Microwaves&RF

LEADERS

In Microwaves

2022

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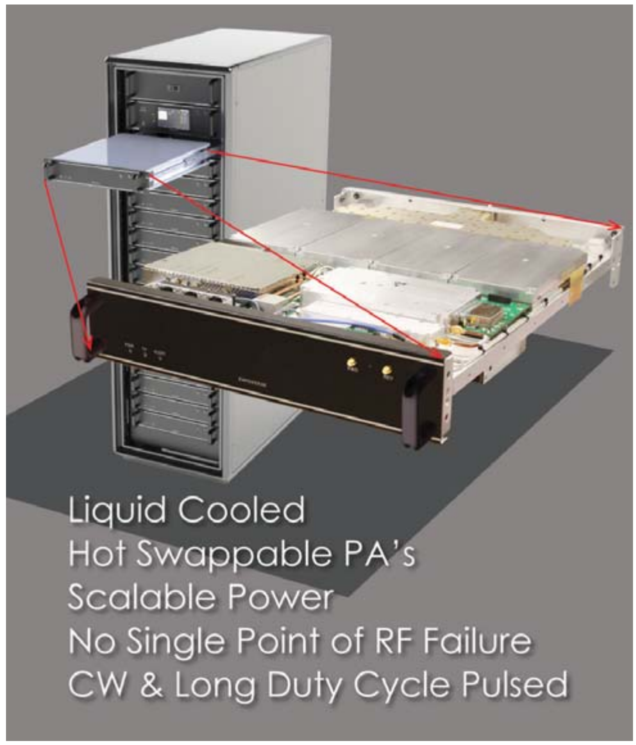

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Editorial

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Drawing Inspiration from Past and Present

IN OUR NOVEMBER 2021 ISSUE, we at *Microwaves & RF* took the opportunity to celebrate our publication's 60th anniversary. Through those six decades, the magazine (and website) have faithfully chronicled the industry's progress, covering great technological advances and how those new and emerging technologies would find themselves deployed in everyday life.

We looked back on history in a couple of ways. One was more of a fun way, by dint of an NCAA bracket-style competition between sets of communications technologies, enabling technologies, applications, and materials that form the backbone of the RF and microwaves universe. Audience members voted on each round until we were down to a Finals matchup between the wildcard winner—software-defined radio (SDR)—and the bracket winner—transistors.

It's an interesting matchup in that SDR, in a sense, represents the future of communications technology, while transistors predate our publication's existence by a good 14 years. With transistors prevailing as the winner in the competition, it shows me that our audience retains a healthy respect for a technology that may be long in the tooth, but remains a foundation of everything created by high-frequency design engineers. Without transistors, there wouldn't be any software-defined radio, or anything else in the communications sphere worth discussing.

The other vehicle for our 60th anniversary bash was a set of decade-by-decade timelines in that November issue. In those timelines, those individuals and organizations blazing the technological trail stand out for their inventiveness, courage, and entrepreneurial spirit. In the 1960s, companies like Hewlett-Packard and Microwave Associates (now MACOM), and individuals like Harvey Kaylie, who founded Mini-Circuits, were driving innovation with important new technologies and resultant products and applications.

The 1970s saw Dr. James Truchard starting National Instruments in his garage, Martin Cooper making the world's first cellphone call, and Rohde & Schwarz launching a groundbreaking 1-GHz signal analyzer. And on it went, year after year and decade after decade, bringing us to current day and beyond.

That combination of creativity and gutsy determination is what defines a leader. In our *2022 Leaders in Microwaves* special issue, we continue our celebration of the industry's present-day leaders through a collection of company profiles and technical articles that exemplify such leadership. Virtually all of the technical articles in these pages have not been seen in print until now. Please enjoy this compendium and we hope you'll take some inspiration from it. ■

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PADDY McWILLIAMS | Director of Product Marketing, CEVA

UWB Spreads Its Wings for **Secure Keyless Access**

UWB is real and seriously important again, especially in high-security keyless entry from your cell phone. Find out why.

Ultra-wideband (UWB) was once thought of as a communications technology that never quite made it—until Apple adopted it. UWB is now built into high-end Apple and Samsung phones, with others following, giving the technology not only brand credibility, but also the volume that comes with those platforms.

What changed? More than anything else, it's related to heightened concerns about security for keyless-entry applications, particularly for our vehicles.

Bluetooth, which has commonly been used for keyless entry, is vulnerable to man-in-the-middle (MITM) attacks. Bluetooth key fobs are intended to tell the vehicle to unlock its doors only when the keyless fob is nearby. However, an attacker can use a relay box to boost the weak Bluetooth signal coming from your key fob inside the house while you sleep, which fools the car into thinking the fob is close by.

In contrast, UWB provides much more accurate measurements of the fob's distance through a process known as "rang-

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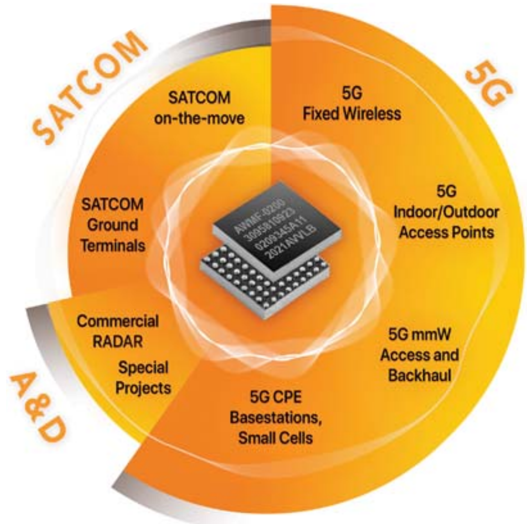
Anokiwave is a fabless semiconductor company providing highly integrated millimeter-wave silicon ICs to enable large scale commercialization of phased array active antennas for 5G, SATCOM, and Aerospace & Defense markets.



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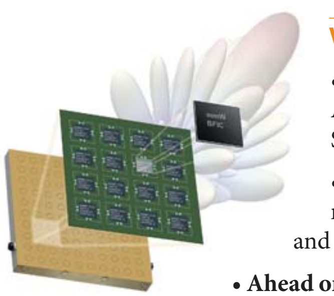

WHAT MAKES ANOKIWAVE DIFFERENT?

- **mmW Experience:** With a clear focus on providing ICs to enable mmW Active Antennas, Anokiwave brings industry's longest experience in designing and providing commercial mmW Silicon ICs.
- **Multi-Market:** Only company providing silicon ICs for mmW phased array needs for multiple markets and use cases ranging from 5G infrastructure and consumer equipment, SATCOM ground and aero systems, and Aerospace and Defense systems.
- **Ahead on the learning curve:** With multiple generations of released Silicon ICs, Anokiwave leads the learning curves for KPI improvements, reliability, and cost reduction.
- **Optimized array level performance:** Anokiwave silicon ICs are specifically designed to optimize overall system performance instead of just optimizing an individual RF spec.
- **Digital Advancements:** With features such as ZERO-CAL® and Kinetic green, Anokiwave is radically simplifying the way phased array active antennas are produced commercially.
- **Scalable Platform approach:** With parts that are pin- and control software-compatible across all bands within a generation, Anokiwave allows OEMs to complete one design and leverage it across multiple bands and use cases.
- **Ready now:** Anokiwave shipping mmW ICs in high commercial volume today into deployed and working systems.

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ing," down to just a few centimeters—as compared to a few meters for Bluetooth, Wi-Fi, and other technologies. In addition, it has strong security by dint of its physical layer (PHY), making it immune to those MITM attacks that have plagued Bluetooth fobs.

UWB Fundamentals

UWB debuted about 15 years ago as part of the IEEE 802.15.4a standard, but it didn't find great success in the market. Due to its accurate ranging and strong security, UWB has been experiencing explosive growth recently, with ABI Research forecasting annual shipments of nearly 1 billion devices by 2025.

The latest specification is 802.15.4z. Its use cases are being developed by popular industry groups, namely the FiRa Consortium and the Car Connectivity Consortium (CCC), with CCC focusing mainly on Secure Digital keys and FiRa addressing more general, secured fine-ranging and positioning applications.

Unlike most radio standards, which operate over a relatively narrow band, UWB uses around 500-MHz bandwidth per channel. This can be between 3.1 and 10.6 GHz, although typically UWB operates between 6 and 8.5 GHz. It utilizes only very-low-power signals, which means its transmissions are under the noise floor from the point of view of Wi-Fi, Bluetooth, and other standards *(Fig. 1)*. UWB can therefore operate as an unlicensed service, without disrupting other communications, to provide low-latency data transfer from 110 kb/s up to 31.2 Mb/s.

Accurate ranging is achieved using short, 2-ns pulses. Measuring the time of flight (ToF), as shown in *Figure 2*, provides an estimate of the range between the initiator and responder devices. If multiple antennas are used, the angle or direction of the responder also can be estimated by the initiator using angle-of-arrival (AoA) processing.

UWB, Bluetooth, and BLE

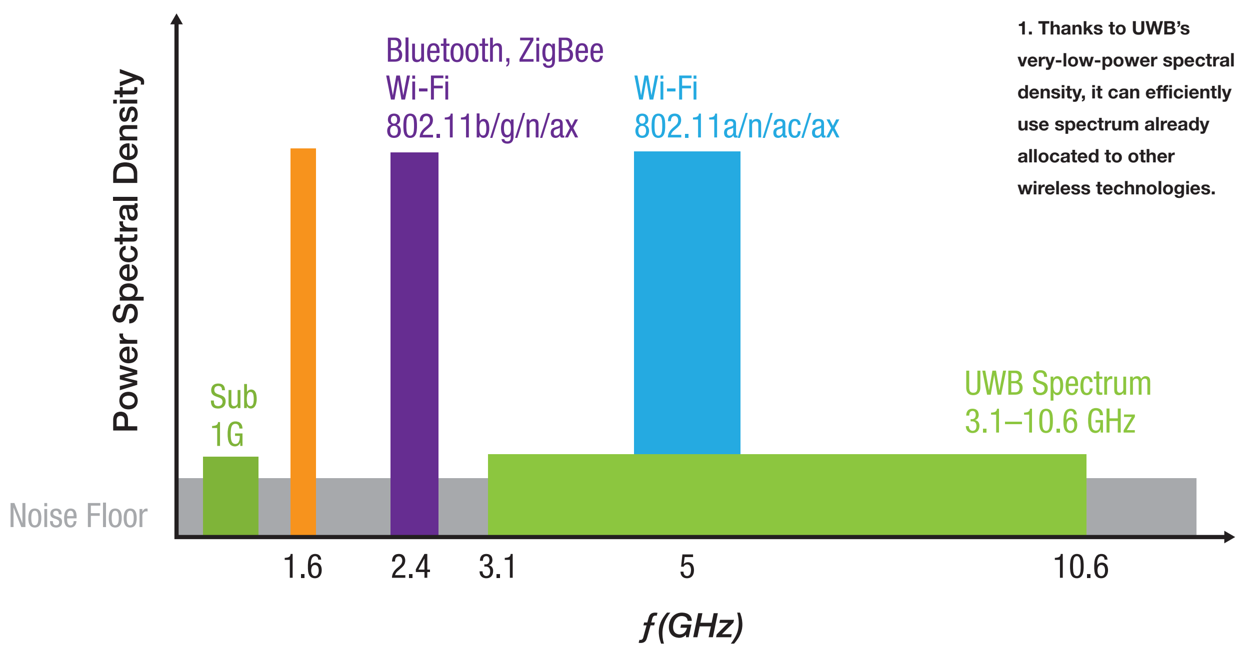
UWB and Bluetooth are both short-range wireless standards operating without licenses—which could mean there's a significant overlap between their target markets. Though that's true, they do have complementary strengths. While UWB has better real-world ranging accuracy, Bluetooth Low Energy (BLE) consumes less power.

A popular approach is to use both together: BLE provides prolonged low-power use and less accurate ranging. Then, once the user is within a defined distance, BLE hands over seamlessly to UWB for secure, fine-ranging access verification. This combination approach has been adopted by both the FiRa Consortium and CCC.

In the meantime, BLE is working on closing the gap; for example, there's been work on an improvement to high-accuracy distance measurement (HADM). A race persists between the standards, and they both have backing from the dominant smartphone builders. But because UWB has the benefit of being a first mover in precision ranging, we'll probably see it around for a long time.

The Digital Key

We've looked at how car key fobs can use UWB for convenient access to your vehicle—with proximity to the car opening the door without you having to retrieve the fob from your pocket or bag. UWB also can help take this one step further via the ubiquitous smartphone, removing the need for a physical key or fob. With UWB becoming increasingly common



1. Thanks to UWB's very-low-power spectral density, it can efficiently use spectrum already allocated to other wireless technologies.

on phones, and Bluetooth everywhere, the technology is there already for many of us.

Beyond the convenience of not needing to carry a separate key or fob, adding "digital-key" capabilities to our phones opens new opportunities. You could authenticate your friends or family as trusted users, giving them access to your car, even if you're away on vacation. Commercial ventures such as car hire and ride sharing could benefit from remote user authentication, too, creating new services or business models.

More UWB Applications

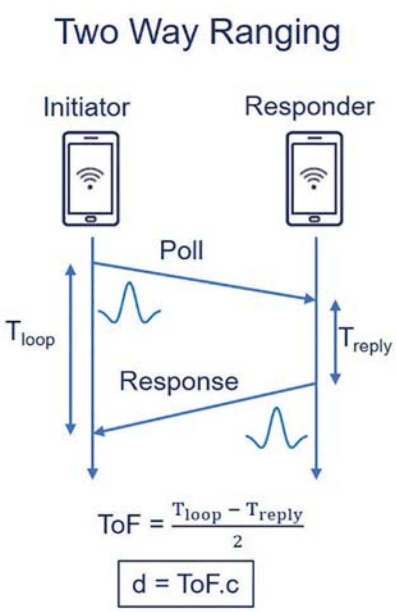
High-security keyless entry to our cars, homes, and hotel rooms is a critical application, but where else could this technology be useful? Industrial real-time location systems (RTLS) represent one possibility, with UWB's centimeter accuracy complementing the many other RTLS mechanisms. Indoor navigation is another application—using your phone to get centimeter-level accuracy in the local supermarket is an appealing use case for advertisers as much as for consumers.

Beyond navigation and "find-my-stuff" applications like Apple's AirTag, the spatial awareness enabled by UWB's precise ranging also creates new opportunities for users to interact with their devices. Instead of the laborious search-select-pair process of Bluetooth gadgets, imagine being able to simply point your phone at a device to take control of it.

Another use case would be seamless music handover between devices when you're moving around the house, either for your headphones or for speakers in each room. On top of that, pulse-based UWB technology is gaining interest in gesture/presence radar applications, which is being explored by leading laptop manufacturers.

One other promising application is mobile payments: NXP has already demonstrated a UWB-based mobile payment system with NTT Docomo and Sony. While near-field communications (NFC) is popular for current tap-to-pay methods such as Apple Pay, it has its vulnerabilities and limitations. This may be another reason Apple is so keen on UWB, as it sees payments being one of the services driving its future revenue growth. And you can bet everyone else using phone-based payment will switch in a heartbeat, if and/or when Apple goes UWB for contactless payment.

One of UWB's unsung strengths is its low latency, which means it could find a natural home in audio applications where latency is critical, such as gaming and VR. It also could be useful for super-high-quality audio streaming, possibly for smart speakers.



2. UWB uses time-of-flight calculations to accurately determine the distance between two devices.

Complementary Technologies

As mentioned above, UWB and BLE are starting to intrude into each other's space, with audio being a typical example. That's great for end users, as competition will drive innovation and cost savings. But what about for OEMs and product builders?

The safest approach is to plan for UWB and BLE by covering both options. UWB has compelling benefits for some applications, while BLE is well-established and offers key advantages in other areas. It's no surprise that much of what you'll hear suggests the two solutions are complementary and should be used together.

For this reason, companies like CEVA, with its RivieraWaves portfolio of IP for Bluetooth and Wi-Fi, have now added support for UWB. This gives customers the flexibility to future-proof their product roadmaps and cover whichever path they decide to take. With multiple wireless technologies available from a single supplier, integration is quicker and easier, thus reducing risk in development as well as time to market.

The RivieraWaves UWB platform consists of a power-optimized hardware PHY along with a flexible, low-latency hardware and software MAC layer. The MAC-layer software can be implemented on a CEVA DSP device when deployed with other connectivity workloads or modes such as direction finding, localization, or radar. Alternatively, it could be used as a standalone UWB MAC on commercial Arm and RISC-V MCUs. A flexible radio interface enables the RivieraWaves UWB platform to be deployed with customers' own RF technology, or with CEVA partners' RF solutions.

Conclusion

It's been around for more than a decade, but UWB is finally finding its feet, with rapid growth driven by secure remote access and other applications. Its ability to accurately determine range to within a few centimeters has made it the technology of choice for keyless car access.

Widespread adoption of UWB by major smartphone vendors, and by Apple, may well be the push that's needed to make UWB truly mainstream soon. For now, OEMs and product designers can minimize their risk by supporting multiple technologies, such as UWB alongside BLE, so that they can respond quickly to any market shifts or new killer applications. Vendors such as CEVA offer flexible platforms that can provide the versatility needed to make this affordable in practice. ■

COPPER MOUNTAIN TECHNOLOGIES

A Decade of Empowering RF Engineers

In 2011, Copper Mountain Technologies launched the industry's first metrology-grade USB VNA. This gave users access to affordable and portable instrumentation **without sacrificing performance**. Since then, the company's focus has been empowering engineers with flexible VNA solutions backed by comprehensive support from expert engineers.

Over the past decade, CMT's product line has expanded to include over 30 instruments and **application-specific VNA solutions** for frequency ranges up to 110 GHz and beyond, including options for direct receiver access, frequency extension, system integration, and software compatibility for Windows and Linux OS. As the product offerings have evolved, the commitment to customer support remains unchanged.

Price

CMT gives engineers access to metrology-grade equipment regardless of budget. The development of metrology-grade USB VNAs resulted in improved cost and accuracy for users. The **FREE** VNA software features an intuitive user interface. Advanced software features, such as time domain reflectometry and gating, frequency offset, TRL Calibration, etc., come at **no additional cost** enabling maximum functionality for ALL users.

Performance

CMT's metrology-grade analyzers provide traceable performance and accuracy. The VNAs are designed for easy customization to deliver **high-performing custom solutions** for unique applications. Customers have successfully integrated CMT VNAs into NASA space station fuel systems, breast cancer detection system, aircraft radome probes, and crops moisture and ripeness sensors. The list of complex environments where CMT VNAs are used continues to grow.

Partnership

CMT delivers VNA solutions that ***Extend the Reach*** of users, with expert RF engineers working as an extension of engineering teams by providing automation scripts and programming manuals, assisting with system integration, performing remote demonstrations, and helping design, develop, and implement measurements.

Software Solutions

In addition to VNA hardware and accessories, CMT offers **advanced software add-ons** such as Manufacturing Test and Automatic Fixture Removal (AFR) plug-ins. The Manufacturing Test Plug-in seamlessly incorporates VNA software functionality into automated manufacturing processes and QMS to streamline production testing. AFR is an intuitive software plug-in that is used to accurately measure hard-to-access devices by de-embedding the fixture effects using one of three comprehensive methods.

10 Years of Growth and Innovation

As the company reflects on the milestone of ten years in operation, CMT is especially thankful for the users who have embraced their products and paved the way for a new kind of VNA solution. The company's success depends on its users' success. CMT wants to thank its customers for their new and continued partnership.

FANG LIU | RF Product Marketing Engineer

Mitigate Interference Using mmWave Arrays **with Integrated Filtering**

Interference from adjacent mmWave bands can be problematic for 5G NR implementations, but a 2x2 antenna array with integrated bandpass RF filters can help.

The 5G New Radio (NR) technology rollout has begun worldwide. Since the 3GPP standardized Release 15 rolled out in late 2018, 5G NR has primarily targeted three different use cases: enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable low-latency communication (URLLC).

Unlike previous mobile network generations, 5G NR will not completely replace 4G LTE. Rather, it will coexist with the established 4G LTE network to seamlessly provide a superior user experience. Release 16, which came out in July of 2020, and the upcoming Release 17 are both intended to enhance 5G NR in terms of capacity, coverage, latency, and more.

