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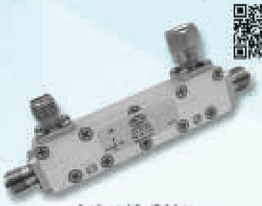

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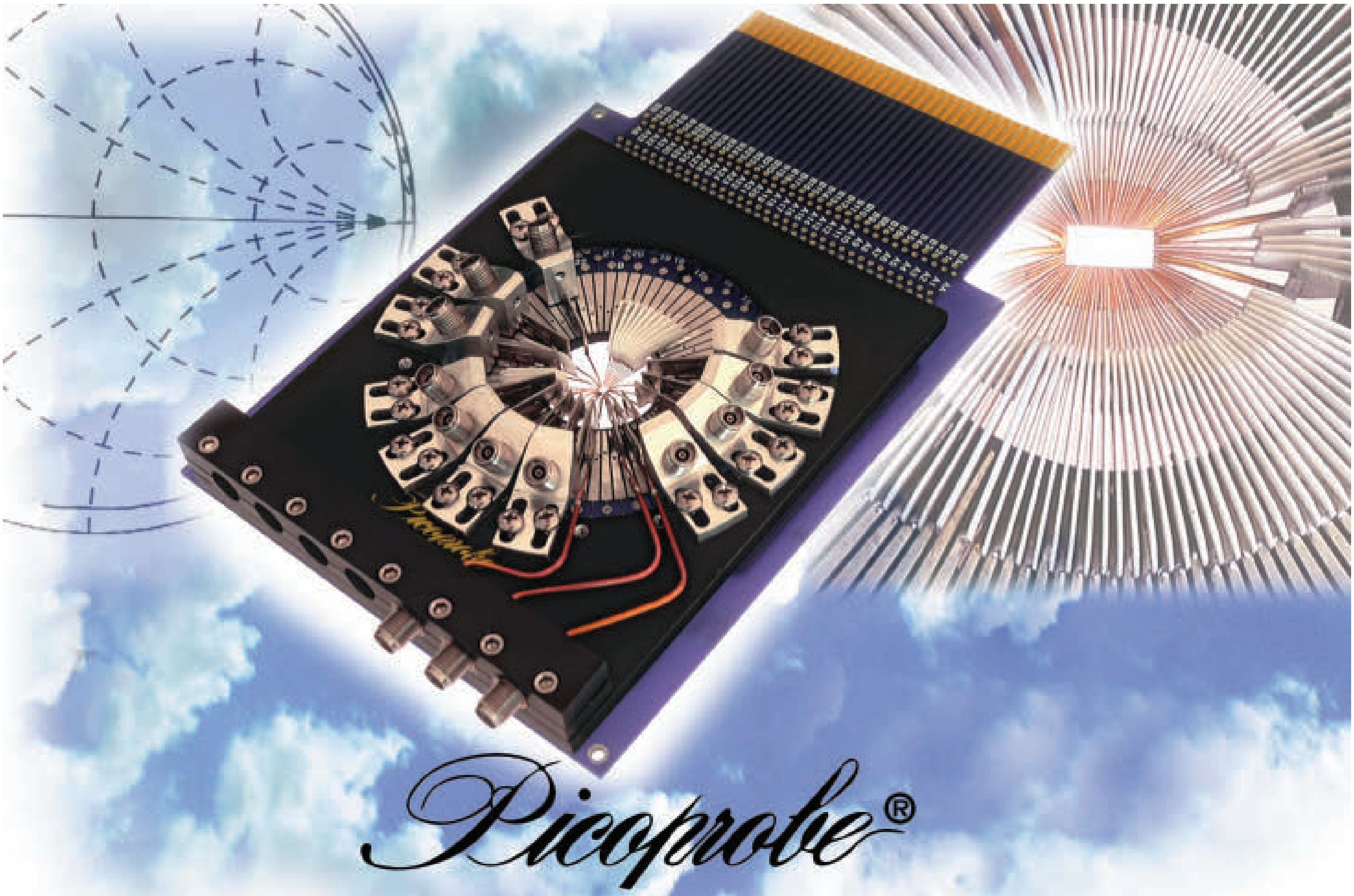

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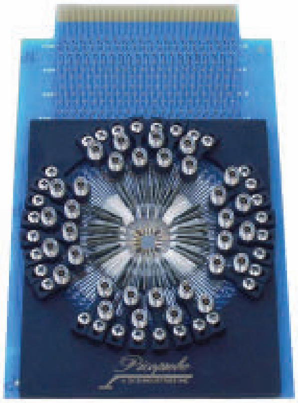

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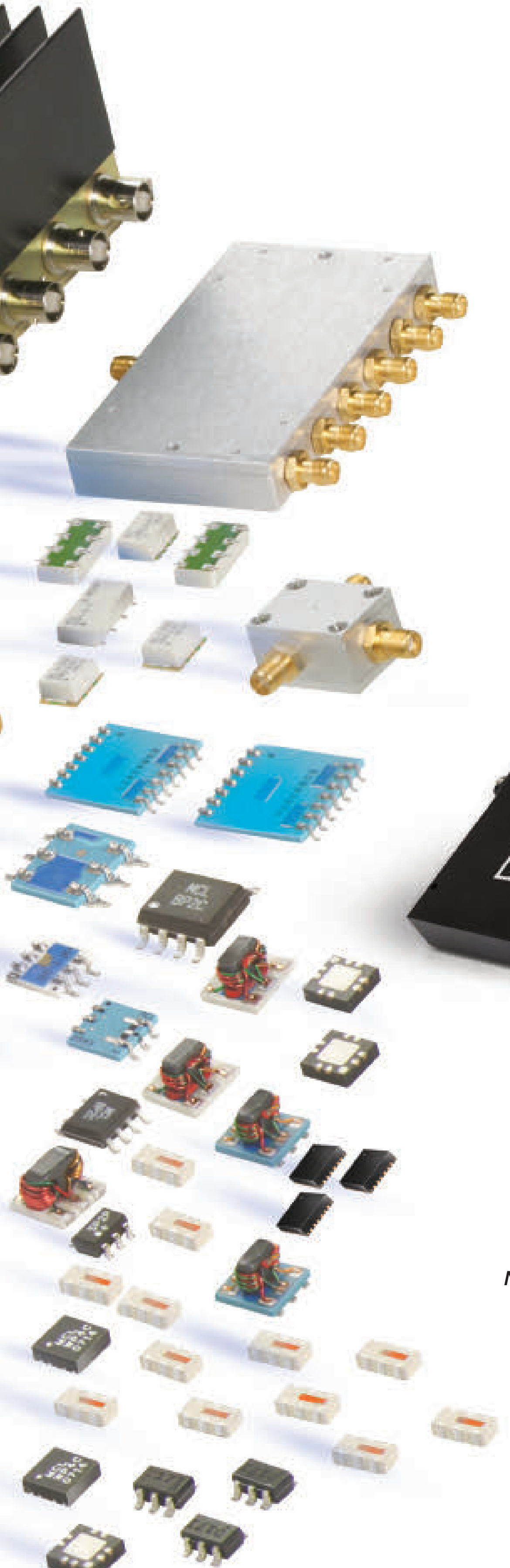

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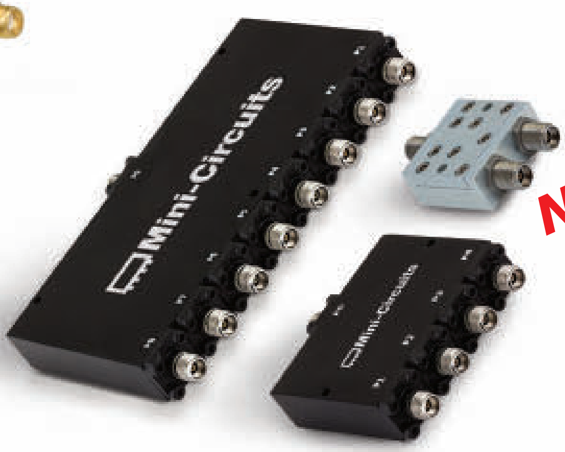

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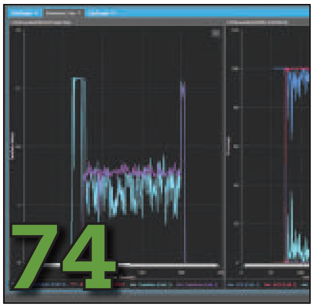

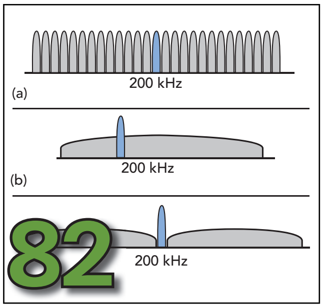

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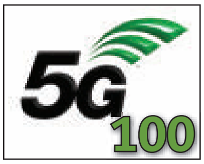

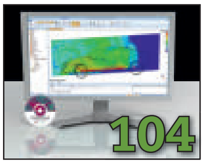

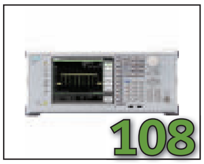

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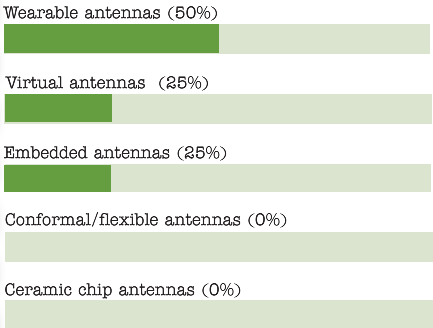

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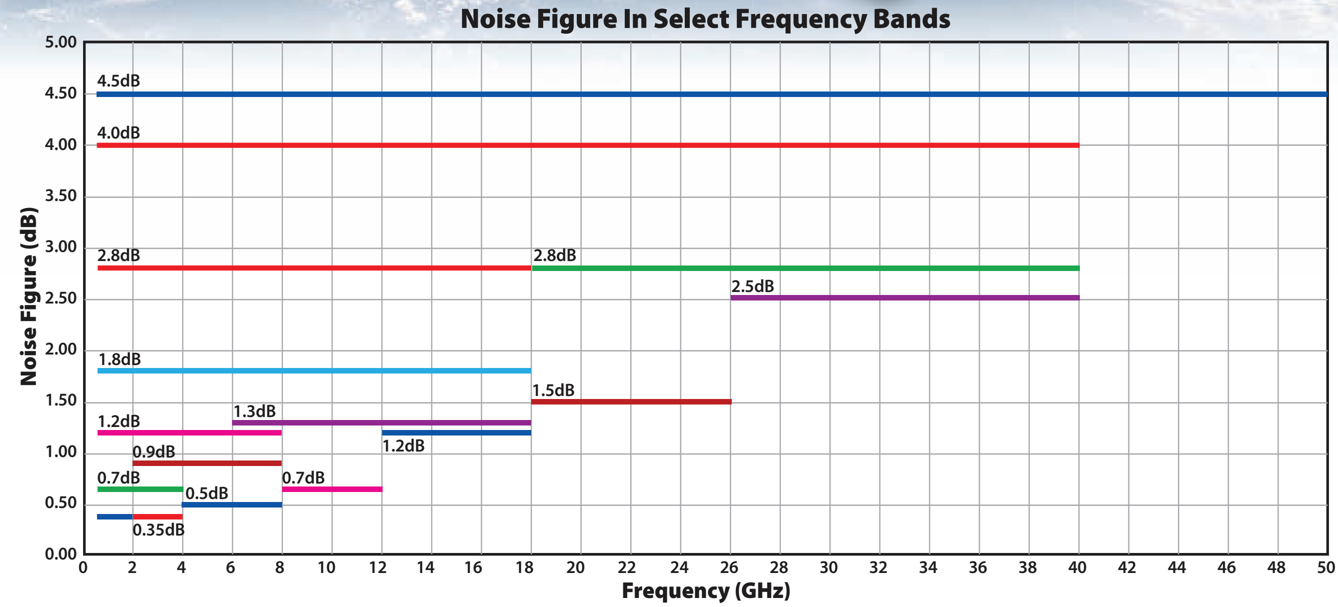
Noise Figure In Select Frequency Bands
Noise Figure (dB)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
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4.5dB
4.0dB
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0.9dB
0.7dB
0.7dB
0.5dB
0.35dB
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
Frequency (GHz)

JANUARY

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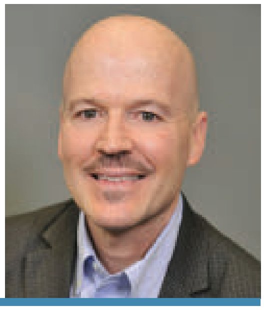
Technology Triumphs in 2017



Pat Hindle, *Microwave Journal* Editor

I have never witnessed anything in our industry with as much buzz and market reaction as 5G. There has never been a time where the standards organizations actually compressed their time frame as they have done for 5G. While the last couple of years have produced a lot of hype, I think the industry is coming to terms with what is practical from a technology standpoint and what makes sense from a business point of view. *Mobile Experts*' Joe Madden recently wrote how he does not think femtocells or robotic surgery will take off because there is currently not a good business model to support them. He thinks small cells in the 3.5 GHz band (Citizens Broadband Radio System) will take off as there are several significant business applications and favorable cost models to support them. Next year, we will start seeing some of the winning applications and technologies with some limited 5G launches.

While many experts had doubted that mmWave technology would be mature enough for early 5G deployments, Fixed Wireless Access at the 28 and 39 GHz bands is being tested for deployment next year. This along with satellite applications has quickly advanced commercial phased array technology, and we see 28 and 39 GHz arrays hitting the market. We have even seen companies testing mmWave handset technology although this seems further away from realization. The production of 802.11ad products at 60 GHz will also drive mmWave, phased array technology and help drive down the cost.

The test and measurement industry is leading the way as they have to develop their systems in advance of the device manufacturers. They have emphasized software driven modular systems in order to build in flexibility to use their systems for the changing needs of their customers. They have also developed more system level test setups and emulators to test various scenarios that would take too much time to do in the field and cost too much to be practical (think of billions of autonomous vehicle or airborne radar scenarios to test). This seems like an area of significant advancement as we implement hardware in the loop or similar practices in the A&D and automotive safety/autonomy markets; expect it to make its way into other markets soon.

Another hot market to watch is autonomous vehicles, which are also coming faster than many realize. While these have been in development for many years, the sensor technologies are finally available and meet both the cost and safety levels needed for commercialization. For the RF and microwave market, this primarily involves mmWave radar sensors that are moving to wider bandwidths for better resolution. At this year's European Microwave Week in Nuremberg, all of the major test and measurement companies were demonstrating radar test systems and the semiconductor companies were developing more highly integrated, lower cost modules.

An interesting trend is the development of USB powered, miniature test equipment such as VNAs and spectrum analyzers that are small and light enough to be put on low cost commercial drones. This is enabling many new applications such as drone borne radar measurements for mapping various things on the ground and spectrum monitoring over wide areas; both at a fraction of the cost of previous methods or not even possible in some cases.

In semiconductors, silicon on insulator (SOI) technology has emerged as a low cost, high performance platform for highly integrated solutions for 5G, IoT and automotive applications. RF applications have previously used older silicon nodes as digital applications and pushed the state-of-the-art, but now RF processes are being released on advanced nodes like 28 and 16 nm processes. This is enabling high performance system on chip designs at relatively low costs compared to previous generations even at mmWave frequencies. Other CMOS/BiCMOS processes are also becoming more capable with higher cutoff frequencies supporting many RF applications.

GaN continues to expand into more markets as it reduces its cost structure. It is finally a strong competitor to LDMOS in the large cellular infrastructure market and several six inch GaN lines are coming online around the world. The interesting battle is GaN-on-SiC versus GaN-on-Si as MACOM and OMMIC attempt to really drive down the cost structure with larger wafers and lower cost Si substrates. Most of the other manufacturers believe the thermal properties of SiC are the only way to achieve the performance needed with GaN devices. I believe 2018 will be the year that GaN-on-Si either proves itself worthy to take a significant share of the larger volume markets or be overtaken by GaN-on-SiC.

It will be interesting to see how these trends develop over the next year and what new trends will emerge in 2018. A couple of areas that should continue to be active are, of course, 5G, as the 3.5 GHz bands should take off, and massive MIMO and higher orders of carrier aggregation should emerge as technologies to increase capacity in the first 5G networks. Additive manufacturing looks to re-shape the way we build complicated structures like antennas and waveguides, another growing market. Although many talk about IoT taking off, there still seems to be too many network standards and too much confusion in the market applications that I think will take another year to sort through. Let me know your comments and feedback online.

From the *Microwave Journal* Team, best wishes for 2018 and happy holidays! ■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5G: Is it Ready for Take Off?

James Kimery
National Instruments, Austin, Texas

Never has there been so much hype and attention paid to a new wireless standard than with 5G. 5G has generated a lot of interest, due to its potential transformational impact on both consumers and businesses across the globe. Has the hype been overdone? Let's look at where we have come from, where we are today and speculate a bit as to what the future may hold.

HOW WE GOT HERE

A little over 10 years ago, Apple introduced the iPhone and opened our eyes to the potential of smart devices combined with wireless broadband data. In 2016, Cisco published their Global Mobile Traffic Forecast, estimating that over 1.5 billion smart devices were sold globally. The report also estimated that by 2021, the world will consume over 49 exabytes of data per month—a 7x increase over the usage in 2016. The acceptance, adoption and pervasiveness of smart devices astounds and has been, in and of itself, transformational. 5G aims to go further. Broadband wireless data will continue to draw attention, and the world's standardization bodies shaping 5G have taken notice.

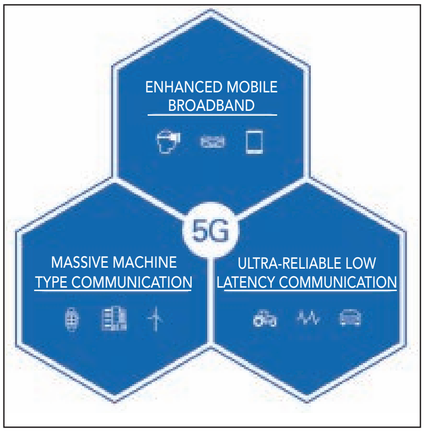
At the outset of the 5G standardization kickoff, the 3GPP outlined three key performance metrics (see ***Figure 1***). The 3GPP defined the enhanced mobile broadband (eMBB) use case and attached a performance target of greater than 10 Gbps peak data rate to expand broadband data services. In response to several industry groups, the 3GPP also set key performance metrics for ultra-reliable low latency communications (URLLC) and increased connectivity, setting the stage for billions of connected devices for massive machine-type communication (mMTC).

Today's wireless standards do not and never have addressed latency and broad connectivity. Latency is quite important because lower latency will not only improve the common data experience for users but create new applications that rely on fast network response. Low latency and, specifically, deterministic low latency responsiveness provide the foundation for "control" applications over the network. Combining robots, drones, cars and other devices that "move" with low latency wireless communications makes controlling these devices from a remote location possible, potentially impacting construction, medicine, manufacturing, retail services and safety. Latency in this context also includes delivering timely information from the cloud or deployed sensors to the brains of these devices, so that decisions can be made on the fly to enhance safety. In this case, the data is delivered real-time, and the control mechanism is deployed on the device.

In 2015, when the 3GPP kicked off the 5G standardization effort, the group outlined the timelines and key performance objectives for this new standard. The 3GPP stated unprecedented guiding principles for the definition process to follow. First, 3GPP broke compatibility with prior releases, setting a goal of forward compatibility. By breaking with LTE and prior-generation standards, the 3GPP opened a path for innovation to meet these very difficult objectives. Second, the 3GPP divided 5G into phases. The first phase, or Phase 1, focused on mobile access below 40 GHz and set a framework for Phase 2 to investigate spectrum above 40 GHz. In all, the 3GPP has been working on 3GPP release 15, also known as 5G New Radio (NR) Phase 1, with an expected release date of June 2018 (see ***Figure 2***).

WHERE WE ARE TODAY

As I write this article, the 3GPP is closing in on the first draft of the physical layer of 5G NR Phase 1, tar-



▲ **Fig. 1** 5G use cases defined by 3GPP.

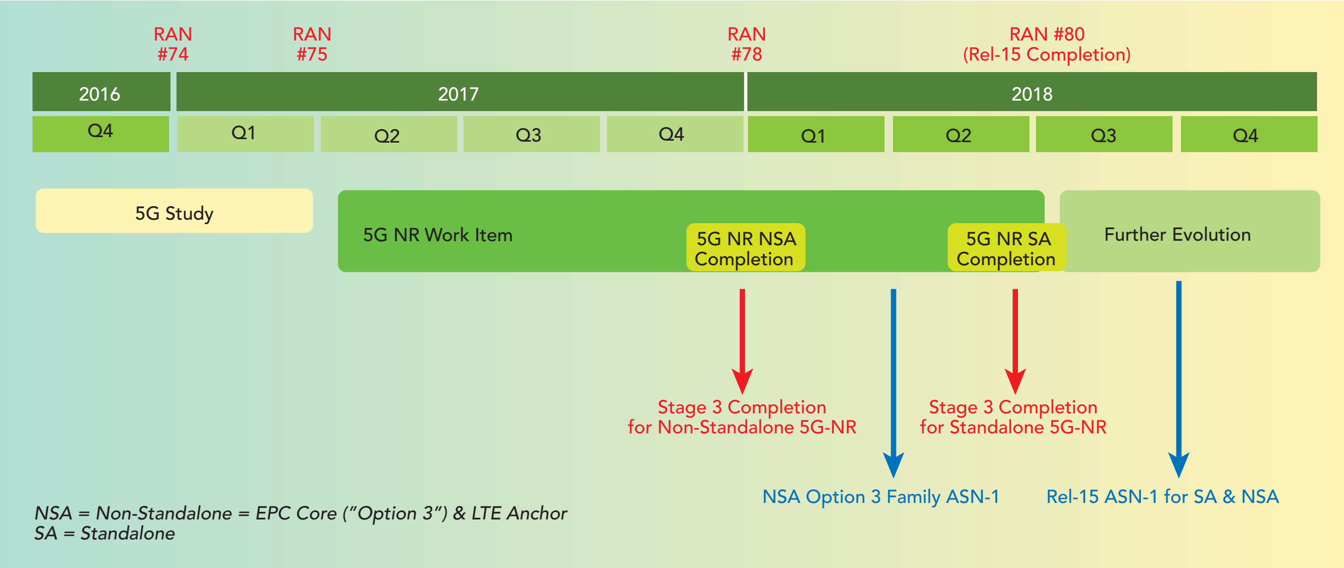


Fig. 2 Timeline for 5G radio access network standardization. The first NR specification release is scheduled for late 2017, with updates during 2018.

geted for December 2017. This first draft is critically important, as it establishes the foundation upon which semiconductor, device, infrastructure, test and measurement and other wireless ecosystem players will plan and build their businesses. Until this point, the development has evolved using system prototypes for field trails with service operators. With a firmer standard in place, the players can develop tangible plans and targets for product and service rollouts.

Interestingly, there have been announcements regarding the availability of 5G technologies—specifically by Intel and Qualcomm—and these early developments are intended to seed other companies to drive adoption. It may seem strange to announce products compliant with a standard before the standard is final, but the shape and structure of 5G NR has been crystalizing for several months. "Final" solutions will inevitably need some tweaking to meet the standard; however, progress toward the creation of the ecosystem has already started with a path toward commercialization.

Service operators have announced 5G plans in all shapes and sizes: SKT and KT are gearing up for 5G trial services to accompany the 2018 PyeongChang Winter Olympics in South Korea. In the U.S., Verizon has aggressively purchased spectrum in the 28, 37 and 39 GHz bands and driven the development of the 5GTF standard, primarily for fiber to the premises (FTTP) applications. Verizon has been trialing pre-commercial equipment in 11 cities in the U.S. since the beginning of this year and announced plans for initial commercial deployments in 2018. T-Mobile, the big winner in this year's FCC auction, won 31 MHz of spectrum around 600 MHz and announced plans to build a "nationwide" 5G network using their newly purchased spectrum. Sprint has approximately 120 MHz of spectrum in the 2.5 GHz band and has been working with Qualcomm and SoftBank, its parent company, to plan 5G rollouts in 2019. Meanwhile, AT&T has announced plans for IoT services in spectrum it currently owns and acquired FiberTower to obtain licenses at 24 and 39 GHz.

Since the 3GPP kicked off the 5G standardization effort in 2015, the mMTC use case has been deprioritized. The 3GPP continues to evolve LTE; in release 14, the 3GPP made several enhancements to LTE specifically targeting the mMTC use case, with development of the NB-IoT and LTE CAT-M standards. The mMTC use case elevates connectivity as a goal, driving device manufacturers to incorporate wireless capabilities into many devices not previously connected, expanding their utility. We have seen a glimpse of the possibilities with new IoT devices, but there are significant challenges: there is no pervasive or ubiquitous wireless IoT standard. As such, there are challenges with interoperability and seamless connectivity to infrastructure and smart devices. With the 3GPP addressing the mMTC use case in release 14 and delivering a comprehensive and widely supported standard, time will tell whether further enhancements are needed in a future evolution of 5G.

WHAT WILL 5G LOOK LIKE?

