though, only one device can talk at one time.

Now imagine a device that can't communicate efficiently and tries to talk continuously. No one else can talk, so no meaningful conversations can take place anywhere in the room. There's little in the Wi-Fi spec that emphasizes performance and spectrum utilization. With the increasing density of Wi-Fi devices, the Wi-Fi Alliance needs to add stringent requirements for good performance on top of adherence to the protocol to pass the certification process.

IoT device manufacturers need to get over the low-cost-only approach to make sure they're not designing Wi-Fi connected devices that are bad performers and bad neighbors for other Wi-Fi devices. Just one bad device is enough to bring down the customer's entire Wi-Fi network.

For a future-proof IoT network, it's important that system designers use robust Wi-Fi connectivity. It's of the utmost important for companies to understand the consequences of bad design as it directly relates to the product's success and the brand's reputation. An IoT product that's unable to connect to the AP is useless for the customer.

When customers face any issues with connectivity, they are likely to return the product or write a bad online review. These contribute to unsuccessful product and negative impact on brand name. Even with a well-designed product, it is necessary to provide extensive technical support for customers who are new to IoT.

The following are the key symptoms of bad Wi-Fi connectivity:

- Poor range
- Low throughput
- High packet error rate
- Bad coexistence

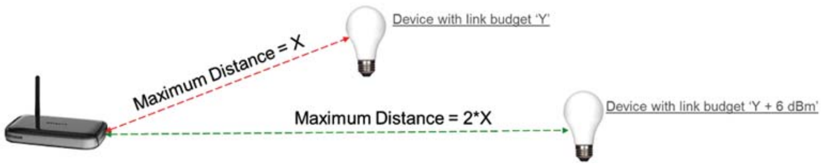
POOR RANGE

Poor range limits the distance at which your IoT product can connect to the AP. This is the very first experience your customer has with your product. If it doesn't even connect, in most cases the customer will return the product and slam a bad review. Your IoT product may not be able to connect to the AP at a distance because of low transmit power, poor sensitivity, or lack of transmit beamforming support.

A Wi-Fi link requires two devices to exchange packets to establish a connection. The distance at which a device can connect to the AP is determined by factors listed here.

Transmit power

The transmit power of IoT devices impacts the ability of the AP to hear it. Beyond a certain level, the output of Wi-Fi's power amplifier starts to distort. To deal with this, most Wi-Fi devices limit Tx power. For instance, Cypress' Wi-Fi devices use proprietary methods to deal with this distortion and provide higher Tx power. Another challenge with Tx power is regulatory limitations imposed by different countries. This means that the maximum Tx power needs to be controlled based on the country to avoid regulatory violations. As a result, the Wi-Fi subsystem must provide an


Maximum Distance = X
Device with link budget 'Y'
Maximum Distance = 2*X
Device with link budget 'Y + 6 dBm'

The link budget can have a significant impact on range.

easy or automated method to control the transmit power so that the IoT device can transmit at the maximum Tx power level while avoiding any regulatory (FCC, CE, etc.) violations.

Receive sensitivity

Receive sensitivity is the device's capability to hear the AP. Good receive sensitivity in conjunction with good transmit power is the key to good range. Some Wi-Fi devices include algorithms that can process inputs with smaller signal-to-noise ratio than others. Thus, the receive sensitivity specification needs to be considered while selecting a device for an IoT product.

Link budget

Transmit power, receive sensitivity, and environmental factors define the link budget between two Wi-Fi devices. Suppose one device has +3 dBm more Tx power than the other and −3 dBm better sensitivity. This results in a 6-dBm link budget improvement. Every 6-dBm increase in the link budget doubles the range *(see figure).*

Transmit beamforming

Transmit beamforming focuses transmit power in a given direction—it helps increase the range in that direction. For instance, if an IoT device supports transmit beamforming, it can connect to the AP at a longer distance. However, not all Wi-Fi devices support transmit beamforming. Beamforming was first introduced in 802.11n. However, its implementation was left to the vendors. This has made interoperability a challenge. In 802.11ac, this feature was well-defined in WLAN specification and allowed implementations that were interoperable. Considering this fact, 11ac becomes a necessity to increase range without requiring repeaters.

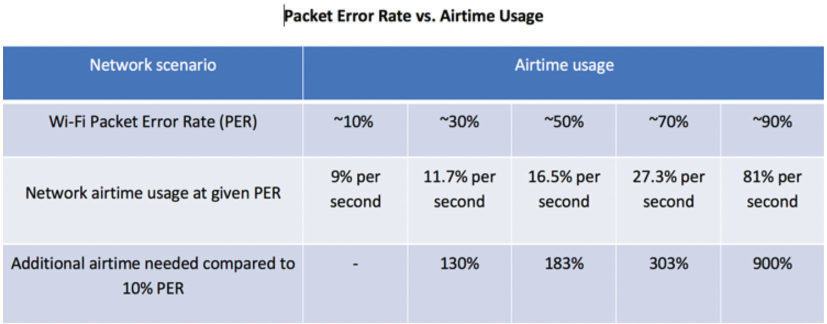
LOW THROUGHPUT

Low throughput has a severe impact on performance, including:

- Latency: The lower the throughput, the higher the latency. Though most IoT devices require only a few bytes of data to be sent, higher latency can result in a poor user experience. Low latency also means reduced reliability in time-critical applications using sensors such as medical and industrial devices.
- Battery life: If the throughput/modulation index is low, the device takes longer to transmit and, hence, has longer active times. That directly translates into short battery life.
- Poor spectrum utilization: Low throughput increases the airtime needed for communication. This directly results in making the 2.4-GHz spectrum even more congested.

A device's throughput is impacted by several factors such as link budget, modulation index, and spectrum availability. Wi-Fi devices adjust their link data rate to accommodate the link budget. A higher modulation index means higher throughput. Higher modulation index support requires improved signal conditioning. So, some devices perform better at a lower modulation index versus a higher modulation index. Good sensitivity and good Tx power across various modulation and coding schemes translates into a good rate versus range.

For good throughput, it's important to investigate the device's throughput at all supported modulation index and coding schemes. Also, it's important to pick a device that supports a higher modula-



Packet Error Rate vs. Airtime Usage

Network scenario	Airtime usage				
Wi-Fi Packet Error Rate (PER)	~10%	~30%	~50%	~70%	~90%
Network airtime usage at given PER	9% per second	11.7% per second	16.5% per second	27.3% per second	81% per second
Additional airtime needed compared to 10% PER	-	130%	183%	303%	900%

tion index. 802.11ac supports 256-QAM (quadrature amplitude modulation) that enables higher throughput in 802.11ac devices compared to 64-QAM supported by 802.11n.

The number of devices trying to communicate in a given area also directly affects throughput. The more devices, the less time there is for each device to send/receive data. This limits the effective throughput. The problem becomes severe in the 2.4-GHz band, where most legacy Wi-Fi devices are trying to communicate along with other wireless devices such as Bluetooth and Zigbee. So, along with higher modulation index to improve throughput, 802.11ac's support for the less-crowded frequency band—5 GHz—also helps in improving throughput.

HIGH PACKET ERROR RATE

In Wi-Fi, whenever there's a packet error, it needs to be resent. A device with a high packet error rate (PER) causes all devices to perform poorly in the network because it takes longer to transmit a packet successfully. It potentially increases the number of collisions, thus requiring other devices to retransmit as well, which further impacts PER. The *table* shows the airtime usage based on different PER. It reveals the percentage of airtime per second that will be taken to transmit 1000 bytes of data by 20 nodes transmitting one packet per second.

Looking at the *table*, a device with a 90% error rate takes about 900% of the airtime compared to a device that has 10% PER. High PER also increases the latency; the packet needs to be retransmitted if there's a packet error. It becomes a challenge in time-critical applications. Therefore, it's important to understand the Wi-Fi device's PER before selecting it for an IoT application. 802.11ac can be very useful—it supports the 5-GHz band, which is less congested and results in fewer packet collisions.

BAD COEXISTENCE

IoT devices often require Wi-Fi and Bluetooth wireless technologies to be co-located. The challenge is that they operate in the same frequency band, so if they're not coordinated, they can clobber each other. Bad coexistence means Wi-Fi throughput suffers significantly.

There are several coexistence schemes, and their performance varies significantly. It takes hundreds of man-years to create a coexistence algorithm that makes real-time decisions in granting medium access to Wi-Fi and Bluetooth. RF chains of Wi-Fi and Bluetooth radios must be optimally controlled to minimize the interference and maximize the performance. A good arbiter needs a lot of information from both Wi-Fi and Bluetooth core to implement coexistence.

Some Wi-Fi and Bluetooth combo devices come with integrated coexistence, which allows an arbiter to communicate with the Wi-Fi and Bluetooth cores over a parallel bus. 5-GHz support for Wi-Fi in 802.11n and 802.11ac is very useful in applications that require both Wi-Fi and Bluetooth to operate at the same time. So, in addition to good coexistence mechanism, a device with 5 GHz should be used for the best coexistence. ed

TRANSTECTOR

JACK BROWNE | Technical Contributor

What's the Difference Between Wi-Fi 5 and Wi-Fi 6?

The enhanced efficiency and capacity of Wi-Fi 6 compared to Wi-Fi 5 promises to support the growing needs of wireless network users.

Wireless local-area networks provide internet access for many users in rapidly growing numbers in homes, offices, factories, and public places. The growth rate is so fast, in fact, that what had been the international standard for wireless networking, IEEE 802.11ac, released in 2014, can no longer keep up. It's now being replaced by a new version of the standard, IEEE 802.11ax. In other words, IEEE 802.11ac is Wi-Fi 5 and IEEE 802.11ax is Wi-Fi 6. The standards are compatible but also different in many ways, with enough disparities to combine for significant improvements in wireless network capacity and efficiency for all users, even in crowded places *(Table 1)*.

TABLE 1: COMPARING WI-FI-5 AND WI-FI 6 STANDARDS		
Parameter	**Wi-Fi 5 (802.11ac)**	**Wi-Fi 6 (802.11ax)**
Frequency	5 GHz	2.4 and 5.0 GHz
Bandwidths (channels)	20, 40, 80+80, 160 MHz	20, 40, 80+80, 160 MHz
Access	OFDM	OFDMA
Antennas	MU-MIMO (4 × 4)	MU-MIMO (8 × 8)
Modulation	256QAM	1024QAM
Maximum data rate	3.5 Gb/s	9.6 Gb/s
Maximum users/AP	4	8

1. Wi-Fi 6 is a wireless networking standard conceived and developed because of the rapidly growing worldwide reliance on wireless devices. *(Courtesy of the Wi-Fi Alliance, www.wi-fi.org)*

Wi-Fi 6 improves on the performance of Wi-Fi 5 by borrowing useful techniques from 4G Long Term Evolution (LTE) cellular radio technology, in the hopes that Wi-Fi 6 will provide the increased capacity needed for a growing number of interconnected wireless devices *(Fig. 1)*. These range from Internet of Things (IoT) sensors and smarter 5G wireless cellular telephones to even connected cars.

In addition to operating within narrow channel bandwidth at 2.4 GHz along with the 5-GHz spectrum already occupied by Wi-Fi 5 at 5 GHz, perhaps the biggest difference between the two Wi-Fi standards is the use of orthogonal frequency-division multiple access (OFDMA) in Wi-Fi 6 compared to orthogonal frequency-division multiplexing (OFDM) in Wi-Fi 5. OFDMA is essentially a multiple-user version of OFDM, making it possible to increase the capacity of a Wi-Fi 6 access point (AP) compared to a Wi-Fi 5 AP.

IN AN EMERGENCY-
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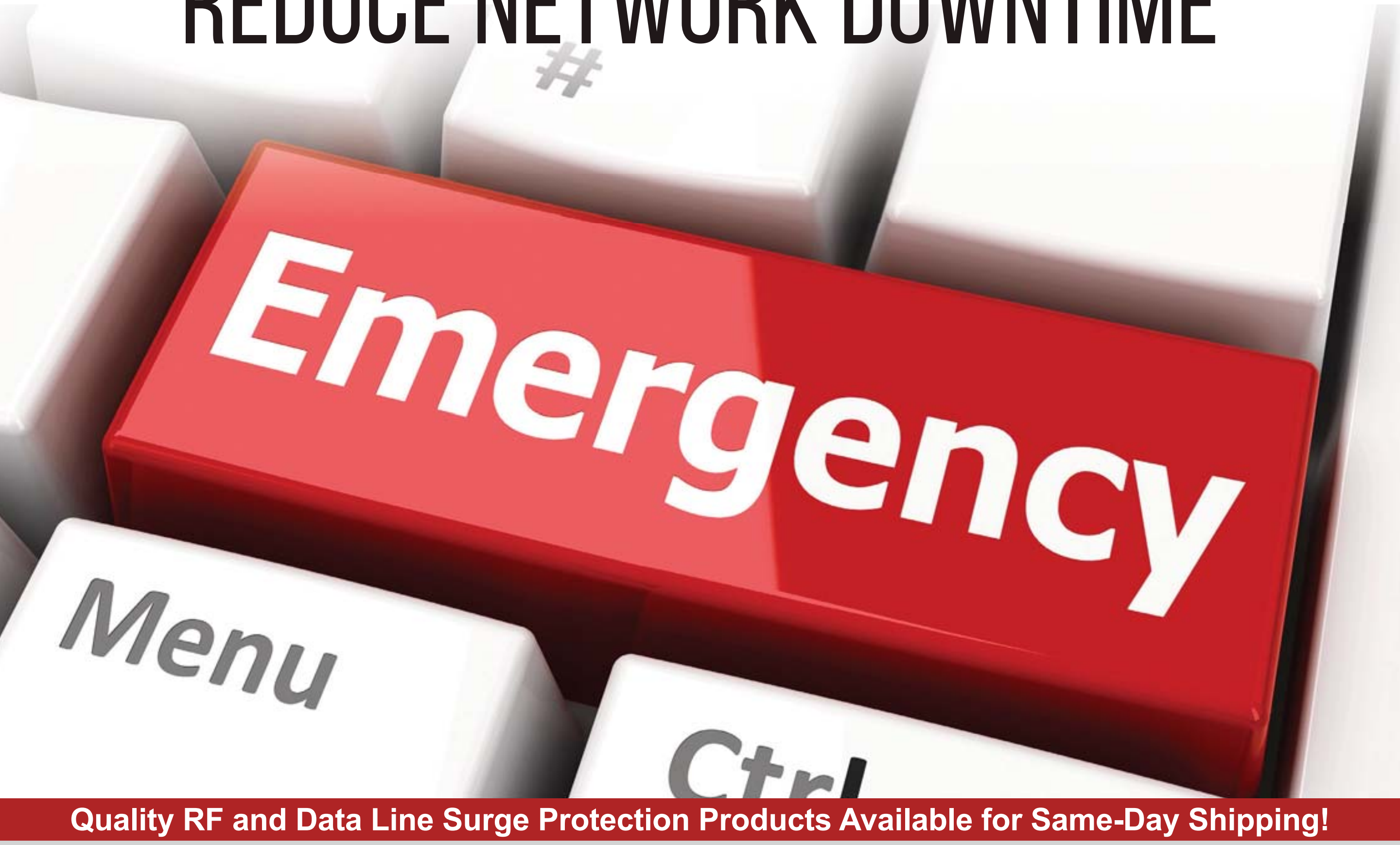

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In both multiplexing formats, a wideband wireless carrier signal at a high data rate is divided into a large set of closely narrowband subcarriers at much lower data rates and then transmitted. To avoid interference between subcarriers, they are orthogonal to each other. The data is divided among all of the subcarriers whereby if any of the subcarriers is degraded or corrupted because of interference, the data can be restored by means of error-correction techniques. At the receiver, the subcarriers with their data contributions are combined to restore the initial high-speed transmission and its full data.