Millimeter-wave (mmWave) technology is an essential aspect of the 5G mobile network, with massive data capacity demand being the primary driving factor to accelerate 5G mmWave implementation. mmWave in 5G NR, known as Frequency Range 2 (FR2, 24.25 GHz to 52.6 GHz), provides superior channel bandwidth, which enables significantly higher data rates and network capacity compared with sub-6-GHz (FR1) 5G systems.

But 5G mmWave technology has its downside, too: It suffers from high propagation path losses and poor penetration through obstructions, which lead to reduced coverage. This fact has mandated breakthroughs in antenna-array beamforming techniques.

Beamforming antenna arrays combine multiple antenna-element signals into a concentrated beam. The beam can be steered in a desired direction by weighting the magnitude and adjusting the phase of individual antenna-element signals. Rather than broadcasting in all directions like traditional antennas, the concentrated beam yields high directivity and antenna gain by complex beamforming configurations that effectively improve the mmWave coverage.

However, interference from adjacent mmWave bands utilized by network operators is critical in complex multi-cell and multi-user environments. A small cell can simultaneously communicate with multiple users via different beams formed by beamforming antenna arrays. Thus, the adjacent beams within the same cell may cause interference for individual users. Meanwhile, users within a given cell's coverage may get adjacent beam interference formed by neighbor cells as well. Furthermore, adjacent to allocated 5G mmWave licensed frequency bands, multiple existing systems/services also can interfere with 5G systems, such as the Earth Exploration Satellite Service (EESS) that operates from 23.6 to 24.2 GHz.

To mitigate all unwanted interference, one promising solution is to use bandpass filters (BPFs) placed physically in series to individual beamforming antenna-array elements to block interference. This article introduces and provides an in-depth overview of a novel 28-GHz, 2x2 antenna array with integrated BPFs.

Design Considerations

Unlike other standard antenna-array structures, the 28-GHz (n257: 26.5 GHz~29.5 GHz), 2x2 antenna array consists of 2x2 dual-polarized antenna elements as well as eight integrated BPFs for the same frequency range. Dual-polarized antenna arrays are a necessity for 5G mmWave massive multiple-input, multiple-output (mMIMO) systems to enhance the channel capacity and spectral efficiency.

As shown in *Figure 1*, the overall structure separates into two sections, with the antenna-array structure sitting atop the BPF structured section. Each individual dual-polarized antenna element is designed with dual feeds, a horizontal polarization feeding port, and a vertical polarization feeding port, with each port having a respective series BPF to remove unwanted interference. This vertical structure enables the shortest connection between each BPF and antenna element, effectively minimizing the parasitic inductance to maintain the lowest overall insertion loss.

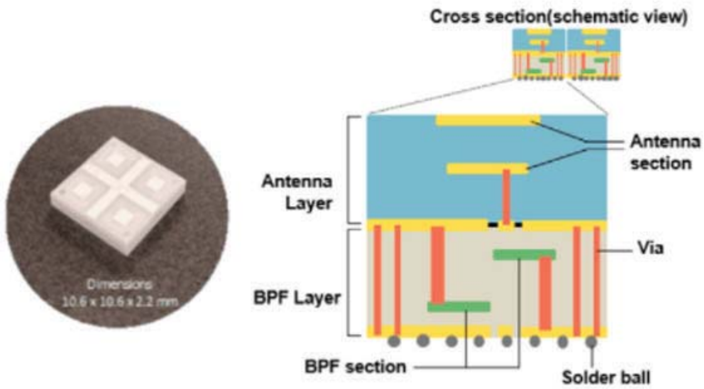
The basis of the featured 28-GHz, 2x2 antenna array is low-temperature, co-fired ceramic (LTCC) technology. LTCC is a multi-layer, glass ceramic substrate co-fired with low-resistance silver (Ag) conductors at relatively low firing temperatures (around 900°C), which is below the melting point of the silver.

Multi-layer design flexibility and low material dielectric loss are key advantages of LTCC technology. Two distinct and optimized ceramic materials are developed and co-fired into one homogeneous multi-layer package. That approach offers:

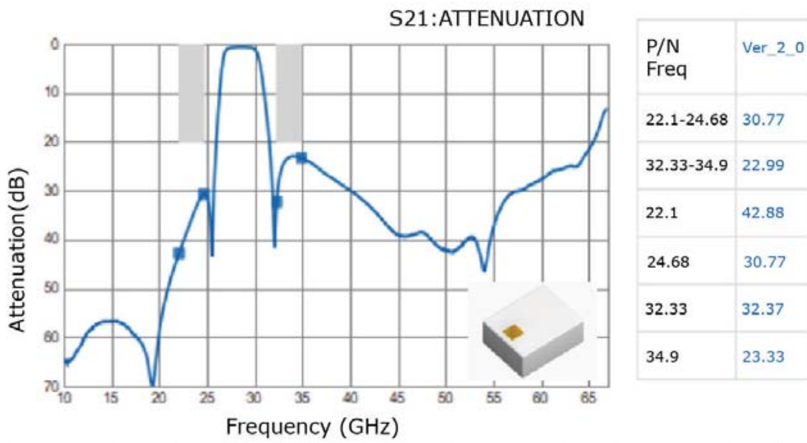
- Dielectric constant around 4 at 28 GHz for the antenna array.
- Dielectric constant around 9 at 28 GHz for integrated BPFs.

- 2 ppm/K temperature coefficient of frequency (TCF) enables ±0.04% frequency shifting at 28 GHz from −40 to 85°C (tested by individual 28-GHz BPF).
- 7.6-ppm/K relative low coefficient of thermal expansion (CTE).
- 3 W/m × K thermal conductivity allows great thermal stability and robustness.

TDK debuted the first mass-produced, multi-layer ceramic 28-GHz BPF (P/N: MMCB2528G5T-0001A3) in 2019. The device offers a typical low insertion loss of less than 1 dB and excellent out-of-band rejection. The discrete 28-GHz BPF frequency response is shown in *Figure 2* and this BPF structure was leveraged into the new 2x2 antenna array.



1. A 2x2 LTCC antenna array's overall structure separates into two sections, with the antenna-array structure sitting atop the BPF structured section.



2. The discrete 28-GHz BPF's frequency response is illustrated here; the earlier device's BPF structure has been leveraged into the new 2x2 antenna array.

Individual antenna elements are configured to implement stacked patch structures, with each of the two stacked patches covering a sub-band to overcome the single patch antenna's bandwidth limitation. The upper patch is referred to as the parasitic patch and the lower patch, which is located above the ground plane and connects to a feeding line, is used as a driven (input) patch. The upper and lower patches resonate at different frequencies, with electromagnetic coupling from the lower patch exciting the upper patch to obtain the desired wideband frequency response.

The influence of inter-element spacing between two adjacent antenna elements must be considered in antenna-array design. To reduce the antenna-array design complexity, we implemented a constant equalized inter-element spacing approach.

When the inter-element spacing exceeds half of the signal's wavelength, grating lobes will become prevalent and have unwanted strong radiation patterns in directions other than the desired main lobe. To avoid these grating lobes, antenna inter-element spacing is designed to be close to the half wavelength (λ/2).

However, at the same time, mutual coupling influences exist between the adjacent antenna elements, which can't be ignored—their impact on performance increases as the inter-element spacing decreases. Individual antenna-element radiation patterns depend not only on their own excitation, but also on electromagnetic (influence) interaction from neighboring antenna elements. The fact that mutual coupling also influences the input impedance of each individual antenna element is intuitive and function of the inter-element spacing as well.

In this case, the input impedance is the active impedance of each individual antenna element in the array when all antenna elements are excited. Therefore, the active impedance of each individual antenna element is given by the sum of its own impedance plus mutual impedances caused by proximity to the neighboring excited antenna elements.

To compensate for the mutual coupling effect, we must use a dedicated antenna-feeding network with proper impedance matching. Otherwise, antenna gain may decline, and a distorted radiation pattern can result.

Based on the above facts, the feeding network is a critical challenge for antenna-array design, especially when one considers integrating BPFs. A coaxial probe feeding method was chosen for the selected design. It's relatively simple for fabrication and it's easy to adjust the position inside the patch to match the antenna impedance.

As shown in *Figure 1*, we used stacked multi-layer feed-thru vias as the coaxial feeding probes for vertical interconnections. In addition, we achieve good isolation between dual-polarized ports of indi-

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vidual antenna elements by optimizing the via type interconnect feeding structure, thereby also ensuring acceptable cross-polarization isolation for complex antenna array patterns. We add another impedance transition network to the antenna feeding port to make a smooth connection with the integrated BPF.

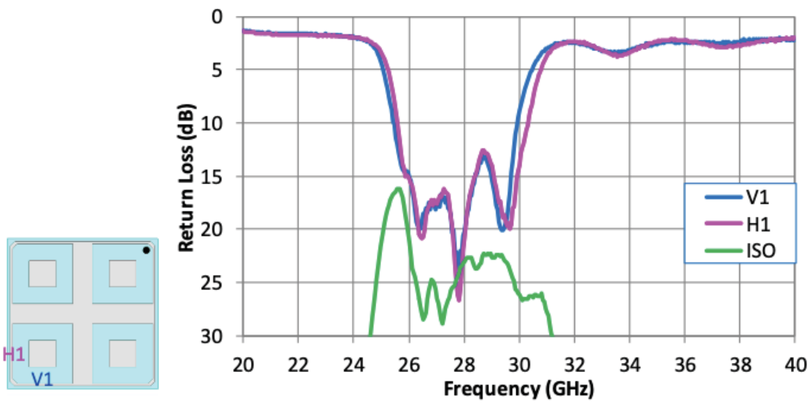
Measurement Results

Figures 3 and 4 provide actual measurement results for the 2x2 antenna array with integrated BPFs. As shown in *Figure 3*, we achieve >10-dB return loss for individual horizontal and vertical polarization ports and >20-dB isolation between dual-polarized ports of individual antenna elements. This results in an average –3.5-dB efficiency of individual horizontal and vertical polarization ports *(Fig. 4)*. The integrated solution clearly shows an overall BPF response with a steep slope out of the passband that can protect individual antenna channels to solve potential interference issues.

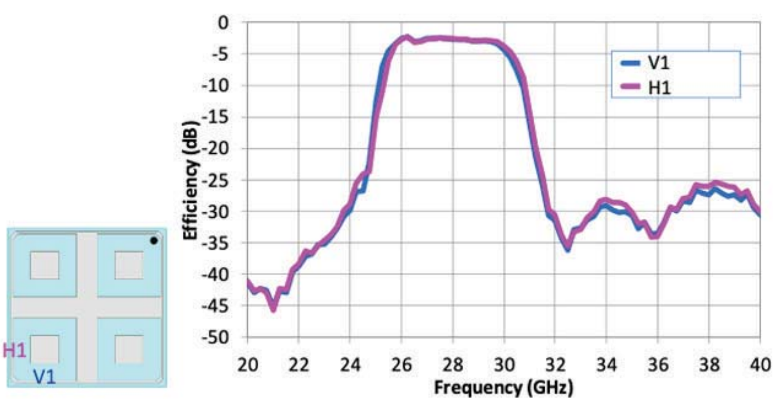
In mmWave beamforming antenna-array designs, installing series discrete BPFs to each individual antenna feeding port is challenged by the space constraints created by mounting beamforming ICs on the backside of the antenna arrays. The connections between discrete BPFs cause elevated insertion losses and phase shifts. On top of that, the individual antenna feeding ports can't be ignored.

With its integrated BPFs, the antenna array described here could solve the space-constraint problem and provide the best integration performance. TDK consulted with multiple customers and obtained early system requirements to address all potential circumstances, and then applied this information to the design and optimization of the antenna array.

For the 2x2 antenna array with integrated BPFs solution in the 10.6- × 10.6- × 2.2-mm package, the result is a cost-effective approach for 5G infrastructure and consumer-premises-equipment (CPE) applications. Where larger arrays are needed, such as 8x8 or 16x16 configurations, the desired numbers of elements can be easily "tiled" up by integrating multiple 2x2 antenna arrays.



3. This plot shows individual port return loss and isolation (V-port/H-port) for the 2x2 antenna array with integrated BPFs.



4. Here, we show the individual port efficiency (V-port, H-port) for the 2x2 antenna array with integrated BPFs.

Conclusion

All industry marketing reports expect worldwide implementation of 5G mmWave systems to experience substantial growth over the next five to seven years. Concurrently, we suspect that adjacent mmWave-band interference will soon grow in severity as mmWave implementations ramp up. The key benefits of TDK's LTCC antenna array with integrated BPFs include:

- Excellent antenna array with integrated BPF performance that can effectively reduce adjacent-band interference.
- High multi-layer design flexibility, convenient for matching different beamforming ICs.
- Cost-effectiveness and compact size, suitable for forming larger arrays by "tiling" multiple arrays.
- Precise process control and proven mature mass-production capability ensure performance and consistency of final products, meeting and/or exceeding customer requirements and being able to bring final products to the market in a timely manner. ■

ACKNOWLEDGEMENT

The author thanks Harvey Espinoza and Chris Burket from TDK Corporation of America for helping review this article and the TDK Japan 5G team (Yasumasa Harihara and Tomoyuki Goi) for providing the antenna-array design and evaluation.

STEPHEN MURPHY | Applications Engineer, Teledyne LeCroy

Six Tips for Power Integrity Debug with an Oscilloscope

Detailed real-world advice and demonstrations of multiple techniques on a sample microcontroller board can help you debug your power integrity problems fast.

An oscilloscope is an essential instrument for making power integrity (PI) measurements, but to apply it effectively, you'll need situational awareness. Be aware of the oscilloscope features, the signal features, and potential measurement artifacts that could impede your view of the real signal. Key scope features include the bandwidth, sample rate, time base, vertical scale, input impedance, channel bandwidth, and probe bandwidth.

Demonstrations of measurements on sample microcontroller boards illustrate six tips that you can apply to your own PI debug tasks. In addition to an oscilloscope, you will need high-performance probes and the ability to choose the optimum versions—including 10x passive, power-rail, near-field, current, and differential probes—for your application.

Tip 1: Get the most out of your 10x passive probe

The 10x passive probe is the workhorse probe for most oscilloscope measurements. The first thing you want to do is apply color bands on your 10x passive probes that match the color of the corresponding oscilloscope trace to keep track of what you're measuring. If using multiple probes, it's easy to get confused about which probe is measuring which location, and color coding can save time in the long run.

If you're probing a circuit under test and expect to see a square wave but see something else, don't assume the problem necessarily lies in your circuit. Check your 10x passive probe's compensation. Fundamentally, your 10x passive probe includes a 9-MΩ resistor with a 10-pF shunt capacitor. The probe and oscilloscope together present a high-pass and a low-pass filter to the signal of interest.

Compensation ensures the poles of the two filters align for optimum measurement performance. To perform compensation, connect your probe's tip to the oscilloscope's COMP signal and use the adjustment near the probe cable's connection to the oscilloscope to obtain a flat response, as shown in *Figure 1* (a recent webinar[1] provides video of it and other demonstrations described in this article).

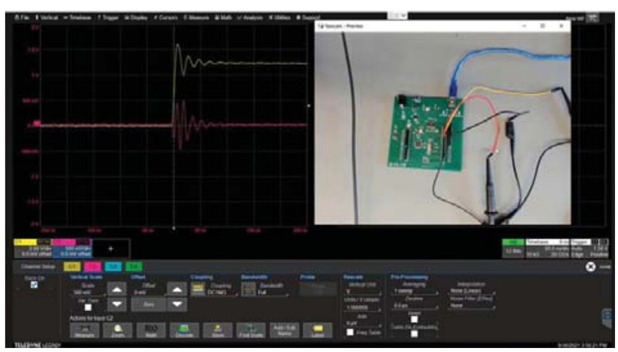
Many anomalies may be measurement artifacts that don't represent the performance of the circuit you're investigating. *Figure 2* shows a microcontroller board digital output that transitions from 0 to 1 (yellow) and a quiet signal that should remain low (red). The ringing on the transitioning signal and the crosstalk induced on the quiet signal result from the loop inductance of the long, floppy wires *(see the Fig. 2 inset)* used to make the 10x passive probe signal and ground connections.

Using low-inductance spring tips on your probes to eliminate the wires also removes the ringing and crosstalk they caused *(Fig. 3)*. And when designing your board, it's a good design-for-test practice to provide sufficient test points and grounds to accommodate your probe tips.

Tip 2: Use dc coupling for power-rail measurements

If you're looking for small variations in noise on a 5-V power rail, you may be inclined to use ac coupling. It lets you zoom in and out on the signal without having to reposition the trace on the screen every time you change the vertical scale. However,

1. Connect your 10x passive probe's tip to your oscilloscope's COMP signal and use the adjustment near the probe cable's base where it connects to the oscilloscope.



2. Long, floppy wires connecting your 10x passive probe to your circuit board can lead to ringing and crosstalk.

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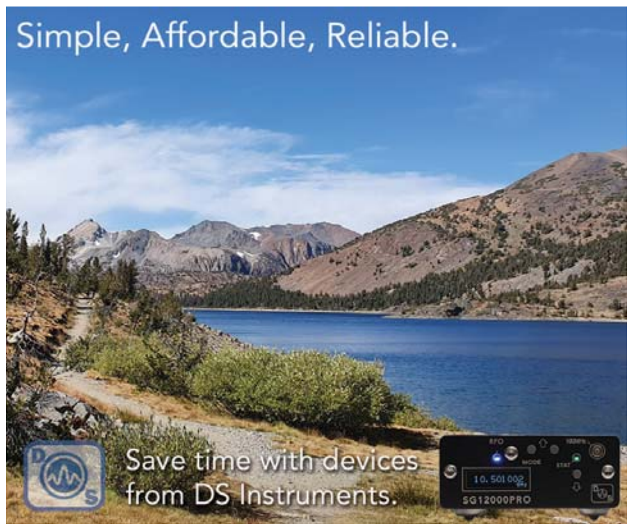

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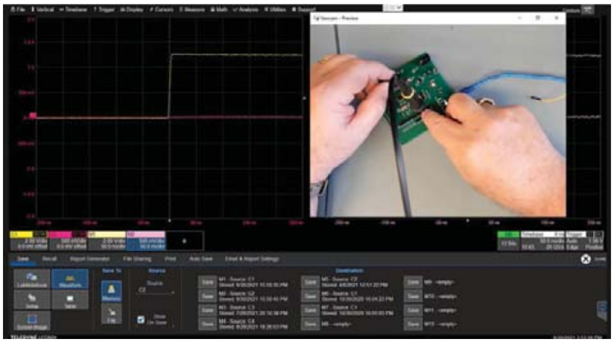


3. Use a probe spring tip to minimize crosstalk and ringing.

when you do that, you lose information about slow drift or other variations, because everything below about 10 Hz is filtered out.

Fortunately, you can adopt a trick to conveniently use dc coupling without constant repositioning. The feature varies among different oscilloscope manufacturers, but on many Teledyne LeCroy oscilloscopes, you use the onscreen menus to navigate from Utilities to Preferences to Acquisition and are presented with two options: Offset Setting Constant in: Volts or Div *(Fig. 4)*. If you choose Volts and center your signal, your signal will remain centered as you expand the vertical scale to zoom in to look for clock-edge noise or other disturbances on the rail.

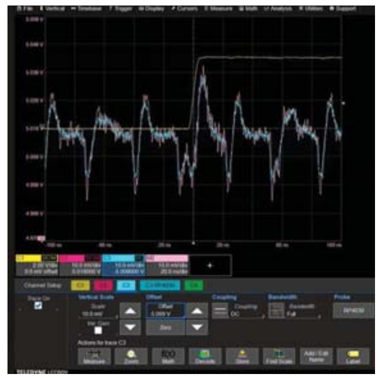
4. When using dc coupling on the WavePro HD, choose "Offset Setting Constant in: Volts" (lower left) to keep your power-rail trace centered as you zoom in to examine noise on the power rail.

Tip 3: Use a rail probe to measure switching noise

When looking at the power rails, consider using a rail probe, such as the Teledyne LeCroy RP4030. The RP4030 is a 4-GHz, dc-coupled active probe designed to measure the low impedances of the power rails but with the benefits of a high signal-to-noise ratio (SNR) and high bandwidth.

