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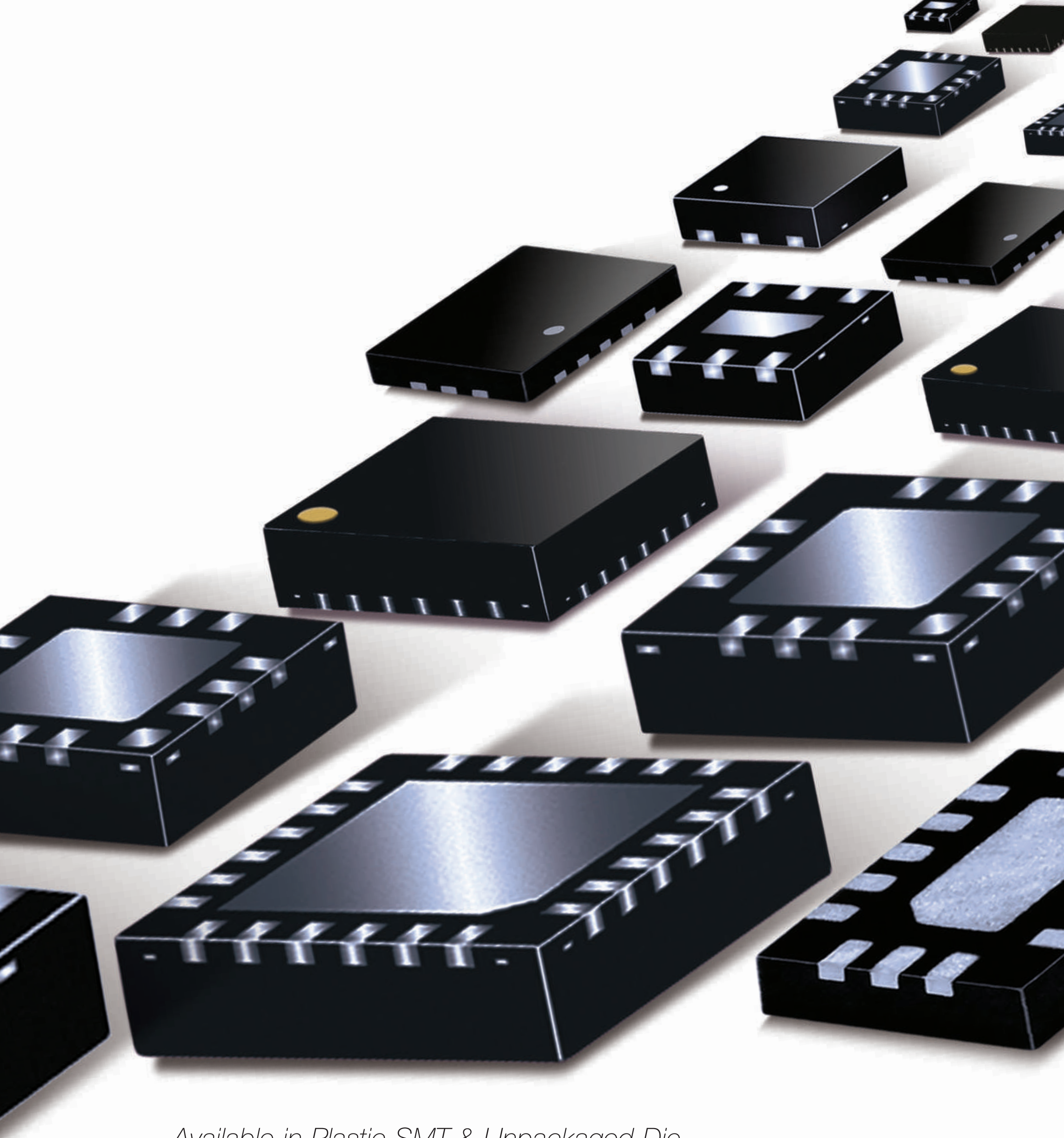

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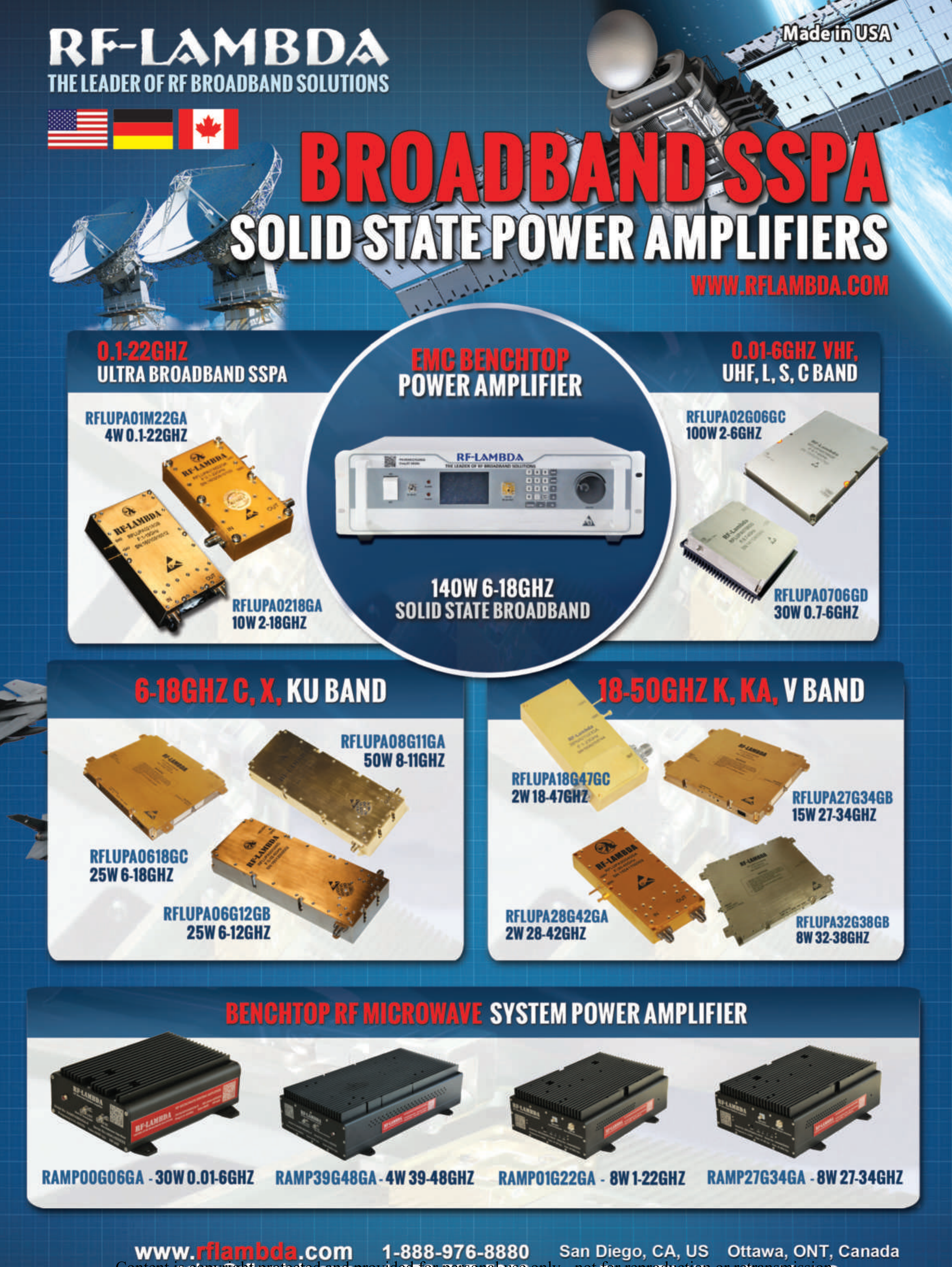
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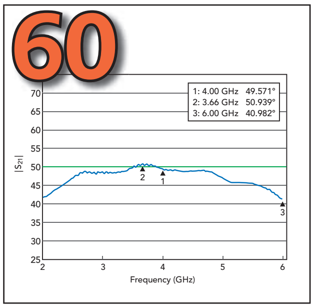

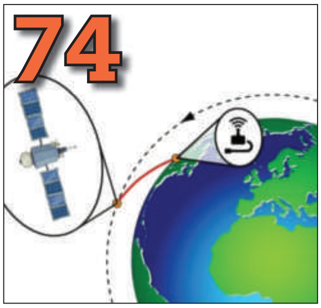

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Dynamic Spectrum Sharing, Key to 5G-LTE Coexistence

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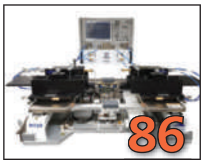

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The First Year of 5G

Pat Hindle, *Microwave Journal* Editor

2019 will be known for the year that 5G started. We have seen the technology evolve as the design challenges were addressed by creative and talented engineers in our industry. A few years ago, we did not think that 5G mmWave transmitters would work over reasonable distances and steer beams accurately to end users or that 5G massive MIMO basestations would provide the throughput we wanted without using an inordinate amount of power. But after several years of careful design and testing, companies are achieving good results.

Signals Research Group, a consulting firm focused on the wireless industry, has been in the field testing the actual performance of 5G, based on measurements of networks in Korea, Switzerland, the U.K. and the U.S., operating at 3.5 and 28 GHz. Signals Research evaluated Verizon's mmWave 5G network in downtown Minneapolis as the service was being launched in April. In these tests, the median download speed was around 380 Mbps, with peak rates approaching 1.5 Gbps. Signals Research also evaluated Verizon's indoor coverage at the US Bank stadium in Minneapolis. They said the coverage extended to "virtually all areas within the stadium" and achieved a physical layer throughput of almost 1.9 Gbps at a typical seat in the empty stadium. They evaluated holding the phone in different places and it did not severely affect the reception unless the entire phone was covered with two hands.

Signals Research ran tests on 5G networks in Seoul, London and Bern operating at 3.5 GHz. Along a 4.6 km route in Seoul, an LG V50 5G phone achieved good coverage and 1.9× the download throughput of an LG G8 LTE phone, normalizing for resource blocks. The median 5G throughput was 512 Mbps, using 100 MHz bandwidth, compared to 268 Mbps for LTE. In London, EE's 5G network was tested along a 6.75 km route in central London, again showing good 5G coverage. EE uses 80 MHz for 5G compared to 95 MHz for LTE using carrier aggregation with five carriers. A OnePlus 7 Pro smartphone achieved 5G download speeds of 220 Mbps average, with peaks to 600 Mbps. In a walk test in Bern, covering an 8 km^2 area, an OPPO Reno 5G smartphone had 1.5× faster downloads than an LTE-only phone, achieving a median download of 234 Mbps compared to 156 Mbps for LTE.

Signals Research simulated the battery life of a Galaxy S10 smartphone with a 4400 mAh battery, assuming several use cases. While the battery life with 100 percent LTE operation was the longest, the estimated battery life for full 5G operation was 14 hours, confirming that a 5G phone will last all day without recharging the battery. One note to these test results is that while Signals Research began measuring 5G networks last spring, the report compiling its findings was sponsored by Qualcomm.

And now China's three major mobile operators officially launched 5G services in parts of 50 cities, claiming the largest rollout in the world, just six months after the government issued licenses. The three operations deployed about 86,000 5G base stations and expect to have more than 130,000 by year-end. Market leader China Mobile aims to install 50,000 sites by December's end, while China Unicom and China Telecom each target about 40,000. China Unicom claimed ubiquitous 5G coverage in 14 cities and 28,000 base stations.

It was an interesting year of activity in the area of 5G and IoT. Next year will be the year that consumers start to really use 5G, and we will see how it performs in everyday use. In parallel, network providers are targeting manufacturing and industrial applications that are viewed as more lucrative in the early days of the 5G rollout as Industry 4.0 takes place. ■


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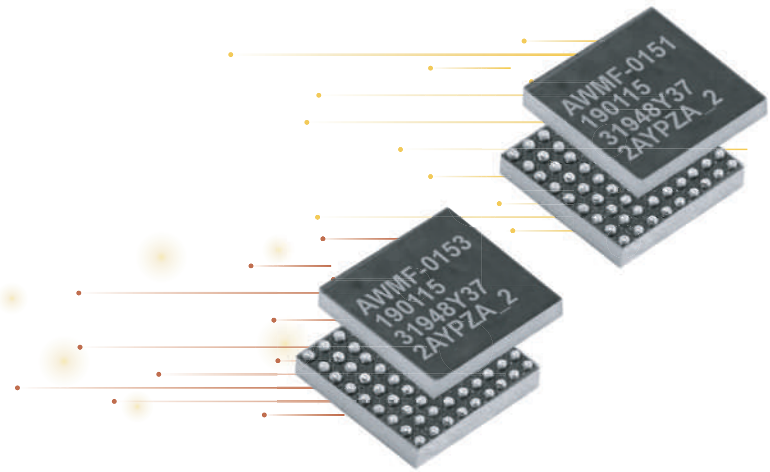

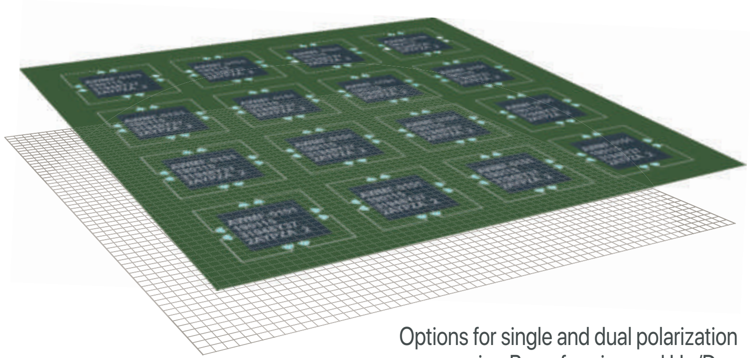

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Industrial IoT Networks Powered by 5G New Radio

Amitava Ghosh, Rapeepat Ratasuk and Anil M. Rao
Nokia Bell Labs, Naperville, Ill.

The fourth industrial revolution (Industry 4.0) triggered by industrial IoT (IIoT) will offer significant revenue expansion through new digital service provider markets. The main technology enablers for the IIoT revolution will comprise of 1.) 5G wireless converged automation protocols which will eliminate wires and support time synchronous operations, 2.) private edge cloud for secure and scalable local computing, 3.) deep slicing for IIoT networks so that multiple stakeholders can be supported using one infrastructure and 4.) machine learning (ML) enabled automated operations for monitoring, prediction and optimization of IIoT networks. Further, the IIoT network will be scalable in connectivity and number of devices and will be designed to deliver optimal performance for all industrial applications using key LTE and 5G New Radio (NR) features like ultra-reliable low-latency communication (URLLC), massive machine type communication (mMTC), 5G positioning, time sensitive communications (TSC) and, to a lesser degree, enhanced mobile broadband (eMBB).

In this article, we will begin with overview, use cases and requirements for IIoT. Next, we will discuss the foundation for URLLC in NR which was laid out in 3GPP Rel-15, mainly in support of IIoT. We then will address several IIoT related features in Rel-16 like URLLC enhancements, NR positioning and TSC and a version of NR known as NR-Light, which is planned to be introduced in Rel-17. NR-Light aims to address use cases that cannot be met by NR eMBB, URLLC or mMTC. Finally, we will present system performance for an indoor ray traced factory using key 5G NR features like URLLC and TSC.

IIoT powered by 5G networks will enable new value creation and offer significant revenue expansion for original equipment manufacturers (OEM) and network operators. IIoT will offer increased efficiency with industrial automation on a shared highly flexible virtualized and scal-

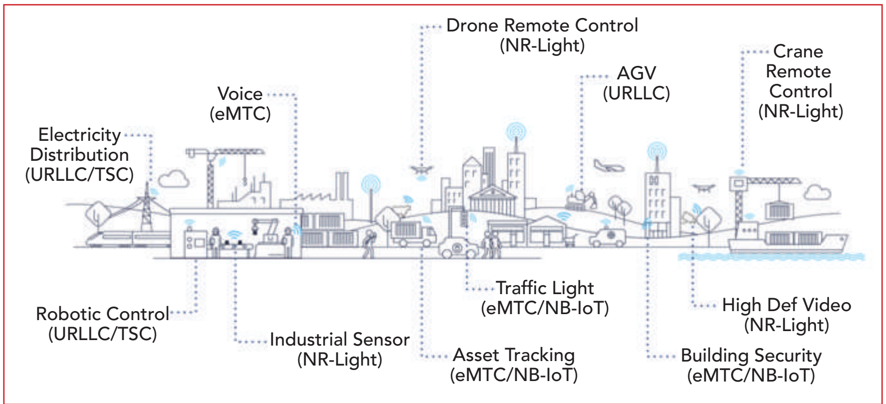

Fig. 1 **Industry 4.0 use cases and corresponding 5G NR features.**

able infrastructure. It will be driven by key 5G NR features like URLLC, 5G positioning, TSC and, to a lesser degree, eMBB. IIoT will also be complemented by MTC technologies developed for LTE and known as enhanced MTC (eMTC) and narrowband IoT (NB-IoT). The foundation for URLLC was laid out in Rel-15 3GPP specifications. IIoT networks will be further enhanced by subsequent releases of 3GPP specifications (Rel-16 and Rel-17) with new features as outlined here.[1-2]

TABLE 1

REQUIREMENTS FOR VARIOUS USE CASES IN A TYPICAL FACTORY OF THE FUTURE

Use Case	Reliability	Latency	Data Rate	Connection Density	
Motion Control	99.9999%	1 ms	1 to 10 Mbps	100,000/km²	URLLC, TSC
Electricity Distribution	99.9999%	5 ms	10 Mbps	1000/km²	
Mobile Robots/ AGV/Drone	99.9999%	1 to 50 ms	1 to 10 Mbps		
Augmented Reality	99.9999%	1 to 5 ms	5 to 25 Mbps		
Video Assisted Application	99.99%	10 ms	10 to 15 Mbps		NR-Light
Industrial Sensor	99.99%	10 to 30 ms	1 Mbps	10,000/km²	
Process Automation–Monitoring	99.9%	50 ms	1 Mbps	10,000/km²	
Hi-Definition Video	99.9%	100 ms	1 to 100 Mbps		
Video	99.9%	100 ms	1 to 10 Mbps	1000/km²	eMTC
Voice	99.9%	100 ms	20 kbps	10,000/km²	
Field Sensor/ Instrumentation	99.9%	10 sec	10 kbps	1,000,000/km²	NB-IoT
Public Safety/ Security	99.9%	10 sec	0.1 to 20 kbps	1,000,000/km²	
Asset Tracking	99.9%	10 sec	0.1 to 20 kbps	1,000,000/km²	

IIoT USE CASES AND REQUIREMENTS

A pictorial representation of Industry 4.0 use cases with the corresponding 5G technology features is shown in ***Figure 1***. The two major Industry 4.0 verticals are manufacturing and transport/logistics industry. For the factory of the future, productivity must be improved while also improving safety and cost efficiency. Processes must be automated, and production uptime

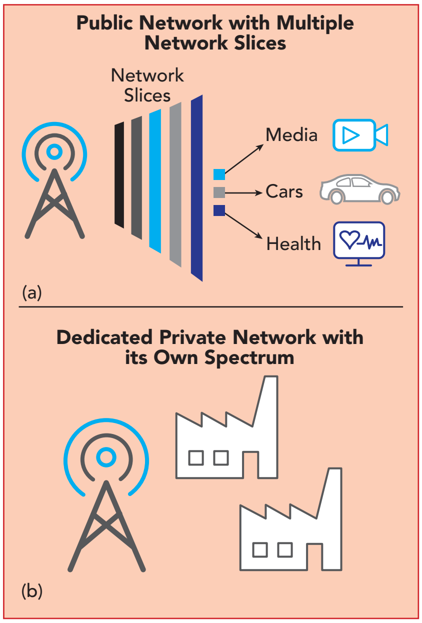

Fig. 2 Two options for industrial networks.

TESTING 5G MMWAVE DEVICES OVER THE AIR

MWC Barcelona
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5G NR networks are currently in the rollout. 5G is the first cellular technology operating at the new cmWave and mmWave spectrum (frequency range 2 or FR2). It uses advanced antenna technologies with a higher number of antennas for beamforming, which is compensating for the increased path loss at FR2. However, advanced antennas are integrated units, with transceiver frontends combined with the antenna array and without traditional RF output ports. The lack of physical connectors makes over-the-air (OTA) testing the default end-user device testing environment in FR2 which necessitates chambers and positioning systems to also cover dynamic beam steering scenarios.

Generally, all OTA measurements shall be executed under far field (FF) conditions where the electromagnetic waves have become planar. With high frequencies, this can lead to big FF distances according to the Fraunhofer equation, requiring large shielded chambers. Even a 15 cm smartphone transmitting at 43.5 GHz would need a testing distance of 6.5 m due to this. To ensure plane waves, either the distance of the DUT from the transmitting or receiving antenna has to be large enough, or the far field conditions have to be created artificially in a smaller distance by converting near field (NF) into FF, which is also referred to as indirect far field (IFF).

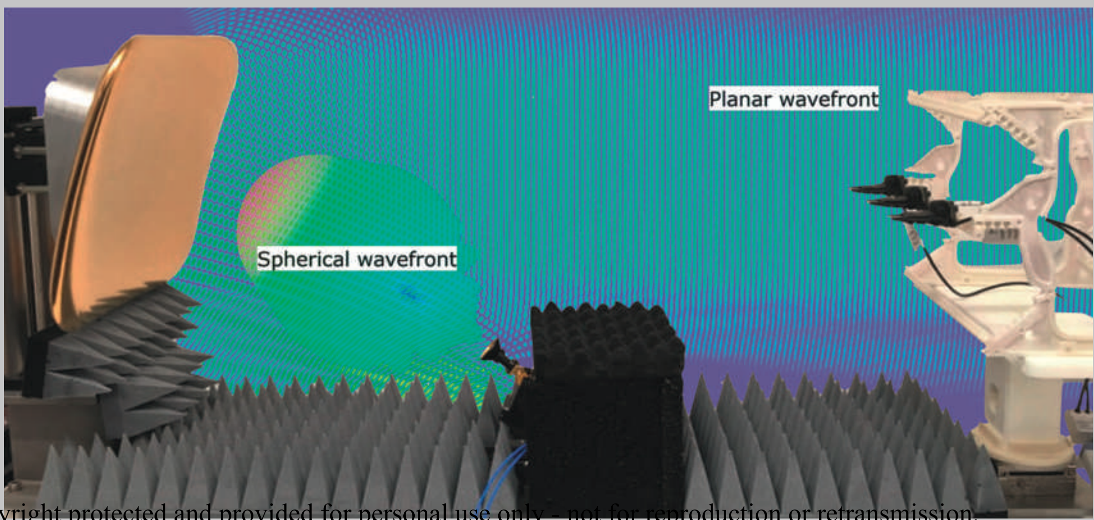
Using an anechoic chamber for radiation shielding and a positioning system for the DUT together with a hardware transformation of the propagating waves makes up an IFF system. If a parabolic reflector is used to transform a spherical wave front from the DUT or feed antenna into a planar wave front it is known as a compact antenna test range (CATR). This reduces the required chamber size as well as the complexity and cost of the test setup.

Rohde & Schwarz has several OTA solutions for mobile device testing that make use of such a CATR setup. These include the R&S®ATS800B benchtop antenna test system, the R&S®ATS800R rack solution and the R&S®ATS1800C 5G NR mmWave test chamber. All these solutions feature the high precision CATR reflector to generate a big usable measurement area (the so called quiet zone QZ) in a very compact setup and a wide frequency range.

