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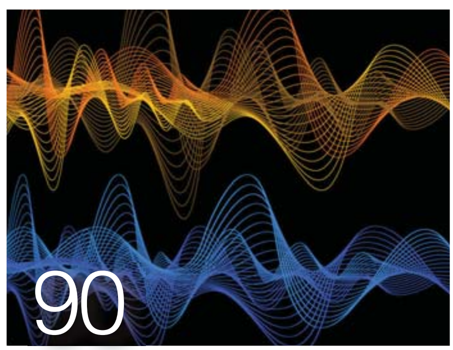
RF OUT

IN THIS ISSUE

FEATURES



NEWS & COLUMNS

Editorial

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

The Winds of Change at *Microwaves & RF*

Senior Content Director Bill Wong bids a fond farewell to outgoing editor Chris DeMartino.

Business is tough everywhere, but especially in our arena where technology and journalism meet. One of the reasons *Microwaves & RF* has been successful is because we have a technical staff that understands the material we cover, including the latest products and tools.

Chris DeMartino has been with us for almost five years as editor after getting his Bachelor of Science in Electrical Engineering from Binghamton University and then Master's in Electrical Engineering from New York University - Polytechnic School of Engineering. He also held positions at major electronics firms like MITEQ, U.S. Dynamics, and Mercury Systems.

He's one of the few who can master the technology as well as be able to write articles that are both informative as well as understandable. Being an engineer turned journalist is no easy task and Chris excelled at it. He has hosted a plethora of webinars and written more technical articles than most writers. He will be sorely missed, and we wish him the best in his new position.

We may wind up reporting on his work—Chris will be moving back into the engineering side of things, where the fun is. His tenure with *Microwaves & RF* has raised the bar in terms quality and quantity, which is apparent from reading our website. We will have a new editor for the magazine in the near future, but he or she will have some big shoes to fill.

Just to give you a preview of things to come, we will be a part of Endeavor Business Media in the new year. This migration includes a range of publications that were part of Informa, including *Electronic Design*, *Machine Design*, *Source Today*, and *Hydraulics & Pneumatics*, just to mention a few. We're looking to continue our growth and coverage.

In the meantime, you may see me in the pages of *Microwaves & RF* in addition to my usual haunts on *Electronic Design*. mw

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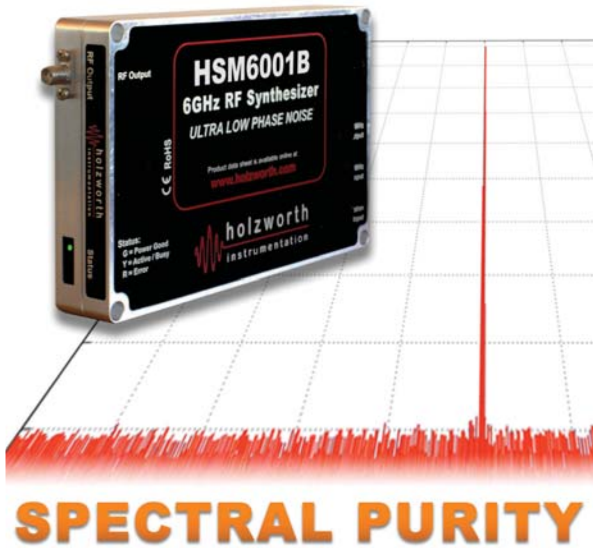

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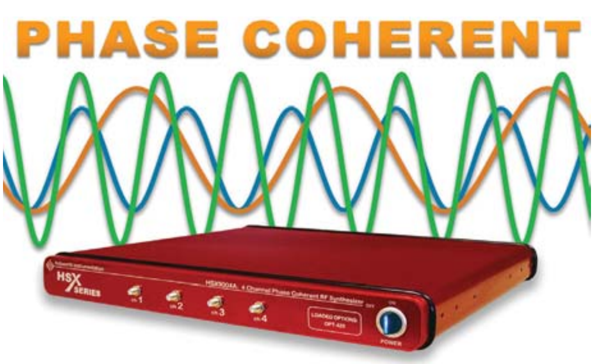

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As the industry has evolved, Mini-Circuits has grown by embracing change, adapting to your needs, and innovating new solutions to keep pushing the wireless world forward. Looking ahead, we will continue our relentless pursuit of advanced technology, finding new opportunities for creative collaboration with customers and blazing new paths to create value and solve tomorrow's problems together.

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LOU FRENZEL | Contributing Editor

Is Wireless Killing Our WIRED NETWORKS?

While wireless grabs all of the headlines, wired networks continue to reliably do their jobs. But, despite their reliability and relative ubiquity, some foresee the demise of the wired side.

Does the relentless expansion of wireless technologies and services signal the end of wired networks? Does the growth of the Internet of Things, forthcoming 5G, and ever-faster Wi-Fi foretell the eventual death of copper cabling? Some are predicting just this. Here are my thoughts.

THE WIRED WORLD

How many times have we wired the world? The first wired network was the telegraph, circa 1850. I'm not making this up. Telegraph lines actually came before the telephone and electrical power transmission. These didn't show up until the late 1870s through the early 1900s. All three—telegraph, telephone and electrical power businesses—eventually created massive networks and grids that remain today. The telephone system grew into a massive enterprise including fiber and DSL wiring.

But that's not all. In the 1960s, we got community TV antenna systems that morphed into the huge cable TV networks. Today these hybrid-fiber-cable (HFC) systems cover most of the U.S. In

the 1970s and later, local-area networks (LANs) began connecting millions of PCs with twisted pair.

Somewhere along the way, factories, process plants, and other industrial facilities got wired with fieldbuses like HART, Modbus, PROFINET, Ethernet, and others. Office buildings, homes and even complete cities were wired with twisted-pair Ethernet. And let's certainly not forget the Internet and all the related fiber connecting the world. Now, wired networks have taken hold in cars, SUVs, and trucks. New vehicles have LIN, CAN, MOST, even Ethernet. What have I left out?

Given the huge wired infrastructure, you would think that the answer to the burning question is a solid "NO, wireless is not killing the wired world."

Clearly, we have taken our reliable wired networks for granted. They're considered old technology and get no recognition or appreciation. However, despite this inattention, even disrespect, wired networks continue to improve.

WIRELESS IS WINNING

However, all of the most recent networking hype, development, and application seems to be wireless-related. Wi-Fi everywhere. Massive expansion of the 5G cellular network and billions of smartphones. The public switched telephone network is fading away as subscribers abandon it for cellular service only. Bluetooth cable replacement, wireless headsets and speakers, and many others. Satellite TV distribution competing with cable TV.

Then there's the Internet of Things that's mostly wireless with its billions of sensors. Wireless utility-meter reading. And no telling how 5G will affect things. Initially, 5G broadband wireless services will challenge the DSL operators and cable companies.

With all those wireless signals floating around, it's amazing that the EMI hasn't compromised at least some of those systems. It's only going to get worse, so we should all be worried.

THE DEATH OF WIRED SYSTEMS IS PREMATURE

Mark Twain is acclaimed to have said "The reports of my death are greatly exaggerated." That's probably the case here. When you think about it, aren't many if not most of those wireless systems tied together to other networks with cables?

The cellular system can't exist without all of those attendant fiber interconnects. Server interconnects in data centers use exotic cabling like Infiniband. And isn't it wired Ethernet that ties all those Wi-Fi access points together to a server in a closet that is connected to outside fiber. Home wireless still needs that cable or DSL wiring to get internet access. Don't all wireless networks actually have a wired connection to some other system?

Clearly, we have taken our reliable wired networks for granted. They're considered old technology and get no recognition or appreciation. However, despite this inattention, even disrespect, wired networks continue to improve. The cable TV HFC systems keep gaining more speed thanks to the latest upgrade to the DOCSIS standard. It can easily handle 1-Gb/s data, and even faster in some instances.

DSL has also ramped up its speed over the years as companies invented technologies that let you put 1 Gb/s of data on a twisted pair. And, after all these years, the telecom companies discovered how to minimize 60-Hz induced voltage and current interference to the PSTN wiring and DSLAMs by using the mysterious Induction Neutralizing Transformer (INT). The INT has been around for a while, but its effectiveness hasn't been fully exploited. Fast data can be achieved over twisted pair by using the latest standards such as VDSL2, G.fast, and others thanks to the INT.

As for other examples of a healthy wired infrastructure, consider these. Many of the small cells needed for 5G will be fiber. IoT nodes are aggregated in gateways wired to some other wired LAN or internet connection. DSL and cable internet connections to homes and businesses aren't going away. New 5G broadband wireless may take some business, but not all.

If you want an in-depth look at this issue, get a copy of the new book, *Computing Network Breakthroughs You've Always Wanted without Needing Fiber Optic Cables…Even in the Age of the Internet of Things*. It's written by an acquaintance of mine, Russ Gundrum, a veteran of the telecommunications and cable businesses. He's also the guy to thank for promoting and deploying the INT.

My conclusion is that wired networks still serve a real purpose. We actually can't get along without them. Yes, wireless is getting all of the attention right now, but we should pay some respect to the wired networks we use every day. mw

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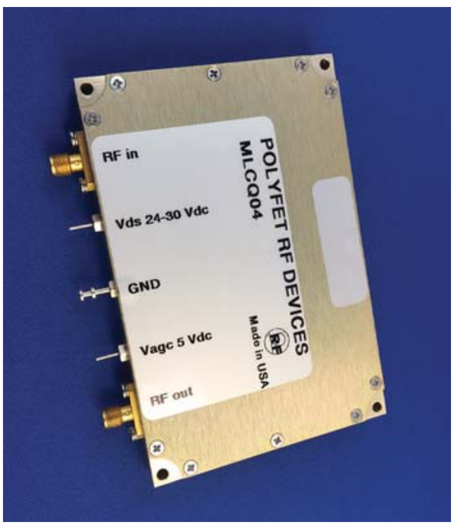
Polyfet RF Devices is a manufacturer of broad band RF power transistors and power modules. We are a private corporation founded in 1987 located in Ventura County California. Our product portfolio consists of Gallium Nitride, LDMOS, and VDMOS technologies and are manufactured in the US. In 1995, Polyfet was one of the first companies to develop LDMOS power transistors. Today we are one of the few companies that manufactures devices from a broad range of technologies including both 28VDC and 48VDC RF power GaN transistors. Our technical staff is employed to assist our customers with extensive technical support ranging from device line-up suggestions to amplifier design assistance. Also available to our customers is access to a wide range of product demonstration amplifiers. Our commitment to long-term production support is welcomed by military contractors who use our products where obsolescence is a concern. Furthermore, we manufacture transistors that are proven to be suitable replacements to others in the industry that have seen EOL.



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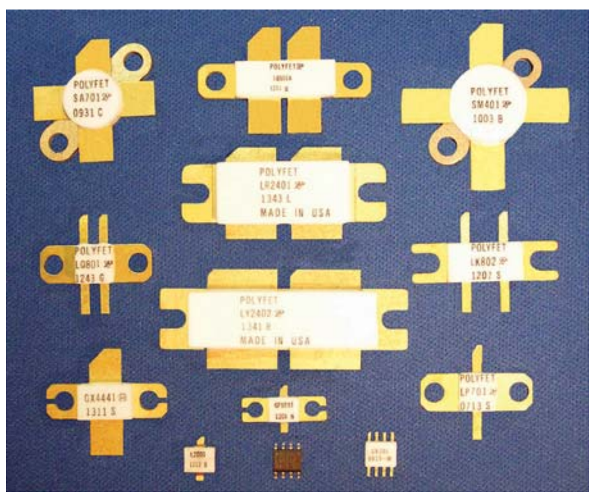

RF POWER SOLUTIONS

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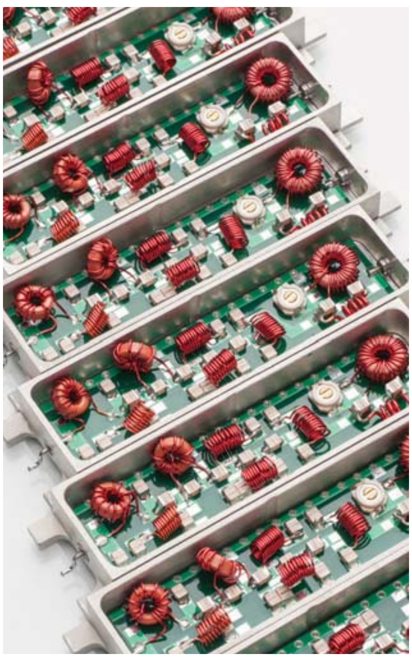

Typical applications for NIC's products include communications, navigation, guidance, surveillance, point-to-point and multi-point radio systems, radar systems, and satellite systems.

NIC's product portfolio includes crystal filters, ceramic filters, cavity filters, LC filters, multiplexers & diplexers, TCXOs & VCXOs, switched filter banks, phase shifters, filter/amplifiers, filter/limiters, and low-noise amplifiers (LNAs).

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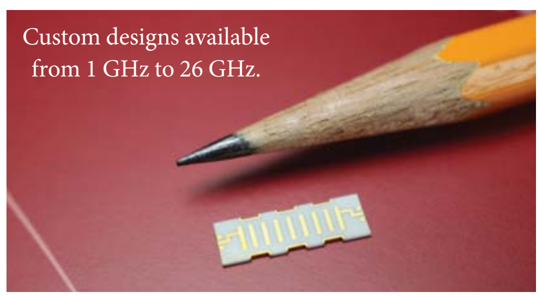


NIC

Networks International Corporation

GORDON WALSH | Senior Systems Architect, S3 Semiconductors, a division of Adesto
www.s3semi.com

Enabling the Internet of Wireless Things

Almost all electronic devices now have the ability to be part of a network, and beyond that a network of networks. This is the vision for the IoT and wireless connectivity is making it a reality.

Control and automation are key features of the Internet of Things (IoT), features that are realized using sensors and actuators. While it's likely that most large automation equipment will now (or soon) be connected to a local network, the IoT will mostly be made up from smaller devices located in relatively remote locations. These "endpoints," as they're now generally known, could be as simple as a temperature sensor or as complex as a weather station. As such, endpoints in the IoT could contain both sensors and actuators, along with power, processing, and connectivity.

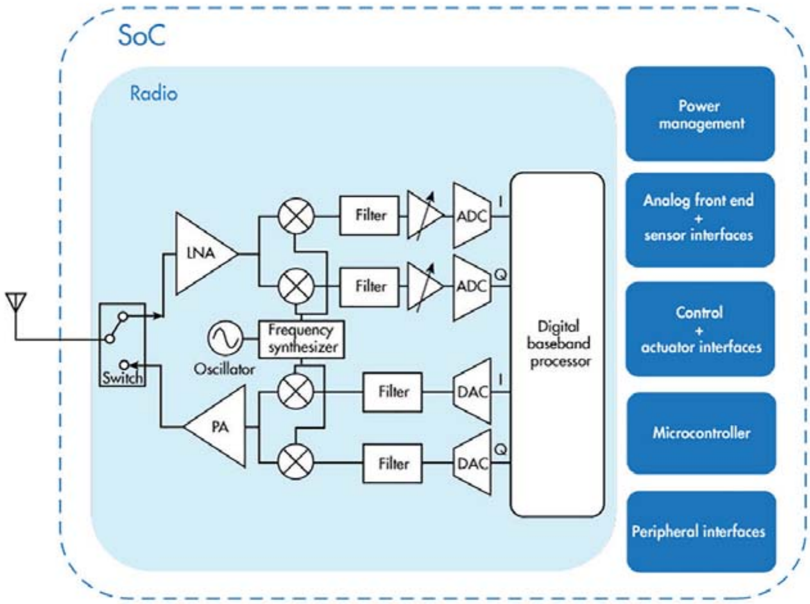
Part of the value proposition of an IoT endpoint is that it will be easily deployed and maintained, meaning it should be a self-contained unit that can be commissioned remotely, operate for hundreds of hours without power failure, and form part of a largely self-healing network. These requirements point to a high level of integration supported by robust and industry-ratified standards.

WIRELESS SoCs FOR THE IoT

The availability of single-chip solutions for wireless connectivity targeting IoT endpoints has been increasing for several years (*see figure*). Semiconductor manufacturers now offer a wide range of devices that conform to this basic design in variants that comply with the most commonly used wireless protocols, as defined by industry standards.

Choosing the right wireless protocol and SoC for a given IoT application depends on many things, which are covered in this article. The most relevant are range, power, and the data rate. While the data rate is largely defined by the protocol, and wireless SoCs must be designed to meet the constraints set by the standards, SoC manufacturers still have significant control over these three main parameters and will trade one off against another to deliver standard parts that meet the "sweet spot" of the emerging market.

Wireless protocols fall within three general categories: personal area, local area, and wide area. The area, in this case, refers to the physical distance between at least two network nodes, which is necessary to form a network. *Table 1* shows a comparison of the most popular wireless personal-area-network (PAN) protocols used in the IoT, in terms of data rate, range, and power.



This is a typical block diagram for a generic RF SoC solution.

Range is important, because it not only defines the maximum physical distance between two endpoints, but depending on the protocol, it can correlate to the power needed to achieve that distance. The physical layer, or PHY, of the wireless SoC must be able to handle enough power to achieve the range defined in the standard, and the efficiency of that PHY will partly determine the overall power requirements of the SoC. This can have significant implications when designing the endpoint, as it may be necessary for the endpoint to operate for several years from a single primary cell, for example.

There's also a physical limitation to how powerful the amplifier in the SoC can be, in terms of the process node used. Wireless SoCs are designed to deliver the best link budget for the available power—some of that will be determined by the receiver sensitivity, while another portion will be defined by how efficiently the RF part of the SoC has been designed and implemented. Mixing RF with sensitive digital and analog CMOS functionality has always been difficult and often leads to the tradeoffs mentioned earlier, such as reducing the total transmit power, sacrificing receiver sensitivity, or restricting the amount of transmissions per hour/day/week.

NETWORK TOPOLOGY vs. RANGE

While those wireless technologies classified as "personal area" have a range measured in tens of meters, their network topologies have evolved to address the limitations of a short range. Most all PANs now employ a mesh network topology, which allows endpoints to operate as waypoints for passing messages from one side of the network to another. In effect, this means that a PAN is no longer limited to the longest span between two endpoints or, therefore, its local proximity.

However, this also means that for a message to travel over tens of kilometers, there needs to be an endpoint every few meters and the message must make multiple hops. The power per bit per kilometer, therefore, should be evaluated, particularly if the network is intended to operate as a low-power wireless sensor network (WSN), which is becoming a typical use-case in the IoT.

On the other hand, wide-area networks, or WANs, are designed to cover large distances in a single hop. Instead of a mesh network, they more commonly use a star network topology. These are essentially direct links between an endpoint and a gateway (although some endpoints can also act as gateways). WANs designed for the IoT are now generally referred to as LPWANs, meaning low-power WANs, and they can cover tens of kilometers with a single connection. As such, they're becoming popular for connecting large urban areas, such as smart cities.

The most prevalent LPWANs today include LoRa, Sigfox, Ingenu RPMA, and Weightless. *Table 2* compares the key features of all four.

Cellular networks now also support an LPWAN use-case, covered by Release 13 of the 3GPP specification. These include LTE Cat-M1 and NB-IoT (also known as Cat-M2). Unlike other LPWANs, the network is managed by the incumbent cellular network provid-

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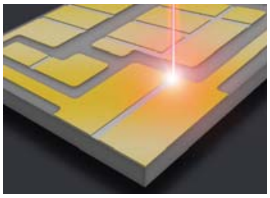

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"*Everyone in the industry has come in contact with something we've processed,*" says Greg Sexton, President and CEO of Accumet. And when you take a look at the vast array of precision processed substrates and materials they deliver from their two fully-equipped Massachusetts facilities, you can't help but believe he's right.

Established in 1970, Accumet is the pioneer in ceramic lapping and polishing techniques that have been used in millions of microelectronic components found in every corner of the RF/microwave industry. Today, Accumet is continuing that innovation across the board, in all facets of their production services.

ADVANCED MANUFACTURING AND PRECISION SERVICES:

- Lapping and polishing
- Laser cutting, drilling, marking and welding
- Raw materials stocking
- Value-added secondary processing including post-metallization laser machining, laser ablation, dicing, filled via planarity, hermetic sealing, cleaning, handling, packaging

"We ship well over 2 million parts a year to more than 400 customers with 95% on time delivery, and less than 2% defects," Sexton continued. *"Our investments in manufacturing equipment, inventory, quality control, and extensive training enable us to get it right the first time. We deliver small to large orders with the shortest cycle times, highest quality, and fastest delivery."*

When RF designers are weighing material choices and considering circuit design during prototype development, Accumet's material and process engineering expertise is there to guide them. Whether it be tapping into Accumet's extensive knowledge of ceramics and other RF materials, circuit design, anticipated yield loss, attainable surface finish, adhesion concerns, or any of the other multiple factors to be considered with regards to circuit manufacturability, Accumet's engineering staff is ready to help. Upon completion of lasered, lapped, or polished raw substrate orders, customers often ship the substrates back to Accumet after their manufacturing processes are complete for secondary processing. Over the last 50 years, Accumet has been routinely depended on by supply chain managers as a trusted vendor offering them streamlined sourcing.