Like the 10x passive probe, the rail probe includes two paths. First is a passive ac-coupled path for high frequencies that acts like a high-pass filter with a pole frequency of about 10 to 100 kHz. The second path consists of two inverting amplifiers with a 16-bit digital-to-analog converter (DAC) that enables precision offset control. This path together with the oscilloscope's input impedance acts as a low-pass filter, and again, it's necessary to align the poles of the high-pass and low-pass filters to obtain a flat response.

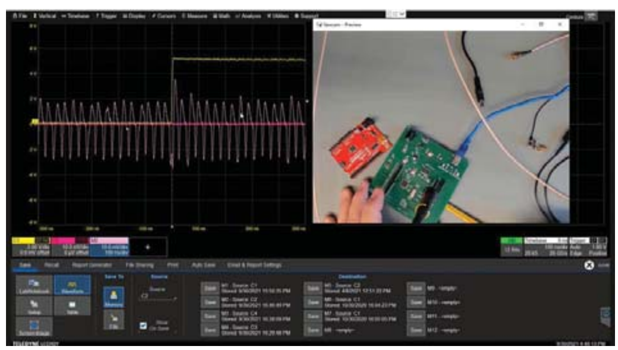
Note that the rail probe presents a very high impedance at low frequencies to minimize dc loading on the rail. For the high frequencies, though, the rail probe matches the 50-Ω impedance of the oscilloscope input to minimize reflections. *Figure 5* shows a noise signal measured with the rail probe (blue trace) overlaid with the same measurement made using a 10x passive probe (red trace). The rail probe provides a cleaner, higher-fidelity view of the clock-edge noise on the board's power rail.



5. A rail probe (blue trace) offers a higher SNR than a 10x passive probe (red trace).

Tip 4: Use a near-field probe to locate EMI problems

When looking for potential EMI problems during the pre-compliance test, opt for a near-field probe. Note that the near-field probe is essentially a low-impedance loop, so take care to connect it to a 50-Ω oscilloscope input—not a 1-MΩ input—to prevent reflections and ringing. In addition, when probing a microcontroller board, a useful technique is to trigger the oscilloscope on a switching I/O signal, so that the observed waveform will be synchronized with the microcontroller's clock.



6. One board exhibits significant near-field emissions (pink trace), while an electrically identical board running the same code but having superior layout exhibits barely measurable levels (red trace).

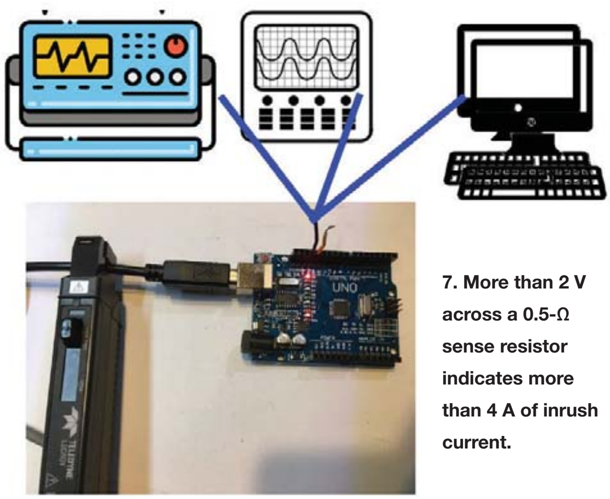
Figure 6 shows superimposed bottom-of-the-board near-field probing results for two microcontroller boards. These boards have the exact same circuitry and are running the exact same code, but one features a superior layout with a copper-pour return plane, as described in a recently released textbook.[2]

As the figure shows, near-field emissions are barely measurable for the board with superior layout (red trace). However, they're substantial for the other board (pink trace), demonstrating that using good return-path control dramatically reduces near-field emissions.

Tip 5: Use a current probe to find ground loops

A high-sensitivity current probe can help measure common ground-loop currents found in USB cables and other external connections. These currents can arise from the different ground potentials of multiple instruments connected to the microcontroller demo board, for example. They can fluctuate quickly if the ground potential differences result from switching within the demo board or the devices connected to it.

This demonstration takes advantage of the Teledyne LeCroy CP031A clamp-on current probe. It incorporates a Hall-effect sensor and a pick-up coil to enable current measurements from dc to 100 MHz and from milliamps to 30 A.



7. More than 2 V across a 0.5-Ω sense resistor indicates more than 4 A of inrush current.

As shown in *Figure 7*, a USB cable connected to a PC powers the microcontroller board without carrying data. The PC in turn connects to earth ground by way of a three-prong plug.

With this setup, no common current flows in the USB cable. However, connecting a ground pin on the microcontroller board to ground on another external device plugged into the wall can result in common currents reaching 75 mA. Only 5 mA is required to fail an FCC part 15 class B test. The current probe is useful in viewing common currents that can occur if you have multiple connected external devices each making their own connection to ground.

Tip 6: Use a differential probe to check a microcontroller's current draw

To measure the actual current that the microcontroller draws in real-time, use a differential probe. First, insert a sense resistor—for example, 0.5 Ω—in the series path of the power rail, and then measure the voltage across it. You could use two single-ended probes, one to measure the voltage to ground on each side of the resistor. However, that would involve subtracting one large number from another to get the voltage across the resistor, which can introduce inaccuracies.

8. Inrush current measures more than 4 A as the demo board's decoupling capacitors charge up.

Instead, use the differential probe, which is designed to measure small voltage differences with a large common dc offset. You can use the differential probe and sense resistor to measure inrush as well as steady-state current.

To look at inrush current, set your oscilloscope's trigger to normal mode, which is used to look at transient signals. *Figure 8* shows more than 2 V across the sense resistor during the inrush period, indicating an inrush current of more than 4 A as the demo board's decoupling capacitors charge up. Within about 200 ms of power being applied, the current nears its steady-state value.

To investigate steady-state current draw in detail, trigger the oscilloscope on a transitioning signal to look for anomalies, if any, that might be synchronous with the microcontroller clock.

Summary

In conclusion, keep in mind that it's easy to do a measurement, but hard to do so without artifacts. Practice situational awareness. Make sure you use the right probe for the right application. Use the 10x passive probe with low-inductance ground connections to the extent possible. Then, use a rail probe for measurements requiring high bandwidth and SNR, use a near-field probe for pre-compliance EMC testing, turn to a current probe to measure common currents, and use a differential probe with a series resistor to measure inrush and steady-state currents.

For purposes of this article, measurements were taken using an 8-GHz, 4-channel Teledyne LeCroy WavePro HD oscilloscope. Some relevant specs for the instrument include 12 bits of vertical resolution, a 20-GS/s rate, and a 5-GS acquisition memory. ■

REFERENCES

1. Bogatin, Eric, *5 Tips for Power Integrity Debug Webinar,* Teledyne LeCroy

2. Bogatin, Eric, *Bogatin's Practical Guide to Prototype Breadboard and PCB Design*, Artech House, 2021.

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CABLE SELECTION TODAY – ALWAYS A TRADE-OFF

Existing coaxial cables on the market today consist of either a solid or stranded inner conductor. Thus, the current cable selection is always a trade-off, with users having to choose between lower loss (solid wire) or more flexibility (stranded wire). The stranded wire causes a higher attenuation compared to the solid wire. The signal only flows in the outermost few micrometers of the inner conductor and so the signal path in the strand is longer than in the solid wire. This behavior is more pronounced with microwave-signals than with low frequency signals and it is called the 'skin effect'. In addition, there are the contact resistances between the individual stranded wires, which also contribute to higher damping. On the contrary, microwave cables with solid wires have greater phase deflection through bending than cables with stranded wires. This is especially true for cable types with a dielectric diameter greater than 2 mm. Here, the cable length is slightly reduced by bending movements, which results in a deformation of the inner conductor. This leads to the phase shift. The effect is caused by interaction with the various construction elements of the cable. To plastically deform the individual wires of the strand, a stronger bending movement is required. This leads to smaller length changes in the overall construct of a microwave cable and to a more stable phase versus bending behavior.

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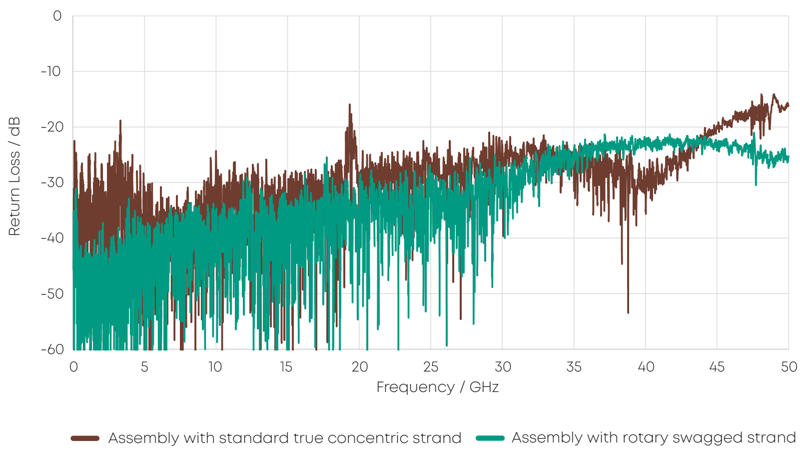
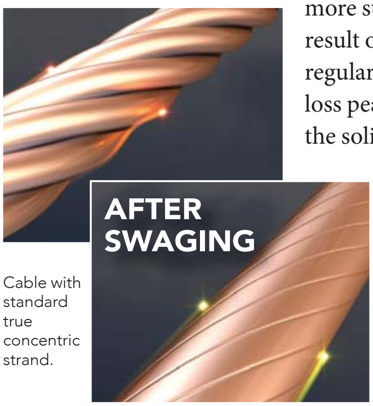
Return loss performance



Thanks to the rotary swaging technology, the surface is smoothed and prevents the occurrence of possible discontinuities in the microwave cable, which reduces regular return loss peaks. The conventional stranded wire has a regular structure and is thus more susceptible to return loss peaks caused by changes in diameter and hence impedance. As a result of the changes, part of the microwave signal is reflected. If several discontinuities occur at regular intervals, this results in a strongly reflected signal at a certain frequency – called return loss peak. The rotary swaged stranded wire eliminates this risk by mimicking the signal path of the solid wire and through that improving the return loss level as well. Additionally, the contact resistance is reduced when compared to a conventional, true concentric stranded wire leading to a lower insertion loss.



Cable with standard true concentric strand.

Rotary swaging is a process of mechanical deformation and is achieved by generating repeated blows to a conventional strand. Using hammers, the surface of the stranded wire is smoothed and a nearly perfect round and smooth surface is guaranteed.

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STEVE TARANOVICH | Freelance Technical Writer, Phoenix Information Communication LLC

How to Shield Your 5G Systems from EMI

5G base stations have far more modems, data converters, and high-speed baseband digital processing, which leads to higher power needs. And they may need as much as 3X more power than existing 4G designs with a marked increase in EMI.

5G system hardware designers are challenged to implement better power solutions that help all necessary electronics to fit into form factors close to those of existing 4G base-station enclosures while maintaining a low EMI.

Increased board component density in 5G systems demands space-saving solutions with higher efficiency and lower EMI than traditional discrete dc-dc ICs with external inductor-based solutions. This will challenge designers to create a careful layout of components for filters to minimize radiated and conducted EMI generated via power converter and inductor switching currents.

It's no secret that dc-dc converters are notorious for conducted EMI coming from magnetic fields emanating from the current loop path. That path is comprised of the output switching node to ground as well as the input capacitor to ground.

Radiated EMI also is generated from the MOSFET switching node to the connection at the inductor. This creates high dV/dT because it's continuously switching from the high input voltage level to ground as well as from inductor-generated electromagnetic fields.

This system design may lead to multiple, costly EMI lab tests in order to meet the standard. An integrated module may be a better option here.

5G EMI Shielding

5G is an awesome technology. Applications in a 5G system can range from smartphones, healthcare, and vehicle-to-everything (V2X) to smart appliances, public safety, and much more. However, one improper shielding device failure could cause a larger communications snafu that possibly affects a broader system disruption.

Designers must avoid open apertures as well as non-conductive regions that diminish the overall electronic enclosure. They allow EMI and RFI to exit the design areas to the outside or enter the system design area to possibly cause the system to malfunction or even fail.

One of the main open apertures and non-conductive regions is cable entry, particularly vulnerable near connectors. Power and signal access panels could contribute to EMI problems here. And finally, viewing windows, as well as heating, ventilation, and air conditioning (HVAC) vents, can be access areas that EMI may enter or exit.

Some other potentially vulnerable use cases include:

5G in the military

Military enclosures will need to pass MIL-STD-461, possibly requiring 60-dB, 80-dB, or even higher attenuation levels to achieve compliance. To achieve such levels of electromagnetic shielding attenuation, open apertures and non-conductive areas may not be larger than a few thousandths of an inch.

5G in the medical arena

EMI in some sensitive medical applications could harm a patient or even cause death. Medical facilities must properly shield operating theater equipment, as well as other areas that need protection, such as where imaging devices are in use.

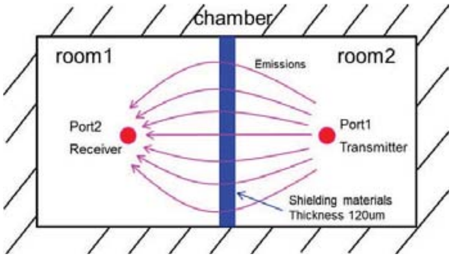
EMI Shielding in Package Module Designs

System-in-package (SiP) module design, and associated assembly technology, plays a key role in IoT, antenna-in-package (AiP), and RF modules. High-speed data transmission and low latency are prime characteristics for 5G RF systems.

Now let's look at EMI coating and partition technology in SiP modules.

EMI Coating

Conformal EMI shielding can be implemented using a metal frame, sputter coating, or spray coating technology to prevent disturbance in an electronic circuit. Unfortunately, though a basic metal frame



To the left is the simulation model setup of the shielding space.

Shown below are the epoxy and metal-frame partition designs for the test vehicle (TV).

(Images from Reference 1)

Characteristics	Epoxy Partition 	Metal Frame Partition 
PKG type	SiP Module (650 mm^2)	
Molding thickness	1.4mm (Compression Molding)	

shield is good, it doesn't always provide the best performance.

A SiP with an EMI shielding structure is absolutely the most innovative technology in a 5G RF system. In the mobile computing market, antennas also are integrated in the SiP module to minimize board footprint.

A 3D SiP solution employs a double-side molding technology and AiP architecture. In 5G, AiP technology has been widely applied in many IoT, RF module, and wireless transmission applications.

For 5G millimeter-wave (mmWave) generation, which operates at frequencies higher than 28 GHz, the antenna wavelength is suitable for small package sizes. This small size presents challenges in AiP design, such as EMI shielding technology, partition design, low-loss substrate material selection, and multi-layer substrate antenna design capability. Partition EMI shielding technology is used to isolate different function blocks in the SiP module.

Copper/SUS ("steel use stainless" or stainless steel) sputter coating is a popular coating method used within assembly industries. A 3- to 5-µm thickness coating has ideal shielding performance as well as very good particle adhesion on coating surfaces.

To facilitate a more flexible shielding design between the different function blocks in a SiP, compartment shielding technology is proposed to isolate the signal noise between the digital and RF/analog circuits within the SiP module.

A metal-frame partition design has the advantages of simple assembly, lower cost, and good shielding effectiveness (SE) for the low-frequency spectrum. However, the SE may degrade in the mmWave range due to possible jagged solder pad design. As a result, epoxy filling is becoming a more popular shielding design that supports a flexible partition shape and good SE performance in mmWave signals.

Comparing EMI Shielding in Conformal Coating and Compartment Technologies[1]

EMI shielding technology, in both conformal and compartment methodology, using the simulation model and real device methods, were shown the same trend and result in an experiment. A test vehicle (TV) was designed with an advanced SiP module employing antenna integration and partition EMI shielding technology. The TV of a compartment SiP module, with a 650-mm^2 package size and 1.4-mm molding thickness, designed using metal frame and epoxy filling partition technology, is shown in the *table*.

In this study, the first stage of a 3-µm metal coating conformal shielding technology, in a 10- × 10-mm package size, involved a single unit and a side-by-side coupling simulation *(see figure)*.

Results demonstrated a marked improvement of SE in the dc to 6-GHz frequency range. Also, the ferrite coating plate was covered on the RF die, and the copper was coated onto the molding compound by sputter technology. The SE improved below the 6-GHz frequency band due to the intrinsic cutoff frequency characteristic of the ferromagnetic material.

Compartment shielding also was demonstrated in this study. The metal frame and conductive epoxy were applied in the simulation model and in the real device. The metal material demonstrated better SE performance in this experiment. According to the SE calculation formula, the SE is proportional to the electric conductivity of the material, which is dominated by skin effect. Based on the calculation result, the SE of Cu-Ni is 8.3X better than conductive epoxy, which is compatible to the simulation condition.

Finally, to verify the SE between the materials of metal, epoxy, and SUS + Cu, with and without the hole on the bottom of the shielding wall, the AiP with partition structure was designed and tested. Both the metal frame and SUS + Cu coating solution improved over 35 dB SE between the 25- and 45-GHz frequency bands due to better conductivity properties.

In summary, the package level reliability was tested by the JEDEC standard, which included the MSL 3, TCT1000, u-HAST96, and HTS1000 test conditions.

Conclusion

No one unique shielding solution is perfect for every EMI problem. Architects and designers need flexible material options when EMI plagues challenging designs. Designers need flexibility in their solutions, which can target board- and enclosure-level EMI problems. For very challenging designs, designers may want to combine multiple options to create a custom solution. ■

REFERENCES

1. EMI Shielding Technology in 5G RF System in Package Module, 2020 IEEE 70th Electronic Components and Technology Conference (ECTC)

EMI Mitigation at Millimeter Wave, Proceedings of the 1st European Microwave Conference in Central Europe

Innovative EMI Shielding Solutions on Advanced SiP Module for 5G Application, IEEE 2019

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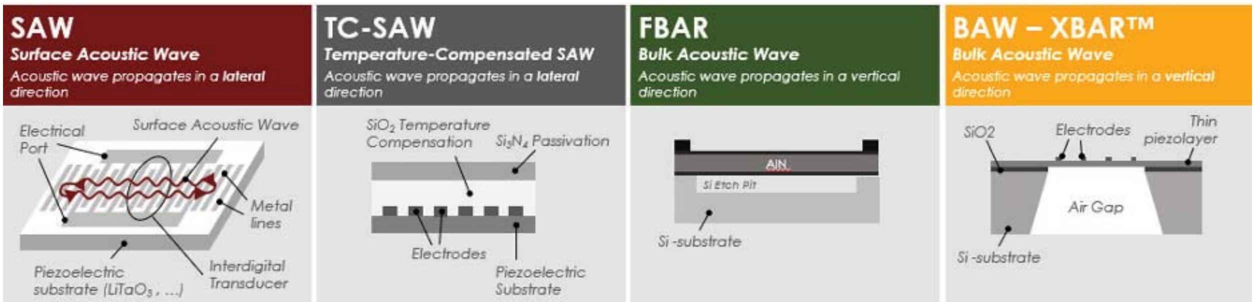


RF FILTER TECHNOLOGY INDUSTRY LEADER RESONANT'S XBAR HOLDS THE KEY TO THE FUTURE OF 5G

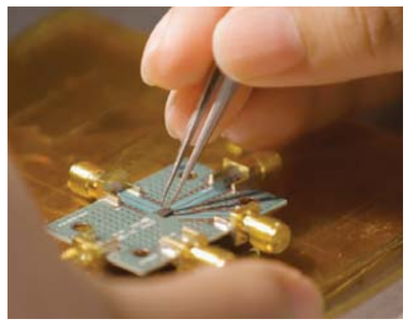
Network operators are currently focused on building the ecosystem for Wave 2, the second wave of 5G, in which we'll begin to see the enhanced coverage and performance that everyone wants in their devices. It is expected that users will be able to download a three-gigabyte movie in about 30 seconds with Wave 2 5G speeds, which is a radical improvement from the 20+ minutes of Wave 1 5G.

This promise, however, will not become a reality without RF filters that can operate in 5G's high frequency bands. Resonant, a leader in transforming the way RF front-ends are being designed and delivered, has developed XBAR, the pioneering resonator technology for 5G filters. We believe this technological breakthrough is the leading RF filter technology today, with the ability to meet the complex requirements for bandwidth and performance demanded by 5G applications.