Get a detailed overall system overview of 5G NR in the new, free 5G eBook, written by top experts at Rohde & Schwarz. The chapters include the technical background of the new communications technology with detailed information on subject matters such as use cases, architecture, access and non-access protocols, quality of service and network slicing.

The eBook '5G New Radio - Fundamentals, procedures, testing aspects' is available at

www.rohde-schwarz.com/5G-ebook



CATR antenna test systems are convenient and accurate solutions for testing 5G mmWave antennas, modules and devices in a compact setup.

maximized to minimize business interruption to gain more efficiency and competitiveness and value for investments. At the same time, carbon emissions need to be reduced and energy be saved. To satisfy the above goals, one will see mass personalization of products, artificial intelligence (AI) backed automated testing, monitoring and analytics for production resiliency and digital value platforms for fast re-configuration of supply chains. The goal of the future transport/logistics industry is to increase throughput using existing infrastructure, eliminate consignment losses and transit time delays and ensure resiliency of IT infrastructure and control systems. To that end, transportation/logistics industry will see massive use of AI managed automated guided vehicles (AGV) for maximum throughput, resilient and secure control systems and massive instrumentation to ensure minimal carbon footprint.

5G NR enables new value creation for Industry 4.0 based on three major use case domains, namely eMBB, URLLC and mMTC. ***Table 1*** shows the requirements in terms of reliability, latency, data rate and connection density for a typical factory complex. Additionally, it shows the various 5G component technologies needed to meet the requirements for the use cases.

The beginning of Industry 4.0 is being showcased in Nokia's 5G "factory of the future" in Oulu, Finland.[3] This pre-production facility uses Nokia's private wireless networks and edge cloud to securely connect all assets within and outside the factory.

FOUNDATION FOR URLLC

Two key requirements were defined by 3GPP for URLLC use cases:[4] 1.) target user plane latency of 0.5 ms in the downlink and 0.5 ms in the uplink and 2.) packet reliability of 99.999 percent for a 32-byte packet with a user plane latency of 1 ms. The coupling of very high-reliability together with very low-latency makes URLLC requirements very challenging to satisfy. However, as noted in Table 1, many IIoT use cases do not require both ultra-reli-

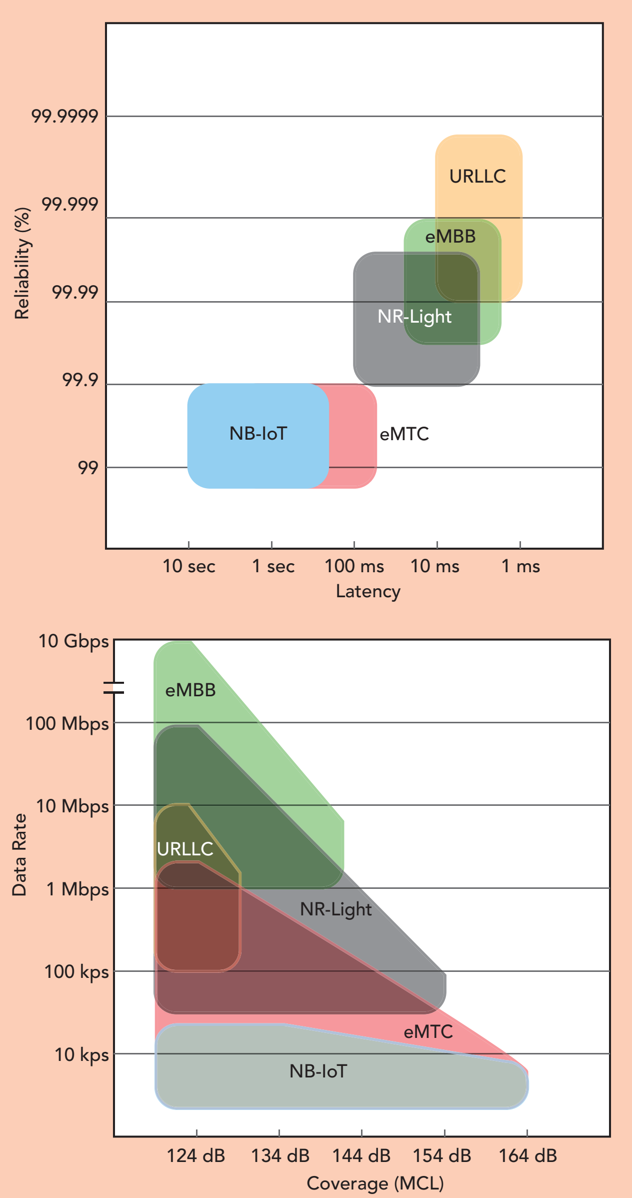


Fig. 3 Comparison of NR-Light to other NR features.

ability and low latency. To this end, 3GPP Rel-15 has separately specified two physical layer (PHY) feature groups to support URLLC.

The first group of PHY features are used to reduce latency. They include:

Flexible slot structure:

- Support of multiple subcarrier spacing values—NR supports subcarrier spacing of 15, 30, 60, 120 and 240 kHz. This translates into transmission slot length of 1, 0.5, 0.25, 0.125 and 0.0625 ms, respectively. Having a shorter slot length helps reduce latency as the data transmission process can be completed sooner. The disadvantage is that a less amount of data can be transmitted per slot. However, this is not crucial as URLLC data packets are typically small compared to e.g., eMBB.

- Sub-slot data transmission—NR allows data transmission that occupies less than a slot (i.e., 2, 4, 7 symbols in downlink, and any number of symbols in uplink). This allows data transmission to be completed in less time. For instance, with a subcarrier spacing of 60 kHz and 2 symbols, a packet can be transmitted in 0.036 ms.
- Self-contained slot structure in TDD—NR allows a slot in TDD to contain symbols for both data and hybrid automatic repeat request (HARQ) acknowledgment feedback. This reduces the wait time in TDD for uplink and downlink slots.

Flexible scheduling:

- Preemption—The base station can pre-empt on-going downlink data transmission to insert URLLC data into the data packet being transmitted. This is done by puncturing the on-going data transmission with URLLC traffic. The pre-empted UE is then notified of the pre-emption so it can appropriately manage the missing data.
- Configured grant or grant-free uplink transmission—User equipment (UE) are configured with periodic resources for uplink transmission. As a result, the UE does not have to transmit a scheduling request to the gNB (i.e., 5G NR base station) and wait for a scheduling grant whenever it has pending data.

Fast feedback:

- Shorter UE processing time—The NR slot structure design allows for UE pipelining to shorten the UE processing time.
- Short HARQ feedback format—A UE can transmit HARQ feedback in one or two symbols.
- Short periodicity for scheduling request—A UE can be configured with a scheduling request slot to request uplink data transmission as often as every 2 symbols.

The second group of PHY features are used to increase reliability. They include:

Data enhancements:

- Transmission of the same data

packet from different transmission points to increase reliability. This is supported by duplicating the data packet at the packet data convergence protocol layer. It can be used, for example, to transmit the same packets from two different gNBs to the UE to increase reliability.
- Multi-slot repetition for data channels—Data packet can be transmitted using 2, 4 and 8 repetitions to improve reliability.
- URLLC-specific modulation and coding values that are designed to support very high-reliability.

Control enhancements:
- Support lower coding rate for the associated control channel and smaller control packet size.
- Enhanced channel state information reporting targeting 99.999 percent reliability.

In addition to the physical layer enhancements, URLLC also requires optimized system architecture design. Two important features are:
- Edge cloud and multi-access edge computing (MEC)—Instead of a centralized architecture, an edge cloud places computing resources at the edge of the network. This allows for reduced end-to-end latency and ultra-fast response time. In addition, MEC is crucial to many IIoT verticals as it allows real-time data analytics and reduces the amount of data that must be sent upstream.
- Network slicing allows for a dedicated set of end-to-end resources to be allocated for multiple applications. For industrial networks, one option is to have public networks with slicing where each slice has guaranteed QoS and security level. The other option is to have a dedicated private network with its own "local spectrum" and customized security and QoS levels. These two options are illustrated in ***Figure 2***.

IIoT FEATURES IN REL-16 AND REL-17

In Rel-16, further enhancements for IIoT are being standardized in two work items. The first work item addresses physical layer enhancements for URLLC and includes the following items:[5]
- Control channel enhancements—Control format with configurable size to improve reliability, increased control channel monitoring capabilities to reduce scheduling delay, transmission of more than one acknowledgment within a slot and support for two simultaneous HARQ codebooks.
- Data channel enhancements—Mini-slot level hopping.
- Scheduling enhancements—Support for out-of-order scheduling and HARQ feedback, multiple active grant-free configurations.
- Uplink transmission prioritization and multiplexing among users—Interference cancellation to support uplink pre-emption and enhanced power control.

The second work item addresses support for new time-sensitive net-


WR 3.4
220 - 330 GHz

work use cases such as factory automation and electrical power distribution. These use cases have tighter requirements than URLLC (e.g., reliability of up to 99.999999 percent) and may also require strict time synchronization for packet delivery (e.g., deterministic services with bounded latency and extremely low variation). The work item includes the following enhancements:[6]

- TSC—Specify accurate reference timing delivery, address support for TSC messages, hard guarantees for QoS characteristics such as packet loss and reliability, latency bounds and synchronization down to the nanosecond level.
- Support PDCP duplication with higher reliability and better efficiency.
- Address resource conflicts and collisions between multiple transmissions from the same user.

In addition to the above work items, positioning is also an important aspect for IIoT deployment. In Rel-16, 3GPP is working to specify positioning support for NR.[7] They include:

- Define interfaces, signaling and procedures.
- Extension of LTE Positioning Protocol (LPP) and NR Positioning Protocol "a" (NRPPa) for NR positioning.
- Specifying reference signals to support various positioning techniques.
- Define UE and gNB measurements and requirements applicable for positioning.
- Study the feasibility of RAN-based location management.

The positioning requirements for commercial use cases are:[8]

- Indoor deployment scenarios—Horizontal positioning error less than 3 m and vertical positioning error less than 3 m for 80 percent of UEs.
- Outdoor deployment scenarios—Horizontal positioning error less than 10 m and vertical positioning error less than 3 m for 80 percent of UEs.
- End to end latency less than 1 second.

Further, there is a need to address use cases that cannot be met by NR eMBB, URLLC, eMTC and NB-IoT. As such, a version of NR known as NR-Light will be introduced in the 3GPP Rel-17/18 time frame. With this new feature, operators can migrate their spectrum to NR which can support both URLLC and NR-Light on the same carrier as well as deploy eMTC/NB-IoT either in-band or in guard-band. The NR-Light comparison to other IoT related technologies with respect to data rates, latency and reliability are shown in ***Figure 3***.

SYSTEM PERFORMANCE FOR A TYPICAL INDOOR FACTORY

In this section, we present simulation results for a typical indoor factory using ray tracing. It may be noted that, various real-time and ray tracing measurements in an industrial environment were done by multiple entities and used to derive IIoT channel model in 3GPP standards body.[9-10]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We chose to study performance using an indoor factory scenario with a 400 MHz bandwidth mmWave carrier at a 28 GHz carrier frequency. The high carrier bandwidths available in mmWave spectrum is very attractive from a capacity point-of-view, and the indoor factory setting inherently provides good isolation against the external environment which allows the possibility of using both licensed and unlicensed high bandwidth mmWave spectrum.

In this study we created a fictitious factory of dimensions 120 m × 50 m × 10 m with 12 single sector gNBs mounted on the ceiling and pointed downward. This is very similar to the indoor office scenario in the 3GPP TR 38.901, "Study on Channel Model for Frequencies from 0.5 to 100 GHz," with the ceiling height increased from 3 to 10 m to be more appropriate of a factory setting.[11] As for the propagation modeling, 3D ray tracing was utilized with the WinProp tool from Altair. Random rectangular metal objects were placed in the factory to be representative of production lines, heavy duty machinery, tool containers, etc. The walls and roof material were chosen to be concrete and metal support beams for the ceiling were added. This is depicted in ***Figure 4***.

We chose to study the TSC use case as it is more demanding than looking at URLLC only. On top of the high-reliability with low latency (i.e., 99.999 percent reliability at less than 1 ms latency) as with URLLC only, TSC now also enforces that the delay between the transmitter and receiver is deterministic rather than variable. As such, a de-jitter buffer is added at the receiver to account for the variability in delay that occurs over the 5G NR air interface from things such as HARQ or variable scheduling delay that is seen with dynamic packet schedulers.

The subcarrier spacing of 120 kHz used in the mmWave frequency band provides a short slot length of 0.125 ms. However, with a 1 ms latency constraint, this means only 1/0.125 = 8 slots are available for scheduling, and this must be split between uplink and downlink as mmWave spectrum is time-division duplex (TDD). For the symmetric traffic expected for the TSC use case, this means four slots are available per link direction, and this means only four analog beams could be configured to serve the entire gNB coverage area. This is typically an insufficient beamforming gain for mmWave spectrum, so

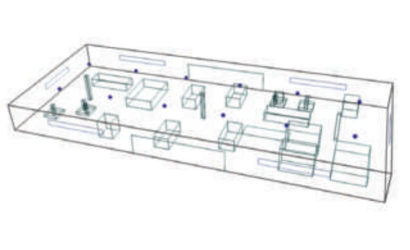
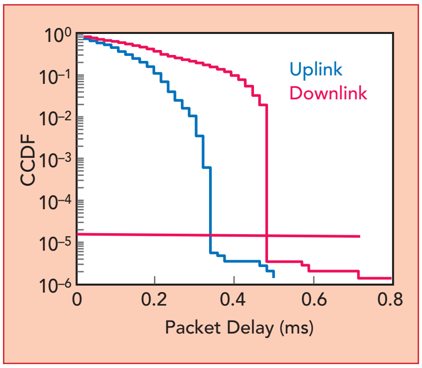


Fig. 4 Fictitious factory floor which was ray traced for system simulations with 12 single gNBs placed on the ceiling in two rows with a spacing of 20 m between each gNB, horizontally and vertically.

TABLE 2 SIMULATION PARAMETERS

Simulation Parameter	Value
Carrier Configuration	28 GHz carrier frequency 400 MHz bandwidth 120 kHz subcarrier spacing 2 symbol mini-slots TDD spectrum
TDD Slot Format	#45: 6 DL, 2F, 6 UL. Flexible assigned to UL
Scenario	Indoor factory: 120 m × 50 m × 10 m as in Figure 3 12 single-sector gNBs mounted on ceiling in two rows, 20 ms horizontal and vertical spacing between gNBs
Channel Model	3D ray traced with WinProp®
gNB Configuration	30 dBm Tx power (4, 4, 2) antenna panel Column spacing 0.5λ, row spacing 0.7λ 8 dBi element gain 65 degrees azimuth and elevation beamwidth per element Front-to-back ratio 30 dB Single sector, down tilt = 90 degrees Noise figure = 7 dB Analog beam configuration: 4 horizontal and 4 vertical DFT beams, for a total of 16 beams
UE Configuration	23 dBm Tx Powder (4, 4, 2) antenna panel, optimally oriented towards serving gNB Noise figure = 10 dB
Scheduler Configuration	FIFO scheduling policy, segmentation-aware SPS in DL and CG in UL Max modulation: 16-QAM Link adaptation: off HARQ: off Target FER < 10^{-6}
Uplink Power Control	Po_nominal = –85 dBm, FPC α= 0.8
Traffic Model	Strictly periodic traffic 32 bytes every 1 ms
Simulation Time	10 Monte-Carlo drops with each drop long enough for 10,000 packets to be transmitted per user in each link direction



▲ **Fig. 5 CCDF of packet delay for both uplink and downlink.**

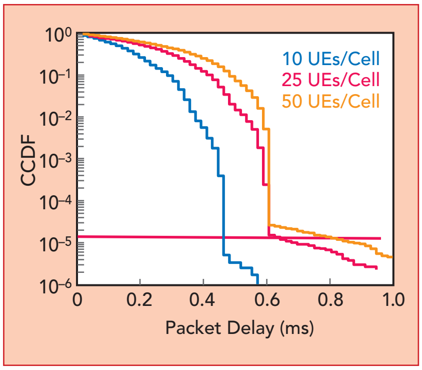
instead it is advantageous to configure mini slots even for the 120 kHz subcarrier spacing. By choosing a 2-symbol mini-slot, which has a duration of just 17.84 µs, we now have 56 mini-slots in a 1 ms interval, leaving 28 mini-slots available per link direction when considering an equal uplink/downlink split when considering the symmetric nature of TSC traffic. Hence up to 28 analog beams can be configured in the system and sweeping over 28 beams in both uplink and downlink can be done in less than 1 ms.

The full set of system simulation assumptions are given in ***Table 2***. The complementary cumulative distribution function of packet delay (CCDF) is given in ***Figure 5***. In this case there were no reported packet failures. It is seen that the target of 99.999 percent reliability is achieved with less than 1 ms latency for both uplink and downlink. In ***Figure 6*** we focus on just the downlink and increase the total number of active users in the factory. We look at 120, 300 and 600 active users, cor-

responding to an average of 10, 25 and 50 users per gNB, respectively. We see that the target 99.999 percent reliability level with less than 1 ms latency can be met even at these higher traffic loading, thanks to the wide bandwidth available in mmWave spectrum.

CONCLUSION

Industry 4.0 powered by 5G networks will offer significant revenue expansion through new digital service provider markets. 5G NR and its evolutions offer features like URLLC and its enhancements, TSC and its enhancements, network slicing and positioning, which are essential for IIoT deployments in both public and private networks. Simulation studies for a typical factory environment shows strict latency and reliability bounds can be met using 5G NR URLLC and TSC features.■



▲ **Fig. 6** CCDF of packet delay in the downlink, with UE density of 10, 25 and 50 users per gNB corresponding to 120, 300 and 600 active users on the factory floor.

ACKNOWLEDGMENTS

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GatorWings Wins DARPA Spectrum Collaboration Challenge

DARPA recently announced that GatorWings, a team of undergraduate students, Ph.D. candidates and professors from the University of Florida are the winners of the Spectrum Collaboration Challenge (SC2)—a three-year competition to unlock the true potential of the RF spectrum with AI. DARPA hosted the championship event at MWC Los Angeles 2019 in front of a live audience. SC2's final 10 competitors and their AI-enabled radios went head-to-head during six rounds of competitive play. GatorWings emerged victorious, taking home first place and the $2 million grand prize.

GatorWings' autonomous radio was able to navigate the various wireless obstacles developed to thoroughly stress each team's AI-enabled radios. GatorWings' unique approach to the SC2 challenge helped it eke out the competition. Using an AI engine that is one-step beyond basic rule-based systems, GatorWings applied foundational reinforcement learning AI techniques to optimize each "pocket" of available spectrum.

During the SC2 Championship Event, the teams' AI-enabled radios were tested during five rounds of competitive, round-robin matches. Each round focused on a different wireless scenario with various obstacles that autonomous radios could face in the real world—from gradually shrinking bandwidth to temporal surges. At the end of each round, the two lowest scoring teams went head-to-head to determine who would move on to the next round and who was eliminated from competition. The final five teams moved onto the final round, which introduced new obstacles for the teams' technologies to overcome, including legacy radio systems that are sensitive to interference. The teams received prize points based on their rank at the end of each round, that were then totaled to determine the final rankings.

Throughout the event, the virtual wireless world came to life with emotional reactions from the 10 finalist teams, live commentary from the event emcees—which included Grant Imahara from the Discovery series "MythBusters" and the Netflix series "White Rabbit Project," DARPA Program Manager Paul Tilghman and GNU Radio President Ben Hilburn—as well as a custom-built visualizer that showed how each radio fared at autonomously navigating the spectrum while avoiding interference with their competitive counterparts.

MarmotE, a team of current and former Vanderbilt researchers, took home the $1 million second place prize and the third place prize of $750,000 went to Zylinium, a three-person start-up with expertise in software-defined radios (SDR) and AI. Andersons, a two-person team of hobbyists and SDR enthusiasts that also successfully competed in the 2014 Spectrum Challenge, and Erebus, a three-person company created specifically to tackle SC2, rounded out the top five.

The SC2 Championship Event provided further proof that collaborative, autonomous wireless networks are capable of beating the status quo of static, human-driven spectrum allocation. While still in the early days for exploration, these technologies show significant promise towards easing the strain increasingly placed on our wireless resources as more commercial and defense technologies become wirelessly enabled.

The event was live streamed and can be viewed at www.youtube.com/watch?v=-a-N8MiMqz0.

NGC Demos Antenna Sharing and Pattern Capabilities

Northrop Grumman Corp. (NGC), in partnership with the U.S. Naval Research Laboratory (NRL), successfully completed a critical test in the development of the Integrated Topside (InTop) Low-Level Resource Allocation Manager (LLRAM) program at NRL's test facility in Chesapeake Beach, Md.

LLRAM, in conjunction with the InTop Electronic Warfare/Information Operations/Communications (EW/IO/COMMS) system, demonstrated the simultaneous sharing of a single antenna, while flexing its adaptable size and antenna pattern capabilities and performing a mission that would have required multiple dedicated antennas in the past. The significance of the test is to enable future antenna reductions on ships that are already capacity-constrained, allowing for more advanced warfighting capabilities in an ever-increasingly complex battlespace environment.

"The NGC/NRL demonstration of LLRAM concepts was conducted in the same environment that proved crucial to the development of the SEWIP Block 3 EDM," said Mike Meaney, VP, maritime electronic and information warfare, NGC. "The efficiency of signal sharing capabilities, scalability and advanced resource management developed on the LLRAM program will allow for a significantly reduced footprint topside."

NG Demo (Source: Northrop Grumman Corp.)

The demonstration showed that the EW/IO/COMMS Advanced Development Model for SEWIP Block 3 can serve as a platform for proving out advanced multi-function concepts using existing NRL test assets.

LLRAM and EW/IO/COMMS were developed under the Office of Naval Research (ONR) Electro-

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magnetic Maneuver Warfare Command and Control (EMC2) InTop Innovative Naval Prototype. The system leverages four AESA arrays (low- and high-band Tx/Rx) and intended platforms include cruisers, destroyers and aircraft carriers.

HENSOLDT's Passive Radar in NATO Measurement Campaign

HENSOLDT's passive "TwInvis" radar sensor solution showed outstanding detection performance during a measurement campaign of the NATO Science and Technology Organization under the leadership of the Polish Armed Forces.

For this purpose, a passive radar sensor cluster with two sensors was installed on the Polish Baltic coast. During the measurement campaign, a system integrated in a container was used alongside a system variant integrated in a van. TwInvis reliably detected a large number of targets in the air and at sea, ranging from light aircraft and combat aircraft to ballistic and ground-to-air missiles. The achieved ranges over the Baltic coast were up to 300 km. The live data from the TwInvis cluster was fed into the Polish MilRad network and analyzed and evaluated in a nearby Polish CRC.

TwInvis Antenna (Source: Hensoldt)

A passive radar acts purely as a receiver, i.e., it does not transmit itself, and locates aircraft by evaluating the signals reflected by the target from existing external transmitters. The TwInvis creates a comprehensive air situation picture, which is generated from the simultaneous evaluation of a large number of frequency ranges. TwInvis can simultaneously evaluate up to 16 FM transmitters (analog radio) and five frequencies with several contributing transmitters from DAB and DAB+ (digital radio) as well as DVB-T and DVB-T2 (digital terrestrial television) due to its advanced digital receiver technology and specialized algorithms.

In civil applications, passive radar enables low-cost control of air traffic without additional emissions and without using scarce transmission frequencies. In military applications, the system enables covert surveillance of large areas using networked receivers and offers the advantage that the "passive radar" cannot be located by the enemy and is very difficult to jam.