By using the orthogonal, low-data-rate subcarriers rather than the single high-data-rate carrier, the transmissions can minimize the effects of signal fading, multipath distortion, and interference from other signals within the same or nearby frequency spectrum. The low data rates of the subcarriers reduce the effects of intersymbol interference (ISI) that are typically more pronounced at higher data rates.

One drawback to OFDM is that a single user occupies each carrier with all its subcarriers at any one time. Multiple users are possible by means of static multiple-access schemes, such as having different transmission times per carrier/subcarriers for each user in a time-division-multiple-access (TDMA) scheme or different transmission frequencies in a frequency-division-multiple-access (FDMA) approach. However, these methods are not efficient in their use of time and/or frequency.

To develop a more efficient version of Wi-Fi 5, having multiple-user APs was an important consideration for Wi-Fi 6—in OFDMA, a single user does not occupy all of the subcarriers at any one time. For enhanced efficiency, the subcarriers are themselves divided among multiple users. Multiple users can access their assigned subcarriers by means of TDMA or FDMA, or both techniques simultaneously. APs use segments of frequency and time known as resource units (RUs) to manage multiple simultaneous users. Because the subcarriers are subdivided in this way, timing synchronization of the multiple Wi-Fi 6 users for a single AP is critical compared to Wi-Fi 5, adding to the complexity of transmitters, receivers, and APs *(Fig. 2)*.

2. Wi-Fi 6 adds capacity by using access points that enable many simultaneous users. *(Courtesy of Cisco Systems, www.cisco.com)*

TIMING IS EVERYTHING

Since multiple users will connect to a Wi-Fi 6 AP simultaneously, timing across the different users must be precise to minimize interference among subcarriers. For Wi-Fi 6 wireless networks to achieve the highest capacity, it's essential to minimize interference between simultaneous users.

Synchronization of multiple users is achieved by a trigger frame broadcast by the AP. The trigger frame contains information about when different users and devices can transmit and which subsets of OFDMA subcarriers' RUs to use. The precise timing required among different users and within each AP emphasizes the importance of the reference-clock oscillators within Wi-Fi 6—they must have extremely low phase noise and low jitter with excellent long-term frequency stability.

For environments with obstructions or interference sources, using different subcarriers per user can be programmed by location to avoid the loss of data due to multipath or fading. In contrast to OFDM, in which all subcarriers are transmitted at the same power level, the subcarriers in ODFMA can be broadcast at different power levels. It's an additional weapon against fading that might occur in part of the frequency spectrum in an operating environment. As with OFDM, in OFDMA, each user's multiple low-data-rate subcarriers are combined at the receiver to form the high-speed data that was originally transmitted for access by that user.

An OFDMA AP can change the amount of frequency spectrum or subchannels occupied by each user depending on the demands of their wireless connections. For example, less bandwidth is needed to send an e-mail than to send streaming video to a Wi-Fi receiver. This functionality boosts the efficiency of Wi-Fi 6 compared to Wi-Fi 5, but also increases the complexity of the hardware in terms of frequency alignment, stability, and accuracy, timing synchronization, and response time of wireless-network system components.

ACHIEVING CONTROL OF POWER

Power control is needed in Wi-Fi 6 systems because of its OFDMA and due to multiple users with simultaneous access to the wireless network. A user close to the AP would present a higher-power signal to the AP than a user operating at the outer sensitivity limits of the AP. If the power levels of multiple users are not balanced, network performance will be compromised by intercarrier interference (ICI) and compression when a Wi-Fi receiver attempts to process multiple signals across a wide dynamic range. Wi-Fi 6 devices will increase or decrease their transmit power levels within a certain response time according to downlink signals from an AP.

This dynamic transmit power control (DTPC) feature of Wi-Fi 6 networks can, of course, be compromised by devices that ignore the power-control instructions in a downlink signal or because they simply lack the power-control capability (as with earlier-generation Wi-Fi devices). The amount of power control and how accurately power is controlled for each device is defined within the Wi-Fi 6 (802.11ax) standard. Devices with tight control of power, within ±3 dB, are considered Class A

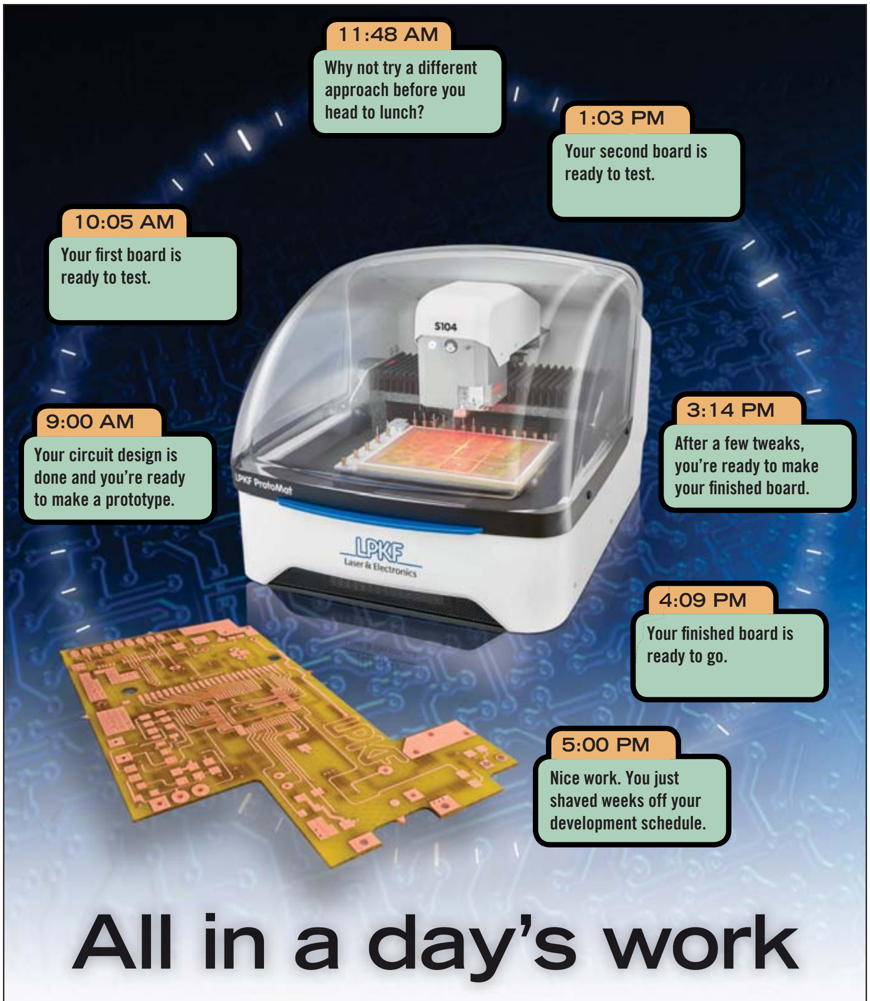
devices, while devices capable of ±9 dB control of power are referred to as Class B devices, somewhat in the manner of amplifier linearity classes.

Wi-Fi 6 includes several unique features to help boost capacity in dense environments, such as convention centers and other public meeting places, and save power for devices like IoT sensors that may only require occasional network access. Basic service set (BSS) coloring identifies shared frequency spectrum by a number or "color code" included within the network physical-layer (PHY) header that's communicated between each device and its AP. BSS makes it possible for Wi-Fi 6 devices to communicate and negotiate with each other to optimize use of shared channel bandwidth. BSS coloring indicates when a channel is unavailable—when two or more devices are coded by the same color. It also provides information to manage multiple devices and users in congested areas by adjusting clear-channel-assessment (CCA) parameters, including dynamic range and power control.

Another unique feature of Wi-Fi 6—target wake time (TWT)—is a method for an AP to monitor device requirements and turn its Wi-Fi 6 radio on and off as needed. For example, one of the devices within range of a Wi-Fi 6 AP may be an IoT proximity sensor that does not require continuous radio contact with the network. The TWT feature can be used to periodically activate the IoT sensor. In working this way, the TWT function can improve network efficiency and conserve battery life in portable/mobile devices.

For multiple users in dense environments with a great many wireless devices, Wi-Fi 6 builds upon the multiple-user, multiple-input, multiple-output (MU-MIMO) antenna configurations used in Wi-Fi 5, with extended capabilities. Wi-Fi 5 routers, with their multiple antennas, are designed to handle as many as four simultaneous users or data streams. Large data transfers are possible, but only on downlinks from routers or APs to user devices.

In contrast, the MU-MIMO antenna arrangements of Wi-Fi 6 support as many as eight simultaneous spatial data streams for eight simultaneous users, without buffering delays, on both downlinks and uplinks between APs and wireless devices. As a result, Wi-Fi 6 wireless networks can handle large data transfers back and forth between wireless devices and APs without data buffer delays. Therefore, a greater number of users (than Wi-Fi 5) per AP can enjoy even data-intensive applications, such as video streaming, simultaneously.


11:48 AM
Why not try a different approach before you head to lunch?
1:03 PM
Your second board is ready to test.
10:05 AM
Your first board is ready to test.
9:00 AM
Your circuit design is done and you're ready to make a prototype.
3:14 PM
After a few tweaks, you're ready to make your finished board.
4:09 PM
Your finished board is ready to go.
5:00 PM
Nice work. You just shaved weeks off your development schedule.
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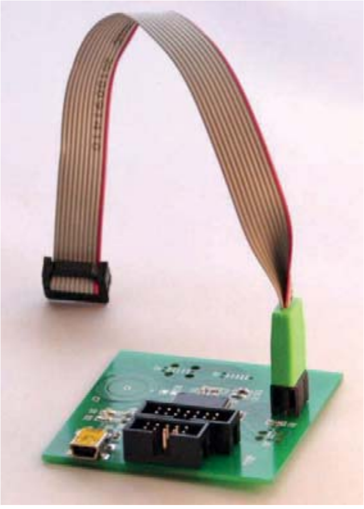
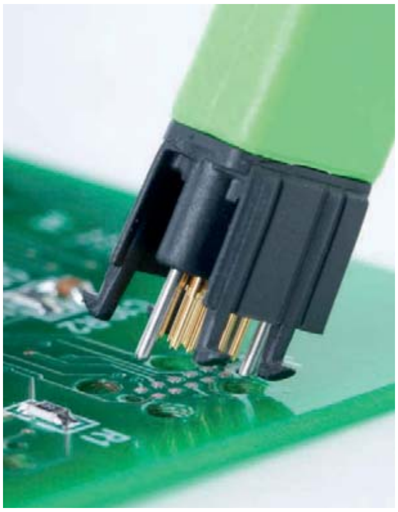
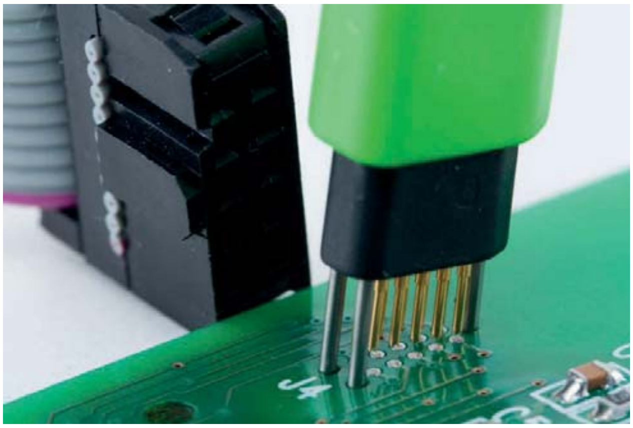
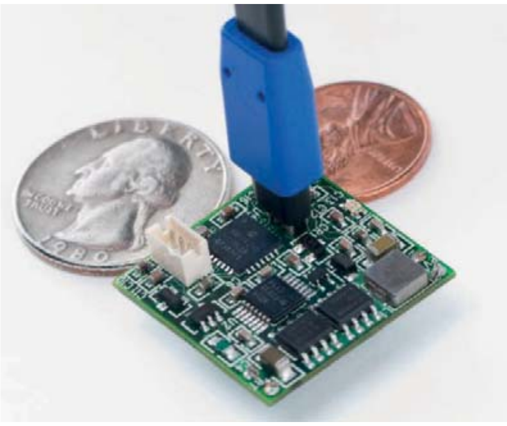








USING THE BANDWIDTH

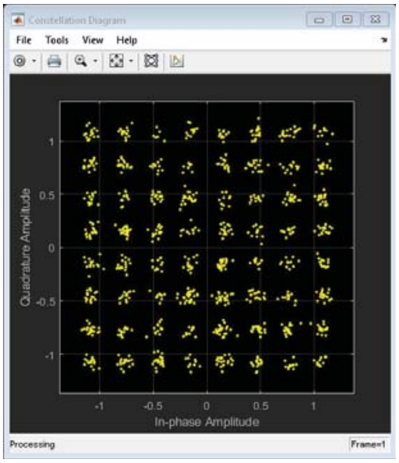
Although Wi-Fi capacity and efficiency will be enhanced by OFDMA and MU-MIMO technologies, the number of users that can be supported per channel starts with available spectrum and channel bandwidth. While Wi-Fi 6 shares the frequency spectrum used by Wi-Fi 5 in the 5-GHz band, from 5.170 to 5.185 GHz with some small gaps, it also takes advantage of the legacy available frequency spectrum in the unlicensed 2.400- to 2.483-GHz portion of the industrial, scientific and medical (ISM) bands. With four spectral streams in the 2.4-GHz band and eight more possible in the 5-GHz range, and channel bandwidths of 20, 40, 80, and 160 MHz available (with wider-bandwidth channels supporting higher data rates), many more users can be supported with Wi-Fi 6 than the four spectral streams of Wi-Fi 5.

