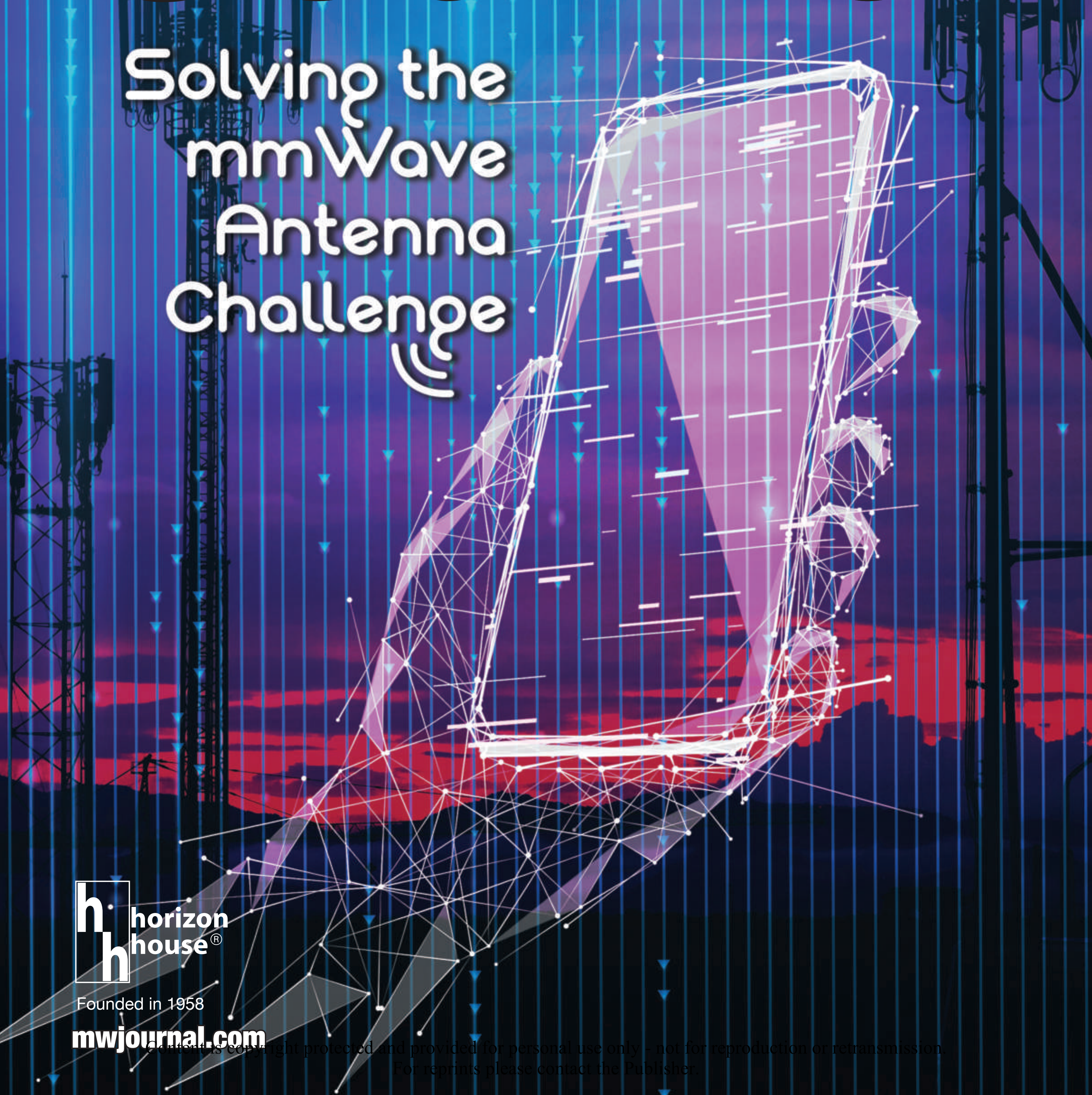
Vol. 63 • No. 11

November 2020

Microwave Journal

Solving the mmWave Antenna Challenge



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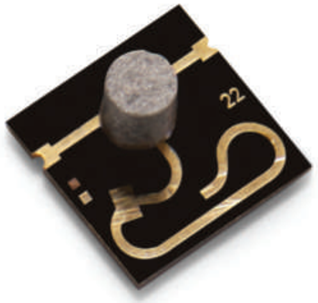

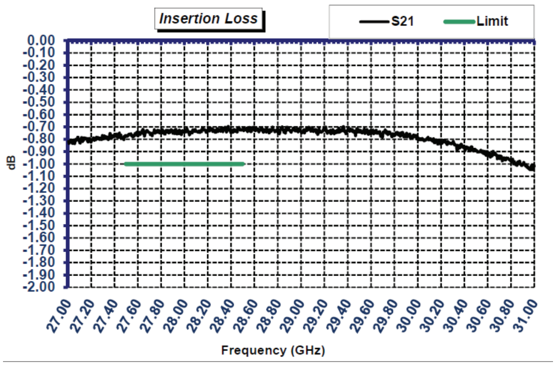

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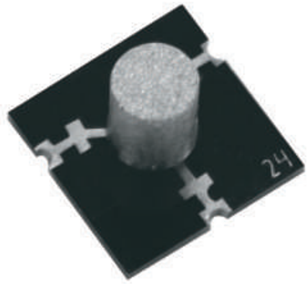

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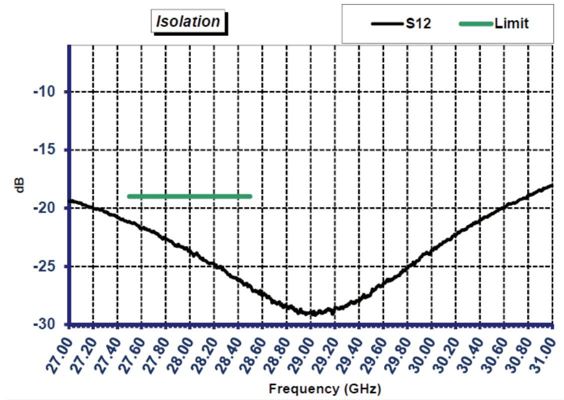


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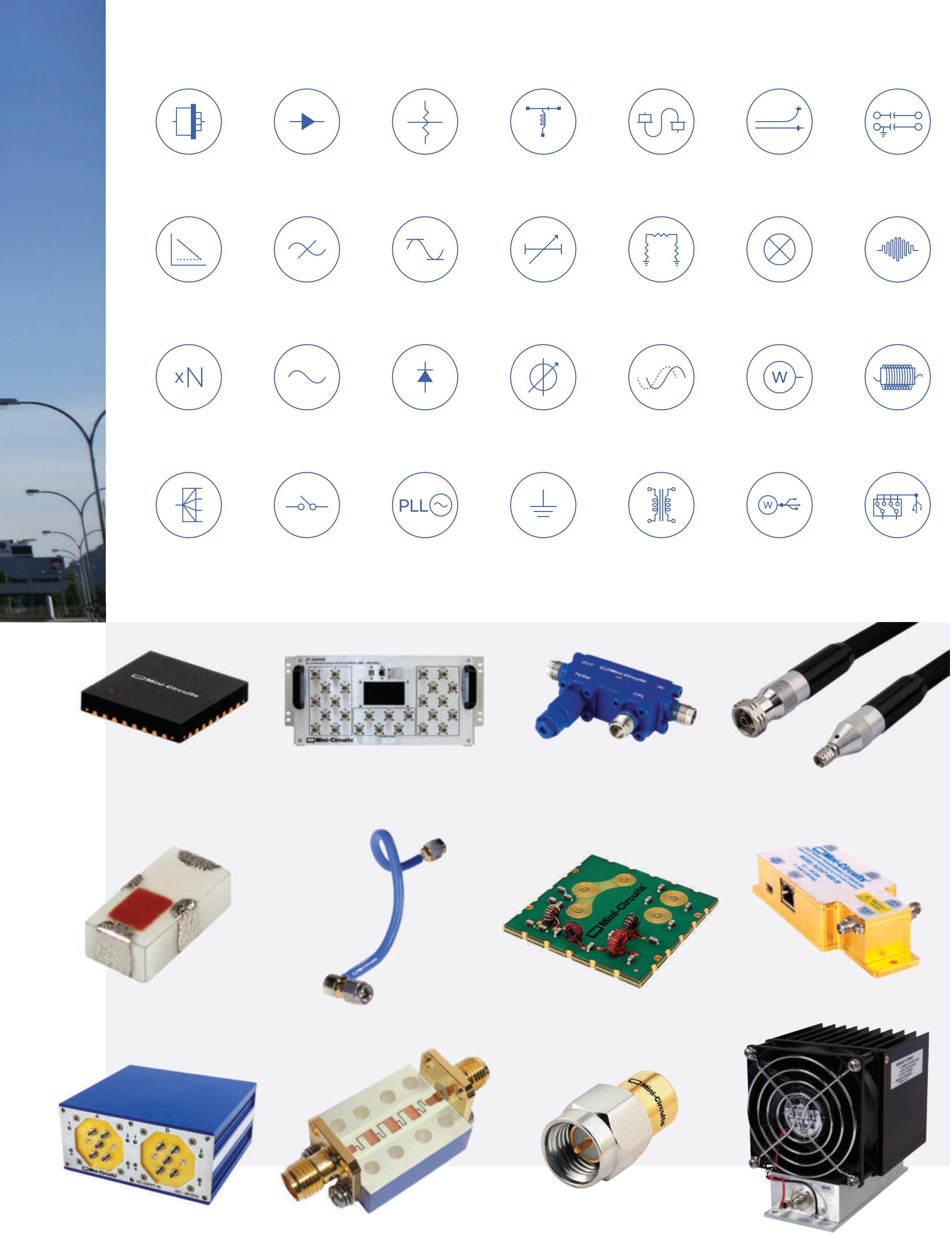
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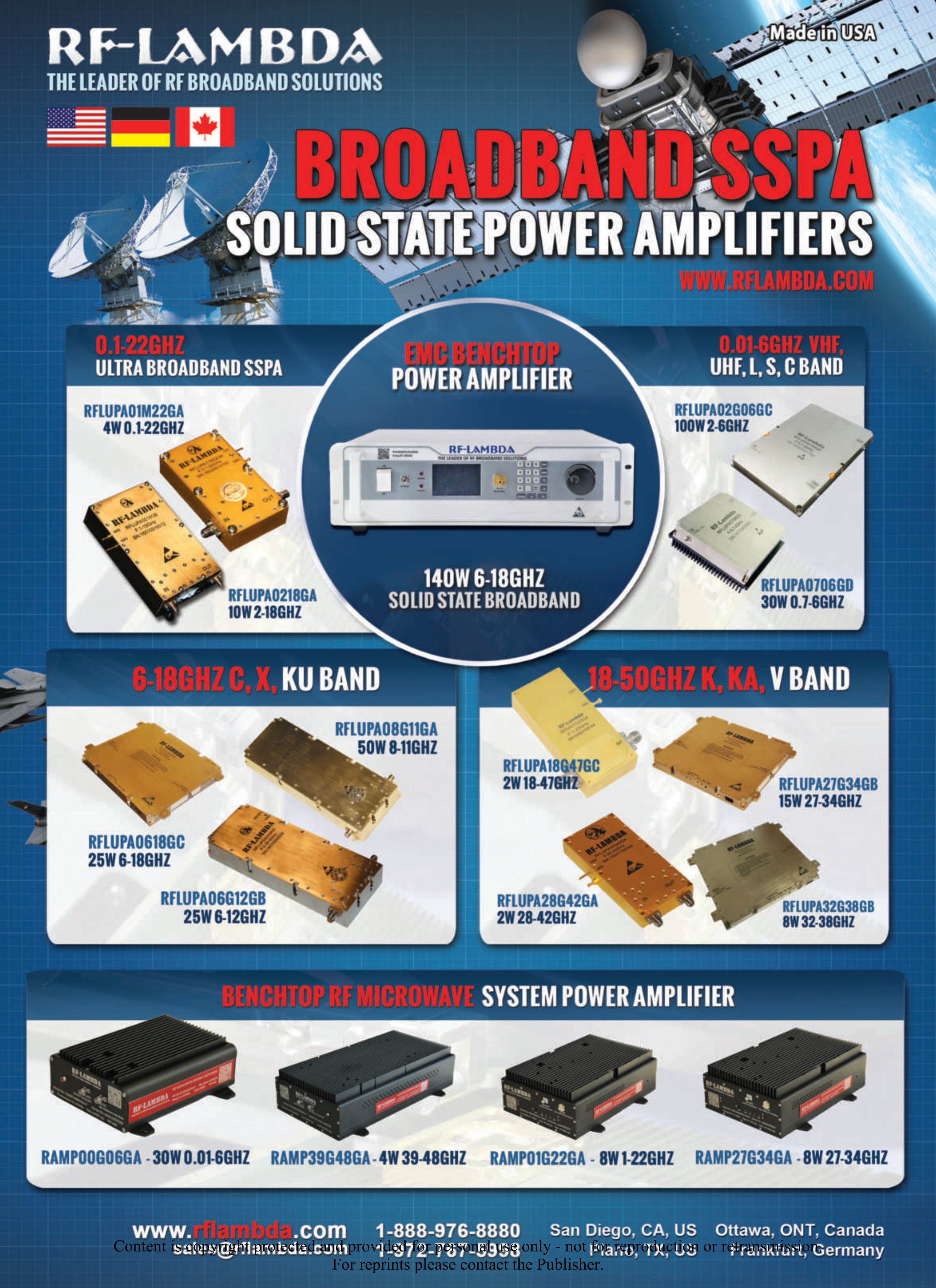
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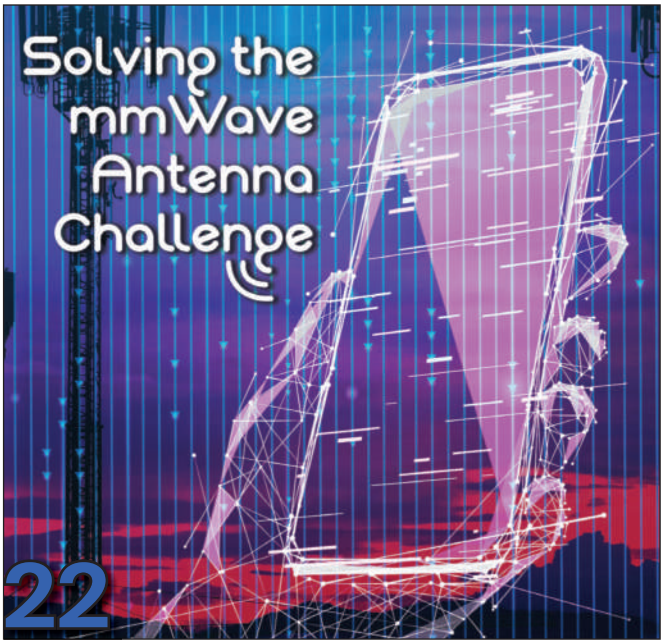

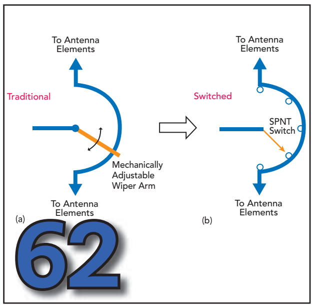

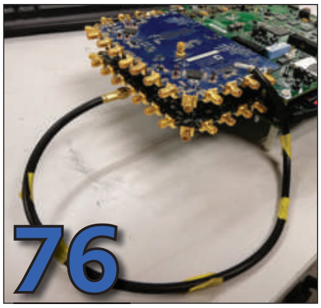

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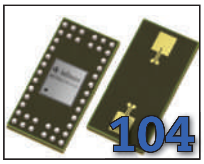

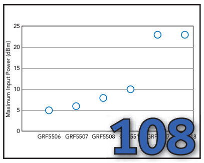

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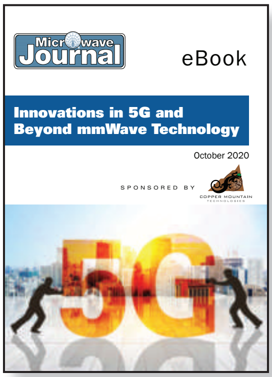

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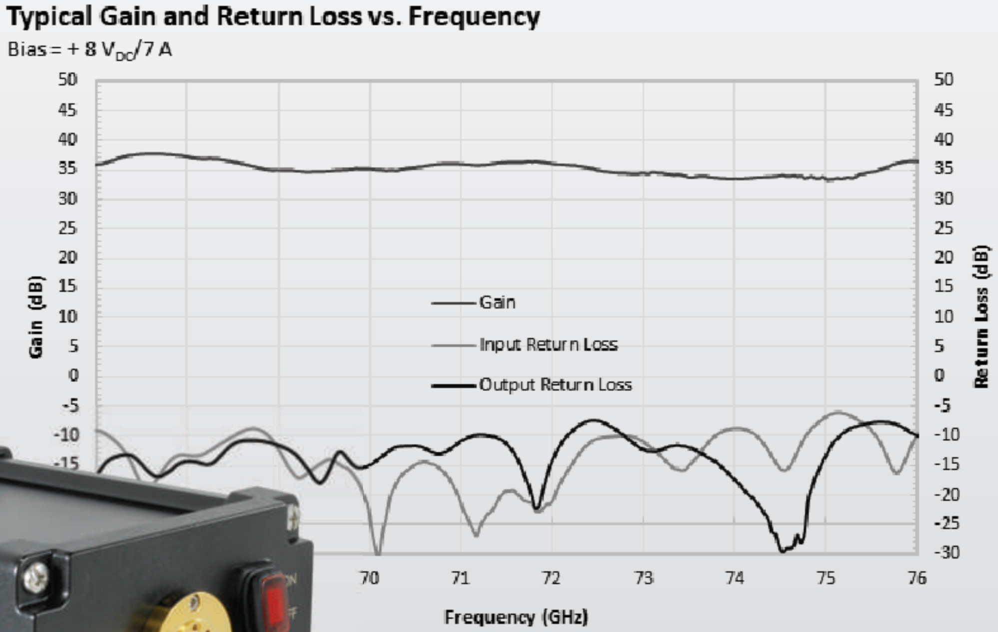

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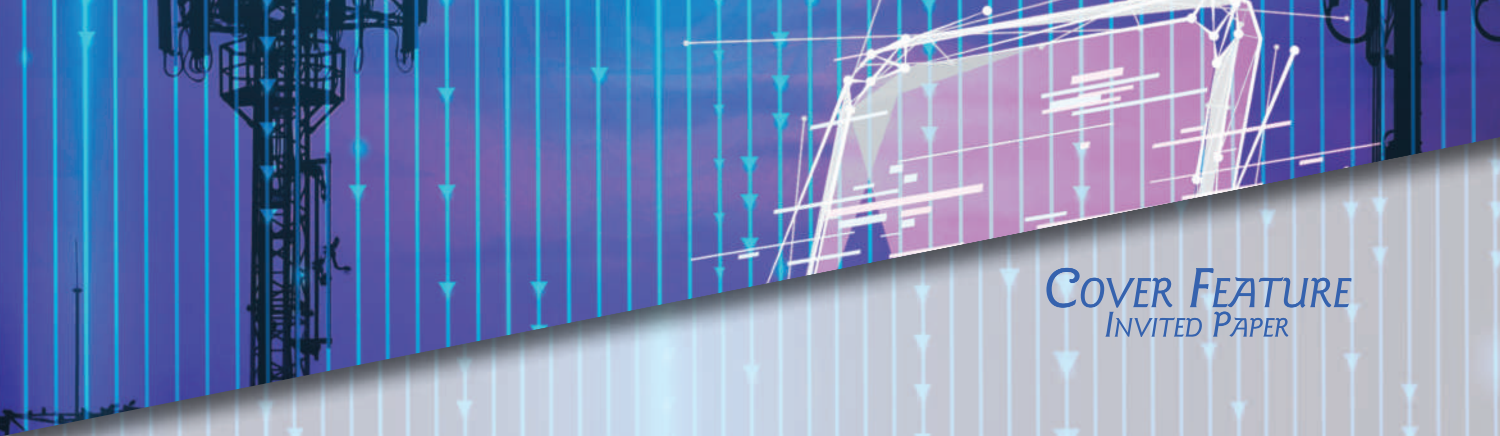

Compact Antenna Designs for Future mmWave 5G Smart Phones

Shiban K. Koul and Karthikeya G. S
Center for Applied Research in Electronics, IIT Delhi, India

Ajay K. Poddar and Ulrich L. Rohde
Synergy Microwave Corporation, USA

Compact antenna designs are necessary for future mmWave 5G smartphones to improve transmit power and battery life. The antennas must have high gain for the available physical aperture and should support orthogonal beams for single hand and dual hand modes. This article gives insight into the design requirements for 5G antennas along with a few design examples to realize these antennas.

R&D investment for 5G design, development and deployment has increased in recent years: for instance, the European Commission has invested €50 million to date with several academic institutions like University of Surrey, TU Dresden, Lund University, etc., have established innovation centers targeted for 5G architecture designs. The Chinese government has initiated IMT-2020 to promote and standardize research in 5G wireless technologies. Leading companies such as Samsung, Qualcomm, Ericsson, Verizon, Nokia Siemens Networks, NXP, NTT Docomo, IBM and Huawei have established dedicated 5G research groups.

Researchers at NYU have performed exhaustive channel propagation studies at 28 and 38 GHz bands to prove the feasibility of mmWave bands for cellular telephony.[1] Free space path loss and the penetration losses are relatively high at mmWave frequencies. The free space path loss for sub-6 GHz is in the range of 80 to 95 dB compared to its 28 GHz counterpart that is about 105 to 110 dB. This difference can be compensated for in the gain of the respective antennas on the mobile device-base station link. Path loss can be managed by changing the gain of the antennas with multi-beams, but penetration loss can be as high as 30 to 40 dB for common building materials such as bricks, concrete and glass windowpanes. This aspect deteriorates the link budget severely and the feasibility of maintaining the link budget with decent power at the base station or access point for a given receiver sensitivity has not yet to be implemented.

DESIRED CHARACTERISTICS OF THE SMARTPHONE ANTENNA

Antennas in the mobile device must have high gain for the available physical footprint. Below is a list of desired characteristics of mmWave 5G antennas.

A. Physical Size

An exploded view of the internal layout of a typical smartphone is illus-

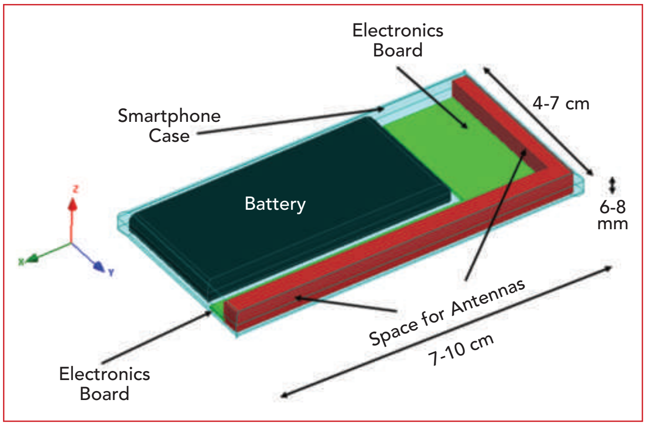

Fig. 1 Physical break-down of typical smartphone.

trated in ***Figure 1***.[2] The length of the mobile device is about 7 to 10 cm. Recent trends suggest that the elongation of the smartphone seems to be desired in the market. The width of the smartphone is 4 to 7 cm and the height of the smartphone is about 6 to 8 mm. 5G antenna researchers must incorporate the design into the mobile panel height when designing 28 GHz antennas. They also must co-exist with 4G-LTE and MIMO antennas to support backward compatibility. Most of the real estate is occupied by the battery and the motherboard along with the battery is enclosed in a RF shield. Antenna designers must not meddle with the RF shielding ground enclosing the motherboard as it will compromise the signal integrity of the motherboard. The remaining space must be judiciously used for the front-end and back-end electronics. Therefore, the effective space for all the antennas supporting various wireless services is (8 × 1 × 0.7 cm) along the length of the smartphone and (6 × 1 × 0.7 cm) along the width of the smartphone. When the 5G antenna is independently designed, additional care must be taken for the radiator's effective area to be within these constraints. For a comprehensive understanding of the mmWave 5G antennas, it is imperative to investigate the effects of co-located antennas, speakers, camera, metal-frame, mold and other electrically close metallic or semi-metallic components.

B. Radiation Pattern

5G is primarily advertised as a high data rate wireless service, which means that the mobile terminal must be beam locked with the base station beam. This indicates that the radiation pattern of the 5G antennas must always be oriented toward the base station, irrespective of the orientation of the mobile device handled by the user. Details of the implementation are separately presented in the eBook by the authors.[3]

Figure 2 illustrates the layout for a generic smartphone and the antenna location. The expected radiation pattern when the mobile device is held in the upright position is also depicted in the illustration. Most of the radiated power must be directed away from the user and toward the base station. The beamwidth can be in the range of 80 to 120 degrees. The front to back ratio must be higher than 10 dB when the user holds the mobile device. Hence, the patterns must be engineered to accommodate the user behavior with the mobile device.