Base Station Vendors Use Sectorization, AASs, Cell Shaping to Tackle 5G

As 5G networks start commercial operations in countries including the U.S., South Korea, China and Japan, base station antenna (BSA) vendors are innovating and coming to grips with the complex feature sets and performance demands required in a modern BSA. "Sectorization, active antenna systems (AAS) and cell shaping are the overarching trends emerging from vendors' roadmaps used to tackle the demands of 5G," says Nick Marshall, research director, ABI Research.

Higher order sectorization using multi-port/multi-band and/or multi-beam antennas is being used to upgrade a cell site from a standard three sectors to six sectors or more. "Sectorization increases the number of sectors without increasing the number of antennas/radiation centers on the tower and represents important cost savings because towers are increasingly occupied by multiple BSAs and other equipment," says Marshall.

An AAS contains active radio electronics inside the BSA radome with the antenna/radio combination connected back to the baseband with fiber. "Although more expensive than legacy passive antennas, AASs enable high-order and massive MIMO features for sector throughput enhancements, reductions in cable losses and power consumption," continues Marshall.

Included in AASs are new types of hybrid active/passive BSAs that are antenna systems integrating massive MIMO antennas with passive antennas sharing electronics, RF components and chassis between the active/passive antennas. "As a compact single unit, hybrid active/passive antennas reduce wind load and, since components are shared, offer a lower initial cost when compared to traditional options," says Marshall.

The third overarching driver is proactive cell shaping, where beamforming is used to shape or sculpt overall cell coverage. Sector sculpting in the cell shapes the RF radiation pattern with directional antennas, which can be steered both in azimuth and elevation. Sculpting delivers precise wireless coverage with minimal interference between neighboring cells.

"The key takeaway from these and other innovations is that antenna vendors are rising to the complex challenges of delivering 5G with highly innovative and technically elegant BSA designs," concludes Marshall.

Securing IoT: A Critical & Attainable Goal

Integrating security into IoT projects is not easy, but is an increasingly urgent necessity. With an installed base of 44 billion connected devices projected for 2023, the amount of data and information generated and shared will reach zettabytes of data, according to ABI Research.

"Much of that data will be sensitive; as such, it presents a lucrative opportunity for threat actors. Add to that the potential of harnessing unprotected IoT devices for botnets, denial-of-service attacks or even holding them hostage to ransomware, the imperative for security cannot be ignored," emphasizes Michela Menting, digital security research director, ABI Research.

From a hardware perspective, semiconductor manufacturers, such as STMicroelectronics, NXP, Renesas, Microchip and Cypress, are offering secure microcontrollers that can service general-purpose IoT applications from smart home appliances to industrial control systems. Boosted by Arm's Cortex M4 (and soon M23 and M33 cores), they can enable a host of secure functionalities, including security co-processors and cryptographic accelerators, secure storage for keys and certificates, secure execution environments and root of trust functionalities.

"These secure microcontrollers come prepackaged with supporting software development tools that can enable developers to leverage these hardware features and deploy secure services, such as key provisioning and onboarding to a cloud platform, as well as lifecycle management (e.g., secure OTA software updates)," Menting says. In a bid to facilitate secure IoT deployments, the semiconductors vendors offer a wide breadth of software development platforms, from their own proprietary solutions but also focusing on interoperability and compatibility with third-party software and connectivity tools, such as those provided by Segger, Eclipse, Visual Studio, IAR Embedded Workbench, Arm Keil & Pelion, AWS & Google Cloud IoT Core, among many others.

The aim is to facilitate the use of secure hardware by providing secure software development and service connectivity tools that can easily allow developers to onboard and securely manage their devices. "Developing and managing secure IoT deployments is no longer the responsibility of security professionals but is a capability that is quickly becoming available to developers of all levels. Enterprises looking to deploy IoT can now more easily engage in securing them, in a more cost-effective manner that can enable faster time-to-market. End-to-end IoT security is within reach for enterprises large and small," Menting concludes.

Cloud Service Providers to Own 18% of Total AI Cloud Chipset Market by 2024

During the last two years, several cloud service providers, including Alibaba, Amazon, Facebook, Google, Huawei and Tencent, have been busy designing their own in-house chipsets for handling AI workloads in their data centers. ABI Research estimates that cloud service providers commanded 3.3 percent market share of the total AI cloud

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chip shipments in the first half of 2019. These players will increasingly rely on their own in-house AI chips and will be producing a total of 300,000 cloud AI chips by 2024, representing 18 percent of global cloud AI chipsets shipped in 2024.

The increasing requirements for intelligent services by many enterprise verticals are pushing cloud service providers to rapidly upgrade their data centers with AI capabilities, which has already created an enormous demand for cloud AI chipsets in recent years. ABI Research expects revenues from these chipset shipments to increase significantly from $4.2 billion in 2019 to $10 billion in 2024. Established chipset suppliers such as NVIDIA, Intel and, to a certain extent, Xilinx will continue to dominate thanks to the robust developer ecosystem they have created around their AI chipsets.

However, these players will increasingly face intensive competition, particularly from their clients, namely the webscale companies. "The approach by webscale companies to develop in-house AI chips allows for better hardware-software integration and resources tailored to handle specific AI networks, which serves as a key differentiating point not only at the chipset level but also at the cloud AI service level," said Lian Jye Su, principal analyst, ABI Research. "The success of these highly optimized processing units provides strong validation for the emergence of other cloud AI application-specific integrated circuits start-ups, such as Cerebras Systems, Graphcore and Habana Labs."

This trend, initiated by Google in 2017, has led other webscale companies to follow: Baidu with its AI chipset, Kunlun, in 2018, and, later that year, Amazon introduced its Inferentia chip to support its Amazon Web Service (AWS). AWS has a strong influence due to the success of SageMaker, its machine learning development platform. Huawei has made a move toward using its in-house chips for its cloud services to reduce its reliance on Western chipset suppliers. Huawei launched Ascend 310 and 910 in 2018, and has expanded into a series of cloud AI hardware, including an AI accelerator card and AI system. Recently, Huawei launched Atlas 900, an AI training cluster which is a direct competitor to NVIDIA's DGX and features over 1,000 Ascend 910 chipsets.

"This further expands the footprint of cloud AI service providers, as they are also competing for the mindshare of developers. By offering end-to-end AI hardware solutions, Google, Amazon and Huawei can ensure that their users enjoy the ease of development while creating an active and vibrant developer community around their chipset solutions and ultimately generating a large user base for their cloud AI services," concluded Su.

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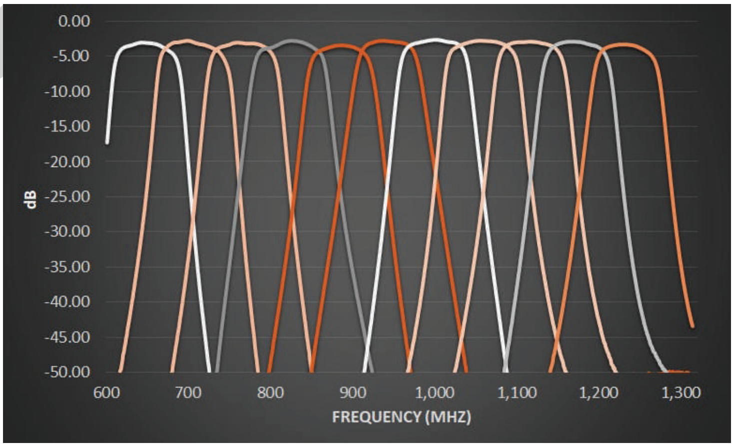

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Altair announced the acquisition of **Polliwog Co. Ltd.**, a software company based near Seoul that provides EDA software to the electronics industry. Polliwog expands Altair's solution portfolio for system-level engineering to PCB design and analysis. Polliwog's customer roster includes major consumer electronics companies such as Samsung and LG Electronics. Its products include a PCB modeler, simulation solvers and design verification tools that seamlessly integrate with customer design environments using any of the leading PCB design solutions. The PollEx Modeler imports complete PCB design data and provides users with convenient ways to explore design details and verify manufacturability.

Dialog Semiconductor plc announced it has signed a definitive agreement to acquire **Creative Chips GmbH**, a prominent supplier of integrated circuits (IC) to the industrial IoT (IIoT) market. Headquartered in Bingen, Germany, with an additional design center in Dresden, Creative Chips is a fabless semiconductor company with a growing IC business supplying a broad portfolio of industrial Ethernet and other mixed-signal products to top-tier, blue-chip manufacturers of industrial and building automation systems. The technology is optimized to efficiently connect large numbers of IIoT sensors to industrial networks.

Fractus, a Spanish company that licenses antenna technology it has developed, will transfer its worldwide portfolio of base station antenna patents to **CommScope**, the outcome of a lawsuit filed by Fractus. Fractus sued CommScope Technologies LLC, T-Mobile U.S. Inc., T-Mobile USA Inc., Verizon Communications Inc. and Cello Partnership DBA Verizon Wireless for infringing on Fractus' patents covering cellular base station antenna technologies. The IP transfer agreement terminates Fractus' lawsuit against Commscope. According to Commscope's most recent quarterly report, filed with the Securities and Exchange Commission on August 8, 2019, the trial was scheduled to begin on September 9 in the U.S. District Court for the Eastern District of Texas.

Ironwave Technologies LLC has acquired **American Microwave Corp. (AMC)**. AMC has been designing and manufacturing solid-state control components and subsystems from DC to 40 GHz for the communication and EW community since 1978. The company is based in Frederick, Md. and is best known for their expertise in developing DLVAs. This acquisition will help Ironwave Technologies enhance its ability to support EW and communication systems clients. The combined engineering and product offerings of AMC and Mu-Del Electronics, another Ironwave Technologies company, will also help them expand into new markets.

COLLABORATIONS

Movandi has joined the **O-RAN Alliance**, an industry consortium formed to move the mobile network to a cloud-based, virtual system of open interfaces and compatible hardware and software from multiple manufacturers. Movandi's Beam XR was developed to improve 5G mmWave coverage by amplifying mmWave signals to better penetrate buildings and propagate around structures. According to the company, Beam XR will help accelerate 5G commercialization by reducing infrastructure costs, simplifying deployment and increasing network capacity, without impacting latency. Movandi announced Beam XR at MWC 2019.

Viavi Solutions has collaborated with **Tait Communications** to provide automated test capabilities for Tait P25 and DMR Series radios on the VIAVI 3920B Radio Test Platform, formerly an Aeroflex offering. These options give end-users automated testing for Tait TP/TM 9100, TP/TM 9300 and TP/TM 9400 radio families. The automated radio test applications use the precision instrumentation of the 3920B to quickly perform automated tests to specifications defined by the manufacturer. Testing can be performed in less time, minimizing service and support costs for end-users and dealers.

NEW STARTS

SAGE Millimeter will become **Eravant** in March 2020, a change that renews its commitment to serve, first and foremost, the RF engineer. Rebranding as Eravant represents the company's promise to continue investing in its customers and as team members. As the company transitions to the new brand, it trusts that your experience with them will continue to set the standard for all supplier partnerships. Not only does rebranding signal a new era for the team, but more specifically, it signals its commitment to the Relationship Era of doing business. The Relationship Era recognizes that companies thrive when they know their clients, and they utilize technology to scale the customer experience.

ACHIEVEMENTS

Rohde & Schwarz has supplied mobile network testing tools used in drone-based network coverage, performance and operation tests managed by **Ericsson**. The unique procedure enables unprecedented 3D accessibility, positional accuracy and repeatability of the testing. It also opens up new possibilities to ensure end user QoS for demanding 5G use cases such as Industry 4.0, automotive and public safety. The deployment of 5G NR brings new applications of cellular networks for subscribers, government and industry.

CONTRACTS

CACI International Inc. announced that it has been awarded a five-year task order, with a ceiling value of nearly $907 million for new and continuing work, on a **U.S. Army Intelligence and Security Command Glob-**

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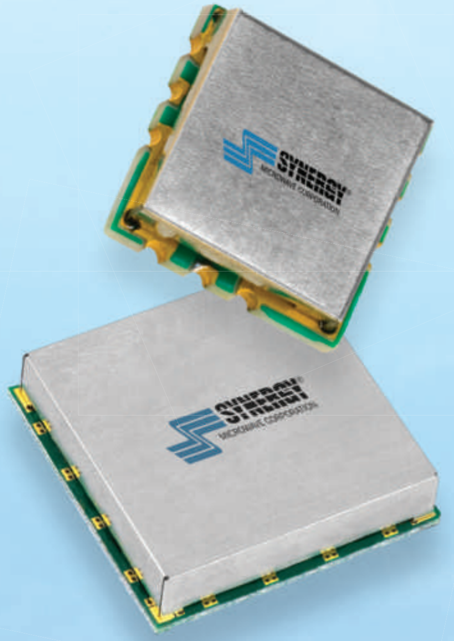
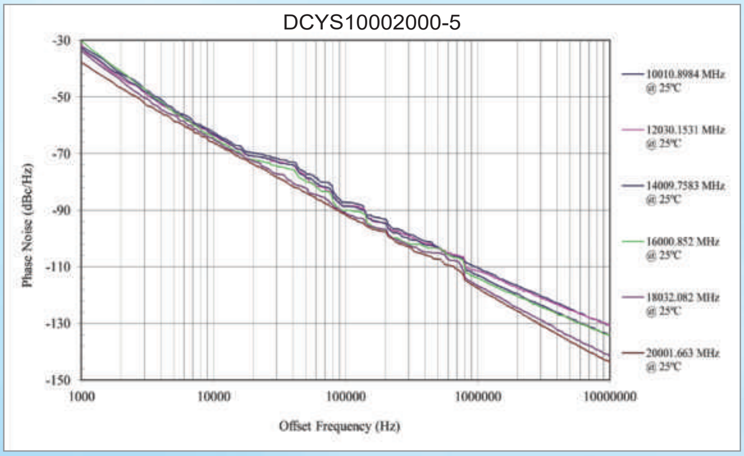
DCO200400-5	2 - 4	-90	-110	0 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0 - 18	0
DCO300600-5	3 - 6	-75	-104	0 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0 - 16	+2
DCO400800-5	4 - 8	-75	-98	0 - 15	-4
DCO5001000-5	5 - 10	-80	-106	0 - 18	-2
DCYS6001200-5	6 -12	-70	-94	0 - 15	> +10
DCYS8001600-5	8 - 16	-68	-93	0 - 15	> +10
DCYS10002000-5	10 - 20	-65	-91	0 - 18	> +10





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al Intelligence Support Service contract task order to protect U.S. forces in Afghanistan by providing intelligence operations and analytic support. Under the task order, CACI intelligence and counterintelligence experts will continue to provide mission expertise in intelligence operations and analytic support from locations both within the U.S. and abroad to support U.S. operations in Afghanistan.

BAE Systems has received a $120 million contract from the **U.S. Marine Corps** for additional amphibious combat vehicles under a third order for low rate initial production (LRIP). This award is an important next step on the path to full rate production. This latest contract is for the ACV personnel carrier variant (ACV-P), an eight-wheeled amphibious assault vehicle capable of transporting Marines from open-ocean ship to shore and conducting land operations. Each vehicle embarks 13 Marines in addition to a crew of three.

The National Geospatial-Intelligence Agency (NGA) has awarded the $68 million Zeus contract to **Science Applications International Corp. (SAIC)**. The Zeus acquisition is the follow-on contract for the Innovative GEOINT Application Provider Program (IGAPP) that SAIC has supported since 2014. SAIC serves as the unbiased trusted broker for NGA, partnering with startups and innovative sources to acquire apps and data content that support geospatial intelligence missions. Zeus expands the scale and scope of the IGAPP program. SAIC will be responsible for identifying, prescreening, price negotiating, recommending and delivering candidate applications and data content to NGA. The program will continue to operate under the IGAPP program name.

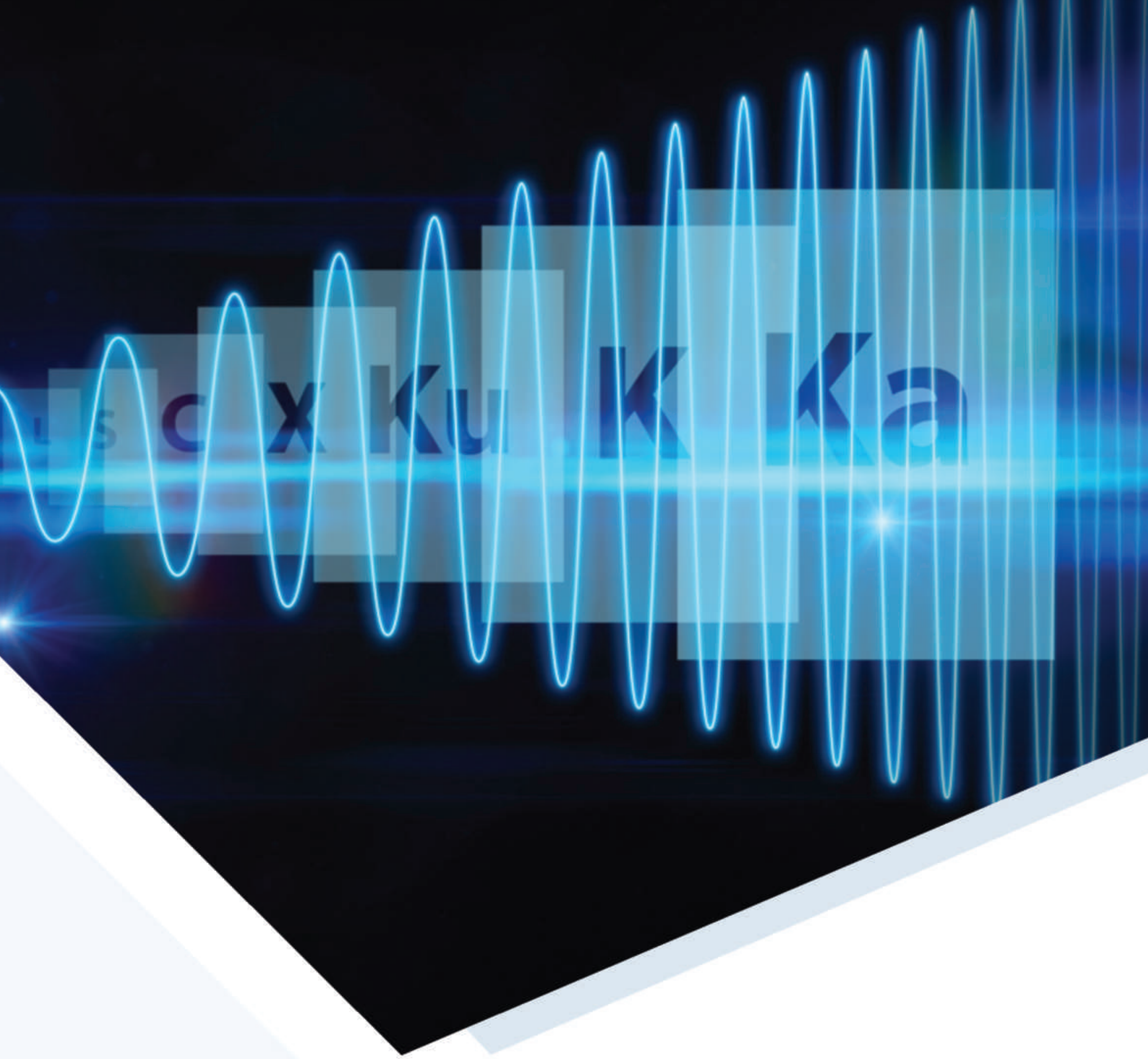
The U.S. Navy has awarded **Raytheon** a $33 million contract to develop a dual-band towed decoy for the F/A-18 E/F. The design will extend the protection capabilities of the AN/ALE-50, which was developed by Raytheon and flies on the F/A-18E/F, as well as the F-16 and B-1B. The new design will leverage the aerodynamic performance of the ALE-50 and use advancements in electronic integration to achieve the required self-protection capabilities. Raytheon will complete the development during the next 27 months.

Comtech Telecommunications Corp. announced that during its first quarter of fiscal 2020, its Mission-Critical Technologies group, which is part of Comtech's Government Solutions segment, received additional funding of $1.2 million to provide very small aperture terminals (VSAT) to support the **U.S. Army**. The Mission-Critical Technologies group is a leading provider of mission-critical, highly-mobile C4ISR solutions. Comtech Telecommunications Corp. designs, develops, produces and markets innovative products, systems and services for advanced communications solutions. The company sells products to a diverse customer base in the global commercial and government communications markets.

PEOPLE

▲ *David Freed*

OnScale announced that it has named **David Freed**, Ph.D., as the start-up company's new CTO. Freed is an MIT-trained digital physicist and an expert in engineering simulation and computational fluid dynamics (CFD). Before joining OnScale, Freed led the commercialization efforts for Dassault's DigitalROCK, a first-of-its-kind "Digital Twin" computational analysis tool for oil and gas exploration, which accurately simulates multiphase flow in digitized rock samples to evaluate oil reservoir productivity. The cloud-based, high performance computing (HPC) DigitalROCK solution was developed based on an advanced version of the Lattice-Boltzmann Method (LBM) for CFD.



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Around the **Circuit**

▲ John Cole

Radio Frequency Systems (RFS) has announced the appointment of **John Cole** to role of CTO. Cole joined RFS in 2018 as VP Base Station Antennas, bringing more than 35 years of experience in the RF/microwave industry, including senior and executive positions in market leading companies. During his first 18 months with RFS, he has already refined RFS's approach to product management to focus on customer driven solutions for 5G. RFS technology and innovation leadership includes the RFS's FUSION programme, which builds on RFS's APA (Active Passive Antenna) launched in 2018.

▲ Eric Starkloff

NI announced that **Alex Davern** will step down as CEO of NI, effective January 31, 2020. The NI Board of Directors has appointed current President and COO, **Eric Starkloff**, as NI president and CEO, effective February 1, 2020. Davern will take up a teaching position at the University of Texas McCombs School of Business starting in the fall of 2020. Davern will remain on staff at NI as strategic advisor to the CEO through May and will continue to serve on the NI Board of Directors.

▲ Amir Faintuch

GLOBALFOUNDRIES® (GF) announced the appointment of **Amir Faintuch** as senior VP and general manager of the company's computing and wired infrastructure (CWI) strategic business unit (SBU). In this role, Faintuch will oversee the strategic direction, roadmap definition and client engagements of differentiated features forthe company's CWI SBU. With more than 25 years of experience in the semiconductor, communications and software industries, Faintuch joins GF with a strong technology background and business acumen in computing, AI, cloud, connectivity, networking and wireless infrastructure. He aims to develop and drive GF's go-to-market strategy that will support the demanding requirements for clients' AI applications in the computing and wired infrastructure markets.

RFMW announced that **David Markman** has joined their organization as director of Business Development–Mil Aero, reporting directly to Mike Carroll, VP –Global Sales. Markman joins RFMW with more than 35 years of new business development, sales, marketing and engineering experience and with an extensive network of contacts within the mil/aero RF/microwave community. Prior to RFMW, Markman leveraged his security clearance and solid understanding of RF/microwave technology to support numerous mil/

▲ David Markman


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Frequency (GHz)
Term
Term1
Num=1
Z=50 Ohm
RES_BAI_1005_001_MDLXCLR1
BAI_RE1005CT_R1
R=50 Ohm
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aero programs. His work with industry-leading companies such as Cobham, Aeroflex and Smiths Interconnect to deliver state-of-the-art products and services were a benefit to customers worldwide.