To add to the capacity of Wi-Fi 6, regulatory agencies such as the Federal Communications Commission (FCC) in the U.S. and European Telecommunications Standards Institute (ETSI) throughout Europe have approved the use of wide contiguous bandwidth in the 6-GHz range starting in 2022. The additional bandwidth is for use by Wi-Fi 6 devices and 5G cellular wireless networks, but not by earlier-generation Wi-Fi systems, such as Wi-Fi 4 (IEEE 802.11n) and Wi-Fi 5.

The 6-GHz band approved by the FCC for Wi-Fi 6 spans 1200 MHz from 5.925 to 7.125 GHz and is identified by Unlicensed National Information Infrastructure (UNII) radio-frequency bands 5 through 8 *(Table 2)*. This generous portion of contiguous bandwidth at 6 GHz will make possible more wideband (160-MHz) channels for high-data-rate transmissions than at the lower-frequency 2.4- and 5-GHz bands, where the Wi-Fi channels tend to compete with more legacy applications and must operate within more narrowband channels.

TABLE 2: SPECTRUM TO COME FOR WI-FI 6—THE 6-GHz BAND

UNII band	Frequency range (MHz)	Bandwidth (MHz)
5	5925 to 6425	500
6	6425 to 6525	100
7	6525 to 6875	350
8	6875 to 7125	250



3. 1024QAM is one of the features implemented in Wi-Fi 6 for increased data speed and capacity. This diagram shows a QAM constellation diagram with 64 symbols. *(Courtesy of MathWorks, www.mathworks.com)*

To efficiently use the available bandwidth with enhanced data throughput, Wi-Fi 6 employs quadrature-amplitude-modulation (QAM) formats at levels as high as 1024-state QAM (1024QAM). This contrasts with the lower-order 256-state QAM (256QAM) of Wi-Fi 5. 1024QAM enables digital bit resolution of 10 bits per symbol in a constellation diagram *(Fig. 3)*, for as much as 25% more data-handling capacity than the 8-bit-per-symbol resolution for 256QAM used with Wi-Fi 5.

On the downside, the 1024QAM data mapping that takes place at a Wi-Fi 6 transmitter, to achieve the conversion of digital bits to I/Q symbols, places great demands on the linearity of power amplifiers (PAs) used for transmissions in a 1024QAM system—more so than in 256QAM systems. If power amplification is not linear and the ratio of the energy per bit to the noise level (Eb/N0) is not properly controlled, data errors can be readily introduced into higher-order QAM systems such as 1024QAM.

EVOLVING TO MEET DEMAND

Whether it's called IEEE 802.11 or Wi-Fi, wireless networks have become an increasingly important part of many lives worldwide, whether in fixed environments such as homes or factories or in large public domains like convention centers, museums, or even in a sporting stadium. Demand for increased capacity and throughput speeds grows as users add more wireless devices to each network and expect faster response times as they download large files or even stream their favorite video programming.

Wi-Fi 6, the former IEEE 802.11ax, builds on the technology legacies of earlier Wi-Fi generations to maintain compatibility with older wireless devices at 2.4 GHz. Simultaneously, it provides increased capacity and enhanced data rates within the 5-GHz channels of newer Wi-Fi generations.

It's a wireless standard that's also poised for evolution, with special features to help save power when networking requirements are minimal or when hordes of new IoT sensors are added in range of a wireless network and must be periodically monitored for their contributions—without "breaking the bank" in power consumption.

And, for the large amounts of new data expected from the next generation of wireless cellular communications systems, namely 5G, Wi-Fi 6 promises something that no earlier Wi-Fi generation can offer: Access for growth into some of the new bandwidth being made available within the 6- to 7-GHz range. If used wisely, this combination of new features and bandwidth should make Wi-Fi 6 a capable companion technology for 5G for many years to come.

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Remote wireless devices connected to the Industrial Internet of Things (IIoT) run on Tadiran bobbin-type $LiSOCl_2$ batteries.

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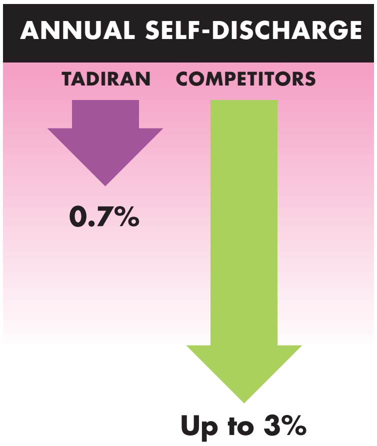

Looking to have your remote wireless device complete a 40-year marathon? Then team up with Tadiran batteries that last a lifetime.

TADIRAN BATTERIES

Tadiran Batteries
2001 Marcus Ave.
Suite 125E
Lake Success,
NY 11042
1-800-537-1368
516-621-4980

www.tadiranbat.com

* Tadiran $LiSOCL_2$ batteries feature the lowest annual self-discharge rate of any competitive battery, less than 1% per year, enabling these batteries to operate over 40 years depending on device operating usage. However, this is not an expressed or implied warranty, as each application differs in terms of annual energy consumption and/or operating environment.

SOL JACOBS | VP & General Manager, Tadiran Batteries

How Long Do Your Batteries Need to Run?

Primary battery chemistries differ in their performance capabilities. Some offer faster discharge rates (sprinters), while others deliver microamps of energy for extended operating life (long-distance runners).

While primary (non-rechargeable) batteries are ubiquitous in modern society, often overlooked are the differences between consumer-grade and industrial-grade batteries.

On the consumer side, many applications require batteries that can deliver higher discharge rates of energy, resulting in very short operating life (alkaline). Consumer-grade lithium batteries can deliver medium to high discharge rates of energy with short to medium operating life. These primary lithium chemistries include iron disulfate ($LiFeS_2$), lithium manganese dioxide ($LiMNO_2$), etc. *(Table 1).*

On the opposite side of the spectrum are a growing number of low-power remote wireless devices that use very small amounts of energy, measurable in microamps of average current. Many of these devices are connected to the Industrial Internet of Things (IIoT), supporting applications that require decades of maintenance-free operation without battery replacement.

ONLY CERTAIN BATTERIES CAN OPERATE FOR DECADES IN EXTREME ENVIRONMENTS

Lithium-based batteries have high intrinsic negative potential, exceeding that of all other metals, with an operating current voltage (OCV) ranging from 2.7 to 3.6 V. Lithium batteries are also non-aqueous, with the absence of water enabling them to endure extreme temperatures without freezing.

Among the available chemistries, bobbin-type lithium-thionyl-chloride ($LiSOCl_2$) cells are overwhelmingly preferred for remote wireless applications in extreme environments, where average current discharge is measurable in microamps. Bobbin-type $LiSOCl_2$ batteries feature the highest capacity and highest energy density of any lithium chemistry, along with an extremely low annual self-discharge rate (less than 1% per year), enabling certain low-power devices to operate for up to 40 years.

This chemistry also features the widest temperature range (−80 to 125°C), and a glass-to-metal hermetic seal that helps prevent battery leakage. Typical applications include AMR/AMI metering, M2M, SCADA, tank-level monitoring, asset tracking, and environmental sensors, to name a few.

PASSIVATION EFFECT REDUCES BATTERY SELF-DISCHARGE

All batteries suffer from self-discharge, where cell capacity is exhausted even when the battery isn't connected to an external load.

Controlled passivation, which is unique to bobbin-type $LiSOCl_2$ batteries, can greatly reduce self-discharge. Passivation occurs when a thin film of lithium chloride (LiCl) forms on the surface of the lithium anode, thus impeding the

TABLE 1: COMPARISON OF PRIMARY LITHIUM CELLS

Primary Cell	LiSOCL2 Bobbin-type with Hybrid Layer Capacitor	LiSOCL2 Bobbin-type	Li Metal Oxide Modified for high capacity	Li Metal Oxide Modified for high power	Alkaline	LiFeS2 Lithium Iron Disulfate	LiMn02 CR123A
Energy Density (Wh/1)	1,420	1,420	370	185	600	650	650
Power	Very High	Low	Very High	Very High	Low	High	Moderate
Voltage	3.6 to 3.9 V	3.6 V	4.1 V	4.1 V	1.5 V	1.5 V	3.0 V
Pulse Amplitude	Excellent	Small	High	Very High	Low	Moderate	Moderate
Passivation	None	High	Very Low	None	N/A	Fair	Moderate
Performance at Elevated Temp.	Excellent	Fair	Excellent	Excellent	Low	Moderate	Fair
Performance at	Excellent	Fair	Moderate	Excellent	Low	Moderate	Poor
Low Temp.							
Operating life	Excellent	Excellent	Excellent	Excellent	Moderate	Moderate	Fair
Self-Discharge Rate	Very Low	Very Low	Very Low	Very Low	Very High	Moderate	High
Operating Temp.	-55°C to 85°C, can be extended to 105°C for a short time	-80°C to 125°C	-45°C to 85°C	-45°C to 85°C	-0°C to 60°C	-20°C to 60°C	0°C to 60°C

FREE WEBINAR

December 19, 2019 | 2:00pm EST

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THE FUTURE OF MODELING IS HERE

Simulation applications run on any hardware, including phones, tablets, and desktop computers.

Ever since the first days of space flight, mathematical modeling that simulates processes, devices, and other physical phenomena has become an integral part of the research and development of engineering designs. However, it has also been restricted to engineers who are experts in the physics being modeled, the software to model such phenomena, or both.

The future of modeling is here. Software that was once the complete tool for mathematical modeling is now the platform to develop simpler and more focused simulation applications for the specific product or process that an engineer is working with. Expanding the use of mathematical simulations to a much larger audience of engineers can only increase the efficiency of accurately modeling processes and decrease the time it takes to bring products to market. The simulation engineer knows the physics, but the design or manufacturing engineer knows the device or process.

This webinar will trace the development of mathematical modeling of complex and multiphysics phenomena from its beginnings to where it is now as well as discuss its future, where mathematical modeling will be taken to the next level.

SPEAKER: Phil Kinnane, VP of sales, COMSOL

Phil Kinnane is the VP of sales at COMSOL, Inc. He has previously worked within the Business Development, Operations, and Marketing departments. Phil has 20 years of experience with modeling and simulation for all fields of engineering. He earned his PhD in electrochemical engineering from the Royal Institute of Technology, Stockholm.

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chemical reactions that result in battery self-discharge. When a load is placed on the cell, the passivation layer causes high initial resistance, resulting in a temporary drop in cell voltage until the discharge reaction slowly removes the passivation layer—a process that repeats itself every time the load is removed.

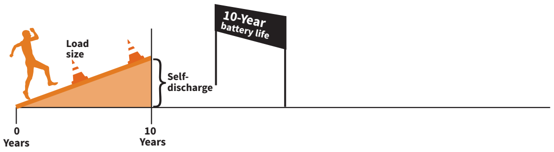
Various factors can influence passivation, including the current capacity of the cell, length of storage, storage temperature, discharge temperature, and prior discharge conditions. Partially discharging a cell and then removing the load increases the amount of passivation relative to when the cell was new.

Passivation involves tradeoffs, too. It's necessary to reduce battery self-discharge rate, but too much of it can block energy flow.

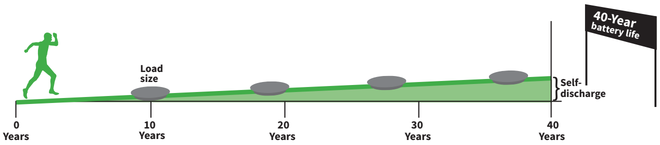
Bobbin-type $LiSOCl_2$ batteries can also be designed with lower amounts of passivation to deliver medium energy-flow rates and higher self-discharge, resulting in a shorter lifespan of 10-15 years.

In addition, battery self-discharge is impacted by the quality of the raw materials and the way the battery is manufactured. For example, a lower-quality bobbin-type $LiSOCl_2$ battery designed for ultra-long life can lose 3% of its normal capacity each year to self-discharge. Thus, 30% of its initial capacity is exhausted every 10 years, making 40-year battery life impossible to achieve. By contrast, a superior quality bobbin-type $LiSOCl_2$ battery can feature a self-discharge rate of 0.7% per year, retaining 93% of its original capacity after 10 years, enabling a 40-year marathon.