As noted, the 3GPP plans to finalize 5G NR Phase 1, 3GPP Release 15 by the end of 2017, with the ASN.1 ratification in June of 2018. The 3GPP has started on the path of defining the transformational radio access network by including wider bandwidths, essential for faster data rates. New spectrum has been identified to deploy these wider bandwidth systems. The 3GPP has also reduced the symbol timing compared to LTE, to enable shorter transfer time intervals (see ***Table 1***). In addition, the 3GPP has aligned on a self-contained subframe, which enables transmission and reception in a single subframe for time-division duplexing (TDD) systems. With this initial work, the 3GPP has addressed faster data rates and lower latency. Perhaps most importantly, a new, flexible numerology will enable operators to accommodate different types of devices and support diverse use cases.

For mmWave, the 3GPP has identified specific frequency bands and incorporated beam management and control for phased array anten-

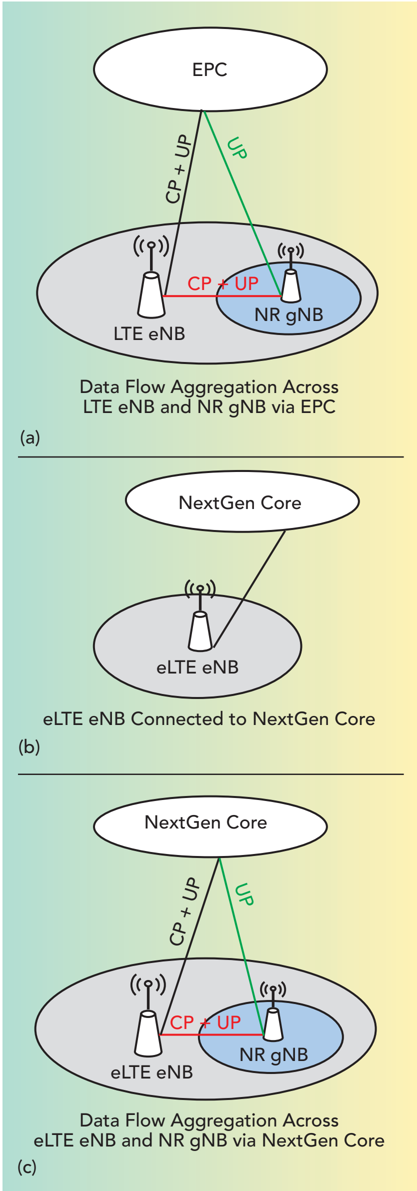
TABLE 1
LTE VS. 5G NR PHASE 1

	LTE	NR Phase 1
Number of Streams	SISO	SISO per Polarization per Antenna Panel
BW	20 MHz	800 MHz
Subcarrier Spacing	15 kHz	240 kHz (Maximum)
FFT Size	2048	2048, 4096
Number of Occupied Subcarriers	1200	~1600 (FFT Size 2048) ~3300 (FFT Size 4096)
Spectral Occupancy	90%	98%
Slot Duration	0.5 ms [7 Symbols]	125 μs [14 Symbols for 120 kHz Subcarrier Spacing]
Antenna	Omni	64 Beams (for SS Block)

nas (PAA). Although the stage is set for mmWave deployments, many practical challenges remain for widespread adoption (more on this later).

The 3GPP defined two main network architectures for Phase 1. With the non-standalone (NSA) architecture, the 5G NR uses the existing LTE radio access network and evolved packet core or EPC (see ***Figure 3a***); NSA includes two additional options (see ***Figures 3b*** and ***3c***). The second main architecture, named standalone (SA), uses the 5G NR and a new 5G core (see ***Figure 4***). NSA enables operators to offer 5G services sooner, taking advantage of the existing infrastructure to deliver services in the short-term, since investments for SA are expected to be much larger and will take more time. In the standards meetings, NSA has been a focus because of the immediate opportunity and, perhaps, a narrower scope. SA will deliver more 5G benefits than NSA and will surely improve data rates and latency to be much closer to the 5G targets. The 3GPP is targeting December 2018 to wrap up Phase 1, release 15, which will include both NSA and SA.

The 3GPP has accomplished much in a very short time. In the short-term, 5G deployments below 6 GHz may look a lot like LTE on steroids, i.e., faster data and lower latency. The first NSA deployments may provide noticeable performance enhancements over LTE, and the lightning fast data speeds will likely appear when network operators deploy mmWave technologies and the new 5G core network, needed for SA operation. What is clear is that this is just the begin-



▲ Fig. 3 Initial 5G deployments will use the existing LTE radio access network and EPC (a). The NSA specification includes architectural options using the new 5G core (b) and (c).

ning. Future evolutions and iterations seem inevitable.

CHALLENGES AHEAD

As the 3GPP finalizes the formative 5G specification, the path forward is not unimpeded. 5G has the potential to be a "game changer," but the transformational impact must come with extensive help from a diverse set of players. Potential challenges exist in three high level areas: mmWave, network topology and ecosystem.

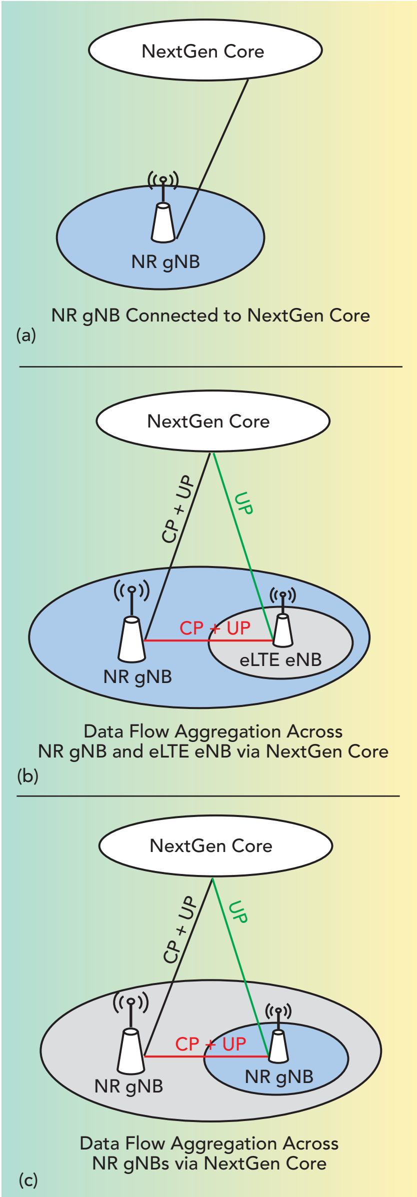
mmWave

The 3GPP chose to incorporate mmWave technologies into the standard due to the scarcity of available spectrum below 6 GHz. More spectrum equates to faster data speeds. Although the 3GPP will specify 5G technologies for use in spectrum below 6 GHz, the 3GPP is relying on mmWave, with its copious spectrum, to meet its goals for the eMBB use case. Over the last couple of years, several researchers have prototyped mmWave systems extensively, but the early prototypes were big, bulky and used very new technologies such as PAAs.

PAAs overcome the free space path loss associated with mmWave transmission and reception using multiple antenna elements and beamforming to enhance gain. With their benefits, PAAs also pose system challenges, as the control of the beams must be incorporated into the standard and, more practically, into the software deployed on these systems. To support mobility, the protocol software must switch the beams in less than 200 ns to maintain the link, requiring fast switching technology in the antenna assemblies and the software architectures that program them.

The testing of PAAs and the systems that incorporate them is being investigated and poses new challenges for the test and measurement industry. As PAAs are often integrated with their transceivers to minimize loss, cable access to these modules and the arrays that incorporate them will not exist. Over-the-air (OTA) techniques for testing PAAs are being explored by several companies, with proposals submitted to the 3GPP RAN4 working group for incorporation into the standard. OTA introduces new variables to the test equation; most significant is the need to minimize test time and test cost. Test and measurement companies must deliver fast, cost-effective solutions to the wireless industry to facilitate the development of the mmWave ecosystem.

Even with PAAs in both the user equipment (UE) and infrastructure (i.e., gNodeB), mmWave propagation is limited, even at the lower mmWave frequencies. Denser deployment of the infrastructure is a foregone conclusion that will likely signal more costly rollouts of the technology and systems. To ad-



▲ **Fig. 4 The SA specification assumes the 5G NR and a new 5G core (a), with two additional options to handle deployment scenarios (b) and (c).**

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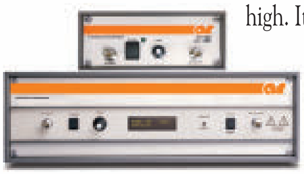

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dress the density challenge, researchers are exploring new techniques for mesh and integrated access backhaul (IAB) to minimize the cost of denser deployments by utilizing the 5G gNodeBs already deployed. IAB would reduce the cost of running fiber to each mmWave access device; however, the technique may introduce more latency.

Network Slicing

One of the more impactful observations for 5G transformation is that the networks must morph and scale to optimize resources to support new applications and services. "Scalable" networks was not an explicit goal outlined by the ITU or the Next Generation Mobile Networks (NGMN) Alliance when the 5G standardization process was kicked off by 3GPP, but the implication was clear.

To describe this flexible network topology, the wireless industry defined the term "network slices." Network slices describes the ability of a service operator to "slice" the network to tailor a unique set of services for users, creating diverse applications and use cases and charging appropriately for the services. With network slices, a company or individual could purchase a service or a set of services to meet specific needs. For example, consider a company that outfits a factory with 1,000 connected sensors. The company may expect to pay less than $40 per month for unlimited data, since those sensors do not transmit or receive the type of data that we consume on our smartphones.

While the 3GPP has, indeed, made great progress toward defining a radio access network capable of achieving these lofty goals, network operators must be able to fairly charge for these services and conserve valuable network resources to sustain a healthy ecosystem and enable all contributors to prosper. To facilitate the creation of network slices, the 3GPP has enhanced the split architecture of the control and user planes to enable separate control and data paths. This is just the foundation. Network slicing also depends on implementing infrastructure elements beyond the physical layer of the protocol stack. Network technologies such as virtual EPC, network function virtualization (NFV), software defined networking (SDN) and mobile edge computing (MEC) are components and services necessary to move network slicing forward. Without these technologies, all data and control traffic must aggregate at the core network, potentially crippling the industry's ability to meet the goals of data throughput, end to end (E2E) latency and massive connectivity.

Creating the Ecosystem

5G's success or failure will depend on the creation of an ecosystem. The 5G ecosystem must extend beyond the traditional wireless value chain of usual participants: the service providers, semiconductor companies, infrastructure manufacturers and test and measurement companies, to name

a few. Application software and service providers, cloud and cloud infrastructure, vertical integrators, software companies and even car, drone, appliance, medical device and construction manufacturers must be an integral part of the 5G landscape to realize the true economic potential. Creating an ecosystem does not occur overnight. The initial deployments of 5G services to enable the ecosystem to grow and evolve are critical.

A 5G FUTURE

Qualcomm recently commissioned a study by IHS Market to assess the economic impact of 5G. IHS Markit speculates that 5G will become a general purpose technology (GPT), a development so impactful that it becomes a catalyst for socio-economic transformation. For perspective, other examples in our history cited as GPTs include the printing press and electricity. IHS Markit expects 5G to contribute $12.3 trillion—yes, that is a "t"—to the global economy by 2035. IHS Markit is not alone in their prediction, as the world's economic leaders continue to invest in 5G with a myriad of funding and regulatory support. These global leaders are betting on 5G to catalyze GDP growth and create economic prosperity. While 2035 is 20 years away, the 5G foundation is being laid today. Creating an ecosystem for these applications will take investment, dedication and perseverance and, above all, time. The various ecosystem players must step up to the plate to realize the vast potential that 5G promises.

As noted, initial rollouts are scheduled for next year, and more meaningful deployments will begin in 2019. To realize 5G's potential, significant innovations must occur in semiconductors and packaging technology, system and network topologies and architectures and, of course, the important verticals that will take advantage of this new network of 5G capabilities and services. It will not be easy, but with the commitment of the industry and the world's government leadership, 5G has unstoppable momentum.

The industry has made great strides in moving the 5G agenda forward, achieving key milestones in both the standardization process and technology development. Demonstrable commitments from academia, industry and governments worldwide have created forward momentum, yet there remains much to do. 5G below 6 GHz may have a shorter runway to deployment, but mmWave is very important to the overall 5G vision. The next year should provide a better picture of the 5G timelines and potential, and the world will be watching the progress on the challenges outlined in this article. The major players have all anted up, but there are real and hard problems to solve for 5G to live up to its promise. 2018 should be an interesting year and this time next year, a clearer picture of the future should materialize.

The central question is not whether 5G will be impactful, the question is when?■

Cliff Drubin, Associate Technical Editor

Technology Helps Aircraft Navigate Accurately Without GPS

Military aircraft and airborne weapon systems may soon be able to guide themselves to targets on land or sea without using Global Positioning System (GPS) satellite signals, thanks to new, high speed navigational technology developed by Northrop Grumman Corporation.

In recent flight demonstrations, the company proved the ability of its All Source Adaptive Fusion (ASAF) software to navigate aircraft safely and precisely to both fixed (land) and mobile (ship-based) locations. Northrop Grumman conducted the flights in partnership with the U.S. Air Force Research Laboratory's (AFRL) Munitions Directorate, Eglin Air Force Base and the U.S. Navy's Office of Naval Research, respectively.

Military platforms and weapons systems must retain their sense of location, speed and direction at all times, even when operating in denied or degraded GPS environments.

"Our absolute (fixed) and relative (mobile) navigation technologies will protect a wide range of critical U.S. military missions between ships and shore from disruption by GPS denial techniques, even in adverse weather and high sea-state conditions," said Scott Stapp, vice president, applied technology, Northrop Grumman Aerospace Systems.

Intelligence, surveillance and reconnaissance; cargo delivery; all-weather targeting and strike are among the missions that would benefit from the new "denied GPS" technology, he added.

ASAF uses high-speed algorithms and hardware to generate navigational solutions from data gathered from a variety of sources including radar, electro-optical/infrared, light detection and ranging, star tracker, magnetometer, altimeter and other signals of opportunity. It is one of several denied GPS approaches used by Northrop Grumman.

The land-based flights, which took place at the Royal Australian Air Force's Woomera Test Range, South Australia, demonstrated ASAF software configured in an absolute navigation mode. In this case, an unmanned aircraft navigated accurately from a known location to a specified location using input from a sensor package and geo-registration software to improve navigation accuracy. An AFRL, Eglin-led team developed the geo-registration software and integrated the sensor package and data processors onto the aircraft.

In the other tests, a Northrop Grumman-led team equipped a Bell-407 helicopter with infrared (IR) sensors and ASAF software configured in relative, precision navigation and landing mode. The helicopter used this software to follow a U.S. Naval Academy YP-700 ship operating in the Chesapeake Bay near Annapolis, Md.

As the helicopter flew, the ASAF software used data from an IR sensor to generate estimates of the helicopter's position, attitude and velocity relative to the ship. Comparison of this relative navigation data to the true trajectories of the ship and helicopter proved that the ASAF software could estimate the landing location of the helicopter with extreme precision.

Raytheon Systems Support International Ballistic Missile Defense Exercise

A Raytheon-built Standard Missile-3 intercepted a medium-range ballistic missile target at sea as part of a multinational operational exercise off the coast of Scotland.

The NATO-led exercise, Formidable Shield 17, was an integrated air and missile defense exercise simulating real-life threat scenarios. The event, supported by the U.S. Missile Defense Agency and U.S. Navy, was designed to evaluate the ability of allied navies' ballistic missile and air warfare defenses to work together quickly and effectively to defeat incoming threats.

In addition to the SM-3 intercept, Standard Missile-2 and Evolved Seasparrow Missile conducted simulated target engagements of cruise missiles.

"Real-world events demand real-world testing," said Dr. Taylor W. Lawrence, Raytheon Missile Systems president. "Strong cooperation between allied nations and industry helps ensure we are ready to defeat complex threats around the world."

Canada, France, Germany, Italy, the Netherlands, Spain, the U.K. and the U.S. were among the NATO nations that participated in Formidable Shield. The exercise built upon a previous At Sea Demonstration in 2015, with a focus on real-world operations.

The SM-3 interceptor is deployed at sea as part of the U.S. contribution to Europe's ballistic missile defense. The first land-based SM-3 site became fully operational in Romania in 2016, and the Poland site is expected to be in service next year.

SM3 Launch (U.S. Navy Photo)

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Increasing Investment in C4ISR Systems Propelling Market Growth

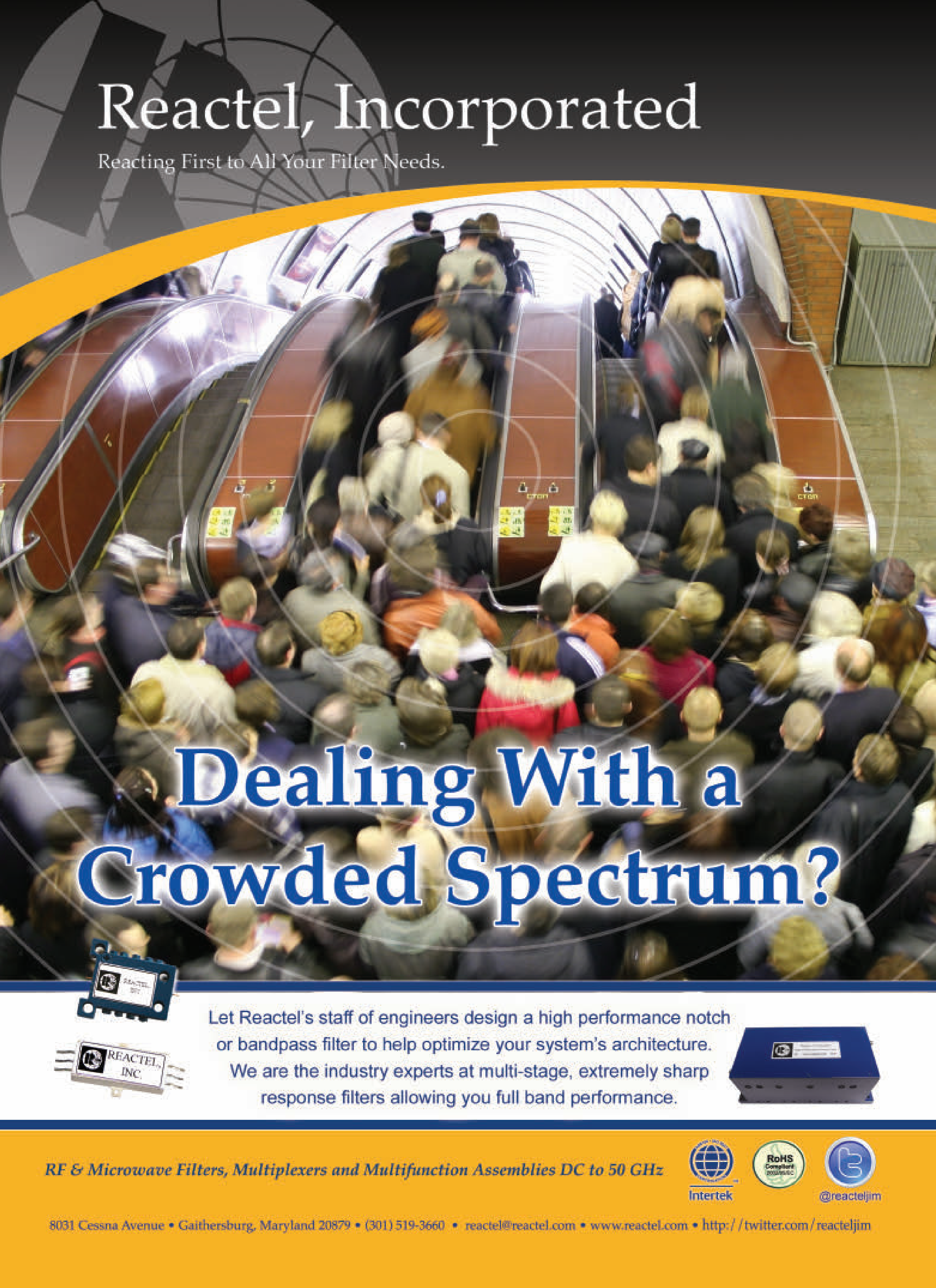
The C4ISR market is buzzing with an intense competition among a large number of established players. The manufacturers in the market are adopting strategies such as new product launches and developments; partnerships, collaborations, contracts and agreements; expansions and mergers; and acquisitions, with the most prominent being partnerships, collaborations, contracts and agreements. Most of the C4ISR systems manufacturers have a similar financial capability, hence, the market is extremely competitive. Because of this, innovation and development have been the keys for gaining growth in this market.

Raytheon, Lockheed Martin, Northrop Grumman and BAE Systems are some of the prominent companies which have remained in the limelight because of their wide range of product launches and partnerships, collaborations, contracts and agreements. In August 2017, it was announced that U.K. MoD granted Airbus a contract to oversee the manufacture, assembly, integration and launch of Skynet 6.

Another recent development in the market came from BAE Systems, which now has software to track and intercept ISR data. Movement Intelligence (MOVINT) software joined the BAE Systems' Geospatial eXploration Products (GXP) line in June 2017, enhancing intelligence, surveillance and reconnaissance operations by helping operators to analyze and interpret movement and activity patterns instead of simply tracking them.

"Global market is expected to cross $100 billion by 2021, growing at a CAGR of 4.05 percent between 2017 and 2021..."

Acknowledging the high potential growth of the defense industry in the future and the crucial role of C4ISR in the industry, BIS Research has compiled a report titled "Global C4ISR Systems Market, Analysis & Forecast: 2017–2021." According to the analyst, "the global market is expected to cross $100 billion by 2021, growing at a CAGR of 4.05 percent between 2017 and 2021. The market is driven by a number of factors, such as improved situational awareness with C4ISR systems and rising defense spending on these systems. However, the increasing reliance on information technology and interoperability issues are expected to hamper the growth of the market."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Richard Mumford, International Editor

Final Work Programme for Horizon 2020

On 27 October 2017, the European Commission (EC) presented the final Work Programme for Horizon 2020, covering the budgetary years 2018, 2019 and 2020 and representing an investment of around €30 billion.

The new Work Programme introduces measures to support market creating innovation, through a first phase of a European Innovation Council (EIC). This will be open to innovations in any technology or sector, including novel innovations that cut across technologies and sectors. The first phase of the EIC will support innovative firms and entrepreneurs to scale up their businesses rapidly at European and global levels, and help Europe better capture innovative ideas with the potential to create new markets and strengthen the industrial base.

With a budget of €2.7 billion, it brings together existing instruments: the SME Instrument, inducement prizes, FET-Open and Fast Track to Innovation. Further changes include making the SME instrument fully "bottom up" so that innovative projects that cut across sectors and technologies can be supported.

The Work Programme aims to address political priorities of EC through defining targeted research and innovation actions that can deliver significant impact. "Focus areas" have been designed around four political priorities: a low-carbon, climate resilient future; circular economy; security union and digitising and transforming European industry and services.

The latter, with a budget of €1.7 billion, will address the combination of digital technologies—5G, high-performance computing, AI, robotics, big data, IoT, etc.—with innovations in other technological areas, as emphasised in the EU Digital Single Market strategy. This field offers huge opportunities for increasing industrial competitiveness, to create growth and jobs and to address societal challenges.

Leonardo, Microsoft Collaborate on Industry 4.0

Leonardo and Microsoft will collaborate on an Industry 4.0 solution to provide the manufacturing sector with a new tool to enable the complete and integrated control of all the processes and assets of a production plant. The "Secure Connected Factory" solution, developed by Leonardo, leveraging its own security by design approaches and on Microsoft technology, enables businesses to increase the efficiency of their production processes and reduce the time and cost of development.

Source: Leonardo & Microsoft

The Secure Connected Factory allows any type of machine, automation system, Computer Numerical Control (CNC) and Programmable Logic Controller (PLC) or sensors of the world's leading manufacturers to connect to Microsoft's cloud "Azure," thanks to the technology provided by the Microsoft partner ecosystem.

"Innovation has always been part of our DNA and, thanks to this collaboration, we have been able to bring together in one project the opportunities of transformation offered by the new technology trends of Industry 4.0, from the IoT to mixed reality," commented Andrea Campora, manager of Leonardo's Cyber Security & ICT Solutions Line of Business.

"We are proud to collaborate with Leonardo in developing an innovative solution that we are sure will contribute to the digital transformation of the production sector in a genuine Industry 4.0 perspective. Secure Connected Factory combines cloud computing, IoT, business intelligence, machine learning, AI and mixed reality to enable the most advanced remote monitoring and predictive maintenance systems and to enhance heterogeneous industrial data by translating them into strategic information," said Vincenzo Esposito, director of Enterprise Business Division of Microsoft Italia.

CCS Microwave Backhaul Selected for London's Square Mile

Cambridge Communication Systems (CCS) Ltd. announced that its Metnet solution has been selected to provide neutral host backhaul for a new, ultra-fast next-generation wireless network being deployed to serve the businesses, residents and visitors of the Square Mile in London.

The new wireless network includes a combination of Wi-Fi for free public access—now live—and 4G small cells, available to carry traffic for all U.K. mobile network operators. Small cells and Wi-Fi access points are being deployed on street furniture including lampposts, street signs and CCTV columns, to improve wireless coverage and capacity in the heart of London's financial centre.

The neutral host backhaul of the Wi-Fi and small cells network is built on CCS Metnet—claimed to be

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the world's only self-organising 5G microwave backhaul—operating in the licensed area-based 28 GHz band. Fibre will also be deployed at strategic points to aggregate the traffic from the Metnet nodes for connectivity into the Wi-Fi and small cell core networks.