Copper Mountain Technologies (CMT) welcomes RF and telecom industry veterans to its U.S. sales team. To support its rapidly expanding customer base in the U.S., CMT welcomes new territory managers in the Southeast, Central, Southwest and Midwest regions. With background and experience in various aspects of RF, telecom, test & measurement, these sales engineers are great local resources for the company's customers and partners. The company continues to grow its team as it brings to customers innovative USB and PXIe network analyzers and integrated test & measurement solutions for design, production and field applications.

REP APPOINTMENTS

Advanced Test Equipment Corp. (ATEC) announced a new agreement was reached and contracts executed between **L3 Harris's Narda STS group** and ATEC, making ATEC the North American distributor and the only authorized service center for calibration and repair of Narda STS and PMM equipment. ATEC provides companies with equipment that meets all types of testing and monitoring requirements. ATEC partnered with Narda STS, a supplier of measuring equipment in the EMF safety, RF test & measurement and EMC sectors. The RF test & measurement sector provides analyzers and instruments for identifying, measuring, locating and tracking mobile and stationary radio signal sources (ILT Analyzer).

PLACES

Keysight Technologies Inc. announced that the company has established a joint 5G test laboratory in Shenzhen, China with OPPO, one of the world's top five mobile device manufacturers, further extending the collaboration between the two companies. The new lab uses Keysight's 5G platform to help verify the performance of new 5G NR designs, a key activity that will help the Chinese-based smartphone manufacturer expand its global market presence. Keysight's solutions, which are widely adopted by leading chipset and device makers, enable OPPO to comprehensively test their 5G multimode devices in different form factors.

Mini-Circuits has expanded its amplifier design capabilities with the addition of a new design engineering group dedicated to developing high-power amplifiers up to and beyond 1 kW through 8 GHz. The new team, which will be based in a new corporate design center in Lincoln, R.I. with a satellite office at the Novio Tech Campus in Nijmegen, Netherlands, brings over 100 years of combined experience designing and developing RF amplifiers and power products.

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INVITED PAPER

Wideband, High-Resolution Phase-Amplitude Control Test System for 5G

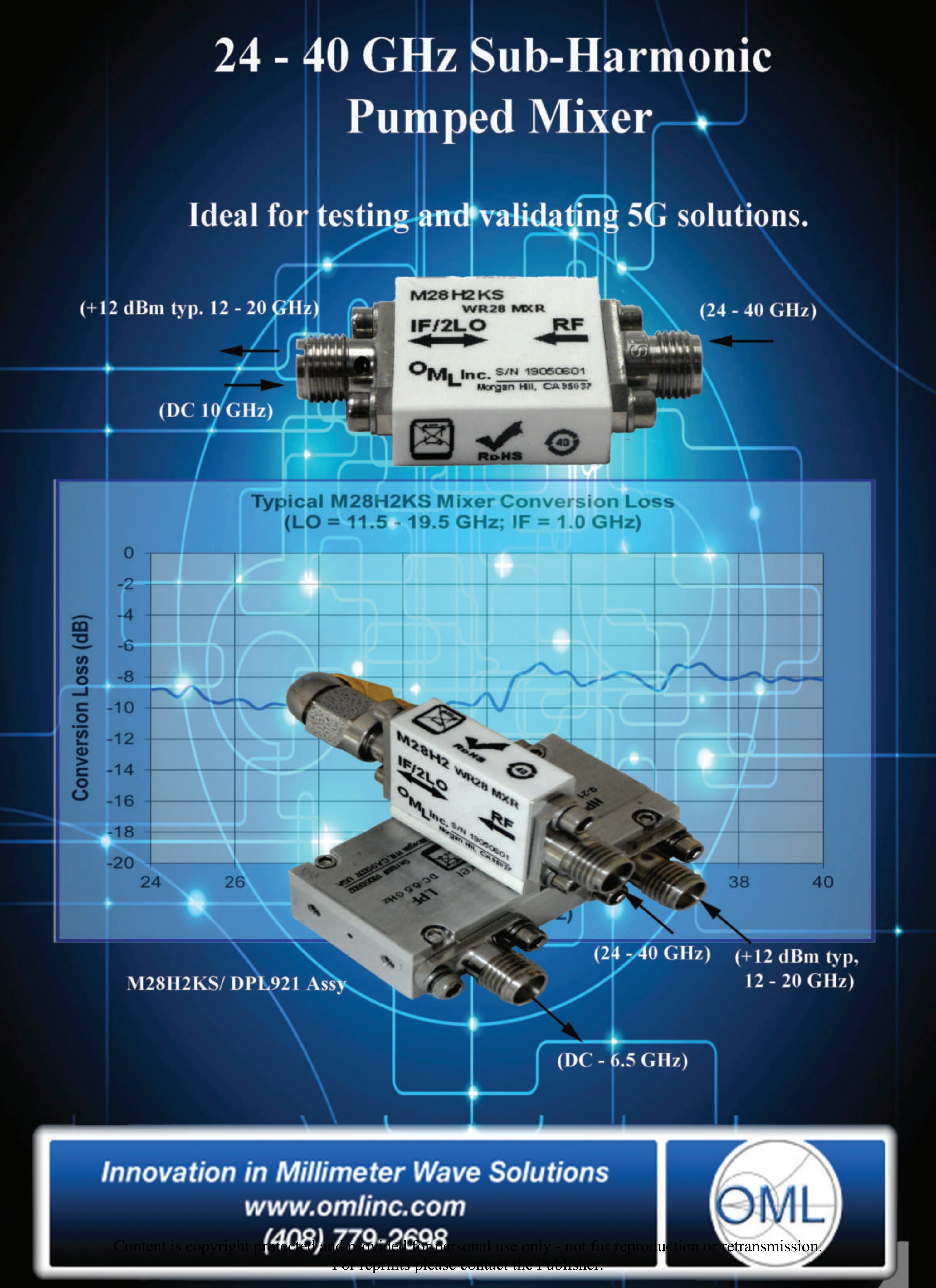
Wei Liu
Mitron Inc., Fuzhou, China

Massive MIMO (mMIMO) phase and amplitude controlled networks are the key RF technology of 5G. However, available phase shifters and attenuators that provide phase and amplitude control are narrowband, with typical bandwidths of only 200 MHz and have control resolution no more than 7 bits for sub-6 GHz and 6 bits for the mmWave bands. So building test systems to cover the 5G bands requires a significant investment in narrowband equipment, with performance insufficient to meet high test accuracy requirements. This article describes wideband designs for controlling phase and amplitude, offering the widest bandwidth—1.7 to 6 and 24 to 40 GHz—and highest resolution and accuracy commercially available. Two modules cover the 5G microwave and mmWave frequency bands with full 360 degree control and dynamic range to 50 dB and a resolution and accuracy of 0.1 dB and 1 degree sub 6 GHz and 0.2 dB and 2 degrees at mmWave. These phase and amplitude control modules serve as building blocks for beamforming, mMIMO, over-the-air (OTA) and multichannel signal simulator test systems. With their wideband coverage, resolution and accuracy, building test scenarios is simple and fast, reducing cost.

With 5G services being deployed commercially, the market's demand for 5G test equipment is urgent. The most significant difference between 5G and 4G is the application of mMIMO and mmWave technology, using these capabilities to enable broadband, high capacity, high data rate transmission. 5G test applications include simulating the signal environment, assessing multichannel mMIMO, evaluating phased array OTA beamforming and automating production testing. As the test methods and systems for 4G are already refined, combining mMIMO and mmWave technology with existed test technologies is key to developing 5G test systems.

mMIMO requires precise and synchronous control of the phase and amplitude of multiple signals in the microwave or mmWave frequency bands. mMIMO channel emulators and OTA test products are available; however, they tend to have the following deficiencies:

Accuracy and coverage—Existing test systems use the same attenuators and phase shifters as used by 5G system suppliers, which do not meet the higher accuracy requirements for test equipment. Testing is only effective if the accuracy of the test equipment is higher than the accuracy of the system being tested. Otherwise, it is difficult to guarantee the validity of the test results. These digitally-controlled phase shifter and attenu-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ator MMICs have smallest steps of 1.4 degrees and 0.25 dB to 6 GHz. While these step sizes provide theoretic accuracies of ±2.8 degrees and ±0.5 dB attenuation, the products typically have poorer performance. Few digitally-controlled MMIC phase shifters and attenuators cover the 5G mmWave frequencies, i.e., from 24 to 40 GHz. Reported products have only 5.6 degrees and 0.5 dB step resolution, and their accuracies will be worse than the ±11.2 degrees and ±1 dB theoretical values—far from the accuracy required for 5G. Further, most of these are narrowband, typically with only 200 MHz bandwidth. Building test systems to cover the various 5G bands would require multiple narrowband systems, a significant investment.

Phase and amplitude not independent—When the attenuator changes attenuation, the phase will change. When the phase shifter adjusts phase, the attenuation will change. During operation, the temperature and signal amplitude will also affect the phase and attenuation, complicating system calibration and temperature compensation. High accuracy across wide bandwidths is difficult to achieve. Because of these challenges, most of the microwave MIMO channel simulators on the market only simulate fading and cannot simultaneously adjust phase or simulate signal routes. For mmWave, MIMO channel simulators have not yet been announced.

Difficulty scaling—The complexity of the test system makes it difficult to expand the number of channels and maintain the technical performance at a reasonable cost.

IDEAL PHASE-AMPLITUDE CONTROL

The ideal multichannel phase and amplitude control system should have the following characteristics:

High accuracy and stability—The system should have phase and amplitude accuracy sufficient to meet the requirements of future test systems, offering 5G equipment suppliers and operators a one-time

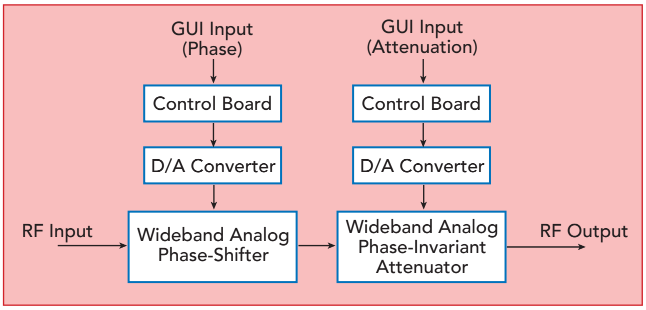


Fig. 1 Phase and amplitude control module block diagram.

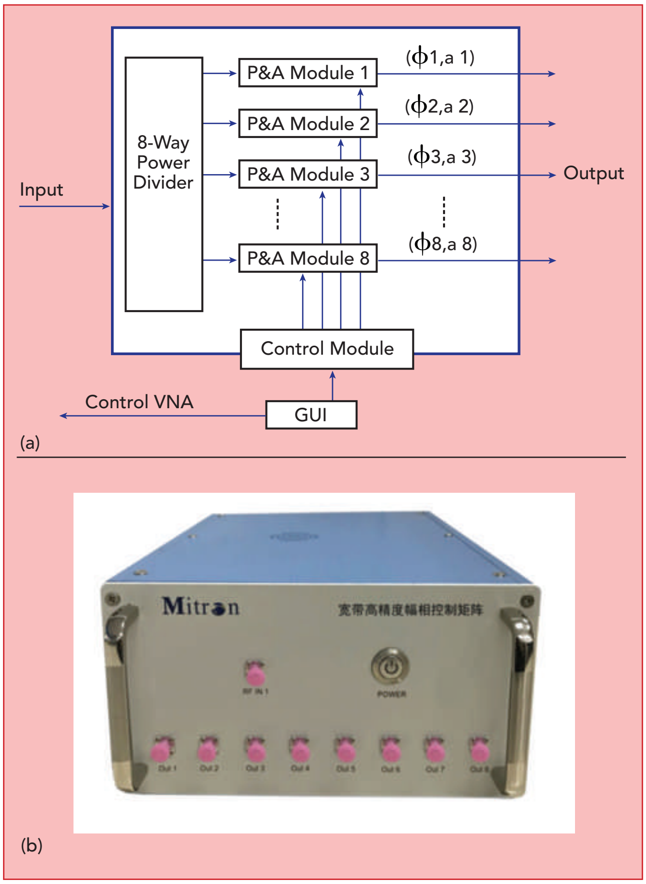
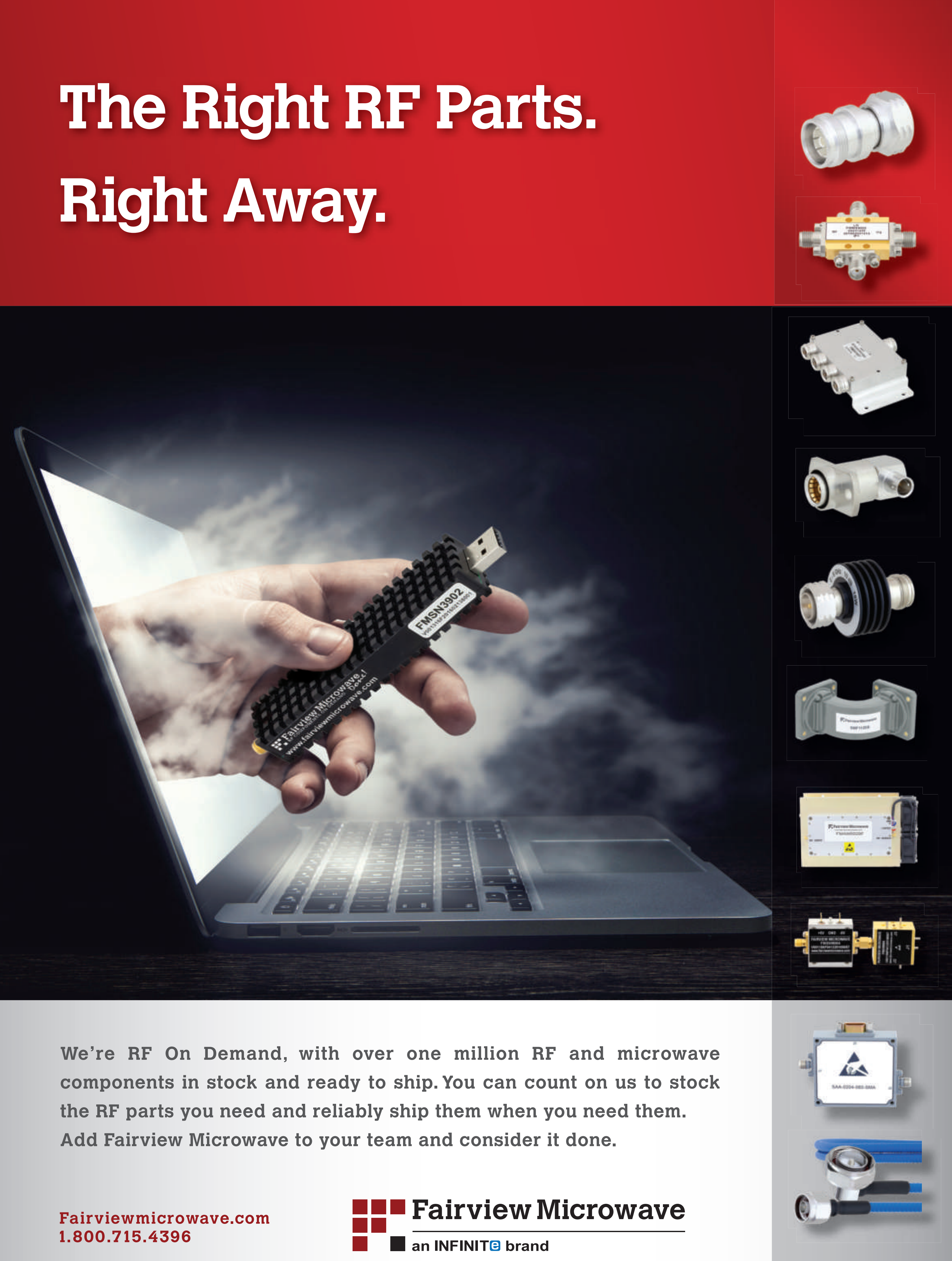


Fig. 2 Block diagram of a 1x8-way phase and amplitude control matrix (a). The size of the unit is 220 mm x 290 mm x 150 mm (b).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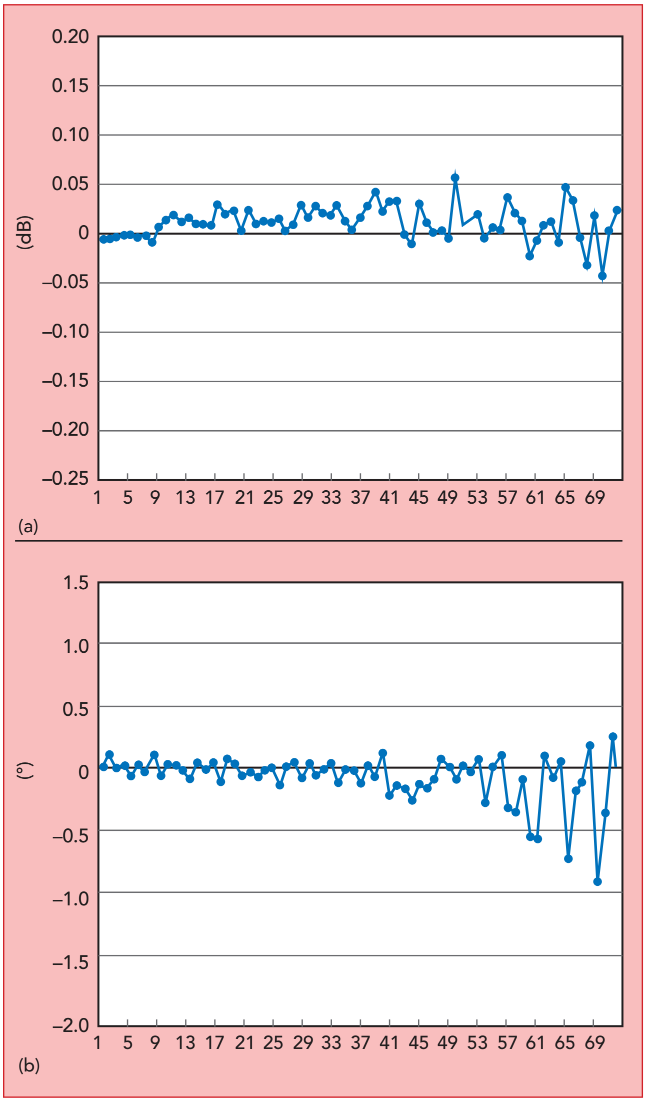
investment with long-term benefit. The performance must be stable with time, temperature and input signal level, providing assurance of performance repeatability and reliability.

Broad bandwidth—A single unit should cover all the 5G microwave or mmWave bands. This enables a single system to test either the sub-6 GHz or mmWave bands, avoiding investment in additional equipment and reducing dedicated space for testing. Each unit should have wide instantaneous signal bandwidth with low distortion, to achieve high signal quality and data rates.

Simple to use for multiple applications—To maximize test efficiency, calibrating the equipment should be simple, and the system should be easy to operate and connect to other equipment for automating tests. It should be easy to synchronize across multiple channels and MIMO systems.

Each of these requirements is a difficult challenge, prompting a different approach to the design of the phase and amplitude controller. The approach pursued by Mitron was to first develop analog phase shifters and attenuators, then digitize the control to create a digitally-controlled analog phase shifter and attenuator. With an analog device as the foundation, the number of control bits can be chosen to achieve the desired control accuracy. For example, to get 5 degree phase accuracy, choose 8-bit phase control; for 60 dB dynamic range with 0.5 dB attenuation accuracy, choose 9-bit amplitude control.

To miniaturize the equipment, the analog phase shifter and attenuator were integrated into a single phase and amplitude control module, controlled with a USB or TTL interface (see ***Figure 1***). The unit measures 203 mm × 88.9 mm × 21.59 mm. At any amplitude and phase combination, the phase control provides 1 degree minimum step and 2 degree absolute accuracy (typically 1 degree). The amplitude control provides 0.1 dB minimum step and 0.2 dB absolute accuracy. The overall dynamic range of the module is 360 degrees and 50 dB. To reduce the influence between the phase and amplitude adjustments, the design uses a "combination cali-



▲ Fig. 3 Amplitude (a) and phase (b) accuracy of the 1x8 matrix at 3.5 GHz, showing a sequence of individual amplitude and phase settings between 40 dB and 360 degrees.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bration method" to automatically test and record the various phase and amplitude combinations, creating a database accessed by the test software. For any phase and amplitude selected by the user, the corresponding control code is looked up by the software.

The individual phase and amplitude control modules are combined to create multichannel matrices for 5G test applications. ***Figure 2*** shows the block diagram and photo of a 1×8 channel matrix covering 1.7 to 6 or 24 to 40 GHz. Both versions fit in the same housing, including the power supply and control circuitry, which measures 220 mm × 290 mm × 150 mm. The units are powered with 110 to 220 V AC and controlled via USB. A high speed synchronized trigger in every module enables the phase and amplitude of each channel to be set to its respective value at the same time. As each unit's calibration is internal, no external equipment or vector network analyzer calibration is necessary. The units have very good repeatability and reliability, with tests showing the matrices maintain the same accuracy

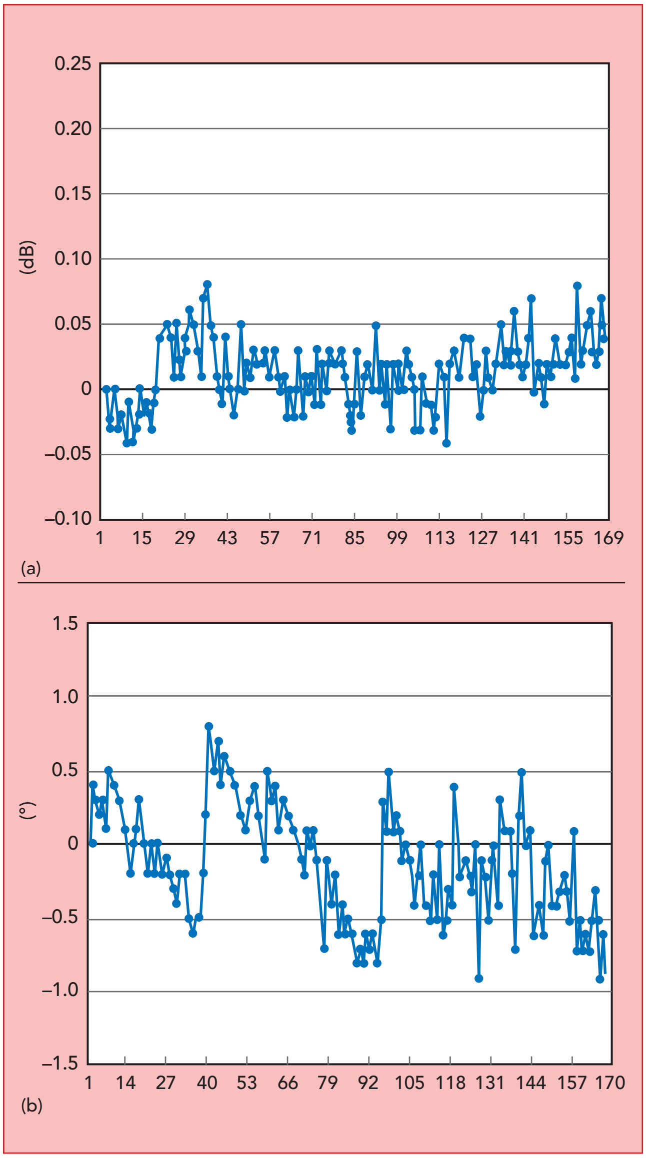


Fig. 4 Amplitude (a) and phase (b) accuracy of the 1x16 matrix at 28 GHz, showing a sequence of individual amplitude and phase settings between 40 dB and 360 degrees.