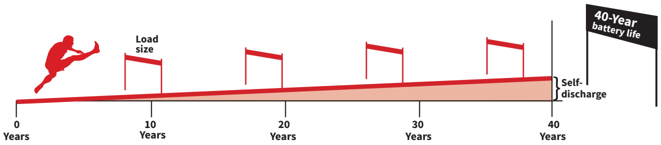
Medium Rate Bobbin-type Lithium Thionyl Chloride



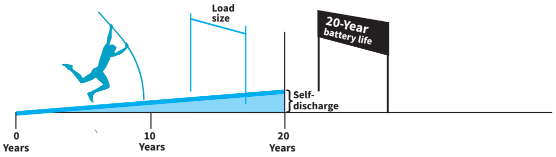
Low Rate / Low Self-Discharge Bobbin-type Lithium Thionyl Chloride



High Rate / Low Self-Discharge Bobbin-type Lithium Thionyl Chloride with Hybrid Layer Capacitor



TLM - Lithium Metal Oxide



THE RACE ANALOGY: SEPARATING THE SPRINTERS FROM THE MARATHONERS

The Distance is equivalent to the battery/device operating life. The longer the runner can run, the more years a device will be able to operate.

The Incline is equivalent to the battery self-discharge. The higher the self-discharge rate, the larger the incline. Just as the incline draws more power from the runner and shortens his run, the self-discharge of the battery reduces the availability of useful power for device operation and lowers the operating life.

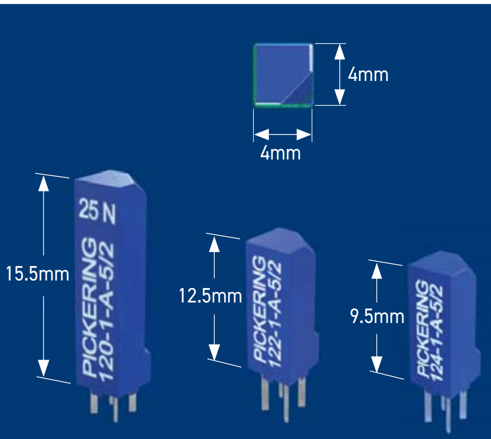
Hurdles are equivalent to pulses. The higher the hurdle, or obstacle, the higher the pulse ability of the battery.

Generally, applications that require very high energy drain rates and high pulses, such as medical power tools, with average current measurable in amps, may be well-suited for lithium metal-oxide batteries. Applications requiring moderate rates of discharge, measurable in milliamps to amps, such as powering a flashlight or consumer toy for limited operating times, may be best suited for alkaline, $LiFeS_2$, and $LiMNO_2$ batteries that are able to deliver medium pulses.

Ultra-long-life, low-drain applications, with average current measurable in microamps, including many remote wireless sensors, require the use of standard bobbin-type $LiSOCl_2$ batteries that can run marathons due to their very low self-discharge rates. However, they're not designed to deliver high pulses due to their low rate design.

For ultra-long-life applications that require periodic high pulses of energy to power two-way wireless communications, standard bobbin-type $LiSOCl_2$ batteries must be modified using a patented hybrid layer capacitor (HLC). The standard bobbin-type $LiSOCl_2$ cell delivers low daily background current (to continue running marathons) while the HLC delivers periodic high pulses (for steeple jumping). The patented HLC also features a special end-of-life voltage plateau that can be interpreted to deliver low-battery status alerts.

Supercapacitors deliver high pulses electrostatically rather than chemically. Supercapacitors are often used in consumer electronics where environmental conditions are moderate (indoor track). However, supercapacitors are rarely used in industrial applications (cross-country running) due to inherent drawbacks such as short-duration power, linear discharge qualities that prevent use of all available energy, low capacity, low energy density, and high annual self-discharge rates (up to 60% per year). Supercapacitors linked in series also require the use of cell-balancing circuits, which adds to their cost and bulkiness and consumes additional energy, increasing their self-discharge rate even further.



SHORT-TERM TESTS FAIL TO SIMULATE A MARATHON

Long-term battery performance is difficult to simulate with short-term tests, so appropriate methods must be used to deliver verifiable results that predict long-term performance. Proven techniques include:

- *Long-term laboratory testing:* The ideal way to monitor battery self-discharge is to continually test batteries over time under various conditions, covering almost every possible scenario. The accumulated data points can measure cell size, temperature, load size, etc., resulting in a vast and ever-growing database that enables highly accurate predictive models.
- *Accelerated testing:* The Arrhenius equation (involving a two-fold increase of reaction rate for every 10°C rise in temperature) can be helpful in shortening the time it takes to simulate long-term operation. Arrhenius tests are run at 72°C, equivalent to about 32 times the theoretical lifetime of battery at 22°C. However, short-term tests using the Arrhenius method tend to show inaccurate results.
- *Calorimeter testing:* A highly accurate test method is to measure actual heat-energy losses using a state-of-the-art microcalorimeter, which can detect energy dissipation down to the 0.1-W level.

Heat energy is generated three ways: entropy change, often referred to as reversible heat; cell over-protection, often referred to as irreversible heat; and chemical reactions, including self-discharge reactions that affect cell capacity, and side reactions that don't affect cell capacity.

Calorimeter testing can measure losses in battery capacity caused during long-term storage or operation (including self-discharge), which is typically computed using thermodynamic equations and cell-voltage considerations. Accurate long-term tests require that the batteries be stabilized for one year prior to testing, as self-discharge during the first year tends to be higher than subsequent years. Other test methods include:

- *Lithium titration:* In special circumstances, where sufficient long-term data points may not be available (i.e., exposure to extreme temperatures, prolonged high current pulses, short lifetime applications, etc.), lithium titration can be used to measure available cell capacity. The battery is cut open, and titration is used to dissolve the remaining lithium. The higher the self-discharge rate, the less amount of lithium will remain in the cell.
- *Field results:* Lab tests create theoretical models that can be verified using actual results from the field. For example, Tadiran works closely with its customers to randomly test batteries taken from long-term deploy-

Design Note

ADI's RF Front-End Family Enables Compact 5G Massive MIMO Network Radios

Bilge Bayrakci

Massive multiple input, multiple output (M-MIMO) radios have seen their popularity surge in the late stage deployment of 4G LTE cellular base stations, particularly in dense urban areas where small cells effectively filled the cellular coverage voids while boosting higher data speed services. The success of this architecture clearly proved its worth. It is poised to be the architecture of choice for nascent 5G network radios, as required spectral efficiency and transmission reliability characteristics are inherent to this architecture. The challenge to making 5G a reality is that designers must vastly increase the number of simultaneous transceiver channels operating in multiple bands, while also squeezing all the necessary hardware into a form factor that is as large as or smaller than the previous generation's equipment.

The implications of doing so are:

- More channels means higher concentrated RF power in and around the base station, so the problem of isolation between channels without mutual interference is exacerbated.
- Receiver front-end components must have improved dynamic range performance in order to remain robust in the presence of high power signals.
- Solution size matters.
- Thermal management must be addressed with the increased electronics' and transmitters' power.

In this quest for higher data rates to support a variety of wireless services and different transmission schemes, system designers face higher circuit complexity but must meet similar budgets for size, power, and cost. Adding more transceiver channels in a base station tower yields higher throughput, but utilizing each channel at a higher RF power level is equally essential for keeping system complexity and cost at acceptable levels. For higher RF power, hardware designers do not have many alternatives in their RF front-end design but to rely on legacy solutions that need high bias power and complex peripheral circuits, which makes achieving design goals more difficult.

Analog Devices recently introduced an integrated high power switch with a low noise amplifier (LNA) in multichip modules for time division duplex (TDD) systems. The ADRF5545A/ADRF5547/ADRF5549 family covers cellular bands from 1.8 GHz to 5.3 GHz and it is optimally designed for M-MIMO antenna interfaces. Incorporating a high power switch in silicon process and a high performance low noise amplifier in GaAs process, this new family of devices offers high RF power handling capability together with high integration without any compromise—meaning it's the best of both worlds.

Dual-Channel Architecture

An ADRF5545A/ADRF5547/ADRF5549 application block diagram for a M-MIMO RF front-end design is shown in Figure 1. The device has channels that incorporate a high power switch followed by a two stage LNA. During receive mode operation of the transceiver, the switch routes the input signal to the LNA input. During transmit mode, the input is routed to a 50 Ω termination to ensure proper matching to the antenna interface and to isolate the LNA from any reflected power from the antenna. The integrated dual-channel architecture allows designers to easily scale their MIMO to exceed the legacy equipment's limit of 8 × 8 (8 transmitter × 8 receiver) configurations—to 16 × 16, 32 × 32, 64 × 64, and beyond.

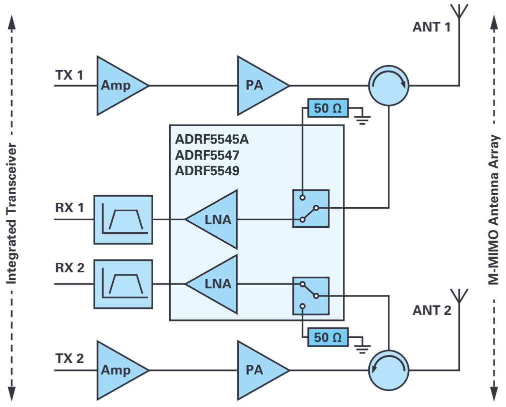


Figure 1. M-MIMO RF front-end block diagram.

Wide Operation Bandwidth

ADRF5545A/ADRF5547/ADRF5549 gain characteristics of each device and their respective frequency coverage is shown in Figure 2. Parts are optimized for commonly used cellular bands and aligned with other tuned components used in the same design, such as power amplifiers and filters.

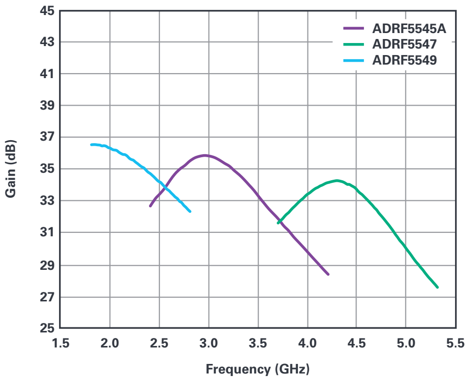


Figure 2. ADRF5545A/ADRF5547/ADRF5549 gain characteristics.

High Power Protection Switch

The device incorporates a high power switch designed in silicon process that does not need any external components for bias generation. The switch runs on a single 5 V supply with only 10 mA current consumption and can interface to standard digital microcontrollers directly without need for any negative voltages or level shifters. Compared to an implementation using PIN diode-based switches, the silicon switch saves the user around 80% bias power and 90% circuit board area.

The switch can handle 10 W average RF signal with 9 dB peak-to-average ratio (PAR) in continuous operation and can withstand double the rated power in a fault condition. The ADRF5545A/ADRF5547/ADRF5549 are the first products in the market that feature 10 W power handling capability, which makes them ideal for high power M-MIMO designs. If more power can be transmitted from each antenna element, the number of transmit channels can be reduced to get the same RF power out of the base station. The ADRF5545A/ADRF5547/ADRF5549 architecture is shown in Figure 3, which reveals that the high power switch for both channels are supplied and controlled on the same device pin. The LNAs have their supplies and control signal separate.

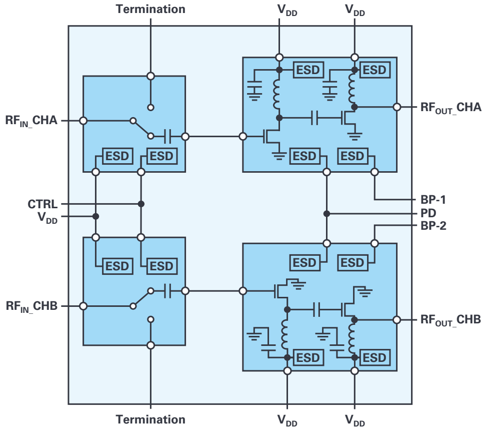


Figure 3. ADRF5545A/ADRF5547/ADRF5549 circuit architecture.

Low Noise Figure

A two stage LNA is designed in GaAs process, supplied by a single 5 V supply, and does not need any external bias-tee inductors. The gain has flat characteristics over frequency and is programmable to 32 dB and 16 dB in high and low gain modes, respectively. The device also features a low power mode to save bias power where the LNAs can be powered down during transmit operation. The device has a noise figure of 1.45 dB including the insertion loss of the switch, which is well suited both for high power and lower power M-MIMO systems. Figure 4 shows the noise figure performance of the ADRF5545A/ADRF5547/ADRF5549 in specified bands.

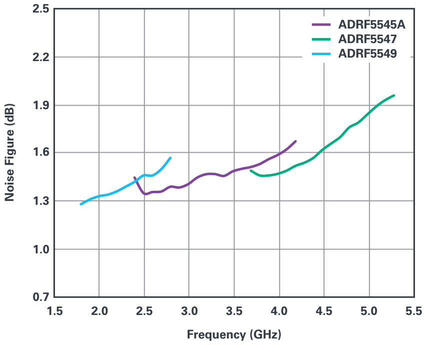


Figure 4. ADRF5545A/ADRF5547/ADRF5549 noise figure.

Compact Size, Minimum Set of External Components

Besides the primary decoupling capacitors on supply pins and dc blocking capacitors on the RF signal pins, the device does not need any tuning or matching components. The RF input and outputs are 50 Ω matched. The LNA has the matching and bias inductors integrated in the design. This reduces the bill of material for expensive components such as inductors, but also simplifies the hardware design for channel-to-channel crosstalk between adjacent transceivers. The device comes in a 6 mm × 6 mm surface mountable package with a thermally enhanced bottom paddle. The device is specified to operate at case temperature in the range from –40°C up to +105°C. All three parts are assembled in the same package and have the same pinout. They can be used interchangeably on the same circuit board. The device is shown as mounted on its evaluation board in Figure 5. Evaluation boards are available from ADI directly or through its distributors.

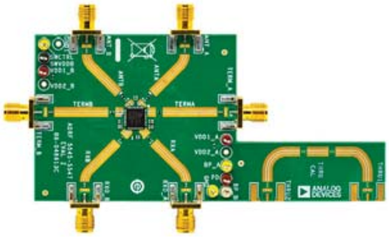


Figure 5. ADRF5545A/ADRF5547/ADRF5549 evaluation board.