CCS CEO Steve Greaves said, "We are very excited to be deploying Metnet to enable enhanced wireless coverage and performance in the number one global financial centre. The Square Mile's tall buildings and narrow streets have posed significant mobile service problems for the city's 400,000 workers and 10 million annual visitors—issues that our self-organising mesh-based Metnet system is uniquely positioned to solve."

ETSI Introduces Software Radio Reconfiguration

Drivers expect navigation systems to be connected, to download real-time traffic information and map updates, while automotive manufacturers increasingly provide remote diagnostics and vehicle software updates. However, currently these vehicles use 2G, 3G or 4G mobile networks to connect, while long before the end of their useful lives, 5G networks will be more common.

Significantly, the European Telecommunications Standards Institute (ETSI) Technical Committee for Reconfigurable Radio Systems has developed a system which can help solve this and similar issues. ETSI's Software Radio Reconfiguration model provides a modular and scalable solution to the challenge of deploying and using software radio systems.

> "...gradual and stepwise deployment..."

The solution, described in a recent ETSI white paper and in the EN 303 146 series of European Standards, allows a gradual and stepwise deployment of software reconfigurable radio. This enables device manufacturers to gradually implement software reconfigurable radios, developing confidence at each step of the way.

With the use of software reconfigurable radio, the radio system on board a vehicle can evolve and improve over time with new software upgrades. Software reconfigurable radios will also help in other situations. For example, security concerns may require the upgrade and patching of radio systems deployed in the field. Yet manual intervention would be costly in the case of vehicles, or even impossible in the case of inaccessible IoT devices.

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CMA-82+	DC-7	15	20	42	6.8	5	8.95
CMA-84+	DC-7	24	21	38	5.5	5	8.95
CMA-62+	0.01-6	15	19	33	5	5	7.45
CMA-63+	0.01-6	20	18	32	4	5	7.45
CMA-545+	0.05-6	15	20	37	1	3	7.45
CMA-5043+	0.05-4	18	20	33	0.8	5	7.45
CMA-545G1+	0.4-2.2	32	23	36	0.9	5	7.95
CMA-162LN+	0.7-1.6	23	19	30	0.5	4	7.45
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Cliff Drubin, Associate Technical Editor

MIMO is the Next Hero Technology for 4G Cellular Networks

As LTE progresses to more advanced versions such as 3GPP standard LTE-Advanced, LTE-Advanced Pro and the recently marketed Gigabit LTE, it is expected that multiple-input multiple-output (MIMO) will become an increasingly important part of mobile network operators' (MNO) options in their evolution to 5G. Massive MIMO will be a key feature of 5G and deploying advanced MIMO for 4G is a long-term investment which will prepare the ground for the deployment of the next generation of networks.

"While MIMO has not delivered on its promises so far, we are left with no doubt that the technology will become a foundational building block for mobile networks in the evolution of 4G and 5G and advanced antenna systems will receive increasing attention and R&D by both vendors and MNOs," says Nick Marshall, research director at ABI Research. "We expect increasing acquisition activities in the antenna market, particularly involving MIMO technology."

> Multiple-input multiple-output antenna systems are now just starting to realize their full potential in LTE networks.

Overall the installed base of MIMO-enabled LTE antennas will grow by more than double worldwide from 2017 to 2021 to reach almost 9 million, with the Asia Pacific region outpacing this with a growth rate of 3x. The Asia Pacific region will grow to represent most of the market by 2021. Although the MIMO-enabled LTE platform retains the largest installed base through 2021, growing by a factor of almost 2x, it is the MIMO-Enabled LTE-Advanced platform growing at a faster rate and MIMO-enabled LTE-Advanced Pro at almost 6x which will rise rapidly to match the scale of the earlier MIMO-enabled LTE platform. The cellular antenna market forms a very dynamic and innovative ecosystem with many vendors including Amphenol, Comba, CommScope, Huawei, Kathrein and RFS all competing to include these advanced multi-antenna features.

Source: extremetech.com

"Advanced antenna systems including complex passive antennas and large scale massive MIMO active antennas will become part of the roadmap to advanced LTE and 5G," concludes Marshall. "The need for active antennas when MIMO becomes more advanced will also change the market map, which has largely depended on passive antennas for previous generations."

Smart Home Will Drive Internet of Things to 50 Billion Devices

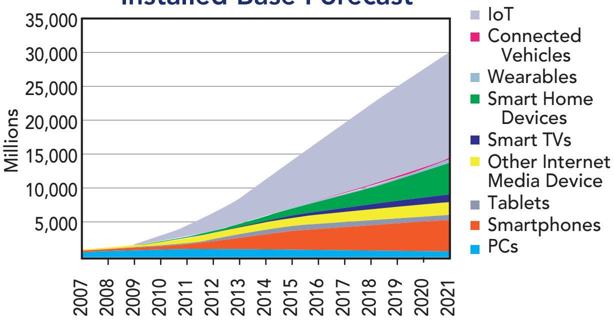
The Internet of Things (IoT) continues to expand rapidly, and the smart home will be one of the keys to further growth through the 2020s, according to new research from Strategy Analytics. The report, "Connected World: Smart Home Is Key To Tomorrow's Internet of Things," found that nearly 20 billion IoT and connected devices will be deployed worldwide by the end of this year, and a further 10 billion will be added over the next four years. Enterprise IoT has been the key sector in recent years but longer term projections suggest that the smart home is likely to become a major generator of connected and IoT device deployment growth during the 2020s, taking the total figure towards 50 billion.

> Internet of Things will reach 20 billion devices this year.

- Other key findings from the research include:
- Smart home devices will overtake smartphones by 2021 as a share of deployed connected/IoT devices.
- The IoT will grow by 17 percent in 2017, but annual growth will decline to 9 percent by 2021.
- Enterprise IoT currently accounts for 52 percent of the total connected/IoT installed base.

"The original connected device, the PC, now represents only 5 percent of the total market, which illus-

Global Connected and IoT Device Installed Base Forecast



Source: Strategy Analytics Research Services

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trates how the internet has permeated so many aspects of our lives," says David Mercer, principal analyst and the report's author.

"The smart home is only at the beginning of its evolution, and as homes install increasing numbers of connected devices, it is set to become one of the largest segments in the wider IoT over the coming decade," comments Bill Ablondi, director, Smart Home Strategies.

New Technologies Rapidly Advancing Commercial Transportation

Evolutionary technical developments and business models are moving rapidly into commercial transportation and telematics. ABI Research's recent industry survey ranked Freight as a Service (FaaS), also known as "Uberization of Freight," as the primary disruptive trend for commercial transportation.

"This can have an immediate impact on underloaded freight assets like the estimated 20 percent cargo capacity utilization deficit in the U.S. alone. FaaS can help fleets absorb unexpected demand, as well as level out seasonal fluctuations," says Susan Beardslee, senior analyst at ABI Research. "Companies like TruckerPath, Convoy and Uber Freight are emerging with a great deal of buzz and significant venture capital attention and investment."

> "Uberization," Prognostics and Blockchain Disrupting Status Quo

Advances in telematics and numerous ADAS features are driving growth in vehicle health management systems, including prognostics and repair management. The industry is moving to proactive solutions targeting preventable occurrences, including work from leading industry suppliers Bendix and Eaton.

Blockchain architecture is moving into transport solutions to address cybersecurity for supply chain tracking. Beardslee states, "These emerging solutions can be adapted for payments, smart contracts, improved capacity utilization, history, fraud prevention and quality control through industry leaders like IBM and startups like IMMLA."

Finally, digital marketplaces like those from Geotab, Navistar and Scania One/Ericsson are leveraging usage data to create further customer engagement and retention by integrating telematics and CRM.

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Microsemi Corp. and **Knowles Corp.** jointly announced that Microsemi has entered into a definitive agreement to acquire the high performance timing business of **Vectron International**, a Knowles company, for $130 million. Vectron is a leader in the design, manufacture and marketing of frequency control, sensor and hybrid solutions using the very latest techniques in both bulk acoustic wave (BAW) and surface acoustic wave (SAW)-based designs from DC to microwave frequencies. Products include crystals and crystal oscillators; frequency translators; clock and data recovery products; SAW filters; SAW oscillators; crystal filters; SAW- and BAW-based sensors and components used in telecommunications, data communications, frequency synthesizers, timing, navigation, military, aerospace, medical and instrumentation systems.

DragonWave Inc. has been acquired by **Transform-X**, a U.S.-based, privately held company. The new company will operate as DragonWave-X and will expand its portfolio with new radio solutions that integrate "disruptive waveform, antenna and hardware technologies" for 5G backhaul. Founded in 2000 and headquartered in Ottawa, DragonWave's carrier-grade point-to-point packet microwave systems have been installed around the world in next-generation IP networks. Transform-X, headquartered in Tucson, Ariz., has acquired rights to several patented technologies that offer dramatic increases in bandwidth and efficiencies for existing wireless and wired networks.

MACOM has entered into an agreement to sell the **Compute Business** it acquired in its **AppliedMicro** acquisition to **Project Denver Holdings LLC**, a new company backed by The Carlyle Group. Under the terms of the sale, MACOM will be issued a minority equity ownership interest in NewCo. The Carlyle Group is one of the world's largest and most successful global investment firms, with over $170 billion in assets under management. Equity for Carlyle's investment came from Carlyle Partners VI, a $13 billion U.S. buyout fund.

AC&A Enterprises LLC, a leading supplier of composite and metallic parts in the aerospace, defense, space and specialty automobile markets, announced that it has acquired **Applied Composites Engineering Inc. (ACE)**, a leader in advanced composites engineering and manufacturing for aerospace and defense applications. Terms of the transaction were not disclosed. AC&A is a portfolio company of AE Industrial Partners, LLC, a private equity investor specializing in aerospace, power generation and specialty industrial companies. Located in Indianapolis, Ind., ACE provides advanced composites solutions to many of the most well-known aerospace and defense original equipment manufacturers (OEM).

COLLABORATIONS

Keysight Technologies Inc. announced that its mobile IoT test system was selected by **China Mobile Research Institute**. Based on the E7515A UXM wireless test set, Keysight helps CMRI study the power consumption, RF and positioning performance and verification, of new IoT technologies, devices and products. The mobile IoT module bridges the mobile IoT chipset and device, fulfills the specific requirements of IoT fragmentation applications and helps with the quick deployment of new products. While the IoT module plays a key role in ensuring the quality of IoT applications, a standard testing platform and method is indispensable to ensure the key performance of the IoT module's power consumption, RF and positioning capabilities.

Analog Devices has entered into a strategic relationship with **China Mobile IoT**, a wholly owned subsidiary of China Mobile Communications Corp. for advancing internet-connected applications around the world. Both global leaders in the IoT ecosystem, Analog Devices and China Mobile IoT expect to collaborate to develop IoT solutions for customers across industries. Through this milestone cooperation, the companies will work together to enable customer outcomes such as higher efficiencies and safer environments, by bringing the best of each organization's capabilities to the entire spectrum of IoT technology, from the sensor level through to the cloud.

Mobile filter start-up **Resonant Inc.** has signed an agreement with an established surface acoustic wave (SAW) and GaAs foundry serving the RF market; the third foundry agreement Resonant has secured to support its design services business model. The agreement expands the manufacturing capacity available for Resonant's filter designs and gives licensees additional foundry choices. Resonant said the new addition is a "full service" foundry serving first-tier filter suppliers and processing the filter designs for two Resonant licensees. Resonant's Infinite Synthesized Network® foundry program includes non-captive SAW foundries and backend and packaging partners, the latter enabling Resonant's filters to be integrated into front-end modules.

Verizon and **Ericsson** reached another milestone in 4G LTE advanced technologies that will also serve as a stepping stone to 5G technology by completing their first deployment of Frequency Division Duplexing (FDD) Massive MIMO on Verizon's wireless network in Irvine, Calif. This deployment will improve both spectral and energy efficiency, increasing network capacity for current devices in the market. Further significant enhancements are expected to come as new devices evolve toward 5G. For customers, the result will be higher and more consistent speeds for using apps and uploading and downloading files.

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ACHIEVEMENTS

For the fourth consecutive year, **Lansdale Semiconductor Inc.** achieved a 4-Star Supplier Excellence Award from **Raytheon's Integrated Defense Systems (IDS)**. This annual award for supplier excellence program was instituted by Raytheon's IDS to recognize top suppliers who have provided outstanding quality service and partnership in exceeding Raytheon's strict requirements. All award candidates are judged on U.S. military specifications criteria, including overall hi-rel quality, on time delivery and demonstrated supplier commitment to meeting and exceeding Raytheon's highest defense/military industry's standards. This prestigious award was presented to Lee Mathiesen, Lansdale's operations manager, recently at Raytheon's Suppliers annual appreciation ceremony.

Thales has developed COMTICS, the world's first shipboard information distribution system. Intuitive, resilient and designed for mobility, it offers an expansive array of operational services in a highly secure environment. COMTICS by Thales is a multimedia communication device resembling a smartphone that allows naval personnel permanent shipboard mobility and connectivity with all types of military radios. It provides services ranging from video and data transfers to web browsing and social media, if the operational situation allows, and the ability to chat with colleagues. Thales has designed COMTICS on the basis of its NGIN (Naval Voice Over IP) and FOCON IP (Fibre Optical Communication Network) solutions, which are fully proven at sea and have been adopted by 15 navies to date.

Mitsubishi Electric Corp. has begun field testing the world's first autonomous driving solution using centimeter-level augmentation service (CLAS) broadcast from the Quasi-Zenith Satellite System (QZSS). Driving tests are being conducted to verify the possibility of infrastructural driving, utilizing CLAS signals and high-precision 3D maps combined with Mitsubishi Electric's intelligent driving technology, including sensing technologies such as mmWave radar and cameras. CLAS is a positioning-augmentation service for high-precision positioning, distributed free of charge in Japan from the QZSS, which operates under the auspices of the Cabinet Office. It is scheduled to begin operation in April 2018 and is currently in the final stages of verification.

CONTRACTS

Lockheed Martin received a $158.5 million contract for the second phase of the **German Navy P-3C Mission System Refresh** program. The program will upgrade the mission system processing suites on the fleet of eight P-3C Orion maritime patrol aircraft to support operations through 2035. The Mission System Refresh is part of an overall fleet upgrade that includes structural mid-life upgrades as well as an upgrade to the Instrument Flight Rules (IFR) cockpit capability. The Lockheed Martin P-3C Orion Maritime Surveillance Aircraft provides maritime patrol, reconnaissance, anti-surface warfare and anti-submarine warfare capabilities over extended periods of time. Upgrades to the German Navy aircraft include mission system refresh kits, operator training and spares.

Harris Corp. has received a $133 million contract to supply electronic jammers to protect U.S. Navy and Australian F/A-18 Hornet and Super Hornet aircraft against electronic threats. The contract was awarded during the first quarter of Harris' fiscal 2018. Under the contract, Harris will manufacture and deliver ALQ-214(V) 4/5 Integrated Defensive Electronic Countermeasures (IDECM) jammers for the F/A-18C/D/E/F variants. The ALQ-214(V) 4/5 is the key onboard electronic warfare jamming system for the IDECM program and protects the aircraft from sophisticated electronic threats, including modern integrated air defense systems.

L3 Technologies has received a production contract for the **U.S. Army's MUMT-X** program for Apache attack helicopters. The Manned/Unmanned Teaming-eXpanded Capabilities helicopter program is for the teaming of communications and data between manned and unmanned aircraft. MUMT-X provides the Apache AH-64E with such a capability that is more robust, lighter and less expensive than the original Unmanned Aircraft System control system. The production contract, worth $97 million, follows L3's completion of a 2015 MUMT-X communications upgrade contract for systems for high-speed transmissions of wideband video and data. Under the contract, L3 will provide Apache MUMT-X above-rotor Unmanned Aerial System Receive technology solutions to support MUMT operations and air-to-air-to-ground line-of-sight data links.

BAE Systems has begun production of its sensor technology for the Long Range Anti-Ship Missile (LRASM) following a $40 million order from prime contractor **Lockheed Martin**. The sensor enables the missile to seek and attack specific high-threat maritime targets within groups of ships, including those protected by sophisticated anti-aircraft systems. The missile's range, survivability and lethality capabilities are designed to help warfighters more effectively conduct missions in denied environments from beyond the reach of return fire–meeting a pressing need for both the U.S. Navy and U.S. Air Force. LRASM is a next-generation, precision-guided stealth missile capable of semi-autonomously detecting and identifying targeted enemy ships.

CACI International Inc. announced it was awarded a $34.5 million task order to provide technology updates and operations and maintenance to the **U.S. Customs and Border Protection (CBP) Air and Marine Operations Surveillance System (AMOSS)**. This four-year task order, awarded under the Department of Homeland Security's Enterprise Acquisition Gateway for Leading-Edge Solutions II contract vehicle, represents continuing work in the company's Intelligence Services


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market area. Under this contract, CACI will deliver new capabilities, software updates and 24/7 operations and maintenance services for AMOSS. The company will also continue to provide data analysis and analytics to the Air and Marine Operations Center, as well as evaluation, testing and integration of new technologies and sensor feeds into the AMOSS system.

OSI Systems Inc. announced that its security division received a multi-year service contract valued at approximately $6 million from an international customer to provide continued service and support for Rapiscan® high energy X-ray cargo inspection systems, which are being utilized for border security.

Anaren Microwave Inc., a subsidiary of Anaren Inc., announced it has received a $5 million order from a leading defense prime contractor for hardware support of an airborne electronic warfare application. The order was booked at the end of last quarter and is expected to ship over the next several quarters.

Mercury Systems Inc. announced it received $4.7 million in orders from a leading defense prime contractor for high performance RF subsystems integrated into an advanced airborne electronic protection system. The order was booked in the company's fiscal 2018 first quarter and is expected to be shipped over the next several quarters. Mercury's entire suite of high-reliability RF and microwave solutions include components, modules and pre-integrated subsystems that deliver differentiated capabilities for electronic warfare and radar applications. With an industry-leading portfolio of solutions up to 140 GHz, the company's innovative packaging expertise enables optimization of size, weight and power without sacrificing performance or affordability.

Cobham Antenna Systems has been awarded a contract from **Korean Aerospace Industries Ltd.** to design and supply the fully conformal antenna suite for the future KF-X, next-generation indigenous multi-role and fighter aircraft. Cobham Antenna Systems has been a leader in conformal antenna technology since the company's inception over 50 years ago. This wealth of experience has allowed the company to develop a full suite of conformal antennas for the KF-X platform. Unlike traditional antennas which stand proud of the skin of a platform, conformal antennas are built into the skin and allow for reduced drag, improved aerodynamics and reduced life-cycle repair costs.

C3 IoT announced that it has been selected by **Defense Innovation Unit Experimental** to provide the AI and IoT software platform for rapidly delivering a new AI-based predictive maintenance solution for the **U.S. Department of Defense (DoD)** to increase asset availability and reduce maintenance expenditures, thereby enhancing operational value and DoD mission effectiveness. DIUx is a DoD organization focused on accelerating adoption of innovative commercial technologies such as AI for national defense. After a rigorous evaluation process that

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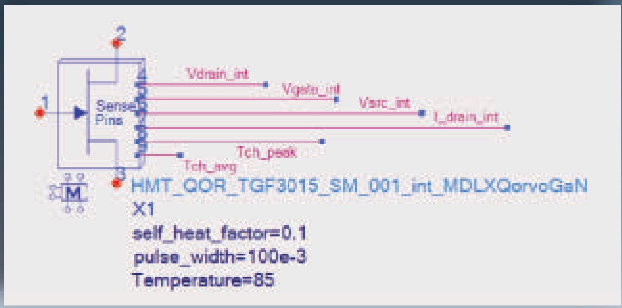

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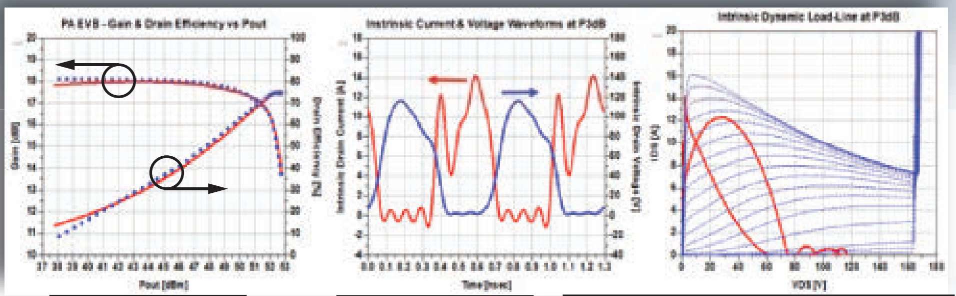

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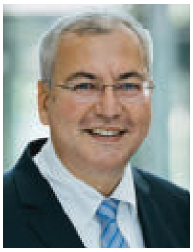
proved the maturity and scalability of the C3 IoT Platform, the DoD, via DIUx, has contracted C3 IoT for a multi-year agreement to deliver the C3 Predictive Maintenance™ solution for aircraft platforms.

PEOPLE


▲ *Jürgen Meyer*

Jürgen Meyer has been appointed director of the automotive market segment at **Rohde & Schwarz**. The company is currently developing an extended portfolio of automotive Ethernet and radar test solutions that includes radar target simulators for development and end-of-line production testing as well as analysis systems for testing the quality of high-frequency radar signals and determining how they are influenced by radomes and coatings. In his new role, Meyer will be instrumental in helping the company to consistently pursue its strategy of offering customers all-in-one solutions for automotive test and measurement tasks, taking responsibility for developing the market segment in relation to product positioning and expanding the customer base.

REP APPOINTMENTS

RFMW Ltd. and **CML Microcircuits (USA) Inc.** have announced a distribution agreement effective September 8, 2017. CML designs, manufactures and markets innovative analogue, digital, mixed signal and RF integrated circuits. CML is a world leader in low-power analogue, digital and mixed-signal semiconductors for telecommunications systems globally. The company is a member of the CML Microsystems Plc. group of companies. RFMW is a specialized distributor providing customers and suppliers with focused distribution of RF and microwave components as well as specialized component-engineering support. Under the agreement, RFMW is franchised to market and sell the CML product offerings in the Americas.

PLACES

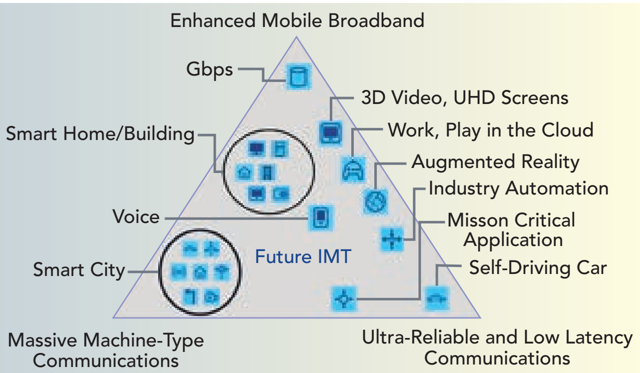
NAI has announced the opening of its new Solutions Center in Troy, Mich. This new facility is staffed by experienced design and application engineers who partner with NAI customers to provide the right connectivity solution for the customers' applications. The facility also works in close coordination with NAI resident engineers now located on-site with key customers. The NAI Solution Center's capabilities can be scaled to meet NAI customers' needs, ranging from design assistance to full service. Their engineers are available to help their customers in selecting the appropriate off-the-shelf materials and perform VA/VE (value-added/value-engineered) reviews of existing applications as well as design an entire connectivity solution.

INVITED PAPER

Pre-5G and 5G: Will The mmWave Link Work?

Andreas Roessler
Rohde & Schwarz, Munich, Germany

Any next-generation mobile communications technology has to provide better performance than the previous generation. With the transition from 3G to 4G, for example, theoretical peak data rates spiked from around 2 Mbps to 150 Mbps. Subsequently, LTE-Advanced Pro has reached Gbps peak data rates, with 1.2 Gbps data throughput recently demonstrated.[1] In a recent survey on 5G conducted by Qualcomm Technologies and Nokia,[2] 86 percent of the participants claimed that they need or would like faster connectivity on their next-generation smartphones. The conclusion that can be drawn from this is that data rates are always a driver for technology evolution.



▲ **Fig. 1** 5G application scenarios defined by IMT-2020.

But 5G is not only targeting higher data rates. The variety of applications that can be addressed with this next generation is typically categorized into what is commonly called the "triangle of applications," shown in ***Figure 1***. The hunt for higher data rates and more system capacity is summarized as enhanced mobile broadband (eMBB). Ultra-reliable low latency communications (URLLC) is the other main driver, with an initial focus on low latency. The requested lower latency impacts the entire system architecture—the core network and protocol stack, including the physical layer. Low latency is required to enable new services and vertical markets, such as augmented/virtual reality, autonomous driving and "Industry 4.0." The triangle is completed by massive machine-type communication (mMTC); however, initial standardization efforts are focusing on eMBB and URLLC. All these applications have different requirements and prioritize their key performance indicators in different ways. This provides a challenge, as these different requirements and priorities have to be addressed simultaneously with a "one fits all" technology.