5G will bring unprecedented changes to the way we communicate and exchange information. 5G's fast throughput and low latency combine to create versatile technology for a wide array of applications, in large part due to advanced RF filter technology. Smart cities, augmented and virtual reality, robotic surgeries, and autonomous vehicles are a few of the many new applications that will depend on 5G's fast throughput and low latency characteristics. Existing 3G and 4G filters are not sufficient to unlock the full potential of 5G technology because they cannot properly protect the full 5G bandwidth and associated issues of interference – they lack the intrinsic acoustic performance needed for higher frequency and wider bandwidth RF bands, deteriorating above 3 GHz.

Resonant's XBAR is one of the key technologies developed to enable optimal 5G performance. XBAR resonators consist of a single crystal, piezoelectric layer, with a metal interdigital transducer (IDT) on the top surface. The metal traces excite a bulk acoustic wave within the piezoelectric, the primary frequency and coupling characteristics being determined by the physical dimensions and properties of the piezoelectric. The inherent flexibility of XBAR resonators allows tailoring for different requirements by changing the piezoelectric layer and its orientation.

XBAR has demonstrated the required performance for the future of 5G and beyond.



XBAR Invented Using Resonant's WaveX Design Platform

Resonant has developed its WaveX RF filter design tool to rapidly simulate the complex physical and electrical interactions that are required to design an RF filter. The use of WaveX reduces RF filter time-to-market from years to months.

In a market that is critically constrained by limited designers, tools and capacity, Resonant addresses these critical problems by providing customers with ever increasing design efficiency, reduced time to market and lower unit costs.

Working with Resonant, customers enhance the connectivity of current mobile devices, while preparing for the demands of emerging 5G applications. Visit *resonant.com* for more information.

LI TAO | Business Development Manager, W. L. Gore & Associates

Improve 5G Testing with **Reliable Cable Assemblies**

Microwave/RF cable assemblies are essential to the reliability and accuracy of 5G test and measurement. That's why engineers must understand the impact assemblies have on test systems and how to ensure reliable performance during use and over time.

As cellular network infrastructure expands to 5G technology, it will significantly affect various industries, such as telecommunication, aerospace, defense, and automotive, to name a few. Examples of applications include 5G cellular communication; aviation communication links; intelligence, surveillance, and reconnaissance (ISR) systems *(Fig. 1)* and processing; autonomous driving; smart city; and smart factory. Therefore, a highly reliable and resilient 5G network is crucial to our economic development and national security.

That said, testing of 5G system components faces new challenges compared to testing existing LTE/LTE-A (LTE and LTE-Advanced) communication system components. Firstly, 5G system components utilizing mmWave use higher-frequency bands than current LTE/LTE-A system components, which means 5G test system designs must overcome technical challenges associated with these bands.

Next, 5G system components increase the usage and density of multi-port interconnect systems to support massive multiple-input, multiple-output (MIMO) antennas. Thus, 5G test system designs must incorporate higher levels of integration in small spaces without negatively impacting signal integrity.

Lastly, 5G system components require more over-the-air (OTA) testing to reduce test-scheme complexities and increase throughput. Therefore, 5G test system designs must overcome technical challenges associated with OTA testing *(Fig. 2)*.

1. Shown is Keysight's FieldFox handheld analyzer connected with W.L. Gore's Phaseflex microwave/RF test assemblies used during flight-line testing. *(Courtesy of Keysight Technologies)*

Engineers Need to "Reconnect" with Assemblies

However, one of the last components often considered when designing or incorporating a test system is a microwave/RF assembly. Such assemblies play a critical role in ensuring overall test stability, measurement accuracy, and repeatability.

A previous study conducted by W. L. Gore & Associates showed that 75% of cable assemblies worldwide are frequently replaced because they get damaged. As a result, there's a need to educate engineers on the importance of more reliable performance from cable assemblies to improve test outcomes. You can't trust the product or system performance if you can't trust the test results.

Choosing a high-performance RF cable assembly can be complicated when it comes to electrical performance, stability, and durability. Engineers should better understand what key factors can negatively impact cable-assembly performance during usage and over a length of time, and which attributes to consider to best support their test system. Otherwise, poor cable-assembly performance can lead to production yield losses and delays, extra troubleshooting and maintenance, frequent calibrations cycles, signal-integrity issues, unnecessary retesting, higher total costs, compromised system performance, and reduced test throughput.

Key Factors that Impact Cable-Assembly Reliability

When it comes to electrical performance, most cable assemblies perform well right out of the bag. But problems start when they're exposed to daily use.

For example, the slightest movement when handling an inferior cable assembly can cause phase and amplitude instability. Frequent connecting and disconnecting a poorly designed connector interface also can wear it down, causing premature VSWR, insertion loss, and measurement accuracy and repeatability issues.

Furthermore, a cable assembly that's designed without durable materials and/or is poorly built can easily and quickly get damaged *(Fig. 3)*. In a short time, a poor-performing cable assembly will

2. An instrument such as Rohde & Schwarz's Spectrum Rider FPH handheld microwave spectrum analyzer, connected with W.L. Gore's Phaseflex microwave/RF test assemblies, is suitable for field spectral measurements of OTA 5G signals. *(Courtesy of Rohde & Schwarz)*

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Privately held, Micro Lambda Wireless Inc. has been formed from a core of individuals with specialized YIG-based component experience combined with analog, digital, and PLL specialists to yield a strong, dynamic technical staff. High-volume manufacturing techniques have been implemented across all product lines along with standardized mechanical and electrical design, which lend themselves to low-cost and high-volume applications.

We maintain a commitment to Total Quality Management and Just-in-Time concepts throughout the organization. Our integrated manufacturing system combines sales orders, word orders, accounting, inventory, and scheduling. Material planning is supported by an MRP module, which coordinates subcontractor material requirements. Product standardization focusing on a repeatable manufacturing process enables our company to stock material, allowing for very short build cycles.

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become a liability and compromise a test system's performance, leading to frequent recalibration and doubts about measurement accuracy.

Durability with high crush resistance and tensile strength is a key factor in ensuring overall cable-assembly performance. A leading cause of mechanical stress is when cable assemblies are constantly handled. Operators can kink, pinch, crush, and pull a cable assembly by accidentally overbending it in a sharp corner, stepping on or rolling over it with a chair, and pulling it to move heavy test equipment.

Cable assemblies attached to portable equipment used to test defense systems—such as radar, navigation, communication, and ISR—often encounter sharp edges that can cut into or scrape materials. Thus, abrasion resistance is another key factor to consider when choosing a cable assembly.

Stability is a critical feature of cable-assembly performance that is often overlooked or misunderstood. An example is stability in phase and amplitude with movement. Without this feature, users can't move or flex a cable assembly once the test system is calibrated. Stability with consistency over time is another critical factor for cable assemblies to perform reliably no matter how long they have been in service. Without it, a cable assembly's performance could drift over time, causing measurement accuracy and repeatability issues.

Finally, a cable assembly's operating temperature range is a key factor to consider. In addition to testing at room temperature, test systems often need to test a device under test (DUT) at its specified operating temperature range to guarantee its performance. Examples include semiconductor aging test, wafer probing, and thermal vacuum test.

Important Attributes of Cable Assemblies

To support 5G testing successfully, cable assemblies must include certain attributes. They should deliver phase and amplitude stability with movement and over temperature without distorting conveyed signals. In addition, they should deliver reliable, repeatable performance without negatively impacting the test system's measurement accuracy.

On top of that, cable assemblies must be durable enough to perform consistently under many environmental conditions; tolerate constant handling, connecting, and disconnecting; and withstand hard use over the test system's lifespan. They also must exhibit excellent RF shielding effectiveness against electromagnetic interference (EMI), especially in 5G OTA chambers. Lastly, cable assemblies should be highly flexible, easy to use, and simple to route without any springback to simplify test system setup.

3. Cable assemblies that are durably constructed of quality materials are essential in mmWave testing. An example, shown here, is W.L. Gore's Phaseflex microwave/RF test assemblies.

Microwave/RF cable assemblies play an integral role in testing that supports 5G cellular network infrastructure for various industries.

Ensuring Precise, Repeatable Test Measurements

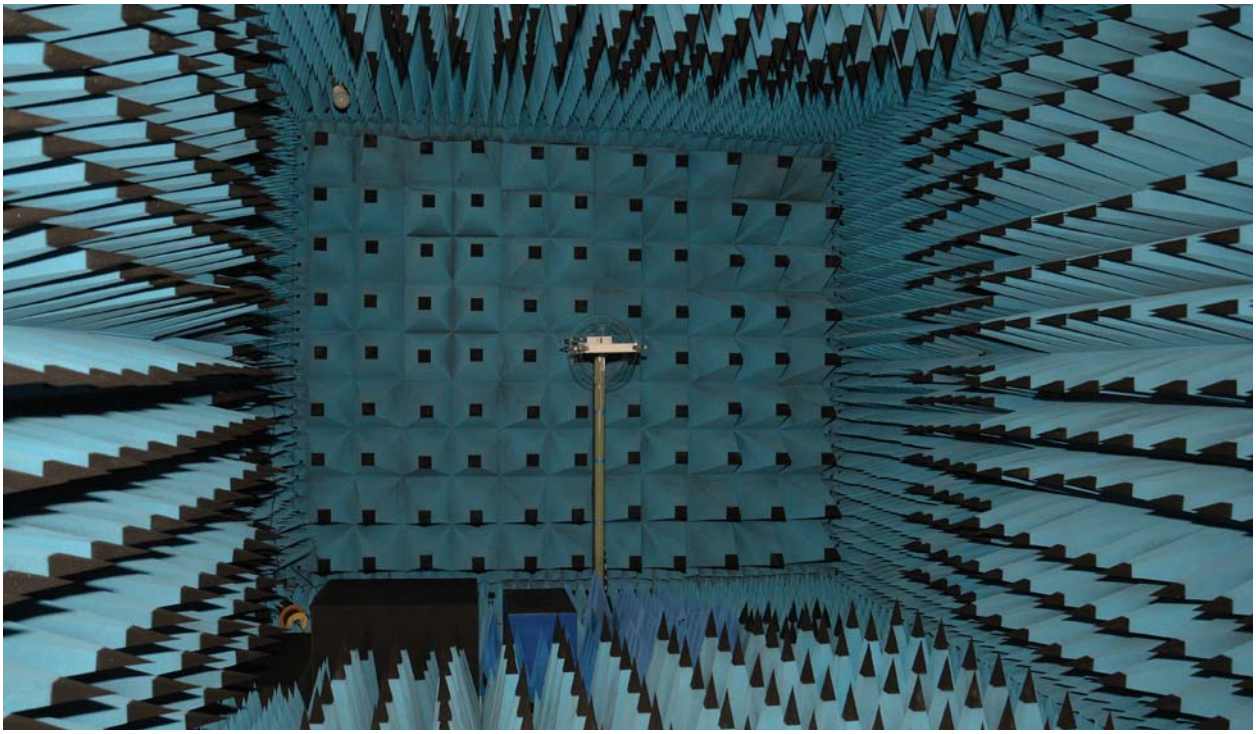
Microwave/RF cable assemblies play an integral role in testing that supports 5G cellular network infrastructure for various industries. But not all cable assemblies are engineered the same way in electrical performance, durability, and stability. Engineers should fully understand how various test environments can negatively impact cable-assembly performance, including constant handling and sharp edges, to avoid production yield losses and delays, retesting, recalibration, and higher total cost of ownership.

When choosing a cable assembly, engineers should carefully consider cable-assembly attributes, such as precision; signal integrity; internal ruggedness; flexibility; RF shielding effectiveness; and reliable, repeatable performance over time. Ask the supplier if the cable assembly has a proven track record of delivering reliable performance in real-world applications, such as a wide temperature range, continuous movement, extensive flexing, and frequent connecting and disconnecting.

Ultimately, a reliable, high-performing microwave/RF cable assembly will ensure precise, repeatable measurements now and over time, so you can always trust the test results. ■

FOR ADDITIONAL INFORMATION, read Gore's white paper, "Improving 5G Testing with Reliable Microwave/RF Cable Assemblies."

GEOFF SCHULTEIS | RF Antenna Application Specialist, Antenova



Overcome LTE Certification Challenges in Your Wireless Design

You need your wireless design to pass network certification in its initial attempt. This article sets out an approach to help you prepare for testing and certification, and probably achieve better results from the antenna, too.

U.S. carriers will switch off their 3G networks and move to 4G/LTE by the end of 2022, with carriers in other world regions likely to follow. Thus, the IoT and telematics devices that will operate on those networks must be redesigned for 4G/LTE and may need to undergo testing to gain network certification. This article sets out to shed some light on the requirements and an approach to pass certification the first time around.

For designers who are new to RF, a wireless design will need a slightly different approach that considers the antenna and allows it to perform well. If the antenna is embedded, i.e., a surface-mount-device (SMD) antenna, it needs to be placed in the design with care or it may not behave as intended.

Even if the device doesn't require certification, the design approach we outline here to prepare for testing also will help you garner better results from the antenna.

Transmitters and Testing for LTE

All electrical products are tested for electromagnetic compatibility (EMC) and safety, but if the product contains

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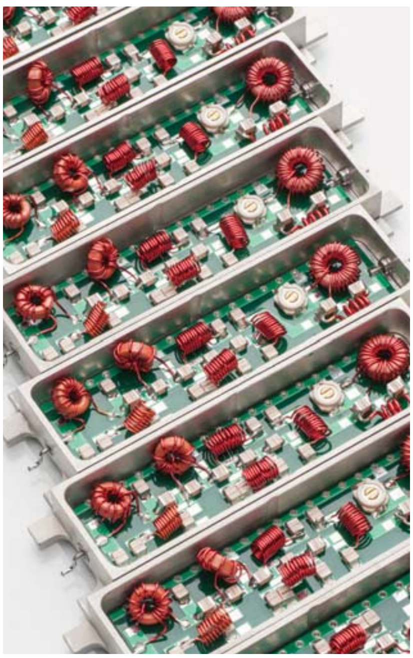
CUSTOM RF & MICROWAVE SOLUTIONS FROM DC TO 40 GHZ

Networks International Corp. (NIC) is a leading manufacturer of radio-frequency and microwave filters and assemblies that provides custom solutions for advanced communications systems. For over 30 years, NIC has partnered with its customers to transfer value through superior engineering design, manufacturing, and continuous support. NIC is a small business that serves the Military, Space, and Commercial markets. The company's heritage lies in the military market, where precision, high reliability, repeatability, and service are mission-critical.



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).

CAPABILITIES & TECHNOLOGY

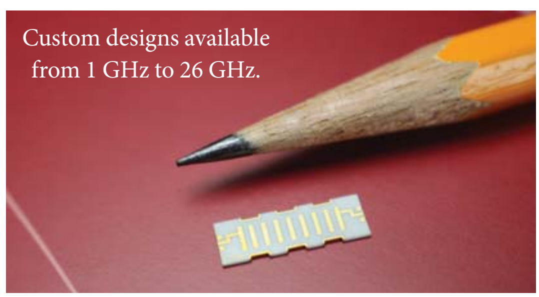
NIC is a vertically integrated company that maintains all assembly and testing in its 15,000 sq. ft. facility with the flexibility to handle high volume and high product mix. NIC operates a state-of-the-art in-house suite of environmental testing that is compliant with MILSTD-202, MIL-STD-883, as well as space-level screening. NIC is AS9100 & ISO 9001:2008 certified.

NIC has consistently incorporated industry-leading design techniques and technologies to create practical, cost-effective, and repeatable solutions. NIC's staff engineers have >100 years in RF design experience and are staffed to provide quick-turn prototypes.

PRODUCT FOCUS: LOW PROFILE THIN-FILM PRINTED FILTERS

NIC introduces a Thin-Film Bandpass filter centered at 17.5 GHz which is manufactured using a low loss, high permittivity alumina substrate. The filter offers high selectivity (60 dBc) in adjacent bands, temperature stability and a compact package size of **0.545 x 0.140 x 0.080 inches**.

Exceptional electrical performance in a low profile surface mountable package makes this filter a perfect fit for many Ku and Ka band applications. These filters are designed for use on industry standard RF specific PCB materials.



NIC

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a transmitter, it must pass further tests to ensure that it's safe in wireless terms. These tests ensure that:

- It will not interfere with the use of any other, unrelated telecoms products.
- It uses the limited wireless spectrum correctly and efficiently.
- It doesn't pose any kind of health issue to human beings, i.e., the RF must be within the level that's known to be safe.

Therefore, any product with a wireless connection—whether it's Wi-Fi, Bluetooth, ISM, satellite, or cellular—must undergo an additional series of tests to ensure that it meets the required standards.

If a device is to use LTE networks, testing becomes more challenging for several reasons. First, LTE uses a number of different frequency bands. The minimum for the U.S. is three bands, but if the device is to be employed in more countries and regions of the world, the device has to be tested for a range of different frequency bands. Thus, more tests are required.

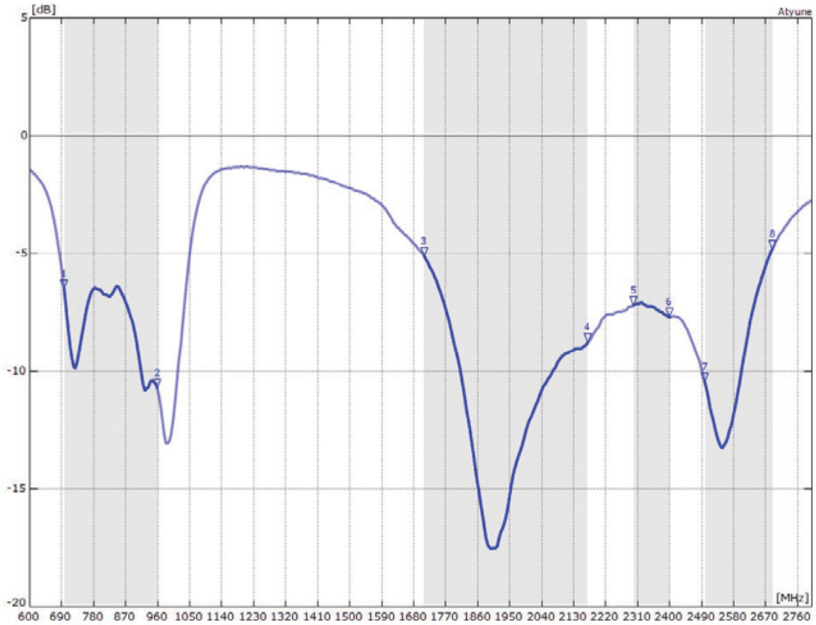
Designing for RF Performance

For a device to operate on a global scale, the design should allow the antenna to operate at all of these frequencies. As a result, special attention must be paid to the antenna in the design. The antenna must be placed with the correct ground plane for it to perform properly for each of the frequencies. In addition, the antenna will need to have a matching network, which should be specified on the antenna manufacturer's datasheet.

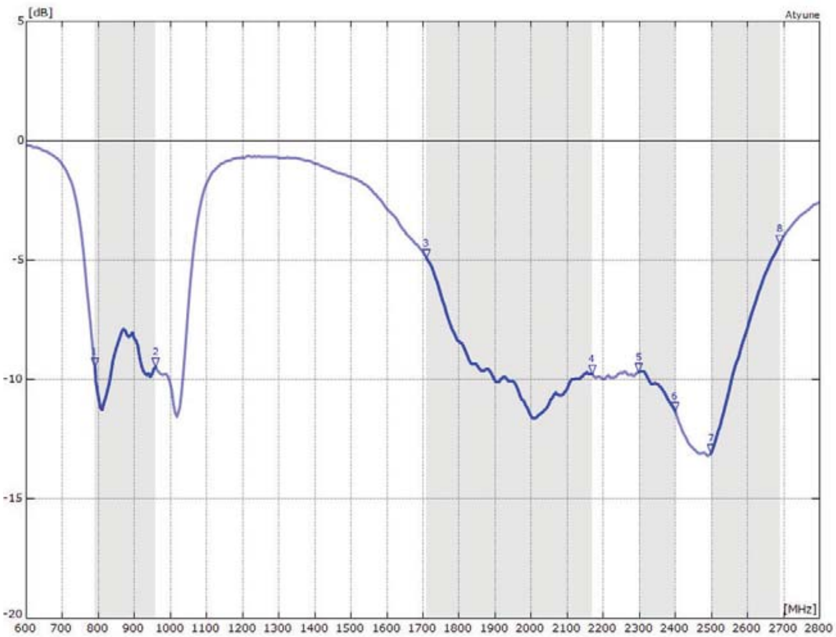
LTE devices sometimes use multiple-input, multiple-output (MIMO) or diversity techniques where more than one antenna operate together to improve the device's performance. In this case, the design needs an additional test: The envelope correlation coefficient (ECC) test measures the pattern of the radiated beam of each antenna, and the results must fit set criteria.