C. Beamwidth

In current commercial smartphones, the antennas would be radiating in an omnidirectional pattern for most of the wireless services. The same design process would fail to achieve the link budget in a 5G mmWave context. The beamwidth control can be realized using a phased array approach with individual ports and controllers.

D. Gain

Probably the most discussed parameter in the context of 5G antennas is the gain. A gain of 8 to 15 dBi would be feasible for the constraints

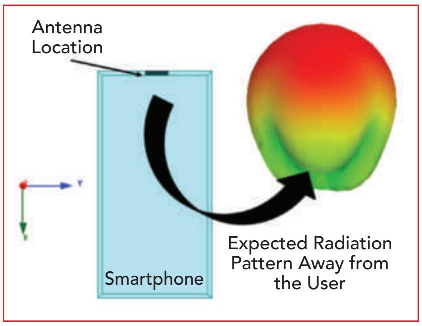

Fig. 2 Antenna location on a smartphone.

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	APMSXXG-X	300 kHz to 6, 12, 20, 33 or 40 GHz	25 µs	ultra-low phase noise | phase coherent switching option | 2 to 4 phase coherent outputs with outstanding channel-to-channel phase stability
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of the available space on the mobile device. A gain lower than 5 dBi would indicate a poor front to back ratio sacrificing beam integrity, when the antenna is mounted on the mobile panel. A gain higher than 15 dBi would have a pencil beam sacrificing the angular coverage necessary. As an engineering decision, it is better to have reasonably high gain to maintain the link budget. It must also be noted that the complexity of implementing the antenna module at the mobile terminal must be simpler in architecture and lower cost compared to its counterpart in the base station.

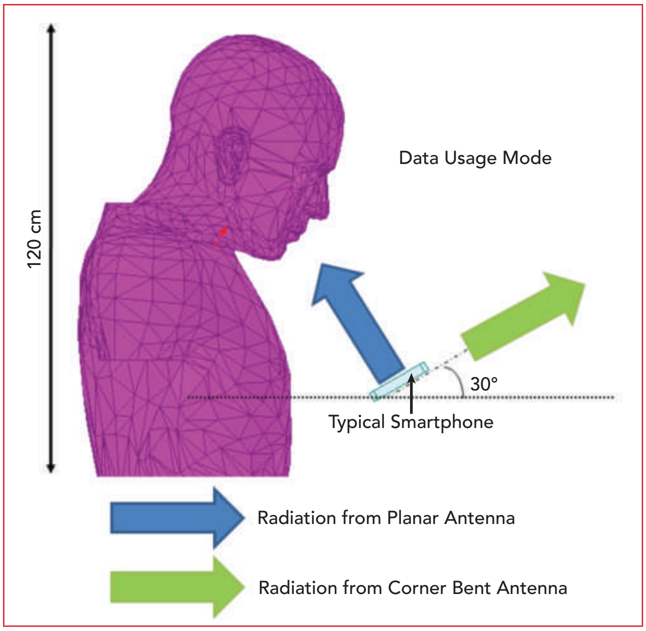

Fig. 3 Typical human interaction with smartphone.

E. Radiation Efficiency

Radiation efficiency above 80 percent is recommended. Efficiency can be high since half wavelength designs could be easily integrated in the mobile device compared to the electrically small antennas of the previous generations. As far as the 5G antennas are concerned, electrically thin low-loss substrate-based designs would lead to high radiation efficiency.

F. Impedance Bandwidth

A 10 dB impedance bandwidth of 26 to 30 GHz is suitable for the 28 GHz band, but specific bandwidth depends on standardization procedures and the regulatory authorities of local geography. Care must be taken so that the antenna has minimal spurious radiation in neighboring bands. Also, 5G antenna designs can afford to have a 10 dB impedance bandwidth due to the feasibility of electrically large designs.

G. Specific Absorption Rate (SAR)

The question of SAR is important for lower bands, especially sub-6 GHz, due to significant penetration of these waves into human tissue. In addition to this, mmWave 5G is mainly intended for data-oriented applications which inherently means that the proximity of the user's head with the mobile device can be significantly higher compared to voice applications.

The primary issue in designing a hardware ecosystem at 28 GHz is the high free space path loss according to the Friis transmission formula. This phenomenon can be mitigated by incorporating high gain antennas in both the mobile device and base stations to maintain a reasonable communication link budget, a forward gain of 8 to 10 dBi is desirable. Hence, high gain antennas with minimal physical footprint

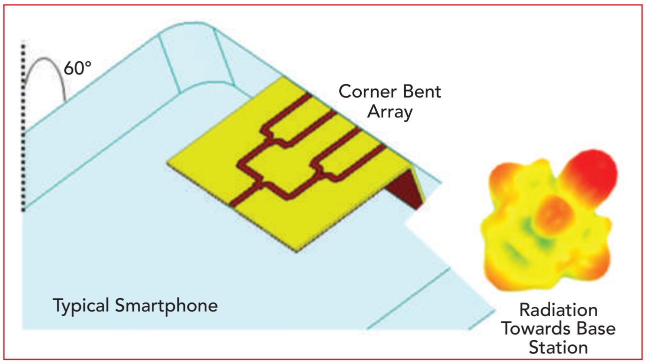

Fig. 4 Radiation of a corner bent radiator.

are essential to be integrated in the mobile device. The gain must be almost invariant across the operational bandwidth.

mmWave 5G wireless services are mostly dedicated to data applications. Statistically speaking, the user holds the mobile terminal at an angle of 30 to 50 degrees with respect to the horizontal axis as illustrated in the ***Figure 3***. In this context, the antennas must radiate away from the user to achieve a good link budget. Also, planar broadside radiators would be radiating toward the user where a corner bent design would radiate away from the user as shown in ***Figure 4***. A simpler solution to solve this issue is to integrate end-fire antennas which would radiate mostly away from the user, when integrated with the motherboard of the mobile device, but the effective physical footprint of the antenna would be larger compromising the real estate available in the smartphone.

Wasted space could be attributed to the expected interference from the back-end electronics board at or near the transmission lines feeding the end-fire antenna. The corner bent antenna would occupy minimal footprint post integration with the smartphone casing with radiation toward the base station. Corner bent antennas would have the feeding plane along the plane of the back-end electronics board of the smartphone. The radiator, on the other hand, would be on the panel of the smartphone, as illustrated in Figure 4. A conductor backed radiator would radiate away from the user. It is also interesting to note that when corner bent antennas are integrated with the mobile device, the attenuation caused by the user's hands is minimal.

mmWave 5G is for data hungry wireless services and not necessarily for voice. When it comes to data usage, the typical data usage modes of the smartphone are portrait and landscape mode, but some users might have a different way of using the phone. The presented cases are generally true for over 80 percent of the use cases. The usage scenario for portrait or single hand mode is illustrated in ***Figure 5a***. In portrait mode, the user uses one of the hands to operate the smartphone. The mmWave 5G antenna for this case must radiate away from the user and toward the base station as

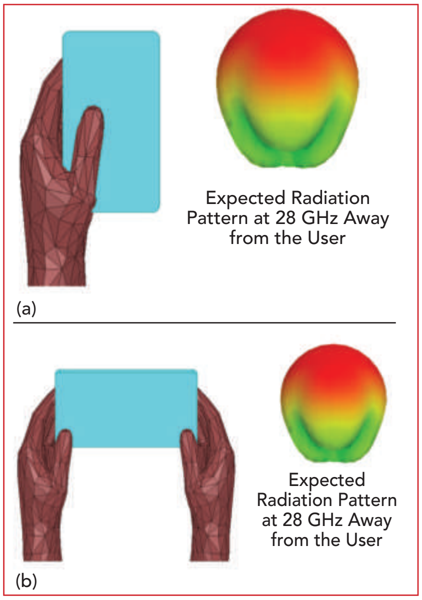

Fig. 5 Portrait or single hand mode (a) and landscape or dual hand mode (b).


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illustrated in Figure 2. In addition to the pattern requirement, the antenna must be integrated along the panel of the smartphone to keep interference and mutual coupling to a minimum with the RF board, which is common all the way back to the early mobile phones. The user might use either of their hands during operation and hence the radiation from the antenna must also be operational irrespective of the user's hand position. To satisfy this criterion, the forward radiating antennas can be installed on the top edge of the phone. The other popular mode is landscape or dual hand mode as demonstrated in ***Figure 5b***.

The de-facto industry standard is to implement a phased array, but phased arrays suffer from high scanning loss and would not work when the beams are fired orthogonally.[4,5] A single element inset fed strongly resonant patch antenna operating at 28 GHz is initially designed and the same element is extended for phased array operation with four elements with half wavelength spacing. Beam scanning of four-port phased array is illustrated in ***Figure 6***. As evident from the 3D patterns, the beam in the boresight axis is speckle free and gives highest gain of 12.6 dBi. As the beam is scanned away from the boresight, significant gain drop in the beam is observed. When the beam is scanned at 60 degrees and beyond, beam integrity is compromised. The gain drop is close to 5 dB and the patterns become unusable at this scanning angle. The story is identical for an end-fire antenna array as well. Beam scanning for any well-designed phased array is typically limited to ±40 degrees with respect to the 0 degree axis. A simple solution to solve this issue is to mount two identical phased arrays on the appropriate edges of the smartphone. This method increases the complexity of the controllers and beamformers by at least four-fold. Therefore, the phased array solution might not be as efficient for portrait and landscape mode scenarios as other approaches.

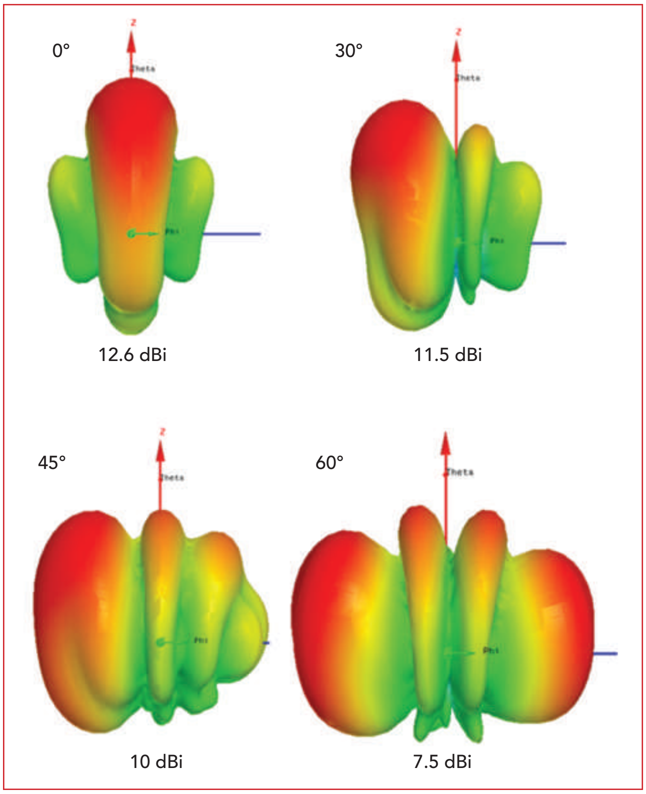


Fig. 6 Beam scanning of four element array.

MICROSTRIP FED SHARED GROUND DESIGN

A. Compact Array

A wideband phased array antenna operating at 28 GHz is designed and the schematic is shown in ***Figure 7a***.[6] The antenna is designed on Nelco NY9220 substrate with a dielectric constant of 2.2± 0.02 and a dielectric loss tangent of 0.0009. The antenna is designed on 0.508 mm thick substrate. The antenna is 32.54 mm wide and 28.86 mm long. The radiators are placed more than 10 mm from the feeding port to minimize interference from the electrically large end-launch connector. The

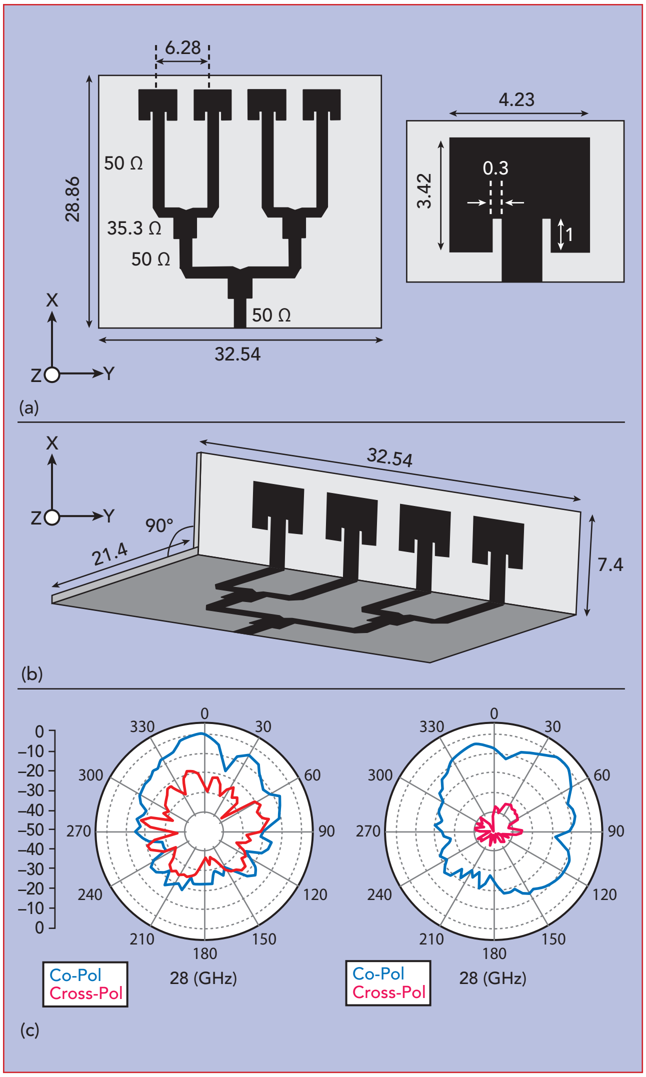


Fig. 7 Planar array operating at 28 GHz (a); corner bent array (b); and radiation patterns of the corner bent array in H-plane and E-plane at 28 GHz (c).

feed line is a standard 50 Ω line. The number of elements is chosen for a desired gain of 8.5 dBi in the boresight. All the four elements are also fed by the 50 Ω transmission lines. To design a wideband transition from the feeding line and the radiators, a corporate feeding network with appropriate quarter wave transformer is used. The spacing between the radiators is optimized for maximum gain in the boresight and found to be 6.28 mm.

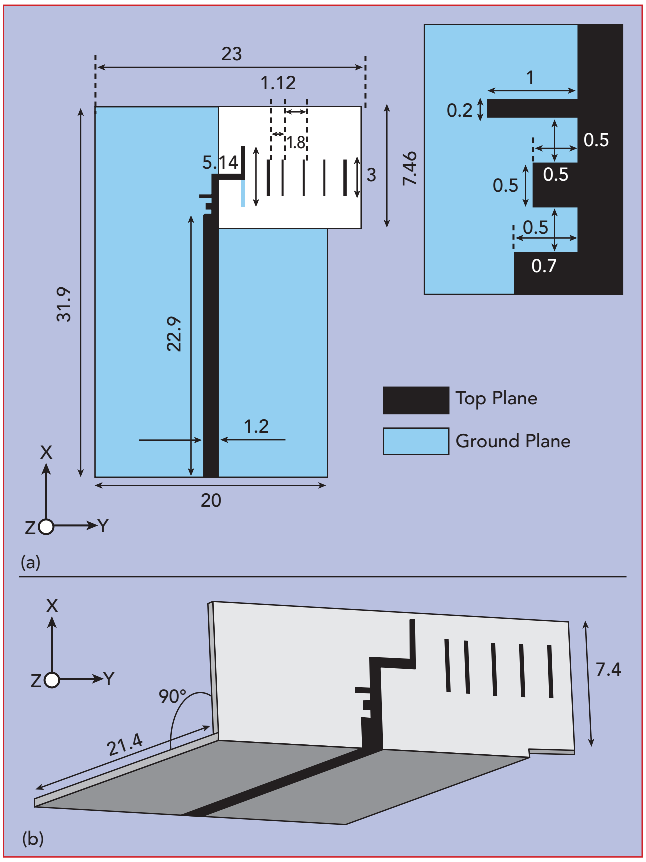
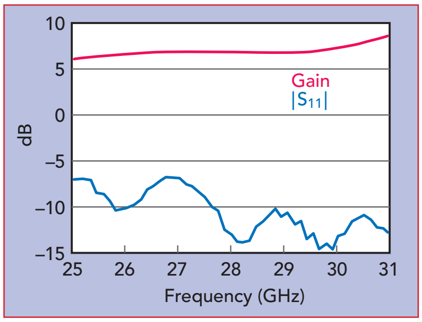


Fig. 8 Planar printed Yagi antenna (Units in mm) (a); corner bent Yagi antenna (b).



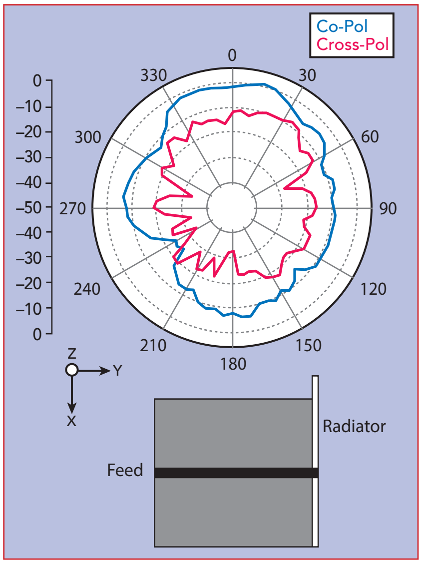
▲ Fig. 9 $|S_{11}|$ and forward gain of the corner bent Yagi antenna.

The radiator is a standard inset fed patch antenna operating at 28 GHz as shown in the inset of Figure 7a. The planar antenna, when integrated into a smartphone, will radiate toward the user since the beam would be directed that way. Also, the physical footprint of the antenna is high and might be unsuitable for a smartphone application as it is here. Hence, the antenna is corner bent as depicted in ***Figure 7b***. This corner bent or conformal antenna is bent before the radiators, hence the radiation would be away from the user and toward the base station. The actual height of the antenna is 7.4 mm, when this antenna is wrapped around the mold of a typical commercial smartphone the height of the antenna decreases to nearly 6 mm which is compliant with most of the smartphones available on the market today.

The E- and the H-plane radiation patterns are illustrated in ***Figure 7c***. As the beamforming is happening in the YZ plane (H-plane) the beamwidth is narrower compared to the XZ plane (E-plane). The front to back ratio is more than 20 dB across the band of operation, which indicates that when the conformal phased array is integrated onto the smartphone platform, the radiation toward the user is minimal.

B. Compact Yagi Antenna

The wideband corner bent array presented will be operational for portrait mode. Hence the second antenna's feed line and the beam radiated from the antenna must be orthogonal to meet the requirements of Figure 5. To meet these requirements, a new wideband antenna is proposed, whose schematic is shown in ***Figure 8a***.[6] The antenna is 20 mm wide to accommodate the end-launch connector. The antenna is 31.9 mm long and its feed line is 1.2 mm wide feeding the dipole arms, which are orthogonal with respect to the feed line. The feed line



▲ Fig. 10 H-plane pattern of the antenna.

is connected to stubs as depicted in the inset of Figure 8a to achieve wide impedance bandwidth. The parasitic radiators aid in gain enhancement. The conformal design of the antenna is shown in ***Figure 8b***. The input reflection coefficient of the corner bent orthogonal antenna is shown in ***Figure 9*** and it operates from 27 to 31 GHz translating to 13.8 percent of impedance bandwidth.

The H-plane (YZ plane) radiation patterns are shown in ***Figure 10*** at 28 GHz. The front to back ratio is more than 10 dB across the band, indicating minimal radiation toward the user post integration with the smartphone. The forward gain is also depicted in Figure 9. The gain is 7 dBi at 28 GHz indicating a high gain for minimal physical footprint.

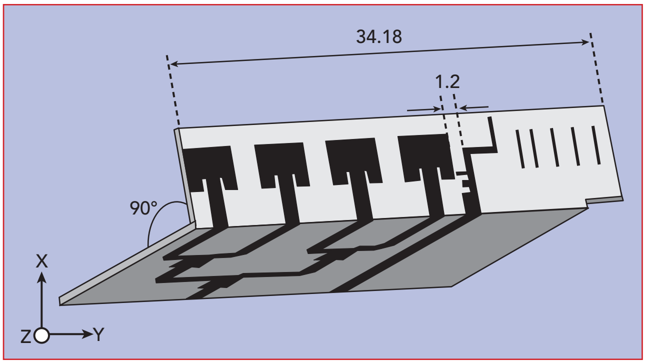


Fig. 11 Shared ground orthogonal pattern diversity module.

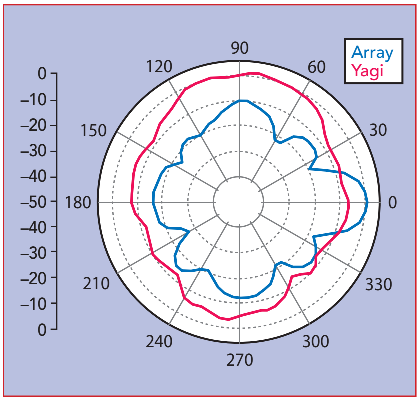


Fig. 12 Radiation patterns of the module at 28 GHz.

C. Shared Ground Orthogonal Pattern Diversity Module

The orthogonal pattern diversity module is illustrated in ***Figure 11***. Both the proposed conformal antennas are integrated in the same dielectric with a spacing of 1.2 mm. The integrated antenna would cater to both landscape and portrait modes of a smartphone with minimal physical footprint and minimal radiation toward the user. The input reflection coefficients of the respective ports remain intact despite the closely spaced antennas. The mutual coupling is less than 20 dB across the

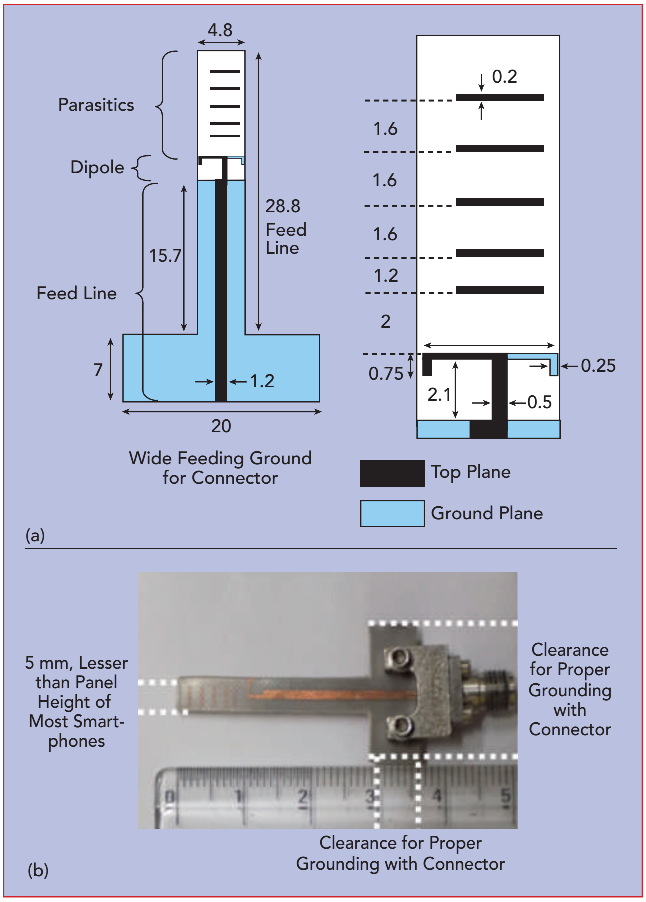
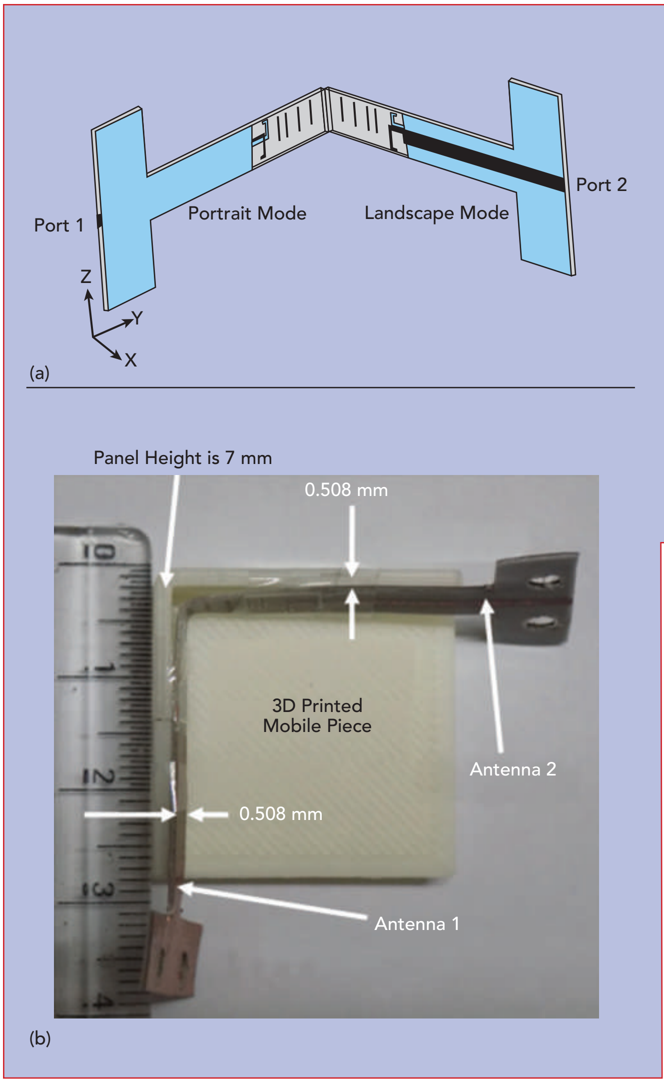
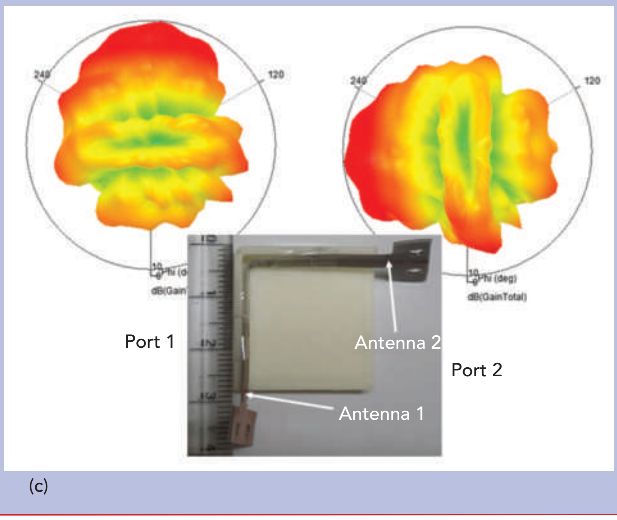


Fig. 13 (a) Schematics of the compact printed Yagi antenna; (b) photograph of the fabricated prototype.[7]





▲ Fig. 14 **Orthogonal pattern diversity module (a); fabricated prototype with smartphone mockup (b); 3D radiation patterns at 28 GHz (c).[6]**

band. The patterns of the module at 28 GHz are depicted in ***Figure 12***.