TechnicalFeature

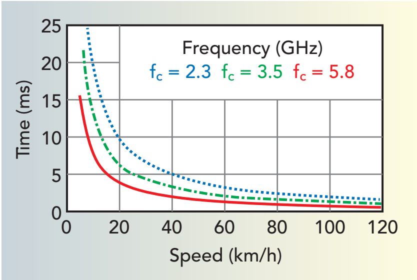
PRE-5G VS. 5G

It takes quite some time to define a "one fits all" technology within a standardization body, such as the 3rd Generation Partnership Project (3GPP). Several hundred companies and organizations are contributing ideas recommending how the challenges and requirements of 5G should be addressed. The proposals are discussed and evaluated and, finally, a decision is made on how to proceed. At the beginning of defining a new technology and standard that address the radio access network, air interface and core network, the process can be quite time consuming—time that some network operators do not have.

Often, one application is addressed and, in that case, a standard is developed that targets just one scenario. LTE in unlicensed spectrum (LTE-U) is one example in 4G. The goal was to easily use the lower and upper portion of the unlicensed 5 GHz ISM band to create a wider data pipe. 3GPP followed with its own, standard-embedded approach called licensed assisted access (LAA) about 15 months later. 5G is no different. Fixed wireless access (FWA) and offering "5G services" at a global sports event like the 2018 Winter Olympic Games in Pyeongchang, South Korea are two examples within the 5G discussion. For both, custom standards were developed by the requesting network operator and its industry partners. Both these standards are based on LTE, as standardized by 3GPP with its Release 12 technical specifications, enhanced to support higher frequencies, wider bandwidths and beamforming technology.

Take the example of FWA. The network operator behind this requirement is U.S. service provider Verizon Wireless. Today's service providers do not just offer traditional landline communications and wireless services; they also supply high speed internet connections to the home and are expanding into providing content through these connections. Verizon's initial approach to bridge the famous "last mile" connection to the home was fiber to the home (FTTH). In some markets, Verizon sold that business to other service providers, such as Frontier Communications.[3] To enhance its business model, Verizon is developing its own wireless technology for high speed internet connections to the home. To be competitive and stay future proof, Gbps connections are required that outperform what is possible today with LTE-Advanced Pro.

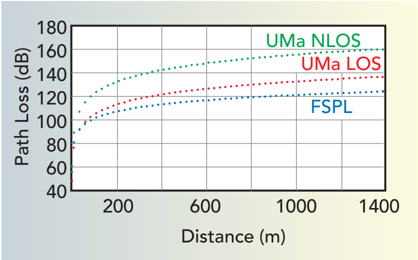
The achievable data rates over a wireless link depend on four factors: the modulation, achievable signal-to-noise ratio (SNR), available bandwidth and whether multiple-input-multiple-output (MIMO) antenna technology is used. From the early 90s to the millennium, the wireless industry optimized its standards to improve SNR and, thus, data rates. At the turn of the century and with the success of the Internet, this was no longer acceptable; bandwidth was increased up to 5 MHz with 3G.



▲ **Fig. 2 Coherence time vs. speed for three carrier frequencies below 6 GHz.**

TABLE 1
RECEIVER SENSITIVITY LIMIT

Thermal Noise Level (kT)	−174 dBm/Hz
Bandwidth Correction (100 MHz)	80 dB
Typical User Equipment Noise Figure	10 dB
Receiver Sensitivity Limit	−84 dBm



▲ **Fig. 3 28 GHz path loss vs. cell separation, comparing FSPL with LOS and NLOS for an urban macro deployment, using the ABG channel model.**

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Initially with 4G, wider bandwidth—up to 20 MHz—was introduced, as well as 2 × 2 MIMO. Today, with higher-order modulation up to 256-QAM, 8 × 8 MIMO and bundling multiple carriers in different frequency bands using carrier aggregation (CA), peak data rates have reached 1.2 Gbps. To further increase data rates, for the use case of FWA, in particular, wider bandwidths are required. This bandwidth is not available in today's sweet spot for wireless communications—between 450 MHz and 6 GHz. More bandwidth is only available at higher frequencies with centimeter and mmWave wavelengths. But there is no free lunch. Moving up in frequency has its own challenges.

TABLE 2
28 GHz DOWNLINK LINK BUDGET

Parameter	Assumptions	Value
Receiver Sensitivity Limit	100 MHz	−84 dBm
Required SNR	16-QAM, ½ FEC	8 dB
Total Array Gain	16 Elements	17 dB
Estimated Path Loss	1000 m ISD	133 to 156 dB
Required Transmit EIRP*		40 to 63 dBmi

*EIRP = Receiver Sensitivity + SNR – Rx Antenna Gain + Path Loss

TABLE 3
REQUIRED MINIMUM CONDUCTED POWER

Required Tx EIRP	40 to 63 dBm
Array Size	64
Beamforming Array Gain	17 dB
Single Element Gain (Typically 5 to 8 dBi)	6 dBi
Minimum Conducted Power	17 to 40 dBm

TABLE 4
28 GHz UPLINK LINK BUDGET

Total Tx EIRP	40 dBm
Path Loss	133 to 156 dB
Bandwidth	100 MHz
Thermal Noise	−94 dBm
Rx Noise Figure	6 dB
Minimum Detectable Signal	−88 dBm
Required SNR with QPSK and ½ FEC	5 dB
Total Rx Beamforming Gain	24 dBi
100 MHz Rx Signal Bandwidth	−107 dBm
Link Margin*	−9 to +14 dB

*Link Margin = Total Tx EIRP – Path Loss – Rx Signal

HIGH FREQUENCY CHALLENGES

Analyzing the free space propagation loss (FSPL), path loss increases as frequency increases. Wavelength (λ) and frequency (f) are connected through the speed of light (c), i.e.,

$$\lambda f = c$$

and as frequency increases, wavelength increases. This has two major effects. First, with decreasing wavelength the required spacing between two antenna elements (usually λ/2) decreases, which enables the design of practical antenna arrays with multiple antenna elements. The higher the order of the array, the more the transmitted energy can be focused in a specific direction, which allows the system to overcome the higher path loss experienced at cmWave and mmWave frequencies. The second effect relates to propagation. Below 6 GHz, diffraction is typically the dominating factor affecting propagation. At higher frequencies, the wavelengths are so short that they interact more with surfaces, and scattering and reflection have a much greater effect on coverage.

mmWave frequencies also challenge mobility. Mobility is dependent on the Doppler shift, f_d, defined by the equation:

$$f_d = f_c v/c$$

where f_c is the carrier frequency and v is the desired velocity that the

system supports. The Doppler effect is directly related to the coherence time, $T_{coherence}$, which may be estimated with the approximation:

$$T_{coherence} \cong 1/(2f_d)$$

Coherence time defines the time the radio channel can be assumed to be constant, i.e., its performance does not change with time. This time impacts the equalization process in the receiver. As shown in ***Figure 2***, the coherence time decreases with increasing speed. For example, to drive 100 km/h and maintain the link at a carrier frequency of 2.3 GHz, the coherence time is about 2 ms. That means the radio channel can be assumed to be constant for 2 ms. Applying the Nyquist theorem, with a time period of 2 ms, two reference symbols need to be embedded in the signal to properly reconstruct the channel. Figure 2 shows that coherence time decreases at higher frequencies. For cmWave frequencies, the Doppler shift is already 100 Hz at walking speed, and it increases with higher velocity. Thus, the coherence time decreases significantly, making the use of cmWave and mmWave frequencies in high-mobility scenarios inefficient. This is the major reason why 3GPP's initial focus standardizing the 5G new radio (5G NR) is on the so called non-standalone (NSA) mode, using LTE as the anchor technology for the exchange of control and signaling information and for mobility. With FWA, mobility is not required, so Verizon's technology approach can completely rely on mmWave frequencies, together with the exchange of control and signaling information between the network and connected device.

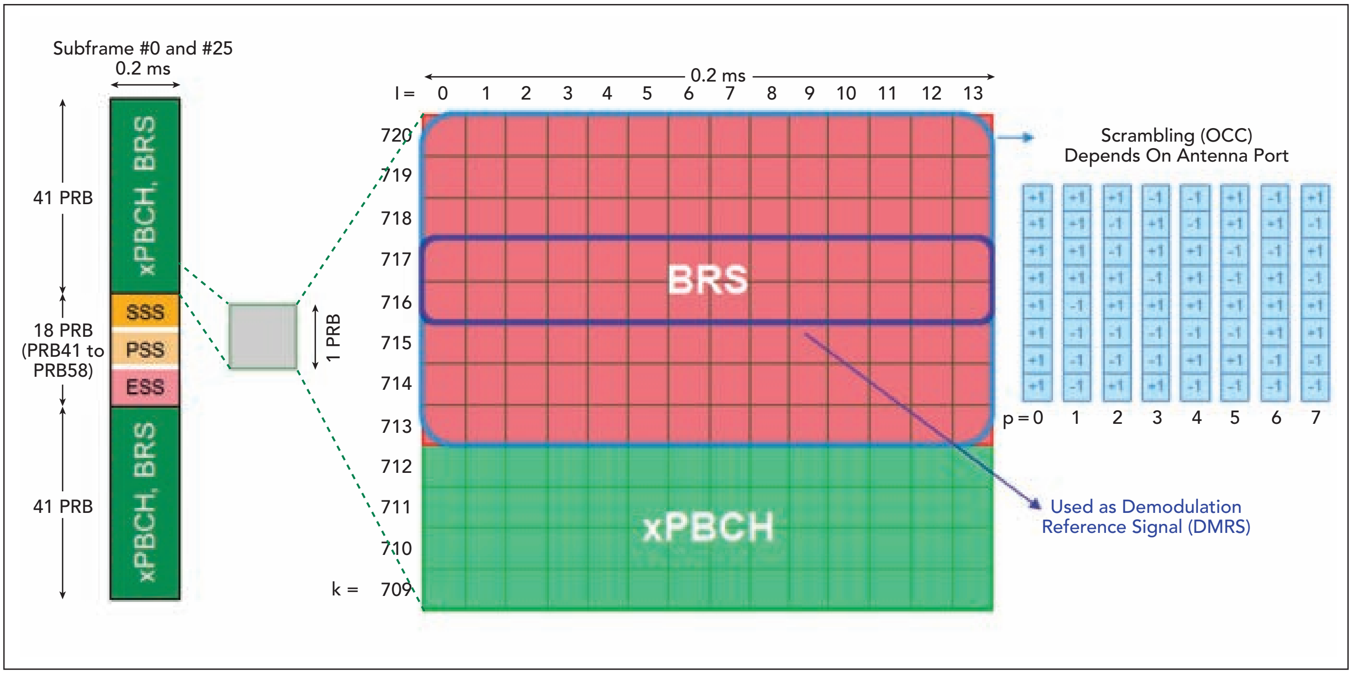
TABLE 5
V5GTF VS. LTE PHY COMPARISON

PHY Parameter	LTE Release 8-14	Verizon 5G TF
Downlink (DL) Modulation	OFDM	OFDM
Uplink (UL) Modulation	DFT-S-OFDM (SC-FDMA)	OFDM
Subframe Length	1 ms	0.2 ms
Subcarrier Spacing	15 kHz	75 kHz
Sampling Rate	30.72 MHz	153.6 MHz
Bandwidth	20 MHz	100 MHz
NFFT	2048	2048
OFDM Symbol Duration, No CP	66.67 µs	13.33 µs
Frame Length	10 ms	10 ms
# of Subframes/Slots	10/20	50/100
CP Type	Normal and Extended	Normal Only
Multiplexing	FDD/TDD	Dynamic TDD
Maximum RBs	6, 15, 25, 50, 75, 100	100
DL/UL Coding	Turbo	LDPC

28 GHz LINK BUDGET

As explained, the use of antenna arrays and beamforming enables the use of mmWave frequencies for wireless communication. Verizon targets the 28 GHz frequency band that was allocated by the FCC as 5G spectrum in 2016,[4] with a bandwidth up to 850 MHz. With its acquisition of XO Communications in 2015,[5] the operator gained access to 28 GHz licenses and is planning to use these for its initial roll-out of its own (Pre-)5G standard, summarized under the name 5G Technical Forum.[6]

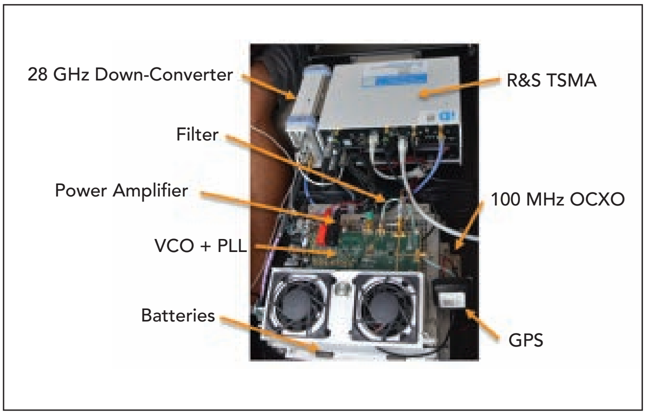
From an operator's perspective, the viability of a new technology depends on fulfilling the business case given by the business model. The business case is governed by two main factors: the required capital expenditure (CAPEX), followed by the cost to operate and maintain the network, referred to as OPEX. CAPEX is driven by the number of cell sites deployed, which depends on the required cell edge performance (i.e., the required data rate at the cell edge) and the achievable coverage. cmWave and mmWave allows beamforming that helps overcome the higher path loss, but



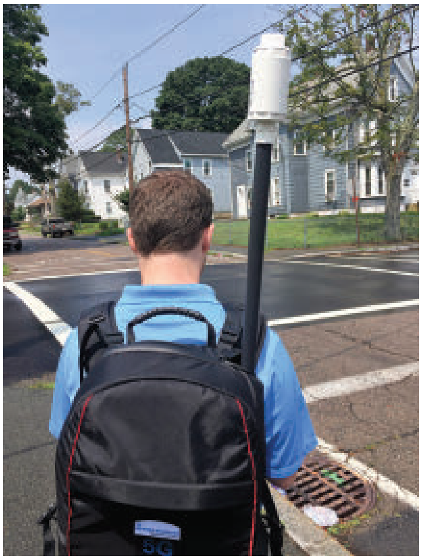
▲ **Fig. 4** 5GTF synchronization and beamforming reference signals.

coverage is still limited compared to frequencies below 6 GHz, the primary spectrum being utilized for wireless communications.

To ensure adequate coverage, a link budget analysis is essential. Considering the 28 GHz band with 100 MHz carrier bandwidth, first the receiver sensitivity limit is calculated. The thermal noise level is -174 dBm/Hz and needs to be adjusted to the supported bandwidth of 100 MHz per component carrier, as defined in the 5GTF standard. In this calculation, the typical noise figure used for the receiver is 10 dB, which results in an overall receiver sensitivity limit of -84 dBm/100 MHz (see ***Table 1***). Next, the expected path loss is determined. Free space path loss is based on a line-of-sight (LOS) connection under ideal conditions. In reality, this is not the case, so extensive channel sounding measurement campaigns have been executed by various companies with the help of educational bodies, resulting in channel models describing the propagation in different environments and predicting the expected path loss. These are typically for LOS and non-LOS (NLOS) types



▲ **Fig. 5** R&S 5GTF coverage measurement system.



▲ **Fig. 6** Using the R&S system in the field.

▲ Fig. 7 Example 5GTF coverage measurements.

of connections. With FWA, NLOS connections are normally used. Early on, Verizon and its industry partners used their own channel models, despite 3GPP working on a channel model for standardizing 5G NR. There are, of course, differences between these models. For the link budget analysis considered here, one of the earliest available models is used.[7]

Assuming an urban macro (UMa) deployment scenario, ***Figure 3*** displays the expected path loss at 28 GHz for LOS and NLOS connections compared to FSPL. From an operator's perspective, a large inter-cell site distance (ISD) is desired, since the higher the ISD, the fewer cell sites are required and the lower the CAPEX. However, the link budget determines the achievable ISD. Various publications show that an ISD of 1000 m is a deployment goal. Such an ISD results in a path loss of at least 133 dB for LOS and 156 dB for NLOS links using the alpha beta gamma (ABG) channel model. The next step is to decide on the required cell edge performance, i.e., the required data rate. The data rate per carrier depends on the modulation, MIMO scheme and achievable SNR. A typical requirement is, for example, to achieve a spectral efficiency of 2 bps/Hz, i.e., 200 Mbps for a 100 MHz wide channel. To achieve this, an SNR of around 8 dB is required, which increases the receiver sensitivity limit further. However, as the receiver is using an antenna array, beamforming gain is available, determined by the gain of a single antenna element and the total number of elements.

A good approximation in this early stage of 5G development is 17 dBi for the total receive beamforming gain. Based on the estimated path loss, the required total equivalent isotropic radiated power (EIRP) and the required conducted transmit power can be determined. Given the above calculations, the required total EIRP for the transmit side is between 40 and 63 dBm (see ***Table 2***). It is a fair assumption that using a larger antenna array at the 5G remote radio head results in larger beamforming gain. ***Table 3*** provides an ideal calculation of what conducted power is required to provide the required EIRP (17 to 40 dBm). For mmWave components, these are high output powers, and it is a challenge to the industry to design power amplifiers and the required circuitry to drive the RF front-end and antenna arrays. As not all substrates can provide such a high output power, the industry faces a philosophy battle among companies designing these RF components. One of the challenges is to provide components with an acceptable power-added efficiency to handle the heat dissipation.

Based on this analysis, establishing a viable communication link in the downlink direction with an ISD of 1000 m is possible. However, previous generations of wireless technologies were uplink power limited, and 5G is no exception. ***Table 4*** shows the uplink link budget assuming a maximum conducted device power of +23 dBm and the form factor of a customer premise equipment (CPE) router with a 16-element antenna array. Depending on the path loss and the assumed channel model, a link margin can be calculated that spans quite a range (i.e., -9 to +14 dB). Everything below zero indicates, of course, that the link cannot be closed. Based on these rather ideal calculations, it can be concluded that an uplink at mmWave frequencies with an ISD of 1000 m is problematic.

For that reason, 3GPP defines a 5G NR user equipment (UE) power class that allows a total EIRP of up to +55 dBm.[8] Current regulations in the U.S. allow a device with such a high EIRP but not in a mobile phone form factor.[9] However, achieving this EIRP is a technical challenge by itself and may come to the market at a much later stage. From that perspective, a service provider should consider a shorter ISD in its business case. Current literature and presentations at various conferences indicate that cell sizes of 250 m or less are being planned for the first-generation of radio equipment. Now it needs to be determined if a shorter ISD, such as 250 m, fulfills the business case for 5G mmWave FWA.

5GTF INSIGHTS

The Verizon 5G standard uses the existing framework provided by 3GPP's LTE standard. Moving up in carrier frequency and factoring the increasing phase noise at higher frequencies, wider subcarrier spacing is required to overcome the intercarrier interference (ICI) that will be created. The Verizon standard uses

75 kHz instead of 15 kHz. A comparison of all major physical layer parameters is given in ***Table 5***.

In determining 5G network coverage, several physical signals should be understood. Compared to LTE, the synchronization signals (PSS and SSS) are transmitted in Verizon's 5G standard in a frequency-division multiplexing (FDM) technique, versus the time-division multiplexing (TDM) approach for LTE. Also, a new synchronization signal is introduced, the extended synchronization signal (ESS) that helps to identify the orthogonal frequency-division multiplexing (OFDM) symbol timing. ***Figure 4*** shows the mapping of the synchronization signals (SSS, PSS, ESS) contained in special subframes 0 and Z5; they are surrounded by the beamforming reference signal (BRS) and extended physical broadcast channel (xPBCH).

A device uses the synchronization signals during the initial access procedure to determine which 5G base station to connect to and then uses the BRS to estimate which of the available beamformed signals to receive. The standard allows for a certain number of beams to be transmitted, the exact number depending on the BRS transmission period. This information is provided to the device via the xPBCH. In its basic form, one beam is transmitted per OFDM symbol; however the use of an orthogonal cover code (OCC) allows for up to eight beams per OFDM symbol. Depending on the selected BRS transmission period —there are four options: one slot, one, two or four subframes—multiple beams can be transmitted, on which the CPE performs signal quality measurements. Based on these BRS received signal power (BRSRP) measurements, the CPE will maintain a set of the eight strongest beams and report the four strongest ones back to the network. In general, the same principles apply as for determining coverage for existing 4G LTE technology. A receiver (network scanner) first scans the desired spectrum, in this case 28 GHz, for synchronization signals to determine the initial timing and physical cell ID that is provided by PSS and SSS. The ESS helps to identify the OFDM symbol timing. The next step is to perform quality measurements—same as a CPE would do —on the BRS to determine which has the best receive option and maintain and display the set of eight strongest received beams.

Due to the aggressive timeline for early 5G adopters, Rohde & Schwarz has designed a prototype measurement system that uses an ultra-compact drive test scanner covering the frequency bands up to 6 GHz. This frequency range is extended by using a down-conversion approach: down-converting up to eight 100 MHz wide component carriers transmitted at 28 GHz into an intermediate frequency range that can be processed by the drive test scanner. The entire solution is integrated into a battery-operated backpack, enabling coverage measurements in the field, for example,

in office buildings. ***Figure 5*** shows the setup and its components, and ***Figure 6*** shows the scanner being used during a walk test in a residential neighborhood.

An example of the measurement results is shown in ***Figure 7***. In the screen to the right, the eight strongest beams for all detected carriers (PCI) are plotted, including the discovered beam index. The two values below the actual bar show the PCI (top), secondly the beam index. The beams are organized based on the best carrier-to-interference ratio (CINR) being measured for the BRS, rather than BRSRP. At the top of the screen, the user can enter a particular PCI and identify the eight strongest beams for that carrier at the actual measurement position. Also, the scanner determines the OFDM symbol the beam was transmitted in, as well as which OCC was used. Based on the measured BRS CINR, a user can predict the possible throughput at the particular measurement position. Next is the measured synchronization power and CINR for the synchronization signals. In a mobile network, based on the CINR, a device would determine if the detected cell is a cell to camp on. That is usually determined based on a threshold defined as a minimum CINR based on the synchronization signals. This is −6 dB for LTE and, for pre-5G, is being evaluated during the ongoing field trials. In Verizon's 5GTF standard, the synchronization signals are transmitted over 14 antenna ports that ultimately point these signals in certain directions. Therefore, the application measures and displays synchronization signal power, CINR and, in addition, the identified antenna port.

SUMMARY

As discussed throughout this article, the business case for using mmWave frequencies in a FWA application scenario stands or falls depending on whether the link budget can be fulfilled at an affordable ISD. When deploying 5G FWA, network equipment manufacturers and service providers will require optimization tools to determine the actual coverage before embarking on network optimization.■

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INVITED PAPER

Ready to Test 5G Data Throughput?

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With mobile operators fast-tracking their 5G deployment plans, the realization of 5G is rapidly approaching. To keep pace, chipset and device manufacturers will need to accelerate their own development activities. If these efforts pay off, 5G will deliver new and powerful capabilities to support use cases requiring much faster data rates, ultra-reliable low latency (uRLLC) and massive machine-type communications (mMTC). However, that is easier said than done, given the challenge that comes with testing 5G's high data rates.

5G USE CASES

There are three main use cases for 5G. They are enhanced mobile broadband (eMBB), uRLLC and mMTC. The eMBB use case is targeted in the Verizon 5G Technical Forum (5GTF) specification, as well as phase 1 of the 3GPP new radio (NR) specification. Due to strong industry demand, this use case and its definition have been accelerated. 3GPP has agreed to the early completion of the non-standalone (NSA) 5G NR mode for eMBB. In NSA mode, the connection is anchored in LTE with 5G NR carriers used to boost data rates and reduce latency. Data rates up to 20 Gbps in the downlink and 10 Gbps in the uplink are on the horizon for network rollouts in the next few years.

The 5G eMBB use case provides functionality to support high speed data rates, improved connectivity and system capacity. That is critical, since consumers want the ability to connect to the network wherever they are, such as attending a sports event, traveling in a car or riding on a high speed train or other public transport. High data rates and greater capacity are essential to using virtual reality (VR) and augmented reality (AR) applications, which include new video formats with increased resolutions ($8K^+$) and higher frame rates (HFR). For interactive AR and VR applications, low latency is a key requirement. With the number of users increasing and simultaneously consuming or sharing premium content, 4G networks will struggle to provide the capacity. That underscores the necessity of improved capacity with a 5G network.