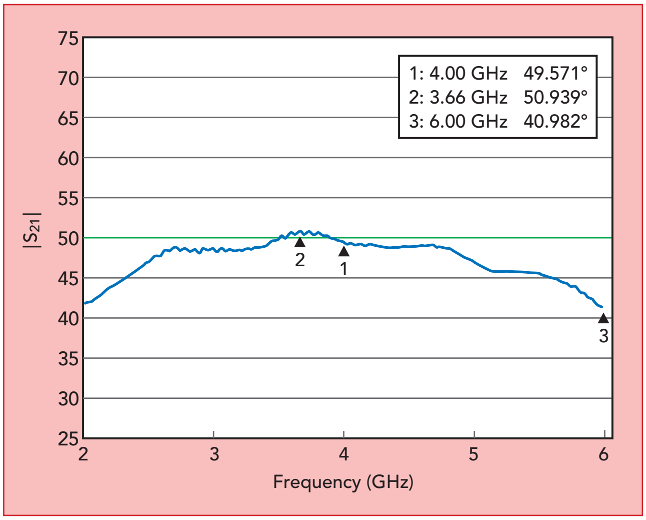
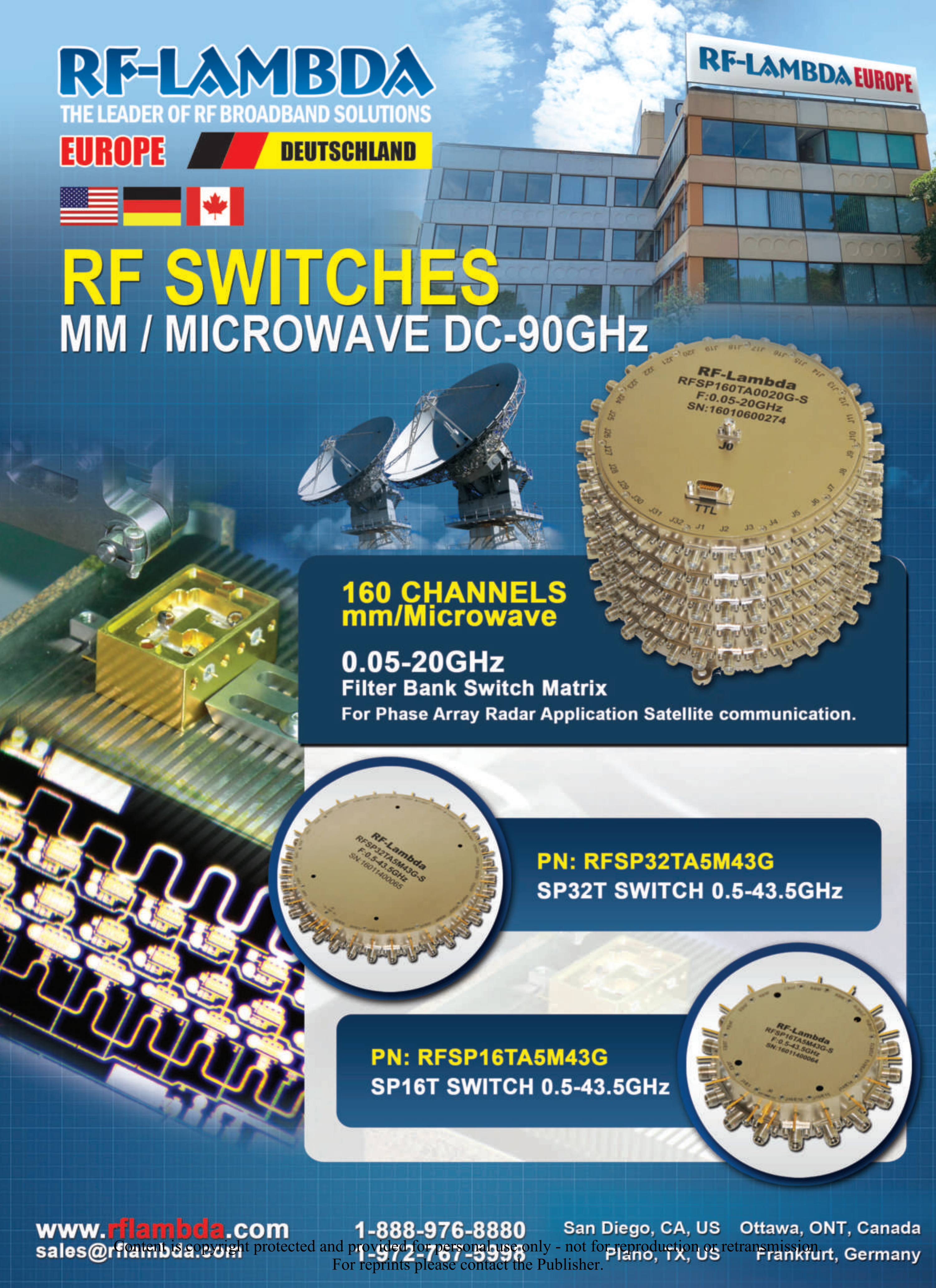


Fig. 5 Typical phase response from 2 to 6 GHz for the 1.7 to 6 GHz matrix with 15 dB attenuation and 50 degrees phase.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without recalibration after one year.

To demonstrate the capability of the phase and amplitude control matrices, Mitron built a 1×8 channel matrix covering 1.7 to 6 GHz and a 1×16 channel matrix covering 24 to 40 GHz. The two cover all current 5G sub-6 GHz and mmWave bands and can realize any arbitrary phase and amplitude combination with 2 degree phase and 0.2 dB amplitude accuracy. Since the designs use repeatable devices with fault-tolerant optimization and effective compensation and calibration, both units actually achieve 1 degree and 0.1 dB accuracy.

Figure 3a shows the amplitude accuracy of the 1×8 matrix at 3.5 GHz with various phase settings between 0 and 360 degrees and amplitude settings between 0 and 40 dB. ***Figure 3b*** shows the phase accuracy at 3.5 GHz with the same range of phase and amplitude settings. For the mmWave matrix, ***Figure 4a*** shows the amplitude accuracy at 28 GHz with various phase settings between 0 and 360 degrees and amplitude settings between 0 to 40 dB. ***Figure 4b*** shows the phase accuracy at 28 GHz with the same range of phase and amplitude settings. For the sub-6 GHz matrix, ***Figure 5*** shows the phase flatness across a 4 GHz frequency span, with the phase set to 50 degrees and the amplitude at 15 dB. For the mmWave design, ***Figure 6*** shows the phase flatness across a 4 GHz frequency span, again with the phase at 50 degrees and the amplitude 15 dB.

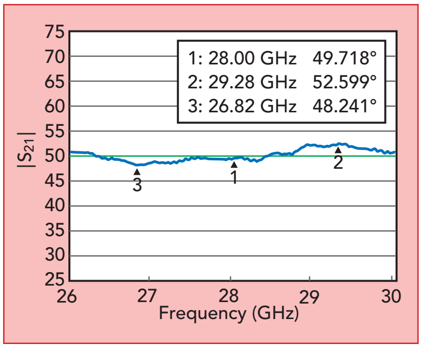


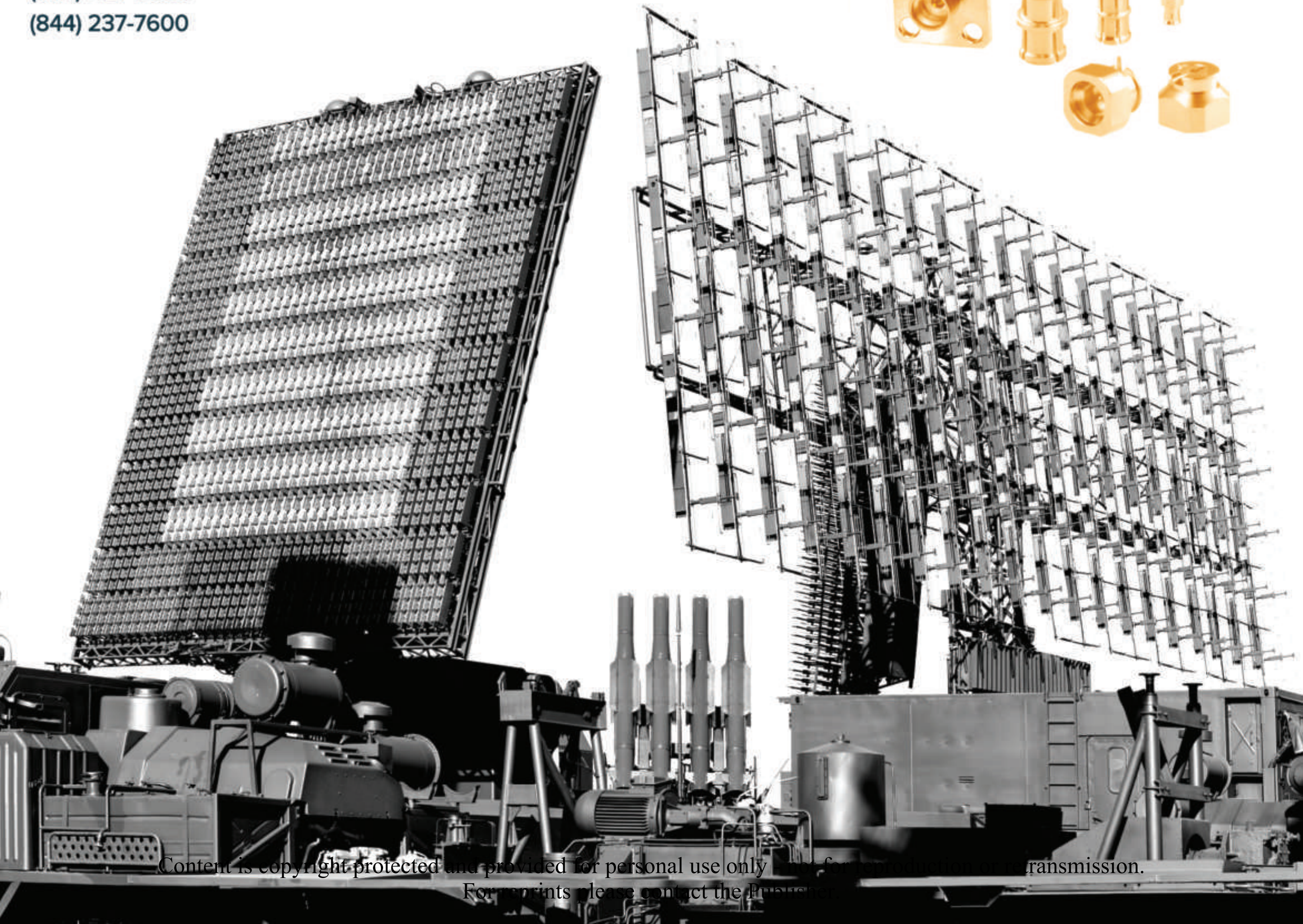
Fig. 6 Typical phase response from 26 to 30 GHz for the 24 to 40 GHz matrix with 0 dB attenuation and 50 degrees phase.

APPLICATIONS

The utility of the phase and amplitude control matrices is illustrated by considering several applications.

Beamforming algorithms—To test beamforming, M signals with unique phase and amplitude values can be generated and combined without antennas or OTA transmission (see ***Figure 7***). This setup is useful for testing and validating beamforming algorithms. Evaluation of the test system shows the matrix has a 1.6 percent error compared to the theoretical signal combination.

Phased array OTA—To test the antenna elements of a phased array, including the power amplifiers driving the elements, the phase and amplitude control matrix can be used to create a feed network, providing signals with precise phase and amplitude values to each feed (see ***Figure 8***). The signals will have no more than 2 degrees and 0.2



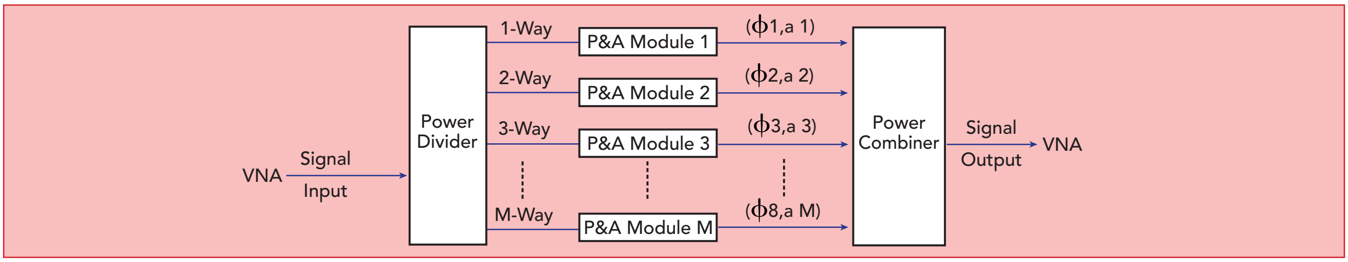


Fig. 7 Setup simulating an ideal beamformer, useful for evaluating beamforming algorithms.

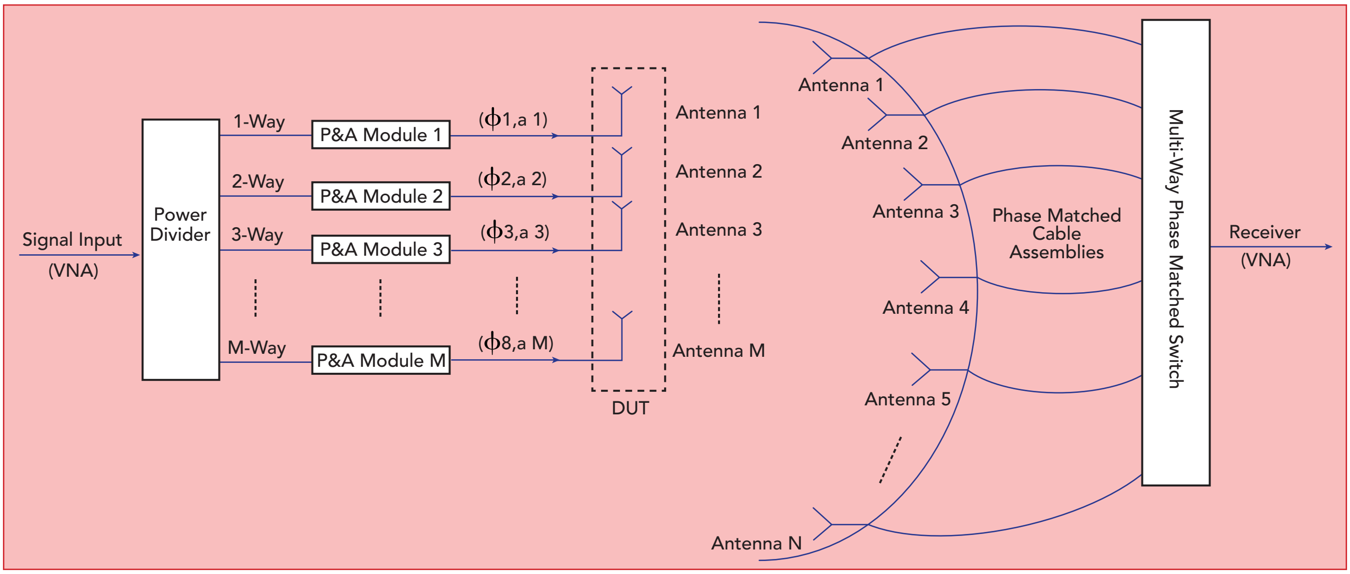


Fig. 8 Setup for antenna array and OTA testing.

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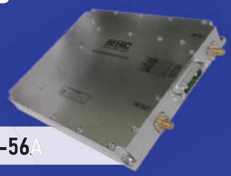

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dB error over the sub-6 GHz and mmWave bands. Using this system, the beam steering and frequency performance of the array can be evaluated. The system can also be used as a reference array for comparison with arrays with integrated front-end modules.

Base station links—Since the phase and amplitude control modules are reciprocal and can transfer signals in both directions, networks of matrices using phase and amplitude modules with multi-way power dividers and combiners can be configured to simulate various MIMO cases between base stations and users. ***Figure 9*** illustrates two scenarios: four base stations and four users (4×4) and two base stations and eight users (2×8). Additional configurations, such as 4×16 and 16×64, are straightforward by combining modules like LEGO® blocks.

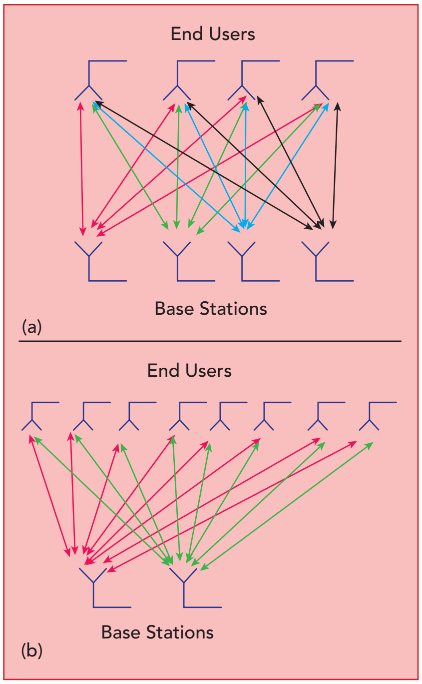

Fig. 9 The reciprocal matrices can simulate various base station and user scenarios, such as 4x4 and 2x8.

Other environments—This system can be used for any test application requiring multiple synchronized signals, each with unique phase and amplitude values. For example, it can emulate multichannel signal fading, routing or a Doppler shift to simulate a moving object, such as a vehicle or aircraft, generate the complicated electro-magnetic signal environments. Because of its wideband response, the matrix is also useful for supplying signals for testing carrier aggregation and adjacent channel interference.

CONCLUSION

Wideband and accurate phase and amplitude control modules and integrated matrices simplify testing over the sub-6 GHz and mmWave 5G bands. Modules have been developed to cover 1.7 to 6 and 24 to 40 GHz, and the upper frequency can be extended to 43 GHz. With simple calibration, the modules are easily combined with power dividers and combiners to create custom test systems, well-suited for R&D labs and production lines. The inherent accuracy of the design approach ensures the matrices will support future generations of communications standards.■

INVITED PAPER

Providing Narrowband IoT Coverage with Low Earth Orbit Satellites

Kenneth M. O'Hara and Gregory J. Skidmore
Remcom Inc., State College, Pa.

This article describes the modeling of a SATCOM link, specifically the use case of using a satellite overlay to extend service continuity to IoT devices in a poorly covered rural area.

Non-terrestrial wireless networks (e.g., satellite constellations or high altitude platforms) have unique advantages—wide area service coverage and long-term reliability—which make them important components in the heterogeneous 5G global system of networks. Non-terrestrial networks (NTN) will likely play a critical role providing service to locations not covered by terrestrial 5G networks, such as rural and remote areas, moving platforms and disaster-stricken zones. One use case for NTNs is providing service continuity for machine-to-machine (M2M) or IoT devices as they move out of 5G terrestrial network coverage.[1] This is particularly important for M2M/IoT devices which provide critical communications (e.g., applications in eHealth or vital asset tracking).

NARROWBAND IoT

Requirements for M2M and IoT communications can differ significantly from those for voice and data streaming: data throughputs are typically much lower. A prominent feature of M2M and IoT devices is a requirement for low-power consumption. Fortunately, these aspects of M2M/IoT communications can be simultaneously satisfied using a narrow bandwidth, low-power, wide area network (WAN). Narrowband IoT (NB-IoT) is an example of one such network standard, incorporated into 3GPP release 13 and further enhanced in releases 15 and 16 to ensure the ability to operate within a 5G ecosystem. The low signal power of these devices is accommodated through the lower bandwidth of the NB-IoT standard, which helps to reduce RF noise. Fortunately, this narrow bandwidth requirement is consistent with the low data rates acceptable for these communications.

NB-IoT is based on a simplified LTE standard with a maximum bandwidth of 200 kHz, transmitted either in dedicated bands, in-band within LTE or 5G NR carriers or within their guard bands. The peak downlink and uplink rates using the full bandwidth are 250 kbps; systems with lower data throughput can use individual subcarriers.

LEO SATELLITES

While satellite networks have the advantages of wide service coverage and reliability, their communication links unavoidably suffer from comparatively large latencies and propagation losses. To minimize both, satellite constellations in low Earth orbit (LEO) can be used to communicate with NB-IoT devices on the ground (see ***Figure 1***). For example, the round-trip latency for a LEO satellite orbiting at 1000 km is less than 10 ms when the satellite is directly overhead. The free space propagation path loss, FSPL, is given by the Friis transmission formula:

$$\mathrm{FSPL(dB)} = 20\log\left(\frac{4\pi d}{\lambda}\right) \qquad (1)$$

where d is the distance and λ the wavelength. The FSPL is the dominant contributor to loss in the satellite link budget and is

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minimized by the smaller propagation distances associated with a LEO satellite and using larger wavelengths. For λ = 14 cm (a 2.1 GHz carrier) and d = 1000 km, the FSPL = 159 dB for a satellite directly overhead (elevation = 90 degrees). The propagation path increases for lower elevation angles due to the longer slant range to the satellite associated with line-of-sight (LOS) propagation with refraction and absorption in the Earth's atmosphere. Using L- and S-Band carriers, rather than higher frequencies, keeps the atmospheric absorption relatively small.

LEO satellites have the disadvantage of the communications channel being complicated by relatively large Doppler shifts. To maintain its orbit, a LEO satellite at an altitude of 1000 km must have a velocity, v, of 7.4 km/s. The Doppler shift due to this motion is given by:

$$\Delta f = \left(\frac{1}{2\pi}\right)\vec{k}\cdot\vec{v} \qquad (2)$$

where $\vec{k}$ is the wave vector of the radio signal at the position of the satellite. The wave vector has a magnitude of k = 2π/λ.

For a LEO satellite in polar orbit, ***Figure 2a*** shows the Doppler shift as a function of time for downlink and uplink carrier frequencies near 2 GHz, where t = 0 is the instant when the satellite passes directly overhead. The corresponding elevation angles are shown on the upper axis. The uplink (UL) (1.7 GHz) and downlink (DL) (2.1 GHz) signals experience different shifts due to their different wavelengths. To accurately account for the direction of the signal wavevector $\vec{k}$ at the location of the satellite, an in-house ground-to-satellite propagation model based on ITU-R P.676-11[2] and ITU-R P.834-8[3] has been used to account for the refraction in the atmosphere (which bends the radio wave toward the surface of Earth) compared to direct LOS propagation. The time rate of change of the Doppler shift is shown in ***Figure 2b***. To avoid inter-band interference, the common mode component of the shift must be dynamically compensated for by the satellite, with the remaining differential shift across a coverage area being compensated for by the user equipment (UE).[4]

Other factors which affect satellite-to-ground link budgets include rain fading, ionospheric and tropospheric scintillation, terrain masking, foliage attenuation and multipath effects. For L- and S-Band carriers, typically employed in NB-IoT communications, rain fading and tropospheric scintillation effects are relatively small.[5-6] Ionospheric scintillation, on the other hand, can cause deep time-dependent fades during the hours following sunset for UEs located within 20 degrees of the equator or at high latitudes near the poles.[7] Link budgets for UEs locat-

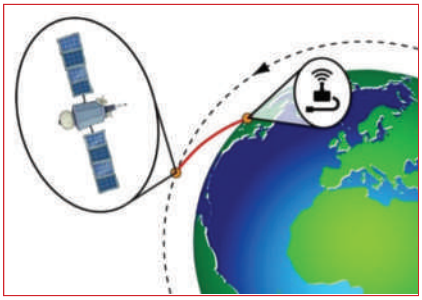


Fig. 1 A LEO satellite can communicate with IoT devices in rural or remote regions.