VERTICALLY MOUNTED END-FIRE ANTENNAS

The schematic of the compact Yagi antenna is depicted in ***Figure 13a***.[7] It is designed on Nelco NY9220 substrate with dielectric constant of 2.2. The thickness of the substrate is 20 mil, which is essential to maintain an electrically smaller microstrip trace. Electrically thick substrates would yield higher bandwidths at the cost of increased cross-pol radiation. Initially, a standard microstrip based dipole antenna is designed as shown in the inset of Figure 13a. The dipole arm length is varied to achieve a strong resonance at a higher band, i.e., at 30.5 GHz for a dipole arm length of 5 mm, but the desired band is at 28 GHz. Hence the dipole arms are extended by 0.75 mm on both the planes to tune the antenna to 28 GHz. The parasitics are optimized for gain enhancement of 3 dB in the end-fire. The dipole antenna is fed by a 1.2 mm wide microstrip line through a quarter wave transformer of width 0.5 mm.

The arms of the dipole are 0.25 mm wide to achieve impedance matching with the feed line. The width of the ground plane is maintained at 4.8 mm, which is very well within the limits of commercial smartphones assuming a vertical mounting of the presented elements. The width of the ground plane does not hamper the impedance characteristics of the antenna since the insertion loss offered by the electrically compact ground plane is minimal. The width of the ground plane is 20 mm at the feeding edge of the antenna, which is designed for clearance to accommodate the end-launch connector as evident from ***Figure 13b***. The feeding portion extension is a common practice for measurements with end-launch type of connector. SMP or mini-SMA could also be used without the need for extension.

The front to back ratio is more than 10 dB indicating 90 percent more power in the forward direction compared to backward direction. This in turn translates to minimal radiation toward the user when integrated in a mobile device. The cross–polarization level is less than 20 dB. The presented element is placed orthogonally as shown in ***Figure 14a***.

To verify the validity of the proposed architecture, a 3D printed corner piece is designed as shown in the photograph of ***Figure 14b***. The height of the 3D printed panel is around 6 mm with corner tapering, which mimics most mobile phones. In actual deployment scenario, the dielectric used in the commercial mobile case would alter the radiation pattern and impedance characteristics of the antenna minimally as the dielectric is attached to one side of the radiator. The 3D patterns when each port is excited are shown in ***Figure 14c***.

CONCLUSION

Detailed requirements for future antennas to be integrated in mmWave 5G smartphones and mobile devices are reviewed in this article. The requirements for single hand and dual mode operation are illustrated. Compact antenna module design examples are shown that meet the design requirements with better gain than current patch antennas. More details about "Compact Antenna Designs for Future mmWave 5G Smart Phones" is presented in the eBook by the authors.[3]

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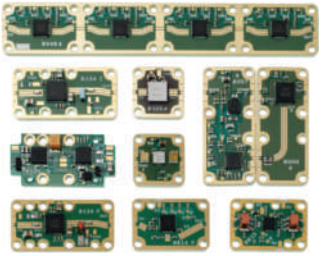

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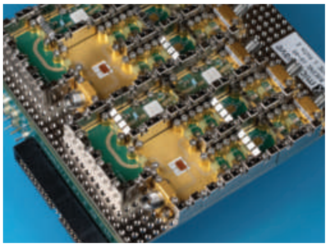

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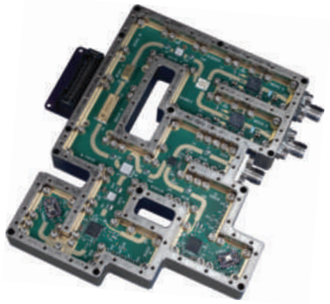

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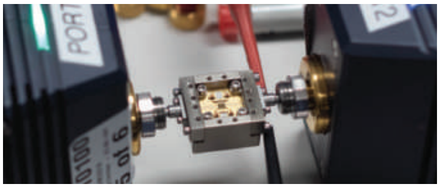

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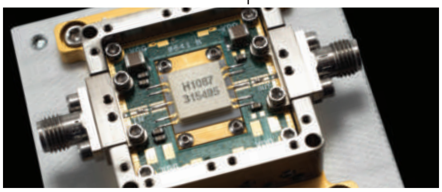

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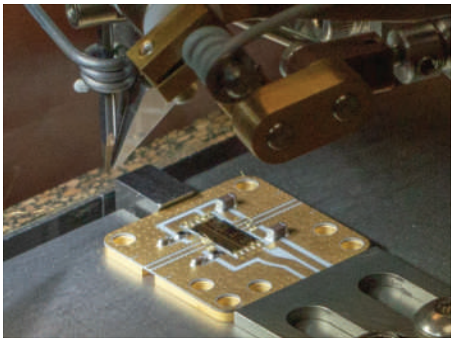

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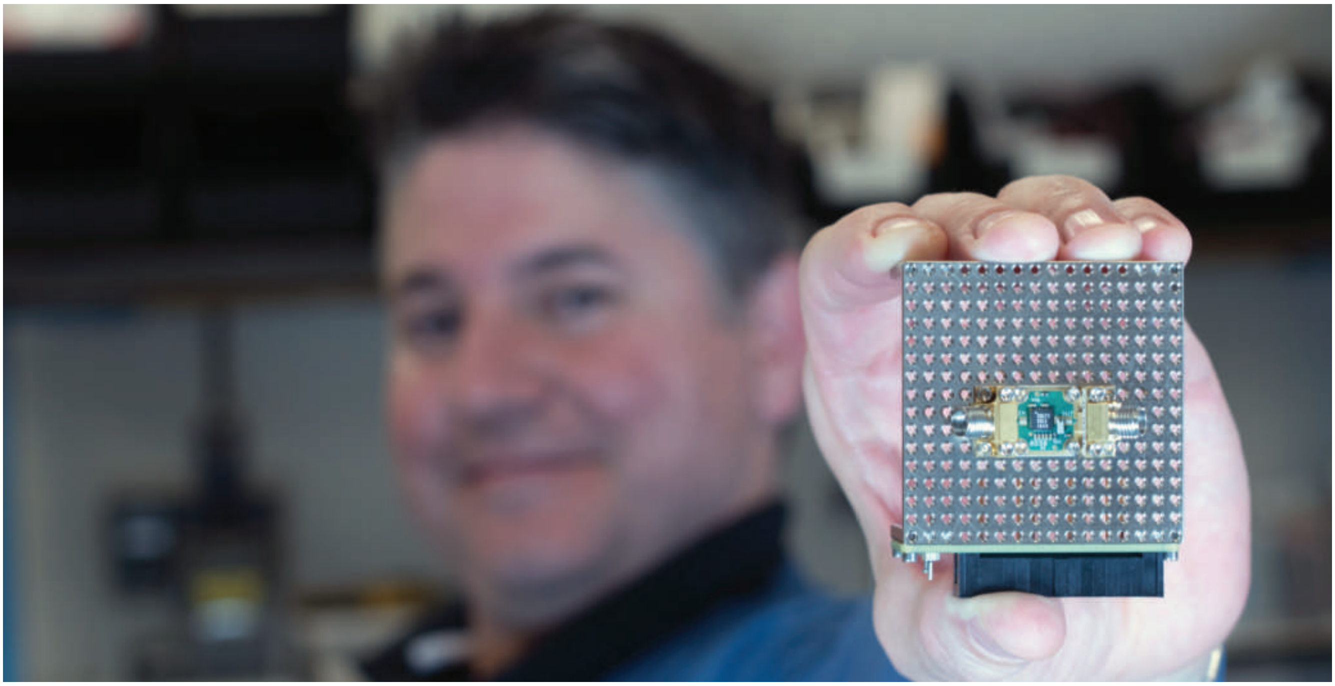

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Cliff Drubin, Associate Technical Editor

Teams Demo Swarm Tactics in Fourth Major OFFSET Field Experiment

DARPA's OFFensive Swarm-Enabled Tactics (OFFSET) program envisions future small-unit infantry forces using swarms comprising upwards of 250 unmanned aircraft systems and/or unmanned ground systems to accomplish diverse missions in complex urban environments. By leveraging and combining emerging technologies in swarm autonomy and human-swarm teaming, the program seeks to enable rapid development and deployment of breakthrough capabilities.

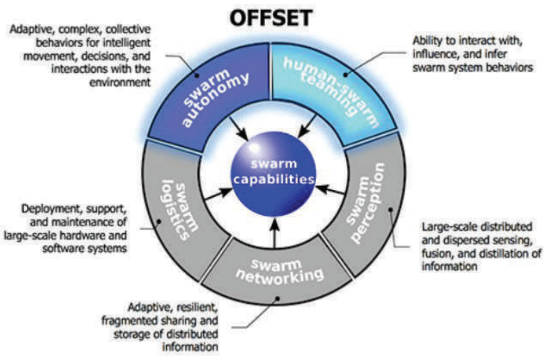
DARPA OFFSET researchers recently tested swarms of autonomous air and ground vehicles at the Leschi Town Combined Arms Collective Training Facility, located at Joint Base Lewis-McChord in Washington. The Leschi Town field experiment is the fourth of six planned experiments for the OFFSET program, which seeks to develop large-scale teams of collaborative autonomous systems capable of supporting ground forces operating in urban environments.

Two Swarm Systems Integrators, Northrop Grumman Mission Systems and Raytheon BBN Technologies, are creating swarm systems architectures, advanced interfaces and virtual and physical swarm testbeds for OFFSET. The Swarm Systems Integrators tested their autonomous platforms—comprising ground vehicles, multirotor and fixed-wing aircraft—in a multi-stage, interactive scenario to locate and secure multiple simulated items of interest relevant to the urban operational scenario.

"The Swarm Systems Integrators have been steadily improving their capabilities, each approaching the testing scenarios in unique ways," said Timothy Chung, the OFFSET program manager in DARPA's Tactical Technology Office. "Being able to test large-scale swarms in complex urban environments will allow us to extract new insights into the best ways to use a swarm, especially as our field tests increase in size, complexity and duration."

How the swarm commanders chose to approach the test series was dependent on a given swarm's capabilities as well as the strategies and tactics available at their disposal. Using real-time swarm data and scenario analysis provided by the DARPA experimentation team after each run, the Swarm Systems Integrators extracted insights from each mission and generated new strategies to improve their following test runs, in addition to future technology development.

As OFFSET field experiments continue, Swarm Systems Integrators will look for opportunities to incorporate novel swarming technologies, including those developed by Swarm Sprinters, into their own respective architectures.



SWARM (Source: DARPA)

GA-ASI Completes First Flight of Protector Unmanned Aircraft

General Atomics Aeronautical Systems Inc. (GA-ASI) recently completed the first flight of the Protector RG Mk1 Remotely Piloted Aircraft System (RPAS), the fourth MQ-9B SkyGuardian® air vehicle (the first three MQ-9B air vehicles are company-owned assets supporting the certification qualification). The first Protector RPAS, known within GA-ASI as UK1, will be used to support system testing as part of a combined U.K. Ministry of Defence, U.S. Air Force and GA-ASI test team. Upon completion of this initial testing, UK1 will be delivered to the U.K. Ministry of Defence in the summer of 2021 but will remain in the U.S. to complete the Royal Air Force's test and evaluation program.

SkyGuardian (Source: GA-ASI)

MQ-9B is GA-ASI's most advanced RPAS. The RPAS is available as the SkyGuardian, the maritime SeaGuardian® (fitted with a multi-mode 360-degree field-of-regard Maritime Patrol Radar and optional sonobuoy capability) or, as with the U.K. Protector, in a special customer specified configuration. The first MQ-9B customer delivery will be to the U.K., but the RPAS has also been selected by the Belgian Defense and Australian Defence Force, with significant interest from customers throughout the world.

"Protector will be deployed in wide-ranging Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR) operations where its ability to fly consistently for up to 40 hours will offer a vastly improved ISTAR capability. Given that it is designed to fly in non-segregated, civil airspace, the Protector RPAS will be able to respond rapidly and offer flexibility, delivering many types of military or civil authority support missions, including search and rescue," said

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Group Captain Shaun Gee, the RAF's director of Air ISTAR Programmes.

MQ-9B development began in 2014 as a company-funded program to deliver an RPAS to meet NATO's stringent airworthiness type-certification standard (STANAG 4671). STANAG certification will enable SkyGuardian, SeaGuardian and other MQ-9B variants to operate in civil airspace and better perform border patrol, fire detection and firefighting support, maritime patrol and resource monitoring missions. MQ-9B is provisioned for the GA-ASI-developed detect and avoid system to enhance safety of operations in civil and military airspace. The MQ-9B is built for adverse-weather performance with lightning protection, a damage tolerant airframe and a de-icing system.

AEHF-6 Protected Communications Satellite Concludes On-Orbit Testing

The sixth Lockheed Martin-built Advanced Extremely High Frequency (AEHF-6) protected communications satellite recently completed its on-orbit test (OOT) period.

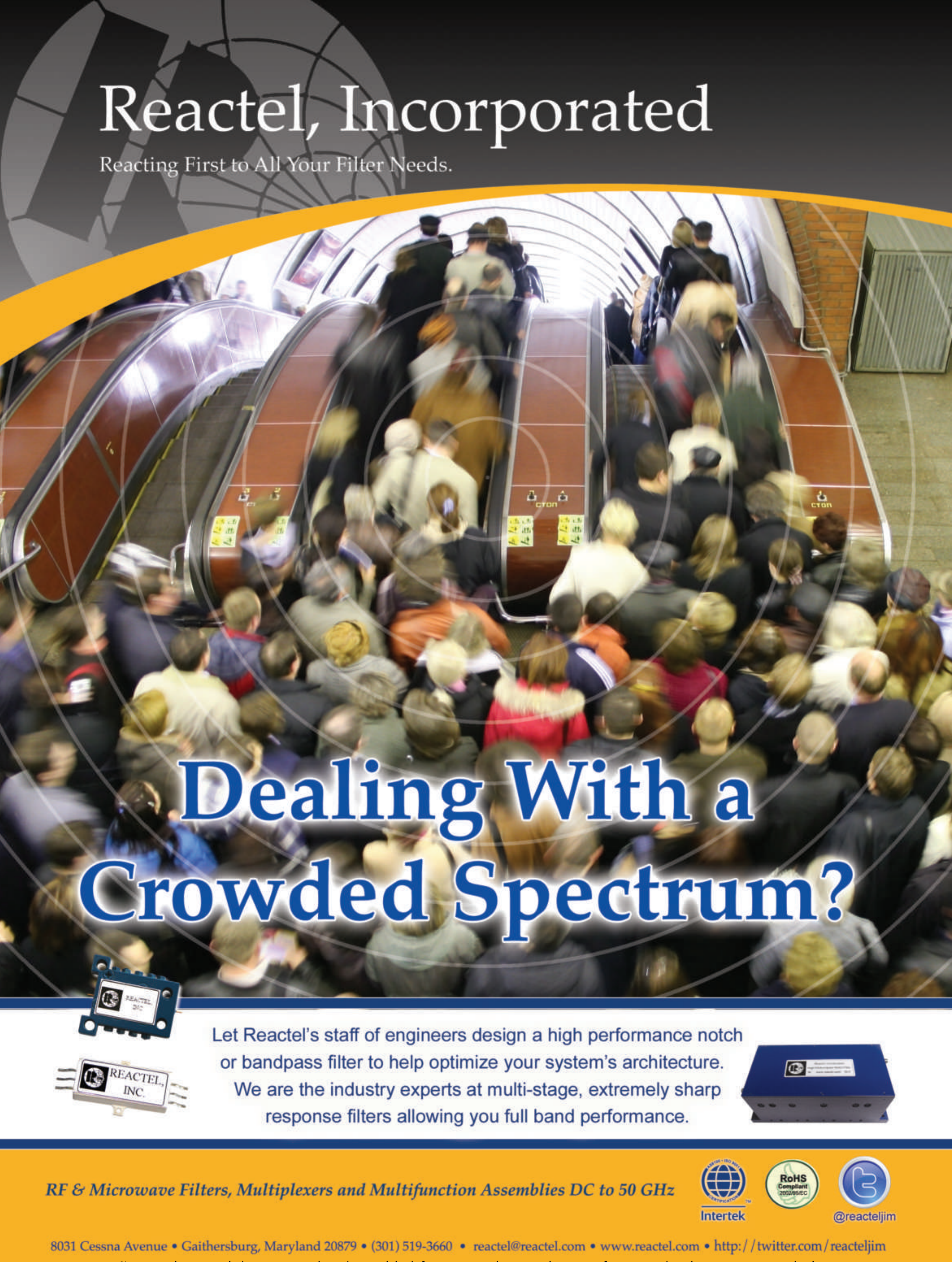
"Successful OOT demonstrates that all space vehicle performance requirements have been met and that we are on track for satellite control authority handover to Space Operations Command before the end of the year," said Erik Daehler, director of Lockheed Martin's Protected Communications mission area. "This is a great accomplishment for the industry-government team, bringing incredible capability for our warfighters."

AEHF-6 (Source: United Launch Alliance)

AEHF-6 will be part of a geostationary ring of ten satellites in the AEHF-MILSTAR constellation delivering global coverage for survivable, highly secure and protected communications for strategic command and tactical warfighters operating on ground, sea and air platforms. The satellite adds increased resiliency and advanced capabilities to this constellation, which ensures the ability to transmit data anywhere, anytime.

Besides U.S. forces, the AEHF system also serves international partners Australia, Canada, the Netherlands and the U.K.

AEHF-6 was successfully launched on March 26 from Cape Canaveral Air Force Station, Florida, aboard a United Launch Alliance Atlas V 551 rocket. The launch was the first mission launch for the U.S. Space Force.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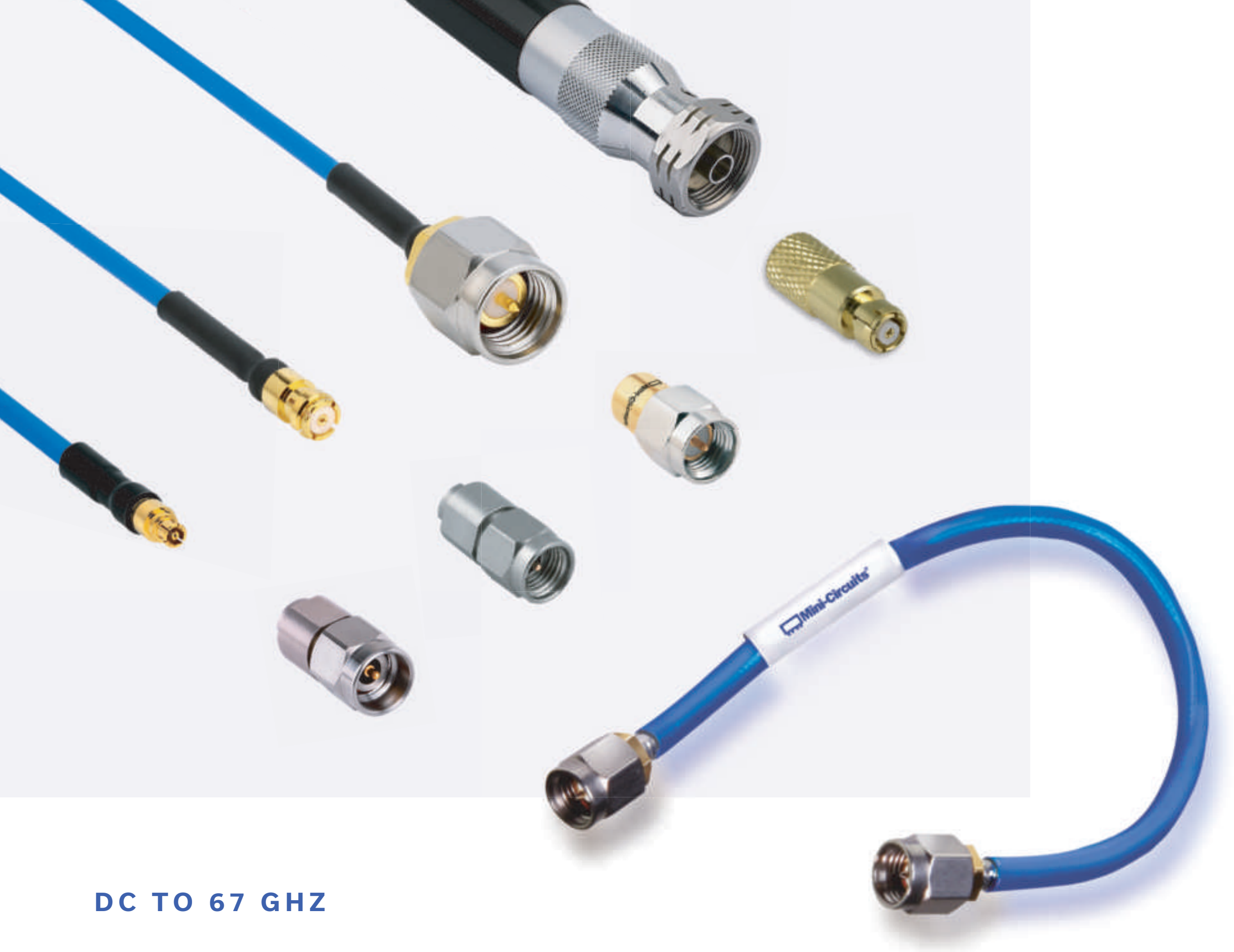

Drone Industry Powers in a Post-COVID-19 World

The small Unmanned Aerial System (sUAS) market continues to develop at an impressive pace and is unmarred by the challenges of COVID-19. While the pandemic has dented consumer shipments and hindered commercial rollout, this has been mitigated by increased use of drones for public service responses and surveillance by both local and national police forces. Looking forward, new regulatory changes and the slow rollout of remote ID and 5G will enable an enormous upscaling of drone operations, from single remotely operated aircraft to semi-autonomous fleets that will be able to operate beyond visual line of sight courtesy of an impending unmanned traffic management infrastructure. This will provide the base from which companies like Amazon can launch drone delivery services.

"We have gone through various phases of the drone industry, from its genesis in the military to the proliferation of consumer drones. Since Chinese developer DJI monopolized that space, the attention has shifted to commercial applications," explained Rian Whitton, senior robotics analyst at ABI Research. "While some of the initial hype has subsided, providers and end-users are refocusing on developing the necessary supporting infrastructure and services to make drone technology viable at scale."

Overall, the drone market is set to be worth US$92 billion by 2030, with a CAGR rate of 25 percent over the US$9.5 billion in annual revenue for 2020. Of this revenue, 70 percent is in the commercial sector (US$63 billion). The largest number of drone registrations are currently in the U.S., where the Federal Aviation Administration tracks 1.7 million consumer drone pilots and 400,000 commercial operators. China is catching up with 400,000 registered drones, while the European Union has over 1 million registrants. Among the biggest markets are security and industrial inspection, with growing opportunities in delivery, agriculture and emergency services.

With their involvement in the public response to the pandemic, drone companies highlighted their value. Now, the story of the next decade will be the development of key technologies like edge computing, cloud services and 5G connectivity enabling mass deployments in tandem with regulatory harmonization. "While cloud services will help enable the collection and orchestration of massive amounts of data, 5G will significantly reduce latency for mission-critical drone operations. The advancement of edge computing and processing hardware will also be important, as drones can be untethered and become truly autonomous," Whitton concluded.