To achieve the higher data rates, improved connectivity and greater system capac-

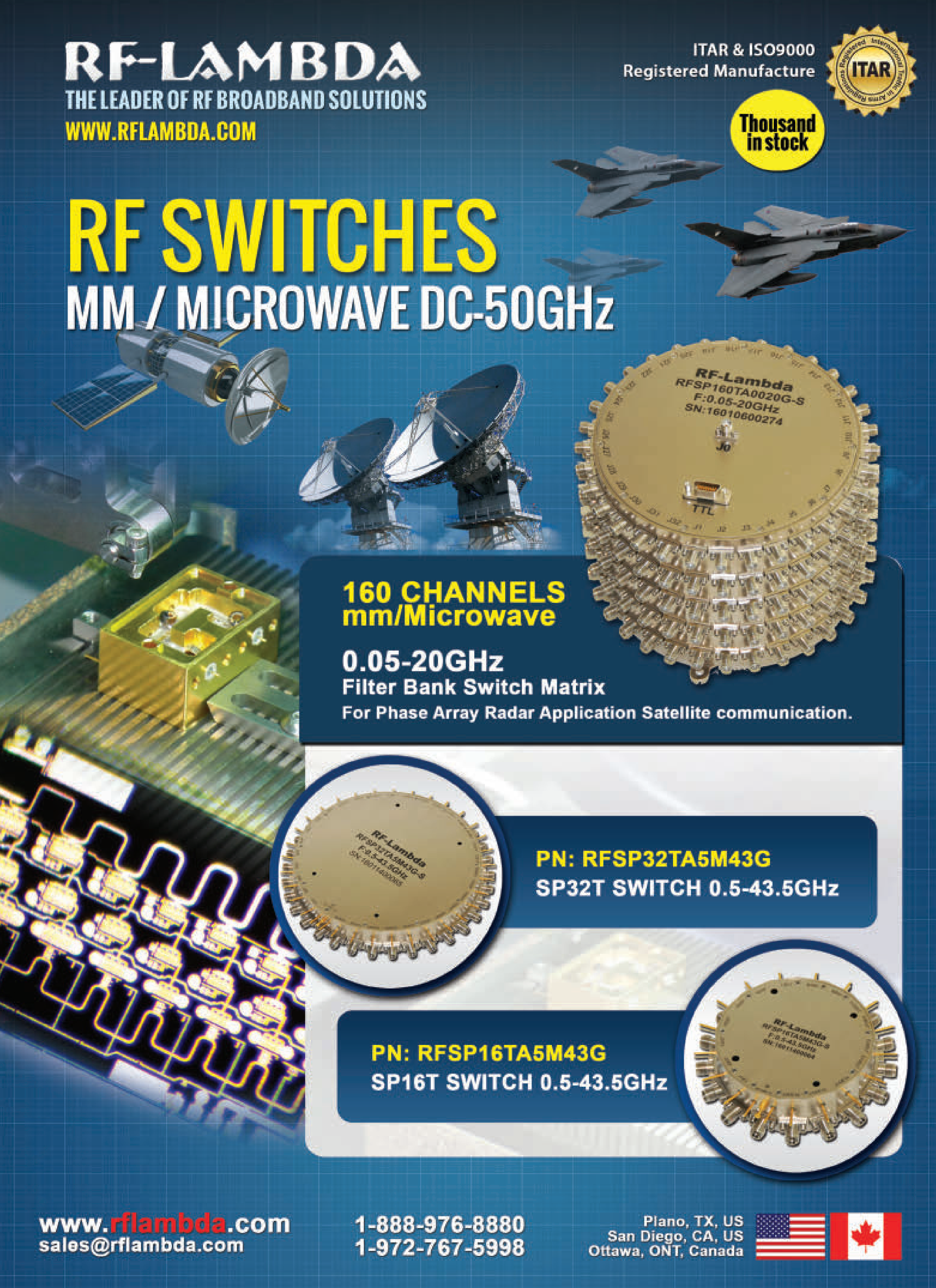
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TABLE 1

PHY COMPARISON. 3GPP 5G NR SPECIFICATIONS MAY CHANGE.

Characteristic	LTE	5GTF	3GPP 5G NR
Frame Structure			
Radio Frame	10 ms	10 ms	10 ms
Subframes/Frame	10	50	10
Slots/Frame	20 (Each 1 ms)	100 (Each 0.1 ms)	20 (Each 1 ms)
Resource Blocks	100 max	100 max	≥100
Frequency Domain			
Carrier Aggregation	5 (Rel.10)/32 (Rel.12)	8	16
Subcarrier Spacing	15 kHz	75 kHz	Flexible: $2^n \cdot 15$ kHz (n= -2, 0, 1, …, 5)
Carrier Bandwidth	1.4, 3, 5, 10, 15, 20 MHz	100 MHz	Variable, Maximum per CC is 400 MHz
Frequency Bands	Under 6 GHz	28 GHz	Up to 100 GHz
Beamforming	Applicable to Certain Transmission Modes	With DL/UL Reciprocity	With and Without DL/UL Reciprocity
Modulation	Up to 256-QAM	QPSK, 16-QAM and 64-QAM	QPSK, 16-QAM, 64-QAM and 256-QAM
MIMO	Up to 8 x 8	2 x 2 Only	Up to 8 x 8
Channel Coding Scheme	Turbo Coding for Data	LDPC for Data	NR Polar Codes (Control); NR LDPC (Data)

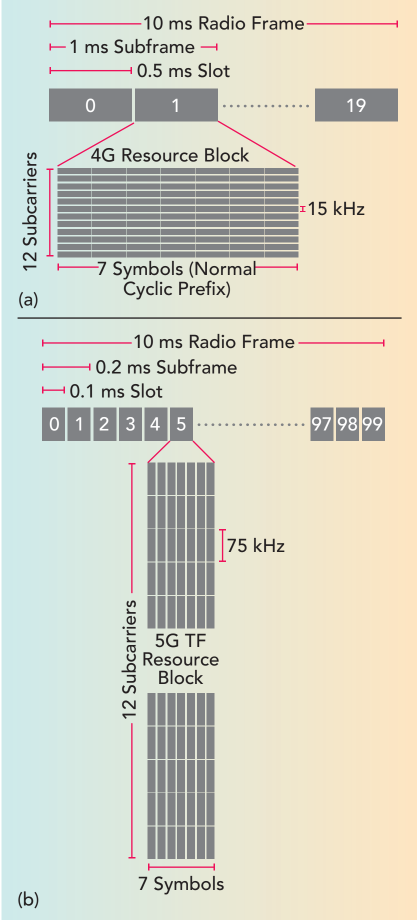

Fig. 1 LTE (a) and 5GTF (b) frame structures.

ity for eMBB than is available using sub-6-GHz frequencies, 5G is also being deployed in the higher frequency mmWave spectrum, which offers significantly greater bandwidth. While LTE operates at frequencies up to 6 GHz, mmWave frequencies up to 100 GHz are under consideration for 5G. 5GTF specifications covering 28 and 39 GHz are also being considered by other operators. At higher frequencies, propagation and penetration losses increase. To overcome the high path loss and improve connectivity to users at the cell edge, beamforming techniques will be employed. Beamforming increases the signal level received by a device, which results in a stronger signal-to-noise ratio, by providing high gain in specific spatial directions.

eMBB TEST CHALLENGES

The introduction of beamforming in the 5GTF and 3GPP NR specifications creates several new test challenges. Adding to these are the changes in the physical layer (PHY)—the frame structure, new reference signals and new scheduling and transmission modes—to support the eMBB use case. Understanding the new frame structure and beamforming concept is critical. To aide in this discussion, consider ***Table 1***, which compares the PHY characteristics among the LTE, 5GTF and 3GPP 5G NR specifications. Note that all changes from the LTE standard are denoted in red. As shown in the table, the 5GTF frame structure parameters (e.g., subcarrier spacing and carrier bandwidth) are fixed compared to the 3GPP NR values. The 3GPP NR values are scalable to accommodate a wider range of use cases. As previously mentioned, 5GTF targets the eMBB use case. In this specification, higher subcarrier spacing, carrier bandwidth and use of higher frequencies all contribute to a higher data rate and improved connectivity, compared to LTE.

The radio frame size in LTE and 5GTF is the same: 10 ms (see ***Figure 1***). In LTE, each frame contains 10 subframes and 20 slots, compared with the 50 subframes and 100 slots in 5GTF. This means that 5GTF slots (0.1 ms) are shorter than LTE slots. A resource block is the smallest entity that can be assigned to a device. Both LTE and 5G resource blocks consist of one slot in the time domain and 12 subcarriers in the frequency domain. LTE has a typical subcarrier spacing of 15 kHz, compared to 75 kHz in 5GTF. The maximum carrier bandwidth in LTE is 20 MHz, compared to 100 MHz in 5GTF if 100 resource blocks are being used. The higher 5GTF and 5G bandwidth results in higher data rates and improved network capacity.

The 5GTF specification supports the use of carrier aggregation (CA) in the downlink and uplink using a maximum of eight component carriers (CC). If CA is used, the bandwidth will be 800 MHz (8 × 100 MHz). The throughput rate is calculated using transport block size (TBS), which is the number of bits

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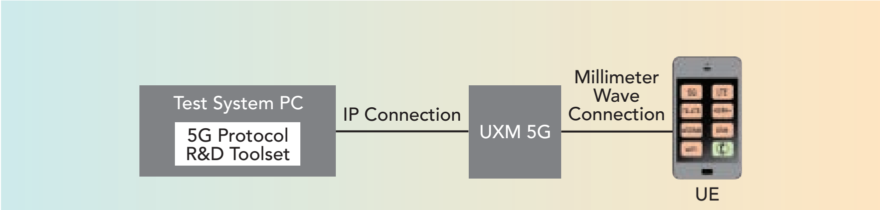


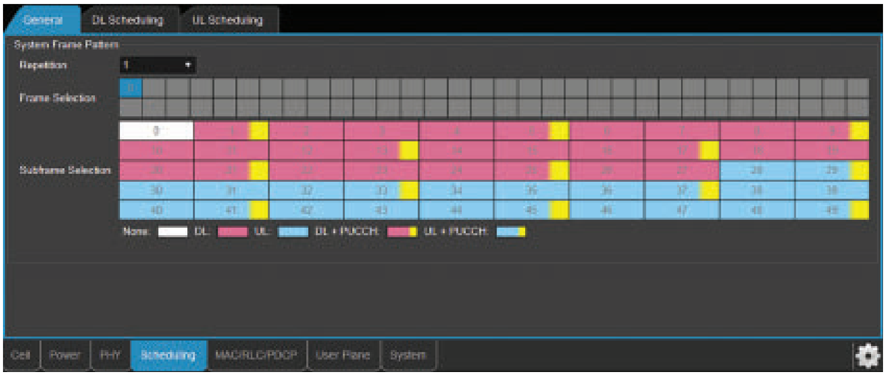
▲ **Fig. 2** **Example system for eMBB data throughput testing, including Keysight's 5G UXM network emulator and Protocol R&D Toolset.**

transmitted in one subframe every transmit time interval (TTI). TBS is dependent on the number of resource blocks allocated to the user equipment (UE), as well as the modulation and coding scheme (MCS) used. In the 5GTF specification, the highest MCS is 64-QAM, while the highest TBS is 66,392 bits. This results in a throughput rate of 663.92 Mbps per CC. If eight CCs are used, the throughput becomes 5.3 Gbps per UE (663.92 Mbps × 8).

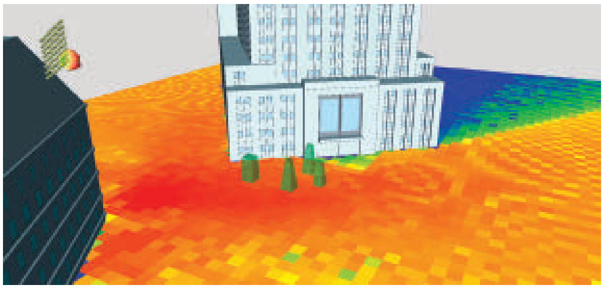
TESTING eMBB

While beamforming and mmWave are being utilized to maximize the capabilities of the available spectrum, use of these technologies makes 5G implementation and testing all the more challenging. When testing 5G data throughput at higher frequencies, for example, a test setup equipped with additional hardware is required. An example of the type of 5G test system needed for eMBB data throughput testing is shown in ***Figure 2***. The system consists of a 5G network emulator that is connected and controlled by a PC running software for prototyping advanced 5G protocol features, like beamforming at mmWave frequencies. In this setup, the UE is connected to the test system using a mmWave connection, to support the high frequency link required to achieve the high data throughput of eMBB. The high frequency challenges from incorporating antenna connectors in chipsets and handsets means that any data throughput testing must be done over-the-air (OTA).

To ensure ease of use, the optimal 5G test system should allow designers to create, edit, configure and run tests (scripts) directly from a graphical user interface (GUI). With this capability, the script elements for activating, deactivating and reconfiguring 5G cells, inserting radio resource control (RRC) and non-access stratum (NAS) messages and inserting user prompts and verdicts can be easily dragged and dropped into an editor and then configured. If sample scripts are available within the tool, these can be loaded into the editor and modified as needed. Data throughput test cases are created by loading scripts and configuring script elements. Examples of parameters that can be configured are power levels for synchronization and reference signals, beamforming parameters and resource blocks for transmitting and receiving control information and data.



▲ **Fig. 3** **GUI for configuring subframe patterns.**

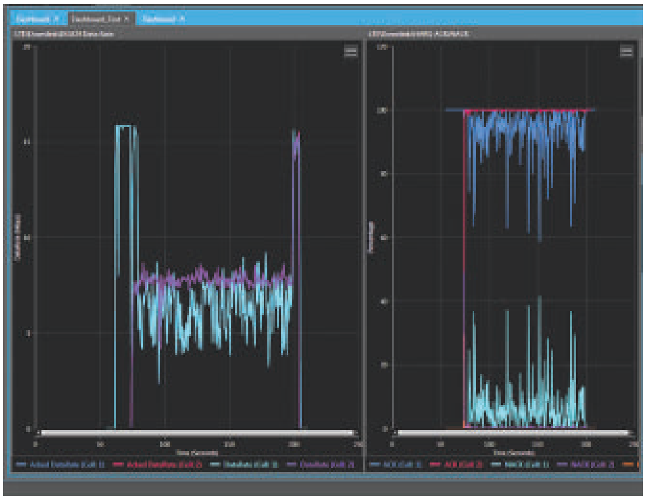


During testing, dynamic control points (DCP) are used to allow the 5G network emulator state machine to behave like a live network until a certain exit condition is met. The exit condition might be the device sending a particular message (e.g., attach complete), the user performing some action (e.g., sending data for data throughput testing) or the end of a configured guard timer. During a script run, at a DCP, the user should be able to modify the parameters using a L1/L2 configuration application (see ***Figure 3***). Some of the parameters that can be configured include:

- Scheduling subframes for the connected cell, including the subframes to be used for uplink (UL) and downlink (DL) control information and those to be used for UL and DL data.
- Layer 2 parameters (e.g., frequency, beam reference signal (BRS) transmission period, BRS transmit power, system information block (xSIB) default configuration and physical broadcast channel (xPBCH) transmit periodicity).

To ensure rapid device development, the optimal 5G test system should allow access to detailed logs and log analysis tools to help diagnose issues quickly, reliably and efficiently. A good log application should provide message decoding, enhanced search facilities and rapid navigation tools for easily finding records of interest. A tool that allows for the addition of bookmarks to facilitate troubleshooting and exporting of features is highly recommended.

A graphical key performance indicator (KPI) view may be helpful, enabling designers to make informed decisions more quickly (see ***Figure 4***). For data throughput, typical KPIs include graphs of data rates at different layers (PHY, MAC, RLC, PDCP and application), channel quality information (CQI), MCS, block error rate (BLER) and acknowledgment/negative-acknowledgment (ACK/NACK) versus time. It is also important to measure the quality of the signal since that affects data throughput. KPIs like beam state information (BSI) and beam refinement information (BRI) are used to check that the UE has selected the strongest beam, as reported by the network.



▲ **Fig. 4** Graphical KPI view.

SUMMARY

Achieving 5 Gbps and higher data rates is an exciting prospect, although it presents unique implementation and test challenges. Addressing these demands requires test methods and platforms that can handle very high data rates without requiring time consuming, costly and complex test programming. Performing 5G testing efficiently and accurately is important. Just as important is easy access to 5G network parameters and test results. With this information, design changes can be made quickly and efficiently, guaranteeing a smooth transition from prototype to product. With the right test methods and platforms, engineers can better ride the wave to successful 5G development.■

INVITED PAPER

Simulation Speeds NB-IoT Product Development

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Analysts from technology research firm Gartner are predicting a population of over 26 billion devices—excluding smartphones, tablets and computers—connected to the internet of things (IoT) by 2020. This volume of connected devices will require massive support from existing wireless networks. Among the mobile IoT (MIoT) technologies to be standardized by the 3rd Generation Partnership Project (3GPP), narrowband IoT (NB-IoT) represents the most promising low power wide area network (LPWAN) radio technology, enabling a wide range of devices and services to be connected using the cellular telecommunications bands (see ***Figure 1***).

This article presents an overview of NB-IoT requirements, how they compare with LTE and the resulting challenges for component development. The use of simulation tools for system analysis and design is demonstrated using NI AWR Design Environment, specifically, Visual System Simulator™ (VSS) system design software. VSS test bench examples are presented, including NB-IoT signals operating in the same band as an LTE signal and in the guard band of an LTE signal.

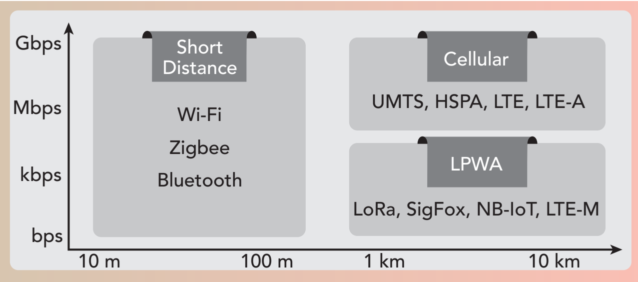


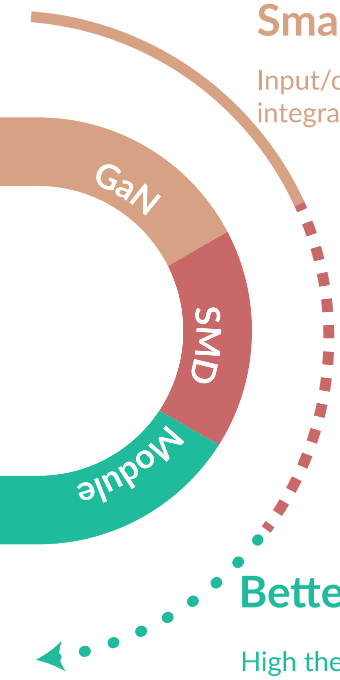
Fig. 1 Universe of networking technologies.

SYSTEM REQUIREMENTS

In release 13, the 3GPP specified a new radio air interface for MIoT applications. It focuses on improved indoor coverage, low-cost devices (less than $5 per module), long battery life (more than 10 years), massive connectivity (around 50,000 connected devices per cell) and low latency (less than 10 ms). NB-IoT will enable operators to expand their wireless services to applications such as smart metering and tracking and will enable nascent opportunities such as "smart cities" and eHealth infrastructure. NB-IoT will efficiently connect these many devices using the existing mobile networks, adding small amounts of fairly infrequent two-way data, securely and reliably. The standard utilizes 180 kHz user equipment (UE) bandwidth for both downlink and uplink and can operate in three different deployment modes. As shown in ***Figure 2***, these mode are:

- Standalone operation, in which a GSM operator replaces a 200 kHz GSM carrier with NB-IoT, re-farming dedicated spectrum in, for example, GSM EDGE radio access network (GERAN) systems. This is possible because both the GSM carrier's bandwidth and the NB-IoT bandwidth,

GaN SMD Module for 4G/5G Small Cell



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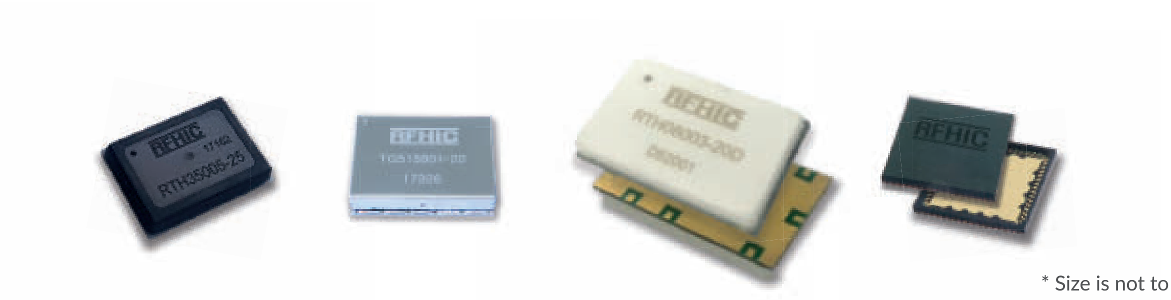

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inclusive of guard band, are 200 kHz.

- NB-IoT inside an LTE carrier, where the operator allocates one of the 180 kHz physical resource blocks (PRB) to NB-IoT. The NB-IoT air interface is optimized for harmonious coexistence with LTE without compromising the performance of either.
- Guard-band deployment, utilizing the unused resource blocks (RB) within an LTE carrier's guard band.

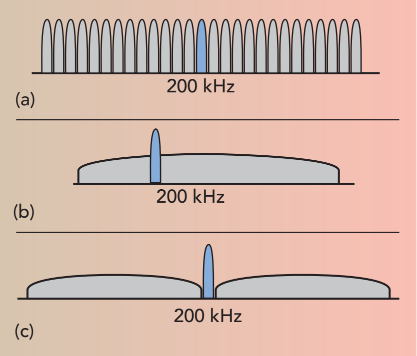


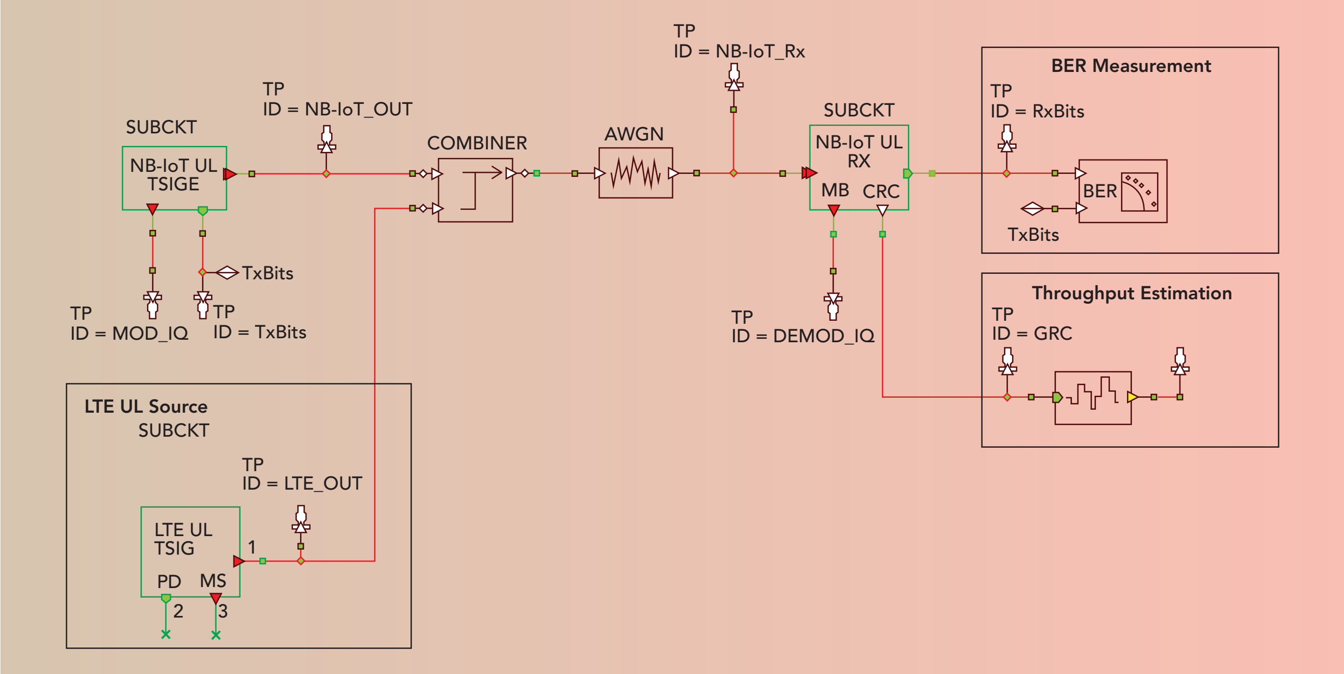
Fig. 2 Deployment modes for NB-IoT: standalone GSM (a), in-band LTE (b) and guard-band LTE (c).

Table 1 shows the specifications for NB-IoT, which are quite different than the specifications for existing cellular technology. Where cellular technologies require large bandwidth with high data rates and low latency at the expense of lower device battery life, IoT requires robust data transmission with significantly lower data rates, long range coverage and long device battery life. While LTE uses

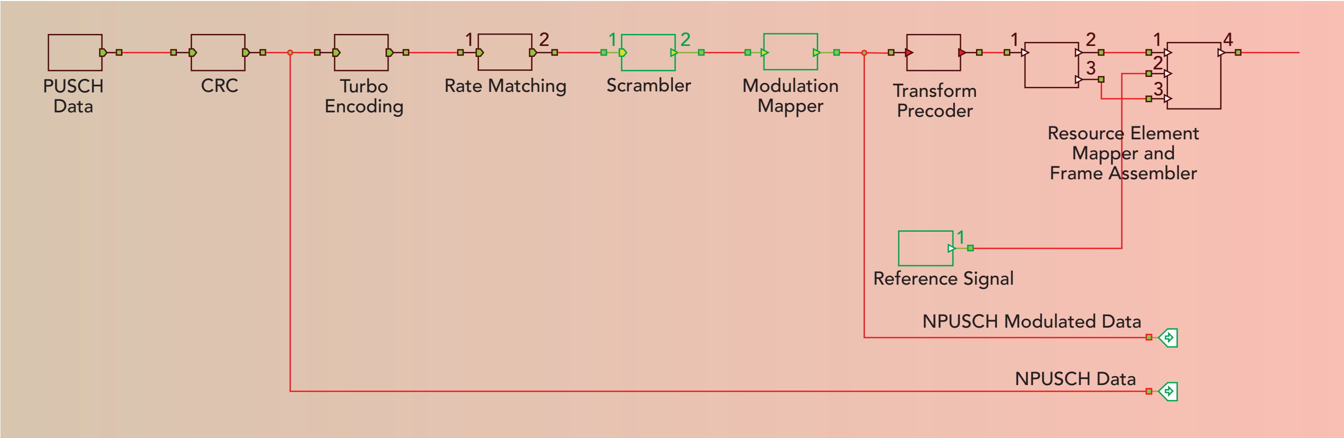
TABLE 1

NB-IoT SPECIFICATIONS

	NB-IoT
Deployment	Standalone GSM, In-Band LTE, Guard-Band LTE
Coverage (Maximum Coupling Loss)	164 dB
Downlink	OFDMA, 15 kHz Tone Spacing, TBCC, 1 Rx
Uplink	Single Tone: 15 kHz and 3.75 kHz Spacing, SC-FDMA: 15 kHz Tone Spacing, Turbocode
Bandwidth	180 kHz
Highest Modulation	QPSK
Link Peak Rate (DL/UL)	DL: ~30 kbps UL: ~60 kbps
Duplexing	HD FDD
Duty Cycle	Up to 100%, No Channel Access Restrictions
MTU	Maximum PDCP SDU Size 1600 B
Power Saving	PSM, Extended Idle Mode DRX With Up To 3 h Cycle, Connected Mode DRX With Up to 10.24 s cycle
UE Power Class	23 or 20 dBm



▲ **Fig. 3** Test bench for the NB-IoT in-band uplink mode.