Detailed technical information, product data sheets, and other supporting documentation can be found in product pages on *analog.com*.

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ments to demonstrate in real-life how long-term exposure to extreme temperatures can affect battery self-discharge.

Another useful indicator is to calculate the number of failures in time (FITs), measurable in billions of device operating hours for devices in the field. For example, Tadiran batteries achieve FIT rates ranging between 5 and 20 batteries per billion, which is extremely low compared to the industry average.

HOW TO CHOOSE AN INDUSTRIAL-GRADE BATTERY

Short-term tests generally under-represent the true effects of passivation and long-term exposure to extreme temperatures. If extended battery life is a critical requirement, then thorough due diligence must be performed to properly evaluate competing batteries. Complete verification requires fully documented long-term test results, in-field performance data from similar applications, and customer references.

Obtaining verifiable test data is essential to critical applications such as meter transmitter units (MTUs) used in AMR/AMI utility metering, as a large-scale battery failure can disrupt customer billing systems and disable remote service startup and shutoff capabilities. The possibility of such wide-scale chaos could force a utility to prematurely invest millions of dollars to replace batteries early so as not to jeopardize data integrity.

TABLE 2: CONSUMER VS. INDUSTRIAL LI-ION RECHARGEABLE BATTERIES

		TLI-1550 (AA)	Li-Ion
		Industrial Grade	18650
Diameter (max)	[cm]	1.51	1.86
Length (max)	[cm]	5.30	6.52
Volume	[cc]	9.49	17.71
Nominal Voltage	[V]	3.7	3.7
Max Discharge Rate	[C]	15C	1.6C
Max Continuos Discharge Current	[A]	5	5
Capacity	[mAh]	330	3000
Energy Density	[Wh/l]	129	627
Power [RT]	[W/liter]	1950	1045
Power [-20C]	[W/liter]	> 630	< 170
Operating Temp	deg. C	-40 to +90	-20 to +60
Charging Temp	deg. C	-40 to +85	0 to +45
Self Discharge rate	[%/Year]	<5	<20
Cycle Life	[100% DOD]	~5000	~300
Cycle Life	[75% DOD]	~6250	~400
Cycle Life	[50% DOD]	~10000	~650
Operating Life	[Years]	>20	<5

Other factors need to be considered when specifying an industrial-grade lithium battery, including the amount of current consumed in active mode (along with the size, duration, and frequency of pulses); energy consumed in standby or sleep mode (the base current); storage time (as normal self-discharge during storage diminishes capacity); expected temperatures (including during storage and in-field operation); equipment cutoff voltage (as battery capacity is exhausted, or in extreme temperatures, voltage can drop to a point too low for the sensor to operate).

If a remote wireless application draws milliamps of average current, this may be enough to prematurely exhaust a primary battery. In some cases, the application may better suited for an energy-harvesting device in conjunction with a rechargeable lithium-ion (Li-ion) battery to store the harvested energy.

Consumer-grade rechargeable Li-ion batteries can operate for up to five years and 500 recharge cycles, within a moderate temperature range, and no ability to deliver high pulses (an easy 10K jog at moderate temperatures with no big hills). By contrast, industrial-grade rechargeable Li-ion batteries can operate for up 20 years and 5,000 full recharge cycles (half-marathoners). Other benefits of industrial grade Li-ion batteries include the ability to be charged and discharged at extreme temperatures, and the ability to deliver up to 15-A pulses to power two-way wireless communications *(Table 2)*.

Every application is unique, so it's important to specify the right battery, be it a sprinter (high discharge potential); a medium distance runner (moderate to high discharge rate with fairly low self-discharge); or a 40-year marathoner (including elite runners who can jump periodic high pulse hurdles). ed

RICHARD BELLAIRS | Perforce Software
www.perforce.com

Survey Says Safety, Security, Quality Software Dev are Top Auto Industry Concerns

A recent survey among 400 automotive design professionals uncovered opinions around current trends in automotive software development in modern vehicle design, highlighting new processes, tools, and standards.

We all know that modern vehicles depend heavily on software, not just physical components. Ensuring that software is safe, secure, and of high quality are clearly high priorities. However, the results of a recent survey among automotive design professionals suggest that many find it challenging to address those concerns during the development of that software, including compliance to ISO 26262 requirements (necessary for the majority of those surveyed).

Depending on the vehicle, whether a standard modern passenger car through to a more sophisticated connected one, there might be up to a billion lines of code. The scale and complexity of those codebases will continue to grow as the market for connected and autonomous vehicles accelerates (to upwards of three hundred million lines of code). Of those surveyed, 74% are already working with connected components to a lesser or greater degree. Similarly, 70% are involved in autonomous vehicle design.

DEVELOPMENT CHALLENGES

With projects having teams and external contributors from various companies and all over the world, keeping control over software-development projects requires lots of hard work. One survey respondent mentioned that over 30 software vendors are involved in a single vehicle design. On top of that, complex interactions between hardware and software can bring major organizational and process challenges, adding complexity and exacerbating risk.

The good news from the survey results is that there are signs that companies are beginning to adopt methods to deal with these challenges—ultimately to make software safer, more secure, and high quality. Widely available methodologies, standards, and tools support those efforts; more on that later. First, here's an overview of the survey and the main results.

SURVEY RESULTS

The survey, commissioned by Perforce across 400 automotive design professionals around the world, asked a range of questions concerning software development in modern vehicle design. Respondents included employees from some of the world's largest tier 1 automotive brands, as well as a variety of other firms involved in vehicle design or component manufacture.

Of those who cited safety as their top concern, 49% said it was difficult and time-consuming to fulfill every requirement for ISO 26262, the functional safety standard that's widely adopted within the automotive industry. Almost a third said that verifying and validating software was the most time-consuming task, followed by documentation for ISO 26262 purposes (20%). Around 20% admitted that they found it challenging to ensure software safety across the supply chain.

Software quality was the highest concern for 20% of survey respondents and 42% expressed concern that their software testing efforts aren't exhaustive. And 35% said that they experienced difficulties in enforcing software coding best practices, which can have an impact on final software quality. About 20% also mentioned that the complexity of their codebases hinders software quality control.

Only 14% said security was their top concern, but of those, their biggest fear is hackers, which was highlighted by 55%. This isn't surprising, given several high-profile cyberattacks on connected vehicles hitting the news. Approximately 20% of respondents mentioned a lack of developer skills to combat security risks, and around the same percentage said that security testing takes too long and thus slows development.

ADDRESSING THESE CHALLENGES

Survey respondents indicated they're taking positive steps to deal with these multiple issues in several ways. For instance, 60% are using artificial intelligence (AI) and/or machine learning

(ML) within their software-development processes. While AI and ML are never likely to completely replace manual or human effort, they help automate complex processes, reduce risk, and most importantly, create a "learning" environment of continual improvement.

However, while AL and ML bring improvements, the use of coding standards is as important as ever. They're already used by 70% of survey respondents and anecdotally, usage is growing across all safety-critical markets. One of the drivers is the growing prevalence of C++, a programming language that gives developers lots of flexibility to be innovative, but also introduces far more room for interpretation and therefore risk. While C is still the top programming language used by survey respondents, C++ follows hot on its heels at almost 50%.

Coding standards can contribute hugely to software quality and compliance, making it easier to comply with ISO 26262 and other standards that require the use of coding standards.

A coding standard is a set of rules and/or guidelines that developers follow to prevent common defects entering code during development. For instance, a common example is when a program is receiving data without any checks in place to ensure that an input buffer can't overflow. Someone could design an input, or "payload" containing malicious code. A coding standard will include a rule to prevent this, along the lines of "do not form or use out-of-bounds pointers or array subscripts."

MISRA AND AUTOSAR

A collaboration between vehicle manufacturers, component suppliers, and engineering consultancies, MISRA is probably the best known in the automotive industry and has been around since the late 1990s. Oriented toward more modern versions of C++ in connected and autonomous vehicles, AUTOSAR is a partnership of over 180 companies with the common aim to standardize open architectures for automotive software and embedded-systems development. MISRA now plans to merge the AUTOSAR coding standard into the MISRA C++ standard, giving developers the best of both worlds.

Of the automotive survey respondents, MISRA is the most popular coding standard at 53%, closely followed by AUTOSAR at 45%. Teams are also using other coding standards, including C++ Core Guidelines, Embedded C (Barr Group), and CERT, and in many cases, employ multiple coding standards. Approximately 60% use static code analyzers to automate adherence to coding standards, thus reducing the additional workload on developers and minimizing the risk of errors.

In tandem, organizations around the world are looking at how software is tested, including greater emphasis on automated and continuous testing. The idea is that the more testing is automated, the "smarter" it can become. Moreover, the earlier and more frequently it happens, the faster it becomes to find and deal with problems.

NEW METHODOLOGIES AND PROCESSES

The survey's respondents are also revisiting the development methodologies and processes they're using, to achieve quality, security, and safety while still meeting time and market pressures. While the traditional Waterfall methodology is still used by just under a quarter, the most popular is Model Driven Development at 48%, followed by Agile at 45%. Others making the list include test-driven development and automatic code generation.

Model-driven development is at a higher abstraction level than traditional methods; as the model is developed, it's automatically transformed into a working software application. The result is a quicker development cycle with much less code. It's also easier and faster to change and maintain the model as the behavior can be more readily understood. Validation and testing can focus on the functionality rather than syntax checking, resulting in higher quality.

Greater use of Agile underlines the growing realization that Agile can work well in compliance-driven markets, whereas in its early days, it was often viewed as suitable for more disruptive, less safety-critical markets. It also reflects the fact that there's a shifting balance from hardware to software in many automotive projects. That's because when the two coexist, there can be huge logistical and cultural barriers to overcome.

Agile helps to engender better collaboration without sacrificing individual autonomy, but only when solid Agile project management is in place. Otherwise, there's the risk of losing control and missing goals.

The automotive industry is going through one of the most innovative and fast-changing periods in its history, presenting design engineers with exciting opportunities but also a new set of challenges. Software is now no longer an add-on. Instead, it's at the very heart of modern vehicle design. Making sure that it's developed safely, securely, and with consistent high quality—without adversely affecting time-to-market or competitiveness—is the name of the game. The challenges are big, but given the right tools and processes, they can be overcome.

A copy of the survey results is available at *https://www.perforce.com/resources/qac/state-of-automotive-software-development-2019*. ed

RICHARD BELLAIRS has 20+ years of experience across a wide range of industries. He held electronics and software engineering positions in the manufacturing, defense, and test-and measurement industries in the nineties and early noughties, before moving to product management and product marketing. He now champions Perforce's code quality management solution. Richard holds a Bachelor's in electronic engineering from the University of Sheffield.

BRAD REX | Senior Manager, Microcontroller Business Development, Renesas Electronics
KAUSHAL VORA | Director, Strategic Partnerships & Global Ecosystem, Renesas Electronics
www.renesas.com

Conquer the Common Security Challenges Plaguing Embedded IoT Designs

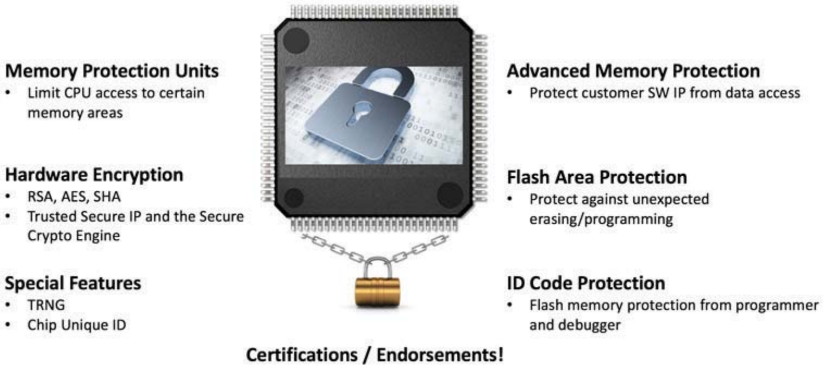
Multiple standards and new threats further complicate the already complex fabric of embedded IoT security. However, embedded developers can explore a number of approaches to build a stronger-than-ever root-of-trust.

Security is a fact of life for embedded IoT development—but that doesn't mean that it's simple or straightforward. In fact, even veteran developers can be puzzled by the multiple standards, evolving threats, and contrasting approaches to IoT security. Before starting design and development, embedded developers can explore a number of approaches to help ensure the security of their designs.

IoT SECURITY IS A MOVING TARGET

By 2020, the world will be home to an estimated 31 billion IoT (Internet of Things) devices—almost four times the number of humans on earth. However, many of these devices will have limited or flawed security controls that will make them vulnerable to hacking.

Why are so many IoT devices designed with weak security? The primary reason is that developers confront a phalanx of challenges and complexities as they begin securing their embedded applications and devices. The threat landscape continues to evolve while security standards multiply and grow more complex. Increasingly, applications are expected to meet multiple standards, limiting device compatibility and flexibility.


Memory Protection Units
• Limit CPU access to certain memory areas
Hardware Encryption
• RSA, AES, SHA
• Trusted Secure IP and the Secure Crypto Engine
Special Features
• TRNG
• Chip Unique ID
Advanced Memory Protection
• Protect customer SW IP from data access
Flash Area Protection
• Protect against unexpected erasing/programming
ID Code Protection
• Flash memory protection from programmer and debugger
Certifications / Endorsements!

1. What do you look for in a holistic security solution?

THE FOUNDATION FOR SECURING YOUR EMBEDDED DEVICE

Not so long ago, securing applications wasn't such an overriding concern as it is today, because most devices and applications weren't connected like they are now. Even the most basic items—from toasters to bathroom mirrors—can now be connected through the IoT to the internet or the cloud. In the rush to get these products to market, security is often overlooked or only addressed when it's too late.