Over 100 Commercial 5G Networks Now Launched Worldwide

The Global mobile Suppliers Association (GSA) confirmed that a total of 101 mobile operators in 44 countries/territories have now launched one of more fully commercial 3GPP-compliant 5G services. Of these commercial networks, GSA data records that there are now 94 operators live with 3GPP-compliant 5G mobile services (up from 63 at the end of March 2020), while 37 have launched 3GPP-compliant 5G fixed wireless access or home broadband services (up from 34). As of September 2020, the GSA GAMBoD database included detailed data and analysis on a total of 397 operators in 129 countries that have announced investment in 5G, including trials, acquisition of licenses, planning, network deployment and launches.

"5G remains on track to become the fastest adopted mobile technology ever," said Joe Barrett, president, GSA. "There are now over 400 announced 5G devices; 5G subscriptions are doubling quarter on quarter; there are 20 commercially available 5G mobile processors and platforms and eight discrete 5G modems from five different semiconductor companies. With over 100 commercial 5G networks now launched, and many more still being invested in by operators worldwide, we are seeing the mobile industry working together to drive 5G uptake at an unprecedented rate."

Work/School from Home Fuels 223 Million SOHO Consumer Wi-Fi CPE Shipments in 2020

The COVID-19 pandemic continues to drive demand for small office/home office (SOHO)/Consumer Wi-Fi Consumer Premise Equipment (CPE) as millions are still forced to work and learn from home. ABI Research forecasts that the worldwide SOHO/Consumer Wi-Fi CPE market will ship more than 223 million units in 2020, a surge of 10 million units from 2019.

"Stay-at-home orders imposed in the first quarter of 2020 forced millions of consumers to work from home and students to do home-based learning, creating the need for ultra-reliable broadband and Wi-Fi connectivity in households worldwide," explained Khin Sandi Lynn, industry analyst at ABI Research.

"There has been a sudden spike in the adoption of Wi-Fi routers and extenders as consumers seek a reliable Wi-Fi network that can simultaneously support multiple users and devices. That spike and the growth in the use of applications such as video conferencing, live TV streaming and online gaming at home resulted in consumers adopting Wi-Fi CPE for better coverage and higher capacity."

For More Information

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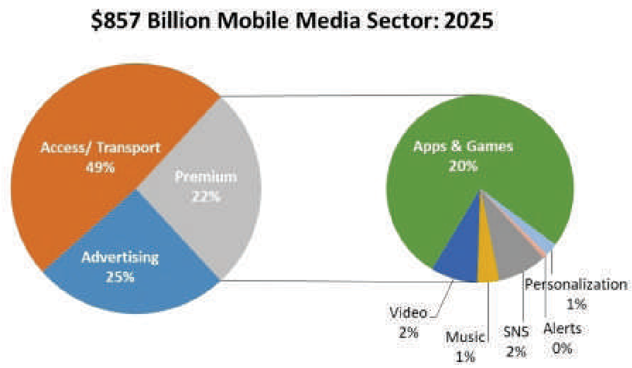
Although governments are reopening the economy, the demand for higher efficiency Wi-Fi solutions will continue beyond the pandemic. The adoption of entertainment platforms and IoT devices in broadband households are driving increasing shipments of Wi-Fi mesh systems and CPE with higher Wi-Fi standards. CPE with 802.11ac standard represents 80 percent of total CPE units shipped at present, however, Wi-Fi 6 (802.11 ax) devices are set to grow. Operators such as Com Hem and Telefonica have introduced CPE supporting Wi-Fi 6 to their customers. Availability through both the service provider and retail markets is expected to significantly drive adoption in the years to come.

"Not surprisingly the COVID-19 pandemic caused delays in enterprise Wi-Fi deployments in Q1 2020," Lynn pointed out. As businesses evaluate their investment priorities based on economic conditions, the adoption in the enterprise segment is likely to remain limited in the short term. In addition, carrier Wi-Fi deployments have been slowing down as LTE network coverage expands across different regions. This will further slow Wi-Fi CPE unit shipments to the enterprise segment.

"Nonetheless, the migration to Wi-Fi infrastructure with CPE supporting higher Wi-Fi standards such as Wi-Fi 6 (802.11ax) creates an opportunity for the enterprise CPE market in the long term. The increasing use of live video streaming during corporate events and in health-



Mobile Media Sector-2025 (Source: Strategy Analytics)

care and education is expected to further drive Wi-Fi 6 adoption," commented Lynn.

Wi-Fi 6 will become the dominating Wi-Fi standard by 2023 in both the consumer and enterprise Wi-Fi market while the industry prepares for the next generation Wi-Fi standard, Wi-Fi 6E. Chipset makers such as Qualcomm and Broadcom have announced chipsets supporting Wi-Fi 6E, and the first Wi-Fi CPEs are likely to arrive in 2021. In addition to supporting the latest Wi-Fi standard, the integration of IoT connectivity and cloud-based Wi-Fi network management features will enable CPE makers to differentiate among competitors in both consumer and enterprise Wi-Fi segments.

IN MEMORIAM
Remembering Bob Gore, Inventor of Expanded PTFE

Bob Gore, who discovered an expanded form of PTFE (ePTFE) that spawned countless products from lightweight RF cable assemblies to GORE-TEX® fabrics, died September 17 at age 83. His discovery of ePTFE enabled W.L. Gore and Associates, started by his parents in 1958, to become a billion-dollar company, where he served as president and CEO from 1976 until 2000.

In October 1969, researching a process for stretching extruded PTFE into tape for pipe threads, Gore unexpectedly found that a sudden yank—rather than slow stretching—expanded the solid PTFE nearly 1000 percent, creating a microporous structure that was mostly air. Used as the fabric for GORE-TEX clothing, ePTFE is lightweight and waterproof, yet allows water vapor to pass through.

▲ *Bob Gore reenacting the unexpected discovery of ePTFE.*

Paul Warren, a Gore associate for 37 years and a senior application engineer, reflected, "Bob was always looking for the next great idea, and his innovative spirit certainly shaped our enterprise. Today, this innovative spirit is simply among our company's DNA. Bob's innovation led to products that have touched so many lives and in different ways. Medical devices, protective fabrics, cables, filtration and sealants—all improving lives around the globe."

Gore was awarded nine patents related to fluoropolymers and, among his many honors, was elected to the National Academy of Engineering and inducted into the National Inventors Hall of Fame. In addition to his technical contributions, Gore is remembered for his leadership and commitment to quality, promising "our products will do what we say they will do." The company's RF cable assemblies are highly regarded for performance and reliability in rugged environments.

Committed to the development of future scientists and engineers, Gore served as a trustee of the University of Delaware Research Foundation and a member of the school's board of trustees. With his mother and wife, he donated funds to construct a classroom building at the university in 1998 and science and engineering laboratories in 2013. He also contributed to the University of Minnesota and other institutions.

Gore is survived by his wife Jane, four siblings and a large family of children, grandchildren and great-grandchildren.

MERGERS & ACQUISITIONS

Vishay Intertechnology Inc. announced the acquisition of the worldwide business and substantially all of the U.S. assets of **Applied Thin-Film Products**, a California-based, privately-held manufacturer of custom, build-to-print thin-film substrates for the microwave, fiber optic and life science industries. Concurrently, a Chinese subsidiary of Applied Thin-Film Products entered into an agreement to sell certain property and equipment to a subsidiary of Vishay at a later date. The total acquisition price is approximately $26.5 million, subject to customary post-closing adjustments.

Integrated Polymer Solutions (IPS), a portfolio company of Arcline Investment Management, has announced the strategic acquisition of **MAST Technologies**. MAST is an expert in designing, developing and manufacturing innovative RF, microwave and EMI absorbing materials for integration into military and electronics solutions. These include reliable high temperature, corrosion resistant products for harsh environments on military aircraft, ships and ground vehicles as well as EMI shielding for electronics packages, wireless antennas and telecom data transmission applications.

COLLABORATIONS

A new collaboration between **UMass Lowell** and **Analog Devices Inc.** enables employees of the global semiconductor manufacturer to advance their education through tuition assistance offered by the company. The Analog Devices/UMass Lowell Master's Fellowship Program provides a fully funded, accelerated path for employees in the company's Aerospace and Defense Business Unit to pursue master's degrees in electrical engineering, mechanical engineering or computer science. The aerospace and defense industry continues to grow at a rapid rate and the scholarship program is designed to help Analog Devices meet its need for skilled engineers to design innovative technologies for this market.

Movano Inc., a health-focused technology company developing non-invasive solutions to enhance the quality of life for people affected by chronic health conditions, announced a strategic collaboration with **GLOBALFOUNDRIES® (GF®)** to advance the commercialization of Movano's wearable, non-invasive continuous glucose monitor, which is currently in development. The announcement was made at GF's annual Global

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DCYS100200-12	1 - 2	-105	-125	0.5 - 28	+4
DCO200400-5	2 - 4	-90	-110	0.5 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0.5 - 18	0
DCO300600-5	3 - 6	-78	-104	0.3 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0.1 - 16	+2
DCO400800-5	4 - 8	-75	-98	0.3 - 15	-4
DCO5001000-5	5 - 10	-70	-95	0.3 - 18	-4
DCYS6001200-5	6 -12	-70	-94	0.5 - 15	+2
DCYS8001600-5	8 - 16	-68	-93	0.5 - 15	-1
DCYS10002000-5	10 - 20	-53	-79	0.5 - 15	-4

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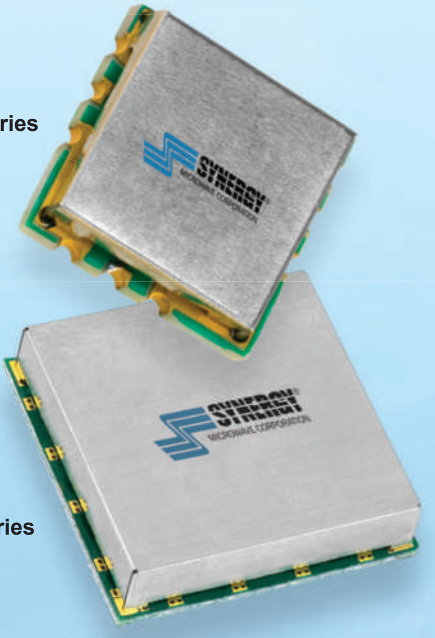
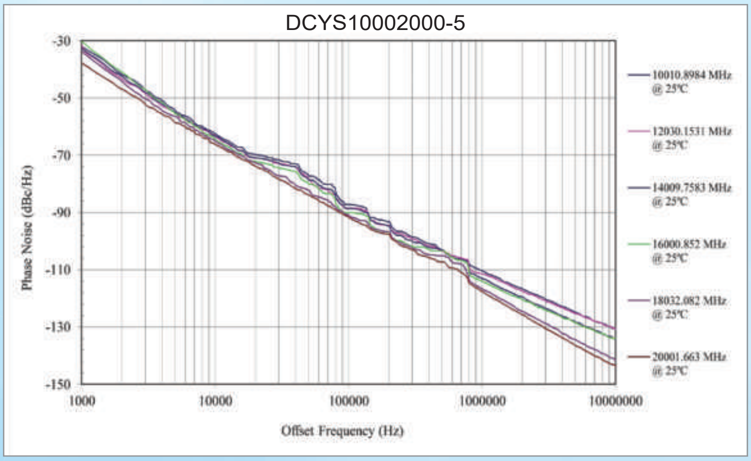


DCYS Series



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Technology Conference. Movano's novel approach to glucose monitoring is based on its patent-pending RF sensor platform, which is built on GF's 22FDX® (22 nm FD-SOI) solution, to enable the creation of high performance and small form factor sensors that are low-power and cost-effectively manufactured at scale.

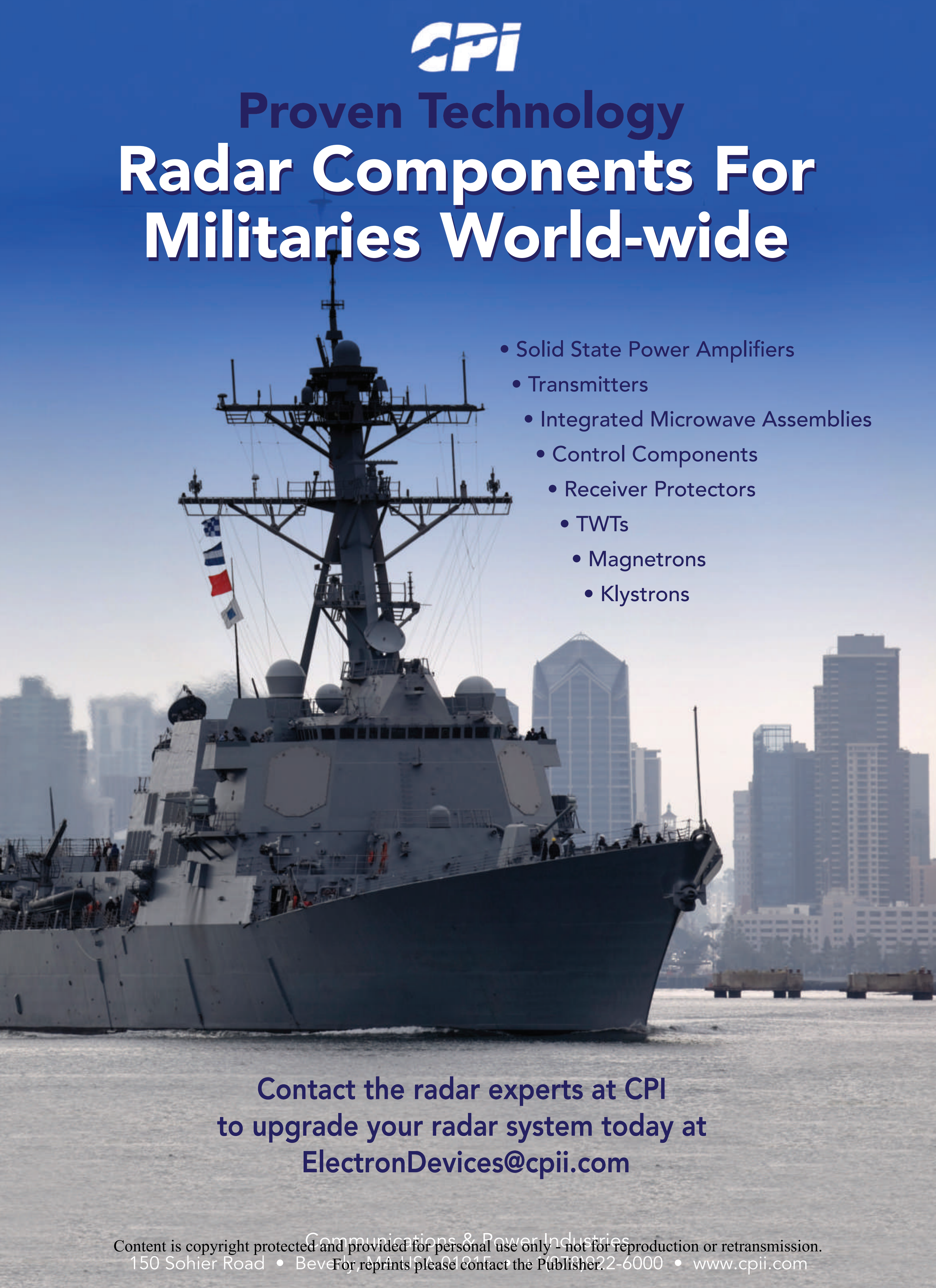
ACHIEVEMENTS

The **IEEE** Region 1 has selected **Dr. Ulrich L. Rohde** as the recipient of the 2020 IEEE Region 1 Technological Innovation (Industry or Government) Award. The selection was made by the Region 1 Awards and Recognition Committee and approved by the Region 1 Board of Governors. The award states, "Technological Innovation Award – For pioneering research and leadership in signal processing," recognizing Dr. Rohde for his important work in the industry. The Technological Innovation (Industry or Government) Award is given for significant patents, discovery of new devices, development of applications or exemplary contributions to industry or government fitting Dr. Rohde's accomplishments in the industry.

Radio Frequency Systems (RFS) celebrated its 120th birthday and stated invention is why it is one of the industry's longest standing players. Throughout its history, RFS has been responsible for a number of key inventions in cable and antenna technology. These range from creating the world's first insulated wire for telecommunications in 1900, to designing the first radiating cables to deliver connectivity in-tunnels which are used in 41 percent of all metros worldwide today. This year alone, RFS's R&D teams have developed Dragonskin, the first standalone cable to meet the most stringent fire safety standards, while integrating 5G ready capabilities across its entire portfolio.

Milliwave Silicon Solutions announced they have reached 100 installations of MilliBox mmWave test chambers and positioners. The main market drivers for MilliBox are 5G NR, mmWave automotive radar, academic research and defense. Milliwave's mission is to accelerate the adoption of mmWave products across a wide range of applications by improving time-to-market and product quality for our partners in the semiconductor and technology industries. Milliwave created the MilliBox product line of compact, modular test chambers and accessories to address the growing need for a cost-effective mmWave over-the-air measurement solution.

Mitsubishi Electric Corp. announced that it will begin shipping samples of its 100 Gbps electro-absorption modulator laser (EML) CAN for high speed, large-capacity optical data transmissions in 5G mobile base stations on radio access networks. The new model also supports enhanced manufacturing productivity. Mobile communication systems worldwide are being required to handle increasing data communication volume due to the transition from 4G to 5G, the spread of mobile terminals including smartphones and tablets, and the shift of information to the cloud. The expansion of 5G mobile networks will require the transmission of huge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volumes of data to/and from base stations in high speed optical communication networks, which in turn will drive the demand for high speed, low-power consumption optical devices.

Kymeta announced that the **FCC** has granted blanket authorization for the operation of its next-generation electronically steered, flat-panel Earth station in motion (ESIM) platform, the Kymeta™ u8 terminal. The authorization is a major milestone toward the release of the u8. In addition, Kymeta has received type approvals from several leading satellite service operators that include Intelsat, Echostar, Hellasat, KTSat and Telesat for use with Kymeta u8 terminal. The u8 is the industry's only commercially available electronically steered, flat-panel ESIM platform with no moving parts, built specifically for mobility and designed for the needs of the Department of Defense (DoD), government, first responder and commercial customers.

CONTRACTS

Elbit Systems Ltd. announced that it was awarded a contract valued at approximately $33 million to supply tactical radio systems to a customer in Asia-Pacific. The contract will be performed over a 12-month period. Under the contract, the company will equip the customer's artillery and infantry forces with tactical radio systems including vehicular, man-packed and handheld configurations. The radio systems feature advanced networking capabilities enabling reliable and secure voice and data communication services over extended ranges.

Battelle continues its work helping the nation develop and validate quantifiable assurance tools and approaches mitigating the threat of counterfeit and untrustworthy integrated circuits and embedded system in the military's supply chain. Building upon its proven expertise in cyber hardware trust and assurance, Battelle was awarded a $16.6 million task order contract under the Microelectronics and Embedded Systems Assurance (MESA) IDIQ contract vehicle, where Battelle is a prime contractor. On the new task order, which continues through 2022, Battelle will develop and validate techniques for quantifiable assurance of microelectronics devices and systems.

L3Harris Technologies has been awarded a multi-million-dollar contract to deliver two low-frequency active towed sonar (LFATS) systems to a **NATO** member. The LFATS system is used on ships to detect, track and engage all types of submarines. L3Harris specifically designed the system to perform at a lower operating frequency against modern diesel-electric submarine threats. The U.S. DoD recently awarded this 26-month delivery order under VSE Corporation's Foreign Military Sales contract with the Naval Sea Systems Command International Fleet Support Program Office.


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EXODUS ADVANCED COMMUNICATIONS

Around the **Circuit**

AFWERX, the innovation program of the **U.S. Air Force**, initiated a Base of the Future Challenge to seek new technologies that greatly enhance the security and defense of Air Force Bases. AFWERX received over 1,500 submissions and accepted 374 proposals for the challenge. **McQ** was down-selected in an initial group of 92 proposals followed by a virtual presentation by McQ of their "Global Multi Domain Security and Base Defense" solution.

PEOPLE

▲ *Satish Dhanasekaran*

Keysight Technologies Inc. announced that **Satish Dhanasekaran** has been appointed chief operating officer (COO), effective immediately. Dhanasekaran has been president of Keysight's largest business, the Communications Solutions Group, since 2017. In his role as COO, Dhanasekaran has responsibility for growing orders and increasing annual recurring revenue for the company. He oversees the functions that contribute to these objectives, including market and technology research; development of new technologies, products and solutions; services; marketing; and sales.

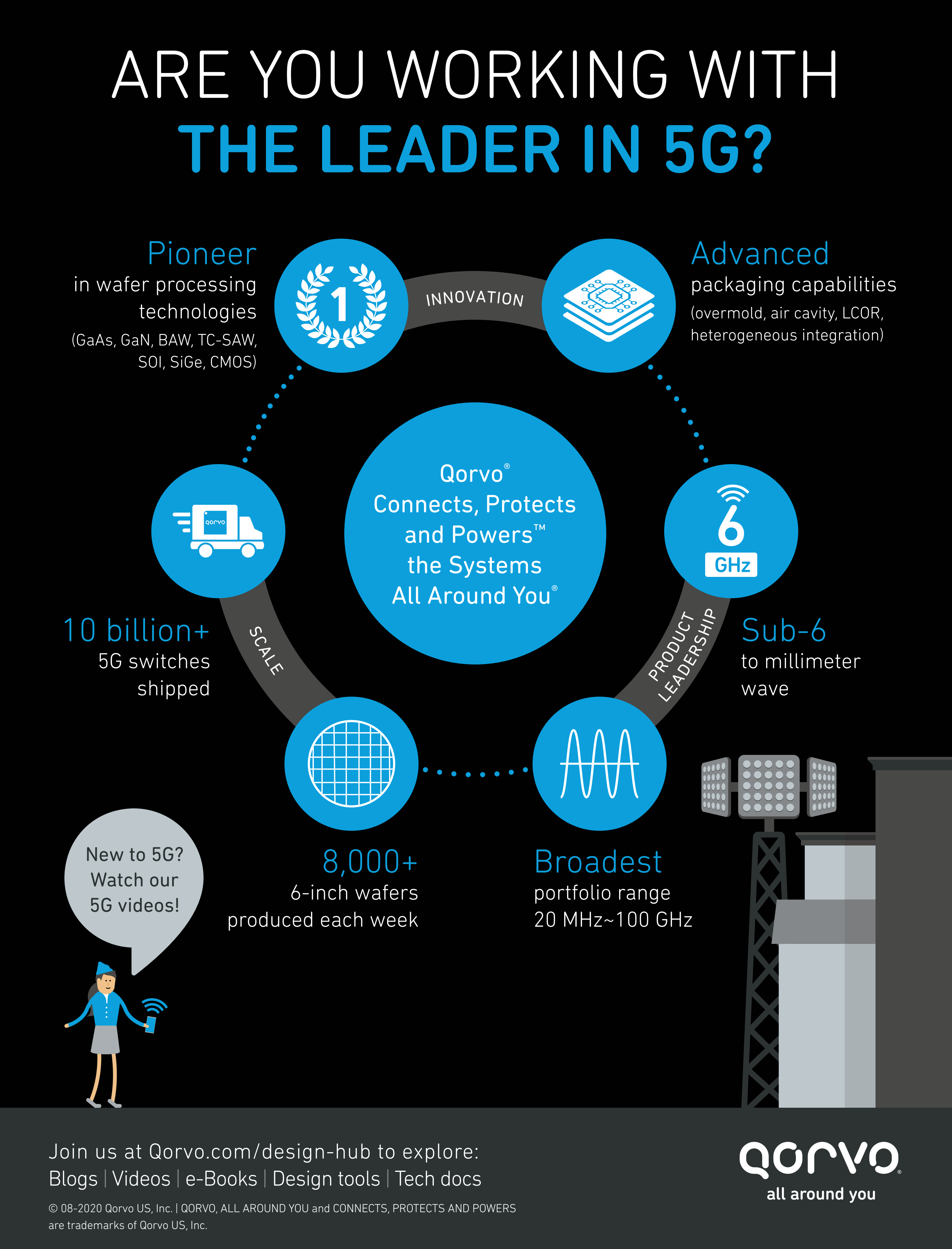
▲ *Jaap Groot*

Jaap Groot is the new CEO at **Fractus Antennas**. He takes the lead now that they are entering into a new era for Fractus Antennas. Not only have they proven to be a very innovative company, developing disruptive antenna technologies and solutions, but they are also on the verge of a scale-up period within the ever-growing IoT markets. They are confident the team is knowledgeable, energetic and ready to find answers for your complex, edge to cloud requirements and look forward to driving the success of Fractus Antennas whilst having some fun along the way.

▲ *Ronald van der Breggen*

KebNi AB has announced the appointment of **Ronald van der Breggen** as special advisor to the CEO. In this role, Breggen will help develop KebNi's winning strategy for the large opportunity that the future LEO satellite services represent. Breggen brings over 25 years of telecommunication and satellite experience, which includes working for several of the most prominent satellite operators, the last five years of which has been exclusively for LEO operators, most notably LeoSat, in the areas of strategic and commercial planning and sales management.