▲ **Fig. 4** NPUSCH encoder simulated in VSS.

bandwidths greater than 1.4 MHz, IoT communication can suffice with kHz bandwidths. Given these differences, using the existing GSM and LTE systems for IoT wastes spectrum and data rate. The introduction of a narrowband channel, such as 3.75 kHz, quadruples the number of connections in LTE's traditional 15 kHz subcarrier spacing. Device cost is another factor differentiating mobile devices designed for voice, messaging and high speed data transmission from NB-IoT applications that require low speed and reliable data transfer. Many NB-IoT use cases require a low device price to be viable, as well as consideration of installation and potential risk of theft.

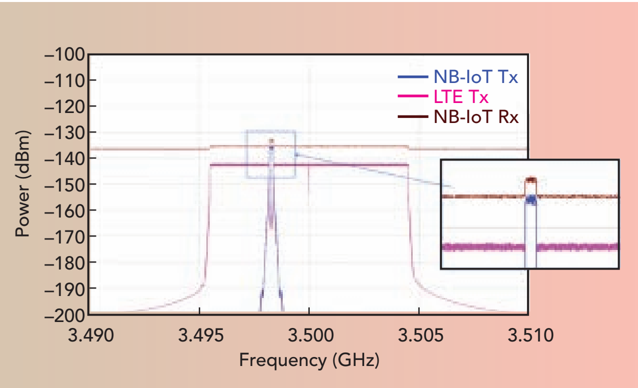
NB-IoT will heavily utilize LTE technology, including downlink orthogonal frequency division multiple access (OFDMA), uplink single carrier frequency division multiple access (SC-FDMA), channel coding, rate matching and interleaving. This is reducing the time to develop specifications and NB-IoT products by LTE equipment and software vendors. However, developing robust, low-cost and power-efficient IoT devices that handle low data rates with large area coverage is a departure from component design efforts driven by the different system requirements of cellular. As the following examples illustrate, RF system simulation can help solve these challenges and support the design and analysis of the UE modules, antennas, RF front-ends and wireless networks that will co-exist with NB-IoT and LTE signals.

IN-BAND IoT SIMULATION

The VSS project shown in ***Figure 3*** simulates the operation of NB-IoT inside an LTE carrier. The NB-IoT uplink signal is configured as in-band, narrowband physical uplink-shared channel (NPUSCH) format 1 and compliant with the 3GPP release 13 specification. In this example, the NB-IoT signal is placed in an unused RB within the LTE band. The available NB-IoT examples in VSS enable studying in-band and guard-band operation modes.

The NB-IoT uplink supports both multi-tone and single-tone transmissions. Multi-tone transmission is based on SC-FDMA, with the same 15 kHz subcarrier spacing, 0.5 ms slot and 1 ms sub-frame as LTE. SC-FDMA is an attractive alternative to OFDMA, especially in uplink communications. The lower peak-to-average power ratio (PAPR) greatly benefits the mobile terminal in transmit power efficiency, which extends battery life and reduces the cost of the power amplifier. Single-tone transmission supports two subcarrier spacing options: 15 and 3.75 kHz. The additional 3.75 kHz option uses a 2 ms slot and provides stronger coverage to reach challenging locations, such as deep inside buildings, where signal strength can be limited. The 15 kHz numerology is identical to LTE and, as a result, achieves excellent coexistence performance. The data subcarriers are modulated using $\pi/2$ binary phase shift keying (BPSK) and $\pi/4$ quadrature phase shift keying (QPSK) with phase continuity between symbols, which reduces PAPR and allows the power amplifiers to operate more efficiently (saturated). The number of 15 kHz subcarriers for a resource unit can be 1, 3, 6 or 12, supporting both single-tone and multi-tone transmission of the uplink NB-IoT carrier, with a total system bandwidth of 180 kHz (up to 12, 15 kHz subcarriers or 48, 3.75 kHz subcarriers).

The NB-IoT uplink physical channel includes a narrowband physical random access channel (NPRACH) and NPUSCH. The NPRACH is a new channel designed to accommodate the NB-IoT 180 kHz uplink bandwidth, since the legacy LTE PRACH requires a 1.08 MHz bandwidth. Random access provides initial access when establishing a radio link and scheduling request and is responsible for achieving uplink synchronization, which is important for maintaining uplink orthogonality in NB-IoT. The NPUSCH supports two formats. Format 1 carries uplink data, supports multi-tone transmission and uses the same LTE turbo code for error correction. The maximum transport block size of NPUSCH format 1 is 1000 bits, which is much lower than that in LTE. Format 2 is used for signaling hybrid automatic repeat request (HARQ) acknowledgements for narrowband physical downlink shared channel (NPDSCH) and uses a repetition code for error correction. In this case, the UE can be allocated with 12, 6 or 3 tones. The 6 and 3 tone formats are introduced for NB-IoT UEs that, due to coverage limitations, cannot benefit from the higher UE bandwidth allocation.

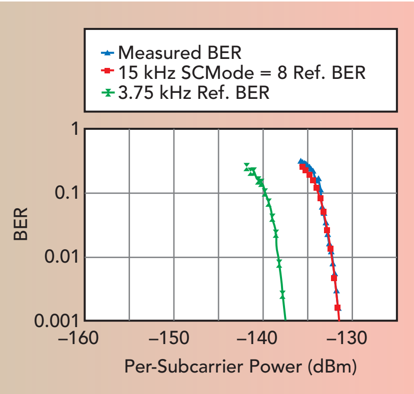


▲ **Fig. 5** NB-IoT and LTE spectra for the in-band mode.

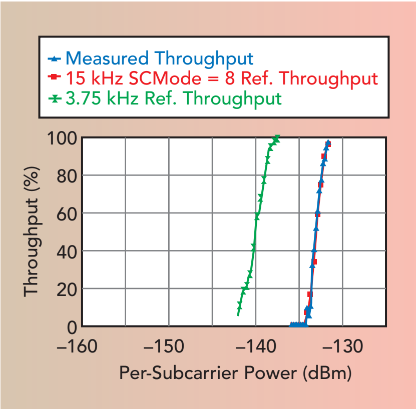
ApplicationNote

A VSS simulation of NPUSCH encoding is shown in ***Figure 4***. This sub-block generates a pseudo-random binary sequence, which undergoes cyclic redundancy check (CRC) followed by turbo encoding and rate matching for uplink LTE transmissions. Sub-block interleaving is performed on the bit stream out of the encoders. For each code word, all the bits transmitted on the physical uplink shared channel in one sub-frame are then scrambled with a UE-specific scrambling sequence prior to the modulation mapping, which has been selected by the system developer through the configuration options.

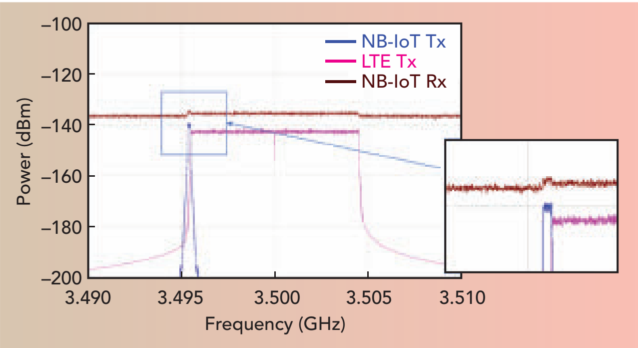
SC-FDMA can be interpreted as a linearly pre-coded OFDMA scheme, in the sense that it has an additional discrete Fourier transform (DFT) processing step preceding the conventional OFDMA processing. A DFT is performed by the transform precoder before the NPUSCH channel is multiplexed with the reference signal subcarriers (either single- or multi-tone) by first mapping them to the appropriate physical resources and then to the orthogonal frequency-division multiplexing (OFDM) symbols and slots within each frame. Much like OFDMA, SC-FDMA divides the transmission bandwidth into multiple parallel subcarriers, maintaining the orthogonality of the subcarriers



▲ **Fig. 6** **Simulated BER for the NB-IoT signal passed through AWGN channel model.**



▲ **Fig. 7** **Simulated throughput for the in-band NB-IoT mode.**



▲ **Fig. 8** **NB-IoT and LTE spectra for the guard-band mode.**

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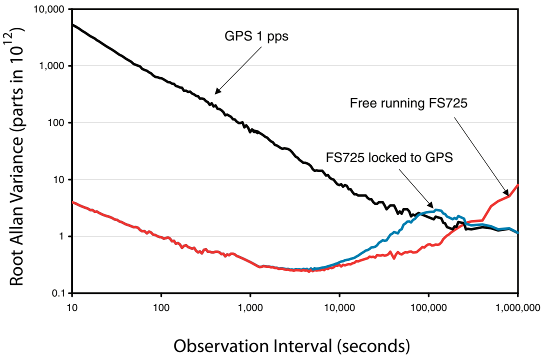
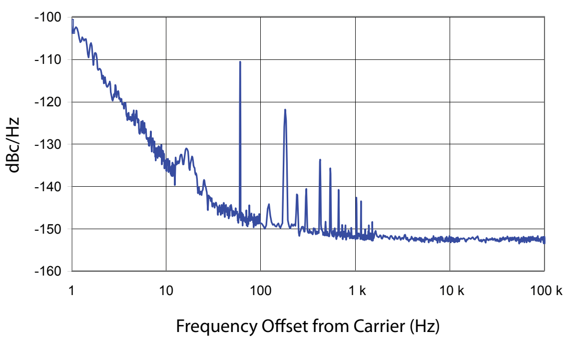


FS725 Single Sideband Phase Noise



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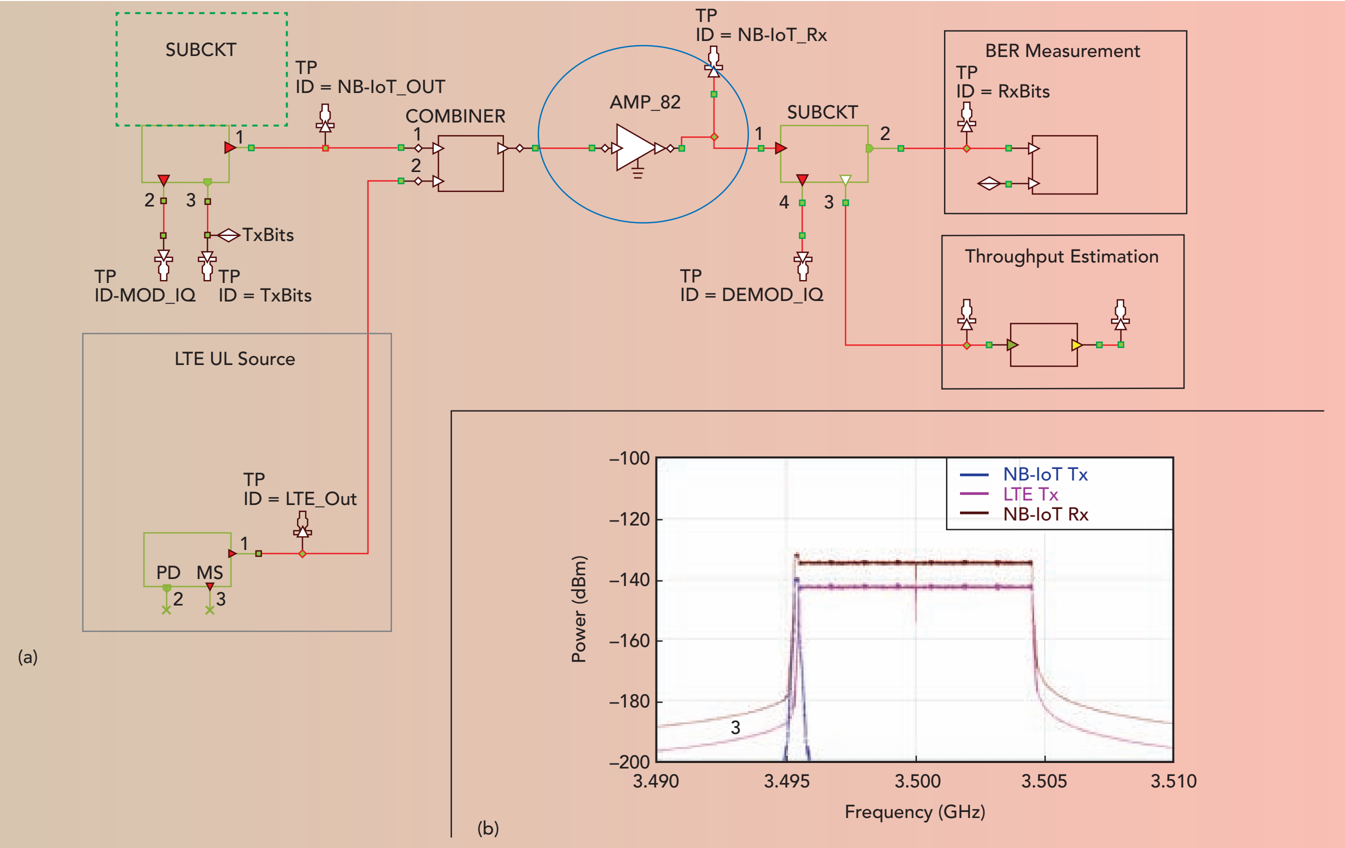

▲ **Fig. 9 Test bench with power amplifier (a) and guard-band mode spectra (b).**

by the addition of the cyclic prefix (CP) as a guard interval. However, in SC-FDMA, the data symbols are not directly assigned to each subcarrier independently, as in OFDMA. Instead, the signal that is assigned to each subcarrier is a linear combination of all modulated data symbols transmitted at the same time instant. The difference between SC-FDMA transmission and OFDMA transmission is an additional DFT block before the subcarrier mapping.

A similar set of blocks is used to generate the LTE signal, which is then combined with the NB-IoT waveform, passed through an additive white Gaussian noise (AWGN) channel and terminated in an NB-IoT UL receiver for demodulation and decoding of the physical uplink shared channel (PUSCH) signal. For component and system designers, the AWGN channel model can be replaced with a different channel model or device under test (DUT).

The test bench in this in-band simulation has been configured to monitor the Tx signal spectrum at various points in the link (see ***Figure 5***), the NB-IoT link performance in the presence of the LTE UL signal, I/Q constellation of the transmitted and demodulated signals, bit error rate (BER) (see ***Figure 6***), block error rate (BLER), throughput (see ***Figure 7***) and the CRC error for each block.

GUARD-BAND NB-IoT SIMULATION

A related example demonstrates operation of NB-IoT in the guard band of an LTE signal. The project is essentially the same as in the previous example with a simple change to the NB-IoT RB location. For guard-band operation, the NB-IoT RB is set to be greater than zero or greater than N_RB_UL, the upper limit, to operate in the lower or upper guard band, respectively. In-band operation is obtained by setting the NB-IoT RB at any value between these limits. The spectra for an NB-IoT channel operating in guard-band mode is shown in ***Figure 8***.

As previously mentioned, a front-end module, power amplifier and antenna design can be added to or substituted for the AWGN channel model, which serves as a placeholder for a DUT. ***Figure 9*** shows an amplifier inserted between the UL transmitter and receiver. The simulation allows designers to sweep various parameters, such as input power, or toggle different NB-IoT subcarrier modulation schemes (π/2 BPSK or π/4 QPSK) to investigate the impact on performance, such as error vector magnitude (EVM).

CONCLUSION

The NB-IoT standard specified in 3GPP release 13 leverages the existing LTE network to support a future ecosystem of low-cost IoT devices. While the use of the existing LTE infrastructure with relaxed performance requirements, due to the lower data rates, will help offset some design challenges, the need for low cost, increased coverage area and longer battery life with sustained reachability introduces some difficult-to-achieve requirements. VSS and other system simulation tools aid NB-IoT system development by simulating designs pre-silicon, saving valuable time and effort bringing these new products to market.■

EditorialIndex

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Advantages & Features:

- Phase stability over flexure: <±5°@50GHz
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- Lab & production testing
- In-box connection
- Equipment/Rack connection

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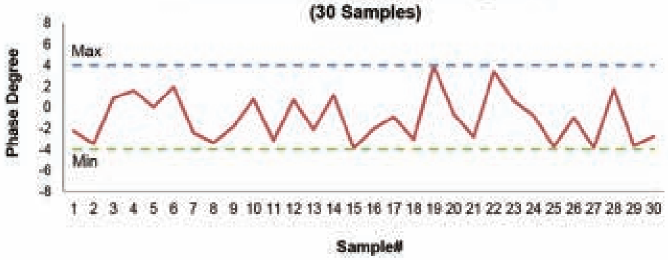

Optional Connetors			
Code	Description	Frequency (GHz)	VSWR*
01	SMA Straight Male	26.5	<1.25
05	SMA Right Angle Male	18	<1.35
37	SMP Straight Female	26.5	<1.30
38	SMP Right Angle Female	26.5	<1.30
39	2.4mm Straight Male	50	<1.45
40	2.92mm Straight Male	40	<1.35

★Same Connectors at both ends

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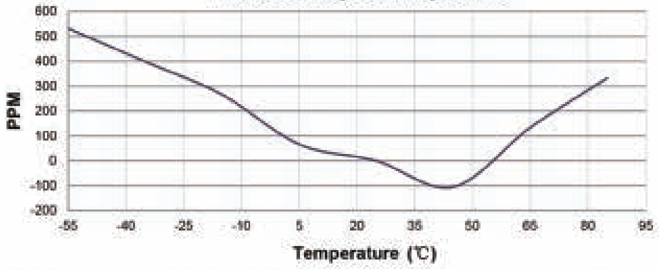
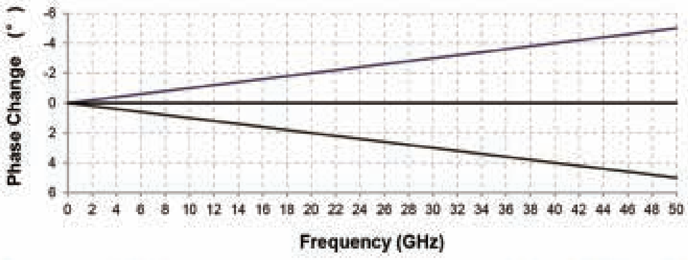
Phase Stability vs. Temperature



Phase Stability vs. Flexure



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2017 • Volume 60

■ SPECIAL REPORTS

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■ SYSTEMS

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Output Power Range	: -40dBm to +5dBm
Frequency Stability	: +/-0.5ppm with internal reference
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Tuning Step	: 0.001Hz
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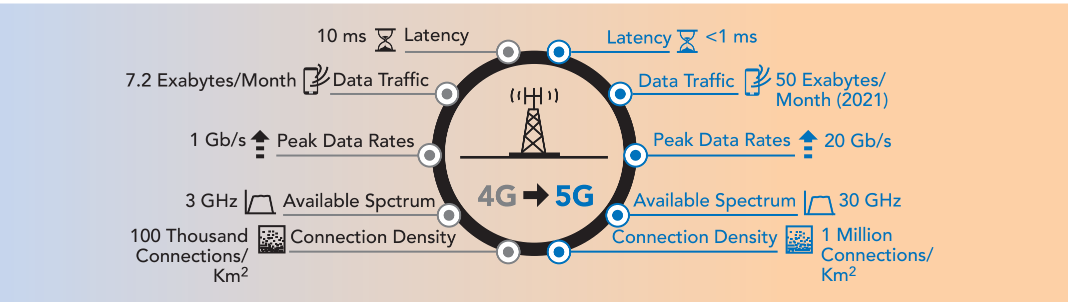
Greensboro, N.C.

Growing demand for mobile video and other applications is driving an accelerated timeline for delivering 5G to smartphones and other mobile devices. In March 2017, the 3GPP standards group approved a new standard, for the 5G non-standalone (NSA) radio. This standard enables mobile operators to deliver 5G enhanced mobile broadband (eMBB) service by leveraging their existing 4G infrastructure. As a result, 5G mobile deployments are expected to start as early as 2019, and initial 5G implementations are expected to use frequencies between 3.3 and 3.8 GHz.

In mobile broadband, 5G will complement 4G rather than replacing it. LTE Advanced and LTE Advanced Pro networks using carrier aggregation are expected to provide peak data rates up to roughly 1 Gbps, which is adequate for many uses. 5G will add much higher peak network speeds—up to around 10 Gbps—to support bandwidth-intensive applications such as live video and augmented reality (see ***Figure 1***). Unlike the 5G standalone (SA) specification, 5G NSA uses the existing 4G LTE radio and core network as an "anchor" for control and management, together with a 5G data carrier.

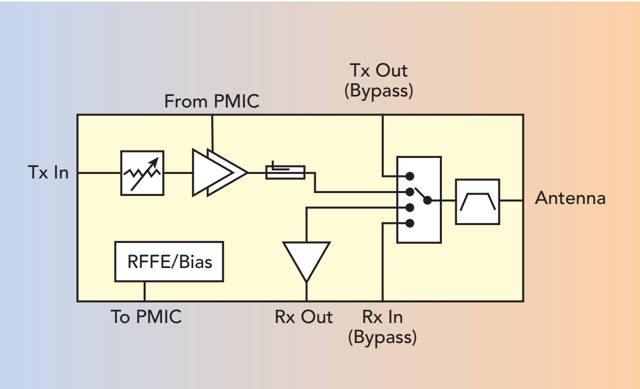
Supporting 5G creates significant challenges for the mobile device RF front-end (RFFE), including new frequency bands, massive bandwidth, high output power and both 4G and 5G waveforms. The Qorvo QM19000, the world's first 5G mobile RFFE, is designed to meet these challenges. As shown in ***Figure 2***, the QM19000 integrates the power amplifier (PA), low noise amplifier (LNA), transmit/receive (Tx/Rx) switch and wideband filter into a single module that supports up to 400 MHz bandwidth over the 3.3 to 4.2 GHz frequency range.

The RFFE power efficiency and linearity requirements for 5G are particularly complex, due to the need for backward compatibility in regional applications where the 3.5 GHz bands have already been utilized for LTE. For example, 5G signals are much wider than those used in 4G; a typical goal for 5G Tx signal bandwidth is 100 MHz, compared with the 20 MHz maximum provided by a single 4G LTE carrier. For 4G, envelope tracking (ET) is widely used in mobile front-ends to maximize power efficiency; it cannot be used for 5G, because today's envelope trackers support a maximum bandwidth of 40 MHz. Instead of ET, average power track-



▲ **Fig. 1** **5G vs. 4G performance capabilities.**

ing (APT) mode (i.e., fixed voltage) must be used for 5G. The PA must provide both high linear efficiency for 5G transmissions as well as high saturated efficiency when using ET for 4G signals. The QM19000 supports sophisticated power management that enables the module to switch between ET and APT mode.



▲ Fig. 2 Functionality of the QM19000 RFFE module.

Adding to the challenges, 5G specifications define two alternative waveforms: cyclic-prefix orthogonal frequency division multiplexing (CP-OFDM) and discrete Fourier transform spread OFDM (DFT-S-OFDM). CP-OFDM offers very high spectral packing efficiency in resource blocks (up to 98 percent) and good support for multiple-input-multiple-output (MIMO). It is likely to be used when an operator's priority is to maximize network capacity, such as in dense urban environments. The combination of CP-OFDM and massive bandwidth generates much higher peak-to-average power ratios (PAR) than with LTE, requiring greater back-off in the PA to avoid exceeding regulatory limits. As a result, the PA must offer high-power efficiency and linearity at a wide range of power levels. The RFFE also must support DFT-S-OFDM, the same waveform used for the LTE uplink, which provides less efficient spectral packing but greater range.

The 5G RFFE also requires support for power class 2, a specification for higher output power to overcome greater propagation losses at high frequencies. Originally approved for specific 4G bands, power class 2 doubles the output power at the antenna to 26 dBm. With 5G SA, power class 2 is a baseline requirement across all new bands.