Building security into IoT devices from the start to protect data and functionality from cyber threats is now a critical concern for developers. Implementing multiple layers of defense that take advantage of the latest security advances in both hardware and software to provide in-depth, comprehensive protections should be the first step of a strategic approach to device security *(Fig. 1).*

In terms of hardware, effective security should include secure key management to ensure that keys aren't accessible in an unencrypted state. For truly secure device-unique identity and provisioning, the device should be able to securely generate and store keys, including private keys. The device also should offer hardware-accelerated encryption, hashing, and true random number generation, which accelerates cryptographic operations. Secure memory access is another important hardware feature, as it enables protection of specific regions of RAM and flash memory from unauthorized access *(Fig. 2).*

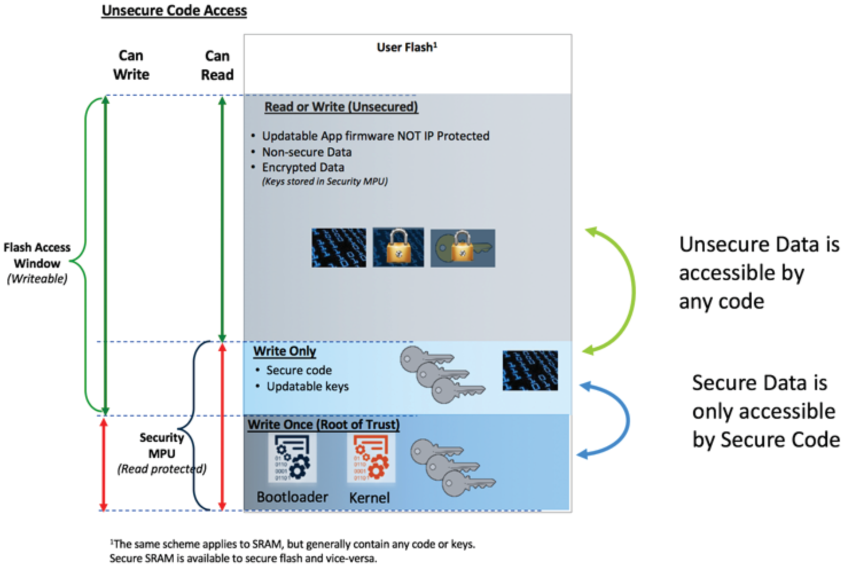
To support comprehensive security, select software that includes driver-level APIs to provide an easy interface to hardware security features. Your software should also offer cryptographic libraries with a wide range of security features available via APIs, including macro-level security functions, root-of-trust, and the ability to recognize trusted sources and code *(Fig. 3).*

Because IoT devices require connectivity, your software should support common communication protocols and transports, such as Hypertext Transfer Protocol Secure (HTTPS), Transport Layer Security (TLS), and other cloud-specific protocols. In addition, to complete your development environment, your software should include compatible and integrated stacks, libraries, HAL drivers, and potentially a real-time operating system (RTOS).

The one-size-fits-all approach to security doesn't address the real-world requirements of device developers. Instead, there are multiple approaches to embedded security, providing a multi-tiered development infrastructure that provides in-depth security protection for a wide variety of embedded products.

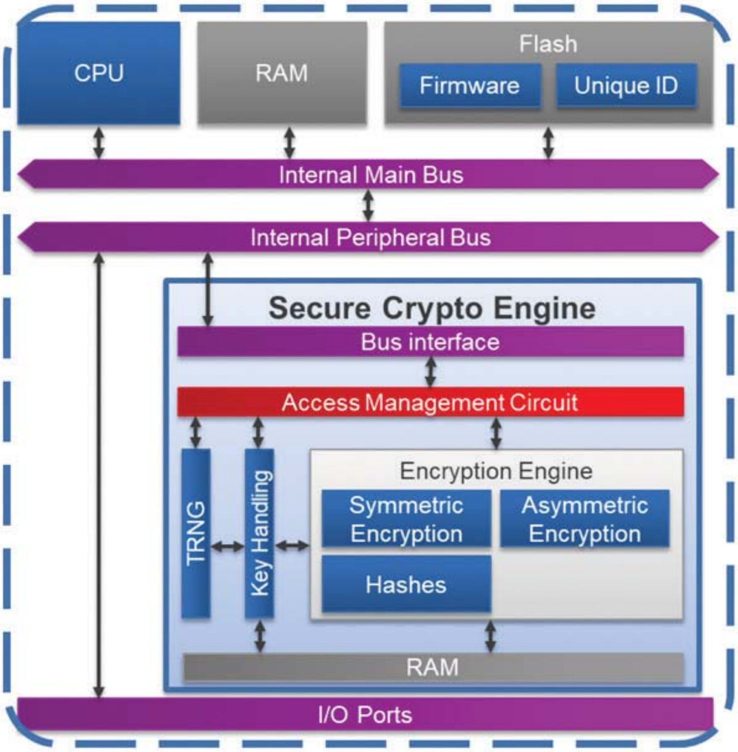
For developers who prefer a platform-based approach, a comprehensive, qualified development environment such as the Renesas Synergy Platform includes production-grade software and a scalable family of pin-compatible MCUs, pre-integrated and pre-tested to provide security at multiple levels.

Developers who prefer greater platform flexibility can explore MCUs like the Renesas RA Family, which delivers an option that combines Arm Cortex-M cores and embedded-system peripheral IP from Renesas. The RA's Flexible Software Package (FSP) provides optimized HAL drivers as well as a baseline software platform leveraging Amazon FreeRTOS and associated middleware. Designed for flexibility, it facilitates incorporation of a developer's middleware and libraries of choice.


Unsecure Code Access
Can Write
Can Read
User Flash¹
Read or Write (Unsecured)
• Updatable App firmware NOT IP Protected
• Non-secure Data
• Encrypted Data
(Keys stored in Security MPU)
Flash Access Window (Writeable)
Write Only
• Secure code
• Updatable keys
Write Once (Root of Trust)
Security MPU (Read protected)
Bootloader
Kernel
Unsecure Data is accessible by any code
Secure Data is only accessible by Secure Code

¹The same scheme applies to SRAM, but generally contain any code or keys. Secure SRAM is available to secure flash and vice-versa.

2. Memory protection units and flash area protection enable isolation and ensure that Secure Data is accessible only by Secure Code.



3. Example of a Secure Crypto Engine—a subsystem managed and protected by dedicated control logic.

Whichever approach you choose, look for hardware acceleration for the most prevalently used cryptographic algorithms (RSA/ECC/DSA/AES/SHA), as well as key generation and a true random number generator (TRNG). In addition, companies like Renesas offer MCU-unique key wrapping *(Fig. 4)* that performs key binding by encrypting keys specifically for each MCU, so that keys are accessible only within the SCE module on the individual MCU that performed the wrapping. The wrapped keys can be stored in non-secure memory; therefore, even if the entire MCU contents are copied onto another device, the keys can't be utilized or exposed.

SECURING YOUR IP FROM UNAUTHORIZED PRODUCTION

Nobody wants their products replaced by imitations or clones. Protecting your intellectual property from unauthorized production requires secure manufacturing systems to mitigate risk and maintain the integrity of your production process.

Secure firmware flash programming solutions, including secure boot manager solutions, enable developers to dependably and securely program authorized firmware into approved flash-memory devices in remote manufacturing facilities. This protects the firmware from being pirated, modified, or installed on cloned hardware.

The boot manager also delivers a strong root-of-trust that provides unique identities, hardware protected keys, secure boot loader, secure flash update module, and cryptographic APIs to interface with the MCU hardware. The boot manager pre-loads the root-of-trust through a secure connection to a high-volume programmer system designed for manufacturing and provisioning of processing units. The provisioned chip stores the data securely and maintains tight control on how it's used.

The secure boot manager is also able to securely update authorized firmware to the MCUs' flash memory even after products are in the field. The on-chip root-of-trust validates and decrypts the firmware before flash programming—all securely provisioned via secure cloud infrastructure made more reliable and trustworthy with cloud connectivity solutions.

MANAGING THE COMPLEXITY OF SECURITY

If you're starting from scratch, designing in-depth, layered security for embedded designs can be challenging and time-consuming. The platform-based approach has all new and relevant protocols and other security safeguards built in, simplifying complex functions encountered while developing secure connected embedded systems.

Any approach, whether it's a closed platform or an open one with greater platform flexibility, support public key infrastructure (PKI) and pre-shared key (PSK) support, increasing development options. PKI is a cryptology methodology that offers authentication via digital certificates. PSK security mechanisms are an encryption model in which authentication is authorized when both peers in a digital connection specify the same key.

In addition, MCUs with integrated security offer the flexibility to reuse and expand upon existing infrastructure, as well as the ability to enhance it efficiently and precisely as required for each application *(Fig. 5)*.

DEFEND AGAINST MULTIPLE SECURITY THREATS

It's scary out there: Today's cyber-threat landscape is filled with multiple bad actors and risks, and exploits and attack vectors await the unprepared and unprotected. Protecting a device against multiple security threats requires securing the device's identity through hardware-based key generation.

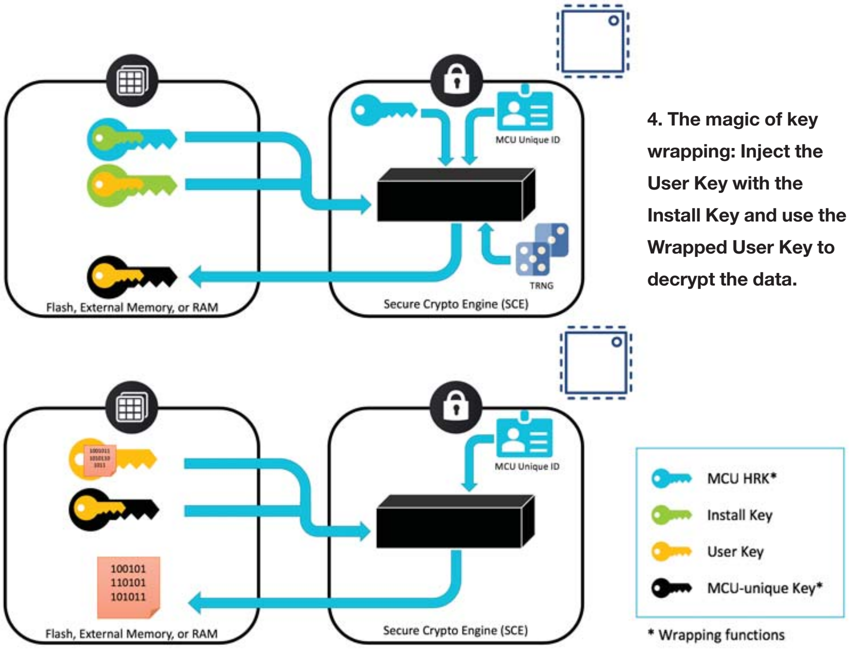
Establishing a strong device identity with layered IoT security protections enables devices to be individually secured and to engage in encrypted communication with other secured devices and services.

- *Trust:* The device must authenticate its identity as soon as it connects to a network to create trust between other devices, services, and users.
- *Privacy:* Certain types of data captured and shared within IoT networks must be kept private and secure to meet regulatory compliance.
- *Integrity:* Data integrity is an often-overlooked requirement of layered

security, involving the assurance that data shared within networks hasn't been altered.

Digital data security for stored data is also a top priority for safeguarding against multiple security threats. Data at rest refers to data not actively in motion between devices or networks, usually parked in SRAM or non-volatile storage. Controlling access to stored data reduces the attack surface and increases system security.

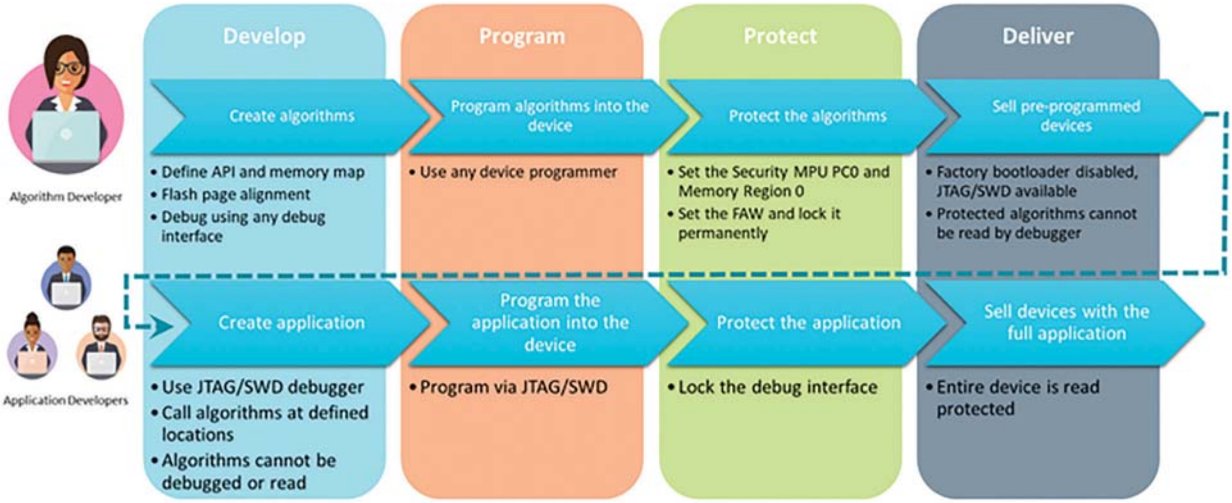
Offering data access controls, including read, write, read-write and write-once protections, helps to safeguard data at rest. Remote updates in the field ensure that security software and firmware are up-to-date and provide protection against the latest cyber threats.


MCU Unique ID
TRNG
Flash, External Memory, or RAM
Secure Crypto Engine (SCE)
MCU Unique ID
100101
110101
101011
Flash, External Memory, or RAM
Secure Crypto Engine (SCE)
MCU HRK*
Install Key
User Key
MCU-unique Key*
* Wrapping functions

4. The magic of key wrapping: Inject the User Key with the Install Key and use the Wrapped User Key to decrypt the data.

ENSURE YOU DELIVER A SECURE DEVICE, EVEN IF YOU'RE NOT A SECURITY EXPERT

Not everyone has the training or experience to understand all of the ins and outs of embedded security, but steps can be taken to ensure that you put in place the basics for delivering a secure IoT application.