Combine your requirements with Accumet's experience, as well as their ISO9001:2015 and AS9100:2016 compliant processes and quality standards, and you have an unparalleled partnership.

PARTIAL MATERIALS LIST

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- RF & EMI Absorbers
- Metals & Foils
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- Beryllium Oxide
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ers, and its use will be subject to fees. Fees may also apply to using other LPWANs, but the infrastructure can conceivably be proprietary and managed by the user, too.

OPTIMIZED FOR WSNs

Potential single-chip solutions for WSNs are now relatively commonplace. Most of the larger general semiconductor vendors, as well as some smaller specialists, offer highly integrated devices that combine RF transceivers with microcontrollers, power management, analog and digital peripherals, memory, and other interfaces. Developing an endpoint for WSNs based on almost any standard wireless PAN, LAN, or WAN can be achieved with a single device or a two-chip solution.

However, the fact that so many vendors are now offering very similar SoCs indicates that subtle differences exist between them; tradeoffs that each semiconductor vendor has deemed necessary for its own target application areas. One size does not fit all.

Also, some manufacturers may wish to implement multiple protocols; for example, combining a PAN with an LPWAN. This would allow the benefits of both network topologies to be exploited, such as high data rates for short-range communication coupled with low data rates for longer ranges. Every application is different, so it may not be possible to find the perfect SoC. For many reasons, choosing a custom solution may be the right option.

For instance, the SmartEdge Platform developed by S3 Semiconductors brings together a library of proven IP covering RF, digital, analog, and power functions that can be optimized for a given application, covering all forms of wireless networking. The value of an ASIC solution can be measured in many ways, but it ultimately means the right solution for the job, with few or no compromises.

> **Of the billions of devices expected to form the IoT in the near future, many will be endpoints in wireless sensor networks.**

CONCLUSION

Of the billions of devices expected to form the IoT in the near future, many will be endpoints in wireless sensor networks. Using an SoC to develop an endpoint makes sense for many reasons, but finding the optimum solution isn't necessarily easy.

Choosing a custom ASIC provides manufacturers with the option to optimize the solution based on their own requirements, giving them a competitive edge over those using standard parts. mw

GORDON WALSH is a Senior Systems Architect at S3 Semiconductors. He received a B.E. in Electrical and Electronics Engineering from the National University of Ireland, Galway in 2000. He holds two patents.

TABLE 1: COMPARISON OF WIRELESS PAN PROTOCOLS

Protocol	Data rate	Approximate range	Relative power
Bluetooth Classic	1 to 3 Mb/s	10 to 100 meters	Low
BLE (V4.2)	1 Mb/s	10 to 100 meters	Low to Very low
BLE 2M (V5)	2 Mb/s	<50 meters	Low to Very low
BLE Long Range (V5)	120 to 500 kb/s	40 to 400 meters	Low to Very low
ZigBee 868/915 MHz	Up to 250 kb/s	Up to 200 meters	Low to Very low
ZigBee 2.4 GHz	250 kb/s	10 to 100 meters	Low to Very low
Z-Wave	Up to 100 kb/s	Up to 100 meters	Low to Very low
6LoWPAN	250 kb/s	10 to 100 meters	Low to Very low
WirelessHART	250 kb/s	10 to 100 meters	Low to Very low
RFID (Active)	100 kb/s	Up to 100 meters	Very low
NFC	Up to 424 kb/s	Up to 20 cm	Very low

TABLE 2: COMPARISON OF KEY FEATURES FOR LPWANS IN USE TODAY

Protocol	Radio frequency	Licensed band	Data rate	Approximate range	Relative power consumption
LoRa	868/915 MHz	N (ISM regional bands)	300 b/s to 50 kb/s	Up to 15 km	Very low
Sigfox	868/915 MHz	N (ISM regional bands)	100 b/s	Up to 50 km	Very low
Ingenu RPMA	2.4 GHz	N (ISM global band)	Uplink: up to 624 kb/s Downlink: up to 156 kb/s	Up to 20 km	Low
Weightless-P	169 – 915 MHz	N (ISM/SRD regional bands)	200 b/s to 100 kb/s	5 to 10 km	Very low

DR. JUN PEI | CEO and Co-founder, Cepton Technologies Inc.
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11 Myths About LiDAR Technology

Cepton CEO and co-founder Dr. Jung Pei tackles the myths around LiDAR technology amid its rising popularity in helping with autonomous-vehicle navigation.

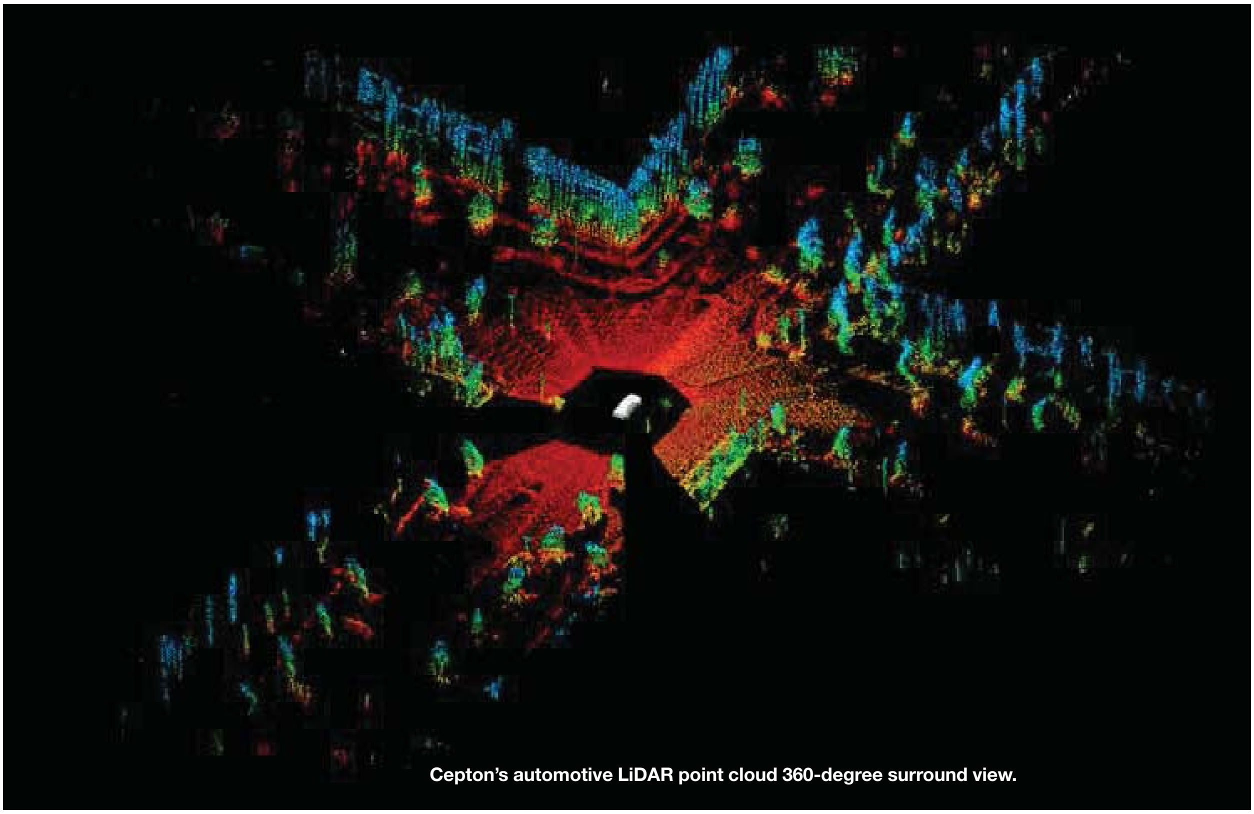
To move our society closer to the reality of fully autonomous vehicles taking over the roadways, a number of different solutions are being tested. One of these solutions is LiDAR (Light Detection and Ranging), which utilizes lasers to calculate the distance between itself and other objects. With all the buzz around autonomous vehicles and a wide range of options in the market, it can be difficult to fully understand the capabilities of LiDAR and separate fact from fiction. What follows are 11 myths that have emerged regarding LiDAR solutions.

1. LiDAR IS A VERY HIGH-TECH SOLUTION.

LiDAR was invented shortly after the invention of pulsed laser, which releases repetitive pulses of light instead of a continuous wave, in the early 1960s. The principle of LiDAR is actually very simple. Like bats that use sound waves during echolocation to register when the waves bounce back from objects in order to measure distances, LiDAR utilizes light waves from a laser to perform this function. LiDAR sends a pulse and measures the time it takes to reflect back from objects. Since the speed of light is constant, distance can be readily calculated by measuring the time it takes for the beam to return. This fundamental working principle hasn't changed in the past half-century; thus, the working principle has remained rather straightforward when developing LiDAR technology.

2. LiDAR IS EXPENSIVE.

While this was true for a very long time, mostly due to the fact that laser sources were expensive, the invention of the laser diode dramatically lowered the cost of LiDAR. Today, a visible pulsed laser diode can be obtained for less than $1, accounting for a very small fraction



Cepton's automotive LiDAR point cloud 360-degree surround view.

of the total cost to build a LiDAR. Imaging LiDAR allows for more than a single point to be measured, and the high cost of building these systems is typically associated with the manufacturing method. By adopting innovative methods to make these systems, for instance, Cepton's Micron Motion Technology (MMT) platform, imaging LiDAR can be manufactured at a cost of no more than a couple hundred dollars.

3. SOLID-STATE LiDAR IS THE BEST APPROACH BECAUSE IT HAS NO MOVING PARTS.

Solid-state LiDAR with no moving parts only improves the reliability of the LiDAR system's construction. This is because a solid-state LiDAR structure is free of wear and tear that would be caused by rotating or frictional parts. However, this advantage means that some performance sacrifices will have to be made, including a reduction in measurement range, smaller field of view, and more susceptibility to ambient light sources like sunlight. In addition, the high cost associated with manufacturing solid-state LiDAR prohibits it from being massively deployed for the consumer market in the near future.

4. FLASH LiDAR IS THE BEST LiDAR FOR IMAGING.

NASA uses flash LiDAR for its space-station docking operations because it enables high resolution and long-distance imaging to see across distances in space. Unfortunately, this system is far too expensive for integration into fleets of autonomous vehicles—it can cost well over one million dollars per unit due to the high cost associated with the components used for 1550-nm wavelength. It also is very power intensive, consuming up to 100 kW of power. While the imaging performance of flash LiDAR is the best available on the market, there will be no everyday automobile that could adopt such an expensive system.

5. LiDAR MUST OPERATE INFRARED WAVELENGTHS.

LiDAR can operate at any wavelength as long as a short pulse is able to be generated. In fact, a number of survey LiDAR systems work with visible green lasers. For automobile applications, any visible laser would be a significant distraction to nearby traffic. As a result, infrared wavelengths are usually chosen since they're not visible to the human eye.

6. LiDAR ISN'T SAFE FOR THE HUMAN EYE.

Eye safety is a complex combination of factors that aren't just based on the wavelength of a laser. The safety rating of a LiDAR depends on the power, divergence angle, pulse duration, exposure direction, as well as the wavelength. Under these conditions, a 1550-nm laser can safely emit more power than a 905-nm laser before it becomes non-eye safe. Meanwhile, 905-nm lasers are more

Utilizing LiDAR for automobile applications is a relatively new trend. When it was first invented, LiDAR was most notably utilized for measuring the distance between the earth and the moon; it was also often used to measure weather systems.

popular since they're more cost-efficient. To help make these 905-nm lasers eye safe, engineers have devised sensitive optical detectors that don't require the use of high-power lasers.

7. LiDAR CAN'T WORK IN POOR WEATHER CONDITIONS.

LiDAR is an optical device just like a camera, so if fog is heavy enough to block all light transmission, LiDAR could become less effective. However, LiDAR will still provide valuable data in typical road conditions. Self-driving cars of the future will integrate a mix of cameras, radar systems, and LiDAR to balance out the advantages and disadvantages of each solution—no one system is perfect—to keep passengers safe in a variety of different weather conditions.

8. LiDAR CAN ONLY BE USED FOR AUTOMOBILES.

Utilizing LiDAR for automobile applications is a relatively new trend. When it was first invented, LiDAR was most notably utilized for measuring the distance between the earth and the moon; it was also often used to measure weather systems. Today, LiDAR can be employed for any application that requires distance information of an object.

In addition to self-driving cars, LiDAR is ideal for numerous transportation solutions, including trains, shuttles, and trucks. LiDAR is also being used with unmanned aerial vehicles (UAVs) for a variety of applications, such as mapping disaster-stricken areas and surveying agriculture fields. On top of that, robots and other types of smart machines are using LiDAR for a range of industrial applications. As the cost of LiDAR continues to drop, it's expected that LiDAR will be integrated into a wider range of machines, such as putting LiDAR in intersections to monitor traffic, security systems to protect property, and many other applications.

9. LiDAR WON'T BE INCORPORATED INTO VEHICLES FOR ANOTHER DECADE.

The promise of autonomous cars is more than just hype. Pilot programs are being conducted around the world to test out autonomous cars, shuttles, and other solutions to make transportation safer. In the next few years, we'll see LiDAR integrated into cars with Level 3 active safety features that provide a range of benefits like assistance with accelerating, steering, and braking. We'll then see LiDAR integrated into Level 4 features that provide cars with even more autonomous functions. The timing of when fully self-driving cars (Level 5) becomes mainstream depends on a number of factors beyond the technology itself, including government regulations and local infrastructure.

10. LiDAR CAN BE FULLY REPLACED BY CAMERAS, RADAR, OR A COMBINATION OF THE TWO.

The most important characteristic of LiDAR is its high spatial resolution while measuring 3D objects. Radar is great for determining the speed at which other objects are moving and can detect a stopped vehicle ahead, but it can't determine whether a stopped vehicle or other object is in the driver's lane or on the shoulder. A camera becomes rather useless when there isn't enough ambient lighting; and when it's dark, a camera can only see as far as the headlights, which can be quite dangerous. In addition, cameras have difficulty navigating when wet roads create glare. Therefore, the combination of LiDAR with cameras and radar will be essential for making self-driving cars safe.

11. FMCW LiDAR IS BETTER THAN ToF LiDAR.

Frequency-modulated continuous-wave (FMCW) LiDAR measures the phase difference of an optical wave instead of its time-of-flight (ToF); thus, it's capable of measuring with greater accuracy (from millimeters to microns). This high level of accuracy is important for survey applications, while it's not needed for obstacle detection for automobiles, which only require a centimeter level of accuracy. The extra complexity and associated costs of FMCW LiDAR make it less attractive even for Level 4 to 5 applications in cars.

It's clear that LiDAR technology will play a pivotal role in reshaping transportation by making it safer. It will also increase the efficiency of a number of other industries, including industrial automation and mapping. mw

DR. JUN PEI is CEO and co-founder at Cepton Technologies, which provides automotive-grade 3D sensing solutions to autonomous vehicles and other related industries. Prior to Cepton, Dr. Pei founded AEP Technology to develop advanced 3D optical instruments for scientific research. Earlier in his career, he worked in technology development at KLA-Tencor, a semiconductor equipment company. Dr. Pei received his Ph.D. in electric engineering from Stanford University, specializing in optical 3D metrology.

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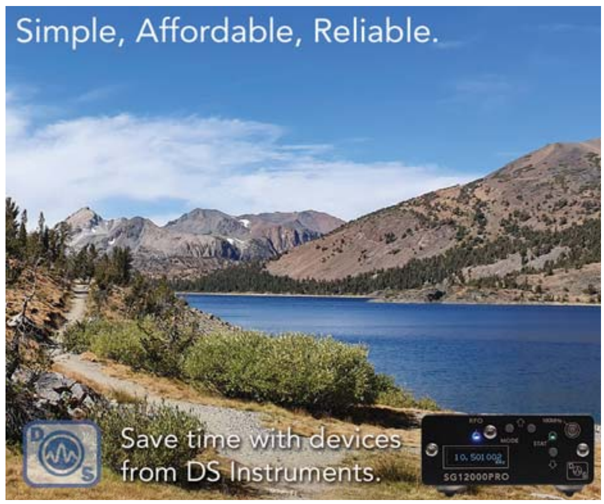
Our affordable dual-control devices combine industry standard SCPI remote operation with simple and intuitive stand-alone front panel controls. DS Instruments currently specializes in developing compact Signal Generators, Programmable Digital Attenuators, Power Meters, Microwave Amplifiers, and Phase Shifters, with new products released regularly. Visit us online for updates!



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Our affordable dual-control devices combine industry standard SCPI remote operation with simple and intuitive stand-alone front panel controls. DS Instruments currently specializes in developing compact Signal Generators, Programmable Digital Attenuators, Power Meters, Microwave Amplifiers, and Phase Shifters, with new products released regularly. Visit us online for updates!

MICHAEL MUNROE | Technical Product Specialist, Elma Electronic Inc.

11 Myths About OpenVPX and the SOSA Initiative

Paradigm shifts in technology initiatives don't come without their skeptics, as is the case with the DoD's Hardware/Software Convergence Initiative. Aimed at developing a common, modular hardware architecture across C4ISR and EW systems, this program combines separate efforts initially undertaken by the U.S. Army under CERDEC (CMOSS), the U.S. Navy under NAVAIR (HOST), and the Air Force under AFLCMC into one, cohesive COTS-based, open standards initiative.

Now managed entirely under Sensor Open Systems Architecture (SOSA), this collection of open architecture standards provides reconfigurable, upgradable, and cost-effective C4ISR capabilities in deployed platforms across sensor applications throughout all major military branches. Using OpenVPX as its basis, it's setting the standard for interoperable systems across several defense branches to improve subsystem SWaP, enable rapid technology insertion, and promote reuse.

It's important to understand how both OpenVPX's history in military environments as well as its pedigree as a ratified industry standard can help facilitate this widespread, and seemingly complex, undertaking to break from the old method of costly proprietary computing systems.

Below, some common misconceptions about OpenVPX are dispelled, and we examine how it can provide the right environment for the SOSA initiative

1. THE CARD ISN'T GOING TO BE COMPATIBLE.

This depends on whether the target backplane is a VITA 65.0 standard development backplane or a customer-driven deployed backplane. The VITA 65.0 standard development backplanes have very simple topologies that are compatible with lots of cards. Actual VPX system backplanes have much more complex topologies with many I/O signals.

Consequently, these backplanes are usually designed for specific cards and map to the unique I/O mapping of one VPX module. With the development of fully defined SOSA VPX slot profiles, even complex backplanes will be wired for standard slot profiles, and the result will be more modules compatible with any given backplane implementation.

2. I WON'T BE ABLE TO GET ENOUGH POWER.

Enough power is no longer the problem—it's properly cooling the amount of available power. In the past, VME64x and CompactPCI cards could each typically draw no more than 150 W from a backplane slot. As large FPGA silicon became available from companies such as Xilinx and Altera, the power needs of an individual card exceeded the amount of power that a card could draw because the pin assignments and contact design did not allow for more power.

3U VPX cards can draw over 270 W and 6U cards could draw over 380 W. It's unlikely that VPX systems will ever be limited due to power availability. And, new cooling standards are being released to allow more of this VPX power to be used in future systems.

3. I'LL NEED A CUSTOM BACKPLANE.

One of the main criticisms of the VPX architecture, and a fair one at that, is that it doesn't consider all of the other VPX features that have made the architecture so desirable. The mandate for custom backplanes is, therefore, being tolerated by designers.

A new solution designed to meet the need for fully customized VPX backplanes is on the horizon. Pioneered by hard-working technical groups under SOSA, emerging standard profile definitions will eliminate much of the need for VPX backplane slots to be wired for specific, unique VPX modules when using SOSA conforming plug-in cards.

4. I CAN'T RUN 10 Gb/s OUT OF THE BACKPLANE.

For some time, PCIe Gen2 and 10GBase-KX4 were thought to be the fastest protocols that could be reliably passed to I/O devices through cables, which plugged into VPX backplane RTM connectors. Recently, a new approach that utilizes new backplane materials, together with improved via design, has pushed this limit to PCIe Gen3 and 40GBase-KR4. It's highly likely that a new, backward-compatible VPX connector may even allow these higher speeds to be exceeded in the near future.

5. VITA 65 MAY NOT MEET ALL MY DESIGN NEEDS.

This was most likely said by those who haven't reviewed the current list of available features added to VPX. In fact, it's hard to imagine an application that could not be implemented within the standard. VPX is rugged and supports two card sizes. Some of the new features include miniature coaxial backplane feed-thru, backplane optical ribbons, radial clocks, 25-Gb/s channels, rugged vibration-resistant connectors, hybrid topologies, XMC sockets, as well as VITA 57.4 FPGA mezzanines that support 28-Gb/s links between the base board and the mezzanine. The coaxial modules now available are causing an explosion of new applications.

6. ALL OF THE VPX CONNECTORS ARE EXPENSIVE BECAUSE THEY ARE SOLE-SOURCED.

OpenVPX was built specifically with the goal of eliminating single-source pitfalls. To date, there are three suppliers of intermatable backplane connectors, one of which already offers three different versions of the VITA 46 connector. All versions are forward and backward-compatible.