How Tests Are Governed

At the highest level, a design has to conform with legislation in the countries where the finished product is to be sold. The FCC is the relevant body for the U.S. and the EU sets similar standards for European countries. On top of that, the telecom industry has its own standards—in the U.S., these are governed by the PTCRB; outside the U.S., it's the Global Certification Forum (GCF).



The antenna's return loss for the tested frequencies (from Antenova's Integra antenna for 4G and LTE frequencies).



Shown is the antenna's voltage standing wave ratio (VSWR) to match the antenna to its transmission line (from Antenova's Inversa antenna for 4G and LTE frequencies).

These authorities don't conduct testing themselves. They work with networks of Accredited Test Laboratories that will know which tests apply for an IoT product, and will conduct the necessary tests in a laboratory with an anechoic chamber.

The tests for 4G and LTE telecom products are well-defined. However, 5G is still relatively new, and the authorities' working parties are still finalizing how tests will operate for 5G designs.

Finally, each telecoms carrier has its own criteria for the results a device must achieve in order to be accepted onto their network. The carriers' tests examine the device's performance on the actual network. For example, AT&T stipulates a minimum performance for an antenna in addition to PTCRB tests. Both the PTCRB and the carriers require over-the-air (OTA) testing.

Two Key Results

Two test measurements are important to understand, since they measure the performance of an antenna directly:

- **Total radiated power (TRP)**: This measures the average spherical effective isotropic radiated power of the antenna. Effectively, this reading ensures that the antenna, and therefore the device, will perform well, without needing to point in a particular direction.
- **Total isotropic sensitivity (TIS):** This test measures the average spherical effective radiated sensitivity of the receiver and indicates its performance and sensitivity. It will detect in-band noise or spurious signals that will cause the design to fail certification.

A further test, the specific absorption rate (SAR), applies particularly to wearable devices, as well as devices that will be used close to the human body.

Planning for Certification During the Design

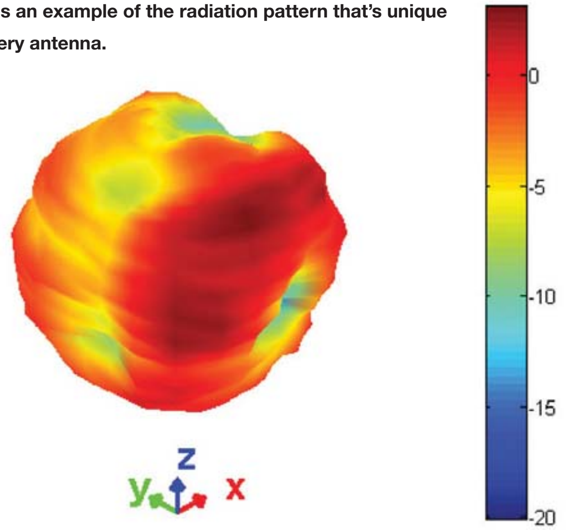
We suggest the following seven-step approach to ensure that your chosen antenna performs well in the design, and that you're ready to apply for formal certification for the finished device:

1. Establish which certifications will be needed for the design. This will depend on the application of the device, the networks it's built for, and the markets where it's to be sold. If the design requires certification, it's a good idea to select a test house in your region early on, choosing one from the list accredited by the authorities.

2. Take care in the choice of the antenna and communications module. A less expensive antenna may not perform as well in tests. The manufacturer's datasheet will specify key measurements for the antenna—its efficiency and its antenna pattern for each frequency. However, the measurements on datasheets apply to the antenna on its own. It will react differently close to a human hand or other components.

3. It's wise to consult with the chosen network carrier at this stage to understand what they require so that the device will operate on their network.

This is an example of the radiation pattern that's unique to every antenna.



4. Have an RF specialist check the Gerber files to be sure that the layout and stack-up will allow the antenna (or antennas) to operate correctly. Usually, the antenna is placed on an edge of the printed circuit board (PCB) so that it can radiate freely in all directions without obstructions. For more complex designs with more than one antenna, seek help from an RF engineer.

5. Send a sample PCB for passive testing in an anechoic chamber. This will provide a useful report showing the antenna's performance. The antenna's output is shown as Antenna Efficiency, Gain, Return Loss, Impedance, and 2D and 3D radiation patterns. These tests will reveal any problems with radiated power and sensitivity.

When these tests are complete, you may be given recommendations to improve the performance of the design, and help you get the best performance from the antenna. The next stage is to tune the antenna to optimize its performance.

6. At this stage, the design may require some revisions and adjustments to the layout to improve the RF performance and be sure that it will perform as intended in the real world.

7. Send a complete prototype or sample typical of the final production unit for OTA testing. The product should be accompanied by its batteries, chargers and cables, and documentation showing details of the antennas and their feeds. Some tests are performed with "phantom" body parts to simulate the device being used next to the human body or head, because RF behaves differently close to a person. These tests are generally done as a precursor to certification, to assess device readiness, and prepare for the final stage of gaining certification for the product.

The final stage will be to apply for certification with the appropriate governing bodies and cellular carriers for the product and its markets. *A good antenna company will support you through the design and testing phase.* ■

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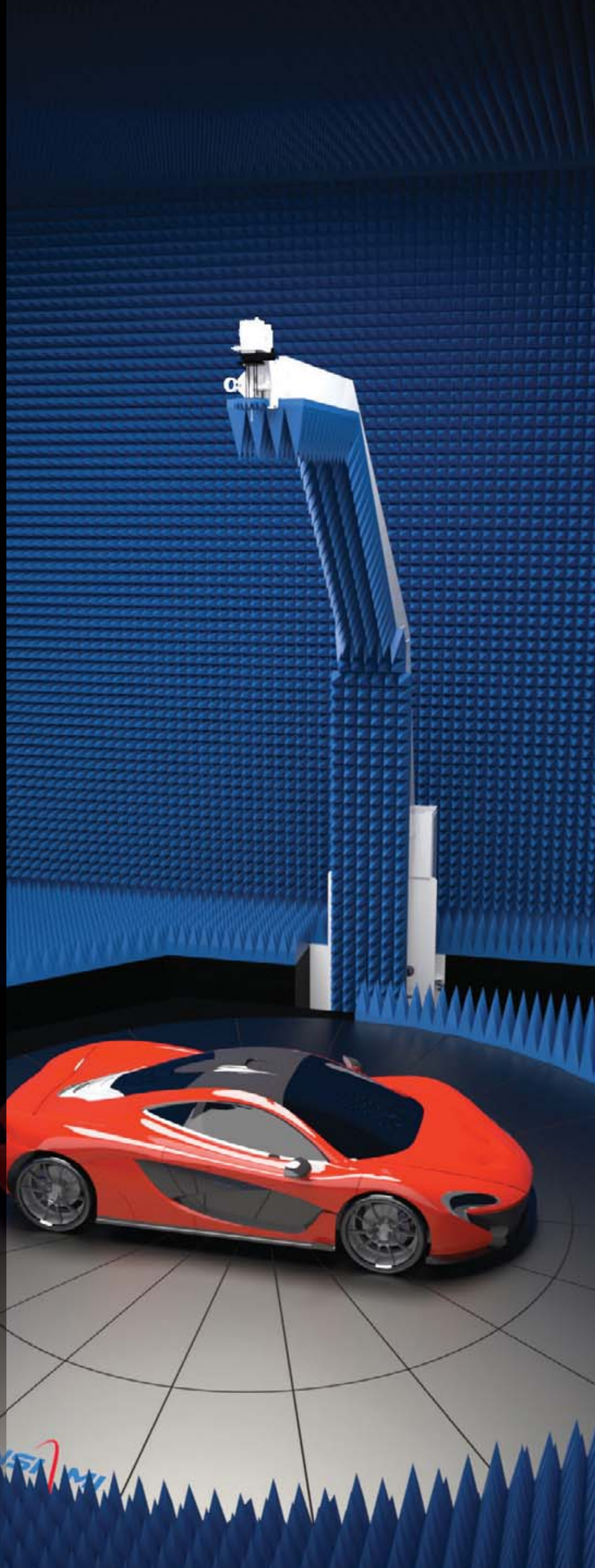

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JAMES MORRA | Senior Staff Editor

Electrical Engineers See COVID Pain **Turn into Salary, Bonus Gains**

Our 2021 Salary Survey revealed that around 60% of engineers expect to see their compensation go up this year, a huge improvement compared to 2020.

As the world collapsed under the strain of coronavirus last year, many companies delayed raises, canceled bonuses, and paused hiring for electrical engineers to reduce costs. Now they are starting to make up for all the belt-tightening.

Employers are raising salaries and boosting hiring for electrical engineers as the economy roars back from the worst of the pandemic, according to the results of the latest annual survey from *Electronic Design* and Endeavor Business Media's Design Engineering Group. As employers grapple with a skills shortage, many are boosting bonuses or other perks to entice engineers from other jobs or hold on to the ones they have.

Last year, engineers made it through the pandemic better than most. Unlike large swathes of the workforce, most engineers were able to work remotely. While they continued to struggle with balancing tight deadlines, continuous education, and other challenges, they prospered for the most part. For more than 58% of survey respondents, their wages have not been directly affected by the economic turmoil caused by the pandemic.

But electrical engineers were not completely unscathed. The economic uncertainty unleashed by the virus pressured wages for many engineers, reversing some of the gains they enjoyed over the last decade or so. Last year, many engineers polled by *Electronic Design* said that, while their employers were keeping raises, bonuses, and a wide range of other perks in place, the wages gains were significantly weaker than usual.

Now companies seem to be picking up from where they left off. Around 60% of respondents say they will see their compensation rise in 2021, a stark improvement from the 42% of engineers who saw raises in 2020.

Around 650 engineers responded to the survey, volunteering to share details about their salaries, bonuses, and other sources of compensation with *Electronic Design*, *Evaluation Engineering*, and *Microwaves & RF*. Engineers said they have gained a stronger hand as jobs are abundant, salaries are rising, and companies compete for talent. A negligible number of engineers say they are losing out on raises or bonuses in 2021.

But they remain upbeat about their prospects. Buoyed by demand for highly skilled engineers, around 70% feel the potential for salary advancement in engineering is at least as favorable now as it was pre-pandemic.

Several factors impact how engineers are compensated, including education, experience, title, seniority, age, location, and the status of the broader economy. But the survey results reveal that electrical and electronics engineers have very high-paying jobs. Engineers say that they will have a median base salary of $100,000 to $124,999 in 2021. Also, 58.5% report a median base salary in the range of $100,000 to $199,999.

Many employers plan to pay out bonuses, supplementing engineers' salaries with a median bonus of $1,000 to $1,999. Around 35% of respondents say they are in store for $5,000 or more in bonus pay this year.

At the top of the pay scale, engineers in management and executive roles not only have higher salaries, but they also earn thousands of dollars more in stocks and through employer-led share-matching programs. In contrast, rank-and-file engineers only get bonus pay and other perks on top of their base salaries. Only 30% say stocks are part of their compensation package, and around 12% are counting on $10,000-plus in stock awards in 2021.

Around 14.5% said that compensations rates will jump by more than 6% in 2021, about twice the percentage last year, and about 30% of respondents revealed they are seeing an increase of 1% to 3% in compensation. According to the data, about 16% of engineers say they will see compensation boosts of 4% to 6% in 2021, signaling that electronics companies are boosting pay for engineers as the economy continues to rebound.

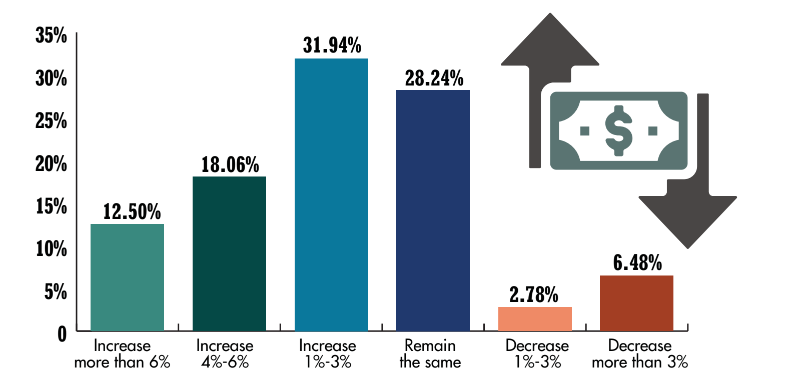
Only around 10% say they expect a pay reduction in 2021—a significant improvement from the 20% who last year said wages would contract due to delayed bonuses, pay cuts, or other cost-saving measures by their employers.

Around 30% say they are not getting raises or seeing pay cuts this year, whether because of economic pressures, business challenges, or other factors, such as older engineers reaching the top of their pay range. But at a time of rapidly rising inflation, those paychecks may not go as far as they once did.

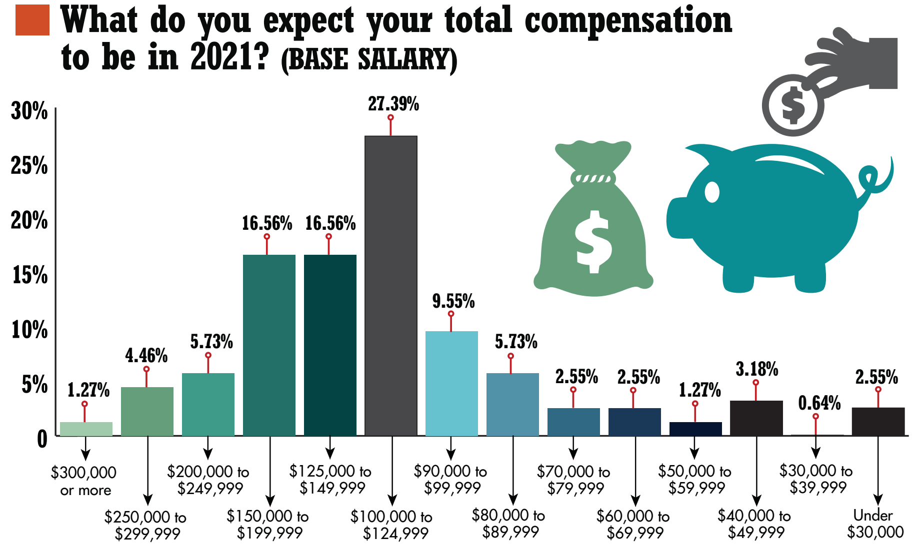
More than 60% of respondents say their employer sufficiently compensates them for their work, and 37% feel that their compensation is as competitive as other firms pay engineers with the same job.

Another 19% report they are probably better compensated than their peers at other employers, while 29% say their wages are "somewhat" less competitive than what others are willing to pay in 2021.

At the same time, given the grind of electrical and electronics engineering, others feel that these wage gains are falling short of what they should be. Many engineers grappling with long hours, tight deadlines, and the challenges of continuing education worry that their salaries are out of step with what they bring to their job. Among engineers who claim to be



How will your total 2021 compensation (salary, bonuses, etc.) compare to what you earned in 2020?



What do you expect your total compensation to be in 2021? (BASE SALARY)

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under-compensated, most feel entitled to a raise of 10% to 25%.

While many engineers feel as though they deserve to be making more money, around 90% say they would recommend engineering as a career with—all things considered—a promising future and competitive pay.

Only 30% of respondents have debated whether to leave engineering permanently or take a detour into another industry. Many workers report feeling burned out by the unrelenting demands of the job and want to pursue a career with a better work-life balance. Others are seeking new challenges to shake up their work situation. Among engineers that have considered leaving, approximately 31% hope to make more money.

As the economy recovers from last year's pandemic-induced slump, employees are quitting their jobs at a record clip this year. The flood of departures is exacerbating a skills shortage in a wide range of industries, forcing companies to pay more to stand out and lure new employees. The mass resignations mark a sharp turn from last year, when workers craved stability as the virus spread, leaving economic turmoil in its wake.

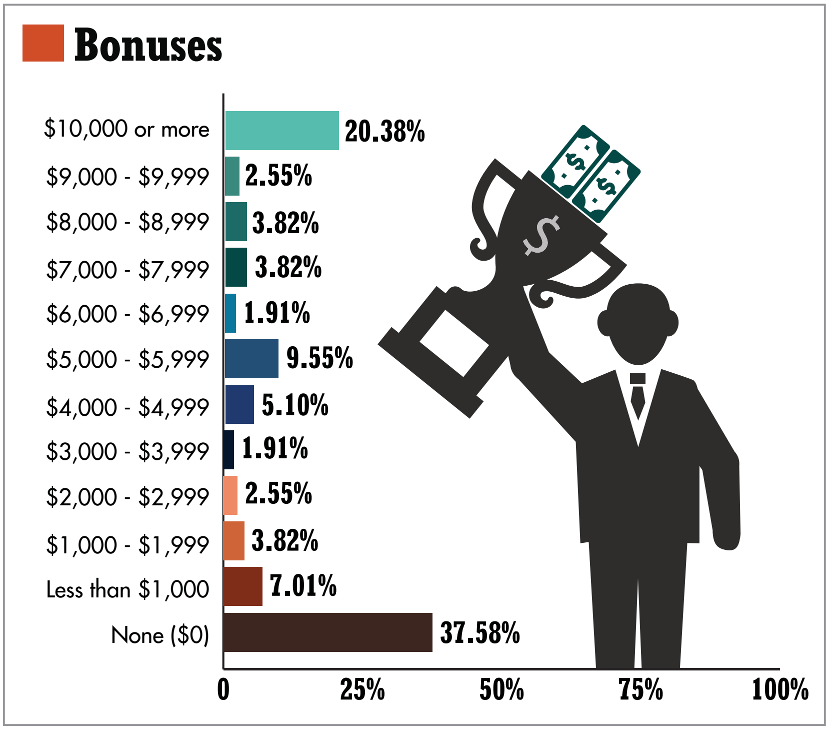
But it is unclear whether the shortages are specifically responsible for making companies in the electronics industry more willing to raise salaries or preventing them from freezing wage growth or delaying bonuses.

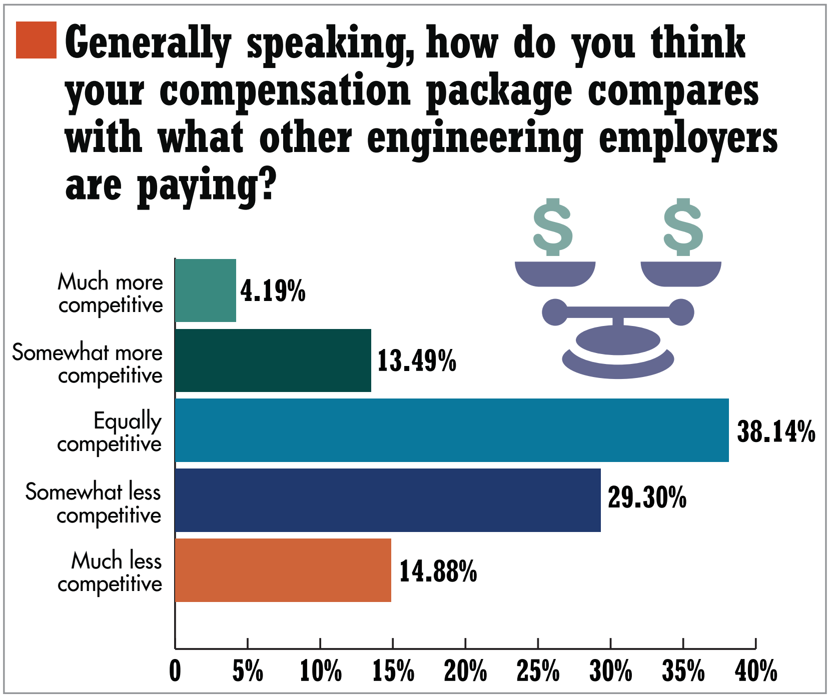
The struggle to find engineering talent predates the pandemic, and it could have to do with the types of jobs engineers are comfortable taking than it does with a worker shortage. Even so, high-end engineering skills continue to be coveted: around 54% of respondents to last year's salary survey said their companies were having hiring troubles. Now? 67% say they are struggling to locate qualified candidates for open positions.