Infinite Electronics has announced the promotion of **Jason Koshy** to global vice president of Sales. In this role, Koshy will lead all Infinite sales teams. Koshy has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Around the **Circuit**

▲ *Jason Koshy*

been with Infinite Electronics for 22 years, starting as an applications engineer with LEA International (later acquired by Smiths Microwave Telecom as part of Transtector). During his tenure, Koshy has held roles of increasing responsibility, including quality and manufacturing engineer, regional sales manager, director of sales for North America and most recently as VP of sales for the Americas and ROW.

Hitachi Cable America announced the addition of **Thomas Stone** as director of sales, Premise and Fiber, Performance Cable Systems and Materials Division. Stone joins the organization with over 18 years' experience servicing the electrical and wire and cable industries as both a distributor and a manufacturer. Stone has a proven track record in leading complex sales organizations with a focus on growth and execution of business strategies. As director of sales for Premise and Fiber, Stone will be working closely with the leadership team to execute company growth objectives with a focus on customer intimacy for Hitachi Cable America's Performance Cable Systems and Materials Division located in Manchester, N.H.

▲ *Thomas Stone*

REP APPOINTMENTS

Filtronic plc, the designer and manufacturer of RF, microwave and mmWave products for the wireless telecoms, mission-critical communications and defence applications markets, announced that it has signed an exclusive agreement with **Global Telecom Partners (GTP)** to develop their Northeastern U.S. telecoms sales channel. Based in Montvale, N.J., GTP and its sales team are experts in developing markets and identifying solution sets for mission-critical telecommunications infrastructure.

Richardson RFPD announced that it has entered into a global franchise agreement with **Hitachi ABB Power Grids**, **Semiconductors**. Hitachi ABB Power Grids is a leading supplier of power semiconductors with production facilities in Lenzburg, Switzerland, and Prague, Czech Republic. The company offers a wide variety of high-power semiconductors using conventional and future-oriented technologies for the traction, industrial and energy transmission market segments.

Septentrio, a leader in high-precision GNSS positioning solutions, has announced a new distributor partnership with **Digi-Key Electronics**, a global electronic components distributor. Digi-Key now offers the mosaic-X5 globally for customers who need secure and reliable high-accuracy positioning in a compact and low power form factor. Septentrio's mosaic-X5 features complete multi-frequency multi-constellation technology and tracks every existing and future signal from all global navigation satellite system constellations.

INVITED PAPER

MEMS Switch-Based Differential Delay Shifter for a 3.5 GHz Beam Steering Antenna

Menlo Micro
Irvine, Calif.

Antenna arrays consisting of multiple radiating elements are widely used in both defense and commercial applications. The individual elements of the antenna array are usually fed with signals of different phases to form the desired radiation pattern, generally a beam or multiple beams. The beam can be steered by controlling the phase of the signals feeding each element, and the amplitudes of the signals are often optimized to minimize sidelobe radiation.

Cellular base stations widely use phase shifters to adjust the "down tilt" of the antenna, called remote electrical tilt (RET), which is used to optimize coverage and minimize interference. This enhances performance, such as increasing capacity, coverage and signal strength. The move toward sophisticated massive MIMO (mMIMO) solutions is an advanced form of beam steering, with the disadvantage that a separate radio is required for each antenna element. Yet significant performance gains can be made at much lower cost than mMIMO, using fewer transmitters and feeding the antenna elements with adjustable phase shifters. The growing momentum in spectrum rollout for the Citizens Broadband Radio Service (CBRS) for 4G and 5G networks will demand increasingly complex multi-array antennas with advanced beam steering to deliver the required quality of service and high data rates for cellular, enterprise and industrial IoT applications. As these applications are very cost sensitive, an adaptable beam former fed from a single transmitter offers significant value.

This article describes a beam steering antenna for the 3.6 GHz CBRS band using MEMS switches. The design supports high-power operation and uses delay lines configured in a patent-pending differential delay shifter (DDS). Although the common term for antenna beamformers is a "phase shifter," the required network is actually a "delay shifter" to maintain the desired beam direction over a wide range of frequencies. Incorporating SP4T MEMS switches and delay lines with standard surface-mount packaging yields a highly compact and integrated form factor. This novel approach creates an all-electronic miniaturized delay shifter that can replace the large and bulky mechanical phase shifter components and motors often used for RET in traditional base station antennas. This all-electronic configuration allows for both horizontal and vertical antenna beam steering, with a significant improvement in switching speed and reliability compared to mechanical designs.

THEORY OF THE SWITCHED DDS

Consider a simple antenna array receiving a signal (see ***Figure 1***). For a given angle of arrival, θ, the extra distance a signal travels to each element is l1, l2, l3 and l4, respectively. The time for the signal to travel


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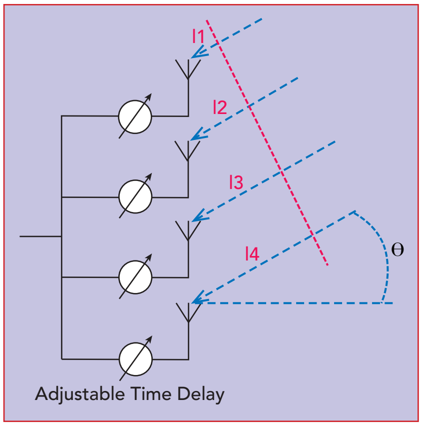
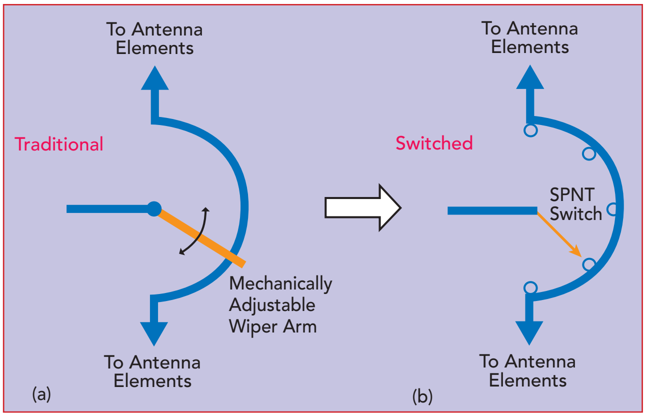


▲ Fig. 1 Four-element array and incoming plane wave.

these distances is independent of frequency and is simply a function of the element spacing, the angle of arrival and the propagation velocity, which is usually the speed of light in free space. By adjusting the time delay of each element's feed for a given angle of arrival, the signals can be combined in phase at the common feed.

Although the time delay elements can be replaced with phase shifters, to ensure a constant beam angle versus frequency, the phase shifters must be adjusted for the specific frequency. This limits the operational bandwidth of the antenna; if the operating frequency is too far away from the design frequency, the direction of the antenna pattern will shift. If the angle, θ, is changed and the beam steered by rotating the incident plane around the center of the antenna, then any change in l1 is equal and opposite to the change in l4. Similarly, the changes in l2 and l3 are equal and opposite. By feeding pairs of elements symmetrically spaced around the center of the array with a differential delay shift network, these conditions are met.

In existing adjustable down tilt antennas for cellular base stations, this functionality is typically achieved using a mechanism controlled by a stepper or servo motor (see ***Figure 2a***). The evolution from this conventional electromechanical phase shifter to a switched topology is shown in ***Figure 2b***. Using discrete, quantized steps for the phase/delay adjustment eliminates the need for large mechanical movement, with more switching steps available to give finer resolution for more accurate beam steering applications. In both topologies, the single input is fed to two antenna elements with the appropriate impedance matching, since the two element impedances appear in parallel to the input. By adjusting the phase/delay, any length added into one path is equally subtracted from the other path, giving true differential phase control.

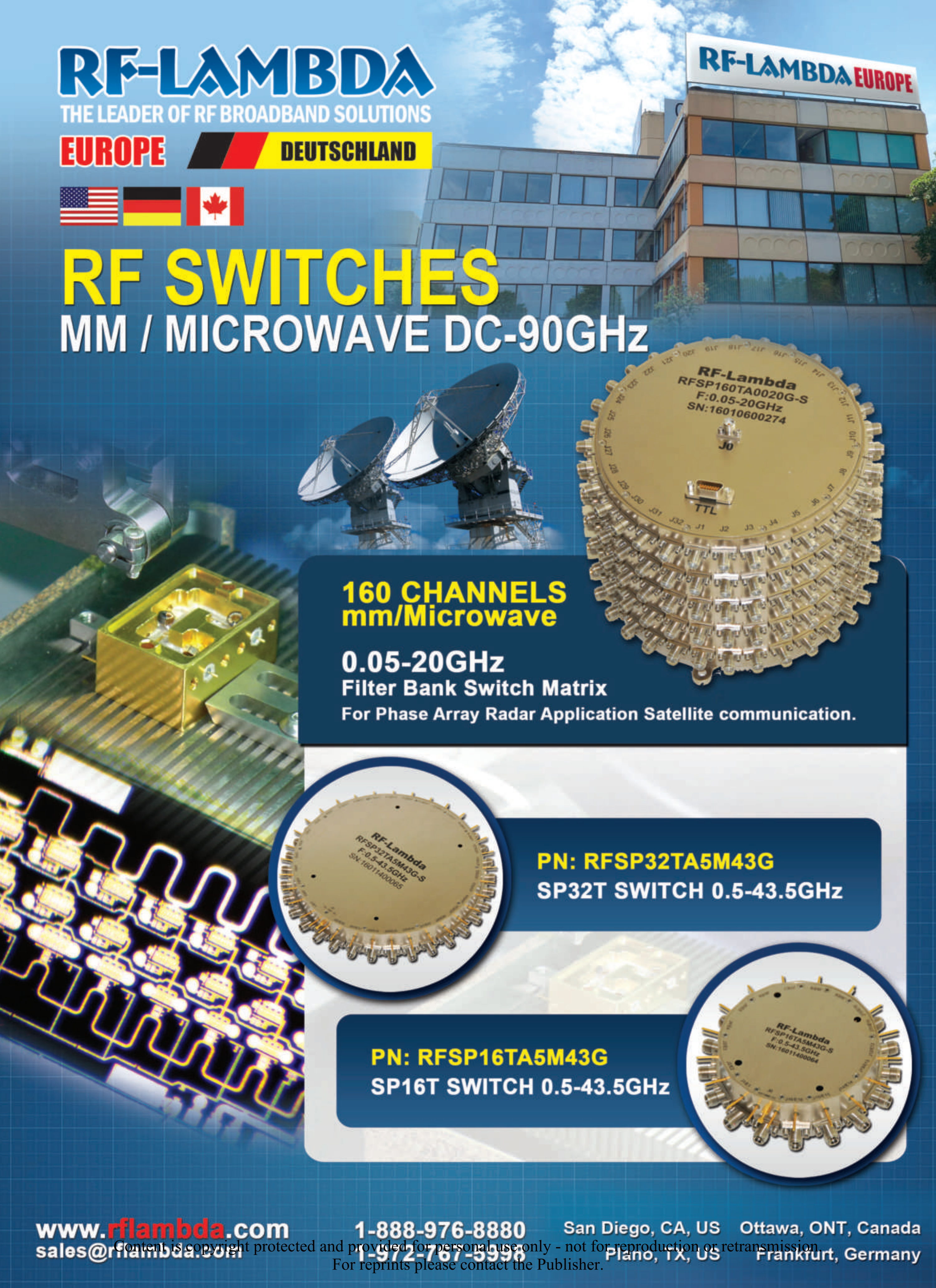


▲ Fig. 2 Traditional (a) and switched (b) phase shifters.

Figure 3 shows how two of these delay shifters with different transmission line lengths may be used to feed the simple four-element array shown in Figure 1. In this case, delay shift DS1 has 3× the delay variation as DS2, since the end elements are separated by 3× the unit element spacing. Although the schematic shows a direct feed to both delay shifters, an asymmetric power divider can be used to provide amplitude weighting or tapering of the individual elements.

3.6 GHZ DDS DESIGN

A four-step DDS for the 3.6 GHz CBRS band was developed using the Menlo Micro MM5130 high-power SP4T switch. Using additional switches, this concept can be extended to eight or 16 delay steps. In this configuration, a key requirement for the switch is a series-only topology with very low parasitic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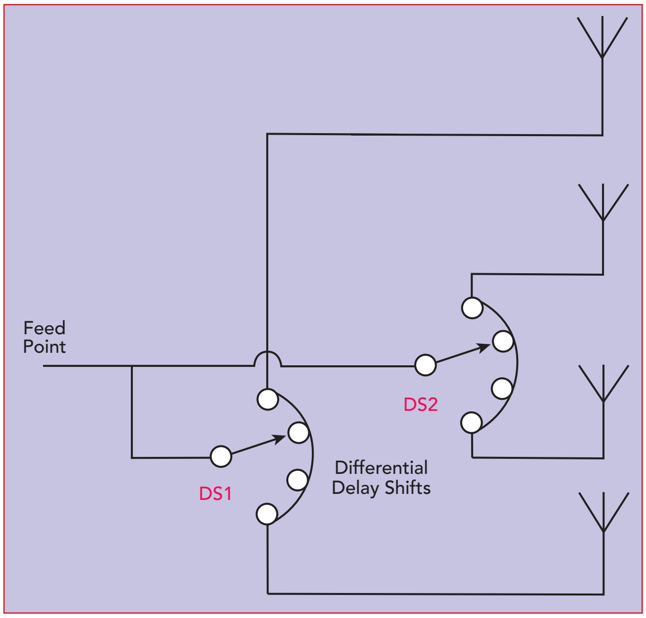

Fig. 3 Two differential delay shifters feeding a four-element array.

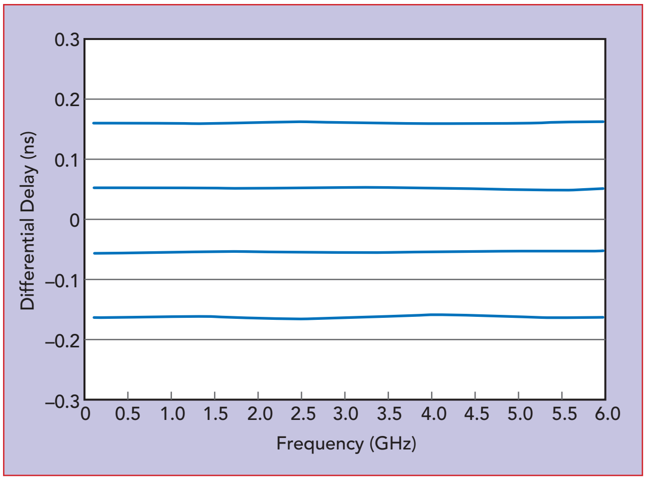

Fig. 4 Four-step delay shifter differential delay vs. frequency.

capacitance for the off ports of the switch. This ensures low loss, wideband performance, as the effect of any parasitic capacitance is minimal.

Figure 4 shows the wideband performance of the four-step delay shifter used for the outer pair of elements shown in Figure 3. The maximum differential delay is approximately 0.16 ns, which corresponds to a propagation distance, d, of 50 mm. For an array with an element spacing, s, of 43 mm or λ/2 at 3.6 GHz, the beam steering angle is given by

$$\theta = \tan^{-1}\frac{d}{Ns}$$

where N is the number of elements between the two outputs of the delay shifter. In this case, N = 3, so the beam steering angle is 21 degrees. ***Figure 5*** shows the simulated radiation patterns for the four-element array at ±21 degrees. The amplitude weights on the elements was adjusted to give sidelobe levels of -24 dB, a reasonable compromise between the main beamwidth and the sidelobes.

DELAY SHIFTER DESIGN

Practical design considerations were considered when selecting the number of elements for the array, with a 4 × 2 array the minimum number of elements to achieve the desired beam steering (see ***Figure 6***). This array configuration requires three types of delay shifters: one for azimuth to switch the pattern among left, boresight and right and two types for elevation. The azimuth delay shift was configured to have three beam positions, -30, 0 and +30 degrees. This is enough for the relatively wide azimuth beam created by the two elements in each row of the array.

The first elevation delay shifter controls the delay states between the two inner patch elements, while the second controls the delay state of the two outer patches. Since the distance between the two outer patch elements is 3× the distance between the two middle elements, the corresponding delay shifter was

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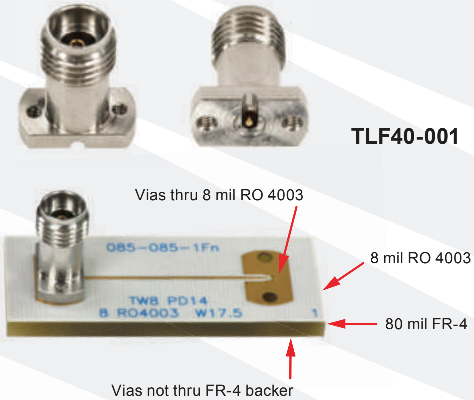

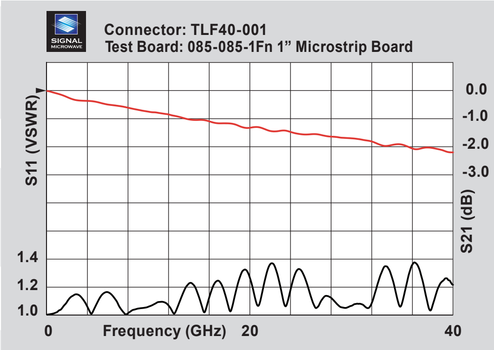

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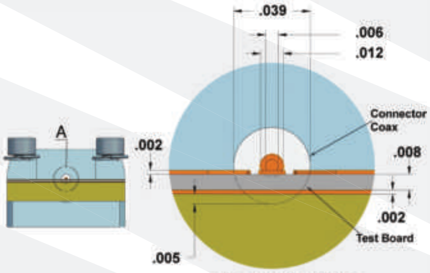
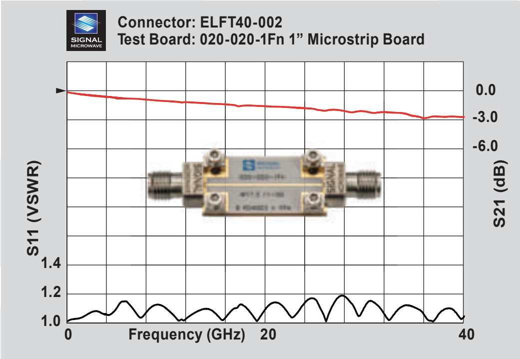
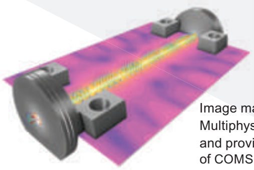


DETAIL A; 8 mil Test Boards and Connector Cross Section



3D models for simulation available at no charge to assist customers in their own development efforts.



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designed with 3× the delay shift. In total, the feed structure encompasses five delay shifters: one for azimuth, two inner pair and two outer pair for elevation. Since the selected switch is a SP4T configuration, the array design uses four delay states in the elevation/vertical plane. Four is not a hard limitation; it can be extended using higher throw switches or several switches in parallel.

The three different types of delay shifters were designed using Keysight ADS and verified and fine-tuned using Keysight EMPro. A multidimensional three-port S-parameter file was exported and used in the top-level simulation. A rendering of the outer pair delay shifter simulation model in Keysight EMPro is shown in ***Figure 7***. ***Figure 8*** shows the outer pair delay shifter being tested. The passive components on the input port provide matching to 50 Ω, so multiple elements can be cascaded, making it relatively straightforward to connect multiple delay shifters in series to form a feed network to control the pattern for both azimuth and elevation.

FEED NETWORK AND RADIATOR DESIGN

Reusing the layouts from the three individual delay shifters, the antenna feed board was designed to mate to the backside of the antenna radiator board. The top and bottom element of each vertical column are fed with couplers, which provides unequal power for tapering and enhancing sidelobe suppression. Equal length lines were used to properly phase the inner and outer pairs. To reduce transmission line losses, microstrip lines transitioned to coplanar lines for the delay shifter layouts. ***Figure 9*** shows the feed network with the three types of delay shifters, the combination of microstrip and coplanar waveguide and a USB control in the lower right.

The radiating elements were designed as planar patches backed with

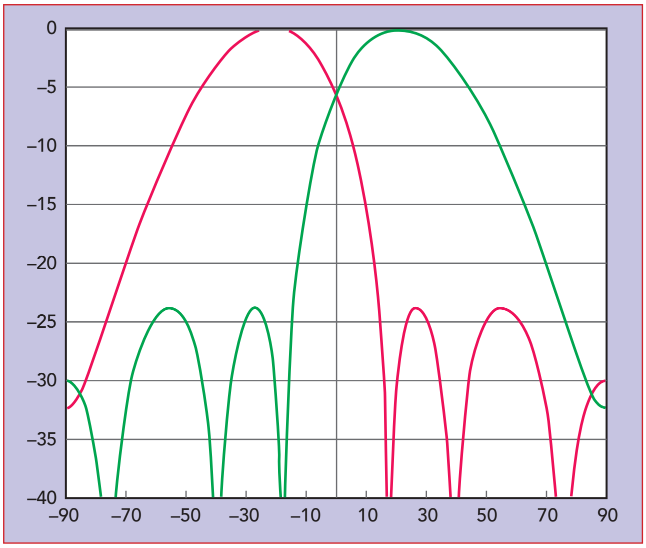

Fig. 5 Simulated radiation pattern for two beam angles.

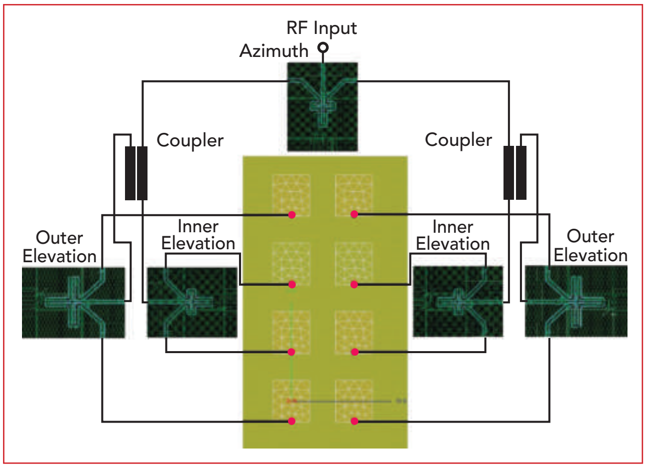

Fig. 6 Feed network topology.

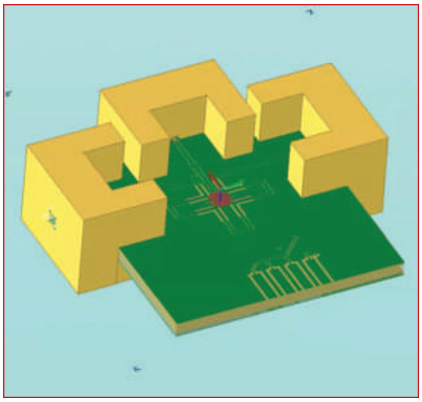

Fig. 7 Keysight EMPro 3D model of the delay shifter.

a ground plane, which provides a low profile (see ***Figure 10***). The feed position and patch shape were chosen for linear polarization, with dual polarization angle coverage. Antenna efficiency is determined mainly by the losses in the substrate between the elements and the ground plane. To achieve good efficiency, a low loss PTFE with a height of 0.187 in. was selected, with a simulated efficiency of -0.3 dB. Since ground currents from the feed network transmission lines can distort the antenna radiation pattern, the antenna ground plane was separated from the feed board ground plane, which solved several other mechanical issues.

The element spacing in the array is an important design variable. Higher spacing usually results in higher peak lobe gain but increases the undesired grating lobe when the antenna is operating at high steering angles. The clean spurious lobe beam steering range is also determined by the number of rows and columns in the array. Since the design was selected to have only two columns, together with a large azimuth steering range, a traditional λ/2 spacing was selected.

To achieve lower sidelobes in the radiation pattern, -20 dB Taylor amplitude tapering was used in the elevation plane. With only four rows in the array, this tapering applies to the top and bottom rows, with no tapering possible across the two columns, i.e., the azimuth plane. To implement the tapering, rather than power dividers and attenuators, two couplers were used to feed the outer elements, which significantly improves the antenna system

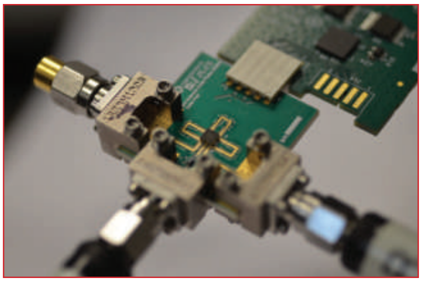

Fig. 8 Testing the differential delay shifter prototype.

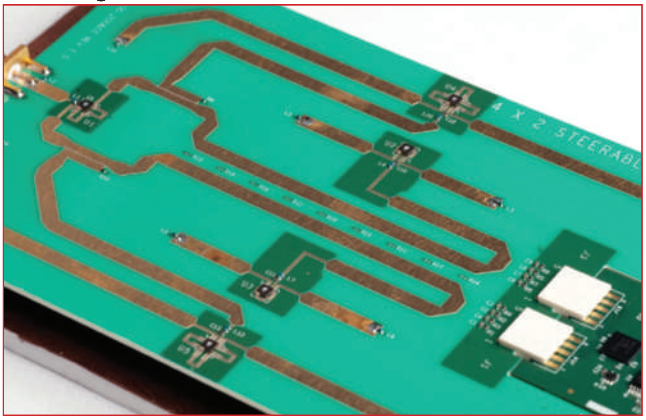

Fig. 9 Feed network with three types of delay shifters.