The connectors cost more because of the performance they provide. These high-density, high-speed connectors allow space for XMC/PMC mezzanine sockets and fit within the 3U and 6U 160 Eurocard packaging formats. In addition, there are space-qualified, high-vibration-resistant, footprint-compatible VPX backplane/daughtercard connectors. Paying for the benefits of performance enhancement is true for whatever architecture you choose.

7. THE MULTI-CONNECTOR IS LIMITED TO 12 Gb/s.

Although the current connector supports signaling up 12 Gb/s, which is just beyond PCIe Gen3 and 10Base-KR Ethernet, a new backward-compatible version of the same MultiGig connector is being standardized and will support Ethernet lanes up to 25 Gb/s and Fat Pipes (FP) supporting 100GBase-KR4. This connector is both backward- and forward-compatible, so that old cards can be used in the new backplanes and new cards will be usable in the old backplanes. However, the speed will always have to be negotiated down to the least capable element in the path.

8. I CAN'T INSPECT VITA 66.1/66.4 OPTICAL MODULES IN THE FIELD.

There's now an inspection card for 6U VPX conduction-cooled chassis that will automatically both inspect—and clean—VITA 66.1 optical modules installed in either the J3 or J6 position in a 6U VPX backplane.

Independent of the VPX system, this tool is tethered to a laptop running software that will execute multiple inspect/clean/inspect cycles until all of the fibers meet inspection requirements. Then, a new card can be inserted into the fully inspected VPX slot in the field. The hope is that this equipment will be extended to 3U VPX slots that are either in accordance with AV 48.1 or AV 48.2.

9. ISN'T AIR FLOW-THROUGH THE SAME AS CONVECTION COOLING?

Not at all. Three different cooling methods are actually included in OpenVPX that all depend on forced air. While technically not "new," since these methods have been used with VME for years for demanding applications, they're now standardized. Check out VITA 48.5, 48.7, and 48.8. Each offer advantages over conventional forced air, because each method allows air to be directed specifically where it's needed.

10. I HEARD THAT THE VITA 46.11 IPMI-BASED SYSTEM MANAGER ISN'T REALLY SECURE ENOUGH FOR CYBERSECURITY.

Your concerns have been heard, and the HOST and SOSA working groups are really beefing up the System Management approach and adding new capabilities, such as large file transfer support and IPMI 2.0 security. These two working groups are supported by a large team at the University of Georgia Research Institute, the U.S. Army, U.S. Air Force and NAVAIR, as well as individual companies and SBIR (Small Business Innovation Research) award winners. It's a level of cooperation never seen before.

11. CAN AN INTERMEDIATE FREQUENCY BE SHARED BETWEEN RADIO CARDS IN A VPX BACKPLANE? I'VE HEARD THAT THERE ISN'T SUFFICIENT ISOLATION.

It's true that the MultiGig signal pins may not provide sufficient isolation between pairs to distribute an intermediate frequency between radio cards. However, VPX slots now support a variety of coaxial interfaces that can distribute an intermediate frequency or very precise clocks such as Precision Time Protocol (PTP) and Network Time Protocol (NTP).

VITA 67.3 only defines the opening in the backplane, the mounting holes, and alignment pins, and supports several sizes of modules as well as a growing number of unique contact configurations, including mixed coax and optical interfaces. These 67.3 modules are easily removed and replaced on the backplane, so reconfiguration is possible.

VITA is working to standardize additional contacts, but users are already employing coaxial contacts such as SMPM (multiple suppliers), nanoRF (TE currently), and SMPS (SVmicro). SMPM (many vendors) is lower density, but it supports the greatest variety of backside cable options including flexible, semi-rigid, and right-angle terminations. Some SMPM configurations are already standardized within VITA documents.

We're only addressing the backplane side because 67.3 was developed to support direct launch from the daughtercard mezzanines, though cable can also be used. Furthermore, VITA 67.3 modules can support new higher-density nanoRF and SMPS contacts. Half-size 67.3 modules with as many as 12 coaxial contacts are already in the marketplace and being used. The denser connectors only support flexible cables presently. These can be used to distribute the precision clocks already mentioned. You can also see a mix of SMPM and either nanoRF or SMPS contacts as well as optical MT ferrules combined in a single 67.3 module. mw

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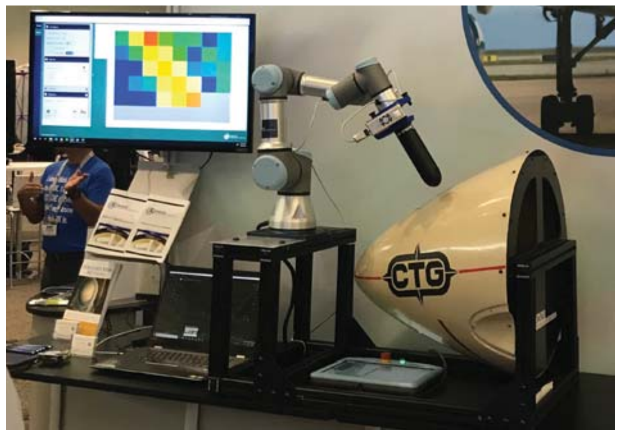
Copper Mountain Technologies develops innovative USB and PXI Vector Network Analyzers for engineers all over the world. Headquartered in Indianapolis, IN with sales offices in Singapore and Miami **CMT pioneered metrology-grade USB VNAs** in 2011 and continues innovating.

CMT understands that every project is different and is focused on delivering **flexible VNA solutions** that empower engineers to reach their goals. The development of the first metrology-grade USB VNA resulted in **improved cost and accessibility** for users, which c**hanged the VNA industry**. To provide maximum accessibility, CMT's free **software runs on Windows or Linux OS** connecting to the measurement hardware via USB interface. All data is stored on an external computer. **Advanced software features** such as time domain reflectometry, gating, frequency offset, linear/log sweeps, TRL Calibration, and more come **at no additional cost** enabling maximum functionality for all users.

The 1-Port VNAs **connect directly to the DUT,** reducing measurement errors and eliminating the cost of expensive test cables. The **Compact Series of VNAs feature a range of options** to give each user their ideal features, performance, and price point. CMT's CobaltFx frequency extension system gives engineers **scalable mmWave measurement capabilities at the lowest possible cost** by using a 9 or 20 GHz USB VNA as a base. The PXIe VNA is the result of CMT's **exclusive collaboration with National Instruments,** bringing world-class VNA performance and speed to the production environment.

CMT VNAs are used in innovative microwave breast cancer detection systems, robotic probe measurements examining aircraft radomes, and cutting-edge wireless power solutions. With more than a dozen integrated solutions to date, CMT partners with industry leaders to offer engineers expanded solutions such as wireless charging technology, antenna measurement, on-wafer measurement, and more. CMT also collaborates with customers to **develop new customized VNA modules** purpose-built to solve specific industry needs.



Each VNA solution is **backed by CMT's application and automation support team of engineers** who work as an extension of your team. The engineering support staff continues to grow, with employment opportunities for customer service driven RF applications engineers striving to help customers across the globe achieve success.

Copper Mountain Technologies is ISO 9001:2015 certified. The Indianapolis calibration lab is accredited by the recognized international standard ISO/IEC 17025 (2017). Repair services are also offered at various Authorized Service Centers throughout the world. Reach out to us. We'd love to hear how we can help Extend Your Reach®.

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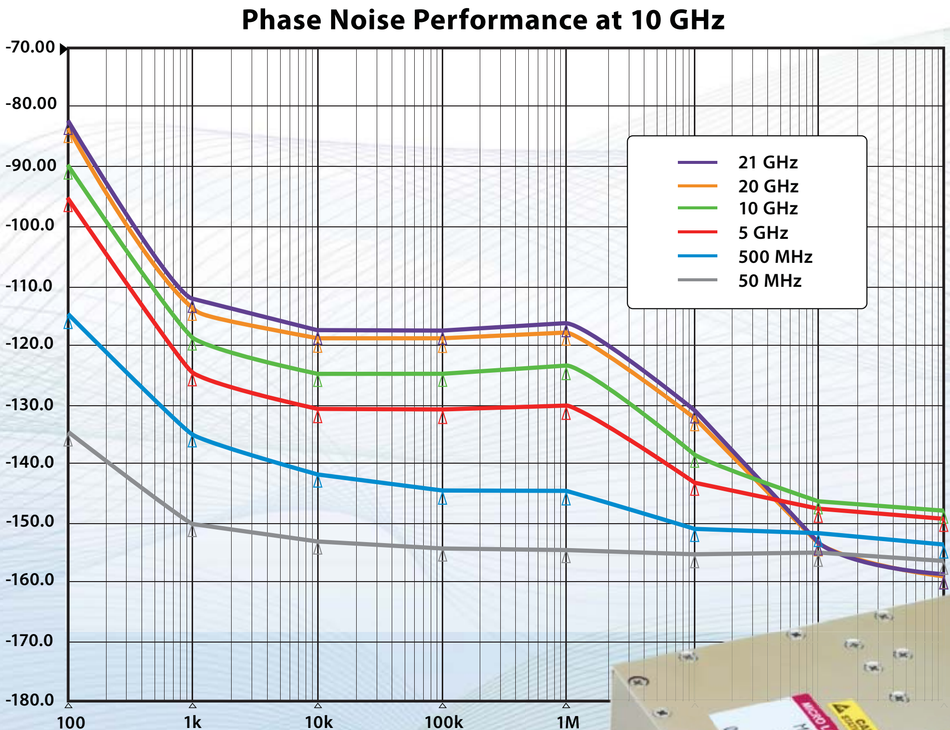

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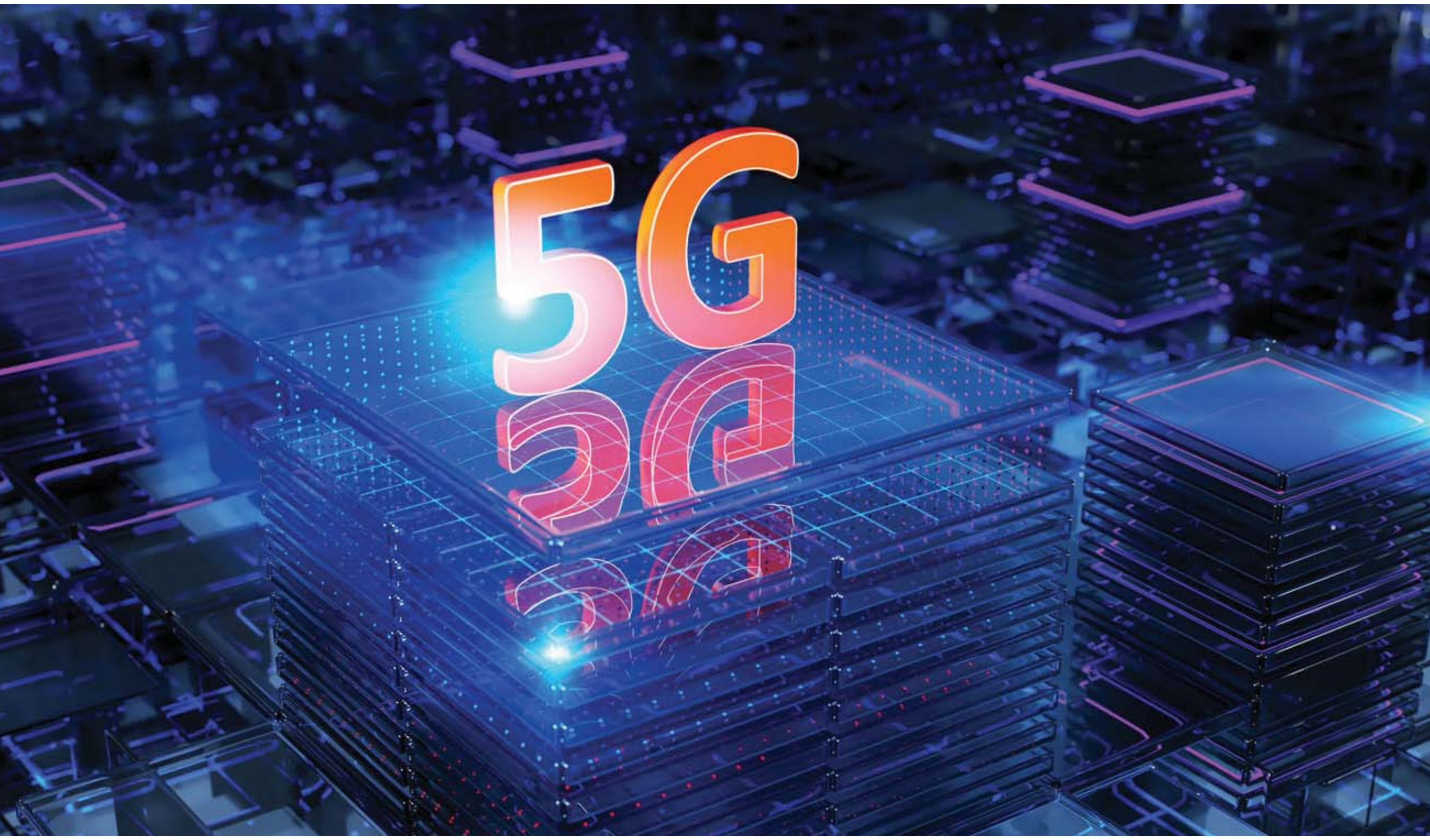

Can 5G Really Live Up to Its Hype, and WHY SHOULD YOU CARE?

As the electronics industry gears up for the eventual massive 5G rollout, questions abound regarding everything from small-cell infrastructure to available spectrum to handset development.

The 5G hype is everywhere. It's telling us that 5G is the best technology ever, and that it will to change the world as we know it. It seems like 5G is going to affect everything we do, and of course make life better. Really?

I know that I'm a natural skeptic. And I'm not the only one. In a recent discussion with a couple colleagues, Bob Landman and Paul Rako, it was clear that we all shared a common feeling. Specifically, is 5G wireless technology really as good as they say? Our doubts are based on valid engineering skepticism and related experience. This discussion actually led to more questions than answers. Questions like: Is 5G really that good? And will 5G really be worth the extra bucks we will be asked to pay?

Anyway, here's a summary of this discussion:

1. The stated goals of 5G are to increase data rates to 20-Gb/s downlink and 10-Gb/s uplink, decrease latency to 0.5 ms (downlink), and increase subscriber capacity 100 times. These are obviously peak specifications that undoubtedly will rarely be achieved in a normal usage. 1 Gb/s seems doable at times, but imagine thousands (even hundreds or dozens) of users seeking 1-Gb/s service at the same time.

2. The whole 5G concept is based on the small-cell architecture. That's ok as far as it goes, but to ensure good coverage and high data rates, thousands of these cells are going to be needed for the millimeter-wave (mmWave) bands where useful signals probably won't travel more that 200-300 meters or so. Even with agile beamforming gain antennas, it will take many cells to cover just an area the size of a city block. And that's hopefully with good line of sight (LOS) all around. Furthermore, mmWave signals just don't penetrate walls and other obstacles all that well, if at all, keeping the range super short. Given that an estimated 80% of all calls occur indoors tends to indicate no connection will be made. To make a call, the cell-phone user will have to go outside near a cell.

3. Another issue involves mounting places for all of these cells—are there enough? Only so many utility poles, lamp posts, billboards, and building corners are available. Numerous cities have said no to small cells in some places and approval delays for mounting requests are slowing the installation of 5G in many areas. And should we be paranoid about the potential EMI storms that could develop from so many cells so close together?

4. What about backhaul for all of those thousands of cells? Some have said that backhaul will be via fiber. Maybe, if some fiber is nearby. Will carriers actually invest in digging up streets and sidewalks to add fiber? Probably not. While fiber is a good choice, what if many users try to get 1-Gb/s downloads about the same time. That could tax the cell with data streams of tens to hundreds of gigabits in the fiber. Is that realistic? What may happen is that backhaul will use more mmWave links. That amounts to another complex radio tied to the small-cell radio. Though that's doable, remember that the backhaul is also going to need its LOS path to work properly.

5. Spectrum is another concern. Is there enough? It doesn't seem so. The FCC is raking in billions selling spectrum, but is there some for everyone? Some of the spectrum that has been freed up is fragmented narrow slices. The 6-GHz spectrum is promising, but that could be designated as unlicensed. The high data rates and wideband mmWave assignments demand more spectrum and bandwidth. Will it materialize? I doubt that the FCC and others really know what will become available and when. At least they're trying.

6. Latency. It's probably not a problem in most use cases. Maybe it's a limitation in some applications like self-driving cars (autonomous vehicles or AVs) and factory robotic automation. The wireless link has been designed to deliver that small latency. But what happens when the signal goes out into the wired (fiber or UTP) part of the attached network? Oops…

> In a recent discussion with a couple colleagues, Bob Landman and Paul Rako, it was clear that we all shared a common feeling. Specifically, is 5G wireless technology really as good as they say? Our doubts are based on valid engineering skepticism and related experience.

7. Eventually all vehicles, including AVs, will get radios that talk to other nearby vehicles, roadside units, and infrastructure sources to improve safety. The older, already blessed DSRC technology appears to be dead. Instead, the new 5G technology called C-V2X is winning. Hopefully it will work in the 5- to 6-GHz DSRC band and not mmWaves. Will you trust your AV with a short, unreliable mmWave link? A beamforming phased array on the top of your car may help.

8. Will 5G be better than 4G LTE? LTE is very good. Most of the world uses it. LTE delivers reasonable "fast enough" rates for video streaming and the like.

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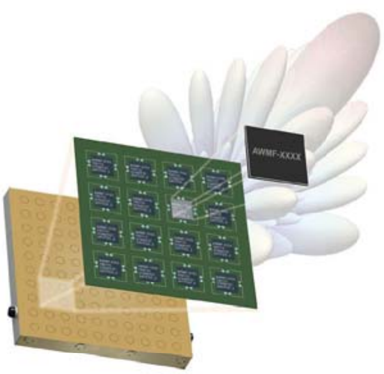

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Do we really need more speed? Is more speed the point where you can't tell the difference between 10 Gb/s and 5 Gb/s? The goal is for 5G to replace LTE eventually. Are we ready for that? Many carrier sites haven't yet upgraded to the faster versions of LTE Advanced and LTE Advanced Pro. The latter upgrade is supposed to get the data rate up to 1 Gb/s. Most of us could live with that. 5G must coexist with LTE on all networks initially. As funding allows expansion, 5G will probably eventually take over the network. The 4G to 5G transition is probably going to take a while.

9. During our discussion, the subject of spectral efficiency came up. The 5G NR specifications say that 30-bps/Hz downlink and 15-bps/Hz uplink are possible. The modulation is some variant of OFDM. But to get to that level of spectral efficiency, you need to use 64QAM or 256QAM on those subcarriers. Good luck with that. With multipath virtually everywhere and the sensitivity of mmWaves to it, those levels of spectral efficiency are a noble goal, but they don't seem realistic.

10. Antennas could be a problem. 5G relies a great deal on MIMO and phased arrays with agile beamforming. The multiple antenna problem of MIMO is an issue, especially in handsets that already have up to 10 antennas in them, with a maximum of 2 for MIMO. As for phased arrays, the antenna elements themselves are tiny at mmWave frequencies. But arrays of these antennas are much larger, so that they can use hundreds of elements and all of the related circuitry. Will these be too big for small cells?

11. Handsets. Just where are the 5G phones? They are in development. Huawei, Samsung, Xiaomi, LG, and ZTE all have 5G phones ready to go now. The multi-standard, multi-band devices will have to support LTE and 3G as well as 5G. More antennas are needed, and power consumption will probably go up, especially on the mmWave phones. 5G phones will undoubtedly be larger with bigger batteries. And how many cellular band filters will be in those front-ends? Maybe all 5G phones will be like the Lenovo-Motorola Moto Mod that offers a standard LTE smartphone but with a clamp-on 5G accessory if you need it. Whatever the format and content, 5G phones will cost more than the upper-end smartphones today, and your battery may not make it through the day. And we are all wondering what Apple will do. Will a 5G iPhone with a folded color screen be in our future?

12. One thing that seems out of whack is the touting of 5G for the IoT, smart grid, and industrial automation. Most IoT applications only need low speed. Several kb/s is often enough. The same with electrical utilities and the smart grid. They use wireless but rarely need more than low kb/s rates for their monitoring and control. Industrial-automation applications are all over the place, but they can usually live with <10-kb/s sensor links and a few Mb/s on some other equipment. Yes, we know that 5G will work, but it seems like overkill for all of those apps.

13. Will the rural areas of the country ever get 5G? Will it ever get LTE? Some rural towns and villages still have 3G. I'm not making this up. Those folks would be thrilled with 4G LTE. I'm guessing they will not get 5G, as it is just too expensive and impractical. There's no money in it for the carriers. I hate to say it, but is this something the government (FCC?) should deal with? I can't help but wonder how many people are just underserved.

14. Do mmWaves cause brain cancer? Probably not unless you talk on voice-over-5G for five or more hours per day with the phone against your head. That's unlikely. But the real answer is we don't know for sure at this time.

15. Will 5G replace Wi-Fi? Or vice versa? I don't know who came up with these ideas. If you don't understand the workings or applications for the various wireless technologies, you may think this is possible. In any case, the answer is a solid no.

> "We're going to get 5G anyway." So, let's get a more positive attitude, people, and start thinking about 6G right now.