To meet all the Tx requirements for both 4G and 5G, including saturated and linear efficiency, the QM19000 uses a two-stage PA manufactured using Qorvo's GaAs HBT5 process. In addition to improved efficiency, HBT5 offers higher gain than other technologies, such as SiGe, at the high frequencies used for 5G. HBT5 PAs also have the thermal performance required to support higher power output and use Qorvo's CuFlip copper-bump packaging technology to efficiently dissipate heat. Even with the HBT PA, additional amplification is needed to meet specific requirements for higher output power, such as power class 2. Additional gain may also be required when using CP-OFMD, when transceiver drive levels are expected to decrease by up to 3 dB. The QM19000 includes an additional variable gain amplifier to meet these needs.

While supporting 5G performance requirements, the QM19000 also helps smartphone manufacturers accommodate complex RF functionality within tight space constraints. For example, MIMO is key to delivering the high data rates promised by 5G. Device manufacturers are expected to use 4 × 4 MIMO for downlink, and some implementations may additionally provide 2x MIMO for the uplink. This means manufacturers need to fit even more RF chains into the essentially fixed space allocated to the RF content within the smartphone. Highly integrated modules such as the QM19000 will be essential to achieving this goal.

Over time, 5G will address a range of different use cases, each presenting new RF challenges. The QM19000 is one element in Qorvo's expanding portfolio of 5G solutions designed to meet those challenges.

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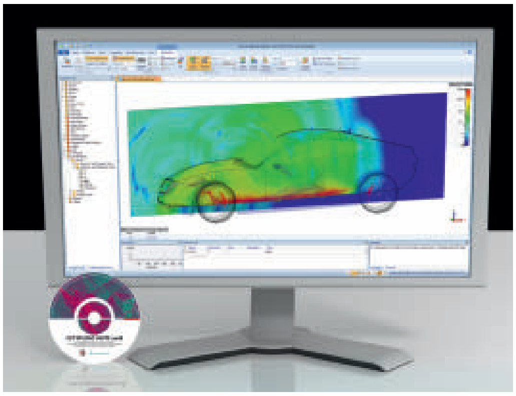

CST STUDIO SUITE 2018 Connects New Technology and Trusted Tools

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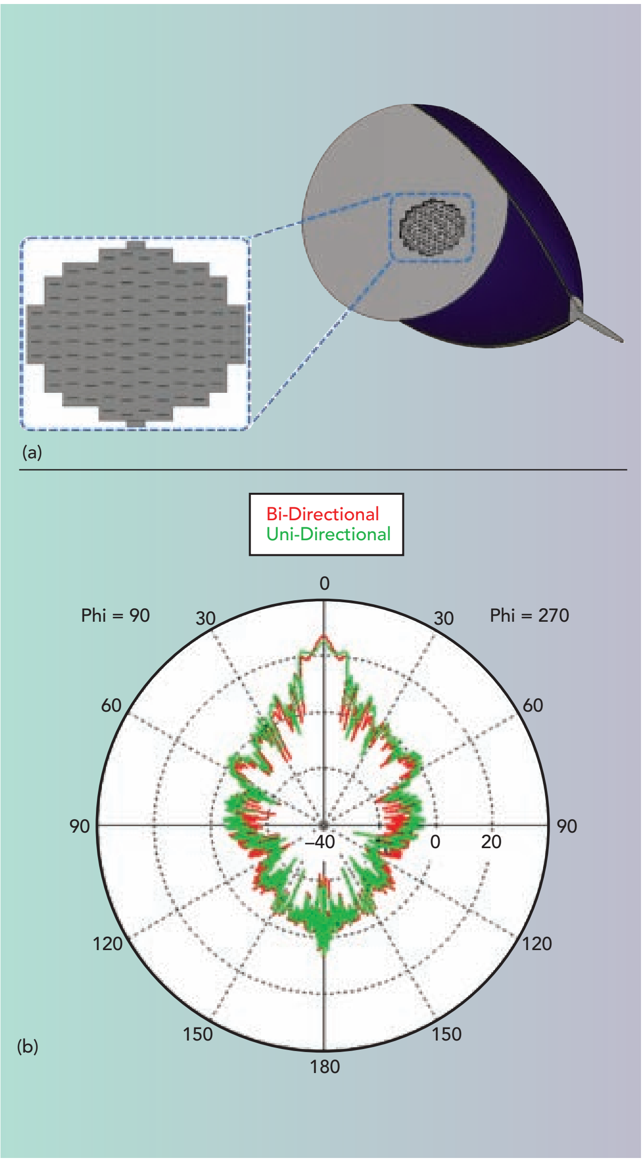
CST STUDIO SUITE is a package of state-of-the-art electromagnetic and multiphysics simulation tools, used by leading companies and research institutes in fields ranging from consumer electronics and healthcare to automotive and aerospace. It allows engineers to design, characterize and optimize devices with virtual prototypes, reducing the cost and time required to develop new products. The latest release, CST STUDIO SUITE 2018, offers a collection of new features for designing, managing and simulating complex devices and systems.

ASSEMBLY MODELER

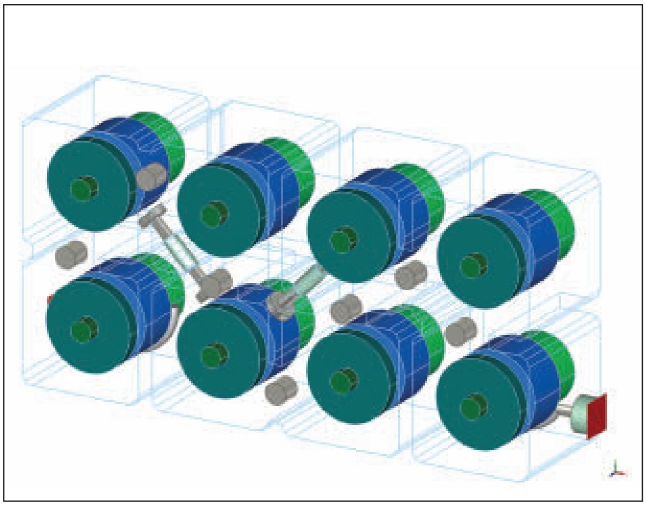
The CST System Assembly and Modeling (SAM) framework, enabling engineers to model and simulate complex systems in a modular way, keeps the company at the forefront of system simulation. In the 2018 version, SAM has been revamped with a new assembly modeler for constructing complex systems. Components representing different simulation projects can be loaded in a 3D design environment and assembled into a single model. This model can then be used as the basis of a hybrid or full system simulation. The assembly modeler provides a fast, natural workflow for system simulation tasks involving many parts, such as antenna placement, feed design and co-site interference.

HYBRID SOLVER

Different solvers are best suited to different problem types. For example, the CST Time Domain Solver, based on the finite integration technique (FIT), is a powerful general purpose broadband solver suitable for many types of antenna simulation, while the Integral Equation Solver, based on the multilevel fast multipole method (MLFMM), is especially efficient for electrically large structures.



▲ **Fig. 1 Antenna array inside a radome (a) and simulated patterns (b).**



▲ **Fig. 2 Cross-coupled dielectric resonator filter tuned with the Filter Designer 3D optimizer.**

In many simulation projects, a system may contain several components, each suited to a different solver type. For example, in a simulation of antenna placement on an aircraft, the time domain solver may be the most efficient solver for the antenna itself, while the Integral Equation Solver is well suited to simulating fields propagating around the airframe. Hybrid simulation allows different solvers to be used in different parts of the system, making more efficient and more accurate simulations possible.

CST STUDIO SUITE 2018 contains the first release of the new Hybrid Solver Task, enabling bi-directional field coupling between simulation domains. These can be resolved either with different high frequency 3D solvers or the same 3D solver. If the antenna is located near to a scattering object, such as a wing, the Hybrid Solver Task will be able to calculate the backscattered radiation more accurately than a conventional field source coupling approach. Other applications include antennas within radomes, antenna-to-antenna coupling, reflector antennas with complex feeds and human exposure on large structures. ***Figure 1*** shows an example of simulating an array within a radome. Simulating each separately with the bi-directional hybrid solver results in a more accurate calculation of the total radiation pattern.

FILTER OPTIMIZATION

Filter Designer 3D (FD3D) is a tool for designing and synthesizing cross-coupled filters and calculating coupling matrices. In the 2018 release, FD3D is now integrated into the built-in optimizers, making the coupling matrix available directly during optimization and allowing faster and more intelligent filter tuning. Using the coupling matrix makes it easier to separate the effect of different parameters on filter performance and reduces the risk of the optimizer failing to find the global minimum.

Combined with the moving mesh feature introduced in 2017, extremely sensitive filters can now be optimized rapidly—the eighth-order cross-coupled dielectric resonator filter in ***Figure 2*** was tuned to a target response of −26 dB. In addition, FD3D includes a new tool for diplexer design, which can be used to synthesize diplexers directly from the specifications.

BODY MODELS

Accurate models of the human body are essential for designing medical equipment and for analyzing the exposure and specific absorption rate (SAR) of devices. CST offers detailed heterogenous human body models suitable for a wide range of applications. These include both voxel-based and CAD-based models, allowing compatibility with both time and frequency domain solvers.

CST STUDIO SUITE 2018 now has a built-in poser for voxel body models, allowing the position of limbs and joints to be adjusted for more accurate simulation. For example, a body model can be set in a sitting position, to fit in a car seat or made to hold a phone for a SAR simulation. Posed voxel models represent real-world exposure scenarios very accurately. The CAD-based body models now model realistic breathing, which is useful for simulating medical devices such as MRI scanners, where the movement of the chest can change how fields behave inside the body.

CO-SIMULATION

SPICE models representing components and circuits can be imported directly into 3D models, offering new workflows for simulating devices that combine electronic and microwave elements. Now, the particle-in-cell (PIC) and wakefield solvers support true transient EM/circuit co-simulation, offering new possibilities for the co-design of high-power vacuum electronic microwave devices, such as magnetrons and traveling wave tube amplifiers.

ANTENNA SIMULATION

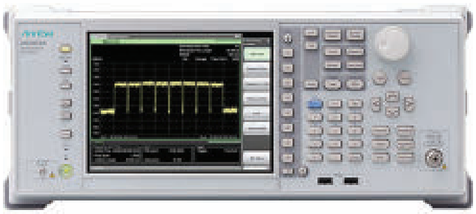
Antenna design and simulation is one of the core capabilities of CST STUDIO SUITE. The 2018 version includes some new features that are especially useful for simulating planar antennas on printed circuit boards (PCB). The software can now directly calculate far fields on complex multilayer substrates, and the characteristic mode analysis (CMA) tool can take dielectric substrates into account.

LIBRARY FOR INTERFERENCE ANALYSIS

The Interference Task in CST STUDIO SUITE offers an intuitive workflow for analyzing the coupling and interference risk between RF systems on a platform. Assessing whether radio systems interfere requires knowledge of the frequency bands and channels where each system operates. The 2018 version includes a library of radio types, and users can add their own predefined radios that can be shared across a network for use by a team; the radios can be tagged for rapid searching.

VENDORVIEW

Computer Simulation Technology (CST)
www.cst.com



High Performance 5G Analyzer for an Attractive Price

Anritsu Co.
Morgan Hill, Calif.

Engineers developing 5G chipsets, modules, components and systems must address design challenges ranging from high frequencies and wide bandwidths, to time and cost constraints. Recognizing the need for performance and efficiency, Anritsu Co. has introduced the Signal Analyzer MS2850A, which provides an attractive price/performance balance and meets the testing requirements of next-generation broadband communications systems such as 5G. The Signal Analyzer MS2850A, with frequency coverage from 9 kHz to 44.5 GHz, has the analysis bandwidth, flatness and wide dynamic range for 5G designs at a price point half that of other analyzers on the market. It features 1 GHz analysis bandwidth to support wideband microwave and mmWave communications, so engineers can analyze frequency and phase, as well as power changes over elapsed time.

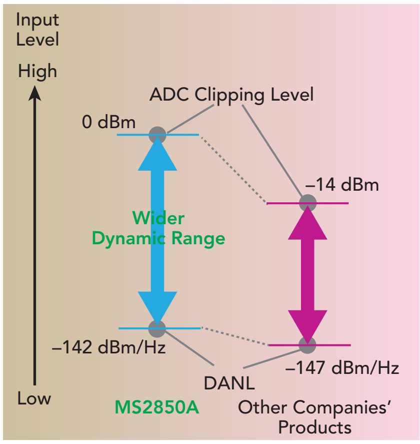
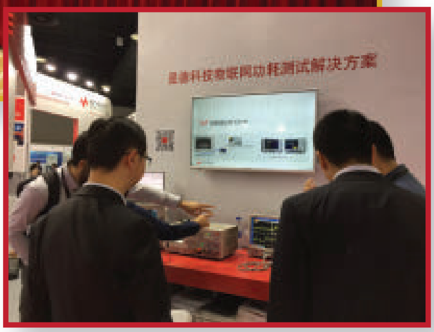


Fig. 1 The ADC clipping level of 0 dBm enables the MS2850A to have a measurement dynamic range greater than 140 dB at 1 GHz.

WIDEBAND SIGNAL ANALYSIS

Both excellent flatness and dynamic range are required for evaluating the wideband wireless signals used in 5G. At 28 GHz, the in-band frequency response of the MS2850A is typically ±1.2 dB, and phase linearity is 5 degrees peak-to-peak. This best-in-class performance over the 1 GHz analysis bandwidth provides high accuracy amplitude and phase measurements for each carrier. Advantageous in a variety of 5G design and production environments, this level of performance provides particular benefits when verifying 5G antenna arrays.

The Signal Analyzer MS2850A has an analog-to-digital converter (ADC) clipping level of 0 dBm over the 1 GHz analysis bandwidth. This enables the instrument to obtain a wider difference from the displayed average noise level (DANL) and suppresses spurious generation. The result is a measurement dynamic range greater than 140 dB at 1 GHz, 8 dB better than similar signal analyzers (see ***Figure 1***). The dynamic range is equivalent to less than a 1 percent error vector magnitude (EVM), which is considered the peak-to-peak of a modulation waveform measuring a single 5G carrier. A built-in at-



tenuator can be set with a resolution of 2 dB, and the level of the input signal to the mixer can be adjusted with high resolution to further leverage the dynamic range.

DEDICATED 5G MEASUREMENT SOFTWARE

Anritsu has written measurement software designed specifically for 5G verification and operational testing, providing advantages compared to off-the-shelf orthogonal frequency-division multiplexing (OFDM) alternatives. It allows the MS2850A, when equipped with 510 MHz or 1 GHz analysis functionality, to support batch measurements of up to eight 100 MHz bandwidth carriers (see ***Figure 2***). Other analyzers can only measure one carrier at a time, which adds time and cost to verification testing during design and production. The software can be installed directly on the MS2850A, eliminating the need for a separate PC, required by most other signal analyzers.

With the software installed, the MS2850A is the first signal analyzer in its price range to support the pre-5G version of cyclic prefix OFDM (CP-OFDM). Frequency error, transmit power, EVM, timing error and other key parameters of every physical layer (PHY) channel for each carrier can be measured with the signal analyzer. Single carrier measurements can be conducted when necessary.

▲ **Fig. 2 The MS2850A can measure up to eight 100 MHz bandwidth carriers, here centered at 29 GHz.**

LARGE MEMORY

To achieve highly accurate results, signal analyzers for 5G designs require large memories to store long-term digitizing data. The MS2850A has a memory that is about 4x more than that available in similar instruments. With the larger memory, the MS2850A can capture 1 GHz signals in only three seconds, creating a more efficient testing environment.

To shorten test times, the MS2850A has a high-speed capability to transfer large capacity digitized data to an external PC. During development, the MS2850A can serve as a digitizer, and test data can be analyzed using custom software developed in-house. In production environments, the digitized data from multiple signal analyzers can be transferred to a server or workstation for intensive analysis and data management.

A signal analyzer function integrates a built-in 255 MHz analysis bandwidth fast Fourier transform (FFT) that supports spectrum, spectrogram and frequency/phase/power vs. time displays, making the MS2850A well-suited for applications where frequency and phase change with elapsed time. With the FFT analysis function, measured signals can be captured and displayed in various domains to improve troubleshooting efficiency, because phenomena such as spectrum transients that cannot be monitored by sweep-type spectrum analyzers can be observed by the MS2850A.

Built on a flexible platform, the MS2850A can be configured to satisfy current test requirements, with an easy upgrade path as requirements expand. This protects the investment in the signal analyzer, providing a greater return on investment.

VENDORVIEW

Anritsu Co.
Morgan Hill, Calif.
www.anritsu.com

256 Element Reconfigurable 28 GHz 5G Active Antenna

Anokiwave Inc.
San Diego, Calif.

As 5G standards come closer to realization, mmWaves technologies are already being used in trials for Fixed Wireless Access. The short wavelengths at mmWave frequencies allow physically compact electronic steerable (active) antennas to be deployed that offer spatial diversity, spectrum reuse and high antenna directivity (gain) to overcome the higher path loss encountered at these higher frequencies.

The advancements in high frequency silicon integrated circuits, that combines the required beam steering functions with the traditional transmit/receive functions onto one chip, enables the fabrication of planar antennas for cost-effective assembly. Only by using silicon in these active antennas can the cost of these antennas be driven down by orders of magnitude, making them suitable for high volume, mass deployment systems like 5G infrastructure.

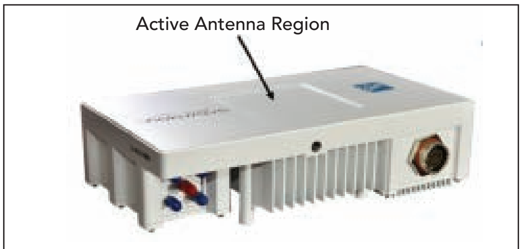


Fig. 1 AWA-0134 256 element active array for 28 GHz 5G wireless applications.

256 ELEMENT 28 GHz ACTIVE ANTENNA

Developed in collaboration with Ball Aerospace, the AWA-0134 is an active array for 5G wireless applications developed using planar antenna technology resulting in a very low profile, lightweight unit (see ***Figure 1***). The surface mount assembled antenna board is based on Anokiwave's AWMF-0108 Silicon Quad Core IC and demonstrates the performance achievable using low power silicon integration and efficient antenna layout and design. Using the AWMF-0108, the antenna provides +60 dBmi (1000 W) of EIRP and a G/T of greater than -2 dB/K at boresight or an effective noise figure for the receive chain of approximately 5 dB. The electronic 2D beam steering is achieved using analog RF beam forming, with independent phase and gain control in both Tx and Rx operating modes.

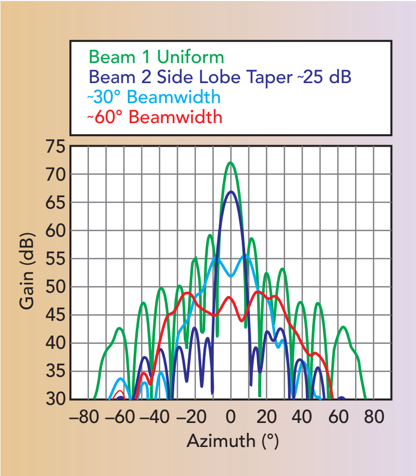
As a planar antenna, it can be used either as a stand-alone component or combined and synchronized with other arrays to support hybrid beamforming and multiple-input-multiple-output (MIMO) functionality

as part of a larger array. The 256 element array can also be used as four 64 element arrays for multi-user MIMO (MU-MIMO) applications. The array measures 26.4 cm × 14.2 cm × 6.9 cm and weighs 3 kg. It can be powered from either +12 V and consumes 47 W of DC power in receive mode and 65 W in transmit mode.

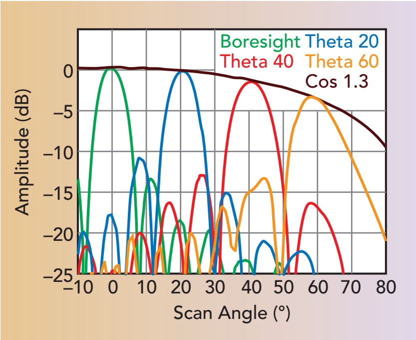
To support 5G beam acquisition and various channel needs, the array supports and provides multiple beamwidths. A wide beam is available to support channel state information measurements, search modes and broadcast channels. Multiple progressively narrower beams can be used for beam acquisition. The narrowest beams allow for interference mitigation, optimizing the signal to noise ratio, maximizing equivalent EIRP and range extension, as shown in ***Figure 2***. A two-dimensional conical scan volume of ±60 degrees in both azimuth and elevation is supported. As this is a time-division duplex (TDD) system, the array operates in a half-duplex mode, enabling the same antenna to support both transmit and receive, with distinct transmit and receive beam settings if required.

The array also includes prestored beam states that, once loaded, can quickly be accessed in a beam acquisition protocol—an essential specification for any 5G radio physical interface. The embedded digital controller receives a desired "look vector" (beam position coordinates in theta and phi or radius and steering angle for a conical scan volume), calculates the required vector modulator settings at each element in the array and communicates with the silicon ICs to steer the beam within the allotted time slot. Completion of this entire operation within a sub-symbol interval is a critical requirement for the beam acquisition protocol of proposed 5G radio systems.

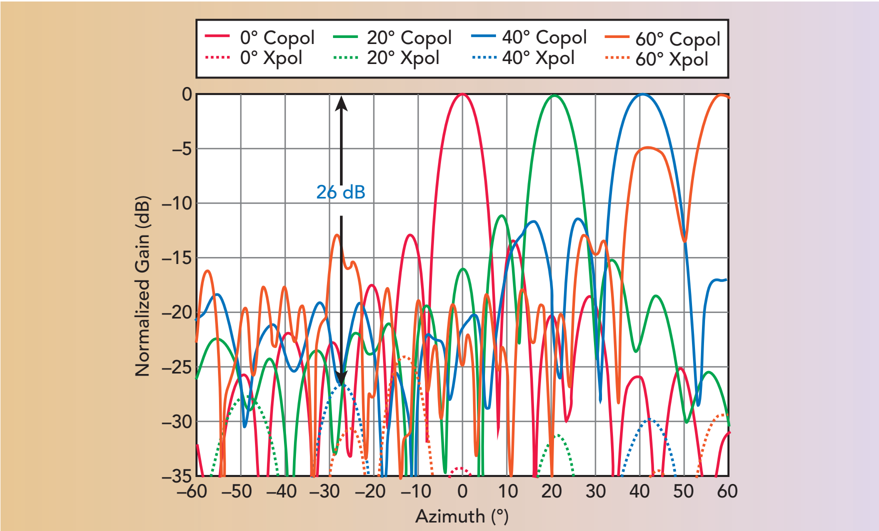
Other features of the array include temperature compensated gain with full array temperature mapping, temperature sense telemetry and transmit output power measurement at each antenna element reported back to the host system as telemetry. Remote monitoring and control of each antenna with real-time operational data allows for greater flexibility. The active array can be controlled through several interface options, allowing the array to be synchronized with the timing and data requirements of the baseband modem or with other antennas. The interface options are Ethernet, USB or high speed control low voltage differential signaling (LVDS).



▲ **Fig. 2 Beam gain for four preselectable states of the active array.**



▲ **Fig. 3 Scan roll-off factor from 0 to 60 degrees.**



▲ **Fig. 4 256 element transmit cuts at 28 GHz over full scan showing greater than 26 dB isolation.**

ARRAY PERFORMANCE

Figure 3 shows the far field antenna pattern of the array in receive mode for scan angles from 0 to 60 degrees. The patterns are well behaved with good sidelobe levels. Cross-polarization antenna patterns of the array in receive mode at both boresight and 60 degrees θ scan are shown in ***Figure 4***. Excellent cross-polarization is observed under both scan conditions, with measured isolation between the polarizations greater than 26 dB. The measured transmit EIRP of the AWA-0134 achieves 1 kW at 1 dB compression.

The AWA-0134 antenna leads the way in showing how 5G coverage can be rolled out by network operators using the mmWave bands, with low power footprint and high energy efficiency, while meeting key operating specifications for data rate, latency, coverage and reliability. Based on highly integrated Si technology that includes embedded functions for remote telemetry and low latency fast beam steering of the entire array, the array enables real-time active beam steering.

VENDORVIEW

Anokiwave Inc.
San Diego, Calif.
www.anokiwave.com

NEW PRODUCTS

FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE
FEATURING VENDORVIEW STOREFRONTS

Mini-Circuits

2.4 mm Female to 2.4 mm Male Adapter Covers DC to 50 GHz for Industry-Leading Value

Mini-Circuits' 24F-24M+ 2.4 mm Female to 2.4 Male adapter expands its portfolio of products in the 40 and 50 GHz range to give you more options and more capabilities.

This model provides 0.12 dB insertion loss with very flat response across the DC to 50 GHz range and 1.06:1 typical VSWR up to 50 GHz. The unit features passivated stainless steel construction and measures only 0.72 in. (l) × 0.36 in. (dia.). Mini-Circuits now offers 50 GHz 2.4 mm adapters in a variety of gender configurations, all offering industry-leading performance and value.

Ultra-Wideband Coaxial LNA, Matched from 0.5 to 15 GHz

Mini-Circuits' ZX60-153LN+ is an ultra-wideband connectorized LNA providing low noise figure of typically 2.4 dB across the entire 0.5 to 15 GHz frequency range, supporting a broad range of applications including Wi-Fi, LTE, S-Band radar, C-Band and X-Band SatCom, test instrumentation and more.

It delivers 17 dB typical gain with ±2.7 dB flatness, P1dB of +16 dBm and +28 dBm IP3. The amplifier operates on a single +12 V supply with low current consumption and comes housed in a rugged, compact unibody case (0.74 in. × 0.75 in. × 0.46 in.) with SMA connectors.