Develop
Program
Protect
Deliver
Algorithm Developer
Create algorithms
Program algorithms into the device
Protect the algorithms
Sell pre-programmed devices
• Define API and memory map
• Flash page alignment
• Debug using any debug interface
• Use any device programmer
• Set the Security MPU PC0 and Memory Region 0
• Set the FAW and lock it permanently
• Factory bootloader disabled, JTAG/SWD available
• Protected algorithms cannot be read by debugger
Application Developers
Create application
Program the application into the device
Protect the application
Sell devices with the full application
• Use JTAG/SWD debugger
• Call algorithms at defined locations
• Algorithms cannot be debugged or read
• Program via JTAG/SWD
• Lock the debug interface
• Entire device is read protected

5. This use-case example demonstrates pre-programmed algorithms—specifics for devices with a security MPU.

First, delivering comprehensive, in-depth security protection for products based on embedded devices requires multiple protocols and safeguards that work together to provide security at many levels.

The platform-based approach can give you a head start by delivering a complete development environment complete with a unique, built-in set of hardware and software security capabilities.

Design and development resources, such as an online library of application projects with step-by-step instructions, provide guidance on building end-to-end security solutions. And a large, robust ecosystem of partners can help speed development and extend deep expertise into your security solution development.

WITH SECURITY SUPPORT, FOCUS ON DESIGN FEATURES THAT DIFFERENTIATE

When it comes to streamlining the process of securing new IoT applications, choosing the right MCU is the first step. This will streamline your security workflows, allowing developers to focus on designing the features and capabilities that will make your product stand out.

Platform-based approaches provide functionalities that work together to deliver security at multiple levels. This is important because malicious agents can take advantage of vulnerabilities in embedded designs when variations in design and security protocols create weak points that are hackable. This is particularly a risk when MCU hardware, software, communication stacks, and drivers haven't been standardized into a fully integrated framework.

A platform ensures that applications are built on a secure, robust technology foundation. It also allows designers to focus their time and skills on innovations that address fast-moving IoT market opportunities and consumer demands.

MCUs outside of a platform can offer flexibility and deliver best-in-class security IP and peripherals that provide a highly optimized feature set for holistic security protections. In addition, an active ecosystem of partners and other resources, such as the Arm ecosystem, provides the flexibility and expertise to deliver innovative designs with the multiple layers of defense now required by the market.

The option of outsourcing development of specific security features or functionalities to trusted partners can save time and strengthen the final product.

CONCLUSION

There are multiple ways to take advantage of the latest breakthroughs in hardware and software security to deliver in-depth, comprehensive protections with layered security. Whether choosing a platform-based approach or a more flexible MCU-based approach, building on a strong root-of-trust enables developers to secure IoT devices, services, and networks at a deep level, and extend protections to secure and scalable manufacturing and defense of intellectual property across the product lifecycle. ed

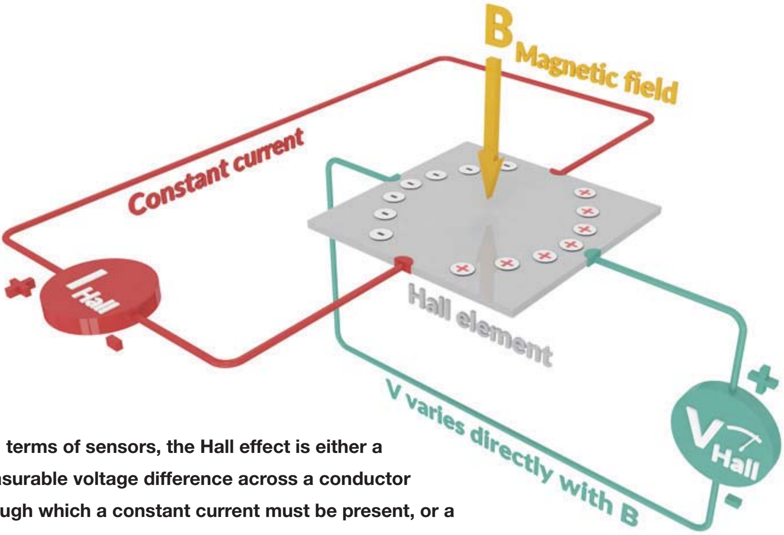
BRAD REX is Senior Manager, Microcontroller Business Development at Renesas Electronics, where he is responsible for marketing Renesas' microcontroller hardware and software solutions. KAUSHAL VORA is Director of Strategic Partnerships & Global Ecosystem at Renesas Electronics, where he is responsible for defining, establishing, and managing the company's microcontroller ecosystem. He leads a global marketing and application engineering team to develop software building blocks for IoT design and collaborates closely with key technology partners to complement and expand Renesas' embedded ecosystem.

NICK CZARNECKI | Product Marketing Manager, Magnetic Sensors, Melexis

What's the Difference Between Hall-Effect Current Sensing and Position Sensing?

Using the Hall-effect for current measurement is inherently robust, but it can be an even more versatile tool when it comes to position sensing.

Sensing, in all its forms, is fundamental to so many applications. It invariably involves a material that acts as a transducer, to convert one property to another. In electronics, the sensing element will have physical properties that change as a result of the action of sensing, such as its resistance or reactance allowing the measurement of a change in either current or voltage.



1. In terms of sensors, the Hall effect is either a measurable voltage difference across a conductor through which a constant current must be present, or a measurable current difference across a conductor through which a constant voltage must be flowing.

HALL EFFECT

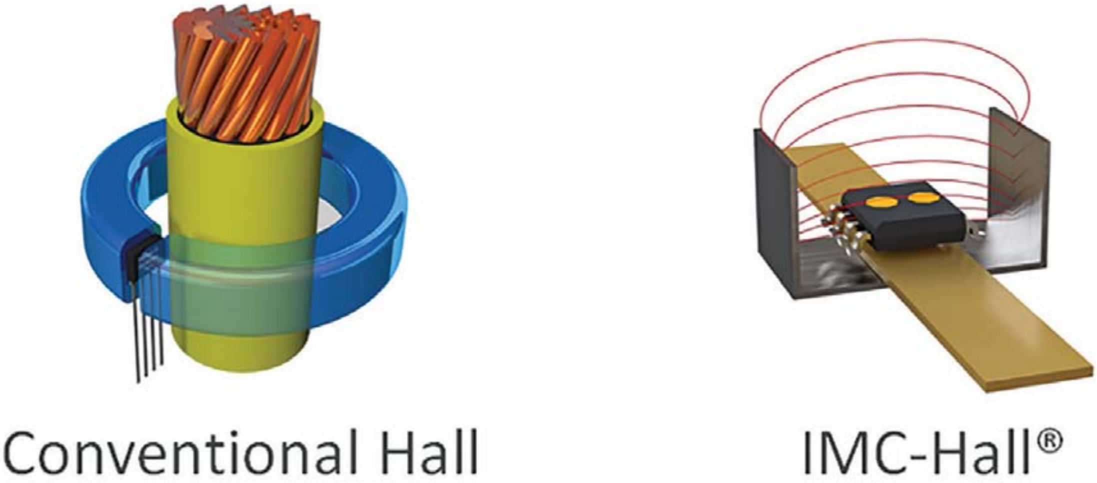
In 1879, Edwin Hall discovered that when a conductor or semiconductor with current flowing in one direction was introduced perpendicularly to a magnetic field, a voltage could be measured at right angles to the current path. It's well-established that the Hall-effect results from the interaction of charged particles, like electrons, in response to electric and magnetic fields.

The Hall effect, as applied to sensors, manifests either as a measurable voltage difference across a conductor through which a constant current must be present, or as a measurable current difference across a conductor through which a constant voltage must be flowing *(Fig. 1)*. The voltage difference is proportional to the strength of a magnetic field. This means the Hall effect can be used in two very specific ways, even though the underlying effect is the same in both cases.

The signal level due to the field variation, relative to background noise, is small (range of µV). Therefore, it requires quite sophisticated signal paths in order to make use of it.

Without wishing to devalue Edwin Hall's discovery in any way, the effect is really an extension of the use of the Lorentz force, which describes the interplay between electric and magnetic forces on a point charge due to electromagnetic-field variation.

In simple terms, in the case of the Hall effect, the Lorentz force describes the effect a magnetic field has on a charged particle, specifically the direction it will be forced to take as it passes through a conductor exposed to a magnetic field. The physical movement



2. Here's a comparison of how conventional Hall-effect and Hall-IMC current sensors are positioned.

results in more or less charge across the conductor's surface, which results in the potential difference known as the Hall voltage.

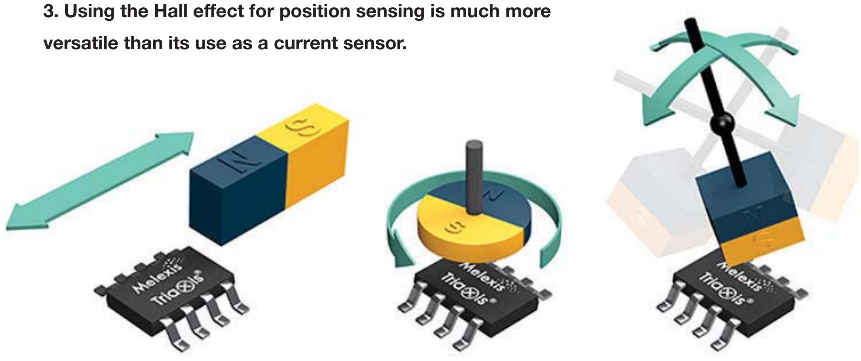
HALL-EFFECT CURRENT SENSING

The fact that the Hall effect depends on a magnetic field means it can be used as a contactless technology. Thus, it's non-intrusive, unlike the most common way of current sensing, which consists of using a low-value resistor as a shunt and measuring the voltage drop across it. Using the Hall effect for current measurement is inherently robust in high-power applications, because it doesn't rely on the ground potential as a reference.

With a conventional Hall-effect current sensor, this means placing the sensor perpendicular to the magnetic field and using a concentrator, normally a ferromagnetic core that's shaped as either a ring or square, placed around the conductor carrying the current to be measured *(Fig. 2)*. The sensor would typically be held in a small air gap formed between the two ends of the ferromagnetic core.

With an IMC-Hall current sensor, the sensing element is positioned in parallel with the current flow *(Fig. 2, again)*. In this case, no ferromagnetic core is needed; however, a shield might be necessary for crosstalk immunity. This means it can be used to measure the current flowing in a bus bar or PCB track just by positioning the sensor over the bar or track. This type of sensor is enabled by the IMC-Hall technology using the Integrated Magnetic Concentrator (IMC) developed by Melexis *(see next page)*.

3. Using the Hall effect for position sensing is much more versatile than its use as a current sensor.



Fundamentally, it's the magnetic field generated by the current that's being detected thanks to the Hall effect, rather than the current itself.

HALL-EFFECT POSITION SENSING

The same principle can be used to detect the presence, absence, or proximity of a magnetic field. Effectively, the Hall voltage that results from the movement of a magnet on top of the sensors can be detected, amplified, and processed. This presents an opportunity to use the Hall effect to detect the position or even the orientation of objects with respect to the sensor.

In a simple application this may be relatively coarse, such as when a laptop is open or closed. Or it may be more sophisticated when it's used to detect linear movement or rotation, such as the variation in position of a movable object *(Fig. 3)*. In this respect, using the Hall effect for position sensing is much more versatile than its use as a current sensor.

THE INTEGRATED MAGNETIC CONCENTRATOR (IMC)

One of the drawbacks of most Hall-effect sensors, which is related to the way the effect works, is that the Hall plate used to sense the field is limited to only one axis.

To address that drawback, Melexis developed the Integrated Magnetic Concentrator, or IMC, which makes the Hall effect much more flexible. The IMC allows the Hall-effect sensors, while remaining in a plane, to detect magnetic fields from the X, Y and Z axes *(Fig. 4)*. Consequently, the application benefits are multiple, including the flexibility of the sensor's orientation.

HALL-EFFECT SENSING IN AUTOMOTIVE APPLICATIONS

With the inclusion of IMC technology, many applications within the automotive industry can employ the Hall effect. By operating in three dimensions, the Hall-effect sensor can be used to detect the position of pedals, the rotation of the steering column and status of the brake lever, and the position of electrically operated seats.

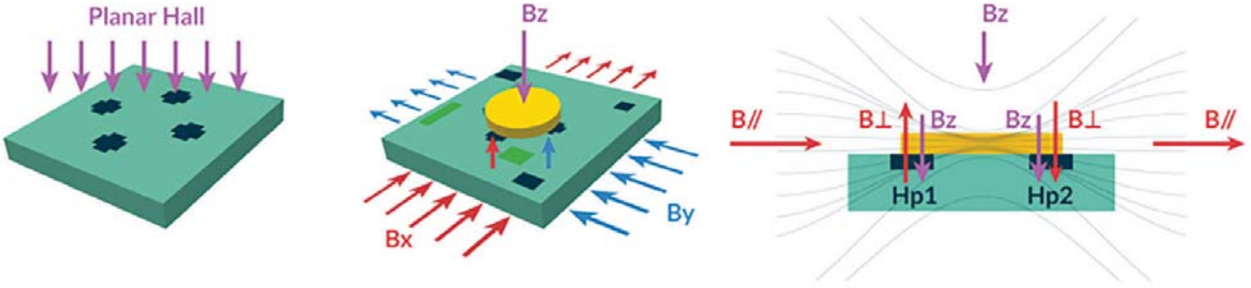
It can also be applied under the hood to monitor moving parts lije pumps and motors, as well as to measure the current drawn by electrified parts of the powertrain, such as the inverter, the battery-monitoring system (BMS), or the on-board charger (OBC).