16. Will the initial 5G broadband wireless internet access service to be offered by Verizon and others really be competitive against cable or DSL? Most wireless ISPs, and there aren't many, haven't done well. They mainly serve the rural and boonie areas with 1 Mb/s or a bit more. If a LOS path can be found, it may work ok. Sprint's Clearwire service with WiMAX didn't do all that well. Results will probably be mixed depending on the local environment.

17. As for why you should care, here are a couple of thoughts. The good news is that 5G is a boon to our electronics industry. Business will be good for a while. The bad news is that 5G will simply perpetuate the ongoing preoccupation and addictive damaging obsession with smartphones. Maybe even make it worse.

Lots of questions. We're not party poopers or negative thinkers. Just a few experienced engineers with opinions and doubts. We trust that the 3GPP developers, equipment manufacturers, and carrier engineers have considered all of this stuff and can reassure us that 5G will be as good as they predict.

If it isn't as good as they claim, why should we care, since we really can't do anything about it. As long as LTE remains available, we won't have to pay the extra they will obviously charge for 5G. In any case, we should be happy and hopeful as my editorial colleague Bill Wong says: "We are going to get 5G anyway." So, let's get a more positive attitude, people, and start thinking about 6G right now. mw

PIETRO SCALIA | Sector General Manager, Communications Equipment and Enterprise Systems, Texas Instruments
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Is 5G Four Times More Power Dense—or Even More?

The drive to achieve 5G network speeds creates an extremely challenging hardware environment from a power- and space-density perspective.

5G is poised to revolutionize connectivity, providing a programmable, intelligent connection between users and cloud services as well as a seamless, ubiquitous, and personalized experience across different environments and devices. With one network for all use cases required by the Big Data explosion, from home to enterprise environments, 5G promises to connect tens of billions of devices that are always online, each with their own slice of the network, dynamically established to provide a dedicated profile of priority, security, speed, and latency.

To realize the convergence of cloud and telecommunications services, the 5G rollout requires significant infrastructure changes to the existing network, both for New Radio (NR) access and backhaul as well as in the core, to bridge wireless and wired networking. Changes include more, smarter radio-frequency (RF) devices to increase network coverage and capacity; more intelligence on demand in the network; and localization of functions in the cloud or at the edge, according to the required level of network service.

The new network scenario *(Fig. 1)* includes significant changes in the NR access network portion to enable higher capacity and coverage, while also requiring that the core networks follow the bandwidth requirements in the switching and optical elements. There is also the introduction of new systems, like mobile edge computing.

DEALING WITH DENSITY

The entire segment industry is contributing new hardware that will enable 5G. The drive to achieve 5G network speeds up to 10 Gb/s in bandwidth—achieved by increasing RF signals to centimeter and millimeter wave in the second phase of 5G deployment, as well as multiple-input mulitple-output (MIMO) beamforming and new, multibandwidth active antenna systems (AASs) to increase spectrum efficiency—creates an extremely challenging hardware environment from a space-density perspective. Similar challenges already exist with macro radio base stations operating at higher frequencies and with multiple power-amplifier (PA) structures and MIMO small cells.

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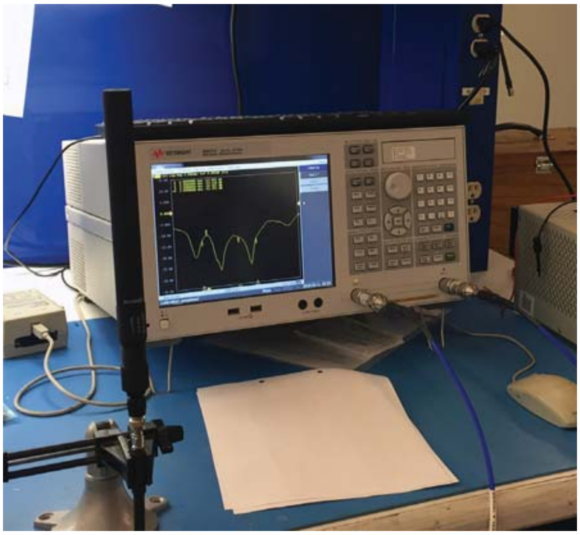

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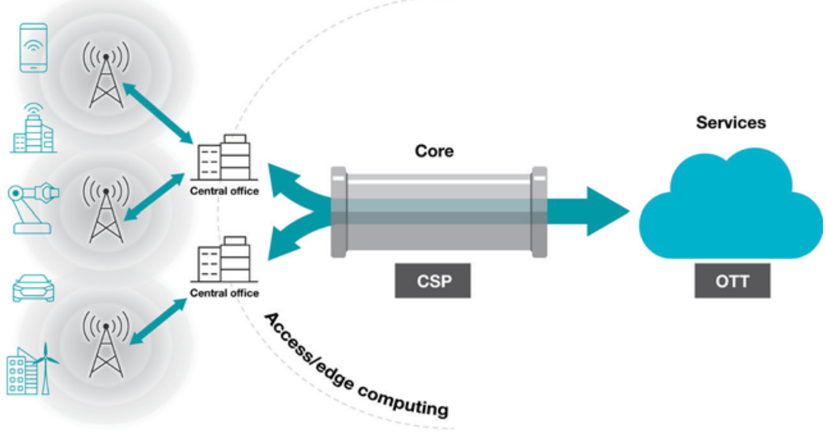
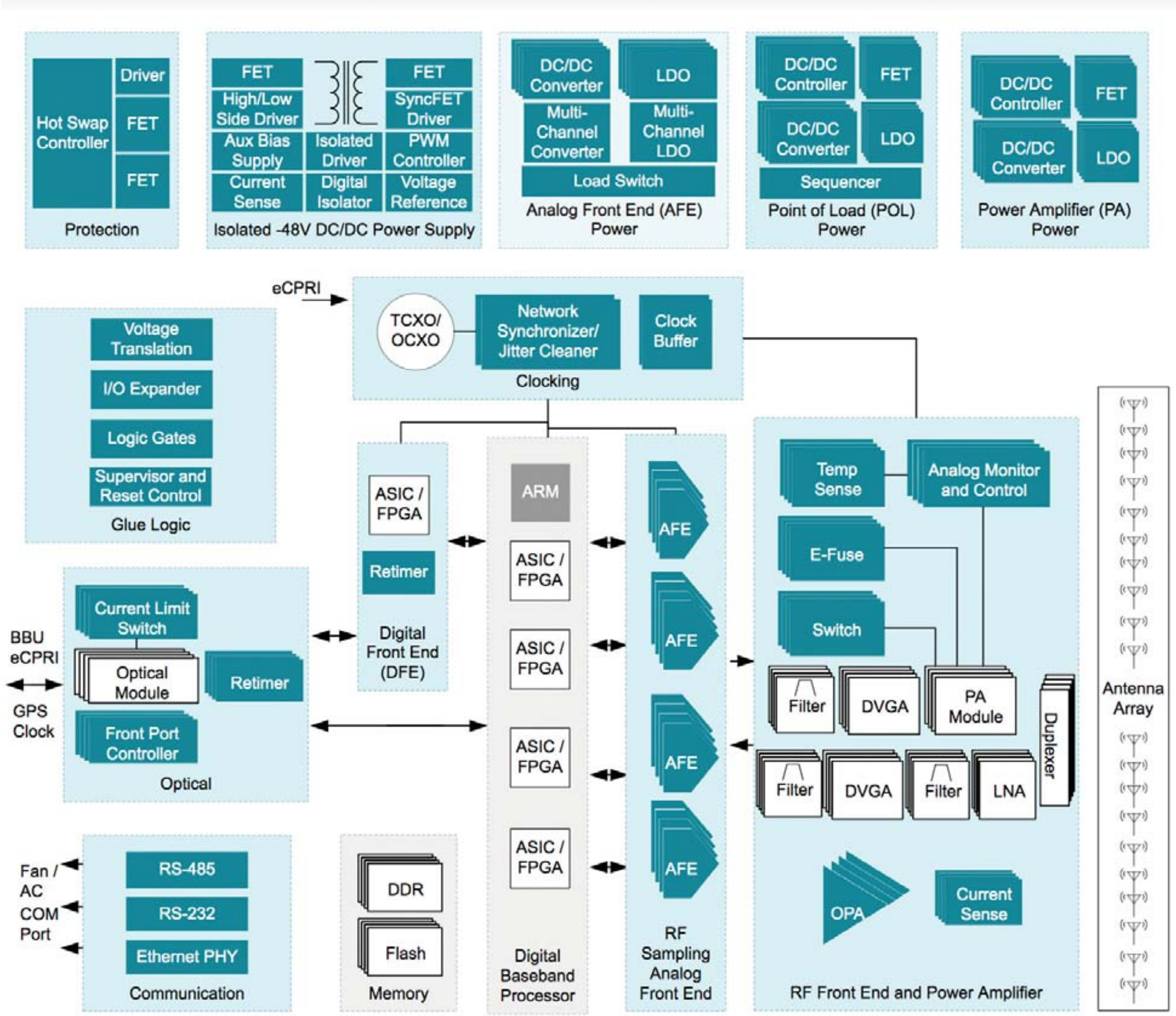


1. 5G transforms the network scenario, adding new end equipment.

On the signal-chain side, density is enabled by the adoption of high-speed, multiband, multichannel transceivers, up to four receivers/transmitters (Rx/Tx) and 1-GHz bandwidth, that employ RF and zero-intermediate-frequency sampling techniques. New, integrated signal-chain components have increased power needs, an obvious requirement for the increasing numbers of PAs. Power per PA decreases while overall power per system increases, requiring a change in architecture to supply that power. Meanwhile, it's necessary to satisfy the low-noise requirements of each specific radio implementation.



2. TI's AAS block diagram shows the fundamental subsystems of the application.

THE CONVERTER FACTOR

An extremely constrained space requires an increased converter switching frequency in order to still fit without efficiency penalties, despite the difficult thermal environment: fully encapsulated, no forced ventilation, and an extremely high (albeit controlled) printed circuit board (PCB) temperature as high as 100°C.

New controller techniques enable converters to meet the requirements of this application environment. Advanced current mode with adaptive gate drive facilitates smooth controller transitions even at high switching frequencies, offering lower noise behavior and improving reliability while reducing the minimum on-time. Packaging is also critical to enable increased switching frequencies and the dissipation of associated losses. Conduction losses, reduced by exceptionally efficient power stages, compensate for that incremental factor for total power consumption. Designers must trade off the maximum switching frequency with the maximum junction temperature over operation and reliability considerations.

Dissipation comes into play, especially when a heat sink is available closer to the RF or system-on-chip (SoC) section. Converters can leverage this heat sink to extract heat from the top. It's possible to reduce the junction temperature if the package offers resistance to the top, comparable even if higher to the bottom, where most of the heat is already directed to be transferred to the PCB. There, it's thermally shunted to the mechanical encapsulation and controlled thermally, modulating the value of input power.

With the 4x increase in transceiver density when implementing the entire analog front-end (AFE) function—with four digital-to-analog converters/four analog-to-digital converters, an oscillator, filtering, and mixing on the same chip—power needs to follow a similar scale of integration. However, considering the multiplication factor introduced by MIMO AASs, when moving from a 4x Tx/Rx configuration to a 64x or 128x Tx/Rx configuration, the scale factor cannot be linear.

It might be possible to integrate one system power solution for more than four AFEs. The converters must supply clusters of multichannel transceivers, respecting the signal-chain integrity at those sensitive points of the RF path. Texas Instruments' AAS block diagram *(Fig. 2)* shows the fundamental elements that constitute this NR element *(Fig. 3)*.

DEVISING AN EFFICIENT POWER SUBSYSTEM

Looking at power subsystems, due to increased power/current—in some cases over 1 kW—a 12-V intermediate bus voltage is common. Other architectural elements now becoming mainstream include multichannel converters and low-dropout (LDO) regulators as well as low-noise converters, which could help improve total system efficiency. These reduce the need for low-noise LDOs with a high power-supply rejection ratio, which are sometimes used across the most critical rails, from phase-locked loop to serializer-deserializer. The point-of-load switching frequency must be higher than 1 MHz to enable a size reduction of passive components.

Combining rails where possible avoids the risk of AFE crosstalking and interference, while still respecting the tight voltage tolerances of the rails and sequencing specifications among different rails. LDOs can provide the simplest sequencing (PG/EN), and that can sometimes be a reason to add some to the bill of materials (BOM). If required by the integrated transceiver, negative rails require special effort in the

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converter. A large ripple in the output makes a simple buck-boost topology an unwise choice.

Placing several integrated transceiver rails on the board within a reasonable distance (drop) and achievable noise immunity simplifies the schematic by reducing the number of converters, mainly LDOs, that are used to separate and supply different AFEs locally. *Figure 4* provides a potential BOM of converters and LDOs that can fit the application, with a detailed list of critical parameters.

A POWER SOLUTION

Figure 5 is a block diagram of a power solution with four integrated transceivers, implementing many of the considerations described above. Ferrite beads aren't shown in the figure, but they're necessary (with associated capacitors) to decouple crosstalk of clustered inputs of the transceiver, inside the single one, and with respect to the others clustered with the same power solution—at least on the noise-sensitive rails. Some next-generation transceivers have lower power-consumption levels that can potentially enable clustering of as many as eight integrated transceivers if the mechanical constraints of the board layout allow.

To evaluate the quality of the power-supply solution, consider these specifications for Rx and Tx performance:

- Rx: signal-to-noise ratio, spurious-free dynamic range, and intermodulation distortion from third order.
- Tx: phase noise and third-order intercept.

You must measure these parameters on the AFE with your proposed power solution to investigate any impact in performance, resolving any issues by filtering, using ferrite beads or changing the power BOM if the issue is more significant.

TIMING

Much like with RF transceivers, with power challenges come new clocking requirements. The new Ethernet-based common public interface (eCPRI) creates a need for timing and frequency synchronization in multipoint connections between the baseband unit (BBU) and remote radio unit (RRU), and challenging delay requirements in the clock tree in a beamforming implementation. Companion system power solutions must minimize BOM and cost as well as increase density while maximizing features with low noise performance and efficiency at higher switching frequencies.

It's possible to combine the same solution for RF transceivers and clocking, following the criteria described earlier, to generate an effective power solution for a specific 5G radio or BBU. The Power Management Bus (PMBus) and Serial Voltage Identification interfac-

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4. The main characteristics of power devices supplying a multi-AFE solution are shown.

es have a fundamental importance in BBUs, even more than in RRUs. They must be available in controllers and converters for multiphase and single-rail solutions in order to power the latest processing SoCs, achieve fast transient performance, and accurately monitor parameters for performance optimization and system reliability.

The cloudization of the BBU, where a centralized BBU connects to many RRUs, requires more functionality inside the RRUs, causing power to increase. The higher power requires adaptive output voltage scaling through PMBus.

Another hot area for power integration is the PA bias portion, which requires 65-V operating converters with a variable current limit as high as 5 to 6 A. Thermal considerations limit the switching frequency. As a compromise to size reductions, the thermal performance of the package is key to enabling a reliable junction temperature, even in the extreme 5G radio ambient. When power exceeds the limit for single-package solutions, solutions based on controller and external field-effect transistors are also viable, especially when combining several PA supplies into a single-power solution.

CONCLUSION

Intelligent connectivity provided by the 5G network will affect several industries and enable new services. Thanks to 5G innovation, these are just some of the great technological advances we will soon enjoy:

- Continuous health monitoring with fully secure and reliable real-time connections.
- Reliable and low-latency remote control of applications, realized with proprioception and tactile internet.
- Efficiency improvements in production lines, with sensor data collection and interactive robots.
- Holographic projection of remote trainings and events.

Smart power requirements for 5G technologies require dedicated components to achieve the best density and efficiency, and survive the extreme thermal conditions of the environment. It's important to resolve technical challenges with next-generation power components, enabling efficiency at high frequencies for maximum density, through innovative control topologies and packaging techniques. mw

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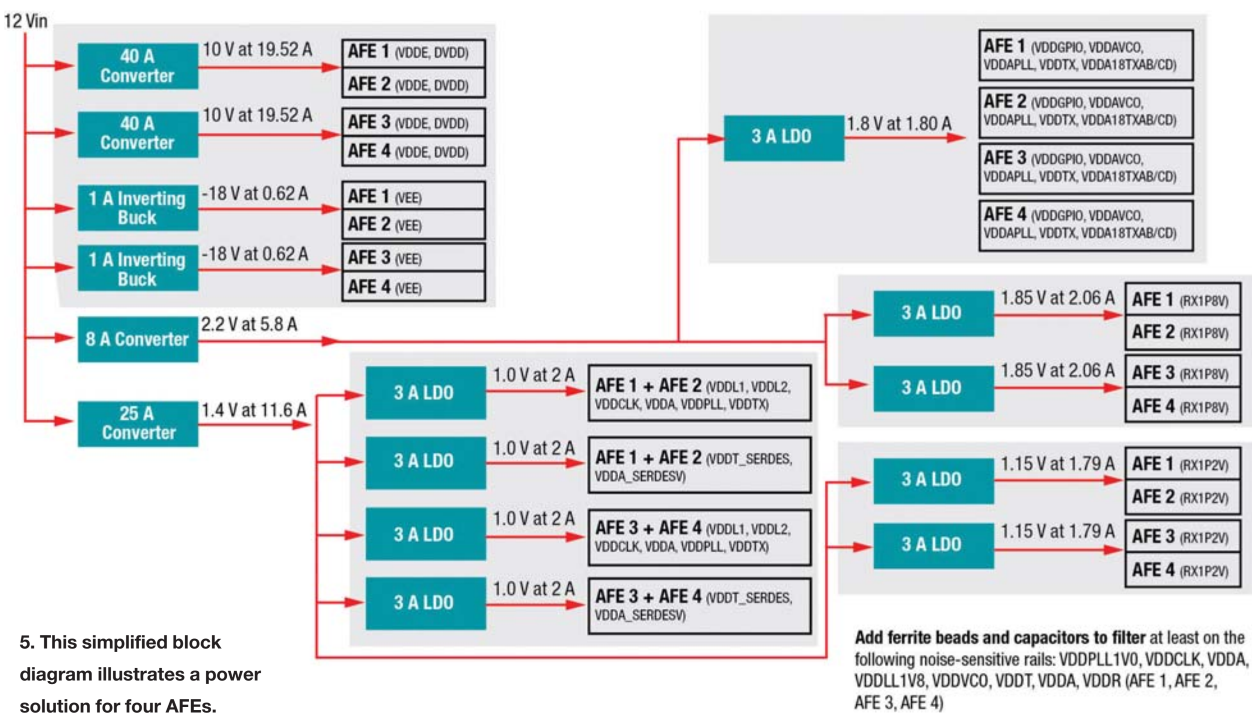

5. This simplified block diagram illustrates a power solution for four AFEs.

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MICROWAVE & RF THERMAL TEST EQUIPMENT

TOTALTEMP, THE NEW LEADER IN MICROWAVE & RF THERMAL TESTING

RF and Microwave electronics have had remarkable progress, yet the basics and standards remain.

Similar to RF systems, Thermal Testing has its basic standards and theory. Likewise there are developments in the industry that make a clear distinction between the new modern testing methods available. Convection and Conduction heat transfer basics do not change but we can do a lot to manage the processes better with smarter controllers and multiple sensors. Many devices that need to be thermally tested have sections that are either more thermally isolated, or have varying heat capacities and even active loads. These variables can be quickly monitored and managed using modern temperature control methods.

Temperature controllers that can read and control from two or more points have been around for decades. However, automating the process with multiple sensors has become a lot easier with newer temperature controllers. Additionally, convenient new automation features such as status/alarm reporting can save time and prevent damaged products. Email or text alert can quickly save an automated production test from going into the weeds wasting time and money. Cloud storage capability keeps results organized and safe.

Temperature chambers have been standard faire since environmental testing standards such as MIL-STD-810 were first written. Applications for thermal platforms have found wide and growing usage in the RF & Microwave industry for several reasons.

1. Fast and easily programmable transitions to temperature.
2. Large heating and heat removal capability.
3. Easy benchtop accessibility to the device under test.
4. Small footprint in the lab where space is so valuable.
5. Reliable wide temperature range with ultra cold temperature capability.
6. Many microwave electronic parts and packages simply have a flat thermally conductive surface that is well suited to heat transfer by conduction.

TotalTemp has a notable unique offering that delivers the benefits of thermal testing with both conduction and convection together. This advantage, along with the advanced control algorithms has customers reporting that they can cut test time in half. The combined effects of conduction and convection results in both speed plus reduced thermal gradients.

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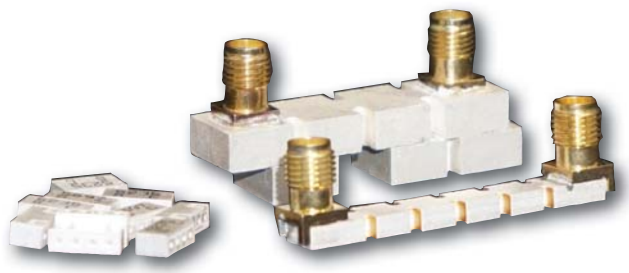
In 1995, two Ph.D.'s inspired to commercialize high Q, low loss dielectric materials at the College of Engineering & Applied Sciences at Stony Brook University on Long Island. They formed MCV Microwave, with MCV an acronym for the pillars of the new company: materials, customer centric and vertically integrated. In the ensuing 23 years, MCV has applied and extended its materials expertise to offer dielectric resonators, filters, antennas and interference mitigation solutions.