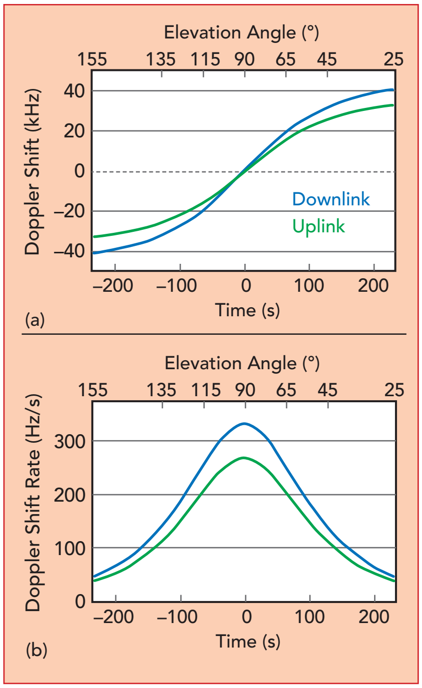


Fig. 2 Doppler shift (a) and Doppler drift rate (b) for a satellite in LEO orbit.

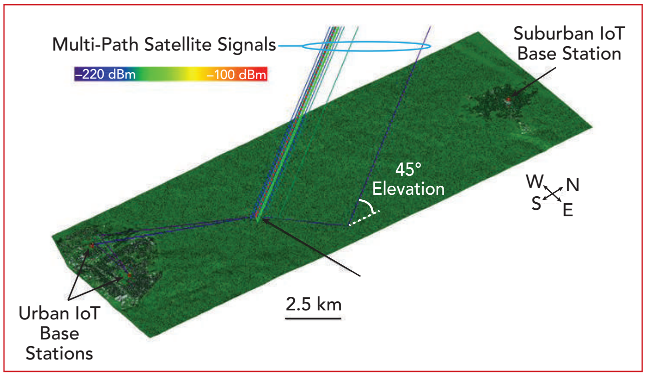


Fig. 3 Urban-suburban-rural scenario used to model terrestrial and satellite coverage.

ed within these regions can require margins of at least 25 dB, especially during periods of high solar activity. At other latitudes, ionospheric scintillation can typically be neglected. To account for terrain masking, foliage attenuation and multipath effects, especially in a well characterized scene, ray tracing techniques can be employed.

MODELING SATELLITE COVERAGE TO RURAL AREAS

We now consider the use case of extending service continuity to mobile NB-IoT devices in rural areas (see ***Figure 3***). The scene shows urban and suburban areas with good terrestrial coverage, with a rural region between them. The northern end of the urban area to the south is serviced by two terrestrial base stations, each with transmit powers of 40 dBm over a 20 MHz bandwidth. The suburban area to the north has one 40 dBm base station. For the rural area between, coverage is provided with a LEO satellite.

First, consider the coverage provided by the terrestrial base stations to NB-IoT devices located anywhere in the scene. To account for terrain masking, foliage shadowing and multipath effects for the signals traveling from the base stations to the NB-IoT devices, we employ a ray tracing model using Remcom's Wireless InSite® suite.[8] This model includes multipath propagation through the outdoor portion of the scene, including paths reflecting and diffracting from terrain and structures. This method incorporates full 3D multipath effects, including polarization and phase. In this scenario, the base stations are assumed to be vertically polarized, while the NB-IoT receivers are assumed to have linearly polarized 0 dBi antennas, with their polarization axes rotated 45 degrees relative to horizontal. The NB-IoT receivers have a 9 dB noise figure and the ambient RF noise floor is assumed to be −167 dBm/Hz, which is consistent with measurements of 1.7 and 2.1 GHz RF noise in urban, suburban and rural environments.[9]

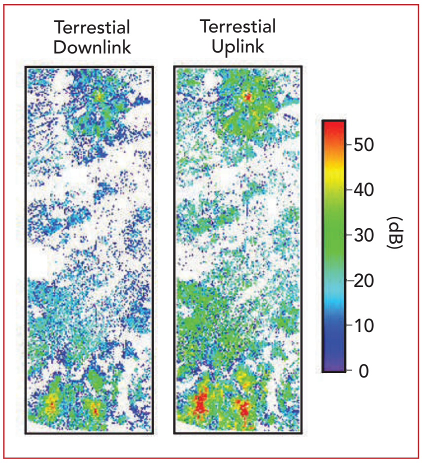


Fig. 4 NB-IoT SNR for a terrestrial downlink and uplink.

For NB-IoT receivers located anywhere in the scene, ***Figure 4*** shows the signal-to-noise ratio (SNR) for both the UL (1.7 GHz) and DL (2.1 GHz) signals with 180 kHz bandwidth. SNRs as high as 57 and 66 dB for DL and UL, respectively, are observed in the urban and suburban areas near the terrestrial base stations. For the rural area, however, the SNR often falls well below 0 dB (shown as transparent), due to terrain masking and foliage shadowing. Wireless InSite models attenuation from foliage by implementing the Weissberger model.[10]

The coverage in the rural area for the NB-IoT devices can be restored by a satellite overlay. The satellite signal is modeled within Wireless InSite and augmented with an in-house model by placing an isotropic trans-

mitter within Wireless InSite at an apparent elevation angle and altitude determined from the calculations using the satellite-to-ground model described earlier. This accounts for the increased path loss due to refraction through the atmosphere.

To model DL coverage, the isotropic transmitter has an equivalent isotropically radiated power (EIRP) of 66 dBm less the power loss from atmospheric absorption, determined by the satellite-to-ground propagation model.[11] Atmospheric absorption within Wireless InSite is then disabled for the satellite links, as it is accounted for by this reduced EIRP. The 66 dBm EIRP assumes the satellite can provide a 36 dBm transmit power in a 180 kHz bandwidth and has an antenna gain of 30 dBi. The satellite antenna is assumed to be circularly polarized, which is typical for SATCOM in order to eliminate polarization rotation due to the Faraday effect. A 3 dB noise figure for the satellite antenna is assumed, as well as a noise temperature of 290 K for the UL,[12] resulting in noise power of −174 dBm/Hz. The DL retains the assumption of a 9 dB noise figure and a −167 dBm/Hz RF noise floor, appropriate for terrestrial communications at the frequency bands used in this scenario.

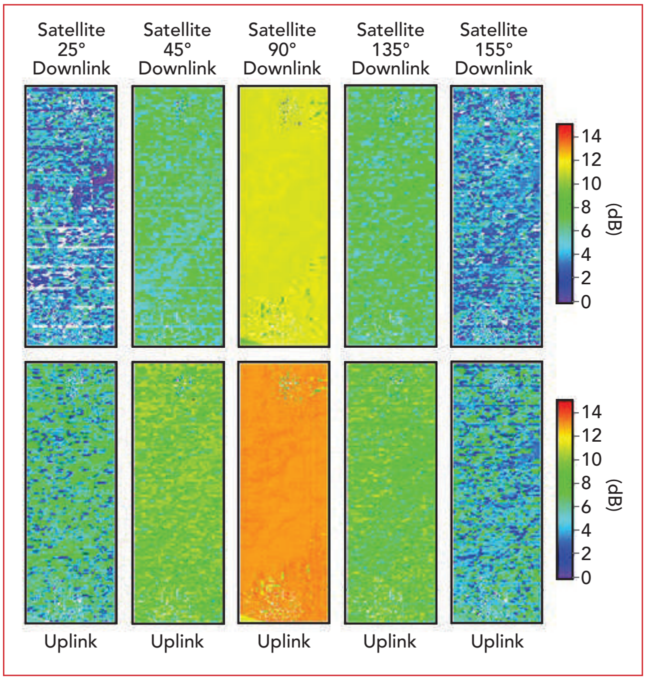
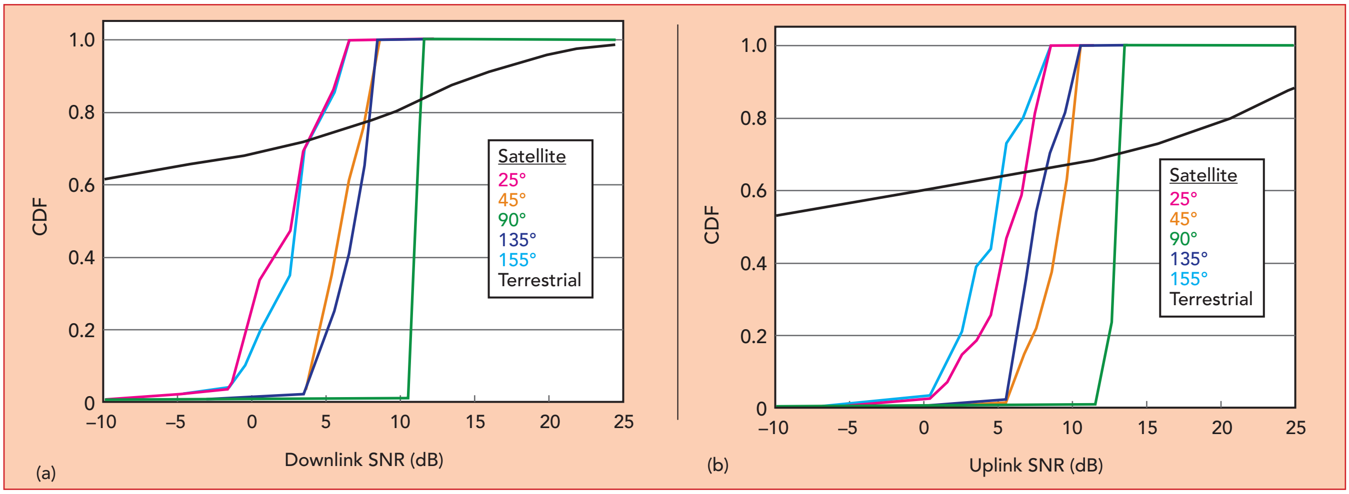


Fig. 5 NB-IoT SNR for LEO satellite links vs. elevation angles.

Figure 5 shows satellite DL and UL SNRs for the scene in Figure 3 at different elevation angles of the satellite above the horizon. SNRs less than 0 dB are transparent. The maximum SNR is achieved when the satellite is directly overhead (i.e., 90 degree elevation angle) because the propagation path loss and atmospheric absorption are minimized. At lower elevation angles, the SNR is compromised by shadowing from foliage and terrain. Despite these losses, an SNR above 0 dB can be maintained over most of the scene for elevation angles of 25 degrees or greater. Despite the lower transmit power of the NB-IoT devices (23 dBm is assumed for this analysis), the SNR for the UL is approximately 2 dB higher on average than for the DL, because the noise figure for the satellite receiver is 6 dB lower than for the low-cost NB-IoT devices. The ambient noise for the satellite is −174 dBm/Hz (approximately 7 dB lower than for the terrestrial systems) and the propagation path loss for the UL signal is reduced by 2 dB at a 90 degree elevation angle relative to the DL, due to the wavelength difference.

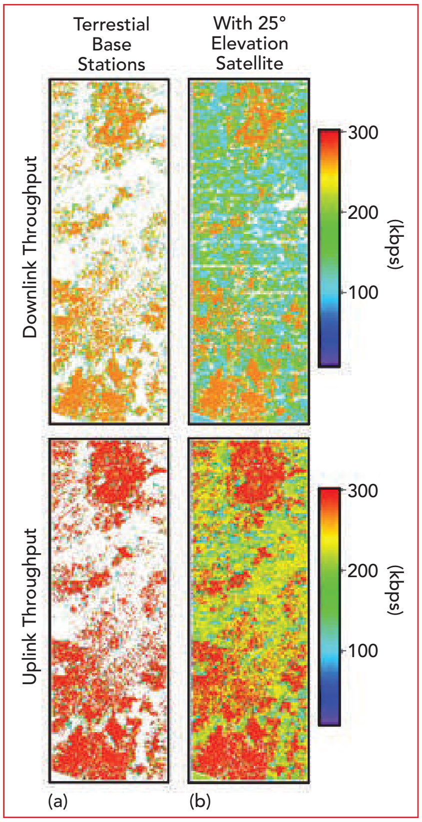
To quantitatively characterize the improved coverage obtained with the satellite overlay, ***Figure 6*** compares the cumulative distribution function (CDF) of SNR values for the terrestrial base station and the satellite at different elevation angles. To focus on the rural area, the CDF is computed for NB-IoT devices located in the central two-thirds of the scene shown in Figure 3. From the CDF for the terrestrial base stations, over 60 percent of the receiver/transmitter locations have SNRs less than 0 dB. In contrast,



▲ Fig. 6 SNR CDF for the downlink (a) and uplink (b), comparing the terrestrial base stations with a LEO satellite at various elevation angles.

nearly 100 percent of the simulated device locations have SNRs greater than 0 dB for UL/DL satellite transmission at elevation angles as low as 25 degrees. When the satellite is overhead, most of the area achieves SNRs of 10 dB or better.

For a given SNR, modulation and coding scheme, the data throughput can be calculated. When using the full 180 kHz bandwidth, both the DL and UL in the NB-IoT standard use QPSK. ***Figure 7*** shows the throughput achieved by NB-IoT devices at different locations in the scene where the throughput estimate is based on the formula provided in 3GPP TS 38.306[13] and limited to the lower order QPSK modulations. Figure 7a shows the DL and UL throughput with just the terrestrial base stations; Figure 7b shows the throughput when the terrestrial base stations are supplemented by satellite coverage, where the satellite is assumed to be located at an elevation angle of 25 degrees. For the UL, the satellite overlay provides complete coverage across the scene, even for a satellite at 25 degrees. The coverage is nearly complete for the DL. As the satellite moves to higher elevations, the overall throughput continues to rise and attains a maximum throughout for the area when the satellite is overhead.



▲ Fig. 7 NB-IoT downlink and uplink throughput, comparing the terrestrial base stations (a) vs. satellite overlay (b), with the satellite at 25° elevation.

CONCLUSION

This case study demonstrates how satellite coverage can be modeled using predictive simulation. Such models can simulate the SATCOM channel, capturing important effects such as terrain masking, shadowing due to foliage and multipath fading, which are essential to a proper evaluation of the link budget. Further, ray tracing models can be used to identify cases where terrestrial coverage needs to be supplemented with a LEO satellite overlay to improve NB-IoT coverage in rural areas. These LEO satellites can provide coverage with relatively low latency, though this comes at the cost of complicating the communications channel, as large Doppler shifts must be compensated by the satellite and/or the UE.■

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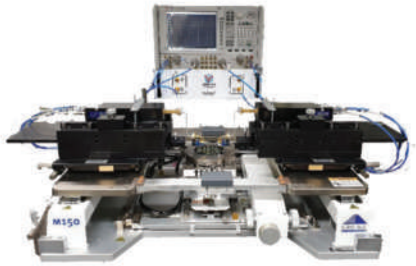

mmWave and THz Gain Compression and Active Load-Pull

Maury Microwave
Ontario, Calif.
Vertigo Technologies
Delft, The Netherlands

Anyone who has worked above 110 GHz will likely agree that performing device characterization measurements at mmWave and sub-THz frequencies is no simple task and can be challenging. First, commercially available waveguide extenders between 110 GHz and 1.1 THz tend to have a fixed output power or a limited range of powers, which are set manually through an integrated or external variable attenuator. This makes it difficult to accurately and repeatably set the power to an arbitrary value at the device under test (DUT) reference plane and limits the range of the available powers. A device's operating conditions are largely defined by its input power, and controlling the power is critical when characterizing its performance over a range of powers and plotting its large-signal gain compression.

Second, load-pull—presenting a user-defined arbitrary impedance or set of impedances to the output of a device—is not readily available above 110 GHz. Even though passive mechanical tuners can be built at these higher frequencies, the ability to present high reflections (i.e., gammas and mismatches) at the DUT reference plane is limited by waveguide and probe losses between the tuner and DUT, making

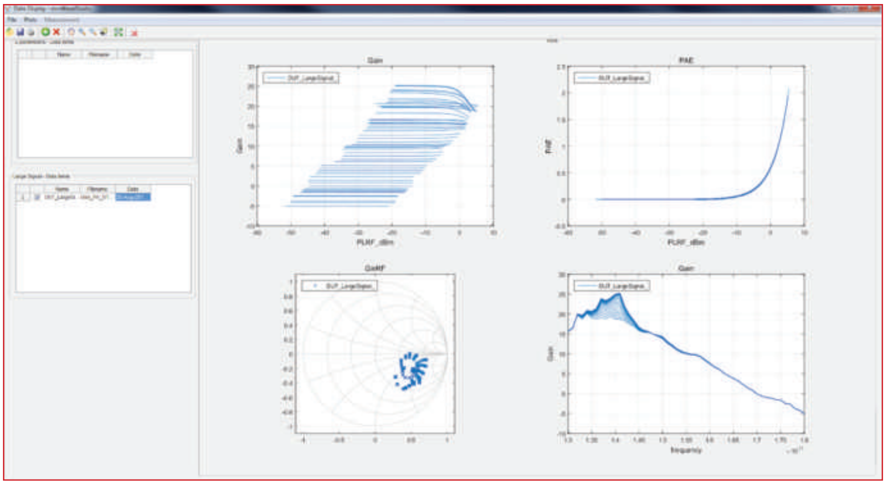

Fig. 1 MMW-STUDIO display showing a large-signal power sweep measurement of a two-stage power amplifier at multiple frequencies from 130 to 180 GHz.

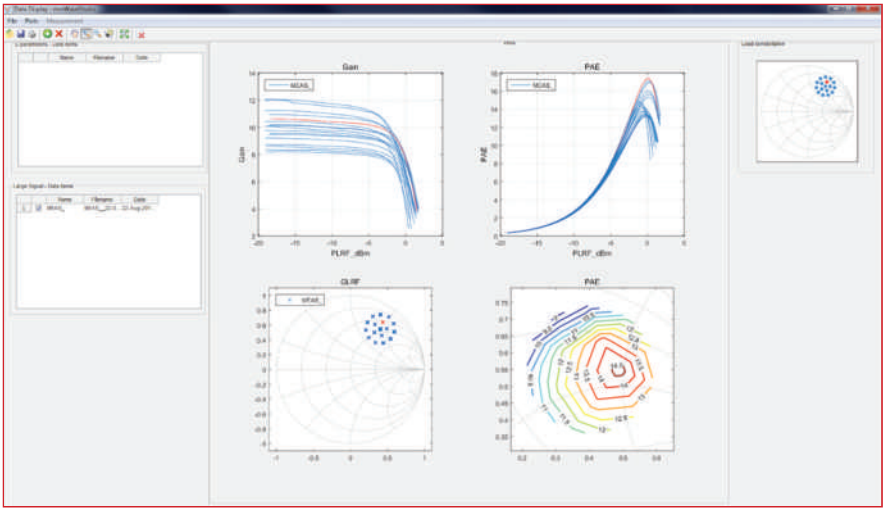

Fig. 2 Active load-pull characterization of a 130 nm SiGe HBT using MMW-STUDIO LP.

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the measurement less meaningful. Higher gamma load-pull measurements are an important tool for transistor designers to characterize and model the behaviors of the device. For circuit designers, load-pull measurements are used to determine the ideal matching conditions and optimize performance at powers where every fraction of a dB is important.

mmWAVE AND SUB-THz CHARACTERIZATION SOFTWARE

To overcome these challenges, Maury Microwave and Vertigo Technologies have released a suite of software and hardware tools enabling high-resolution gain compression and active load-pull measurements at mmWave and sub-THz frequencies to 1.1 THz. MMW-STUDIO is an upgrade to a traditional mmWave or sub-THz S-parameter measurement system, consisting of a low frequency vector network analyzer (VNA) and waveguide extenders, enabling high-resolution power control and arbitrary impedance control for complete device characterization.

MT920A MMW-STUDIO is a software module that works with waveguide-banded mmWave VNAs, adding accurate, repeatable and high-resolution power control. The software enables the direct measurement of vector-corrected power at the DUT reference plane, as well as controlling the power delivered to the DUT. This provides the capability to perform gain compression power sweep measurements over the available power levels and perform S-parameter measurements at any arbitrary power level.

MMW-STUDIO supports most commercial waveguide extenders up to 1.1 THz, enabling users to perform:

- S-parameter measurements at power levels set by the user.
- Power, frequency and bias sweeps, with high-resolution power control for accurate and repeatable vector-corrected gain compression power sweep measurements.
- Large-signal 50 Ω measurements, including Pout, Pin, Pavs, Gt, Gp, device efficiency, power-added efficiency (PAE), Vin, Vout, Iin and Iout.
- Calibrated measurements at the DUT reference plane.

Figure 1 shows a typical multi-frequency gain compression measurement using MMW-STUDIO. The screen shot shows the power sweep characterization of a two-stage power amplifier at frequencies spanning 130 to 180 GHz and input power from −45 to −13 dBm.

ACTIVE LOAD-PULL ADD-ON

MT920B MMW-STUDIO LP is a software add-on that controls the magnitude and phase of the signals delivered to the input and output of the DUT when used with a vector modulation unit (VMU). By setting arbitrary impedances, the system will perform active load-pull mea-

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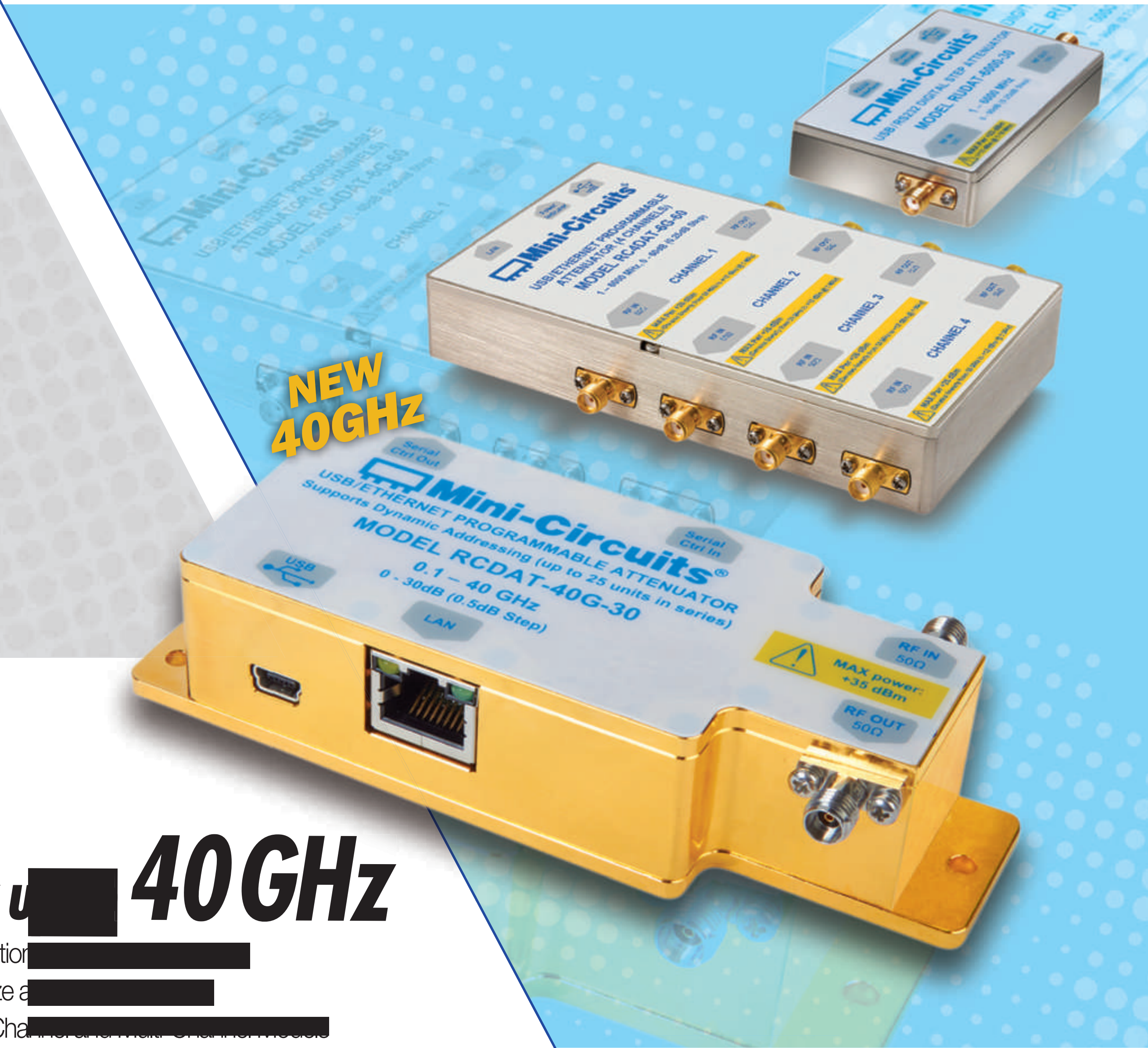

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surements, where the magnitude of the reflection presented to the DUT is achieved by controlling the reflected a2 wave and setting Γ = a2/b2. By providing arbitrary impedance control and active load-pull, the MMW-STUDIO LP option adds the capability to perform large-signal measurements (i.e., Pout, Pin, Pavs, Gt, Gp, Eff, PAE, Vin, Vout, Iin, Iout) at any controlled load impedance.