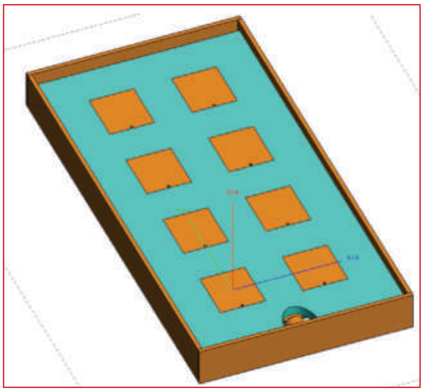

Fig. 10 4 x 2 element patch array with ground plane.

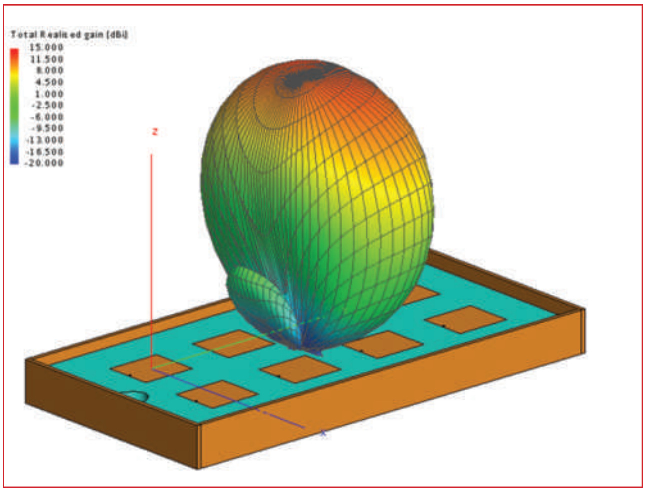

Fig. 11 Array 3D gain pattern, azimuth at boresight and elevation +6.5°.

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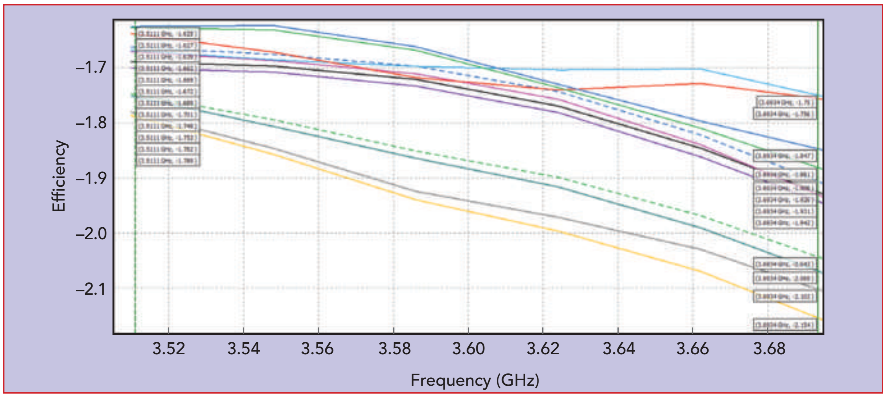

Fig. 12 Simulated antenna efficiency vs. 12 switching states.

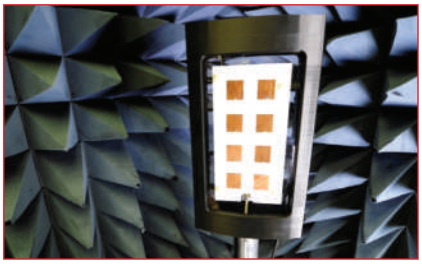

Fig. 13 CBRS antenna in anechoic chamber.

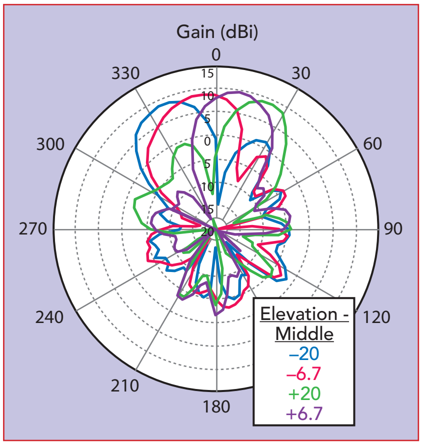

Fig. 14 CBRS antenna measured radiation patterns.

efficiency versus traditional methods. A simulated antenna pattern is shown in ***Figure 11***, and the simulated system efficiency in all 12 beam states—three in azimuth and four in elevation—is shown in ***Figure 12***. A simple USB interface controls the delay shifters steering the beam.

The antenna design was performed using Altair FEKO, a 3D electromagnetic (EM) tool which has method of moments, finite element, finite difference time domain and hybridization solver engines. The high-level design was performed using the finite array tool, which drastically reduced the simulation time and memory. The feed network was designed with Keysight Genesys using the S-parameter files for the delay shifters exported from the EMPro EM simulator. The completed feed network was then exported as a nine-port S-parameter file (one feed port and eight antenna ports) used in the antenna radiation pattern simulation in FEKO.

MEASURED PERFORMANCE

For antenna testing, a plastic 3D-printed radome was designed with transparent windows on the front

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TABLE 1

PHASE SHIFTER COMPARISON

	Mechanical	Solid-State	Differential Delay
Maximum Input Power (dBm)	>50	25	44
Insertion Loss (dB) at Frequency (GHz)	<0.2 0.7 to 2.7	<4.5 2.3 to 3.8	<0.5 3.6
Linearity / IP3 (dBm)	~100	47	>90
Switching Speed	s	μs	μs
Supply Current	1 A When Operating	~1 mA	<100 μA
Size (mm)	150 x 150 + Stepper Motor Actuator	4 x 4	10 x 15

and back, which shows the interconnection of the delay shifters (see ***Figure 13***). Radiation tests confirm the beam can be controlled in both azimuth and elevation in three and four steps, respectively (see ***Figure 14***). The overall efficiency of the antenna system was greater than 40 percent with greater than 10 dBi gain at a beam position of +6.7 degrees. As the beam was steered to greater angles, the loss in both the delay shifters and antenna elements increased slightly, reducing efficiency.

SUMMARY

A novel DDS was designed, mimicking the traditional mechanical RET phase shifters yet using the discrete states of a high performance MEMS switch to emulate the positioning of an analog phase shifter. Implemented in a CBRS antenna yielded a highly efficient and lightweight antenna demonstrator, able to change the position of the beam within 10 μs—impossible with a mechanical phase shifter. ***Table 1*** compares the performance of the DDS design to the mechanical and typical solid-state phase shifters. The main performance benefits of the DDS design are power handling, power consumption, IP3 and insertion loss. The broadband capability of the DDS enables it to be extended into the mmWave bands to support future beam steering antenna systems for 5G, aerospace and defense. Other planned design improvements include increasing the integration to realize simpler surface-mount designs and reduce the footprint.■

Acknowledgment

This article reflects the contributions of Christopher Mobbs, consultant; Mats Lindstrom, CEO of RF2B; and Marten Seth, a senior systems applications engineer at Menlo Micro.

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Dual Band Antenna Array for Digital Beamforming in LTE-A and 5G

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Beamforming is a phased array technique that enables mobile communications base stations to focus higher power in the direction of user equipment (UE), providing higher signal-to-noise ratio (SNR) and increased data rate. It can also prevent signal degradation from interfering transmitters by nullifying their signals, so mobiles can share the same spectrum with other networks and increase spectral efficiency. This article describes an eight-element linear monopole array designed for and tested at 1.8 and 2.6 GHz. Results meet the goals for steering capability, null and sidelobe suppression and multibeam formation.

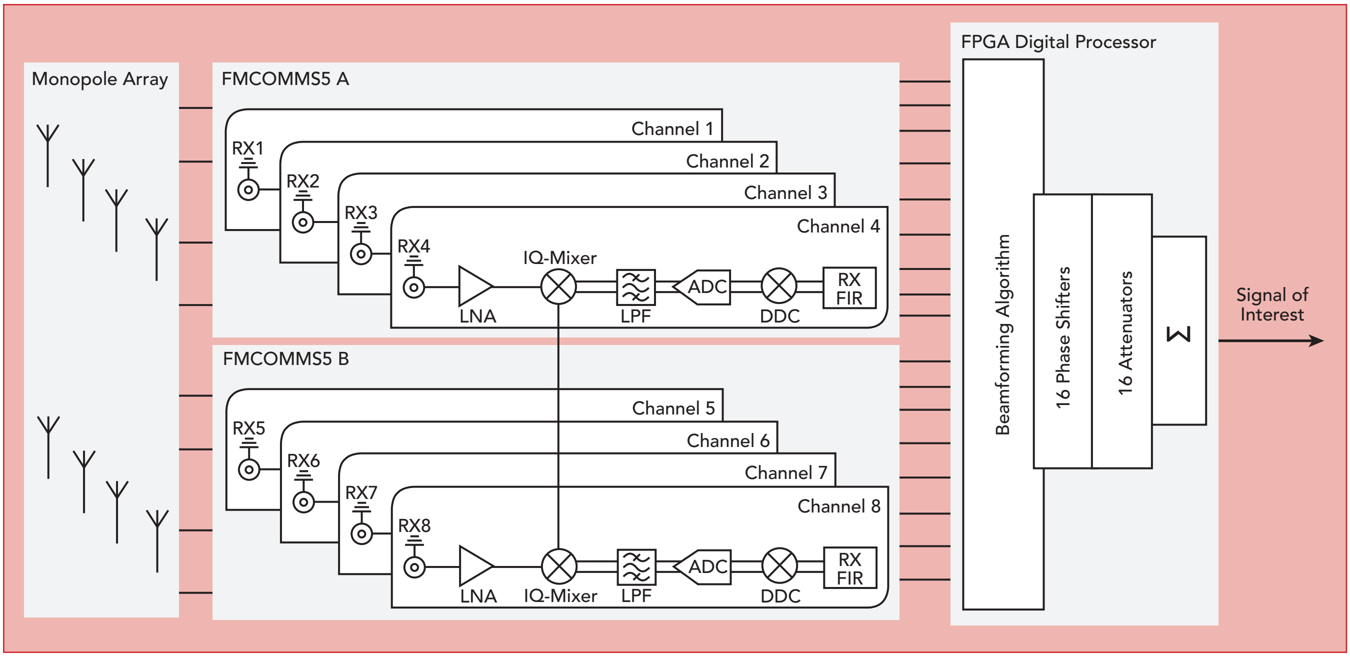
The world's demand for connectivity is rapidly increasing, with mobile subscriptions expected to approach nine billion by the end of 2025, of which some 2.6 billion will be 5G.[1] Supporting this fast growing market requires upgrades to operator infrastructure. Beamforming, a well-known technique in defense radar and military communications systems, is being adopted for commercial mobile communications. Beamforming can be thought of as spatial multiplexing. Antenna array elements are weighted in phase and amplitude to modify the radiation pattern as desired. These modifications may be interactive, as in the case of adaptive arrays, or based on predefined switched beams. With beamforming, a base station can direct its antenna gain to communicate efficiently with other devices in the system, while isolating itself from interferers. Spectrum sharing is also possible. Two communication standards operating at the same frequency will not interfere with each other, since each can place beam pattern nulls in the direction of the other.

Global System for Mobile Communications (GSM) was the first attempt to apply beamforming to mobile communications. A base station equipped with an adaptive antenna array processor, allowing full beam uplink and downlink adaptation in every GSM frame, was proposed and tested by Kuchar et al.[2] For LTE, beamforming was introduced in 3GPP release 10.[3] The standard supports passive arrays with horizontal beamforming and active arrays with 2D and 3D beamforming. Beamforming is becoming more important in the subsequent releases of 3GPP. The 5G new radio (NR) defined in release 15 relies on beamforming and beam management,[4] and the 5G NR description considers the possibility of exploiting beamforming in the uplink and downlink transport channels.[5] Beamforming requirements are discussed, such as null suppression and steering angle range.[6] Digital beamforming enables the efficient evaluation of direction of arrival (DoA) beamforming algorithm performance.

A complete system for testing steering capability, null and sidelobe suppression and multibeam formation using various digital beamforming algorithms is presented in this article. The system is based on commercial transceivers from Analog Devices.[7]

SYSTEM DESCRIPTION

This system implements beam-



▲ **Fig. 1** **Beamforming test bed.**

forming in the digital domain. Calculated complex weights are applied to the received signals at baseband, which requires a complete receiver chain. The system is designed to operate at the LTE-A and 5G NR bands from 1.7 to 1.9 GHz and from 2.5 to 2.7 GHz.[8] 5G NR includes sub-6 GHz bands, referred to as FR1 and mmWave bands, designated FR2.[9]

The number of array elements determines the directivity of the main beam and its half-power beamwidth. As the number of elements increases, the directivity increases and half-power beamwidth decreases.[10] This test bed comprises an eight-element antenna array, an RF front-end and a field-programmable gate array (FPGA) digital processor (see ***Figure 1***). The antenna array is composed of wideband monopoles linearly distributed with uniform inter-element spacing. RF signals transmitted by the UE are received by the antenna array. These signals have different phases and amplitudes, depending on the position of the UE relative to the base station. Dynamically weighting the received signals produces maxima and nulls in the radiation pattern, determined by the weights. This system can evaluate and test the performance of horizontal beamforming algorithms, as well as the performance of new algorithms. To do this, eight full receiver chains are used, with the eight I/Q pair outputs digitized for post processing. The beamforming weights are calculated and applied to the digital baseband signals in the FPGA. Summation of the weighted signals provides the best SNR at the angle of the main beam and the worst SNR at the angle of the null in the radiation pattern.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MONOPOLE ANTENNA ARRAY

CST Microwave Studio 2017 was used for the design and simulation of the antenna array.[11] The single element is a monopole with a rectangular shape and rounded vertices of radius R^{cor1}. The monopole is printed on Rogers RO4003C 0.06 in. thick, which has a relative dielectric constant of 3.38 and loss tangent of 0.0027 (see ***Figure 2***). It is fed from an edge-mounted SMA connector through a 50 Ω microstrip line. The transition between the feed line and the rectangular antenna element is elliptical, with a minor axis length L_{gap}. The width of the element and its length are W_{mono} and L_{mono}, respectively. The antenna is backed by a leaf-like ground plane of width W_{gnd} and length L_{gnd}. The dimensions used in the design are W_{mono} = 57 mm, L_{mono} = 36.5 mm, R_{cor1} = 9 mm, L_{gap} = 6.5 mm, W_{gnd} = 57 mm and L_{gnd} = 24 mm. The ground surface is modified with 10 corrugations in the bottom edge to minimize coupling to the coax. The antenna has a metallic reflector 44 mm from the substrate to direct the antenna's power in the boresight direction. Confirming the monopole's performance, ***Figure 3a*** shows the simulated and measured impedance matching from 1.7 to 2.7 GHz, and ***Figure 3b*** shows the simulated and measured H-plane radiation patterns at 2.6 GHz.

For horizontal beamforming, the single monopole is extended to a linearly distributed eight-element array with uniform element spacing (see ***Figure 4***). Because the antenna is wideband, the choice of inter-element spacing was challenging. The separation was set to 83 mm, which is a half-wavelength at 1.8 GHz. The eight elements are uniformly fed using a Mini-Circuits ZB8PD-362-S+ eight-way power divider. ***Figure 5*** shows the simulated and measured radiation patterns at 1.8 and 2.6 GHz with each element uniformly excited.

RF FRONT-END

Because beamforming is performed digitally, a complete receiver

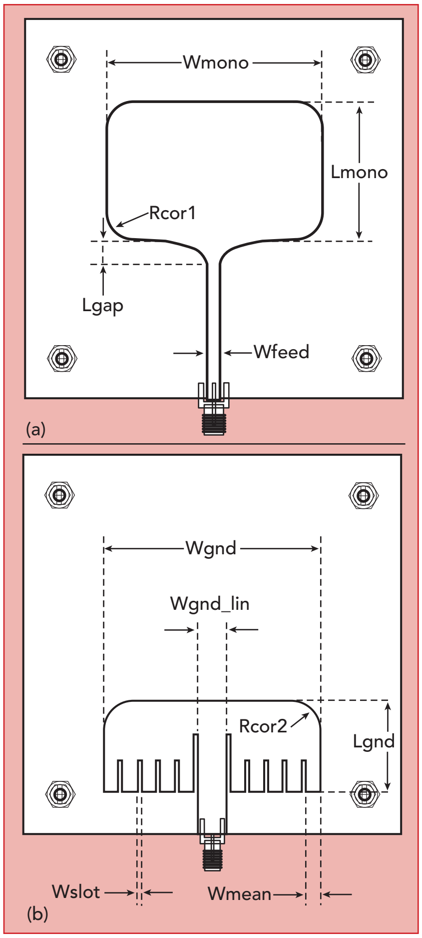

Fig. 2 Top (a) and bottom (b) of the single element antenna.

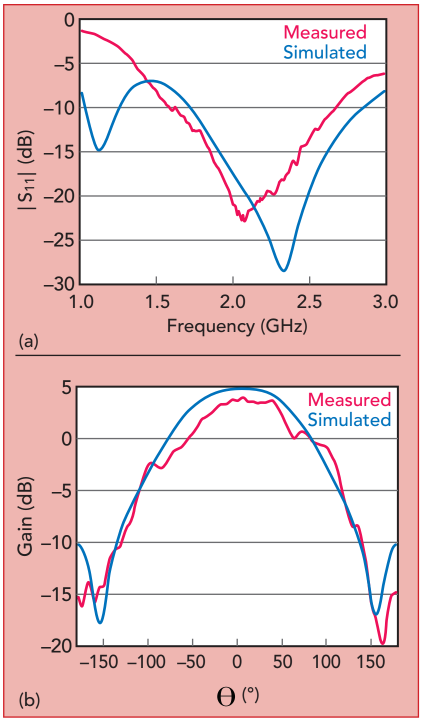

Fig. 3 Simulated vs. measured performance of the single element antenna: $|S_{11}|$ vs. frequency (a) and 2.6 GHz E-plane pattern (b).

chain is needed. The Analog Devices AD9361 wideband receiver was selected, as it meets most common communication standards, including LTE-A, contains two separate receive chains and operates from 70 MHz to 6 GHz.[12] As the demonstration system requires eight receiver channels to capture the signals from the eight antenna elements, the full receiver uses two Analog Devices' FMCOMMS5 transceiver boards with dual FMC connectors, compatible with the Zynq ZC702 FPGA board from Xilinx (see Figure 1). Each transceiver board has four dedicated receiver channels driven by a single local oscillator (LO), requiring two transceiver boards for the eight receive channels.

Fig. 4 Eight-element monopole array.

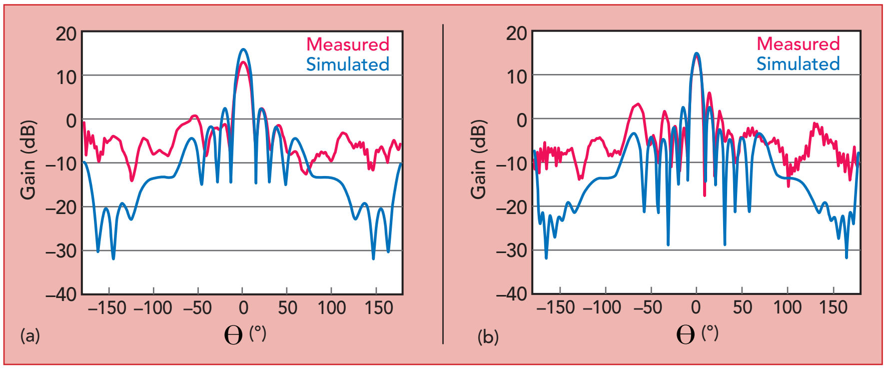

Fig. 5 Monopole array H-plane patterns at 1.8 (a) and 2.6 (b) GHz, simulated vs. measured.

To evaluate digital beamforming in the uplink, weights are applied to the received signals. The signal coming from the antenna element passes through a coaxial cable into an internal low noise amplifier. The amplified signal is down-converted by a mixer, and the I/Q signal pair is digitized by a 12-bit, third-order, continuous time delta-sigma modulator analog-to-digital converter (ADC). After digital down-conversion and filtering with a decimation finite impulse response filter, the signal is ready for post processing.

In digital beamforming, the relative phase between elements is critical. If the eight receivers are not synchronized in phase, accurate post processing beamforming is not possible. There are two challenges: the first, to ensure that all LOs are at the same frequency; the second, to ensure all are synchronized in phase. The LO driving both transceivers in each AD9361 chip is an Analog Devices ADF5355BCPZ phase-locked loop (PLL) with integrated VCO. A 40 MHz temperature compensated crystal oscillator (TCXO) is used as the PLL reference clock.

If the four PLLs were driven from the same reference clock and configured with the same N-divider, all the PLLs would oscillate at the same frequency. Each of the two transceivers on the same FMCOMMS5 board are driven by the same PLL. To synchronize the two transceiver boards, the TCXO reference clock on one, the master, is buffered with an ADCLK846B fanout buffer and passed via a coaxial cable to the external reference input of the other board, the slave (see ***Figure 6***). This locks the two PLLs at the same frequency. However, while the RF paths for the eight channels are almost identical, there is still a length difference between the paths, in addition to the path difference between the master and slave boards.

The phases of all eight elements must be aligned before processing signals from the antenna. To do so, the eight elements' receivers are connected to a ZB8PD-362-S+ eight-way splitter. The input of the splitter is connected to the transmit-

ter channel of one of the transceivers. After coarse phase synchronization, a manual fine alignment of the receiver channel phases is performed on each board, adding a fixed angle to each channel as required to align them. Knowing that the two LOs are at the same frequency, the four signals of the master board now lead or lag the four channels of the slave board by a constant phase, which is also evaluated and compensated manually. After this alignment, the power divider is removed and the antenna array is connected to the eight receivers using equal length cables. For applications where more channels are needed, in the case of massive MIMO, a clock distribution network can be used to synchronize the frequency and phase among all the boards.

TESTING

To test the full system and validate the outcomes, real signals at various angles are recorded, beamforming weights are calculated on the fly and radiation patterns after post processing are recorded. Measurements are conducted in the controlled environment of an anechoic chamber using a Vivaldi transmit antenna, fed from the transmitter channel in the FMCOMMS5 master board (see ***Figure 7***). The transmitter needs nine seconds to transmit one burst of data, so the motor that rotates the Vivaldi antenna is adjusted to an angular speed of 1/9 degree per second as it rotates from -90 to +90 degrees. The processing system captures data from the eight elements simultaneously at each step, accumulating data from the eight signals at 181 angles. The master and slave FMCOMMS5 boards are mounted on the opposite side of the receive antenna array, as shown in Figure 7. Before starting the measurements, phase calibration is performed as described.

The test mimics a UE signal transmitted toward a base station antenna array. Baseband data in LTE-A and 5G NR are modulated with quadrature amplitude modulation (QAM),[13,14] so the test signal is quadrature phase shift keying (QPSK) modulated, with a length around 2,400 samples. At each stop angle, a burst of modulated QPSK data is sent through the Vivaldi antenna and received through the eight-element array. The receiver's ADC sampling rate is set to 30 MSPS, with the channel bandwidth at 5 MHz. After recording data, beamforming weights are applied to the stored signals. In this test, the weights are calculated based on the linearly constrained minimum variance (LCMV) beamformer. An LCMV beamformer passes signals from preferred directions with maximum gain while blocking interference from other directions. The total output power after applying the LCMV weights is minimized under the constraints of source and interference directions.[15] The steering capability of the array is limited to between -60 and +60 degrees for a total azimuth view angle of 120 degrees.

Several scenarios were tested, with two shown here: 1) The normalized radiation pattern with the source at 35 degrees and interferers at 10 and 65 degrees, operating at a carrier frequency of 1.8 GHz (see ***Figure 8a***); 2) The normalized pattern at 2.6 GHz with two sources at 60 and 35 degrees and an interferer at 0 degrees (see ***Figure 8b***).

CONCLUSION

An eight-element antenna array test bed for digital beamforming in LTE-A and 5G was developed and evaluated. The system, using commercial wideband transceivers covering the FR1 LTE-A and 5G NR bands, was tested in an anechoic chamber with an LCMV beamformer at 1.8 and at 2.6 GHz. The measurements agree with the predicted performance. This work will continue, using the system to evaluate DoA estimation algorithms for LTE-A and 5G base stations in noncontrolled environments.■

ACKNOWLEDGMENT

This work is a collaboration between the Lebanese University and Universitat Politècnica de València and partially supported by the Lebanese University. It has been supported by a scholarship from Erasmus Mundus Welcome Program and by the Spanish Ministry of Economy and Competitiveness, under the project TEC2016-78028-C3-3-P.