Beginning with materials, MCV Microwave offers proprietary dielectric resonators operating in TE, TM or TEM mode, with dielectric constants from 6 to 190 and Q•f up to 300,000 at 10 GHz. The resonators, suitable for microstrip and stripline networks, are widely used in voltage-controlled oscillators, dielectric resonator oscillators for frequency source and microwave filter applications from UHF to mmWave.

Competence with high Q materials naturally leads to designing high performance filters. MCV's filter and multiplexer products encompass cavity, ceramic and LC designs, including ultra-narrowband—down to 0.03 percent passband bandwidth—and wideband filters from 2 MHz to 70 GHz and in all configurations: bandpass, band rejection, lowpass, highpass and multiplexers. MCV ultra-low passive intermodulation (PIM) filters, duplexers and triplexers having better than –173 dBc PIM levels at 2 tones, 43dBm each, cover from 350 MHz to 3.5 GHz. MCV offers new products in ceramic waveguide and microstrip filters for WiFi6, 5G sub-6 and mmWave bands. Low loss, phase match and phase stable cable assembles are available up to 145GHz for 50 ohms and 18Ghz for 75 ohms.

Either PIM or frequency interference is such a critical performance parameter in wireless communications — particularly sites with co-located services — MCV offers solutions to carriers and operators to mitigate sources of frequency interference, whether in cellular networks or utility substations.



To meet the company's high standards, MCV is largely vertically integrated, from dielectric materials produced in Japan through product design and manufacturing. US based design team, machining operations and comprehensive test capability supports the development and production of all products.

Reflecting its vision of being "customer centric," MCV Microwave strives to understand each customer's unique needs and to respond quickly with a customized solution at a competitive price, always with exceptional quality and on-time delivery. MCV is ISO9001, AS9100 and WMBE certified and ITAR registered at MCV headquarters in San Diego, California and in Delaware. The firm's many customers include well-known Fortune 500 defense, aerospace and commercial wireless companies and start-ups, an endorsement of its strong technical capabilities and commitment to quality and responsiveness. Bring us requirements and we will provide the best solutions.

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A Practical Design Approach to Custom mmWave SMT Packages

What are the key ingredients for developing customized surface-mount packages that will ultimately achieve good electrical performance from dc to 50 GHz?

After many years of research and development, electrical engineers, physicists, mathematicians, and scientists have come to realize the benefits of operating communications systems at higher frequencies. Some of the most notable advances stemming from this research include smaller circuit implementations for the same functionality, improved antenna gain for a given antenna size, and dramatic increases in data-carrying capacity. However, numerous challenges remain in implementing high-frequency circuits under real-world constraints. Among the non-trivial problems, packaging is one that stands out.

It's critical that packages for RF components allow for the integration of multiple circuital technologies while achieving the best possible balance of performance and cost for a given application. Nevertheless, traditional packaging techniques have proven incapable of translating the same performance typically seen below X-band into the millimeter-wave (mmWave) range due to embedded parasitics and other inherent technological constraints. These limitations have led the design community to leverage the latest packaging technologies, novel design methodologies, and advanced CAD tools to develop cost-effective, scalable packaging solutions for high-frequency markets and applications.

These new packaging techniques are now moving away from performance-degrading implementations, such as molding compounds and long wire-bonding structures, to achieve outstanding performance beyond 55 GHz. In light of these developments, this article explores some of the key concepts that underlie the development of commercially viable packaging solutions for mmWave components (patent pending).

INTRODUCTION

Global mobile data usage is expected to grow from 11.2 petabytes/month in 2017 to 48.3 petabytes/month in 2021. 5G has emerged as a strong proposal to increase mobile data capacity by a factor of 1000 and support the expected data consumption of seven billion people and seven trillion devices. All of this would happen while still retaining energy efficiency and maintaining near-zero downtime.[1]

The advent of 5G has brought about an increase in development of integrated circuits (ICs) to meet the requirements for high-frequency applications. The need also arises for the development of cost-effective packages that not only protect the ICs, but are also capable of maintaining good electrical performance across wide operational frequency bands.

Current surface-mount quad-flat no-leads (QFN) packages are not suitable for packaging devices at mmWave frequencies. Parasitic elements encountered in the signal path—for example, discontinuities in the vertical transition from the printed circuit board (PCB) to the top side of the QFN and from the wire bond to the IC—are negligible at lower frequencies. However, such discontinuities become relevant once the physical dimensions of the elements become a fraction of the wavelength.

Another drawback associated with QFN packages is their reliance on overmolding. This not only increases electrical loss at higher frequencies, but also makes it impossible to package die featuring air bridges. Moreover, QFN packages are incapable of accommodating flip-chip devices due to their standardized nature.

Many solutions have emerged to address these challenges. Air-cavity QFN packages allow for ICs with air bridges, but they still lack a well-matched transition at high frequencies. Micro-Coax structures allow for high-frequency operation but require specialized assembly processes.[2] Custom packaging solutions can compensate for parasitic effects and allow for air-cavity implementation.[3] Fully-custom solutions are most viable when incorporated into a rapid, low-risk design strategy as well as a highly automated assembly process.

Modern RF applications have stringent requirements for components beyond electrical specifications. Dense assemblies, high operating powers, and the need for robust, reliable systems place heavy demands on monolithic-microwave-integrated-circuit (MMIC) package designers in terms of balancing electrical performance with desirable thermal and mechanical characteristics.

Since design features that benefit one aspect of performance may detract from the requirements of others, tradeoffs are often necessary. For example, a tradeoff intended to improve electrical performance at the expense of heat dissipation may produce little benefit due to a temperature rise on conductors and semiconductors. It's therefore critical for designers to understand the simultaneous effects of design choices on the different aspects of a device's performance.

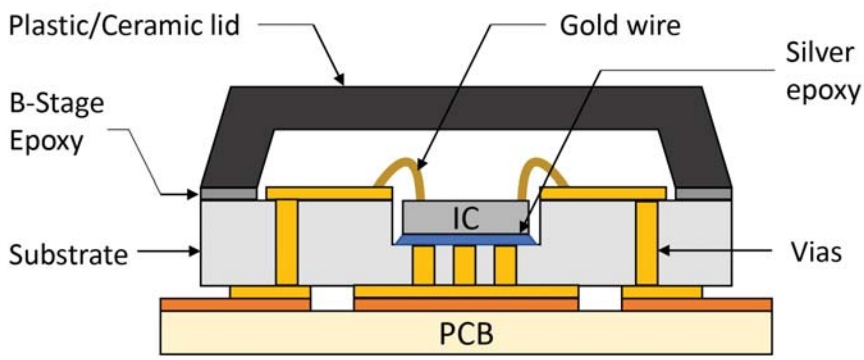
In this article, we present the development of custom surface-mount packages with good electrical performance from dc to 50 GHz, accounting for the PCB, the surface-mount package, and the IC (patent pending). What follows is a discussion of the package's components and design. After that, the article dives into the tradeoff between customization and standardization of design features in the context of performance and cost goals. Measured performance of a broadband MMIC attenuator die in both custom organic and low-temperature co-fired ceramics (LTCC) packages are shown. Also discussed are the benefits of a multi-physics simulation workflow employed in the design of these packages.

DESIGN ELEMENTS

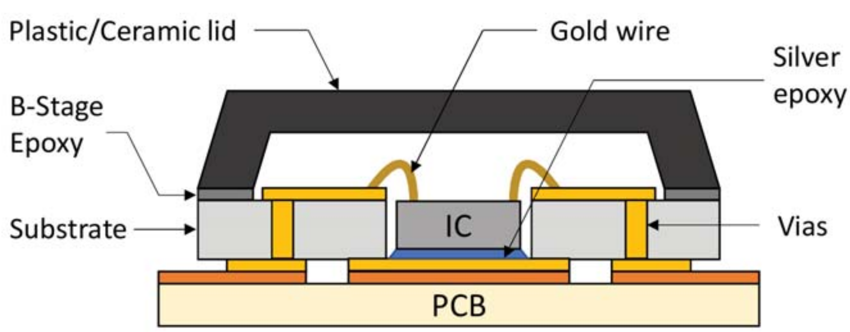
Structure

Schematical cross-section diagrams of the ceramic and organic packages with the PCB are shown in *Figures 1 and 2*, respectively. The description that follows is common to both. The IC is attached to the pocket inside the substrate using conductive epoxy. This implementation minimizes the length of the gold wire bonds. The gold wire connects the RF pads of the IC to the RF pads of the package, forming a lowpass network in which the wire bond is represented as a lumped series inductance, LWB, and the pads are represented as C_{PK} and C_{IC} (*Fig. 3*).

Proper tuning of this matching network is critical for an accurate impedance match and good wideband electrical perf ormance. The package's RF pad is followed by a microstrip line with 50-Ω characteristic impedance, and a matched vertical transition down to the bottom pad. The bottom pad of the package is made to have a 50-Ω characteristic impedance in a grounded-coplanar-waveguide (GCPW) configuration. The package is soldered to the PCB, which employs GCPW with a 50-Ω characteristic impedance. A plastic or ceramic lid is attached to the package with a non-conductive B-staged epoxy.



1. This is the schematical cross-section of a ceramic package.



2. An organic package's schematical cross-section is shown.

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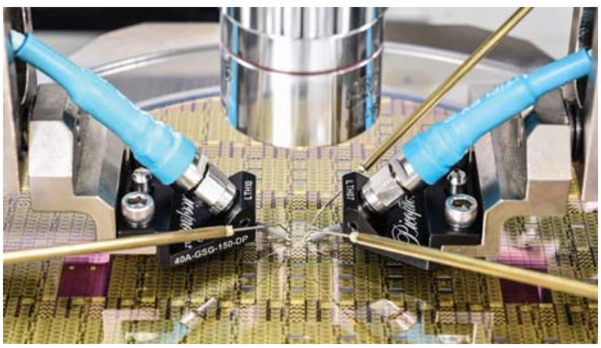

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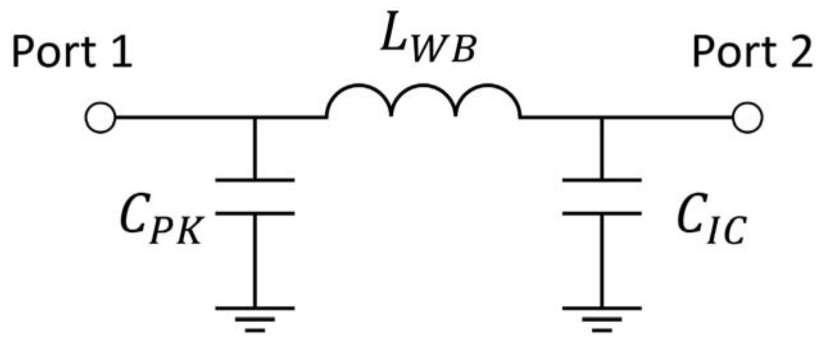


3. Here's a lumped-element representation of the gold wire interconnect between the package pad (C_{PK}), the gold wire (L_{WB}), and the IC pad (C_{IC}).

MATERIALS

Material and technology selection play a big role in the performance of a package. Selecting the right materials will depend on the application requirements, such as hermeticity, maximum operating frequency, package size, package weight, first- and second-level interconnects, thermal management constraints, and tolerable insertion loss of interconnects.[4]

In both the LTCC and organic substrate packages, the selection of substrate material must account for the dielectric constant and loss tangent needed to achieve the desired RF performance. The substrate also determines the package topology and the compatibility with the other materials.

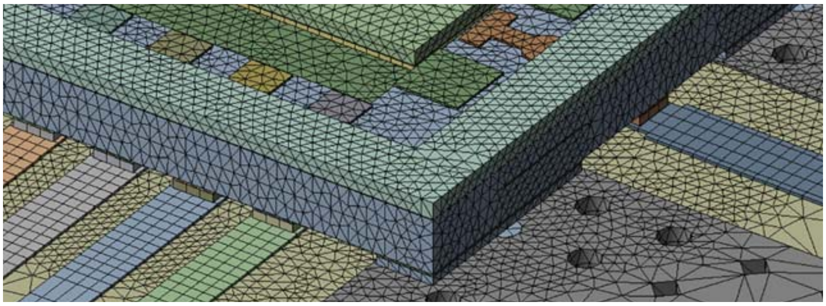
The two substrates explored here are LTCC and organic substrate. The LTCC package consists of a ceramic monolithic structure with a cavity formed in the top tape layers of the substrate (*Fig. 1, again*). The exposed top face of the pocket features a continuous metallization that's connected to the bottom ground pad through multiple vias. Being a stiffer material, it's easier to wire bond.

In the case of the organic package, the pocket is created by removing a portion of the substrate and exposing the bottom metallization (*Fig. 2, again*). This allows for better RF grounding and thermal resistance.

In both packages, the conductor materials and finishes are selected to achieve good RF performance and to accommodate industry-standard assembly processes. The metal conductor on the LTCC package is typically silver with an electroless-nickel-immersion-gold (ENIG) surface finish. The plating protects the underlying silver from oxidation and must have properties compatible with soldering and wire-bonding processes.

The organic package employs copper conductors and may feature any of several different surface finishes. The choice of surface finish may be a critical matter in high-frequency applications, as both surface roughness and electrical conductivity have significant effects on insertion losses.[5, 6]

Selection of the conductive epoxy used to mount the MMIC die has a significant impact on the total thermal resistance of the package. As the main point of contact between the die and the package, the epoxy facilitates most of the die's heat dissipation.



5. This is a close-up of the geometry and mesh employed in thermal and mechanical simulations of the LTCC package with package lid hidden. Note that the model includes solder, die-attach epoxy, and both hollow and solder-filled plated through-holes.

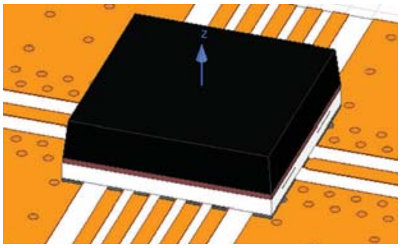
Simulation Workflow

During the design phase of this project, the electrical, thermal, and mechanical performance of the LTCC and organic packages were analyzed using a multi-physics simulation workflow. The simulation workflow employed multiple simulators that were operated sequentially, with each simulator's results being used as part of the next simulator's setup.

The specific simulation workflow is as follows:

1. A full 3D finite-element electromagnetic (EM) simulation is performed on a simplified version of the design's geometry (*Fig. 4*). The simulation yields S-parameter data and a spatial distribution of power dissipation within the design.

2. A full 3D finite-element thermal simulation is run on the EM simulation's model, augmented to include geometry relevant to thermal and mechanical (but not electrical) performance. As shown in *Figure 5*, effort was made to accurately model critical regions of simulation geometry, such as hollow and solder-



4. The electromagnetic simulation model of the LTCC package included only the design elements relevant to electrical performance.

filled plated through-holes (PTHs). The simulation employs the power dissipation computed from the EM simulation and yields a temperature distribution within the model's geometry.

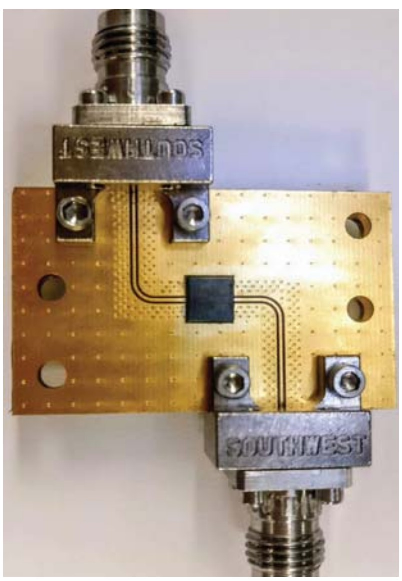
3. A full 3D finite-element mechanical simulation is run on the full model geometry, employing the spatial temperature distribution as part of its setup. The simulation yields mechanical strains and stresses within the model geometry.

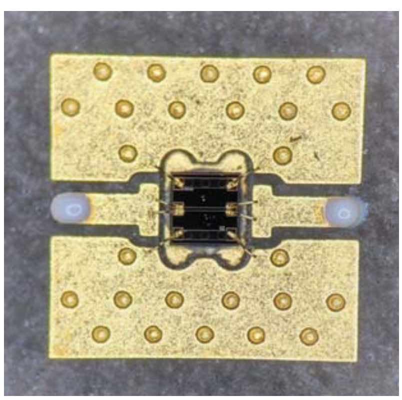
4. If desired, the above process may be iterated until convergence criteria are met, feeding the temperature rise information and model geometry deformation into the electrical simulator for the next pass. In practice, a single pass is often sufficient to achieve outstanding agreement between simulation results and physical measurements.

While more complex than a workflow involving separate electrical, thermal, and mechanical simulation tasks, a true multi-physics simulation workflow gives design engineers a holistic view of a design's performance. For example, a traditional thermal simulation of a microstrip conductor may involve a uniformly distributed heat source applied to the conductor's volume or faces. Such an approach discards valuable information about localized heat generation, since current densities at mmWave frequencies are nonuniform. A multi-physics simulation approach implicitly captures this effect and others without needing attention from the designer.

The ability of a multi-physics simulation to automatically account for conditions too complex to manually set up is especially valuable for LTCC designs. As LTCC designs consist of a monolithic ceramic structure with complex internal conductor geometry, thermal images of the exterior of such a device may not fully reveal its internal thermal behavior.

Because the electrical, thermal, and mechanical aspects of a design's performance are often linked (due to temperature-dependent electrical resistivities, thermal expansion, etc.), such a simulation workflow makes it possible to best understand the impact of design decisions on interrelated aspects of performance. The workflow has been qualified through multiple projects involving several technologies and achieves simulation results in very close agreement with performance measurements. As with other portions of Mini-Circuits' established LTCC process, it's subject to continual evaluation and improvement.





6. The IC in an organic package (with lid) is shown here on an evaluation board (left). A close-up of the package without the lid shows the flip-chip die atop package substrate (right).

CUSTOMIZATION vs. STANDARDIZATION

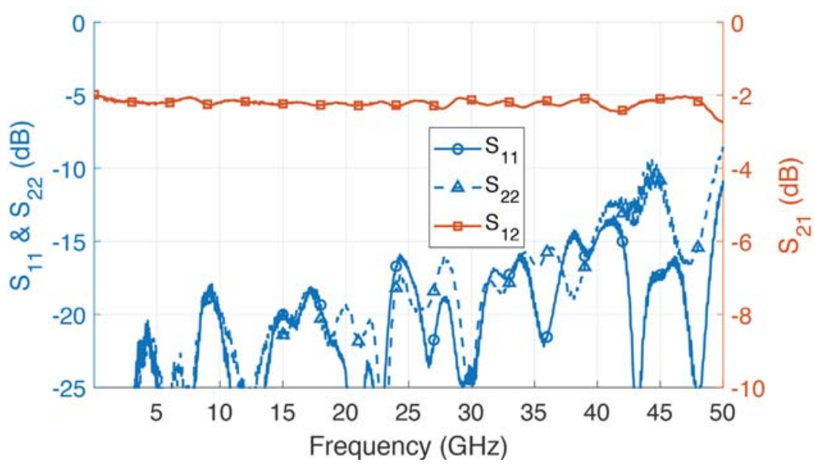
Although the QFN package has been an industry workhorse for both active and passive electronic components up to V-band frequencies, its highly standardized nature makes it a suboptimal solution for some applications.[7] As applications march toward mmWave frequencies, packaging technologies must adapt to widely varying industry needs.

While a one-size-fits-all solution may fit all applications equally poorly, a fully custom solution yielding outstanding results may be cost- and time-prohibitive. To develop a rapid, cost-effective packaging solution that still offers outstanding application flexibility, it was desirable to combine industry-standard processes and tunable design features into a customizable package template.

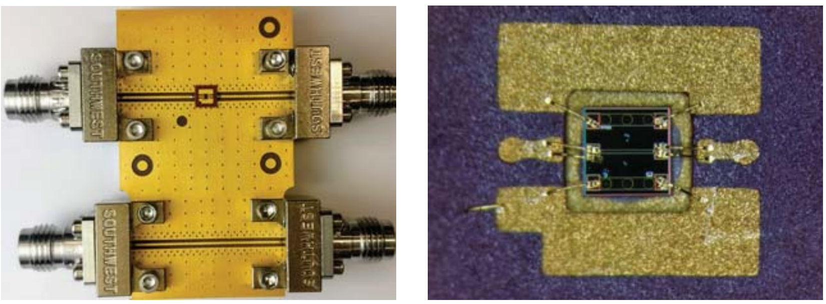
Taking a "templated" approach to package design allows for the reuse of proven design elements, reducing the effort and risk incurred by solutions that require starting from scratch. Facilities for adaptation to an application's specific electrical, thermal, mechanical, and environmental needs are provided while minimizing or eliminating the need for extensive qualification of new designs.