While some industries are churning workers more than others, the number of workers quitting may help explain why so many employers are struggling to plug holes in their engineering departments.

More than 70% of respondents feel that there is a shortage of skilled engineers. Nevertheless, companies plan to keep hiring new workers, with 42% saying that they work for companies looking to hire more engineers in 2021.

Engineers are also keeping the door open to changing jobs. Many say that moving to a management role or changing jobs are the only ways to guarantee salary growth in engineering. Around 11% are seeking out a new job, while 31% say





that, while they are not actively looking to switch, they would follow up if personally contacted with a job. Another 29% say they would follow up if they heard about a promising opportunity.

Around 29% of engineers are staying put and have no plans to start a new job in the foreseeable future.

The survey signals that while some engineers are walking out the door and others are eyeing open positions, most are staying where they are, possibly in part due to the ongoing uncertainty around the virus and the stability of their current jobs. Only 7% of engineers changed jobs within the last year, and among them, 13% were promoted to a new position with their current employer, while 23% left to pursue another opportunity.

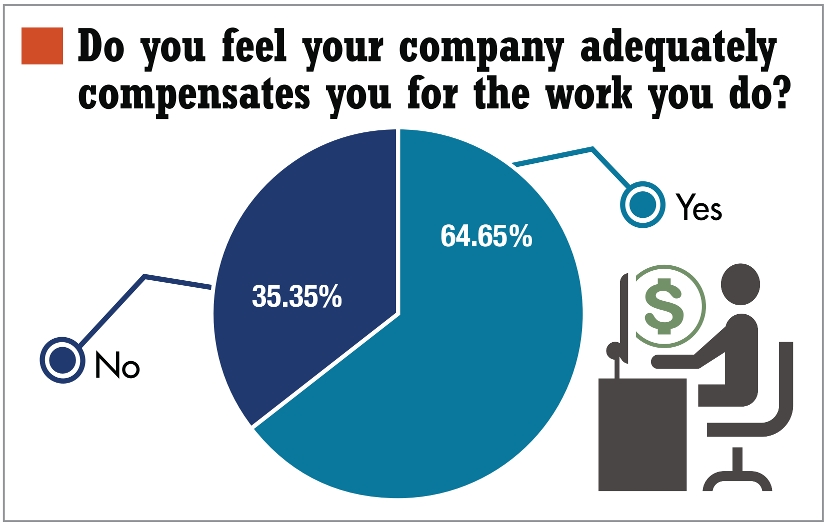
Around 15% of engineers who changed jobs say they landed at a new employer after losing a previous job.

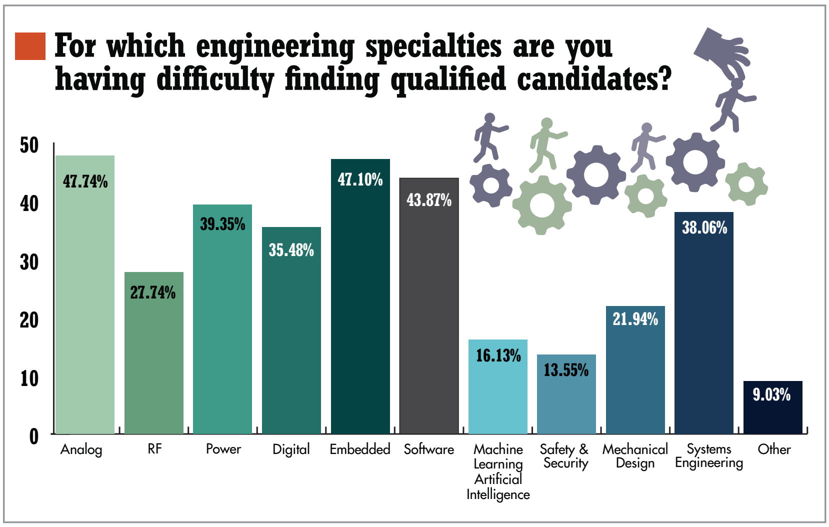
Given the challenges of scouting and hiring engineering talent, many companies are trying to hold on to the ones they already have. More than 60% of respondents say their employers are at least as focused on employee retention this year compared to last year. In the short term, the talent shortages could give engineers more bargaining power to negotiate a raise or promotion, allowing them to avoid changing jobs.

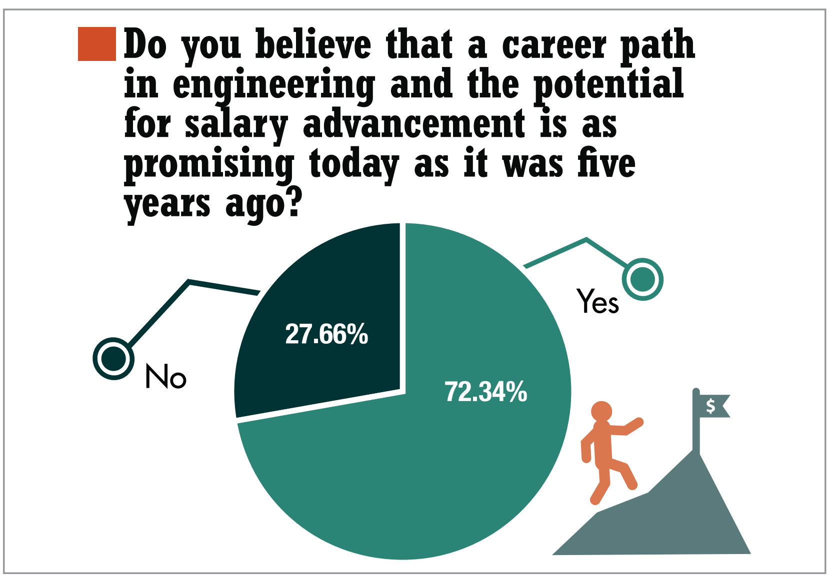
Employers are increasing non-wage compensation and other perks to remain on their engineers' good side. A number are paying for continuing education, as mounting competition for skilled engineers underscores the need to nurture new skills internally. While companies suspended travel because of lockdowns last year, engineers say some are reopening their wallets to pay for travel to industry conferences or training courses.

Covering the cost of healthcare continues to be one of the top priorities for employers, respondents said.

Engineers have long struggled with feeling that employers look at them as interchangeable assets. But the current engineer shortage could help bring about change long-term—and possibly better pay in the process. ■







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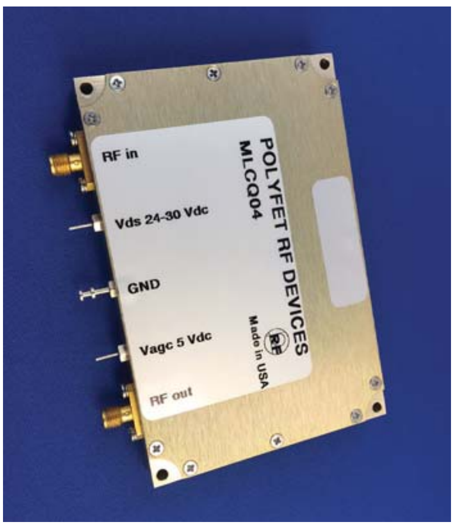

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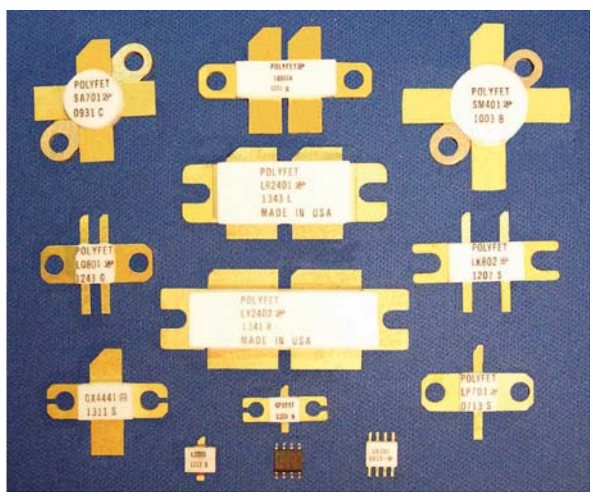

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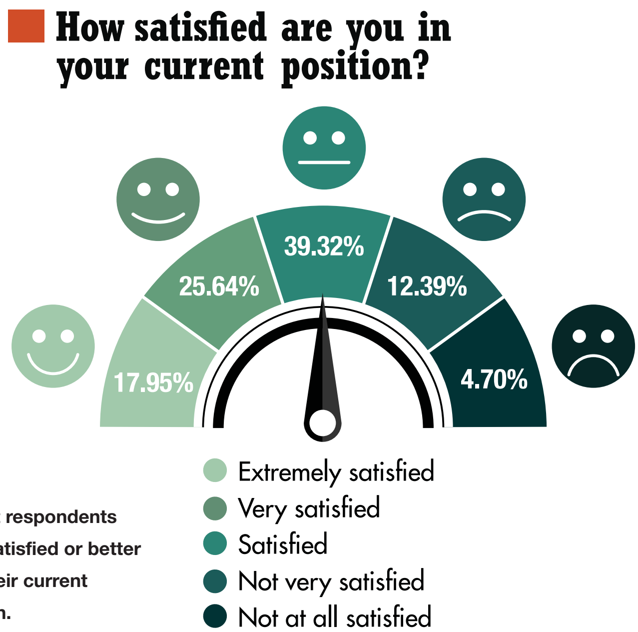
WILLIAM G. WONG | Senior Content Director

Engineering is Still a **Great Job**



1. Most respondents were satisfied or better with their current position.

I was excited about engineering before I was in high school. I discovered programming then and you can tell I've been around for a while—my first exposure to software was programming in BASIC on a Teletype ASR 33 with punch paper tape. The Georgia Institute of Technology was the starting point of being a real engineer with co-op sessions at Burroughs Corp. working with mini and mainframe design.

I've had a lot of jobs since then and backed into the editorial side of things because I had a knack for technical writing. I still dabble with hardware and software, but I've never lost the awe and excitement of engineering.

One thing that's always cropped up along the way was whether engineering was a worthwhile profession. I've always recommended it to those who were interested; I have three children who are all engineers, although none went into electric engineering or software like dear old dad or into mom's engineering field either.

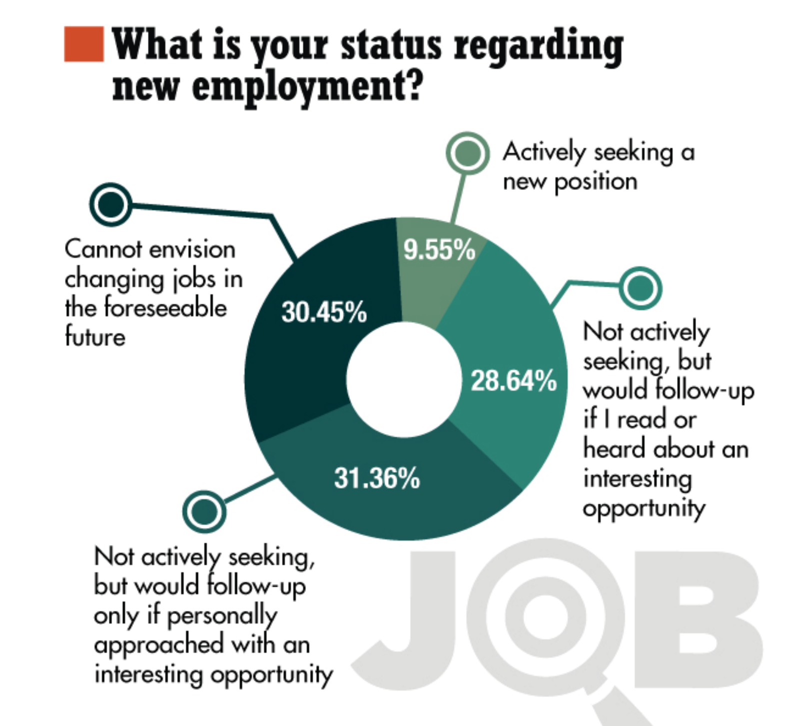
I'm happy to say that most engineers and programmers want to stay in their jobs and would recommend them to others based on the results of our recent salary survey. The majority of engineers and programmers were satisfied with their current position, which is a good indication they chose the right profession *(Fig. 1)*. Likewise, the survey results show that more than 90% recommend engineering as a career choice to others. Still, getting into a good engineering school will be a challenge with an acceptance rate on the order of 8%.

Job satisfaction seems to match well with retention or it may be the sign of the times. Not a lot of engineers or developers are actively searching for a new position *(Fig. 2)*. Still, a substantial portion are keeping their eyes open for opportunities that may arise.

The challenge for companies that want to retain their staff include keeping them happy. Likewise, trying to attract new employees has become more interesting since location sometimes isn't a factor, given the ability to work remotely. Even developers who need to work with hardware may not be limited by remote access.

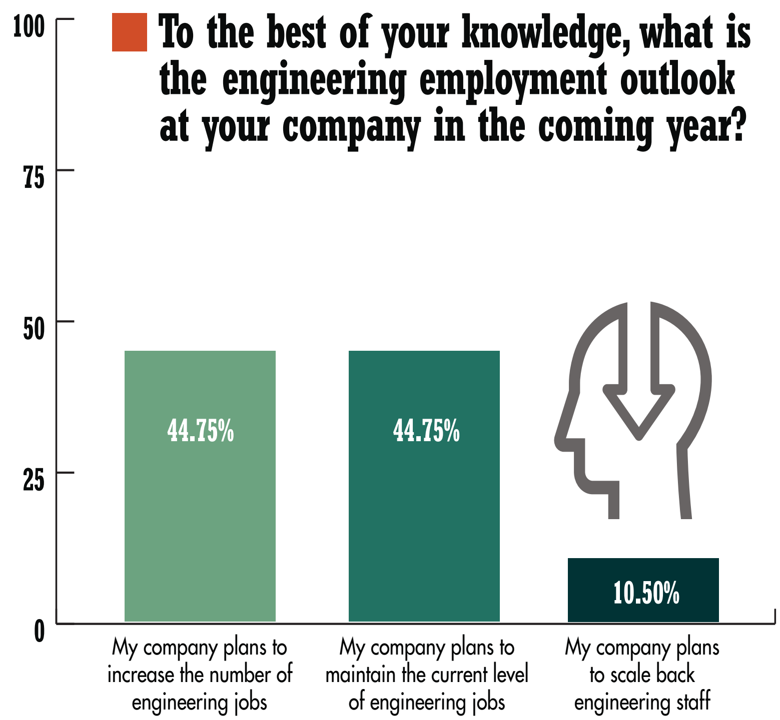
For example, Green Hills Software's Embedded Board Farm allows developers to test software on actual hardware without having it on a nearby lab bench *(Fig. 3)*. The boards are connected to power supplies, scopes, and logic analyzers that can be remotely controlled. Remote collaboration also is part of the mix these days, with access to shared debugging tools and video conferencing allowing people to work together from almost anywhere.

The outlook for engineers who want to stay put or move into new positions looks good, with most companies maintaining or increasing the number of engineers or developers on their staff *(Fig. 4)*. The fact that over 40% are looking for new



2. Most engineers are not actively searching for a new job, but if the opportunity arises, one never knows.

3. Green Hills Software's Embedded Board Farm allows remote developers to test real hardware.

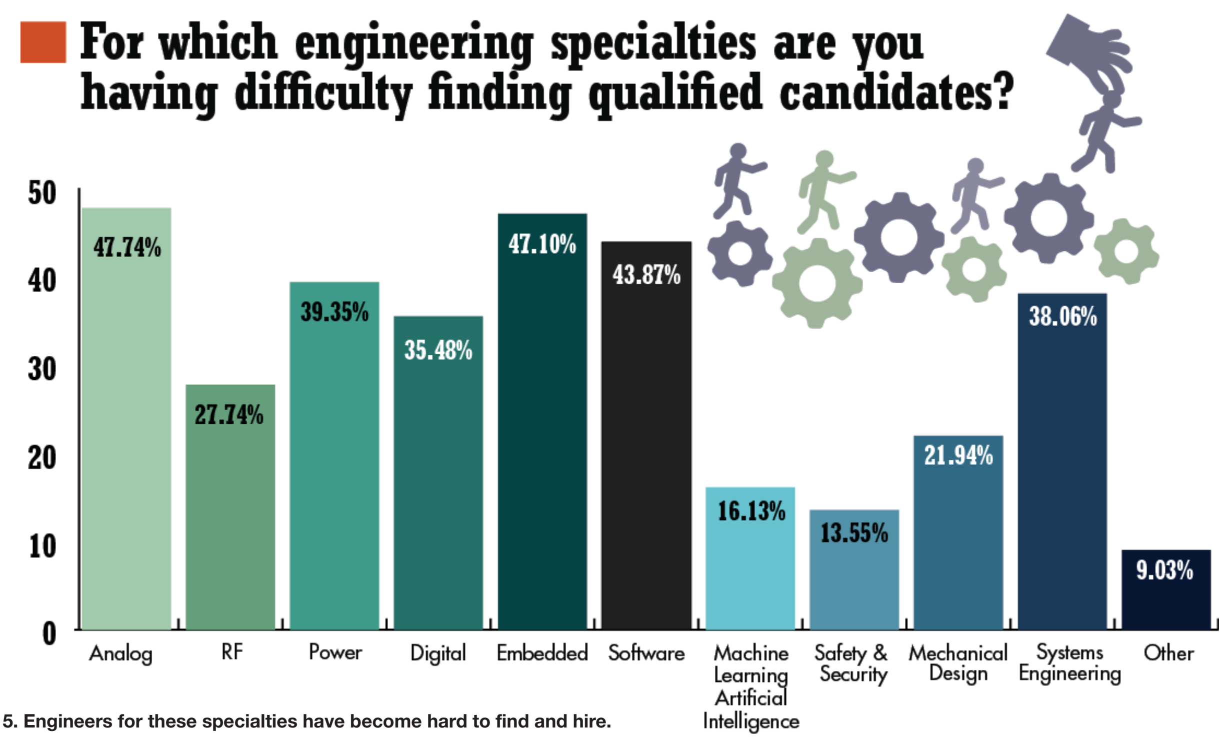


4. The outlook for engineers remains strong.

employees should make those hunting for a new position happy.

On the flip side, matching up the engineers and developers to fill needed positions can be a challenge of human resources as well as engineering managers. Our results based on feedback from both our electrical/electronic and machine design respondents *(Fig. 5)* was pretty similar. Systems engineers are in demand everywhere, with mechanical engineers high on the list as well. Electrical/electronic engineering responses put a higher priority on areas like analog and RF.

The only surprise I noted was that machine learning/artificial intelligence (ML/AI) was on the low side. I suspect that's being driven by two factors. First, ML/AI is being used in specialized areas such as automotive applications and that industrial applications are just starting to ramp up investigation or deployment. It also may mean that the solutions accessible to developers are being packaged in a way that allows their use without requiring lots of expertise. Of course, telling an



5. Engineers for these specialties have become hard to find and hire.

Product quality and availability rank high on the list. The survey was done before much of the major supply-chain issues arose, so these percentages may be increasing. We shall see how things fare in 2022. They weren't really an issue in 2020.

engineer that they can't handle a job is like waving a red flag in front of a bull.