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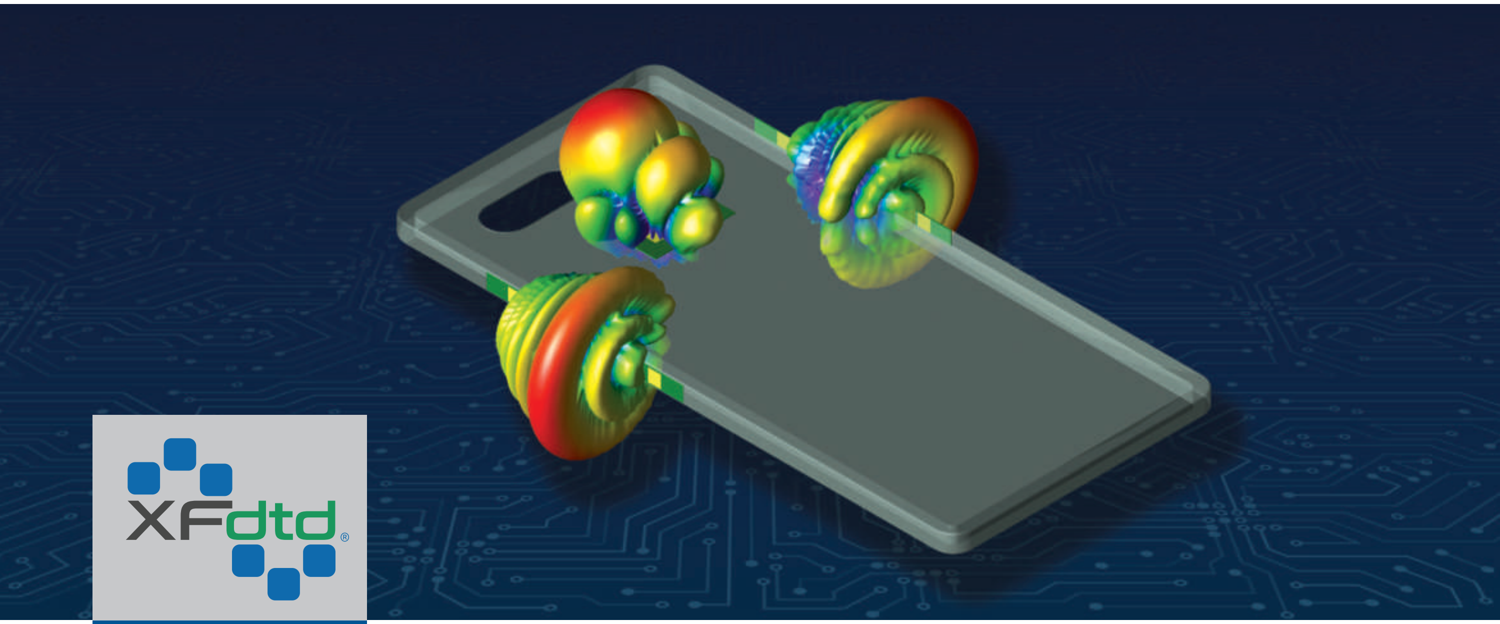

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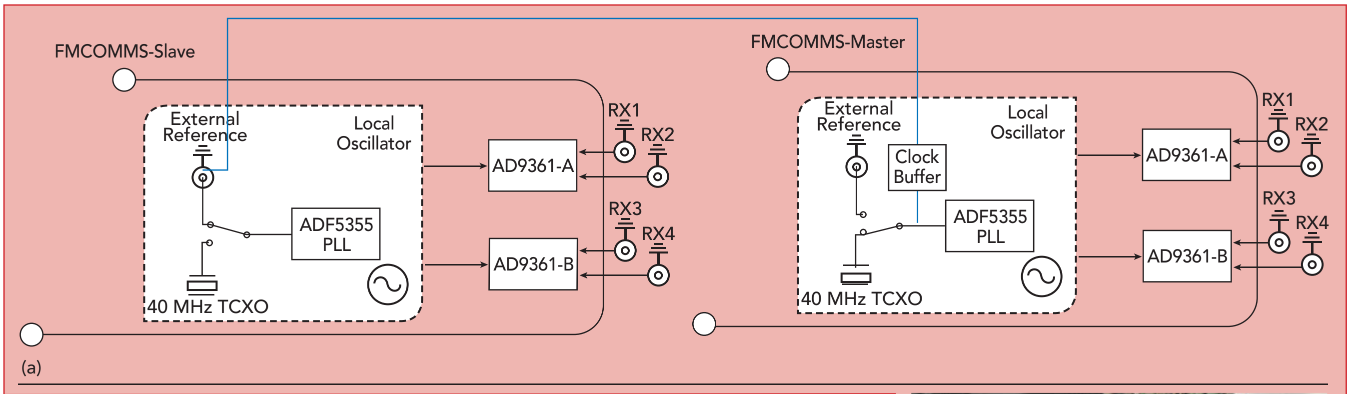

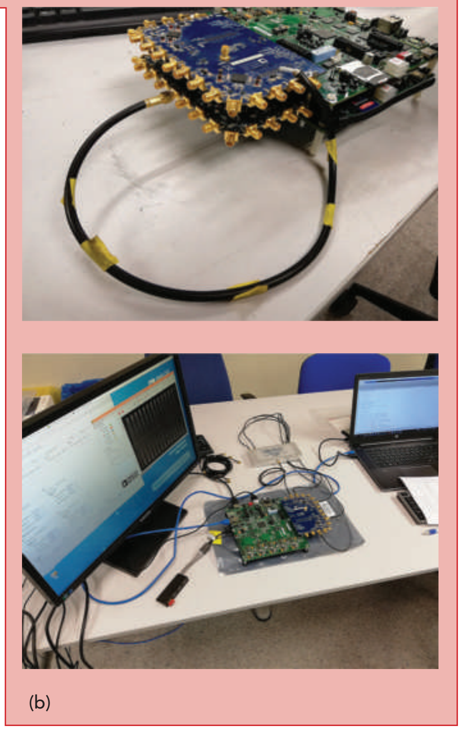

▲ Fig. 6 Master/slave setup (a) for synchronizing the phase between the two FMCOMMS5 boards (b).

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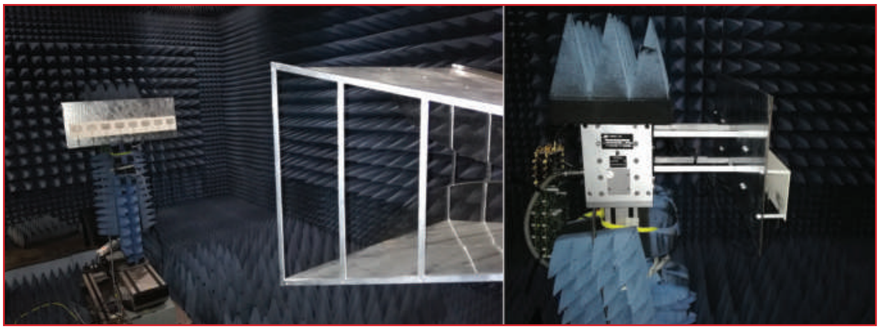

Fig. 7 Monopole array and transceiver boards in the anechoic chamber.

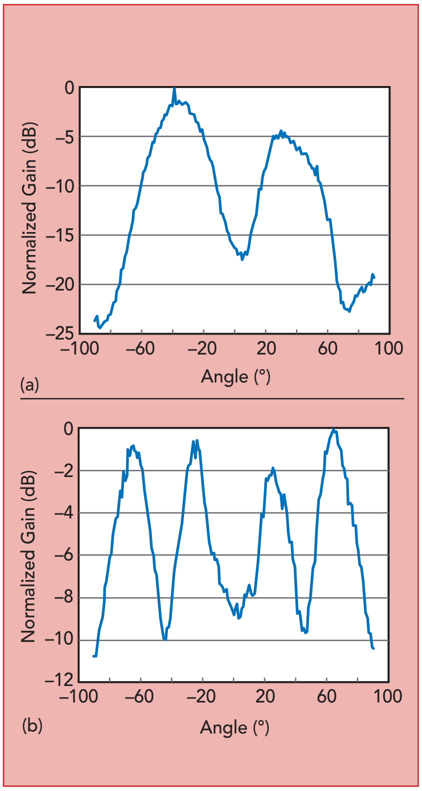

Fig. 8 Normalized radiation patterns at 1.8 (a) and 2.6 (b) GHz, derived from the baseband signal after applying LCMV beamforming weights.

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INVITED PAPER

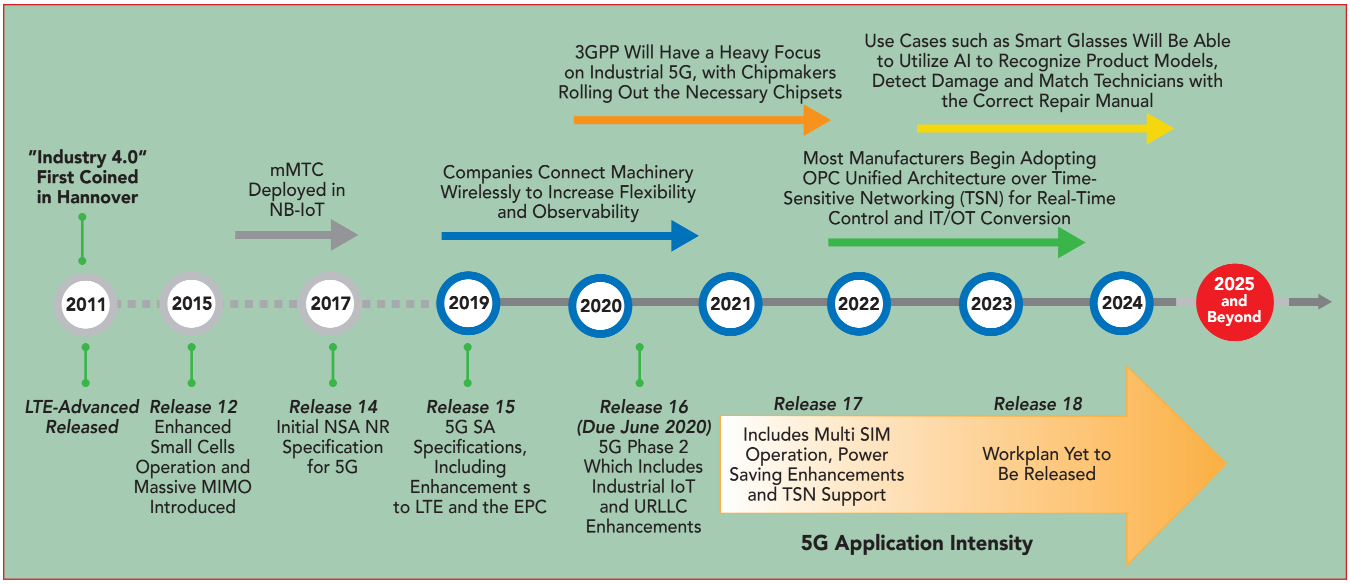
5G for Industry 4.0: Enabling Features, Deployment Options and Test Considerations

Jessy Cavazos
Keysight Technologies, Santa Rosa, Calif.

Cellular technology is expanding beyond traditional consumer applications, with 5G's foray into the industrial space garnering increasing support across the world. Four countries—France, Germany, Japan and the U.K.—have allocated 5G spectrum for private networks. Another 12 are considering taking the same measures.[1]

In the last few years, the manufacturing and cellular industries have invested much effort into defining the use cases needed to implement Industry 4.0.[2-4] For this new phase in the industrial revolution, 5G enables several exciting applications, including:

- Advanced predictive maintenance, which could potentially reduce equipment downtime by as much as 9 percent
- Precision control and monitoring, which leverages wireless connectivity between sensors to increase machines' range of motion
- Augmented reality and remote experts, which enable humans to be involved in specific tasks remotely, potentially reducing equipment downtime by 25 percent
- Remote robot control, which refers to the control logic of a robot



▲ Fig. 1 3GPP timing for 5G industrial features. *Source:* ABI Research.

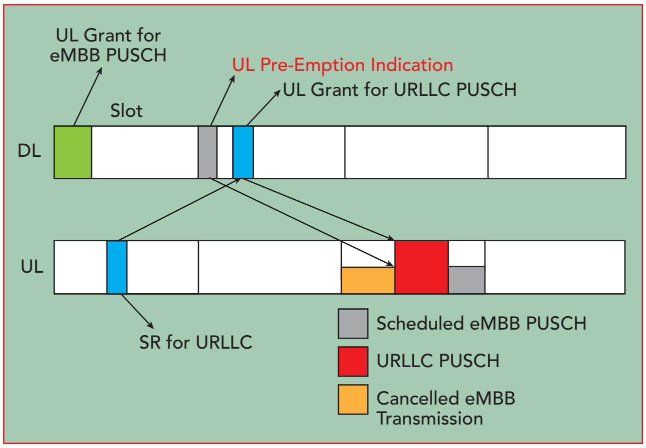


Fig. 2 Uplink pre-emption and grant process in release 16.

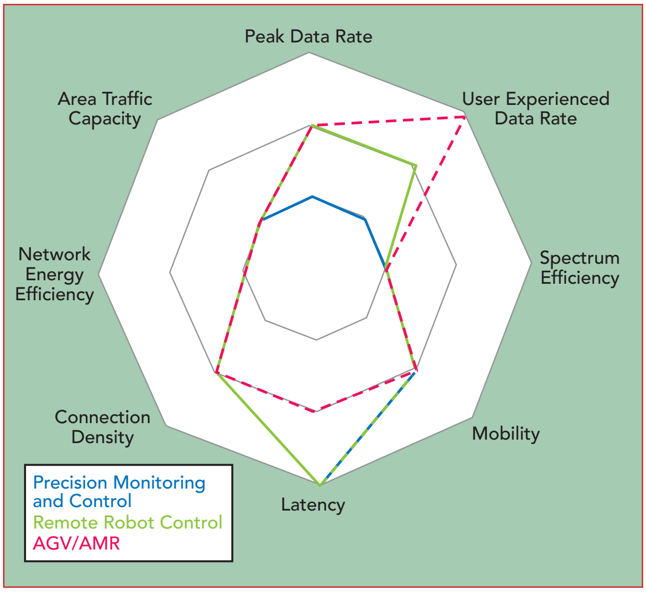


Fig. 3 5G capabilities for precision monitoring, remote robot control and AGV/AMR applications.

running remotely in a high performance compute environment

- Autonomous guided vehicles (AGV) and autonomous mobile robots, which 5G enables to operate in an unstructured environment

Various industry groups have worked on defining the use cases for 5G in industrial applications, with the 5G Alliance for Connected Industries and Automation (5G-ACIA) at the forefront of these initiatives.[5,6] The use cases have played a significant role in the development of 5G performance targets. The first standard release for 5G from the 3rd Generation Partnership Project (3GPP) mainly focused on consumer services, but subsequent releases offer specific capabilities for the industrial space (see ***Figure 1***). The newly completed release 16 enhances low latency features. Release 17 will increase 5G integration into time-sensitive networks, a key en-

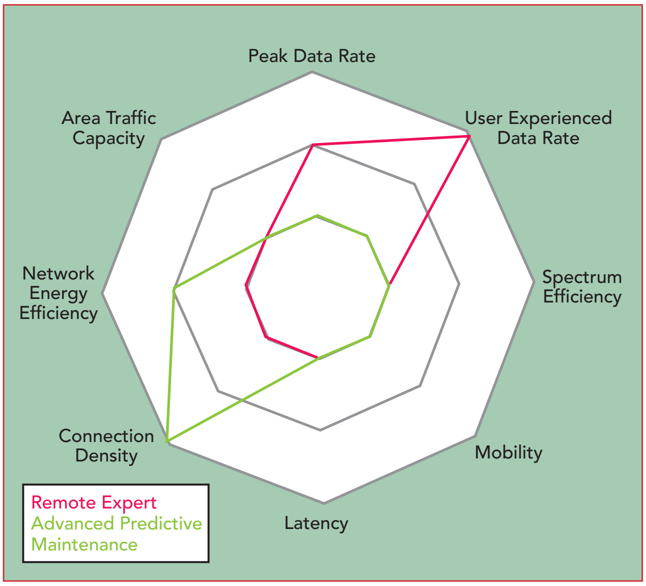


Fig. 4 5G capabilities for remote expert and advanced predictive maintenance use cases.

abling factor for factory automation.

Features for ultra-reliable low latency communications emerged in 3GPP release 15 and were extended in release 16. High-reliability aspects revolve around redundancy. 5G technology uses multiple antennas and dual connectivity to ensure robust connections. Low

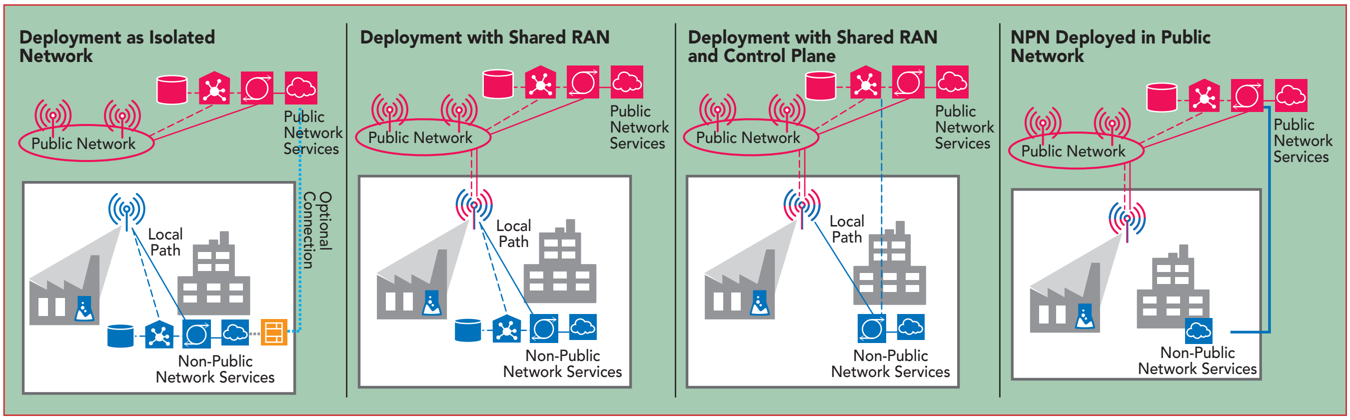


Fig. 5 Deployment options for industrial 5G networks. *Source:* 5G-ACIA.

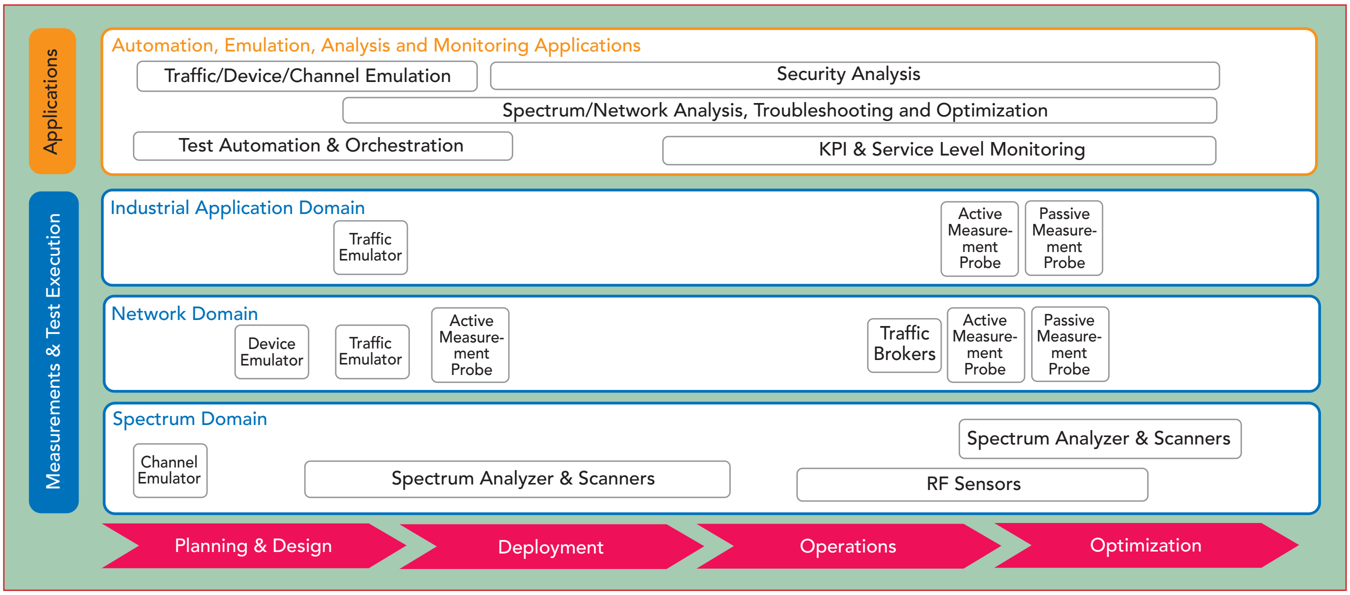


Fig. 6 Test and measurement across the lifecycle of a 5G industrial system.

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LM-10M50G-18DBM-4W-24FF https://www.pmi-rf.com/product-details/lm-10m50g-18dbm-4w-24ff	10 MHz - 50	3.4	4 W CW & 20 W peak, PW 1 µs to 10 µs, 1% duty cycle	+18	100 ns	0.53" X 0.7" X 0.26" 2.92mm (F) Field Removable and SMT (Drop-In)
LM-18G40G-SMT-1 https://www.pmi-rf.com/product-details/lm-18g40g-smt-1	18 - 40	4	20 W peak, 440 - 670 ns PW, PRF 600 - 900 kHz, 40% Duty Cycle	+14	250 ns	0.27" X 0.198" X 0.016" surface mount / drop-in carrier
LM-18G40G-18-1W-292FF https://www.pmi-rf.com/product-details/lm-18g40g-18-1w-292ff-	18 - 40	4	1 W CW	+18	10 ns	0.5" X 0.5" X 0.22" 2.92mm (F/F) Field Removable
LM-26G40G-14-20W-292FF https://www.pmi-rf.com/product-details/lm-26g40g-14-20w-292ff	26.5 - 40	4	20 W peak, 440 - 670 ns PW, PRF 600 - 900 kHz, 40% Duty Cycle	+14	250 ns	0.5" X 0.5" X 0.22" 2.92mm (F/F) Field Removable
LM-26G40G-14-20W-292FF Rev. B https://www.pmi-rf.com/product-details/lm-26g40g-14-20w-292ff-rev-b	26.5 - 40	4	20 W peak, 440 - 670 ns PW, PRF 600 - 900 kHz, 40% Duty Cycle	+14	250 ns	0.5" X 0.5" X 0.22" 2.92mm (F/F) Field Removable
LM-26G40G-14-20W-292FM https://www.pmi-rf.com/product-details/lm-26g40g-14-20w-292fm	26.5 - 40	4	20 W peak, 440 - 670 ns PW, PRF 600 - 900 kHz, 40% Duty Cycle	+14	250 ns	0.5" X 0.5" X 0.22" 2.92mm (F/M) Field Removable
LM-26G40G-14-20W-292MM https://www.pmi-rf.com/product-details/lm-26g40g-14-20w-292mm	26.5 - 40	4	20 W peak, 440 - 670 ns PW, PRF 600 - 900 kHz, 40% Duty Cycle	+14	250 ns	0.5" X 0.5" X 0.22" 2.92mm (M/M) Field Removable
LM-32G36G-14-20W-SMT https://www.pmi-rf.com/product-details/lm-32g36g-14-20w-smt	32 - 36	2	20 W peak, 30 µs PW, 30% Duty Cycle	+14	250 ns	0.53" X 0.7" X 0.26" 2.92mm (F) Field Removable and SMT (Drop-In)
LM-35D5G-14-20W-292FF https://www.pmi-rf.com/product-details/lm-35d5g-14-20w-292ff	35 - 36	3	20 W, 440 - 670 ns PW, PRF 600 - 900 kHz, 40% Duty Cycle	+14	250 ns	0.5" X 0.5" X 0.22" 2.92mm (F/F) Field Removable

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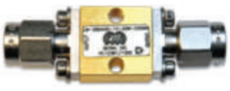

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latency features focus on the design of the 5G interface to enable super-fast transmission. Release 16 improves 5G's latency performance by introducing several new features, including pre-emption and grant-free transmission (see ***Figure 2***). Pre-emption provides the ability to interrupt transmissions with higher priority traffic. This feature is implemented in the low level of the communication stack, enabling more effective, higher layer quality of service. Grant-free transmission eliminates the signaling handshake used in traditional communication infrastructure for the user equipment to enable the transmission. The device can transmit data once it becomes available.

5G's high data throughput capability is also essential for several industrial applications, particularly for remote experts and AGVs that require the transmission of instant video streams (see ***Figure 3***). Massive MIMO, high-order modulation and greater bandwidth are key technologies enabling 5G to deliver such high throughput. Massive MIMO allows many antenna elements to transmit data at the same time. Higher-order modulation enables the encoding of more bits into the available spectrum. Lastly, higher frequencies provide more spectrum bandwidth.

5G enables several industrial applications through massive machine-type communications. Preventive maintenance applications, for example, leverage machine learning (ML) and artificial intelligence (AI). The volume of data and its variety have a direct impact on the effectiveness of ML and AI algorithms, making gathering data from many sensors attractive for manufacturers (see ***Figure 4***). Removing cables also increases flexibility, enabling sensors to be placed across the production line—even building a digital twin of the equipment to take manufacturing performance to the next level.