QFN packages are typically available in a granular range of standardized sizes (3 × 3 mm, 4 × 4 mm, etc.), while a MMIC die may be any size and aspect ratio. A die that's slightly too large to fit one standard QFN-package size must instead use the next size up, necessitating long wire bonds with correspondingly large parasitic inductances. The package itself offers little facility to compensate for these parasitics, a task relegated instead to conductor geometry on the PCB and die. Furthermore, QFN packages employ a plastic encapsulant that envelops the leadframe, die, and wire bonds.

Delicate structures on the MMIC die, like air bridges, are incompatible with such an encapsulation process. Even in the absence of incompatible MMIC features, the encapsulant may detune or degrade the performance of sensitive electronics simply by proximity. Finally, the terminals of the QFN package are



7. These are the measurement results of a 2-dB attenuator on organic package.



8. Here, the IC is in an LTCC package on an evaluation board (left). A close-up of the package without the lid shows the die and wire bonds (right).

highly standardized with little flexibility of the pad sizes and geometries. For some applications, the electrical parasitics associated with the fixed transition geometry may be unacceptable.

Mini-Circuits' custom LTCC and organic substrate packages address the above limitations, offering solutions with sufficient flexibility to meet the needs of a wide variety of applications. In these packages, the die inhabits a pocket atop the substrate (*Figs. 1 and 2, again*). The pocket's dimensions are specified according to the customer's die so that wire-bond pads can be brought as close to the die as possible, minimizing bond-wire length and inductance.

Therefore, the LTCC and organic substrate packages offer greater flexibility with regard to MMIC die sizes, even though they are currently available in the same sizes as standard QFN packages (3 × 3 mm, 4 × 4 mm, and 5 × 5 mm). A plastic lid is affixed over the die and wire bonds with a B-staged epoxy compound, maintaining an air gap above the die and wire bonds and achieving a semi-hermetic seal. Using an air gap rather than an encapsulant permits the packaging of delicate MMIC structures and minimizes degradation of electrical performance.

Unlike QFN packages, the LTCC and organic substrate packages offer the flexibility needed to best suit a wide variety of applications. The package structure contains tunable elements that electrically compensate for the parasitics associated with the transitions from the PCB to the package and from the package to the MMIC die. Furthermore, since the package features printed conductors rather than a solid leadframe, the footprints of the LTCC and organic substrate packages can be customized with minimal tooling cost.

EXAMPLES

To validate the design and to measure the performance of the organic and LTCC packages, multiple packages were designed, fabricated, and tested. The packages were assembled and soldered on 5-mil Taconic TLY-5 evaluation PCBs with 50-Ω GCPW traces. Southwest Microwave *(www.southwestmicrowave.com)* 2.4-mm edge-launch connectors were used to interface the PCBs with the vector network analyzer (VNA). A standard short-open-load-thru (SOLT) calibration was performed up to 55 GHz, up to the reference plane of the connectors. The insertion-loss measurements for each package are normalized by subtracting the losses of the PCB thru-line.

MMIC 2-dB Attenuator on Organic Package

A 2-dB MMIC attenuator is mounted and wire-bonded on top of an organic package. *Figure 6* shows the package mounted on top of the PCB, as well as a close-up of the package without the lid, depicting the die and the wire bonds. *Figure 7* shows the measured data of the device. The S_{21} trace reveals a very flat response of −2 dB up to 48 GHz. A good return loss is also observed for the entire frequency bandwidth.

MMIC 2-dB Attenuator on Ceramic Package

A 2-dB MMIC attenuator is mounted and wire-bonded on top of a ceramic package. *Figure 8* shows the package mounted on top of the PCB, as well as a close-up of the package without the lid, illustrating the die and the wire bonds. *Figure 9* shows the measured data of the device. The S_{21} trace reveals a very flat response of −2 dB up to 55 GHz. A good return loss is also observed for the entire frequency bandwidth.

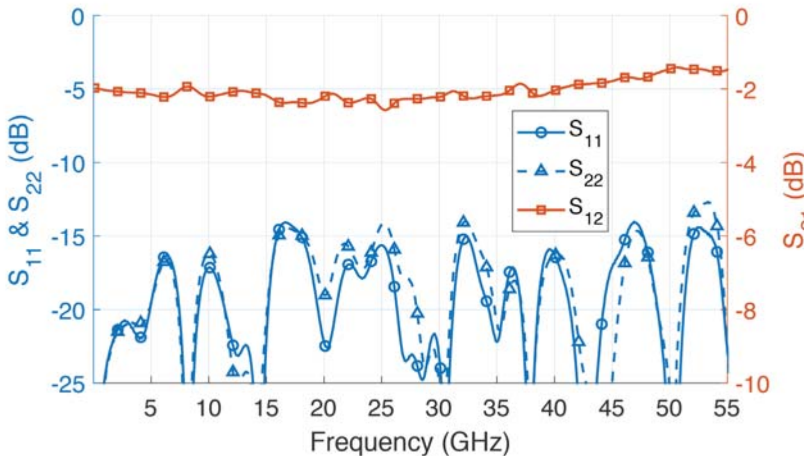
Flip-Chip SPDT Switch on Ceramic Package

A flip-chip single-pole, double-throw (SPDT) switch is mounted on top of a ceramic package. *Figure 10* shows the package mounted on top of the PCB, as well as a close-up of the package with the exposed flip-chip die. *Figure 11* reveals the measured data of the device with the RF2 channel active. A good return loss is observed over the entire bandwidth.

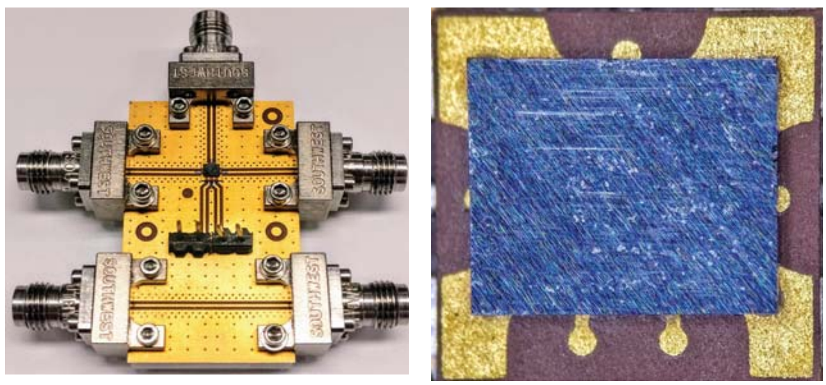
CONCLUSION

Packages employing both LTCC and organic substrate materials have been developed (patent pending). Outstanding electrical performance of both packaging technologies was demonstrated up to 55 GHz. Both packaging methodologies accommodate a wide variety of application-specific needs, including impedance matching, variable die sizes, and a wide range of I/O pad counts, signal types (dc or RF), and PCB geometries. By combining standardized and adjustable features into a tunable package template, Mini-Circuits' approach to packaging achieves desirable electrical performance and broad applicability while minimizing turnaround time, cost, and risk. mw

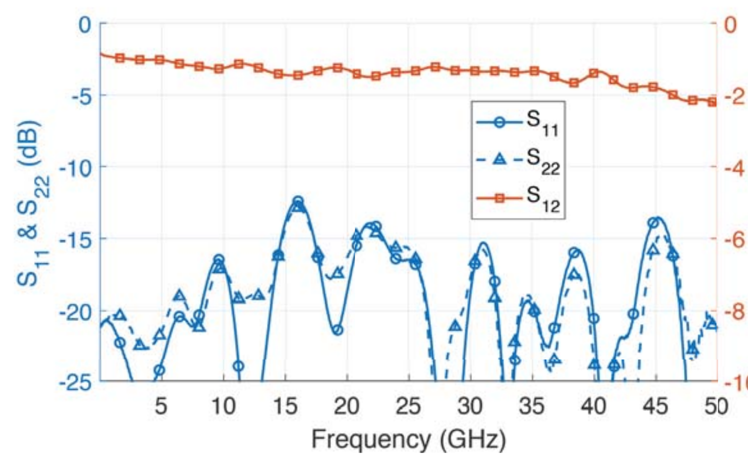
THE AUTHORS would like to thank Mini-Circuits for providing the resources needed to conduct the research and develop the innovations presented in this article.



9. The plots reveal measurement results of a 2-dB attenuator on LTCC package.



10. Shown is the packaged IC on evaluation board (left). One can view a close-up of the package without the lid, showing die and wire bonds (right).



11. Measurement results indicate good return loss for the SPDT flip-chip switch with RF2 channel active.

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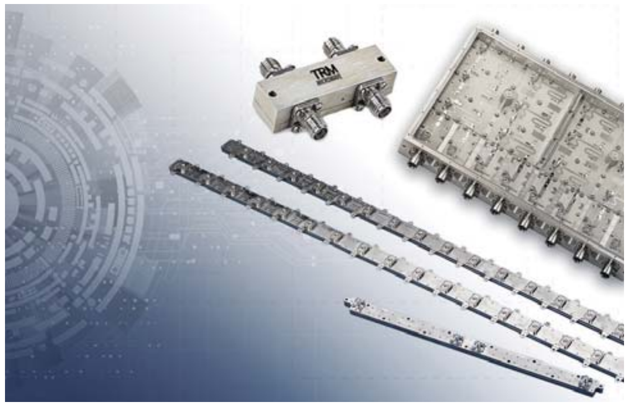

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Identify Modulation for Communications and Radar Using Deep Learning

Signals can be extracted automatically using available frameworks and tools, or via alternate approaches, which can then be used to perform modulation classification with a deep-learning network.

Modulation identification is an important function for an intelligent receiver. It has numerous applications in cognitive radar, software-defined radio, and efficient spectrum management. To identify both communications and radar waveforms, it's necessary to classify them by modulation type. For this, meaningful features can be input to a classifier.

While effective, this procedure can require extensive effort and domain knowledge to yield an accurate classification. This article will explore a framework to automatically extract time-frequency features from signals. The features can be used to perform modulation classification with a deep-learning network. Alternate techniques to feed signals to a deep-learning network will be reviewed.

To support this workflow, we will also describe a process to generate and label synthetic, channel-impaired waveforms. These generated waveforms will in turn provide the training data that can be used with a range of deep-learning networks. Finally, we will describe how to validate the resulting system with over-the-air signals from software-defined radios (SDR) and radars.

Figure 1 shows the workflow, which results in modulation identification and classification.

CHALLENGES OF MODULATION IDENTIFICATION

Modulation identification is challenging because of the range of waveforms that exist in any given frequency band. In addition to the crowded spectrum, the environment tends to be harsh in terms of propagation conditions and non-cooperative interference sources. When doing modulation identification, many questions arise including:

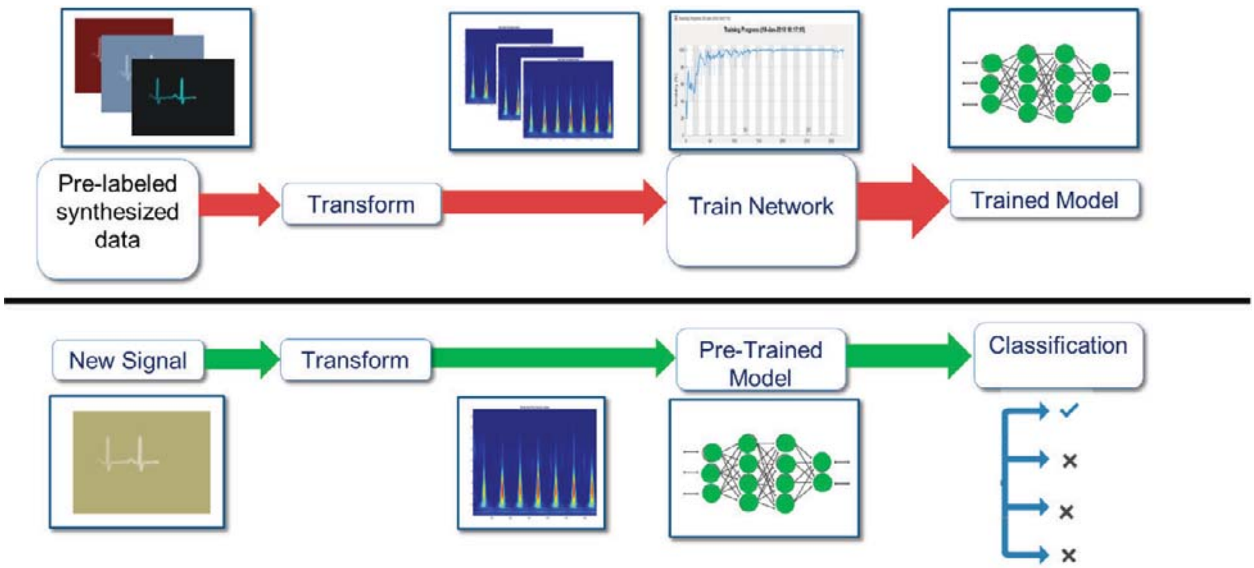
- How will these signals present themselves to the receiver?
- How should unexpected signals, which haven't been received before, be handled?
- How do the signals interact/interfere with each other?

Machine- and deep-learning techniques can be applied to help with modulation identification. To start, consider the tradeoff between the time required to manually extract features to train a machine-learning algorithm versus the large data sets required to train a deep-learning network.

Manually extracting features can take time and requires detailed knowledge of the signals. On the other hand, deep-learning networks require large amounts of data for training purposes to ensure the best results. One benefit of using a deep-learning network is that less pre-processing work and manual feature extraction is needed.

With the requirements for perception generally growing for autonomous driving and computer vision, great investments continue to be made on image- and vision-based learning. These investments can be leveraged by other signal-based applications such as radar and communications. This is true whether the data sets include raw data or pre-processed data.

In the examples described below, deep-learning networks perform the "heavy lifting" in terms of classification, so the focus is on the best way to satisfy the data set requirements for training and validation. Data can be generated from fielded systems, but it can be challenging to collect and label this data.



1. This modulation identification workflow with deep learning uses MATLAB. *(© 1984–2019 The MathWorks, Inc.)*

Keeping track of waveforms and syncing transmit and receive systems results in large data sets that can be difficult to manage. It's also a challenge to coordinate data sources that aren't geographically co-located, including tests that span a wide range of conditions. In addition, labeling this data either as it's collected or after the fact requires much work, because ground truth may not always be available or reliable.

Another option is to use synthetic data, because it can be much easier to generate, manage, and label. The question is whether the fidelity of the synthetic data is sufficient. In the use cases that follow, we will show that generating high-fidelity synthetic data is possible.

SYNTHESIZING RADAR AND COMMUNICATIONS WAVEFORMS

In our first example, we classify radar and communications waveform types based on synthetic data. As previously noted, the occupied frequency spectrum is crowded and transmitting sources such as communications systems, radio, and navigation systems all compete for spectrum. To create a test scenario, the following waveforms are used:

- Rectangular
- Linear frequency modulation (LFM)
- Barker code
- Gaussian frequency shift keying (GFSK)
- Continuous phase frequency shift keying (CPFSK)
- Broadcast frequency modulation (B-FM)
- Double sideband amplitude modulation (DSB-AM)
- Single sideband amplitude modulation (SSB-AM)

With these waveforms defined, functions are used to programmatically generate 3,000 IQ signals for each modulation type. Each signal has unique parameters and is augmented with various impairments to increase the fidelity of the model. For each waveform, the pulse width and repetition frequency are randomly generated. For LFM waveforms, the sweep bandwidth and direction are randomly generated.

For Barker waveforms, the chip width and number are randomly generated. All signals are impaired with white Gaussian noise. In addition, a frequency offset with a random carrier frequency is applied to each signal. Finally, each signal is passed through a channel model. In this example, a multipath Rician fading channel is implemented, but other models could be used.

The data is labeled as it's generated in preparation to feed the training network.

FEATURE EXTRACTION USING TIME-FREQUENCY TECHNIQUES

To improve the classification performance of learning algorithms, a common approach is to input extracted features in place of the original signal data. The features provide a representation of the input data that makes it easier for a classification algorithm to discriminate across the classes.

In practical applications, many signals are nonstationary. This means that their frequency-domain representation changes over time. One useful technique to extract features is the time-frequency transform, which results in an image that can be used as an input to the classification algorithm. The time-frequency transform helps to identify if a particular frequency component or intermittent interference is present in the signal of interest.

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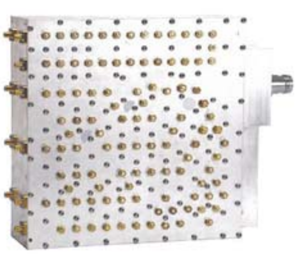

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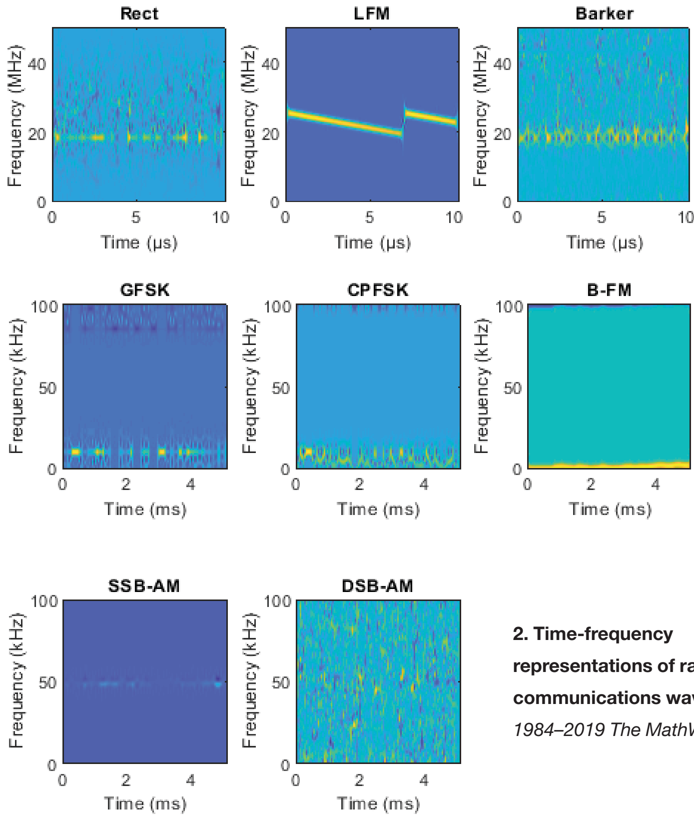
Many automated techniques are available for time-frequency transforms, including spectrogram and continuous wavelet transforms (CWT). However, we will use the Wigner-Ville distribution (WVD) because it provides good spectral resolution without leakage effects of other techniques.

The Wigner-Ville distribution represents a time-frequency view of the original data that's useful for time-varying signals. The high resolution and locality in both time and frequency provide good features for the identification of similar modulation types. We compute the smoothed pseudo WVD for each of the modulation types. This is because for signals with multiple frequency components, the WVD performance degrades due to cross terms. The downsampled images are shown in *Figure 2* for one set of data.

These images are used to train a deep convolutional neural network (CNN). From the data set, the network is trained with 80% of the data and tested on 10%. The remaining 10% is used for validation.



2. Time-frequency representations of radar and communications waveforms. *(© 1984–2019 The MathWorks, Inc.)*

SET UP AND TRAIN THE DEEP-LEARNING NETWORK

Before the deep-learning network can be trained, the network architecture must be defined. The results for this example were obtained using transfer learning with AlexNet, which is a deep CNN created for image classification. Transfer learning is the process of retraining an existing neural network to classify new targets. This network accepts image inputs of size 227-by-227-by-3. AlexNet performs classification of 1,000 categories in its default configuration. To tune AlexNet for this data set, we modify the final three classification layers so that they classify only our eight modulation types. This workflow also can be accomplished with other networks such as SqueezeNet.

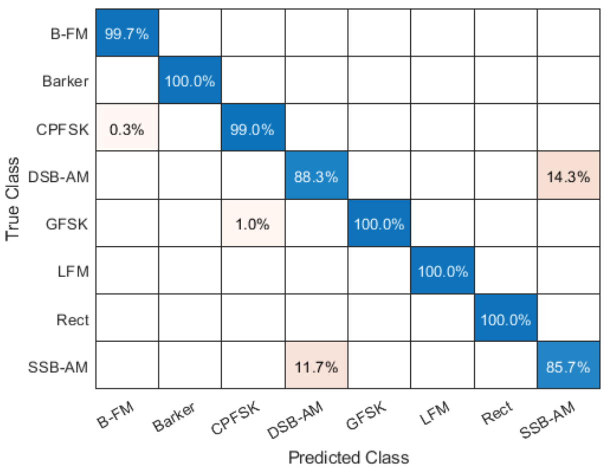
Once the CNN is created, training can begin. Due to the data set's large size, it may be best to accelerate the work with either a GPU or multicore processor. *Figure 3* shows the training progress as a function of time using a GPU to accelerate the training. Training progress is expressed as accuracy as a function of the number of iterations. The validation accuracy is over 97% after epoch 5.