CONCLUSION

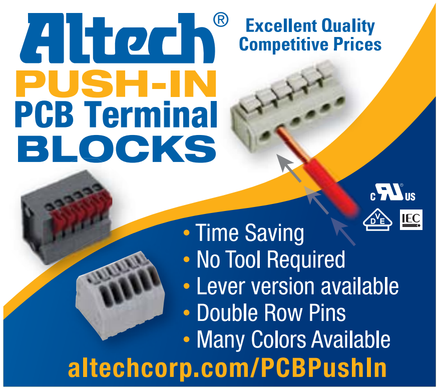
In basic terms, the Hall-effect phenomenon can be exploited in a number of useful ways, including current sensing and position sensing. Despite great challenges, such as the low signal-to-noise ratio or the impact of stray field, the electronics industry has been successful in developing robust and accurate sensing solutions based on the Hall effect.

In particular, the addition of a strong analog front end and digital signal path, along with proprietary technologies such as Melexis' IMC-Hall, means the Hall effect can be applied to current measurement and position sensing—even in harsh environments such as the automotive industry.

NICK CZARNECKI joined Melexis in 2011 as a Field Applications Engineer and transitioned to the Marketing Manager role in 2015. His responsibilities include the definition and promotion of Melexis magnetic sensors, such as the Triaxis angular sensors.



4. The Integrated Magnetic Concentrator allows Hall-effect sensors, while remaining in a plane, to detect magnetic fields from the X, Y and Z axes.



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bill.wong@informa.com

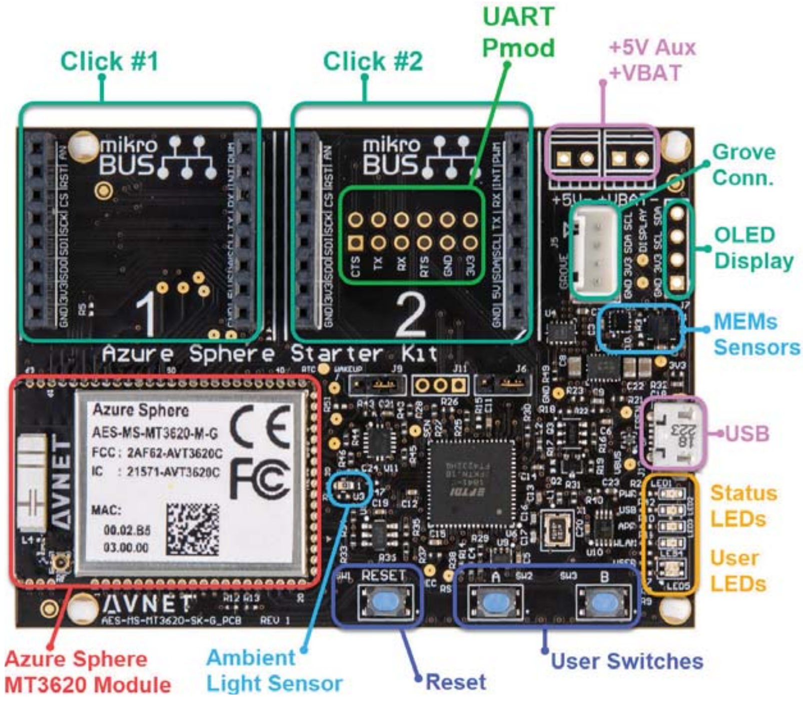
A Linux-to-Cloud IoT Solution the Microsoft Way

Avnet has developed an end-to-end IoT solution that revolves around MediaTek's MT3620 running Microsoft's Azure Sphere OS.

Delivering secure, end-to-end IoT connectivity is no easy task, and properly integrating this support with an operating system is critical to delivering a secure product. Most developers would prefer to concentrate on their part of the solution while leaving the IoT management and security to others. The challenge is that many players are involved, so doing this from scratch is possible but painful, time-consuming, and expensive.

A host of vendors provide end-to-end IoT solutions, from giants like Google to Amazon to open-source platforms. Of course, Microsoft is up there, too, and ties its IoT offerings to its Azure cloud solution. Microsoft does make some hardware, but it usually wants to sell software and services to companies that develop hardware to work with their solutions. The advantage for Microsoft is that IoT devices garner income for the life of the device, since IoT devices these days are locked into one cloud platform.

Currently, IoT is a matter of partnerships and even Microsoft does this with a vengeance. Of course, the company has been doing this for decades. In our case, it has partnered with MediaTek and Avnet to deliver the Avnet Azure Sphere MT3620 development kit *(Fig. 1)*. The module in the kit is based on MediaTek's MT3620 SoC.



1. Avnet's starter kit board includes the compact MT3620 module. It also has sensors and a pair of mikroBUS Click board sockets.

This IoT development kit is similar to many others on the market, but it comes with a few major twists including base security built into the chip and a customized version of Linux that takes advantage of that security. That's right, Microsoft Linux is the base. They don't actually call it Microsoft Linux—it's their Linux that includes the company's own security framework, which is designed to work with its security hardware called Pluton. Microsoft calls its Linux instance Azure Sphere OS.

Pluton is a security subsystem built around an ARM Cortex-M4F *(Fig. 2)*. This core is isolated and controls the rest of the system. It provides secure boot support as well as handles encryption chores. The MT3620 also has a Cortex-A7 with Arm TrustZone support for heavy lifting and running the Azure Sphere OS. Another Cortex-M4F handles most of the peripherals. There's also wireless support, including dual-band Wi-Fi. That has its own dedicated processor.

NXP Semiconductors announced an i.MX 8 platform with Pluton support that's similar to MediaTek's chip. NXP's chip will also run the Azure Sphere OS.

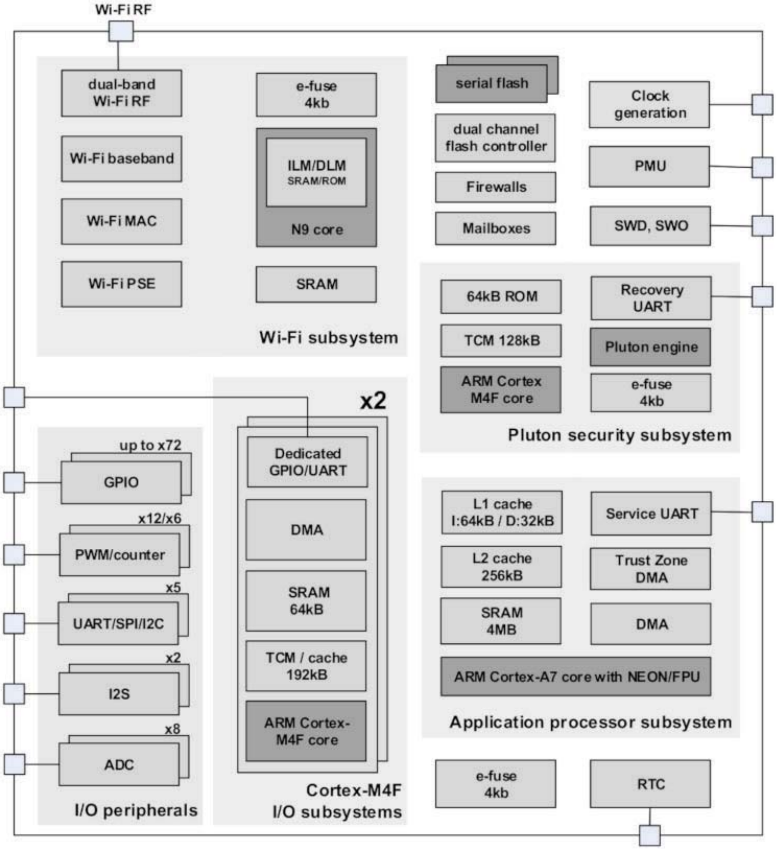
I like the design of the development board. The MT3620 chip is actually on a module *(Fig. 3)* that incorporates the wireless support, which has FCC approval. This makes using the module a snap for developers, since additional FCC approval of a product may not be necessary. An on-module antenna and a connector are included for a separate antenna. The pinouts are nicely portioned, making design of a carrier board a snap.

The mikroBUS Click board sockets are a handy way to add extra sensors to augment the ones already on the board *(Fig. 4)*. These include an ambient light sensor, three-axis accelerometer, three-axis gyro, temperature sensor, and barometric pressure sensor. There's also an unpopulated Pmod socket solder pad, but it shares space with one of the Click board sockets. A couple of I2C sockets for displays and Grove interfaces are in the mix, too. Power sockets can be soldered on, but power can also be supplied by the USB interface used for initial configuration as well as debugging.

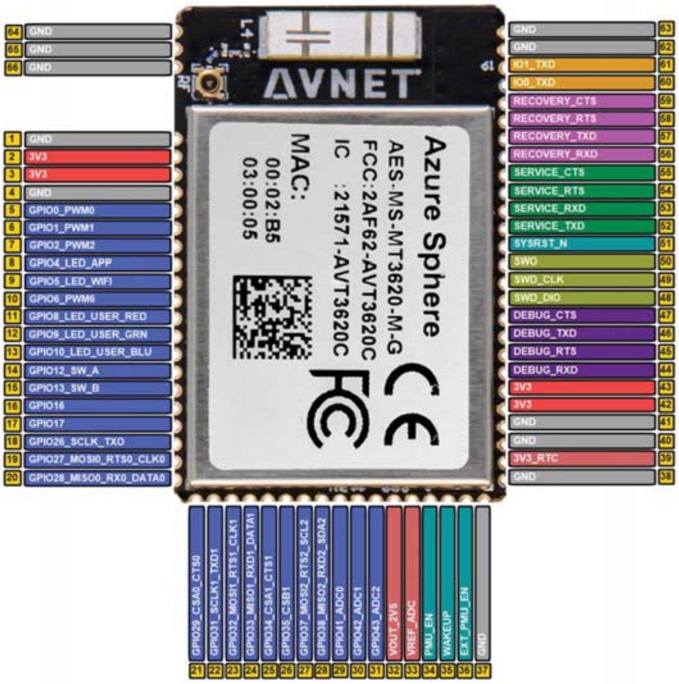
GETTING STARTED

Now that we're done with the long explanation about the hardware and operating system, we can move onto what it took to get started. The kit comes in a small box with the board and a short USB cable. The page of directions, typical these days, directs you to the web for more details.

The board comes preprogrammed, but there's nothing to do with it until you download a bunch of Microsoft software on to your PC, including Micro-



2. The MT3620 block diagram highlights the Corex-M4F-based Pluton security subsystem. The Cortex-A7 runs Microsoft's Linux-based Azure Sphere OS.



3. The MediaTek MT3620 is available on Avnet's module used in the development kit. The pinouts are easy to work with when designing a custom PCB.

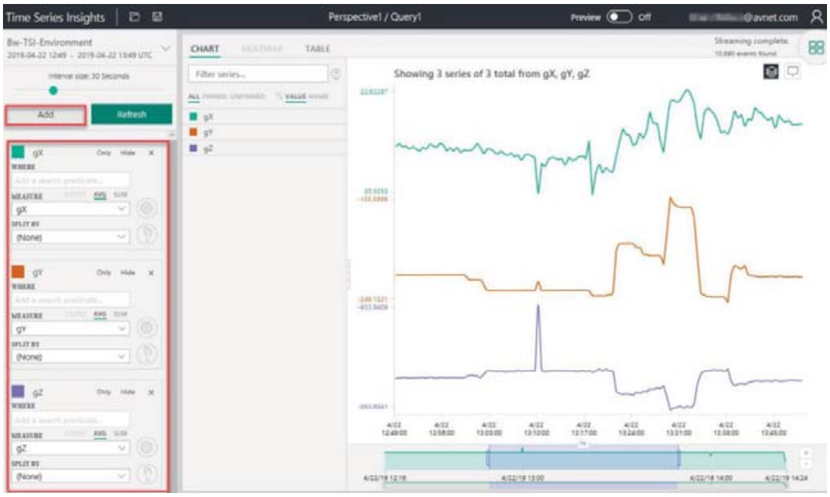
soft Visual Studio and the Azure SDK. You also need a free account on Azure to connect your newly acquired dev board to the cloud.

I won't bore you with the details because there are quite a few. Likewise, a number of blogs, PDF files and videos about this platform are available. Unfortunately, though, there's not one place to find all of them. They're also all over the place from Avnet's website, to MediaTek to Microsoft and also Element 14. This is where I found a three-part blog entitled Avnet's Azure Sphere Starter-Kit (Out of Box Demo). It duplicates information found in other sources, but it's the best for getting started.

The blog and other sources are needed because this kit is designed to be used for development, not just evaluation of an IoT end-to-end solution. In that sense, it's an ideal platform for developers, since it's designed to work with the tools that include Azure Sphere and Visual Studio.

The first blog post addresses initial setup and configuration of the board. The second gets into connecting to the cloud and setting up a logical, cloud-based IoT hub that's used manage the device; in this case, the dev board. The result of this second blog is support for Azure's Time Series Insights *(Fig. 5)*. This is just one aspect of Azure Sphere. The third blog gets into using IoT Central. I still need to finish this one, but I don't get a lot of large blocks of free time.

4. A range of Click boards are available from a number of sources; it's easy to design custom boards given the limited number of interface pins.



5. Azure Sphere's web-based cloud interface provides access to the data delivered from the MT3620.

Though it will take a day or three to get to this point, the results are well worth the effort. Once completed, you have the Visual Studio and SDK all set up and have a couple projects in the bag albeit canned demos from the walk-through.

I still need to explore the development side of things, especially the Azure Sphere OS's security aspects and how they differ from support like SELinux or Ubuntu's AppArmor, which I'm more familiar with. I won't even mention the Azure side of things, as cloud development is a whole other area of development.

In closing, I will mention that the kit differs from many others in that it comes locked down. It's not an open system on a network when you plug it in, and it takes time and effort to get to the point of doing the programming. This is actually a good thing, because it works from the opposite approach of being very open and unsecured. It would be nice if other development platforms followed this rule.

On the flip side, the system locks you into hardware, a toolset, an operating system, and cloud provider. But this tends to be par for the course when it comes to most IoT solutions. The big hook to all the "free software" is monthly charges for cloud support. Again, this is the norm for an IoT solution where you're not providing your own cloud.

Though it's taken me a while to get the kit to do what I expected, I'm happy with the results. I don't claim to be an expert at developing IoT apps for the MT3620, but I have a good starting point. ed

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