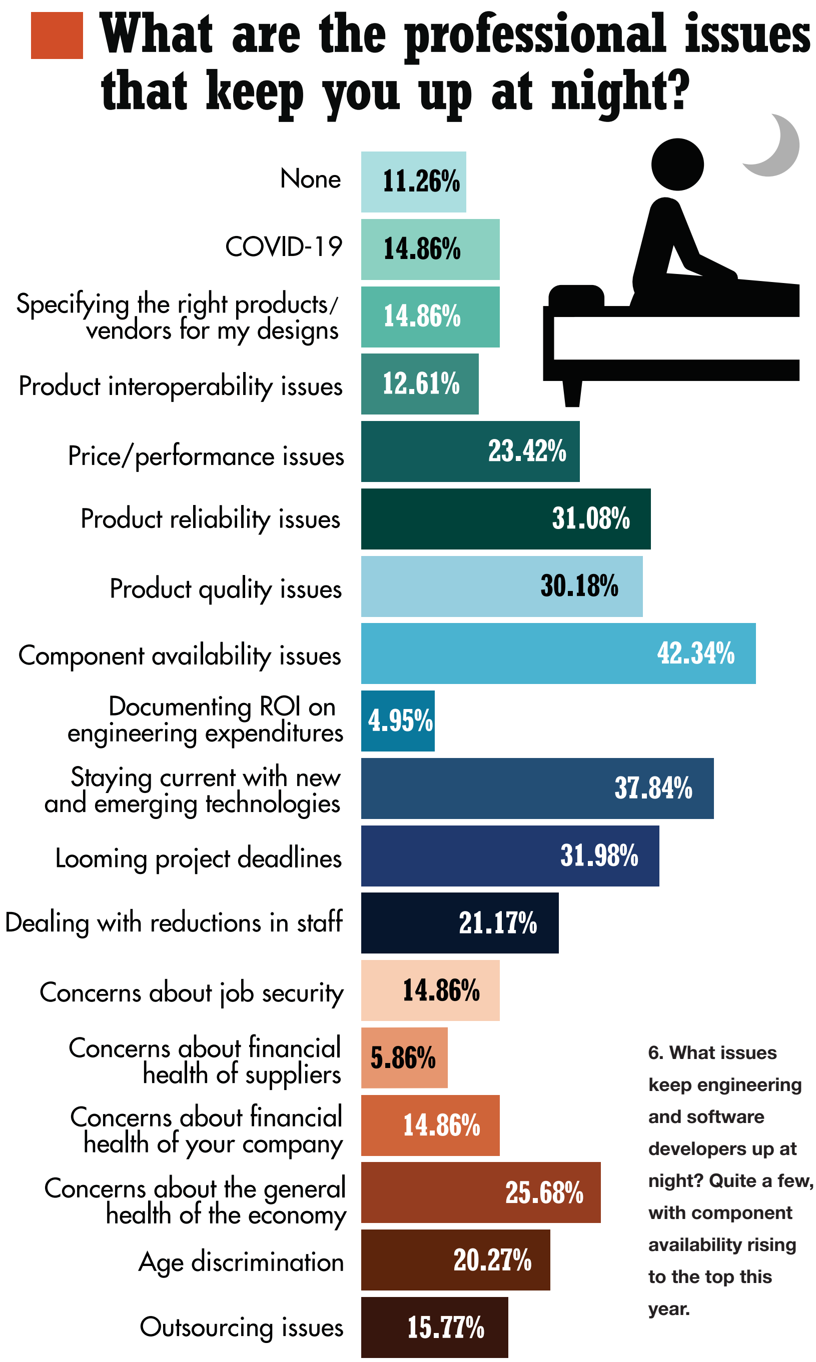
Besides, learning on the job is par for the course for engineers and programmers. But I leave that part of the story to other editors who are writing about our survey results.

It does lead me to the chart highlighting concerns that keep engineers up at night *(Fig. 6)*. I had to contend with quite a few of those at the top end when managing a group of engineers and programmers, including deadlines and staying current with new and emerging technologies. ML/AI would fall in that category for many.

Product quality and availability rank high on the list. The survey was done before much of the major supply-chain issues arose, so these percentages may be increasing. We shall see how things fare in 2022. They weren't really an issue in 2020.

COVID-19 is in the list and one that will likely be with us for at least the near future. It has changed the landscape significantly for trade shows and working conditions, with remote attendance being the norm at this point whenever possible. Vaccinations are making it easier to work and meet in person, but the interest in continuing remote operations is high. As noted, it also can be a selling point for a job these days, with companies being more amendable to it versus just a couple years ago.

I help manage the local, annual Mercer Science and Engineering Fair and I like to let the students know that their interests can lead to fulfilling jobs in industry. Our survey results reinforce this view. I hope everyone's interest in science and engineering will be passed onto new and budding programmers, engineers, and developers so that they can enjoy the benefits and meet the challenges you encounter on a regular basis. ■



6. What issues keep engineering and software developers up at night? Quite a few, with component availability rising to the top this year.

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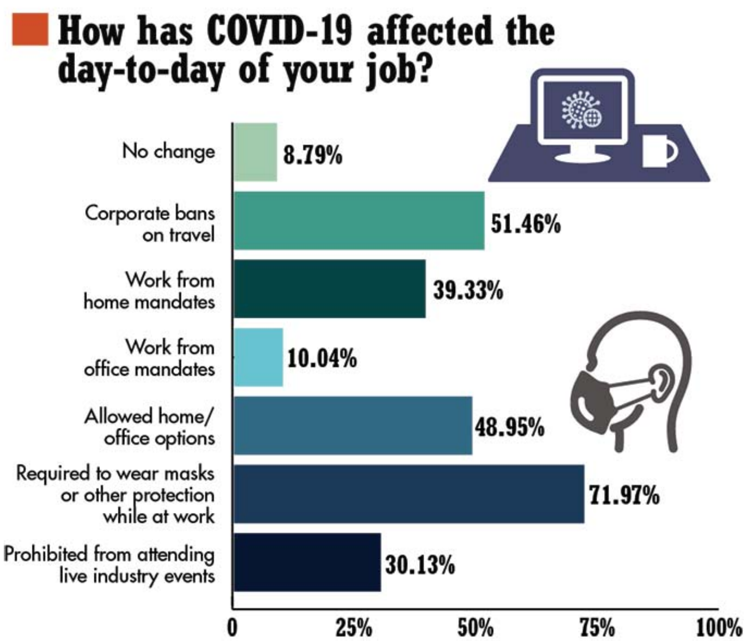
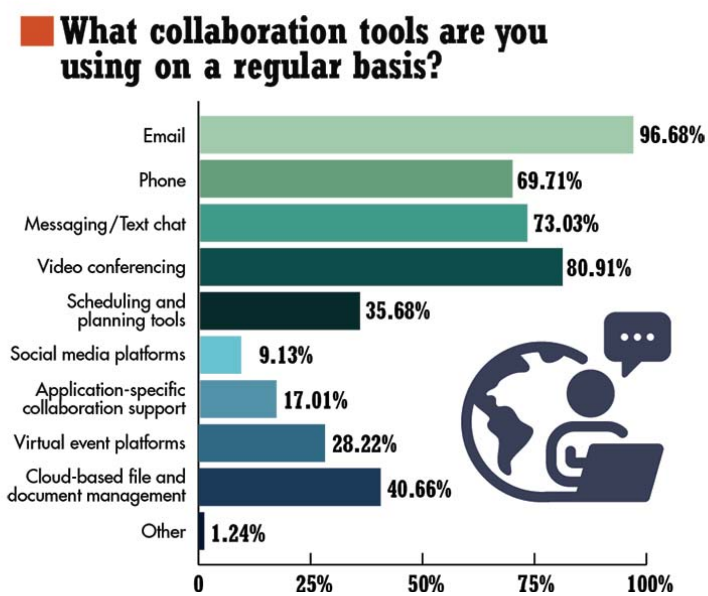
ALIX PAULTRE | Editor-at-Large

How Working Remotely is Spawning a Design Revolution



1. Team separation was among the biggest COVID-19 impacts on day-to-day work.



2. People desire the highest level of interactivity possible in interpersonal communications.

The forced isolation from COVID brought a perfect storm of need to foment a greater acceptance of advanced design and development tools.

The saying "every cloud has a silver lining" is very apt for the situation we've found ourselves in during this age of COVID-19. The forced isolation and need to separate has caused a great deal of hardship on every level and in every venue of society. However, the need to interact at both a social and business level forced us to investigate solutions such as telepresence and other collaborative tools to operate.

Holding meetings with people and sharing data with others online wasn't a new concept a couple of years ago—that movement was already on its way to more widespread adoption. Companies were using these tools to do business before COVID-19, but they were mostly multinationals with far-flung principals and high-end freelancers who needed to be everywhere.

The pandemic created a "perfect storm" of need that significantly increased adoption of remote tools, causing additional development in a fledgling industry. The latest collaborative tools are not only useful for telepresence, they're also fomenting a design revolution based on real-time design and manufacturing.

Impacting Work

In our 2021 Salary Survey, we asked our engineering audience about how COVID-19 affected their day-to-day job *(Fig. 1)*. The most prevalent business actions quoted included corporate bans on travel (51.46%), prohibitions on attending live industry events (30.13%), being allowed to work from a home office (48.95%), and even work-from-home mandates (39.33%). This pretty much forced everyone with the ability to create a home office to make one.

The tools required to perform work vary from company to company and industry to industry, but the common-need denominators include the ability to communicate with team members, schedule and manage event timelines, and share data and documents. These needs are often dealt with using separate software-based solutions, but a growing number of all-in-one collaboration suites are emerging.

This multifaceted need is driving even more functionality into currently available solutions. The collaborative-tool marketplace is a relatively new one, and like many software-based industries, far from mature. Many people now routinely perform a significant number of tasks using collaborative tools—a number that will grow in both number and depth as the tools continue to mature.

When we asked our engineering audience about the collaboration tools they currently use *(Fig. 2)*, email led the list at 96.68%, beating out the telephone (69.71%) and texting (73.03%). Video conferencing has become a primary tool for both social interaction and business, coming in at number two with 80.91% of our respondents using it. This underscores the desire for the highest level of interactivity possible in interpersonal communications.

The next island of responses involved tools used to conduct business. The need to schedule and plan, to share files and documents, and to meet other people in a common industry is important for a business to operate. Tools for cloud-based file and document management (40.66%) narrowly edged scheduling and planning tools (35.68%), followed closely by virtual-event platforms (28,22%). This shows that many functions traditionally done face-to-face are being done virtually, successfully.

Cascading Benefits

Once people begin using a new tool, they also find new places and ways to use it as a solution for the needs around them. Most tools, regardless of type, offer peripheral benefits. Some of these are very apparent to the user and often are the primary purpose the solution was obtained. However, sometimes it takes a while for a tool's full benefits to be appreciated.

For example, a design and development company may start using a collaborative planning tool to integrate the actions of a separated team, finding significant additional benefit in peripheral functionality. This could be something like the ability to create a bill of materials automatically, without the need of an additional engineer to monitor the process. That either reduces headcount or frees up a needed engineer for another aspect of product development.

This aspect directly addresses the shortage of engineers available to work on any given project, as one engineer can fill many boots with cloud-based development tools. In the survey, the most desired were RF (44.81%) and analog (41.54%) engineers. Sharing engineering resources isn't just a software solution, because many of the latest benchtop hardware tools such as oscilloscopes can now be operated remotely. This enables an engineer to troubleshoot hardware from the other side of the globe, if there's someone at the place of need who can place the probes for them.

Another significant benefit that comes from migrating your development process online is the ability to perform real-time design-while-build. Your team can utilize the same collaborative development tools they used to create a product, redesigning it on-the-fly to address manufacturing issues, functionality upgrades, or custom orders. The ability to react immediately to initiatives in a proactive manner can be a major force multiplier in a highly competitive marketplace.

Designing the Future

Not surprisingly, this growth in the market for collaborative tools of all kinds—societal and commercial—and the infrastructures needed for them is reflected in the design projects of our audience. When we asked them what best describes your current design project, 14.81% replied with communications systems and equipment, such as local-area/wide-area networking products, wireless, cellular, RF and microwave, Bluetooth, etc.

Another big area of interest was in industrial control systems and equipment (including robotics) at 9.88%, reflecting the impact of smart systems on manufacturing (Industry 4.0). This area of industry will eventually meld with the aforementioned collaborative development tools, further enabling real-time manufacturing oversight and management, and on-the-fly redesign and custom work.

This also is reflected in the answers to our question about the technologies having a major impact on their designs. Almost half of the responses (40.83%) said it was test equipment, which makes sense in light of the need to test, validate, and optimize these advanced interlaced technologies. Wireless networking came in second at 35.93%, followed by sensor integration at 32.12%, with power management a very important concern at 30.67%. It reflects the growth in the cloud-enabled IoT, the devices, and the infrastructure.

Looking Forward

The impact of COVID-19 may have accelerated the adoption of collaborative design tools, but the functionality they provide, and the cascading benefits offered, would have made the transition to their use inevitable. The latest generation of hardware and software solutions for engineering design and development is only beginning to mature, and the best in many ways is yet to come as these tools more deeply integrate into the engineering community. ■

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Extend Building Automation and Control **with LoRaWAN**

Historically, building management systems were hardwired, making it challenging to update or modify these systems. The advent of LPWANs has changed the equation to simplify and extend existing systems to address emerging smart-building requirements.

Buildings and even entire campuses worldwide are being renovated and repurposed like never before to create healthier, more efficient, and sustainable environments. As systems evolve, they also place greater demands on building management systems (BMS), which handle everything from light, temperature, air, and water to security and servicing.

The global standard communications protocol for building automation and control (BAC) is BACnet. As with many legacy systems, BACnet is hardwired. Consequently, it's expensive to install, hard to expand with respect to coverage, and even harder to add functionality that aligns with emerging building requirements that monitor the cleanliness of air, personal safety, room usage, and social distancing. However, the broad availability of low-power wide-area networks (LPWANs) offers an easy way to augment BMS functionality by combining BACnet and LoRaWAN technologies.

Managed by the LoRa Alliance, the LoRaWAN standard is the leading LPWAN protocol designed to wirelessly connect battery-operated "things" to the internet in private, regional, national, or global public networks. It addresses key Internet of Things (IoT) requirements such as bidirectional communication, end-to-end security, mobility, and localization services.

LoRa Alliance members include technology leaders such as Amazon Web Services, Cisco, Microsoft, Orange, and Semtech, among many more as part of the largest

IoT ecosystem. In the smart-building space, companies like Acklio, Setemi, Talkpool, Voytech, and Wattsense are at the leading edge of deploying LoRaWAN with BACnet. What follows reveals how they do it.

Understanding LoRaWAN

LoRaWAN networks connect devices such as sensors, actuators, and tags that communicate bidirectionally. The LoRaWAN network architecture *(Fig. 1)* is deployed in a star-of-stars topology whereby gateways relay messages between end-devices and a central network server. Gateways are connected to the network server via standard IP connections and act as a transparent bridge, converting RF packets to IP packets and vice versa.

The wireless communication takes advantage of long-range characteristics of the LoRa physical layer, allowing a single-hop link between the end-device and one or many gateways. All modes are capable of bidirectional communication. Furthermore, there's support for multicast addressing groups to make efficient use of spectrum during tasks such as firmware updates over-the-air (FUOTA) or other mass-distribution messages.

A single LoRaWAN gateway can cover tens of thousands of square feet, eliminating the need for deployment of multiple access points or mesh points common in other wireless networking options. Power consumption is exceptionally low, allowing battery-powered devices to operate for up to 10 years without service.

LoRaWAN devices also have excellent range and transmission properties. This enables them to be deployed wirelessly throughout buildings of all kinds, to gather and distribute data. Devices don't link to fixed infrastructure, so they're easy to install and relocate. Communication through dense walls, elevator shafts, or basements is outstanding. Thus, considerably fewer LoRaWAN gateways are used than with other wireless options, which also makes deployments highly cost-effective.

Devices using the LoRaWAN standard are certified through the LoRa Alliance's LoRaWAN Certification program to ensure that they deliver the expected performance and are fully interoperable with any other LoRaWAN infrastructure. Hundreds of millions of devices are now deployed in LoRaWAN networks across the globe.

LoRaWAN Extends BACnet Capabilities

LoRaWAN is well-known for consuming little power and covering vast areas—like entire cities or big farms or even wildlife parks. However, due to its ability to transmit through thick walls, and penetrate concrete and metal, it's ideally suited for BMS use cases.

In helping to digitize building operations, LoRaWAN isn't a replacement for BACnet, nor an alternative to it. Rather, LoRaWAN extends BACnet capabilities. When used with LoRaWAN, BACnet still specifies the functionality that's enabled in a digitized BMS, e.g., acceptable inputs and outputs; networking; data generation and storage; and protocols to manage HVAC, elevators, lifts, fire safety and lighting systems, and more *(Fig. 2)*.

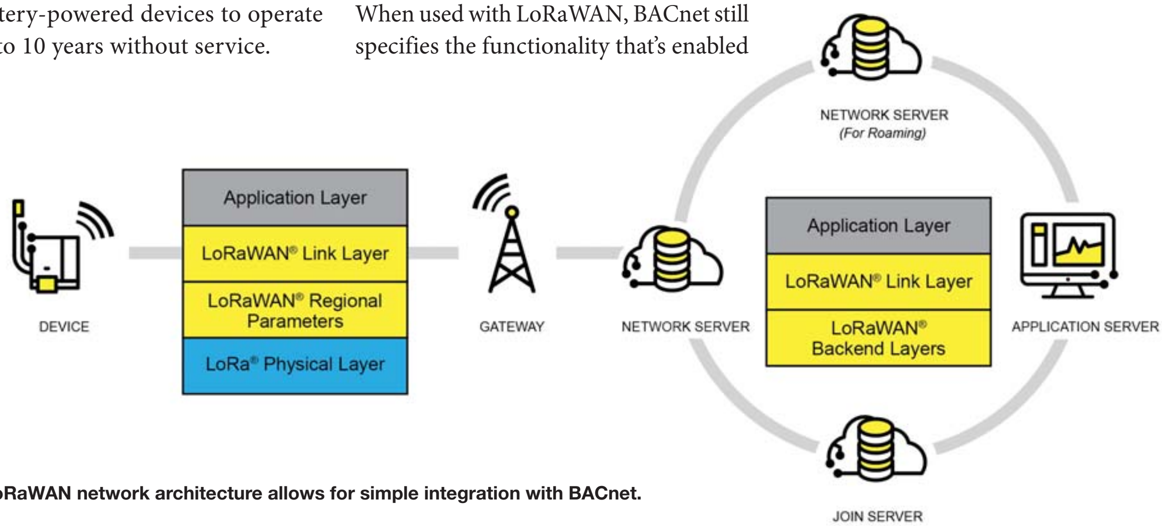
Three approaches have been identified to combine LoRaWAN's flexibility with BACnet's infrastructure. Selecting an approach depends on multiple considerations, like the specific capabilities to be added, the need for scalability, and the importance of security, among others.

"BACnet over LoRaWAN"—or backhaul—is the first approach. LoRaWAN serves as the data channel to the control applications. It's very easy to implement as no changes to the BACnet protocol, network, or BACnet-enabled devices and management systems are needed.

The second approach is to deploy LoRaWAN as a complementary network, focusing on integration with the BMS. The readout from IoT devices is presented to the BMS via an application programming interface, so the LoRaWAN data and sensors appear to be part of the BACnet system.

Finally, instead of integrating LoRaWAN and BACnet at the buildings and control level, the third approach uses data streams from both technologies that are combined in the analytics engine.

The following is a deeper look at each of these approaches.



1. The LoRaWAN network architecture allows for simple integration with BACnet.

BACnet over LoRaWAN

Two methods are employed to deploy the backhaul option. Both use standard BACnet sensors and actuators equipped with a compatible modem, which enables long-range wireless connectivity.