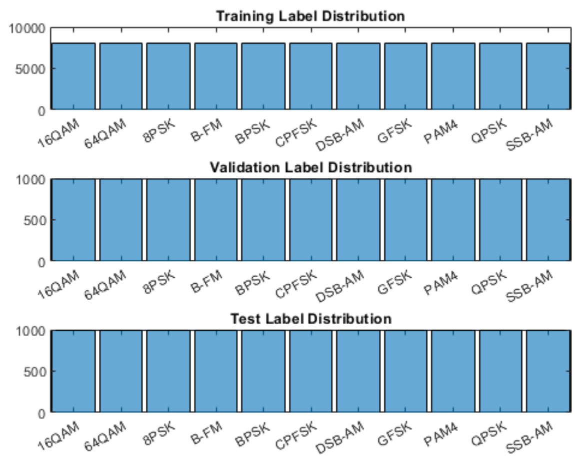
EVALUATING THE PERFORMANCE

Recall that we saved 10% of the generated data for testing. For the eight modulation types input to the network, over 99% of B-FM, CPFSK, GFSK, Barker, Rectangular, and LFM modulation types were correctly classified. On average, over 85% of AM signals were correctly identified. From the confusion matrix, a high percentage of DSB-AM signals were misclassified as SSB-AM and SSB-AM as DSB-AM *(Fig. 4)*.

The Wigner-Ville distribution represents a time-frequency view of the original data that's useful for time-varying signals. The high resolution and locality in both time and frequency provide good features for the identification of similar modulation types.

3. A GPU is used to accelerate the training process. *(© 1984–2019 The MathWorks, Inc.)*





4. The confusion matrix reveals the results of the classification. *(© 1984–2019 The MathWorks, Inc.)*

5. The distribution of labeled data is set by waveform type. *(© 1984–2019 The MathWorks, Inc.)*

The framework for this workflow enables the investigation of the misclassifications to gain insight into the network's learning process. Since DSB-AM and SSB-AM signals have a very similar signature, this explains in part the network's difficulty in correctly classifying these two types. Further signal processing such as the CWT could make the differences between these two modulation types clearer to the network and result in improved classification. Specifically, the CWT offers better multiresolution analysis, which provides the network with better information related to abrupt changes in the frequency of the signals.

This example showed how radar and communications modulation types can be classified by using time-frequency signal-processing techniques and a deep-learning network. In the second example, we will look at other techniques to input data into the network. Furthermore, we will use data from a radio for the test phase.

ALTERNATE APPROACHES

For our second approach, we generate a different data set to work with. The data set includes the following 11 modulation types (eight digital and three analog):

- Binary phase-shift keying (BPSK)
- Quadrature phase-shift keying (QPSK)
- 8-ary phase-shift keying (8-PSK)
- 16-ary quadrature amplitude modulation (16-QAM)
- 64-ary quadrature amplitude modulation (64-QAM)
- 4-ary pulse amplitude modulation (PAM4)
- Gaussian frequency-shift keying (GFSK)
- Continuous phase frequency-shift keying (CPFSK)
- Broadcast FM (B-FM)
- Double-sideband amplitude modulation (DSB-AM)
- Single-sideband amplitude modulation (SSB-AM)

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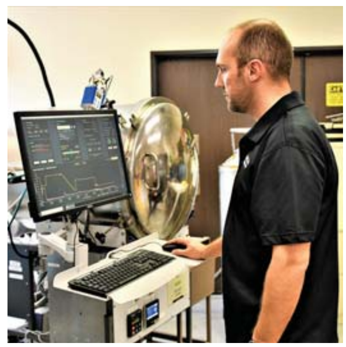

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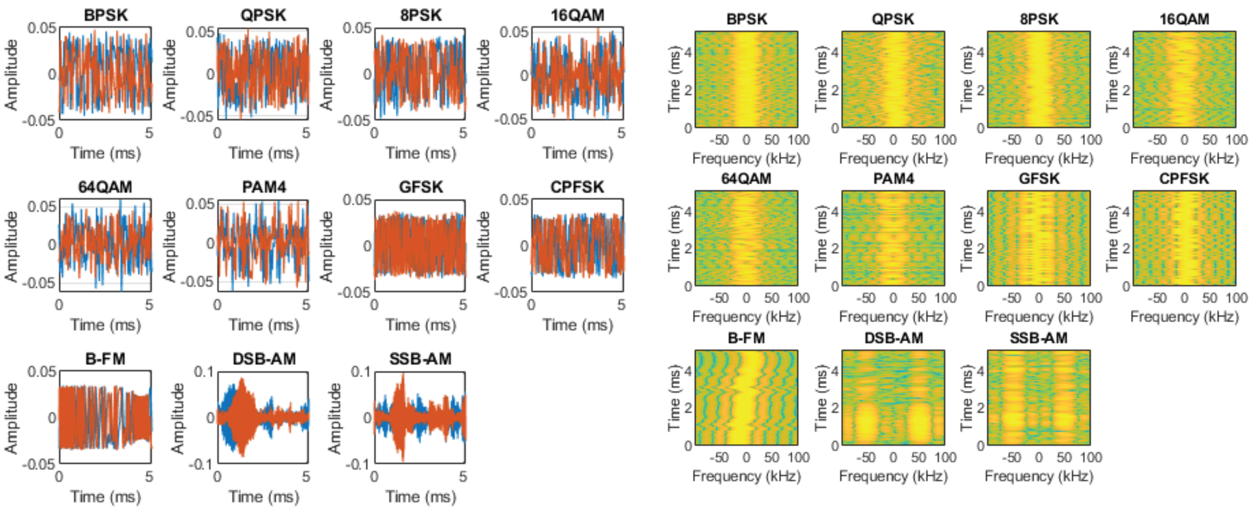
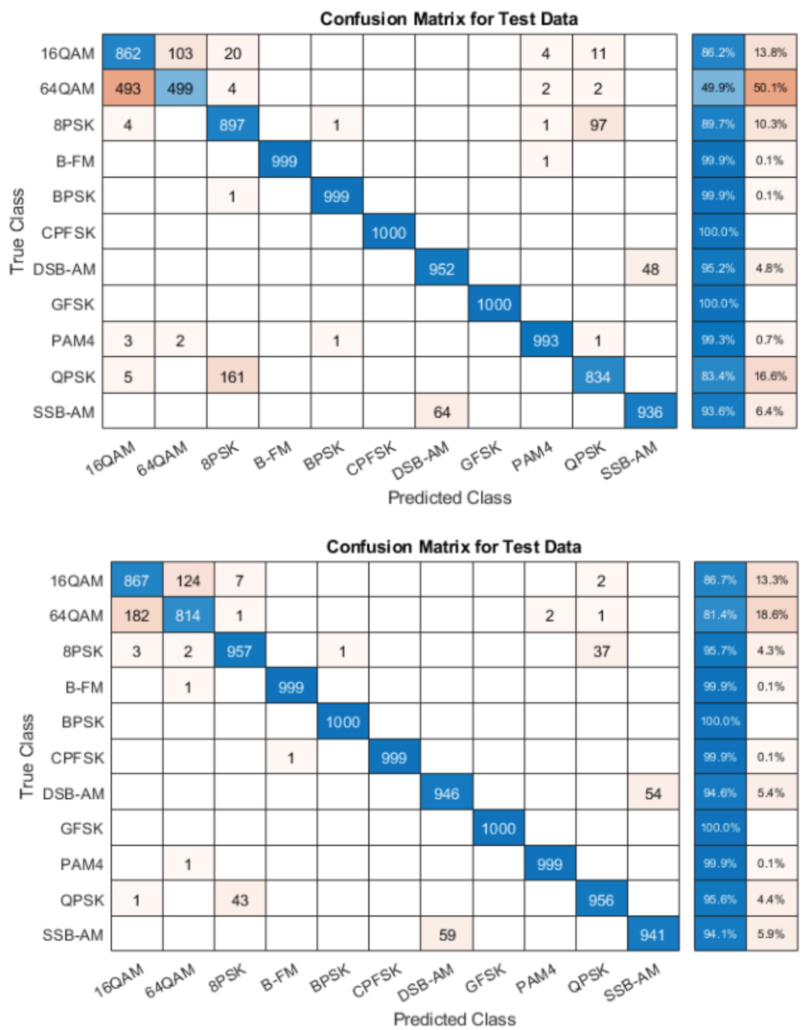


6. Shown are examples of time representation of generated waveforms (left) and corresponding time-frequency representations (right). *(© 1984–2019 The MathWorks, Inc.)*

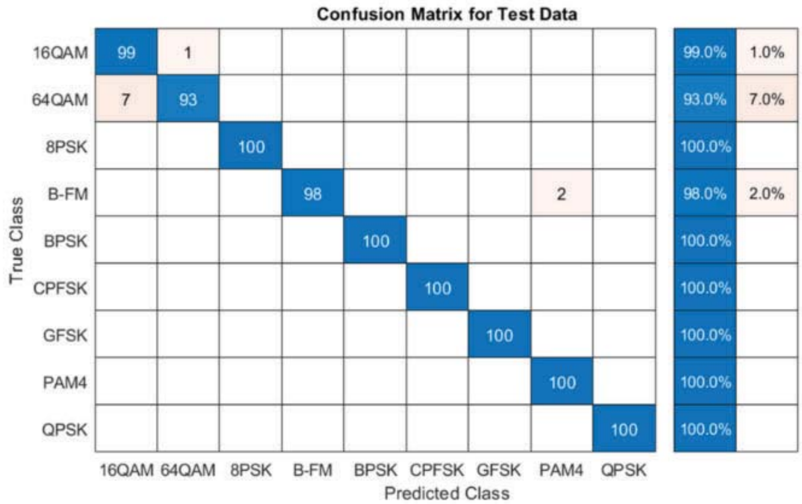
In this example, we generate 10,000 frames for each modulation type. Again, 80% of the data is used for training, 10% is used for validation, and 10% is used for testing as shown in *Figure 5*.

For digital modulation types, eight samples are used to represent a symbol. The network makes each decision based on single frames rather than on multiple consecutive frames. Similar to our first example, each signal is passed through a channel with additive white Gaussian noise (AWGN), Rician multipath fading, and a random clock offset. We then generate channel-impaired frames for each modulation type and store the frames with their corresponding labels.

To make the scenario more realistic, a random number of samples are removed from the beginning of each frame to remove transients and to make sure that the frames have a random starting point with respect to the symbol boundaries. The time and time-frequency representations of each waveform type are shown in *Figure 6*.



7. Results with I/Q components are represented as rows (top) and as pages (bottom). *(© 1984–2019 The MathWorks, Inc.)*



8. The SDR configuration uses ADALM-PLUTO radios (left). Also shown is a corresponding confusion matrix (right). *(© 1984–2019 The MathWorks, Inc.)*

TRAIN THE CNN AND EVALUATE THE RESULTS

For this example, a CNN that consists of six convolution layers and one fully connected layer is used. Each convolution layer except the last is followed by a batch normalization layer, rectified-linear-unit (ReLU) activation layer, and max pooling layer. In the last convolution layer, the max pooling layer is replaced with an average pooling layer. To train the network, a GPU is used to accelerate the process.

In the previous example, we transformed each of the signals to an image. For this example, we look at an alternate approach where the I/Q baseband samples are used directly without further preprocessing.

To do this, we can use the I/Q baseband samples in rows as part of a 2D array. In this case, the convolutional layers process in-phase and quadrature components independently. Only in the fully connected layer is information from the in-phase and quadrature components combined. This yields a 90% accuracy.

A variant on this approach is to use the I/Q samples as a 3D array where the in-phase and quadrature components are part of the third dimension (pages). This approach mixes the information in the I and Q evenly in the convolutional layers and makes better use of the phase information. The variant yields a result with more than 95% accuracy. Representing I/Q components as pages instead of rows can improve the network's accuracy by about 5%.

> Frameworks and tools exist to automatically extract time-frequency features from signals. These features can be used to perform modulation classification with a deep-learning network.

As the confusion matrix in *Figure 7* shows, representing I/Q components as pages instead of rows dramatically increases the ability of the network to accurately differentiate 16-QAM and 64-QAM frames and QPSK and 8-PSK frames.

TESTING WITH SDR

In the first example we described (with radar and communications signals), we tested the trained network using only synthesized data. For the second example, we use over-the-air signals generated from two ADALM-PLUTO radios that are stationary and configured on a desktop *(Fig. 8)*. The network achieves 99% overall accuracy. This is better than the results obtained for synthetic data because of the simple configuration. In addition, the workflow can be extended for radar and radio data collected in more realistic scenarios.

SUMMARY

Frameworks and tools exist to automatically extract time-frequency features from signals. These features can be used to perform modulation classification with a deep-learning network. Alternate techniques to feed signals to a deep-learning network are also possible.

It's possible to generate and label synthetic, channel-impaired waveforms that can augment or replace live data for training purposes. These types of systems can be validated with over-the-air signals from software-defined radios and radars. mw

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Path to Systems: Opportunities and Challenges for Next-Gen Semiconductor Integration

This article explores challenges and solutions to the pace of integration and increased performance needed for tomorrow's embedded applications, and how system-in-package fits into it all.

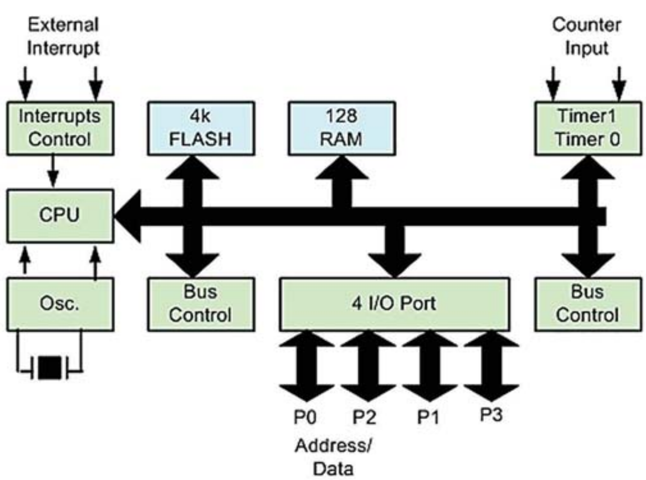
In the 70 years since the transistor was invented[1] and 60 years since the integrated circuit (IC) was invented,[2] we have taken the computer out of large rooms and put them into our pockets. It's been an amazing time where we have been able to impact every aspect of society with the innovations enaby these two moments in history. Now we're in the process of taking the computer out of our pockets and putting it into our clothing, into our bodies, and into our imaginations.

At the same time, we have completely removed the need for wires when communicating with other people throughout the world. Instead of having to fly halfway around the world for a face-to-face conversation, we can do that instantaneously with the push of a button. Now instead of suffering from "jetlag", we instead suffer from "netlag." It's amazing now to find ourselves on the threshold of computers talking and listening to us in the same ways we communicate with other people. Computers, of course, now talk to each other without human intervention. One can only guess what will be next.

These advances have created several challenges (or should we say opportunities) for electronic designs and therefore the semiconductor industry:

1. The focus of electronic design has moved from the component to the system.
2. The demand for performance has outstripped our capacity and capability.
3. The demand for ultra-low power (e.g., long battery life) has become the new performance metric.
4. There's a continuous demand for faster product introduction cycles.
5. The innovation enabled by using technology no longer requires us to understand the technology we're using.

In this article, we'll discuss the opportunities that are ahead for the semiconductor industry and how they will drive the next round of innovation. Then we'll propose an idea on how to enable the next round of innovation. Finally, we'll make some concluding remarks as to our view of that exciting future.



1. The first microcontroller was developed in 1971 by Texas Instruments, which had a block diagram similar to the one shown.

OPPORTUNITY

One of the interesting evolutions that has occurred in the semiconductor industry is the move in focus from the component to the system. That is, instead of just creating components, which can then be used to create systems, the focus is to now create a system design and then determine the optimal set of components needed to implement that system. This may seem to be a subtle change, but is a valuable insight to help us continue the integration path Dr. Gordon Moore envisioned in 1965.[3]

If we look back at early microprocessor and microcontroller devices, they had very little integrated memory and typically had no industry-standard peripherals (*Fig. 1*). Compare that to contemporary microprocessors (*Fig. 2*), which are complete systems with all (yes using the word "all" is a bit of an overstatement) of the memory and peripherals needed for a complete computer system.[4]

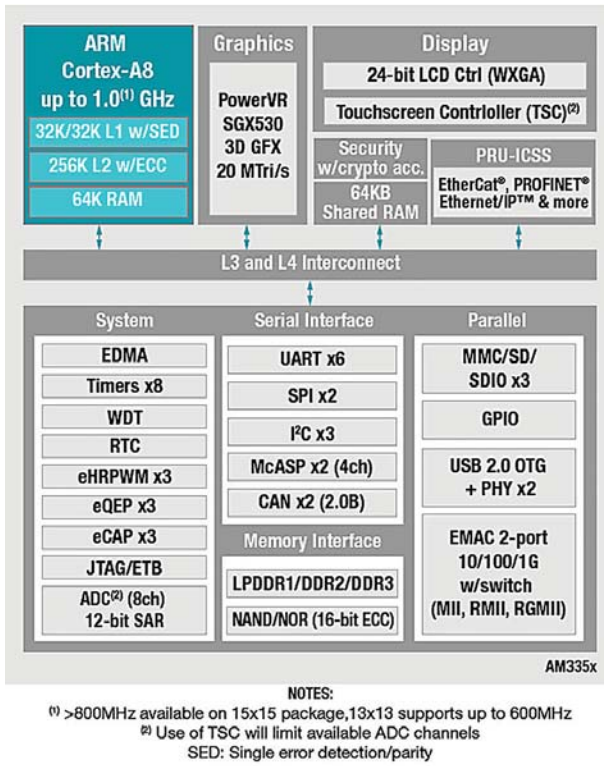
However, the pace of integration and increased performance in processor systems haven't exactly kept up with the demand for performance from the software and embedded-systems designers as they grow hungrier for more every year. The performance demands at the beginning of the microcomputer era to create new audio or video products were well within the state of the art of semiconductor technology.

But we're now seeing opportunities in fields such as artificial intelligence (AI), machine learning, image understanding, and cloud computing stretching the limits of contemporary performance. Not only are these applications demanding exponentially more performance, they also want better integration of heterogeneous components such as FPGAs, GPUs, hardware accelerators, and processors for targeted applications. These demands are driving the performance requirements well beyond Moore's law.[5]

At the same time, we're seeing computer systems shrinking, with the end goal being the concept of "smart dust".[6] To make this possible, the focus changes from driving performance to reducing power dissipation so as to, in the end, power these devices using as little energy as body heat.[7]

During the past 10 years, with the advent of smart devices, the electronics consumer industry has been in a constant state of competition that has driven semiconductor innovation to an unprecedented level. With the design services market segment forecasted to grow with a 7.24% CAGR between 2018 to 2023,[8] there has been a consistent demand for ways consumer electronics companies could reduce/eliminate the effort they have to invest to introduce new products by abstracting the menial tasks of system design.

Finally, the most interesting aspect of the opportunities ahead is the ability to use technology without the need to deeply understand it. Platforms like Arduino,[9] Raspberry Pi,[10] and BeagleBone[11] have made it possible for creative non-engineers to take advantage of the technology to innovate in their areas of passion. As this non-technical creative community begins to create new requirements for semiconductor devices, it's important to make sure those requirements are met in a meaningful way. The goal is to eliminate the increasingly higher barriers of entry that surround electronic design and manufacturing.



2. The block diagram represents Texas Instruments' AM335x ARM Cortex-A8 based microprocessor system-on-chip.

THE SYSTEM-IN-PACKAGE SOLUTION

The key to successfully create any solution is to first find the need to be realized and then find the technology that makes it possible. For the semiconductor industry, this solution needs to enable system designers and product developers to simplify product design while offering them what they need in terms of performance and features, essentially addressing each of the opportunities described earlier. We argue that the solution lies in system-in-package (SiP) (*Fig. 3*).

There are fundamental requirements that the proposed SiP solution should satisfy, without which its usefulness is limited. The requirements are:

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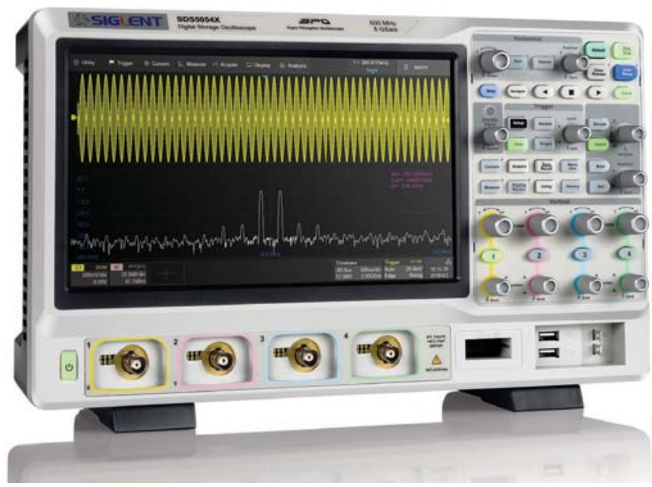

ABOUT US

Innovation is one of the core values at SIGLENT. Over 15% of total sales are invested into research and development annually. The company has acquired numerous patents, with many innovative core technologies that end up leading a global trend. SIGLENT employs over 300 people, with more than 100 engineers working in several departments including hardware, software, industrial design, test, and the advanced equipment environmental lab,

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- The integration of diverse active semiconductor components and passive components into one system where the active components could be microprocessors, memories, specialized processing devices, analog circuits, power management, and sensors.
- The miniaturization of the resulting implementation and system footprint.
- Scalability allowing for low-volume opportunities to high-volume opportunities without a cost burden to either end of the scale.
- The ability to provide system-level hardware sub-modules of often-used subsystems. You might call this subsystem-in-package (SSiP).
- Quick, low-cost, prototyping and testing alternatives through flexibilities in design and interconnection methodologies.