Figure 2 shows a typical mmWave load-pull measurement with nested power sweep using MMW-STUDIO LP. The screen shot shows the performance of a 130 nm SiGe HBT characterized over 15 loads with an input power sweep from −30 to −2 dBm. The measurements include power gain versus the power delivered to the load, PAE versus the available input power, measured load impedances and PAE contours at 1 dB compression.

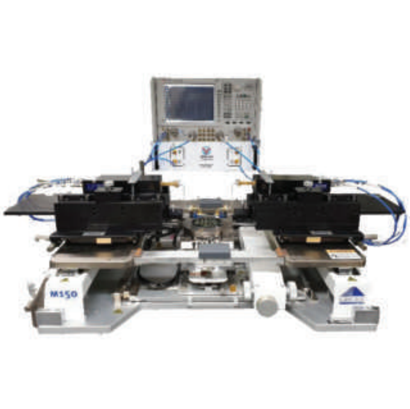


Fig. 3 **Turnkey on-wafer active load-pull system for sub-THz measurements.**

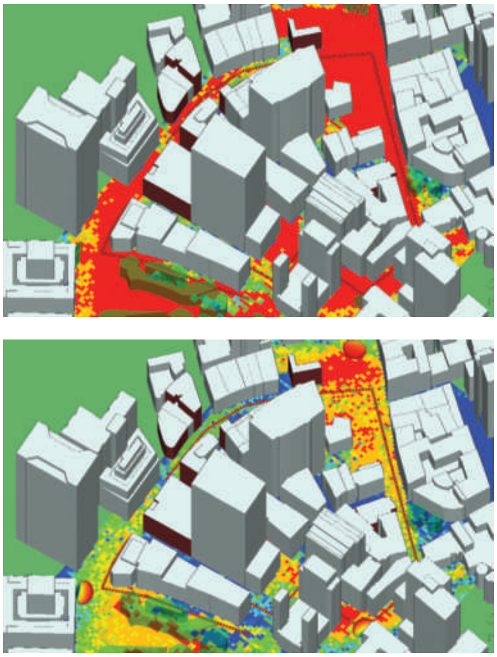
MMW-STUDIO and MMW-STUDIO LP provide the capability for conventional waveguide-banded mmWave VNA systems to perform large-signal characterization, including power and active load-pull, without using power meters, passive impedance tuners or additional test-sets. The approach uses the large dynamic range and high speed of the VNA's receivers, with a seamless setup and user experience. Using this capability, designers can:

- Extract small- and large-signal models of high frequency transistors to f_T and f_{max}.
- Validate small- and large-signal models of high frequency transistors to f_T and f_{max}.
- Test and optimize prototype sub-THz active circuits.
- Support test needs throughout the product life cycle, from R&D to design validation and on-wafer production testing.

Figure 3 shows a turnkey on-wafer active load-pull system comprising a Keysight PNA, VDI waveguide extenders, FormFactor probe station, Vertigo Technologies' VMU and MMW-STUDIO.

Maury Microwave
Ontario, Calif.
www.maurymw.com

Vertigo Technologies
Delft, The Netherlands
vertigo-tech.com



Beamforming with massive MIMO (top) shows significant improvement to throughput over links between single antennas (bottom)

One Box Test Solutions for 5G

Rohde & Schwarz
Munich, Germany

Testing 5G NR products requires new test & measurement approaches. massive MIMO (mMIMO), bandwidths and data rates substantially higher than 4G's and mmWave frequencies require more computing power, make over-the-air (OTA) measurements compulsory and create challenging performance requirements for the RF hardware. With a unified testing environment, it is possible to make 5G measurements in development, acceptance testing and production as effectively as with 4G testing.

COMPACT TEST SOLUTION FOR 5G mmWAVE

For 5G NR testing in the mmWave bands (designated FR2), Rohde & Schwarz offers the R&S CMPQ, a fully integrated, compact solution based on the R&S CMP200 radio communications tester combined with the R&S CMPHEAD30 remote radio head and the R&S CMQ200 shielding cube. The shielding cube uses a drawer concept enabling automated handling in a manufacturing environment for the frequencies from 20 to 77 GHz. The mechanical design ensures millions of test cycles, ensuring a reliable process for mass production.

The R&S CMPQ system can be customized to create solutions suited to individual needs. It can be used at any time in the product life cycle, from research and development through validation and quality assurance to production. The system is created as a robust, flexible solution that will adapt to future requirements and specifications. The R&S CMPQ solution provides users with the tools needed for production testing of FR2 5G components. For the sub-6 GHz (FR1) bands, the solution consists of the R&S CMW100 communications manufacturing test set and corresponding measurement software, the R&S CMsquares.

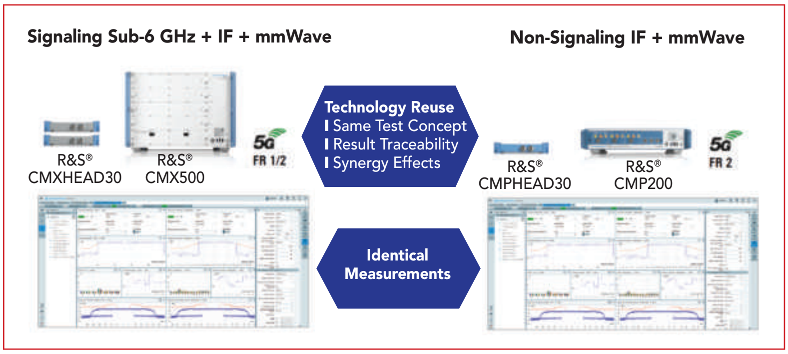


Fig. 1 The one platform strategy enables the same measurements for FR1 and FR2, whether testing signaling or non-signaling.

SIGNALING FOR NETWORK SIMULATION

The R&S CMX500 radio communications tester adds 5G NR signaling tests to the existing LTE test & measurement solution. Users who have already invested in the R&S CMW500 or the R&S CMWflexx system for LTE or legacy 2G and 3G can continue using it, adding the R&S CMX500 as an extension box. From R&D to certification testing, this will perform 5G NR RF, signaling protocol and data throughput and application tests

(e.g., IMS, VoLTE and VoNR). This allows testing 5G NR use cases in non-standalone (NSA, option 3) and standalone (SA, option 2) modes in both the FR1 and FR2 bands. For pure 5G NR test environments in FR2, a single R&S CMX500 radio communications tester with remote radio head and a shielded environment will suffice.

ONE PLATFORM WITH UNIFIED SOFTWARE

The governing principle of the one platform strategy is using the same technology, similar hardware and the same software for all test solutions (see ***Figure 1***). This makes the test results comparable in all stages of testing, from R&D to production. The different testing approaches (signaling or non-signaling) must deliver reproducible and validated test results, providing conclusive information about the characteristics of the devices being tested, without also testing the test solution. With the R&S CMPQ solution, FR2 OTA testing is as reliable as FR1 testing.

Fig. 2 **The test software R&S CMsquares controls all 5G radio communications testers, unifying 5G NR testing.**

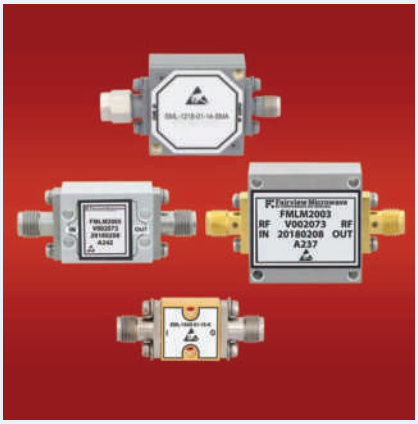
R&S CMsquares is a new, unified test software solution featuring a browser-based user experience and combining everything needed for 5G NR testing. CMsquares controls all new 5G radio communications testers via a standardized graphical interface, integrating test configuration, parameterization, measurements and test execution in a single environment with a dashboard and quick access to the various applications (see ***Figure 2***). The interactive callbox mode rapidly connects to a device under test, changes network parameters on the fly, analyzes real time RF Tx and Rx measurements and trace protocol stack messages on all protocol layers and generates statistics for data throughput testing, offering various chart diagrams. It also integrates a sequencer mode to run preconfigured 5G NR test scripts or it can create 5G NR test scripts from scratch using a simple drag-and-drop approach.

An interactive mode and a sequencer mode can be used in parallel, working together to provide the same test results to the user, whether using the R&S CMP200 radio communications tester for non-signaling tests or the R&S CMX500 radio communications tester for 5G NR network emulation.

The challenges associated with 5G NR require high flexibility, end-to-end data testing solutions and reliable measurement methods. As a long-term partner of the mobile radio communications industry, Rohde & Schwarz offers a comprehensive portfolio of innovative 5G NR test solutions.

VENDOR**VIEW**

Rohde & Schwarz
Munich, Germany
www.rohde-schwarz.com



Hi-Rel Limiters Protect Sensitive RF Receivers

Fairview Microwave has expanded its line of broadband, high-power, coaxial packaged limiters, now comprising 13 unique models designed to protect sensitive components from high-power microwave signals in applications such as radar, electronic warfare, military communications, point-to-point radio, SATCOM, fiber-optic communications, instrumentation and R&D.

The 50 Ω limiter family covers a wide frequency range, from 200 MHz to 40 GHz, and provides high CW power handling to 200 W peak, low leakage power of 10 to 18 dBm and fast recovery within 10 ns to 15 μs, depending on the model. Under hard limiting, the limiters suppress even-order harmonics. The insertion loss varies by frequency band, from 0.8 dB for the 4 GHz unit to 4.5 dB for a 40 GHz model. The input VSWR for the family is typically less than 2:1, except for a couple of the 40 GHz models.

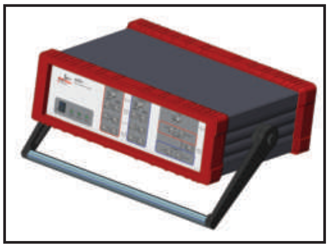
The limiters do not require any external matching components and are packaged in compact housings with thru mounting holes and field replaceable SMA or 2.92 mm connectors, enabling the limiters to be mounted onto circuit boards. Built from high-reliability assemblies, the rugged designs meet MIL-STD-202 environmental test conditions for shock, humidity, vibration, altitude and temperature cycle and are guaranteed to operate from –54°C to +85°C.

Fairview Microwave's high-power coaxial limiters are available for immediate shipment, and no minimum order quantity is required.

VENDORVIEW

Fairview Microwave
Lewisville, Texas
www.fairviewmicrowave.com/rf-products/high-power-signal-limiters.html

New Video



AnaPico presents its latest video, which gives an introduction of the option LO of the signal source analyzer, the APPH. The new option LO provides access to the two internal local oscillators that can be used for additive phase noise measurements. In addition, it gives direct access to the separate channels. This results in additional use cases, such as direct noise floor measurements and external down conversion. The option LO offers improved usability and great new opportunities.

AnaPico Ltd.

www.anapico.com/apph-option-lo/

New Website Launched

Comtech PST has launched a new updated website. The new website contains information about solid-state power amplifiers and high-power control components available as standard or custom products. Datasheets and product information can be downloaded directly from the website. Customers can request quotes by completing information on the site and clicking the link to send it in. Comtech PST serves the military, commercial, aviation, datalink and medical markets with a wide array of narrow and broadband product offerings, for both amplifiers and control components.

Comtech PST

www.comtechpst.com

New Instructional Video

Want to see how Kaelus' Analyzer Calibration Extender (ACE) can self-calibrate your Range-To-Fault (RTF) module in the field? Watch the instructional video to see the simple, intuitive calibration process, including time-saving techniques to calibrate your RTF module with ACE. Kaelus, an Infinite Electronics company, is a recognized leader in test & measurement instruments, cell-site filters, combiners and tower mounted amplifiers.

Kaelus

http://ow.ly/ZLBO50wFy4f

New Website Section

LadyBug Technologies now has on their website a blog section to announce latest articles, updates, new features and more. Recent blog posts include "How to Select a Proper Connector for your LadyBug Power Sensor" and "Important Tips for Selection if RF Power Meters." Customers can review specifications and purchase sensors directly on the website's store. In addition to the new blog section, a new complete programming guide is available on the site.

LadyBug Technologies LLC

www.ladybug-tech.com

Updated Product Page

The Logus Microwave website provides information on all Logus Microwave customizable, premier microwave and RF Switches. All UAV products are of high-reliability and cutting edge design for the nation's defense, homeland security, real-time weather data and surveillance programs. The newly updated coaxial switches product page now features an easy-to-view table of standard switches, including SPDT, DPDT, SPMT, as well as a user-friendly drop-down menu to create your own perfect switch. Request your quote from a company that delivers.

Logus Microwave

www.logus.com/

Research and Educational Kits

The first of the Univeristy Project kits, UVNA-63, includes all the elements students need to build a fully functioning vector network analyzer, develop S-parameter algorithms and perform real-time measurements of 2-port RF devices. The kit comprises Vayyar's high performance transceiver chip with a variety of RF components from Mini-Circuits, along with control software and a development environment for Python and MATLAB®. Mini-Circuits has expanded its collaboration with Vayyar to offer its second kit, VTRIG-74, a ready-to-use, 4D mmWave imaging and sensing application development platform.

Mini-Circuits

www.minicircuits.com/products/researcheducation.html

New Video: "In the Field at 5G Sites"

Testing the RadMan 2 for complex monitoring of the exposure from EMF radiation of 5G antennas. Thanks to its frequency range up to 60 GHz, RadMan 2 covers all mobile services including the new 5G frequencies. By the RF detection mode, the workers at an antenna site check if the antennas are really switched off. Then they change over to the monitoring mode, so they can continually monitor their exposure and their safety while they are working. The RF levels are automatically logged and can be accessed with the PC software.

Narda Safety Test Solutions

www.narda-sts.com

New Demo Video

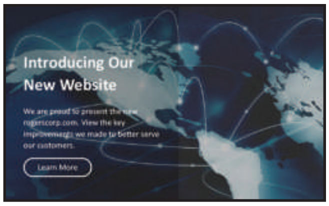
Richardson RFPD demonstrated the latest 5G Massive MIMO at IMS2019, partnering with Analog Devices Inc. (ADI), NXP Semiconductors and NanoSemi. The demonstration included Band 42 TDD-LTE RF front-end with DPD, transceiver and baseband processor, to provide better throughput, wider coverage and increase spectrum efficiency.

Richardson RFPD

www.youtube.com/watch?v=LkMl3TarPY8

New Redesigned Website

VENDORVIEW



View the new redesigned rogerscorp.com website. Based on customer feedback, the company made many improvements to enhance and streamline the user experience. The customer support presence was increased to help locate the right Rogers' resources quickly. The navigation and layout were simplified for more intuitive browsing. The site's search capabilities were enhanced to help find what you are looking for. And the design and graphics were updated for a more appealing look. Check it out today.

Rogers Corp.

www.rogerscorp.com

Enhanced Online Ordering

Signal Hound has enhanced its online ordering process to include add-on options for calibration certificates and extended warranties. All of Signal Hound's devices are calibrated to better-than-box specs during production, however some work environments require a calibration certificate and/or a printed packet of calibration data. This can now be added prior to checkout as needed, along with extended warranty options that go above and beyond the company's standard two year warranty.

Signal Hound

https://signalhound.com/

Redesigned Website Launched

VENDORVIEW

Skyworks recently launched its newly designed website, www.skyworksinc.com. New features include design elements with a lighter look and feel, as well as significantly enhanced search functionality for a better experience. Visitors now have faster access to information in order to quickly find what they are most interested in with fewer clicks. The website provides robust filtering capabilities by market, application and products. In addition, the site's content-rich pages are accessible through consistent desktop and mobile designs.

Skyworks Inc.

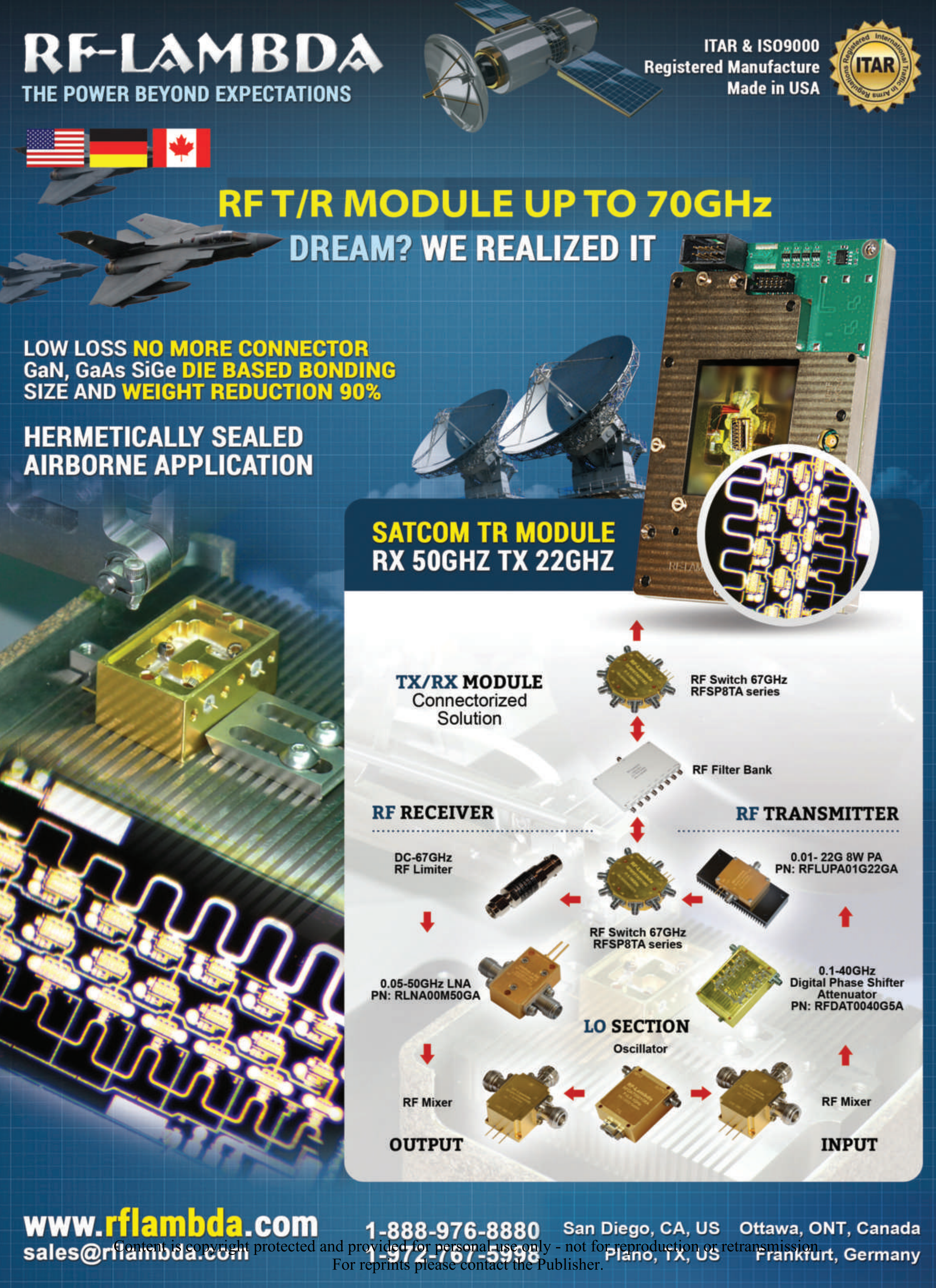
www.skyworksinc.com

Easy RFQ on New Website

Customers can now easily configure their requested cable assemblies or waveguide-to-coax adapters on the new Spectrum Elektrotechnik GmbH website in order to receive a quote. They can choose among more than 100 different cable types for flexible, semi-rigid or hand-formable cables, meeting different requirements with regard to attenuation, power handling, phase stability, etc. For waveguide-to-coax adapters, more than 30 different waveguide designations (rectangular and/or double-ridge) are available in either end- or top-launched orientation. Basically every interface, matching the respective frequency range of the waveguide, can be supplied.

Spectrum Elektrotechnik GmbH

www.spectrum-et.com/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THE POWER BEYOND EXPECTATIONS
ITAR & ISO9000
Registered Manufacture
Made in USA
ITAR
Registered International Traffic in Arms Regulations
RF T/R MODULE UP TO 70GHz
DREAM? WE REALIZED IT
LOW LOSS NO MORE CONNECTOR
GaN, GaAs SiGe DIE BASED BONDING
SIZE AND WEIGHT REDUCTION 90%
HERMETICALLY SEALED
AIRBORNE APPLICATION
SATCOM TR MODULE
RX 50GHZ TX 22GHZ
TX/RX MODULE
Connectorized
Solution
RF Switch 67GHz
RFSP8TA series
RF Filter Bank
RF RECEIVER
RF TRANSMITTER
DC-67GHz
RF Limiter
0.01- 22G 8W PA
PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
0.05-50GHz LNA
PN: RLNA00M50GA
0.1-40GHz
Digital Phase Shifter
Attenuator
PN: RFDAT0040G5A
LO SECTION
Oscillator
RF Mixer
RF Mixer
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INPUT
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sales@rflambda.com
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1-972-767-5998
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FEATURING VENDORVIEW STOREFRONTS

COMPONENTS

Power Dividers and Directional Couplers

Cinch Connectivity Solutions launched 40 GHz power dividers and directional couplers designed to meet the higher frequency requirements in telecommunications and 5G applications. The Midwest Microwave 40 GHz power dividers and directional couplers are small, lightweight and ruggedly built. They cover a wide bandwidth of 6 to 40 GHz with low insertion loss and low VSWR. The Midwest Microwave power dividers use the Wilkinson design for the lowest insertion loss and the highest isolation between output ports.