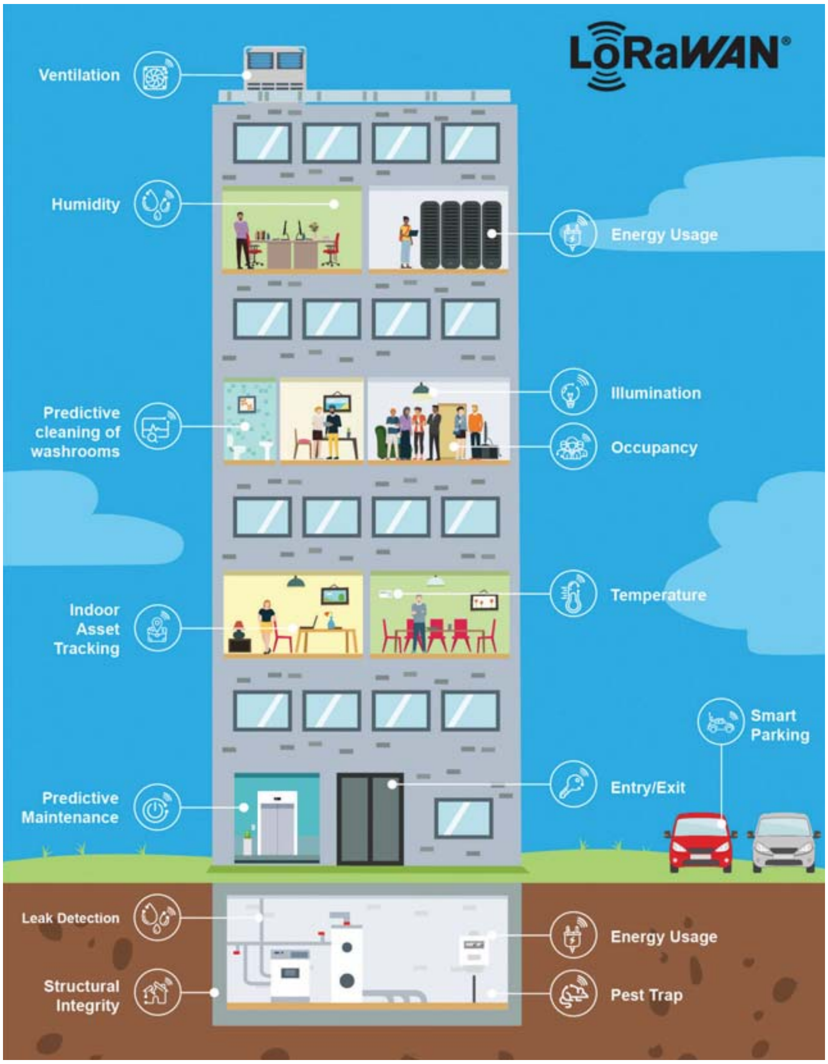
The first method involves enabling existing BACnet devices to communicate via LoRaWAN using BACnet over IP. Static context header compression (SCHC) firmware can be added directly to the BACnet device or supplied via an external bridging device. Note that the Internet Engineering Task Force has just published a new set of standards that codifies how SCHC adapts existing IP-based protocols to LPWAN networks, guaranteeing interoperability of multiple technologies, including LoRaWAN.

The second method involves adding LoRaWAN bridging via SCHC to a BACnet/IP router instead of at the device level. The router will manage sensor data and communicate with the BMS over LoRaWAN. All network elements appear as native BACnet devices but can be deployed at a much lower infrastructure cost than BACnet.

Complementary Networks and BMS Integration

In a complementary network, a LoRaWAN network is independent of the core BACnet infrastructure. The LoRaWAN network then feeds data to the BMS through a virtual BACnet server that makes any LoRaWAN device appear to be a BACnet device.

Due to the ease of deployment of LoRaWAN devices and the fact that they don't need to be connected to a building's electrical system, new sensors can be added in locations not readily available to BACnet systems. This eliminates the need for expensive retrofits, as the BMS perceives data from the LoRaWAN devices as BACnet.



2. LoRaWAN supports a wide variety of smart-building applications, making it ideal to extend BACnet.

Cloud Integration

A third approach is to install a LoRaWAN network fully independent of the BMS and BACnet systems. Integration is provided at the analytics layer, leveraging data from all sources.

Conclusion

Although facilities management teams have been exploring smart-building applications for many years now, the advent of COVID-19 and desire to safely bring employees and customers back to the office is driving rapid adoption of IoT technologies. Leveraging LoRaWAN and BACnet allows facilities to extend, reconfigure, and enhance complex built environments at lower cost, but with greater capabilities. Using new technologies to extend legacy BMS systems will accelerate a transition to healthy, sustainable buildings in a way not previously seen.

Learn More

For developers wanting to learn more about the LoRaWAN standard, ecosystem, and resources, an excellent place to start is the LoRa Alliance website. Its section on "Buildings" provides use cases, white papers, and webinars specific to building automation and control. You also can get the standards documents on the site's Developer pages. ■

ACKNOWLEDGEMENT

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Identifying Vulnerabilities in **Cellular Networks**

This article takes an in-depth look at a systematic framework for the analysis of cellular-network protocols, involving a 4G LTE example, to enhance security.

Cellular networks are a critical infrastructure supporting applications in all domains we may think of, ranging from e-commerce, transportation/mobility, and education to eHealth/personal well-being and manufacturing. Cellular networks will be a key infrastructure for Internet of Things devices, and, indeed, the vision is that next-generation cellular networks will be more about devices than people. In other words, the goal of next-gen cellular networks is to be "sensing networks."

However, even without looking into what next-gen cellular networks will be, it's clear that technologies for cellular networks have made major advances in the past few years. Fourth-Generation Long-Term Evolution (4G LTE) technology has increased the bandwidth available for smartphones, in essence delivering broadband capacity.

The most recent 5G technology further enhances transmission capacity and reduces latency, energy consumption, and error rates through the use of several technologies, including millimeter waves; small cells; massive multiple-input, multiple-output antennas; beamforming; full duplex transmission; and software-defined networks (SDNs). It enhances the flexibility of cellular networks by separating network control and forwarding planes and making the control plane directly programmable.[1]

Because cellular networks are pervasive and used in sensitive applications, their security is a critical requirement. For example, a denial-of-service attack against a cellular network may paralyze communities and service infrastructures, with disastrous consequences.

Securing cellular networks is a challenging task because of their complexity. Cellular networks consist of multiple layers—e.g., physical layer, radio-resource-control (RRC) layer, non-access stratum (NAS) layer, etc. Each layer, in turn, has its own protocols to implement its procedures, such as the protocols for attaching/detaching devices to/from the network and for paging devices notifying of incoming voice calls and Short Message Service (SMS) text messages. Additional requirements, such as backward compatibility and interoperation across different wireless communication technologies, add to the complexity.[1]

Comprehensive approaches to protecting cellular networks require deploying a wide variety of security techniques, ranging from basic techniques such as encryption and digital signatures, to software patching, anomaly detection, network segmentation, device hardening, etc. *(see Reference 2 for an example of security measures for network infrastructure devices).* However, a critical prerequisite to securing cellular networks is that the protocols designed, implemented, and deployed in them must be free of vulnerabilities. Due to the complexity of those protocols, systematic methodologies for their analysis are required.

Methodologies for Verifying Cellular Network Protocols

Perhaps the first systematic methodology for analyzing cellular network protocols is the LTEInspector methodology,[2] developed for the analysis of the NAS layer of the 4G LTE protocol stack. This layer manages the establishment of communication sessions and maintains continuous communications with the user equipment (UE), i.e., the cellular phone, as it moves.

The NAS layer provides a set of protocols governing the interactions between the UE and the core nodes, such as the mobile switching center, serving GPRS support node, or mobility management entity (MME). We refer to the set of core nodes as "core network" (CN). Each such protocol consists of multiple steps. For example, the protocol for UE attach includes the following high-level steps:

1. The UE sends an attach request to the CN, providing its security capabilities.
2. A mutual authentication is executed between the UE and the CN.
3. If authentication is successful, the UE and the CN negotiate the algorithms to use for encryption and digital authentication.

4. Once the negotiation is completed, the CN sends the UE an accept attach message.
5. The UE confirms the attach.

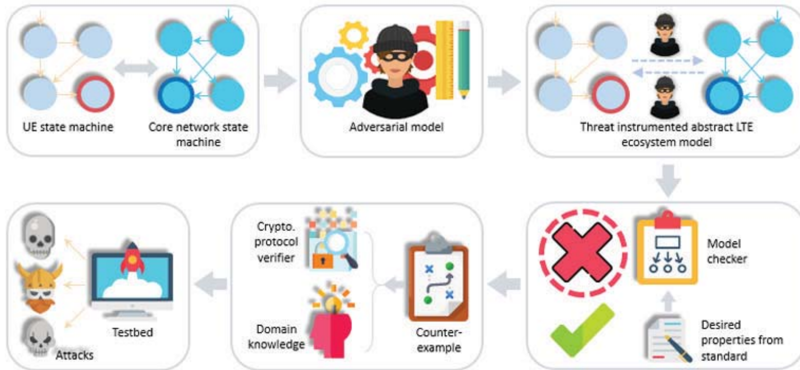
Attacks and other failures may happen during any such step. The goal of the LTEInspector methodology is to analyze multi-step protocols to identify vulnerabilities in these steps.

The input to the LTEInspector methodology is a representation of each protocol in terms of two finite state machines (FSMs), one for each party involved in the protocol—that is, the UE and the CN *(Fig. 1)*. An FSM is an abstract machine that can be in exactly one among a finite number of states at any given time. The FSM can change from one state to another in response to some input; these changes are referred to as "transitions." Preconditions also can be associated to transitions; in such cases, for the input to trigger a transition, the preconditions must be true. Also, as part of a transition, actions can be executed.

FSMs are, thus, a representation well-suited for the analysis of multistep protocols. An example FSM modeling the attach protocol at the UE side is shown in *Figure 2*. In the example, we use the MME as the party, from the CN, involved in this protocol.

From the diagram, we can see that the UE is initially in a disconnected state and then, upon the phone restart (indicated by the condition *mobile_restart*), the UE sends an attach request to the MME and transitions to the state in which it waits for the authentication request (that is, the state *UE waits for auth_request*). Once the UE is in this state, different transitions can happen. For example, the UE is restarted (Transition #3) or the authentication fails (Transition #4), or the authentication of the UE by the MME is successful and, as a result, the UE moves to the state in which it authenticates the MME (Transition #5).

Thus, the goal of the LTE methodology is to determine scenarios (i.e., sequences of transitions) in which the UE, because of attacks, is unable to reach the final intended state (i.e., the state in which the UE has been authenticated by the MME and the MME has been authenticated by the UE).



1. As depicted in this architecture, the input to the LTEInspector methodology is a representation of each protocol in terms of two finite state machines, the user equipment, and the core network. (Image from Reference 3)

To identify such attacks, one must consider the capabilities of the attacker, referred to as "adversarial model," that are relevant to the protocols to be analyzed. Because the focus of LTEInspector is on vulnerabilities in communication protocols (and not, for example, on vulnerabilities in the equipment hardware), LTEInspector adopts the Dolev-Yao attack model.[4]

Under the Dolev-Yao attack model, the capabilities of the attacker include dropping/modifying messages exchanged on the network, injecting false messages, impersonating legitimate parties in communications, and eavesdropping messages. Also, under this attack model, the attacker adheres to the assumption that the attacker is unable to decrypt messages without possessing the proper decryption keys and cannot forge the digital signatures of legitimate parties without possessing the keys used for the signature.

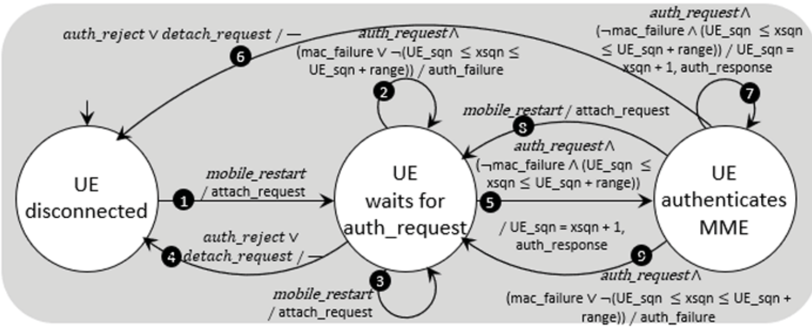
The FSM extended with the inclusion of the adversarial model is then given as input to the NuSMV model checker,[5] together with properties to be verified. Then, by using an iterative process known as "property refinement," each property of interest is verified separately.

In property refinement, additional conditions are added to the property to be verified to exclude spurious cases that can lead to property violations, but which do not represent vulnerabilities. If no violations are detected, the property is considered as verified by the protocol.

On the other hand, when there's a violation, the model checker returns the scenario that leads to the violation of the property. The scenario is then analyzed via a cryptographic verifier to determine whether the violation still occurs under the cryptographic assumptions about the attacker. If this is the case, as a last step, the attack is checked in an actual testbed with commercial UEs to determine whether the attack is possible in practice, as commercial UEs may implement additional defenses.

By using LTEInspector, several new vulnerabilities were identified that can be exploited in actual attacks *(see Reference 3 for details on these attacks)*. Most such vulnerabilities were due to the lack of deployment of well-known security techniques for some messages exchanged by the protocol. Examples include lack of replay protection and lack of digital signature for certain broadcast messages, such as the paging messages broadcast by cellular towers to notify UEs of calls and SMS.[6]

Starting from LTEInspector, other notable methodologies were designed, including 5GReasoner,[7] which extends LTEInspector by modeling, in addition to the NAS layer, RRC, and a fuzzing-based approach to identifying design and



2. A finite state machine—such as this simplified example UE FSM modeling the attach protocol—is a representation well-suited for the analysis of multistep protocols. (Image from Reference 3)

implementation vulnerabilities in 5G code by carriers and device vendors.[8]

Creating FSM Models of Communication Protocols

The application of formal methodologies, like LTEInspector and 5GReasoner, requires formal models of the protocols to be analyzed. Based on our experience, such a model can be extracted from the standardization documents, as in the case of the model developed for LTEInspector, or from the protocol implementations. Both approaches have challenges.

Extracting models from standardization documents requires a huge amount of manual effort, as these documents are often very large and convoluted. Addressing this issue would require the design of specialized natural language processing approaches, perhaps based on artificial-intelligence/machine-learning techniques.

One advantage, though, is that the analysis performed on such models allows one to identify errors and ambiguities in the standardization documents or other specification documentation. Indeed, among the new vulnerabilities found by LTEInspector, more than half were due to issues in the specification from standardization documents.

Extracting models from actual implementations of the protocols has the advantage that automatic or semi-automatic approaches can be used, such as the recent ProChecker methodology.[9] ProChecker leverages the testing infrastructure used for the code to extract from the implementation an FSM model of the protocol. Because the model is extracted from the implementation, it's more fine-grained than a model obtained from the natural language specification.

Using a more detailed model allows one to identify vulnerabilities that aren't identified by more abstract models. For example, when applying ProChecker to an industrial codebase that has a size of around 80 GB, implementation of the NAS layer identified three new protocol attacks. These weren't identified in analysis by LTEInspector using a more abstract model extracted from the standardization documents, as well as six implementation issues.

One disadvantage is that the extracted model may be very large, which results in scalability issues with the formal analysis tools used. Furthermore, the model may contain unnecessary details that make it more difficult for the programmers/software engineers to understand the vulnerabilities.

Key Insights

Ensuring that cellular network protocols are free of vulnerabilities of varying nature is a challenging task that requires the use of several techniques. For example, memory vulnerabilities, such as buffer overflows, are today well-understood and identified in various ways, such as by fuzzing testing. On the other hand, logical vulnerabilities, e.g., lack of digital signatures on messages, are more difficult to identify. Formal verification methodologies, like the ones discussed earlier, are more suitable for identifying these vulnerabilities.

However, the use of these methodologies requires extensive domain knowledge to determine the proper abstraction level(s) for the model and the properties. In general, having an abstract model is useful in defining an initial set of relevant properties and verify whether the protocol, as initially specified, has vulnerabilities. Then a more detailed model can be extracted from the implementation and analyzed by refining the properties defined for the abstract model. In addition, the model extracted from the implementation can be compared with the abstract model to detect whether the implementation is noncompliant with the specification.

To conclude, we have promising techniques and methodologies, and, hopefully, research by industry and academia will enhance and engineer them for practical use. ■

References

1. E. Bertino, S. R. Hussain, O. Chowdhury, "5G Security and Privacy: A Research Roadmap." CoRR abs/2003.13604 (2020).
2. Cybersecurity & Infrastructure Security Agency (CISA), "Securing Network Infrastructure Devices." Last accessed on 7/27/2021 at https://us-cert.cisa.gov/ncas/tips/ST18-001.
3. S. R. Hussain, O. Chowdhury, S. Mehnaz, E. Bertino. "LTEInspector: A Systematic Approach for Adversarial Testing of 4G LTE." Proceedings of NDSS 2018.
4. D. Dolev and A. C. Yao, "On the security of public key protocols." Stanford, CA, USA, Tech. Rep., 1981, http://www.ncstrl.org:8900/ncstrl/servlet/search?formname=detail&id=oai.
5. https://nusmv.fbk.eu/.
6. A. Singla, S. R. Hussain, O. Chowdhury, E. Bertino, N. Li, "Protecting the 4G and 5G Cellular Paging Protocols against Security and Privacy Attacks." Proc. Priv. Enhancing Technol. 2020(1): 126-142.
7. S. R. Hussain, M. Echeverria, I. Karim, O. Chowdhury, E. Bertino, "5GReasoner: A Property-Directed Security and Privacy Analysis Framework for 5G Cellular Network Protocol." Proceedings of ACM CCS 2019: 669-684.
8. H. Kim, J. Lee, E. Lee, and Y. Kim, "Touching the Untouchables: Dynamic Security Analysis of the LTE Control Plane." Proceedings of the IEEE Symposium on Security & Privacy (S&P), 2019.
9. I. Karim, S. R. Hussain, E. Bertino, "ProChecker: An Automated Security and Privacy Analysis Framework for 4G LTE Protocol Implementations." Proceedings of the 2021 IEEE ICDCS.

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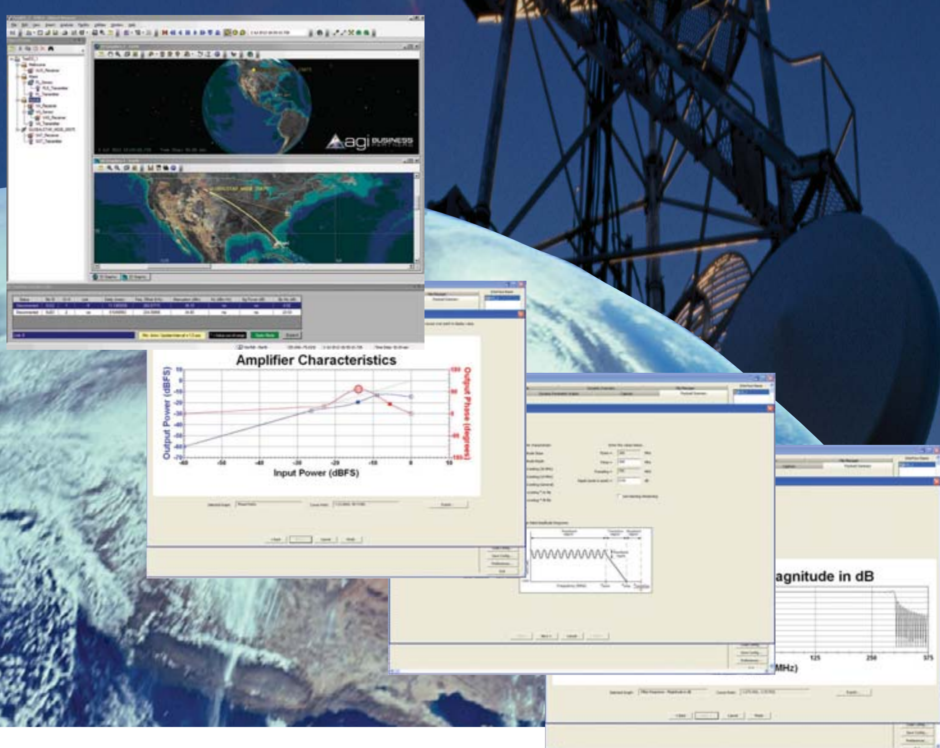

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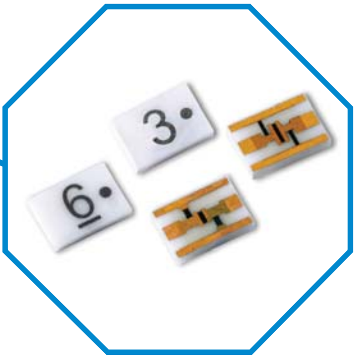

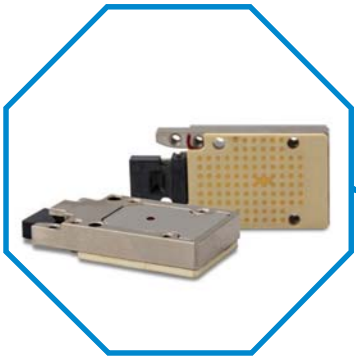

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