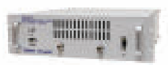
Coaxial DC Block Covers 10 MHz to 40 GHz

Mini-Circuits' BLK-K44+ is a coaxial DC block supporting a wide range of applications from 10 MHz to 40 GHz including 5G systems, Ka-Band SatCom, test and measurement and more. This model provides 0.43 dB insertion loss with flat response across the entire band, 25 dB return loss, RF input power handling up to 2 W and DC voltage handling up to 200 V.

The unit features 2.92 mm Female to Male connectors and comes housed in a rugged, stainless steel body, measuring only 0.36 in. (l.) × 0.87 in. (dia.). Based on their specs, Mini-Circuits 40 GHz DC blocks offer identical performance to competitive models for the best value in the industry, starting at just $159.95 each (qty. 1-9).

Rugged Rack Mount Amplifier Delivers 50 W Across 700 to 6000 MHz

Mini-Circuits' HPA-50W-63+ is a high-power rack mount amplifier capable of delivering 50 W saturated output power over the entire 700 to 6000 MHz bandwidth, supporting high-power test applications for all the primary wireless communications bands. The amplifier provides 56 dB gain with ±4 dB flatness, 97 dB reverse isolation and +50 dBm IP3.



This rugged design features built-in safety features including over-temperature protection, fan alarms and immunity to open and short loads while delivering up to +45 dBm output power. It operates on a 85 to 264 V AC line and comes in a rugged 19 in. wide by 3U high chassis with N-Type Female RF connectors and a 9-pin D-Sub Male connector for temperature and fan alarms on the front panel. It is the ideal workhorse for your power stress testing, EMI and antenna testing, reliability testing, burn-in and more.

Ultra-Wideband Coaxial Amplifier Provides Flat Gain from 5 to 20 GHz

Mini-Circuits' ZX60-24A+ is an ultra-wideband coaxial amplifier supporting a very wide array of applications from 5 to 20 GHz including microwave radio and radar, military communications, countermeasures, SatCom and more.

This model provides 24 dB gain with ±2.2 dB flatness across its entire bandwidth, minimizing the need for external equalizer networks. It also offers 67 dB reverse isolation, +18 dBm typical P1dB and +25 dBm typical OIP3. The amplifier operates on a single +5 V supply and comes housed in a rugged, nickel-plated brass case (0.74 in. × 0.75 in. × 0.46 in.) featuring unibody construction and SMA connectors.

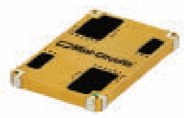
Flexible Test Cables with SMA-Male to N-Male Connectors, DC to 18 GHz

Mini-Circuits' FLC-2M-SMNM+ ultra-flexible test cable is specially designed to minimize performance change versus flexure, giving you reliable results in the most demanding test environments.

Featuring stainless steel SMA-male to N-Male connectors and shielded construction with strain relief, the cable is performance qualified to 20,000 flexures. This model is 2M (6.56 ft.) in length and provides low insertion loss (1.43 dB at 6 GHz, 4.25 dB at 18 GHz), 94 W power handling at 18 GHz and 1.04:1 typical VSWR. The FLC model series features a variety of lengths and connector types to meet your needs.

Surface-Mount Dual-Directional Coupler Provides 300 W Power Handling from 20 to 1000 MHz

Mini-Circuits DDCH-50-13+ surface-mount, high-power, dual-directional coupler provides 50 dB coupling on the through path and reflected path with very high-power handling up to 300 W for a wide variety of applications from 20 to 1000 MHz.



This model provides ±0.15 dB coupling flatness across its entire bandwidth, low insertion loss of 0.15 dB, 30 dB return loss and 24.5 dB directivity. The coupler is designed into an open printed laminate (1.5 in. × 1.0 in. × 0.128 in.) with wrap-around terminations for good solderability and easy visual inspection.

Extra-Long Life Absorptive Electromechanical SP4T Switch, DC to 18 GHz

Mini-Circuits' MSP4TA-18D+ is an ultra-reliable, rugged-duty, absorptive fail-safe SP4T switch, designed in break-before-make configuration. The switch operates from DC to 18 GHz and offers extremely long switch life up to 10 million cycles which can be extended up to 100 million cycles with routine factory cleaning.

Powered by +24 V DC, this model has a typical switching speed of 20 milliseconds, insertion loss of 0.2 dB and high isolation of 90 dB. The MSP4TA-18D+ is suitable for use across a wide range of applications, including switching for automated test equipment and redundancy switching. It comes housed in a rugged aluminum case (2.63 in. × 1.8 in. × 1.7 in.) with SMA female connectors and a 9-pin D-Sub control port to allow easy, solderless connection and disconnection.

Ultra-High Dynamic Range MMIC Amplifier Provides +46.1 dBm IP3 from 0.03 to 2.7 GHz

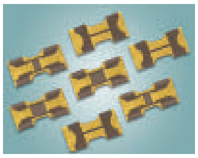
Mini-Circuits' PHA-202+ is an ultra-high dynamic range MMIC amplifier supporting a wide range of applications from 0.03 to 2.7 GHz without the need for any external matching components. This model operates on a single +11 dBm supply and provides +46.1 dBm IP3, +30.4 dBm P1dB, 17 dB gain and input/output return loss of better than 15 dB across its entire frequency range. Fabricated with E-PHEMT technology, the amplifier has highly repeatable performance from lot to lot and comes housed in a 5 mm × 6 mm, 8-pad MCLP package with excellent thermal performance.

VENDORVIEW

www.minicircuits.com

COMPONENTS

RF/Microwave Attenuators



New additions to ATC's AT Series RF/Microwave SMT attenuators include attenuation values from 0 to 10 dB in 1 dB increments. Built with AIN thin film construction in an 0603 case, they are non-magnetic and RoHS compliant. They provide flat loss over a broad frequency spectrum. They also cover from DC to 20 GHz, 1 W input power and VSWR 1:25:1 typical; suitable for microstrip and CPW applications.

American Technical Ceramics
www.atceramics.com

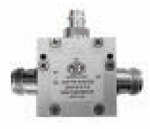
Current Sense Transformers

Coilcraft's new CST2020 Series current sense transformers sense current up to 40 amps over a frequency range of 400 Hz to 1 MHz and offer 4000 Vrms isolation voltage between the sense and output windings. They provide Reinforced Insulation per UL 60950-1. They are qualified to AEC-Q200 Grade 1 (-40°C to +125°C) standards, making them ideal for automotive applications like current measurement in traction motor and battery management systems. They are also well suited for use in 48 V vehicle systems.

Coilcraft
www.coilcraft.com

Low PIM Bias Tees

VENDORVIEW



Low PIM (-140 dBc typical), high-power (7 amp), bias tees for DAS applications, with rugged construction and excellent performance across all wireless bands from 0.698 to 2.7 GHz make them ideal for in-building or tower top systems. Available in various Type N configurations as well as custom. Weatherproof IP67 standard, IP68 available. Made in the U.S. with 36 month warranty.

MECA Electronics Inc.
www.e-MECA.com

Cross Guide Couplers

VENDORVIEW

Pasternack's new line of cross guide couplers consists of 160 parts in three sub-categories: cross guide couplers (4 waveguide ports), cross guide couplers with terminations (3 waveguide ports) and cross guide couplers with terminations and waveguide to coax adapters (2 waveguide ports with either a SMA, Type N or 2.92 mm coaxial connection). These couplers operate over eight waveguide bands in the 5.85 to 33 GHz frequency range. Typical applications include instrumentation, test benches, product development and characterization.

Pasternack
www.pasternack.com

300+ RF & Microwave Switching Products

VENDORVIEW

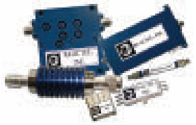
Pickering Interfaces offers 300+ RF and microwave switching products. Available in PXI and LXI formats, they offer signal bandwidths from DC to 65 GHz (including new 50 GHz options) and 6 GHz solid state switching. In LXI, their microwave multiplexer family offers the highest density, packaging 16 multiplexers into a 2U rack. The PXI modules plug into any PXI Chassis as well as their LXI Chassis. These are available in key switching topologies and LED indicators are available on many modules.

Pickering Interfaces
www.pickeringtest.com

New**Products**

Filters, Multiplexers & Multifunction Assemblies

VENDOR**VIEW**



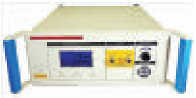
Reactel manufactures a full line of filters, multiplexers and multifunction assemblies covering up to 50 GHz. From small, lightweight units suitable for flight or portable systems to high-power units capable of handling up to 25 kW, connectorized or surface mount, large or small quantities—their talented engineers can design a unit specifically for your application.

Reactel Inc.
www.reactel.com

USB Controlled Switches

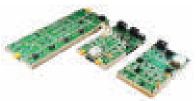
RF-Lambda's USB controlled switches have an ultra wide bandwidth that provides superior performance with high isolation, low insertion loss and fast switching speed across a broad operating frequency range. No additional DC supply voltage is required. Their solid state switches outperform any other on the current market due to its unique design and convenient USB port for control and power. This product is targeted at lab bench applications, production test, aerospace, military applications or anywhere microwave test systems are needed for routing various RF signals between instruments.

Solid State Power Amplifiers



RF-Lambda's new series of wideband solid state power amplifiers possess the industry's most comprehensive portfolio of microwave technologies with a complete solid state solution featuring a user friendly interactive interface and excellent design. The easy to install and standardized enclosure makes efficient use of space. The amplifiers offer efficient cooling, various protection and high-reliability. Their amplifiers are widely used in the wireless telecommunication, medical, EMC and other microwave applications.

Series of Tx/Rx Modules

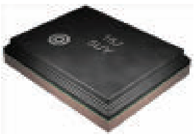


RF-Lambda introduces a new series of customized Tx/Rx modules. Through years of experience designing and devloping the necessary building blocks, RF Lambda creates fully integrated modules to meet customer requirements. These technologies include the company's state of the art PA, LNA, mixer, filter, PLL and power technology for a complete solution with minimal lead times. Please contact the company for more details.

RF-Lambda
www.rflambda.com

NewProducts

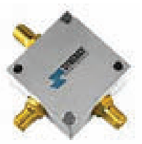
SAW Duplexers



RF360 has extended its range of SAW duplexers for small cell applications. The family covers all standard bands from 770 MHz to 2.7 GHz. With a signal strength of 24 dBm in the Tx-path at the antenna, a useful life of 100,000 hours is achieved in the continuous downlink transmission mode at an operating temperature of 55°C. The duplexers are available in the standard size 2520 packages, are RoHS-compatible and are suitable for lead-free soldering in accordance with J-STD20C.

Richardson RFPD
www.richardsonrfpd.com

5 to 2000 MHz Double Balanced Mixer



The CLK-7B5S is a broadband double balanced mixer covering the LO and RF frequency band from 5 to 2000 MHz. The IF port bandwidth is from DC through 1000 MHz, making this product ideal for applications in prototyping through production of high performance frequency converters, phase detectors and bi-phase and amplitude modulators. It requires +7 dBm local oscillator drive to typically give on average third order input intercept point of +13 dBm. The RF interconnects are SMA type and the package size measures 1.25 in. × 1.25 in. × 0.75 in.

Synergy Microwave Corp.
www.synergymwave.com

Dual Directional Coupler

Werlatone's model C10561 is a new surface mount, 20 to 1000 MHz, mismatch tolerant 50 dB dual directional coupler. The C10561 is compact, and conservatively rated at 250 W CW. Outperforming any competing product, Werlatone's design operates at approximately 30 percent the insertion loss (less than 0.1 dB) and 65 percent less heat dissipation, in a smaller package. The C10561 provides superior main line and coupled port VSWR characteristics with directivity better than 25 dB.

Werlatone Inc.
www.werlatone.com

CABLES & CONNECTORS

Low-PIM Jumper Cables

For use in wireless infrastructure, Fairview Microwave's 36 new low-PIM jumper cables feature a maximum PIM level of -155 dBc and are made with UL910 plenum-rated SPP-250-LLPL cable. The PIM levels of each cable have been fully tested with the results of those tests marked on each cable. They boast a maximum operating frequency of 6 GHz and a maximum VSWR of 1.25:1 up to 2 GHz and 1.35:1 up to 6 GHz.

Fairview Microwave
www.fairviewmicrowave.com

C29F Phase Matched Cable Assemblies

MIcable C29F series phase matched cable assemblies are designed for use in the environment where strict phase matching and/or phase tracking is required over temperature and flexure. The typical phase matching performances are specified to ±2.5°C at 50 GHz between pair and ±5°C at 50 GHz among multi-channels. It's ideal for use in 5G MIMO connecting and testing, and regular use in lab and production line.

MIcable
www.micable.cn

RPC-1.00 Range of Connectors

The Rosenberger RPC-1.00 range of connectors has been completed by the introduction of waveguide-to-coaxial adaptors. The connectors, with 50 Ω impedance and 1.00 mm out-

er conductor, can be used for challenging test and measurement applications up to 110 GHz. With high levels of reliability and repeatability of performance the new revised portfolio covers cable assemblies, in-series and inter-series adaptors and PCB connectors as well as the waveguide-to-coaxial adaptors and gauge kits.
Rosenberger
www.rosenberger.com

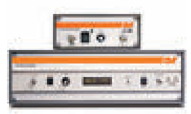
High-Power Adapters of Series 8058

Spectrum Elektrotechnik GmbH is introducing high-power 18 GHz adapters of product category 8058-, which shows series and in-between series adapters of Types N and TNC. The units use special heat dissipating dielectric between center conductor and outer conductor, and have cooling fins to dissipate power to the environment. In addition the high-power hermetic sealed adapter series have been expanded as well, now operating to 18 GHz for N and TNC series.
Spectrum Elektrotechnik GmbH
www.spectrum-et.org

AMPLIFIERS

New "U" Series Power Amplifiers From 10 kHz to 1000 MHz

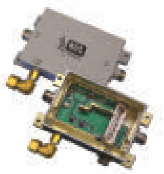
VENDORVIEW



AR's new family of RF solid state Class A power amplifiers cover such a wide bandwidth that they are ideal for EMC, laboratory testing, antenna and component testing, watt meter calibration, medical/physics research and more. These compact, high performance and affordable instruments are available in 1, 2.5, 10, 25 and 50 W output levels and can be directly driven from a signal generator.
AR RF/Microwave Instrumentation
www.arworld.us/html/u-series-amplifiers.asp

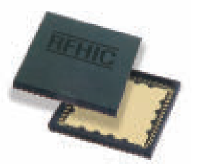
Pre-Filtered Low Noise Amplifiers

K&L Microwave offers pre-filtered low noise amplifiers for GPS and other frequency bands. The GPS offering can cover L1, L2, L5 or combinations of those frequency bands. Gains



available are 16 to 40 dB with noise figures typically 1.8 dB or less. These LNA's are designed for harsh military environments with product supplied to many missile applications. Options are available with or without limiters. DC inputs can be supplied through independent pins or through the RF connector by use of a bias.
K&L Microwave
www.klmicrowave.com

QFN 9 x 9 GaN MMIC



RFHIC is proud to offer QFN 9 x 9 GaN MMIC, used mostly for 5G massive MIMO infrastructure systems. This best-in-class and 50 ohm matched QFN 9 x 9 GaN MMIC provides Doherty efficiency of 38 to 41 percent with Vds 28 V. Delivering 4 W average output power and covers 5G frequency spectrum from 3.5 to 3.9 GHz and 4.4 to 4.9 GHz. Samples are available at the end of Q4 2017.
RFHIC Corp.
www.rfhic.com

SOURCES

Gunn Oscillator

VENDORVIEW

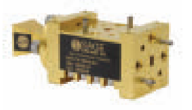
Model SOF-2820-M1 is a Ka-band, wide mechanical tuning bandwidth Gunn oscillator that utilizes a high performance GaAs Gunn diode and proprietary cavity design to deliver +20 dBm typical power with low AM/FM noise and harmonic emissions. The oscillator has a center frequency of 32 GHz and

NewProducts

a mechanical tuning range of ±5 GHz. Compared to its multiplier based counterparts, the Gunn oscillator is a lower cost alternative and a cleaner source.

Horn Antenna Assembly

Model SAR-5037531530-15-S1-DP is a full band, dual polarized, WR-15 horn antenna assembly that covers the frequency range of 50 to 75 GHz. The antenna features an integrated orthomode transducer (OMT) that provides high port isolation and cross-polarization cancellation. At center frequency, the horn antenna offers 15 dBi nominal gain and a typical half power beamwidth of 28 degrees on the E-plane and 33 degrees on the H-plane.

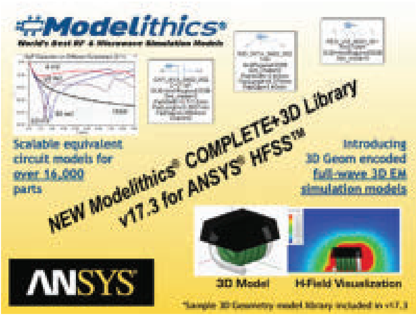


SAGE Millimeter Inc.
www.sagemillimeter.com

SOFTWARE

COMPLETE+3D Library™ v17.3

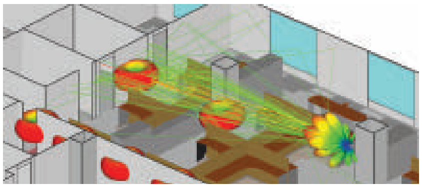
VENDORVIEW



The latest version of the Modelithics Library for ANSYS HFSS has just been released. The COMPLETE+3D Library v17.3 for ANSYS HFSS has 40 new Microwave Global Models™ from 14 different vendors. This release also includes a sample set of Modelithics' new full-wave 3D models for electromagnetic simulation. The Modelithics COMPLETE+3D Library for ANSYS HFSS is now available, with many new scalable equivalent circuit models for popular commercially available capacitors, inductors and resistors.

Modelithics
www.modelithics.com

Diffuse Scattering Simulation For 5G mmWave Channels



Remcom's Wireless InSite greatly improves simulation accuracy for mmWave systems being developed for 5G, WiGig and other emerging technologies. As 5G technology forces expansion into higher frequencies in the mmWave spectrum, the diffuse scattering model further increases precision by revealing how paths interact with a variety of surfaces and structures and how signal power is affected by these interactions. Key effects such as impact on complex impulse response and increased cross-polarization of received signals may be visualized.

Remcom
www.remcom.com

TEST & MEASUREMENT

4-Port Analyzer

Copper Mountain Technologies' C1420 4-port analyzer operates in a frequency range of 100 kHz to 20 GHz, offers a typical dynamic range of 135 dB (10 Hz IFBW) and sweep speeds as low as 12 ms per point. The effective directivity is 46 dB and output power adjustment range is -60 to +10 dBm. Designed for operation with any Windows PC or laptop. C1420 efficiently handles advanced test applications, providing an unmatched price-performance combination for S-parameter measurement for this frequency range.

Copper Mountain Technologies
www.coppermountaintech.com

Multichannel Power Probe

VENDORVIEW

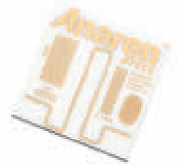
The R&S RT-ZVC02/04 multichannel power probe can measure across large current and voltage ranges without having to switch ranges, making it possible to monitor the power consumption of chipsets, radio modules and wearables such as smartwatches. When used in combination with an R&S RTE or R&S RTO oscilloscope, the current drain can be clearly correlated with analog and digital control signals, enabling developers to optimize the battery life of devices early in the development cycle.

Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

MATERIALS

Advanced Precision Etched Ceramic Substrate

VENDORVIEW



Anaren's state-of-the art Advanced Precision Etched Ceramic Substrate (APECS) technology provides precision ceramic substrate requirements without the expense and turn times, associated with thin film ceramics. Anaren's precision thick film technology pushes thick film ceramics to a best-in-class position from where we can meet or exceed thin-film tolerances, while significantly improve turn times for samples and production parts, at a far more affordable price point. The APECS process lends itself to the higher-frequency, higher-power density trends seen throughout today's RF, microwave and photonics industries.

Anaren
www.anaren.com

MICRO-ADS

From LTE to LTE-Advanced Pro and 5G

Moe Rahnema and Marcin Dryjanski

While 5G has become the darling of conferences, press releases and analyst briefings—its touted use cases tantalizing the imagination—the older sibling LTE can certainly relate to Mark Twain's oft-quoted and wry comment, "The reports of my death are greatly exaggerated." The evolution of LTE, to LTE-Advanced and LTE-Advanced Pro, is addressing two of the broad goals for 5G: enabling higher data rates and IoT connections. And the first version of 5G to be deployed, the so-called non-standalone architecture, will use the existing LTE network.

In 14 chapters, "From LTE to LTE-Advanced Pro and 5G" provides a comprehensive discussion of the workings of LTE, addressing the air interface, evolved packet core (EPC) network architecture, protocols, network planning and optimization and the transition LTE is providing to 5G. After a tutorial on the fast Fourier transform (FFT) and the discrete time Fourier transform (DFT), central to signal processing in digital communications systems, subsequent chapters cover the air interface architecture and operation; coverage-capacity planning and analysis; prelaunch parameter planning and resource allocation; radio resource control and mobility management; inter-cell interference management; SON technologies; EPC network architecture, planning and dimensioning; LTE-Advanced enhancements; optimization for TCP operation; voice over LTE (VoLTE); LTE-Advanced Pro enhancements; and the transition to 5G.

Collectively, the authors have decades of experience in wireless telecommunications. As an independent consultant for the past 15 years, Moe Rahnema has worked with the major network equipment manufacturers and various operators to plan and optimize cellular networks. He was recognized by Huawei for his work planning the first LTE network in Mexico. Marcin Dryjanski has been an architect for physical layer and L2/L3 protocol stack software for LTE and LTE-Advanced. More recently, he supported 5G design through the EU research programs 5GNOW and SOLDER and is consulting with Huawei on algorithm and RAN architectural designs for LTE-Advanced Pro and 5G.

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MAR	Test & Measurement	EDI CON China Microwave & RF WAMICON EXPO Electronica
& SUPPLEMENT	Cables & Connectors	IWCE IEEE MTT-S IMS
APR	Amplifiers & Oscillators	AUVSI Xponential CS Mantech
MAY	5G & IEEE MTT-S IMS Show Issue	Space Tech Expo EW Europe BiCMOS and CSICS
JUN	Diamond Anniversary Issue + Semiconductors & Packaging	Sensors Expo SEMICON West IEEE MTT-S IMS
& SUPPLEMENT	Aerospace & Defense	Sensors Expo MILSATCOM
JUL	RF/Microwave Software & Design	IEEE Symposium on EMC, SI & PI
AUG	European Microwave Show Issue	Mobile World Congress Americas CTIA EuMW
SEP	High Frequency Components and PCBs + EDI CON Show Issue	PCB West IEEE Autotestcon EDI CON USA
& SUPPLEMENT	Military Microwaves	EuMW EDI CON USA MILCOM
OCT	Passive & Control Components	AMTA Asia Pacific Microwave Conference electronica
NOV	Government & Military Electronics	ESC Silicon Valley
DEC	5G & IoT	IEEE MTT-S Radio and Wireless Symposium CES

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FABS and LABS

Mercury Systems' Phoenix Advanced Microelectronics Center

A few years ago, Mercury Systems started their state-of-the-art Advanced Microelectronics Centers (AMC) in Hudson, N.H. and West Caldwell, N.J., offering world-class RF/microwave manufacturing and integration capabilities. Now, they have invested in Phoenix to create their U.S. Manufacturing Operations around surface mount technology to provide a global manufacturing capability. Defense prime contractors now have a secure and trusted supplier of digital microelectronics from a Defense Microelectronics Activity (DMEA)-accredited facility for design, assembly, test and broker services.

The company's new AMC facility is a 115,000 square foot design and manufacturing center of excellence for advanced microelectronic solutions addressing the defense industry's most rigorous performance and quality standards. With 15,000 sq. ft. of class 100,000 clean room space, the facility manufactures EW subsystems, embedded processing modules, high-density secure memory, military-grade solid-state storage and custom built-to-specification microelectronics. The facility has fully automated SMT pick and place capabilities with inline stencil printing, 3D automated solder paste inspection and 10-zone reflow oven, plus 01005 capability. There are also 3D automated inspection and 2D/3D X-ray inspection stations. The products built in the new center are integrated by customers into highly sophisticated computing systems and then deployed in a variety of military applications such as electronic warfare, radar, platform management and command, control, communications and intelligence.

To ensure a seamless and rapid transition from prototype sampling to full-rate production, engineering resources skilled in advanced design and simulation techniques are co-located within the AMC. Recognizing the importance of long-term supply continuity for prime contractors, supply chain security and trust are assured throughout the complete product lifecycle. As a commitment to industrial security, design and manufacturing, records are actively protected with a cyber-security program modeled after the Center for Internet Security critical security controls. They have a secret facility, ITAR control and certifications for AS9100, ISO9001, ISO10012, MIL-PRF-38534/535, SMT J STD 001 and IPC610.

Congressman Ruben Gallego recently helped dedicate the facility, as the expansion represents Arizona's commitment to driving economic growth and prosperity through the creation of sustainable, high-quality jobs. Mercury's Advanced Microelectronics Centers are a key component for the realization of the company's next-generation business model. Through affordable and highly differentiated sensor chain solutions, defense prime contractors can simultaneously secure their supply chain operations, minimize technical risk and meet program schedule and budget demands.

www.mrcy.com/amc/