Cinch Connectivity Solutions
www.belfuse.com/cinch

Switch Cycler

Ducommun's switch cycler is designed to automate switch cycling and allow users to "plug-and-play" versus having to design a custom instrument themselves. The CAT-001 allows users to perform a "burn-in" function for switches that have sat in inventory for long periods of time. The CAT-001 also features an optional strip chart counter to record data for each switch, GUI remote control for automation and a keypad for local control.

Ducommun
www.ducommun.com

High Frequency Couplers

Fairview Microwave Inc. has debuted a new line of high frequency couplers that are ideal for point-to-point radios, 5G telecommunications, SATCOM, automotive radars and aerospace applications. Fairview's new series of high frequency RF directional couplers is comprised of 24 new models that deliver excellent isolation, low insertion loss and very good return loss. These couplers have a high max operating frequency range from 26.5 to 67 GHz and are offered with 6, 10, 15, 20 and 30 dB coupling levels.

Fairview Microwave Inc.
www.fairviewmicrowave.com

2 Channel Attenuator Assembly

VENDORVIEW

JFW model 50BA-043-63 SMA is a two channel attenuator assembly that covers 100 MHz to 18 GHz. Each RF channel consists of a solid-state programmable attenuator with attenuation ranging 0 to 63 dB in 0.5 dB increments. The attenuators can be controlled individually or as a group by Ethernet, RS-232 (GUI provided) or manually via momentary toggle switches on the front panel.

JFW Industries Inc.
www.jfwindustries.com

6.2 to 32 GHz Elliptical Highpass SMT Filter

VENDORVIEW

Lexatys' new elliptical highpass filter delivers extremely low loss without having limited selectivity. Thanks to high Q gold plated structures implementing an elliptical circuit design the typical loss is less than 2.5 dB. The filter has a low profile at 0.36 × 0.21 × 0.65 in. RF connections can be made with silver epoxy or solder on the plated contact surfaces. Mounting supports SMT assembly on microstrip structures.

Lexatys
www.lexatys.com

Coaxial Switch

VENDORVIEW

Exceed all of your RF/microwave requirements: performs to 18 GHz with a VSWR of 1.5:1 max., insertion loss of 0.5 dB max. and isolation of 60 dB min. Series options include latching, failsafe, indicators, TTL, weather sealed and more.

Logus Microwave
www.logus.com

18 to 40 GHz, 20 dB Directional Couplers

VENDORVIEW

MECA expanded offering of 5G mmWave products. Featuring 20 dB couplers covering 18 to 40 GHz with 2.92 mm interfaces. Typical specifications of 1.6:1 VSWR, 13 dB directivity, 1 dB insertion loss and 0.4 dB frequency sensitivity. Also available are attenuators, terminations, bias tee's, DC blocks and adapters. Additionally octave and mulit-octave models covering up to 50 GHz built by J-Standard certified assemblers and technicians. Made in the U.S. with 36-month warranty.

MECA Electronics Inc.
www.e-meca.com

2-Way Splitter for CATV Systems

Featuring 1.8 GHz bandwidth and 25 dB isolation for 75 Ω applications, MiniRF's MRFSP8725 low-cost miniature part is prepared to split RF wideband signals while maintaining high RF performance. MiniRF offers highly repeatable performance with a low-cost, surface mount component. These parts designed to operate over extreme temperature range –40°C to 85°C with minimal variation. Contact MiniRF or RFMW for evaluation samples and support.

MiniRF
www.minirf.com

5G Interference Solution

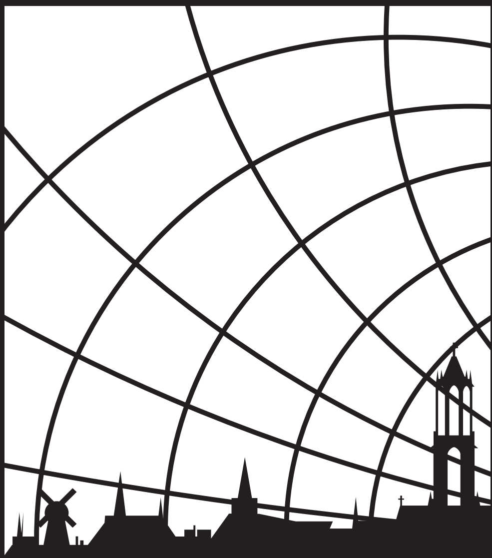
Norsat's latest 5G interference solution consists of a C-Band interference suppression LNB and bandpass filter. Norsat's advanced LNB with internal filtering mitigates 5G signals and is the perfect solution for C-Band operators. For additional filtering, the bandpass filter can be used to reject terrestrial interference. Contact for additional custom solutions and spectrum consulting services.

Norsat
www.norsat.com

Coaxial RF Surge Protectors

VENDORVIEW

Pasternack has launched a new series of coaxial surge protectors designed to protect valuable communications equipment from power surges and indirect lightning strikes. Pasternack's new surge protectors are available with either male to male or male to female 4.3-10 connectors and feature VSWR as low as 1.12:1, low insertion loss, max input power



as high as 500 W, a surge current rating of 20 kA, multi-strike capability and the lowest let-through energy in the industry.
Pasternack
www.pasternack.com

5 to 10 GHz Hybrid Coupler

VENDORVIEW

PMI Model No. QC-5010-NFF is a 5 to 10 GHz hybrid coupler. It has a max insertion loss of 1.1 dB and a min. isolation of 16 dB. This coupler is supplied with N female connectors in a housing that measures 1.87 × 1.315 × 0.787 in.
Planar Monolithics Industries Inc.
www.pmi-rf.com

Uniquely Packaged High Frequency Filters

RLC Electronics expands its line of high frequency cavity filters with non-standard outlines/footprints. Custom requirements for package dimensions and connector orientation are often desired in system integration where space allocation and component arrangement have been pre-defined.
RLC Electronics Inc.
www.rlcelectronics.com

Frequency Multiplier

Model SFA-603903316-12KF-E1 is an active X3 frequency multiplier. The multiplier has an input frequency of 20 to 30 GHz with a

typical input power of +3 dBm and an output frequency of 60 to 90 GHz with a typical output power of +16 dBm. The multiplier also has a typical harmonic suppression of –20 dBc. The DC power requirement for the multiplier is +8 VDC/400 mA. The input port configuration is a female K connector and the output is a WR-12 waveguide with a UG-387/U anti-cocking flange.
SAGE Millimeter
www.sagemillimeter.com

Ultra-Wideband Triple Balanced Mixer

VENDORVIEW

CHK-3500 is a high performance connectorized ultra-wideband triple balanced mixer great for narrow and broadband up-/down-conversion applications. The RF/LO operating frequency range is 10 to 3500 and 1 to 2000 MHz for the IF frequency range. Features include low conversion loss of 7.8 dB typical, isolation of 20 dB min. between all three ports. LO is +23 dBm, 1 dB compression point is +18 dBm and input IP3 is +32 dBm typical. Operating temperature range is –55°C to +85°C.
Synergy Microwave Corp.
www.synergymwave.com

CABLES & CONNECTORS

SMP Self-Lock Connectors

VENDORVIEW

Cost-effective, robust and providing dependable connectivity for aerospace, defense and industrial applications, the HUBER+SUHNER SMP Self-Lock (SMP-SL) connector is designed to speed installation with a secure locking mechanism that prevents accidental loss of connection. The innovative design provides a visual inspection feature to verify full mating engagement, intended to reduce installation and inspection time during systems integration. The SMP-SL is designed to meet the requirements for high vibration and shock environment applications. The unique and pioneering combination of a MIL-STD-348 SMP interface plus a low-profile self-locking design delivers an integral solution with exceptional electrical and mechanical performance.
HUBER+SUHNER
www.hubersuhner.com

Connectors and Terminators

MilesTek announced that it has released a new series of RoHS and REACH compliant twinaxial connectors and bus terminators for use in mil/aero applications. The new connectors are available with TRS, TRT and TRB style interfaces and are designed to be panel mounted. In addition to the new connectors, MilesTek also offers a series of RoHS compliant TRB bulkhead jack, feedthrough adapters with 2 and 4 lug options.
MilesTek
www.milestek.com

SMPM Connectors

withwave's SMPM Connectors are covering wide frequency ranges from RF to Microwave with excellent frequency performance and high density. The proprietary internal insulator enables simple structure with higher performance compared to the conventional SMPM connectors. The best applications could be 5G complex mobile communications modules, systems and various other wireless systems.
withwave co. ltd.
www.with-wave.com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NewProducts

AMPLIFIERS

Ku-Band SATCOM ICs

VENDORVIEW

Anokiwave Inc. announced further expansion of its SATCOM Beamformer IC family with the release of its 2nd generation Ku-Band ICs—AWMF-0146 and AWMF-0147—for the design and deployment of commercial phased array-based ground terminals. The two new ICs enable Ku-Band phased array active antennas that can auto-align and auto-position to support ground and aviation-based use cases for LEO/MEO/GEO satellites.

Anokiwave Inc.
www.anokiwave.com

AR-5000 Series Amplifier

VENDORVIEW

The new AR-5000 Series of rack-mounted amplifiers enable rapid and inexpensive prototyping of custom solutions where tailored, application specific performance is required. Designed for linear operation, AR-5000 Series amplifiers support the latest digital modulations and emerging technologies. With features including maximum level control, automatic level control and gain control—all managed locally and remotely—AR-5000 Series amplifiers ease system integration and get your products into production and delivered to market faster.

AR Modular RF
www.arww-modularrf.com

Broadband Amplifier

VENDORVIEW

Exodus Advanced Communications 26.5 to 40 GHz, 40 W+ solid-state amplifier is designed for general EMC testing applications as well as Mil-Std 461 (RS103) standards. AMP4066-LC compact design provides superb RF performance with unprecedented P1dB power as compared to TWTs. 46 dB min-gain, monitoring parameters for FWD/RFL power, VSWR, voltage, current and temperature sensing for outstanding reliability and ruggedness.

Exodus Advanced Communications
www.exoduscomm.com

Ultra-Low Noise D-PHEMT Transistor

VENDORVIEW

Mini-Circuits' TAV1-331+ is a MMIC D-PHEMT transistor with an operating frequency range from 10 to 4000 MHz, supporting a wide range of wireless communications bands. This model provides a unique combination of low noise (0.6 dB) and high gain (24.1 dB), resulting in lower overall system noise. It also provides high IP3 performance of +31.8 dBm, making it ideal for sensitive receiver applications. Manufactured using highly repeatable D-PHEMT technology, the unit comes housed in a tiny 1.4 × 1.2 mm MCLP package. This model requires external biasing and matching.

Mini-Circuits
www.minicircuits.com

10 W, 20 to 2500 MHz GaN PA

Richardson RFPD Inc. announced the availability and full design support capabilities for a new GaN power amplifier (PA) from MACOM Technology Solutions Inc. The NPA1007 is a wideband GaN PA optimized for 20 to 2500 MHz operation. The new PA is designed for saturated and linear operation, and it is assembled in a lead-free 6 × 5 mm, 8-lead PDFN plastic package. The NPA1007 is a general-purpose device suitable for narrowband and broadband applications in test & measurement, defense communications, land mobile radio and wireless infrastructure.

Richardson RFPD Inc.
www.richardsonrfpd.com

SOURCES

10 MHz OCXO

Morion's ultra-stable MV336M is an ultra precision 10 MHz OCXO with phase noise of < –93 dBc/Hz at 0.1 Hz and –120 dBc/Hz at 1 Hz. Short-term stability (ADEV) is < $1E^{-13}$ at 1 sec and < $3E^{-13}$ until 100 sec, which is accompanied by temperature stability of < $4E^{-11}$ vs. –10°C to +70°C. The MV336M is housed in a 92 × 80 × 50 mm package and operates at 12 V.

Morion
www.morion-us.com

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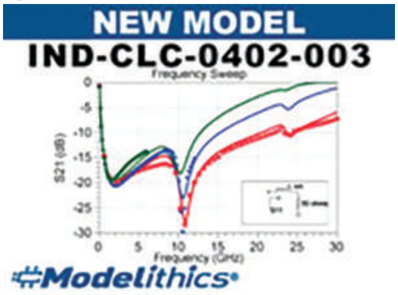
NewProducts

SOFTWARE

Microwave Global Model™ for Coilcraft 0402AF Inductor Series

VENDORVIEW



Modelithics has introduced a new equivalent circuit-based scalable Microwave Global Model for Coilcraft 0402AF series surface mount inductor family. The model is validated up to 30 GHz and features substrate, pad and part value scaling over the full range of the surface mount inductor series, 20 to 560 nH. Coilcraft is a Sponsoring MVP and is sponsoring free 90-day trials of all available Modelithics models for Coilcraft parts by request and with approval.

Modelithics
www.Modelithics.com/MVP/Coilcraft

TEST & MEASUREMENT

Radio Communication Test Station

VENDORVIEW

Anritsu Co. has upgraded its Radio Communication Test Station MT8000A with 5G Protocol Test functions. The upgrade uses NR Fading software that, when implemented with built-in baseband fading tests, allows the MT8000A to support 3GPP TS 38.521-4 B.1/B.2 V15.0.0-compliant 5G NR channel (TDL) model tests. With the software, the MT8000A can conduct fading tests that simulate the actual radio-wave propagation environment and are required for development of mobile devices. Previously, an external 5G RF fading simulator was necessary.

Anritsu Co.
www.anritsu.com

5G New Radio: Beyond Mobile Broadband

Amitav Mukherjee

Fifth-generation cellular radio access networks are currently being standardized as 5G New Radio (NR). The primary objectives of 5G NR are to provide enhanced mobile broadband (eMBB) and ultra-reliable low latency communication (URLLC) capabilities. This innovative resource analyzes these applications in detail to help readers understand how the flexible design of NR makes it suitable for a wide range of use cases and applications. The rationale behind the design decisions made during the NR standardization process are explored. Readers will be able to understand the performance limits of NR when applied to non-eMBB scenarios and how NR compares to 4G and IEEE 802.x connectivity solutions for such scenarios.

The main features of 5G phase 2 are explored, as well as the use cases that can be addressed by 5G phase 2. The mathematical models are included to help explain the future evolution of NR in Release 16 and beyond. This is the only book that describes both the standards features of NR and the mathematical models/open research issues for 5G, appealing to both industry practitioners and academic researchers.

To order this book, contact:

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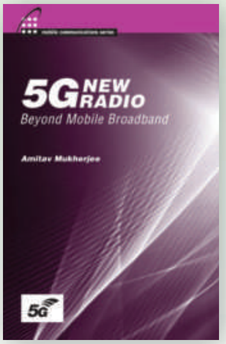

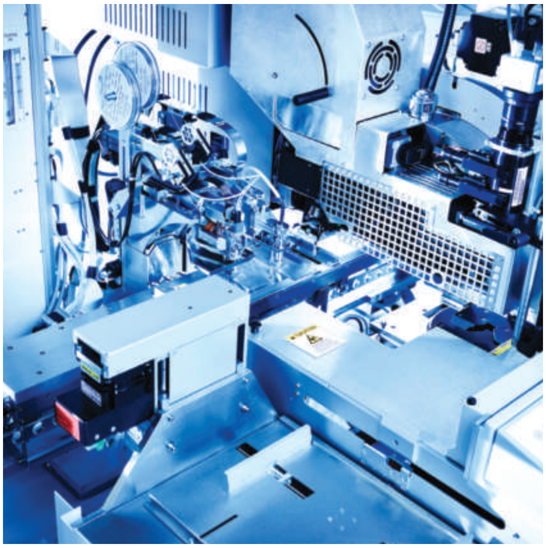

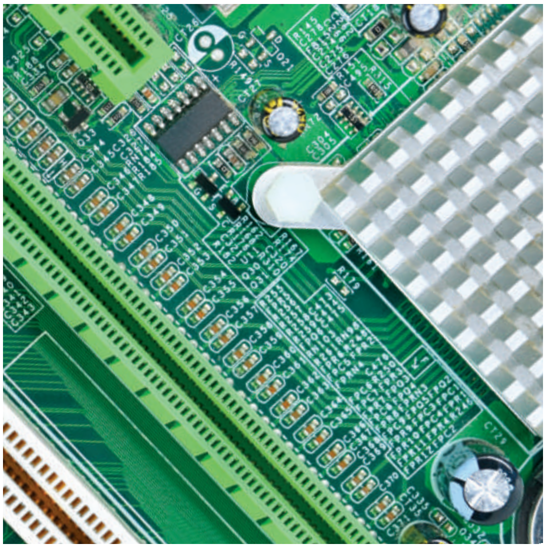

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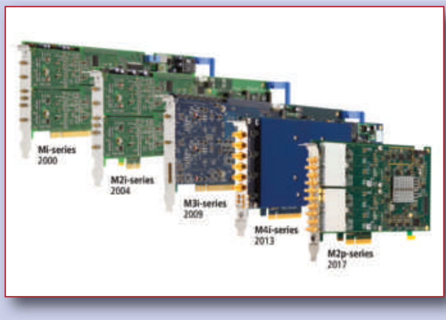
FABS and LABS

Spectrum Instrumentation: Digitizers and AWGs Built with German Quality



During its 30-year history, Spectrum Instrumentation has built a global business developing digitizers, arbitrary waveform generators (AWG) and digital I/O products for the instrumentation needs of leading companies, universities and research organizations. The founders, Gisela Hassler and Michael Janz, began their venture designing custom products, initially used in printer controllers and acoustics applications. Their first catalog product, an 8-bit, 50 MHz digitizer on an ISA card, which plugged into early PCs, was released in 1991. The product was so successful, it remained in the product portfolio for 17 years.

Spectrum soon added an AWG to complement the digitizer, subsequently developing a portfolio of more than 500 products to provide a "perfect fit solution" for each customer's need. Spectrum provides this customization quickly and for a reasonable cost using a modular approach that combines common platform boards with modules tailored to the performance needs of the application. Spectrum supports all industry standard form factors and offers its own NETBOX for benchtop or rack mounting.

Spectrum's digitizers are available in single and multichannel versions, with sampling rates from 1 MSPS to 5 GSPS, maximum bandwidth exceeding 1 GHz and resolution from 8 to 16 bits. Similarly, the AWGs have single and multichannel options with rates from 40 MSPS to 1.25 GSPS, maximum bandwidth greater than 500 MHz and resolution from 8 to 16 bits. Spectrum supports all industry bus standards, including PCIe, PXIe, PXI and Ethernet-LXI. All products use the same measurement software, SBench 6, an easy-to-use interface for controlling the digitizer or AWG. All Spectrum products are designed and manufactured in Germany, in the small town of Grosshansdorf near Hamburg. Proud of the heritage of German quality, Spectrum stands behind all products with a five-year warranty.

During the company's three decades, it has supported many interesting applications. Spectrum cards are used in a Leibniz Institute atmospheric measurement system operating in the ice and snow of Antarctica; 140 of its digitizers control the complicated shutdown procedure for the Large Hadron Collider at CERN. Oliver Rovini, Spectrum's CTO, says of the hundreds of applications he has seen in his 25 years at Spectrum, the inertial confinement fusion research being conducted at First Light Fusion is perhaps the most extraordinary. A Spectrum 256-channel digitizer is helping First Light develop a reactor—in only four years—that will generate more energy than it uses.

Asked about her goals when she started the company, Hassler says, "It was personally important to me to make my ideas work and to live my values." These values are embedded in Spectrum's culture: friendly, cooperative and conscientious, with open communication. This is reflected in the way the company corrects errors. "The focus is not on who made the mistake but rather what we can change so that it cannot happen again," Hassler says. She wants the company to feel like a family. "The well-being of our employees is very important to us." This regard extends to customers. Spectrum's commitment to them is providing fast and high-resolution digitizers and AWGs, built with German quality and supported by outstanding service—meaning direct access to the company's hardware and software engineers. Thirty years and more than 500 products seem like a solid endorsement of Spectrum's success.

www.spectrum-instrumentation.com

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Directional Couplers

Model	Type	Frequency (MHz)	Power (W CW)	Coupling (dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
C8740	Dual	20-512	200	40	0.3	Tabs	1.5 x 0.95 x 0.55
C9655	Dual	20-1000	100	30	0.7	Tabs	1.5 x 0.95 x 0.55
C8631	Dual	20-1000	150	40	0.35	Tabs	1.5 x 0.95 x 0.55
C10561	Dual	20-1000	250	50	0.1	SMT	1.35 x 1.0 x 0.15
C8025	Bi	500-3500	125	30	0.3	Drop-In	1.3 x 1.0 x 0.07
C8098	Bi	800-2000	200	30	0.25	Drop-In	1.3 x 1.0 x 0.07

0° (In-Phase) Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Isolation (dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
D9888	2-Way	1000-3000	500	15	0.35	SMT	2.8 x 2.2 x 0.27
D9922	2-Way	2000-6000	200	15	0.35	SMT	1.4 x 1.1 x 0.14

90° & 180° Hybrids

Model	Type	Frequency (MHz)	Power (W CW)	Amp. Bal. (±dB)	Insertion Loss (dB)	Mounting Style	Size (inches)
QH9056	90°	30-520	400	1.2	0.80	Drop-In	4.0 x 1.7 x 0.29
QH9304	90°	60-1000	150	1.0	1.0	Drop-In	2.0 x 1.0 x 0.16
QH8849	90°	80-1000	250	1.0	0.65	Drop-In	2.9 x 2.1 x 0.31
QH11489	90°	80-1000	600	0.8	0.6	Drop-In	3.33 x 2.25 x 0.31
QH8100	90°	100-512	250	0.5	0.45	Drop-In	3.3 x 1.52 x 0.28
QH8922	90°	150-2000	100	1.0	0.75	SMT	1.47 x 1.13 x 0.16
QH11643	90°	200-1000	200	0.55	0.4	SMT	2.8 x 0.75 x 0.16
QH10900	90°	380-2500	150	0.6	0.55	Drop-In	1.3 x 1.3 x 0.15
QH7900	90°	450-2800	125	0.45	0.55	SMT	1.5 x 1.1 x 0.095
QH7622	90°	500-3000	150	0.6	0.55	Drop-In	1.65 x 1.1 x 0.09
QH11687	**90°**	**500-6000**	**150**	**0.7**	**0.75**	**SMT**	**1.28 x 1.08 x 0.13**
QH11113	90°	600-4000	150	0.7	0.5	SMT	1.29 x 0.99 x 0.12
QH10756	90°	700-6000	100	0.6	0.55	SMT	0.75 x 0.45 x 0.09
QH10541	90°	700-6000	150	0.6	0.5	SMT	0.86 x 0.66 x 0.09
QH10089	90°	800-2800	200	0.4	0.35	SMT	1.25 x 0.55 x 0.08
QH11805	90°	800-3200	200	0.5	0.4	Drop-In	2.2 x 0.8 x 0.174
QH8105	90°	800-4200	150	0.5	0.55	Drop-In	1.5 x 1.08 x 0.09
H10125	180°	1000-3000	350	0.3	0.5	SMT	2.31 x 1.21 x 0.25
QH10827	90°	1000-7500	100	0.7	0.65	SMT	0.86 x 0.61 x 0.09
QH10828	90°	1000-8000	100	0.7	0.9	SMT	0.65 x 0.5 x 0.07
QH10148	90°	2000-6000	100	0.5	0.3	SMT	0.75 x 0.45 x 0.08
H10126	180°	2000-6000	100	0.4	0.8	SMT	1.15 x 0.6 x 0.14

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