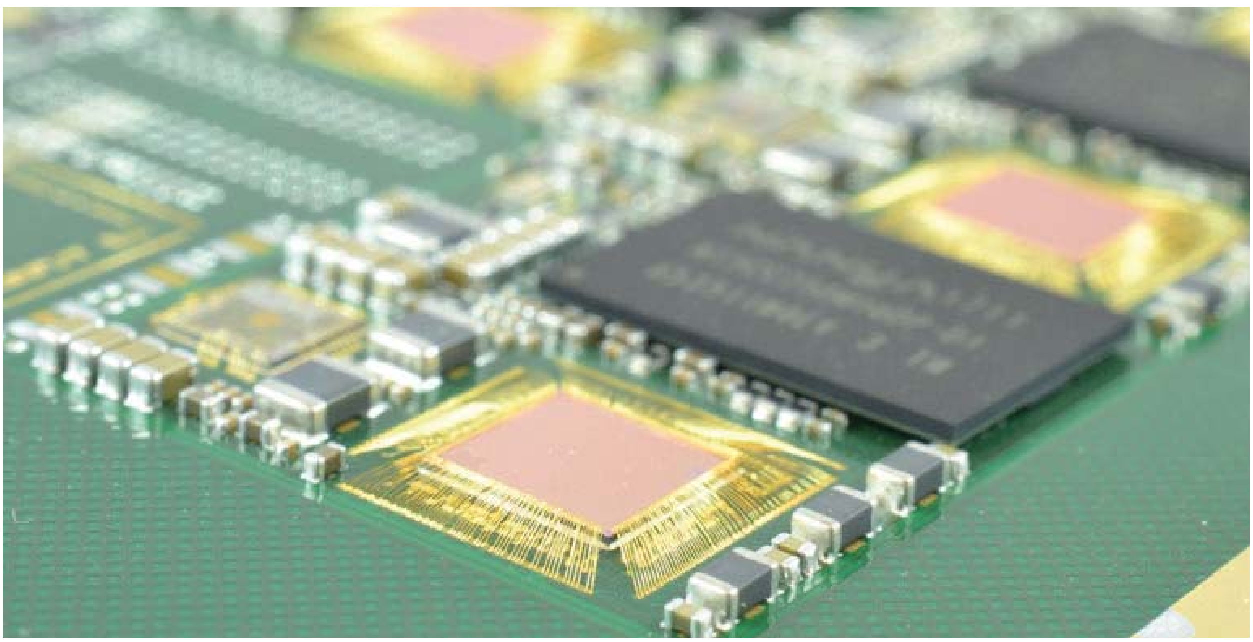
This is where the concept of "what is good in the world of semiconductors" complements the concept of "what is good in the world of systems." For example, the concept of fan-out wafer-level packaging (FO-WLP)[12,13,14] has been developed to allow the creation of semiconductor devices that shrink feature size of the IC beyond the physical constraints of a system design. The result is taking semiconductor die that are too small to use as a system-level component and putting them in larger packages, made up of low-cost materials, which are large enough to be used in system designs. The size of these larger packaged components enables them to be used on printed circuit boards (PCBs) to create custom systems.

This currently existing technology is one proposed solution that addresses some of the opportunities that we discussed. Though it's a step in the right direction, it doesn't satisfy all of the requirements of a system component. It partially addresses the complexity of design and manufacturing issues, but doesn't allow for miniaturization or higher level of integration, both of which can be addressed in a SiP solution. As we discuss more about the proposed SiP solution in our series, we will delve into how each of these requirements can be satisfied (*Fig. 4*).

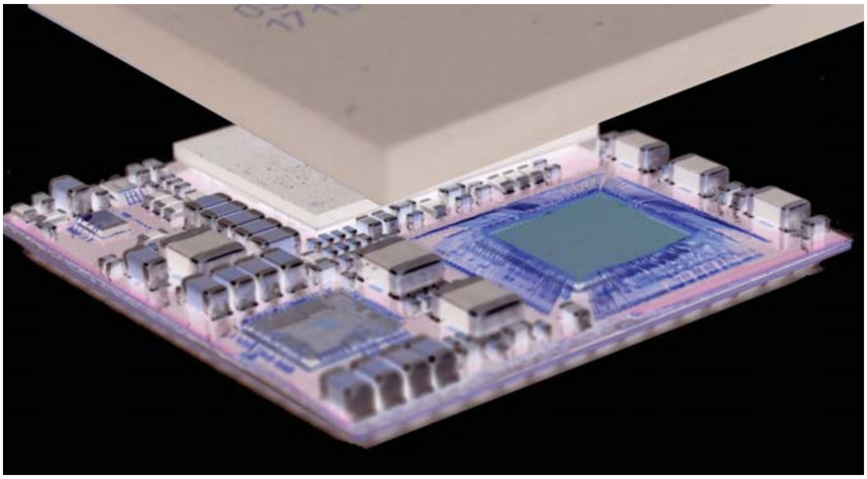
Finally, it's important to characterize the target areas and markets for SiP technology, as the semiconductor industry is also vastly diverse in its requirements. These requirements may sometimes include specialized functionalities and custom hardware that might not fit within the SiP framework. But, advances and improvements to the existing SiP architecture can help address most use cases. The goal of this article series will be to make a compelling value proposition for system-in-package technology while addressing how it beats the challenges presented by the opportunities introduced in this article.

LOOKING AHEAD

Significant levels of semiconductor integration have already been achieved, and consumers are already benefiting from this through smaller and better performing smartphones and other electronic devices. As we develop new ways of 2.5D and 3D integration that reduce cost and increase manufacturability, it's important to look at the bigger picture in terms of needs and technologies and to connect them in a meaningful way.



3. System-in-package integrates a diverse set of semiconductor components and passives into one package, miniaturizing the hardware while also simplifying design and manufacturing.



4. SiP technology can solve a lot of existing electronics design and manufacturing issues, allowing for faster and easier development of electronics.

The bigger picture for electronic system design would be to have a design flow that's both systems-centric (SiP and PCB) and component-centric (SoC). The system-centric portion of the design flow requires the ability to integrate various semiconductor devices that are each manufactured with its own optimized process, along with hundreds of passive devices.

Finally, the overall design flow from IC creation to system creation needs to economically scale up or down (both volume and cost) without burdening either end of the design flow. System-in-package technology provides a perfect sweet spot to solve many design and manufacturing problems while addressing new opportunities and requirements. mw

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MASOOD MURTUZA is the Manager of Package Engineering and a founder of Octavo Systems. Prior to joining Octavo, Masood was a Fellow at Texas Instruments, where he held various leadership roles in the Packaging and Assembly Process Engineering teams. During his tenure at TI, he introduced a number of new semiconductor packaging technologies. He also helped advance innovation in technology development across the company by establishing new methodologies in package and assembly development process. Masood holds 25 patents and has authored or co-authored over 15 papers. He received his BTech in Mechanical Engineering from the Indian Institute of Technology, Madras, India, and an MSc in Naval Architecture from University College, University of London.

GENE FRANTZ is one of the founders and the visionary behind Octavo Systems. He currently serves as Chief Technology Officer. He is also a Professor in the Practice at Rice University in the Electrical and Computer Engineering Department. Previously, Gene was the Principal Technology Fellow at Texas Instruments, where he built a career finding new opportunities and building new businesses to leverage TI's DSP technology. Through this work he became highly regarded in the industry as a leader in DSP technology. Gene holds 48 patents, has written over 100 papers/articles, and presents at conferences around the globe. He has a BSEE from the University of Central Florida, a MSEE from Southern Methodist University, and a MBA from Texas Tech University. He is also a Fellow of the IEEE.

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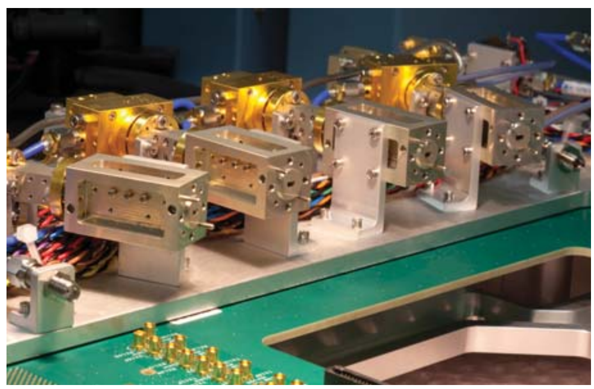

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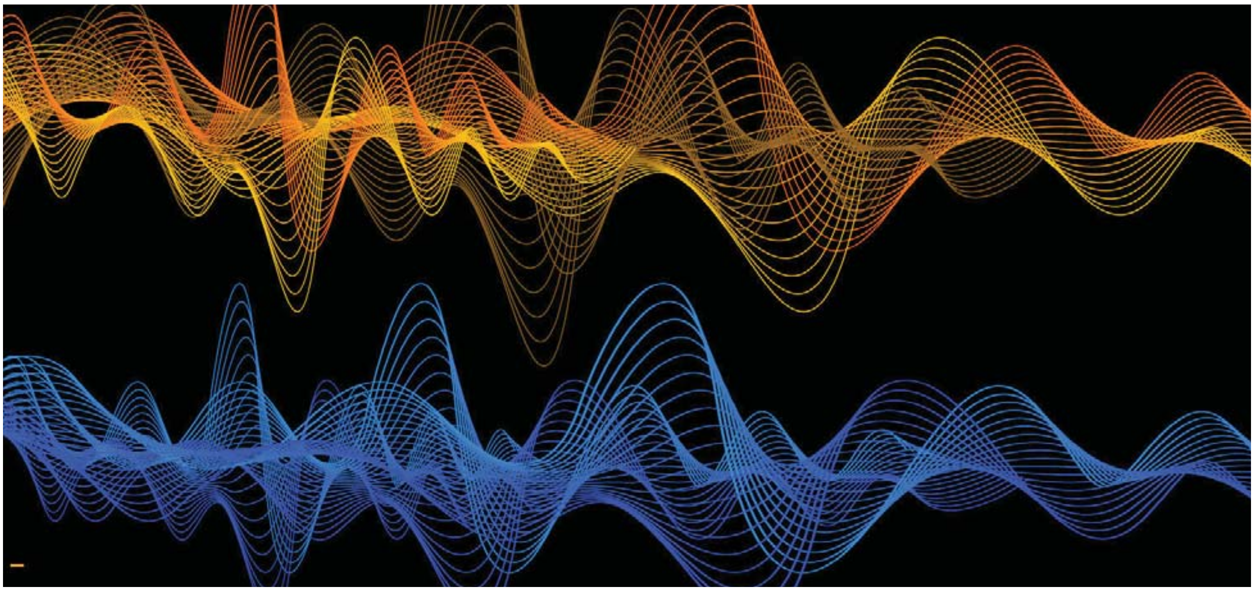
Comparing Narrowband and Wideband Channels

Narrowband and wideband communications channels make use of available bandwidth in different ways—so employ them according to the requirements of a particular application.

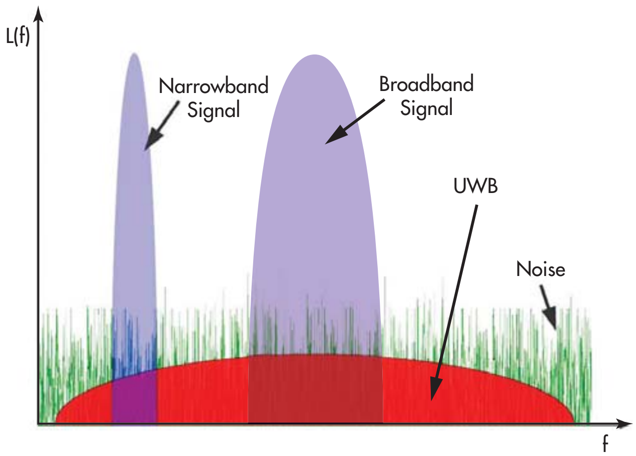


Bandwidth is limited at all frequencies. This holds true whether we're discussing those in the kilohertz range used for amplitude-modulated (AM) radio broadcasting; microwaves and millimeter waves for commercial and military radar systems; or those frequencies bands with the shortest-wavelength electromagnetic (EM) signals, including infrared (IR), ultraviolet (UV), x-rays, and gamma rays.

No single component, such as a filter or amplifier, has enough bandwidth to handle them all. But some components are designed for more narrowband use while some are wideband and can process (for example) a number of different communications frequency bands at the same time. It might make economic sense to use a single amplifier or filter rather than two of each to tackle two different frequency bands in a system. But just what are the tradeoffs (other than cost) in using wideband rather than narrowband components in an RF/microwave system?

Narrowband communications channels have long been used in many applications that have depended upon achieving reliable links in different operating environments, such as in tactical military radios and industrial monitoring purposes. But as more information must be conveyed between two points by wireless means, such as for video streaming and advanced surveillance systems, wideband communications channels with their greater data capacities become more attractive.

In terms of transmitted and received signal information, more bandwidth translates into higher data rates. For instance, depending upon the speed of available analog-to-digital converters (ADCs) and digital-to-analog converters (DACs), achieving a data rate of 1 Gb/s with a wireless communications system will require at least 100 MHz of contiguous bandwidth.



Narrowband signals occupy much less frequency spectrum and require less transmit power for a given application than wideband signals, while UWB signals are short pulses that send information while briefly occupying a large portion of the traditional communications frequency spectrum.

However, finding that much contiguous bandwidth in today's crowded spectral environment can be quite difficult, especially at lower frequencies.

This is one of the several reasons why planners of the emerging 5G wireless communications network are looking to millimeter-wave frequencies and their available bandwidths in support of high-speed data communications links, both for terrestrial links and those incorporating low-earth-orbit (LEO) satellites. Transmitting and receiving more voice, video, and data over wider-bandwidth frequency channels comes at a cost, however, since wider sections of frequency spectrum also contain greater numbers of noise sources and higher levels of noise *(see figure above)*.

In contrast to narrowband channels, where the amount of noise within the channel is limited by effective filtering to suppress any noise and interference outside of the frequency band in use, wideband channels can limit the noise appearing at frequencies outside of the channel. However, any signals that are transmitted within the band must compete with the noise floor of that section of spectrum.

As a result, typically higher transmit signal power is needed in a wideband channel to overcome the noise level—as well as other factors, such as signal propagation losses—so that a significant signal level will appear at the receiver and meet the receiver's minimum signal-to-noise-ratio (SNR) performance requirements for reception and processing.

In short, wideband channels can carry more information than narrowband channels, but they typically require more power to do so. Narrowband channels typically carry much less information than wideband channels and operate over shorter distances between transmitter and receiver. But because narrowband channels have less noise and typically lower noise floors (depending upon the channel bandwidth) than wideband channels, they require less transmit power levels than communications systems with wideband channels and can typically operate with lower transmitter and receiver power supplies than communications equipment with wideband channels at nearby frequencies.

In fact, the lower operating-power requirements of narrowband communications equipment often makes it the preferred solution for applications that require transmission of limited information over relatively short distances, but may require operation by means of battery power, such as in a portable and/or mobile electronic device.

The frequencies intended for different communications (and other) systems are tightly orchestrated and allocated by federal organizations within a country, such as the U.S. Federal Communications Commission (FCC) and the International Telecommunications Union (ITU). Without this control, it would be possible for multiple signals from different applications to occupy the same segment of bandwidth, such as tuning to a frequency channel on an AM or FM radio and receiving two broadcast stations at the same time (and not being able to make sense of either station).

Similarly, two different radio communications systems with different center frequencies, but with overlapping bandwidth, will serve as interference sources for each other, depending upon such factors as transmit power and receiver selectivity and sensitivity. If the sensitivity of one radio is high enough to detect a signal that falls within its bandwidth, that outside signal will act as interference. For this reason, both center frequencies and their bandwidths must be monitored and controlled.

In terms of practical applications, if given an available portion of spectrum (such as 100 MHz), does it make more sense to use the entire radio bandwidth in one application or to break it into multiple applications? In some cases, such as in pulsed ultrawideband (UWB) communications systems, most of the available bandwidth may be used at extremely low power levels to send a great deal of information, albeit transmitting for very short pulse periods *(see sidebar on page 94)*.

Different wireless applications have different electrical performance requirements. Narrowband communications channels are limited in the amounts of instantaneous voice, video, and data they can carry compared to wideband channels. The movement of a receiver and/or transmitter, as in a mobile wireless radio application, can also impact the capability of a narrowband receiver compared to a wideband receiver attempting to detect higher broadband signal levels. Narrowband radio channels are typically used for shorter-range, fixed-location wireless applications, such as radio-frequency identification (RFID) and commercial vehicle remote keyless entry (RKE) devices.

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MAKING ENDS MEET

In cellular communications networks (e.g., the 4G LTE systems currently in service), a variety of relatively narrow bands are employed to support different service applications, including emergency service functions. While this use of narrow bands within the available spectrum helps to minimize interference, it poses challenges to infrastructure and mobile device manufacturers to specify suitable components for devices in each band without having to acquire an enormous volume of inventory in components—such as receiver and transmitter components—to support a different block diagram for each cellular service band.

A number of component and integrated-circuit (IC) suppliers for modern wireless communications systems that employ any number of multiple narrowband channels, including Skyworks Solutions *(www.skyworksinc.com)*, have turned to integrating the functionality for multiple frequency bands within a single IC or module. As an example, the SKY13713-21 from Skyworks is a low-noise-amplifier (LNA) diversity module capable of supporting multiple wireless standards and narrower frequency bands using a single device.

It is supplied in a compact surface-mount package for ease of installation in a portable, mobile device, such as a man-pack radio or cellular telephone, and allows switching among different operating frequencies and cellular service bands (including 3G and 4G cellular bands), so that one part can be used for many different block diagrams. The integration of front-end components, such as amplifiers and filters, within a single component for these different narrowband designs eases inventory issues for system integrators and manufacturers. It also provides a practical solution for designing communications systems with dedicated or multiple narrowband frequency ranges.

Both narrowband and wideband communications channels have their purposes, and components and modules are needed for both approaches, since they will support different applications. As noted, the multiple-function promises of 5G wireless communications networks with their "instant data and video" assurances will require wideband channels—and for many of them, so much so that 5G system planners are reaching into millimeter-wave frequencies with their wide bandwidths for the capacity to carry all the information expected to be carried through 5G wireless networks.

But 5G is only one of a number of emerging global wireless applications expected to change the world, with such applications as "connected cars" and Internet of things (IoT) sensors sending data to the Internet wherever they can provide information. The potentially billions of IoT sensors that will require wireless connectivity for access to the internet will, for the most part, be sending their data by means of narrowband channels, at whatever frequencies those channels can be formed. The need for front-end components and integrated front-end modules will only grow during the next few years, as the applications for both wideband and narrowband channels continue to expand, and this truly starts to become "a wireless world." mw

WHAT ABOUT USING UWB COMMUNICATIONS?

TRADITIONAL ELECTRONIC COMMUNICATIONS SYSTEMS have employed wideband channels, narrowband channels, and sometimes a combination of both, with different types of signal modulation typically based on changes in amplitude, frequency, or phase. But pulses have also been used in a form of communications system known as ultrawideband (UWB) communications.

In UWB communications systems, information is transmitted and received over wide bandwidths, typically greater than 500 MHz or 20% of the arithmetic center frequency (such as 200 MHz of 1 GHz), in a way that will not interfere with conventional narrowband and wideband communications systems, sharing the same spectrum among many users. Once known as pulse radios, UWB radios transmit short pulses at low power levels that occupy a wide designated bandwidth. They may operate at low or high pulse repetition rates (PRRs).

In contrast to conventional communications systems that transmit information by varying a sinusoidal signal's amplitude (in amplitude modulation), frequency (frequency modulation), or phase (phase modulation), UWB pulses occupy a wide bandwidth by use the timing of the pulses to transfer large amounts of information, although by also occupying a large bandwidth for those short durations.

Some UWB communications systems are designed to transfer information by encoding the polarity of a pulse, by changing its amplitude, or even by using orthogonal pulses. Other UWB systems are designed to send pulses sporadically, while still others transmit pulses continuously, at pulse rates exceeding 1 Gpulses/s for high-capacity (high-data-rate) transmissions.

UWB communications technology has never become widespread, in part because of availability of building-block components (such as wideband mixers and amplifiers) and concerns about interference with existing narrowband systems where a short pulsed signal at sufficient energy level could block the reception of a low-level narrowband signal. Although UWB communications technology provides the means for relatively long-distance communications, its most practical use may develop as a short-range solution for wireless applications requiring transmission of large, high-speed data rates.

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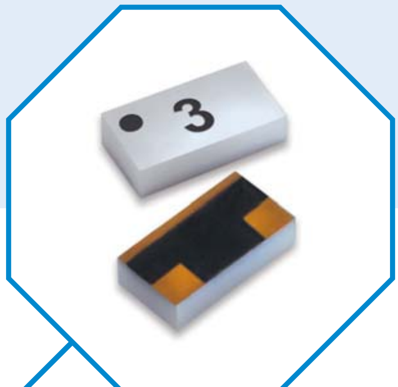

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