5G deployment in a factory environment can take multiple forms, ranging from dedicated standalone non-public networks (NPN) to various hybrid models involving network operators (see ***Figure 5***). A network operator can host a non-public network on the same physical infrastructure used for public services by implementing network slicing, a concept that enables operators to tailor the network to deliver customized services to specific customers. Some hybrid models share the radio access network infrastructure, but not the edge computing infrastructure. All options have implications for data privacy and service management. The choice in deployment depends on the use case and business strategy. As mentioned, several countries have made spectrum available exclusively for industrial use, and many others are considering spectrum access models for industrial purposes. In Germany, for example, more than 40 enterprises and institutions have received industrial spectrum. Spectrum availability is increasing the interest in NPNs.

Industrial 5G network deployments largely involve replacing

relatively costly communication infrastructure based on wired connections with a complicated system that requires various infrastructure components to work together smoothly. Testing becomes an integral part of the system lifecycle (see ***Figure 6***). Pre-deployment testing for security and performance is critical at the application level, requiring different types of traffic, network and device emulation before new features go live in the infrastructure to avoid issues. Test automation is key before adding a new device in the system, requiring coverage planning and spectrum clearance in the design and planning phase. Depending on the use case, channel measurements and emulation to understand future network performance may be warranted.

During deployment and acceptance, application and network load scenarios are used to stress the network with industrial traffic before implementation, and simulating network impairments to understand application performance under various conditions should be considered. Security conformance and performance testing for new devices or device types is strongly recommended before adding them to the network. In the operation and optimization phase of the lifecycle, spectrum and network analysis, troubleshooting and optimization are essential tasks. In parallel, a solution for ongoing monitoring of key performance indicators (KPI) and service levels is required. The critical nature of many 5G industrial use cases makes monitoring KPIs for end-to-end latency and security essential for success.

5G is unlike any previous generation of cellular technology. It encompasses a greater number of attributes that are step functions above the capabilities of previous generations. These features enable 5G to expand into industrial applications, which will introduce major changes in the industrial space—posing challenges that require deep expertise in wireless communication technologies. It's the start of a very exciting journey for design and test engineers.■

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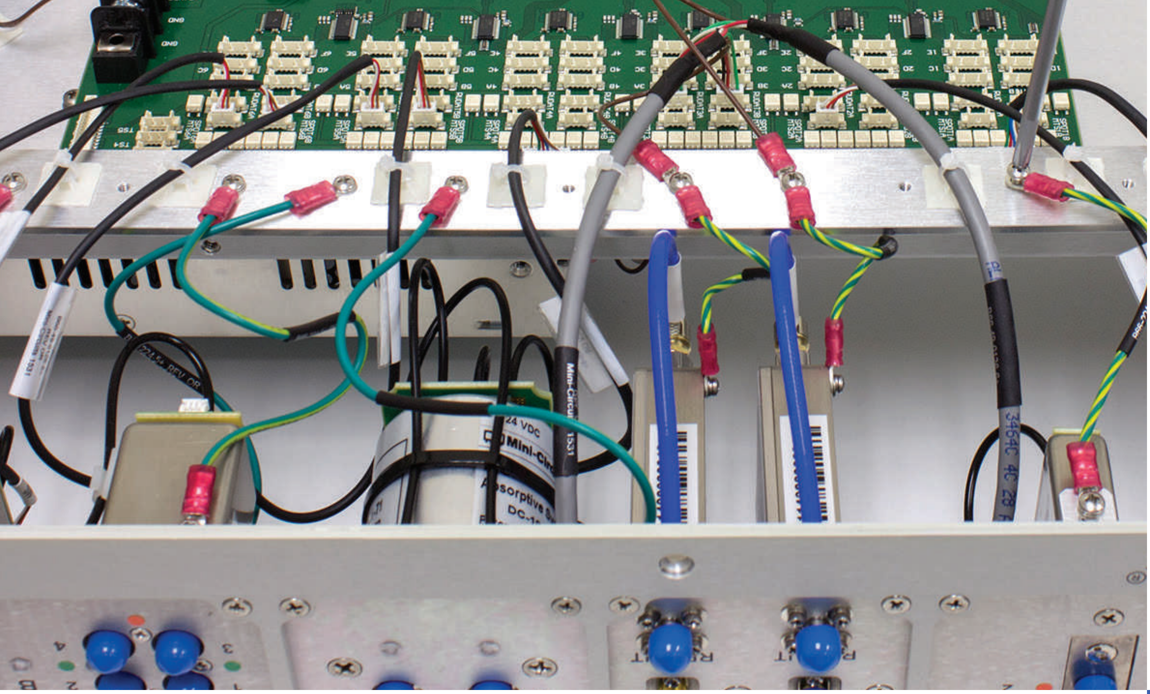

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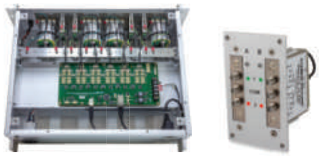

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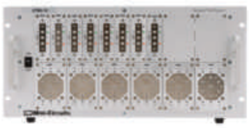

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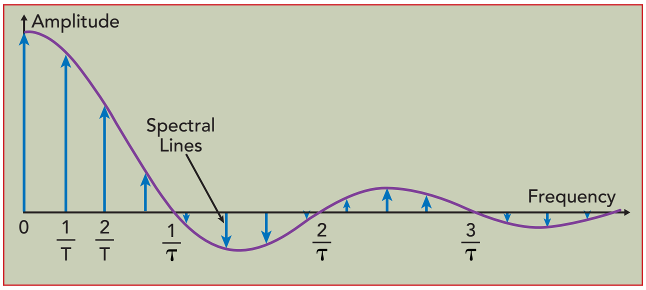
Measuring Absolute and Additive Phase Noise of Pulse-Modulated Signals

AnaPico Ltd.
Zurich, Switzerland

Berkeley Nucleonics
San Rafael, US

Phase noise is an important parameter for the performance of a radar system. Most radars employ pulse modulation, and the velocity of the target is derived by detecting the Doppler shift of the radar's reflected signal relative to the frequency of the transmitter. The transmitter's own phase noise strongly affects the resolution and accuracy of this measurement, limiting the detection threshold and accuracy of the radar. Therefore, the phase noise of pulsed signals has become an increasingly important measurement.

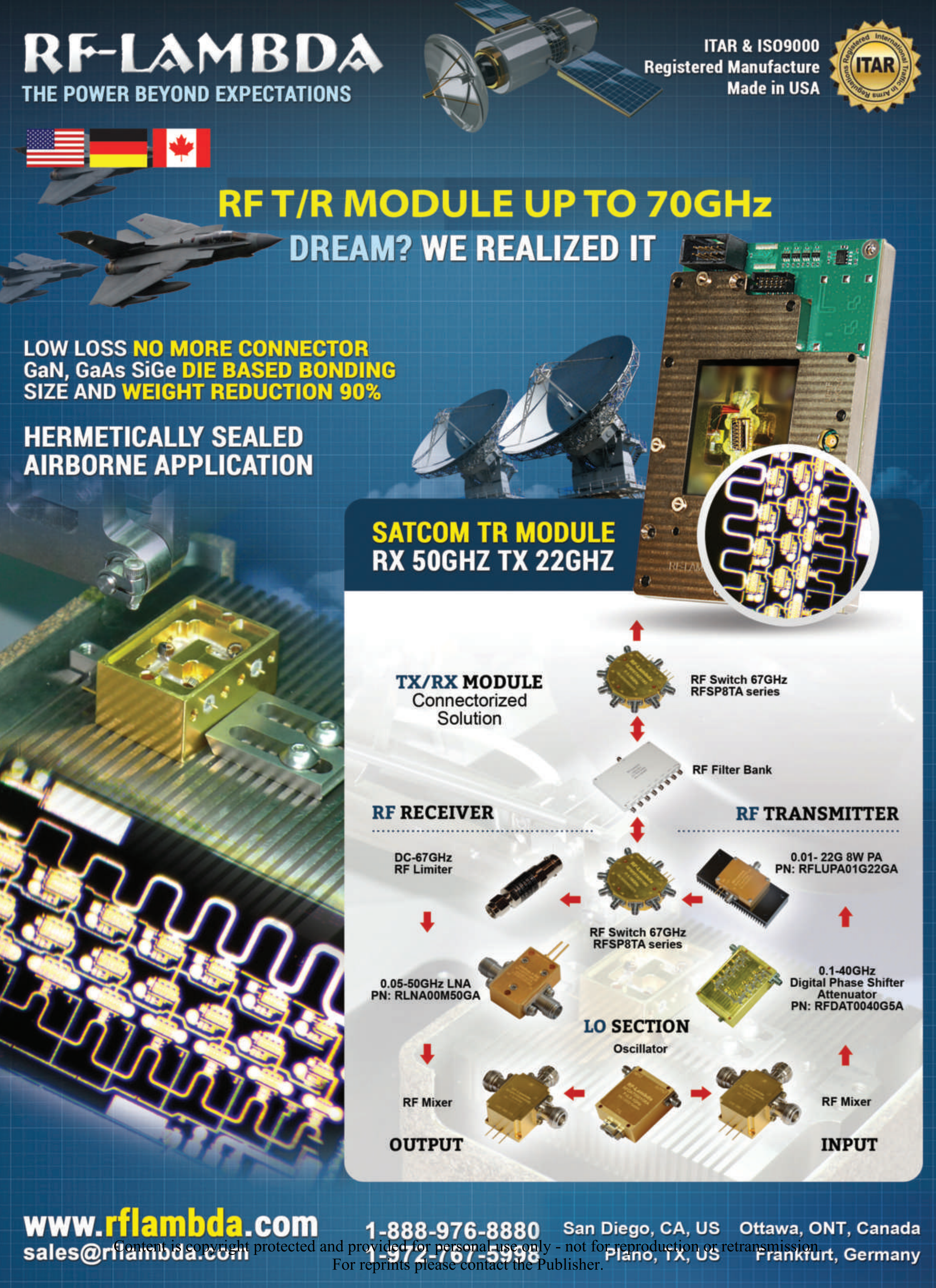
The contributors to phase noise in pulsed radar systems can be additive or absolute, with different methods used to measure them—each with advantages and disadvantages. Offering a solution for both additive and absolute measurements, the phase-locked loop (PLL) method is well suited to characterizing phase noise performance, as it provides high dynamic range with a low noise floor and is repeatable and reliable. AnaPico's APPH signal source analyzer with a new local oscillator (LO) option is a useful tool for characterizing the phase noise of pulsed signals. This article first discusses its use for absolute phase noise measurements, then addresses additive phase noise measurements of non-oscillating components such as amplifiers.



▲ **Fig. 1** **Spectrum of a pulse modulated signal with pulse width τ and pulse period T.**

ABSOLUTE PHASE NOISE

The noise of a pulsed signal consists of the noise coming from the reference and the noise introduced by the pulse modulation. ***Figure 1*** shows the spectrum of an ideal, pulsed signal with pulse period T and pulse width τ. Above the pulse repetition frequency (PRF), the pulse modulation completely masks the phase noise; therefore, data for the offset frequency above the PRF is usually omitted. Close to the PRF, the phase noise of the signal is increased by the pulse modulation: the summation of the carrier noise with the first spectral image, which is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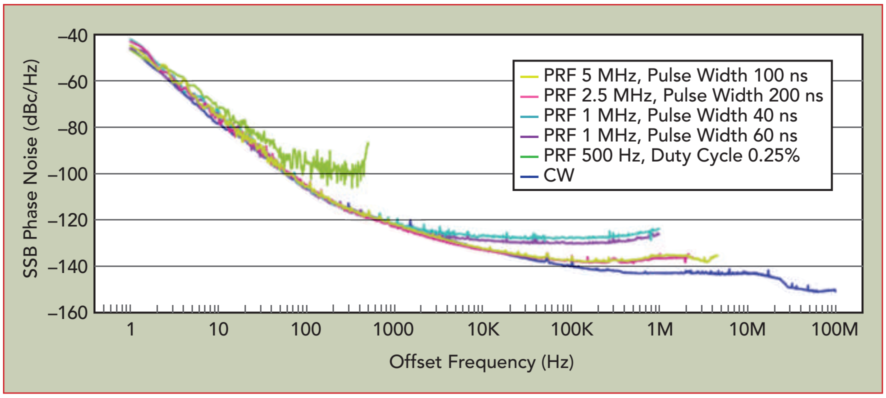

Fig. 2 **3.8 GHz pulsed signals, with pulse widths ≥40 ns and PRF ≤5 MHz.**

shifted to the right by 1/T. The increase depends on the duty cycle of the pulse modulation, τ/T, and is deterministic.

The PLL measurement method requires a tunable LO to be phase-locked to the signal of the device under test (DUT). Under pulsed conditions, maintaining phase-lock may be tricky. Rejecting instrument noise while the DUT signal is off is also challenging, particularly when measuring very short pulses or very low duty cycles. Low PRF or short pulses may lead to phase drift from phase quadrature, even to a loss of phase-lock if not properly handled. In AnaPico's APPH, sophisticated pulse detection circuitry reliably maintains phase-lock and actively rejects background instrument noise when the pulse is off. As a result, the APPH is capable of reliably measuring pulses at extreme pulse parameters (see ***Figure 2***). Since the locking process can only be active during the "on" period and has to wait during the "off" period, low pulse widths, low duty cycles and very high or very low pulse rates may prove difficult to measure. Despite these challenges, the APPH can measure pulses as short as 40 ns and PRFs from 500 Hz to 5 MHz, with duty cycles down to 0.1 percent.

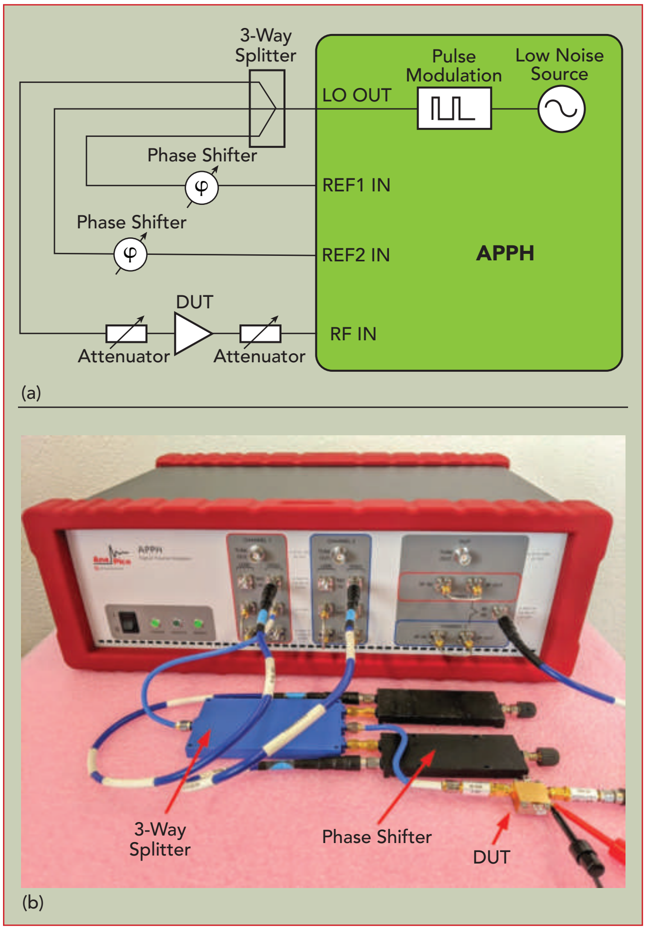

Fig. 3 **Pulsed additive phase noise measurement using the internal LO of the APPH: block diagram (a) and photo (b) of the setup.**

ADDITIVE PHASE NOISE

Phase noise in radar systems comes from various sources, not only the frequency synthesizer: most notably, the pulse modulator and power amplifiers. So, when analyzing a pulsed radar system, it is informative to assess the added phase noise from the amplifier stages. To measure additive noise, the amplifier must be operated under real conditions using a low noise, pulse-modulated signal source.

The LO output of the APPH signal source analyzer can be used for this. ***Figure 3*** shows the setup of a two-channel, cross-correlated additive phase noise measurement of an amplifier. The pulsed driving signal for the DUT is synthesized directly in the APPH and split into three paths and fed into the two REF inputs and the RF input of the signal source analyzer. Besides a three-way splitter, only two mechanical phase shifters are required to tune the reference paths into phase quadrature, where the phase noise of the driving signal is cancelled and the residual noise of the DUT can be measured. The cross-spectrum measurement rejects instrument noise and substantially enhances instrument sensitivity. The APPH software guides the user through two calibration steps, making the measurement virtually as simple as an absolute phase noise measurement.

SUMMARY

AnaPico's APPH signal source analyzers enable easy and reliable measurements of the absolute and additive phase noise of pulsed signals up to 65 GHz. Using an advanced PLL method, the analyzer provides great dynamic range and, combined with cross-correlation analysis, low noise floor. The instrument offers intuitively usable standard (option PULSE) or enhanced (option NPS) pulse measurements. The newly released LO front-end option provides access to the internal low noise, pulsed signal sources, eliminating the need for external sources to measure additive phase noise and making the measurement setup faster and more intuitive.

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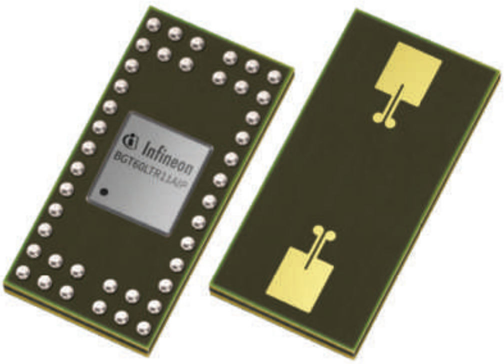

Autonomous Radar Sensor Enables Smart Motion Sensing

Infineon Technologies AG
Munich, Germany

Infineon's new autonomous radar sensor adds "smartness" to traditional motion sensing applications, like lighting control, automated door opening and security alarms (see ***Figure 1***). The XENSIV™ 60 GHz radar sensor BGT60LTR11AIP is a Doppler motion sensor using the 60 GHz ISM-band, provided as a single package radar solution. Operating in autonomous mode, the radar can detect a human at a distance up to 5 m, while consuming less than 5 mW.

Its high level of integration overcomes the complexities of antenna design, RF knowledge and radar signal processing. The radar sensor can be hidden inside a product, since it transmits and receives through non-metallic materials, enabling the adoption of radar technology into daily life. The sensor can be integrated into systems like laptops, tablets, TVs and speakers, awakening them when it detects motion or direction of motion. When no motion is detected for a defined time, it can put systems to sleep or lock them, saving power and eliminating the need for a keyword to activate the system.

Fig. 1 **Radar sensors enable traditional motion sensing applications to become smarter.**

LOW-POWER DOPPLER RADAR

Figure 2 shows the functional block diagram of the BGT60LTR11AIP MMIC. The MMIC package includes one transmit and one receive broad-beam antenna. The two antennas have horizontal and vertical half-power beamwidths of 80 degrees for maximum coverage.

An integrated voltage-controlled oscillator (VCO) generates the 60 GHz radar signal, which is stabilized by a phase-locked loop. The transmit signal chain consists of a medium power amplifier with configurable output power, controlled via the serial peripheral interface (SPI). Integrated power detectors monitor the transmitted power. The MMIC has a low noise quadrature receiver

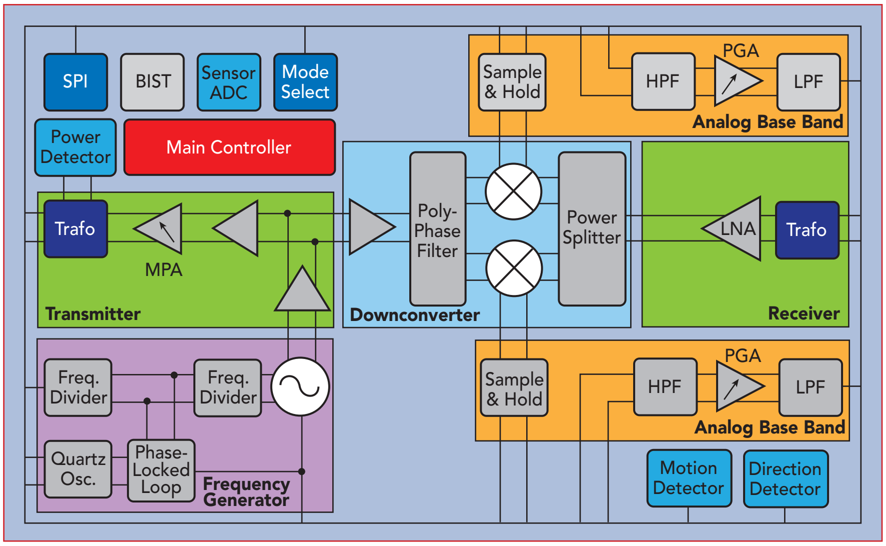

Fig. 2 Functional block diagram of the motion sensor.

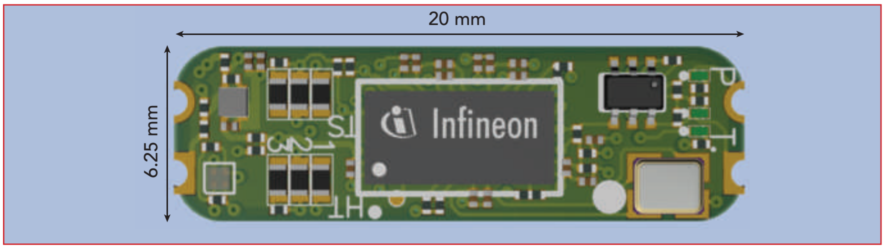

Fig. 3 The PCB holds the supporting circuitry for the motion sensor MMIC.

with a low noise amplifier in front of a quadrature homodyne down-conversion mixer, which provides excellent sensitivity. Derived from the internal VCO signal, a RC polyphase filter generates quadrature local oscillator signals for the quadrature mixer.

The integrated analog baseband consists of a sample-and-hold circuit for low-power, duty-cycled operation, which is followed by an externally configurable highpass filter, a variable gain amplifier and a lowpass filter. The integrated target detectors are analog comparators generating pulses based on target movements in front of the radar. The detectors provide two digital output signals, one indicating motion and the other the direction of motion—approaching or departing—of a target. The detector circuitry offers a user-configurable hold time, hit counter and detection threshold, which provide flexibility and robustness against false alarms. Hold time is the duration the output of the detectors remain active after target detection, and hit counter refers to the number of comparator output pulses required to determine valid target detection.

To provide flexibility in setting the performance parameters, even when running in autonomous mode, the MMIC has four quad-state input pins, QS1–QS4 (see ***Table 1***). For example, with QS2, users can select among four threshold values to increase or reduce detector sensitivity. For experienced radar users, semi-autonomous and SPI operating modes can be selected with the QS1 pin. In these modes, raw radar data can be extracted for signal processing with customized algorithms on a PC or external microcontroller via the SPI. For external processing, the evaluation board can be attached to an Arduino MKR board or an Infineon radar baseboard (MCU7).

Infineon's Toolbox supports the BGT60LTR11AIP MMIC platform with demonstration software and a radar graphical user interface, which displays and analyzes the acquired data in the time and frequency domains. The sensor meets the ETSI and FCC regulations.

TABLE 1

QUAD-STATE PARAMETER SETTINGS

QS	Parameter
1	Radar Operation Mode
2	Detector Sensitivity (Comparator Threshold Voltage)
3	Signal Hold Time After Target Detection
4	Device Operating Frequency

EASY TO USE

As a fully integrated microwave motion sensor, the BGT60LTR11AIP provides both motion and direction of motion information, and a state machine controls the device. In fully autonomous mode, the radar offers unprecedented simplicity.

The small 3.3 × 6.7 × 0.56 mm MMIC includes two antennas within its two-layer laminate package, which eliminates the complex antenna design for the user. It also enables standard FR4 materials to be used for the PCB design with this MMIC. The BGT60LTR11AIP MMIC requires little support circuitry (see ***Figure 3***): a low noise voltage regulator, a 38.4 MHz crystal oscillator and external capacitors. Two LEDs indicate the functioning of the radar sensor: green when a target is detected and red for direction of motion.

In addition to simplifying system integration, this all-in-one solution enables fast prototyping for evaluating product features. The demonstration board shown in Figure 3 is a turnkey solution to show the features of the radar sensor MMIC, and it can be used as is for a system, by connecting a power supply between the VCC and ground connections on the board.

The BGT60LTR11AIP MMIC is a small, compelling and cost-effective replacement for conventional passive infrared sensors in low-power or battery-powered applications.

Infineon Technologies AG
Munich, Germany
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¼ W Cellular PAs: Linear Without DPD or CFR

Guerrilla RF
Greensboro, N.C.

Guerrilla RF is introducing a family of 10, ¼ W linear power amplifiers (PA), part of the company's expansion into the cellular market (see ***Table 1***). These new InGaP HBT amplifiers were designed specifically for 4G and 5G wireless infrastructure applications requiring exceptional native linearity over temperatures from -40°C to 85°C. The GRF55xx family covers the primary 4G

TABLE 1

GRF55xx FAMILY PART NUMBERS AND AVAILABILITY

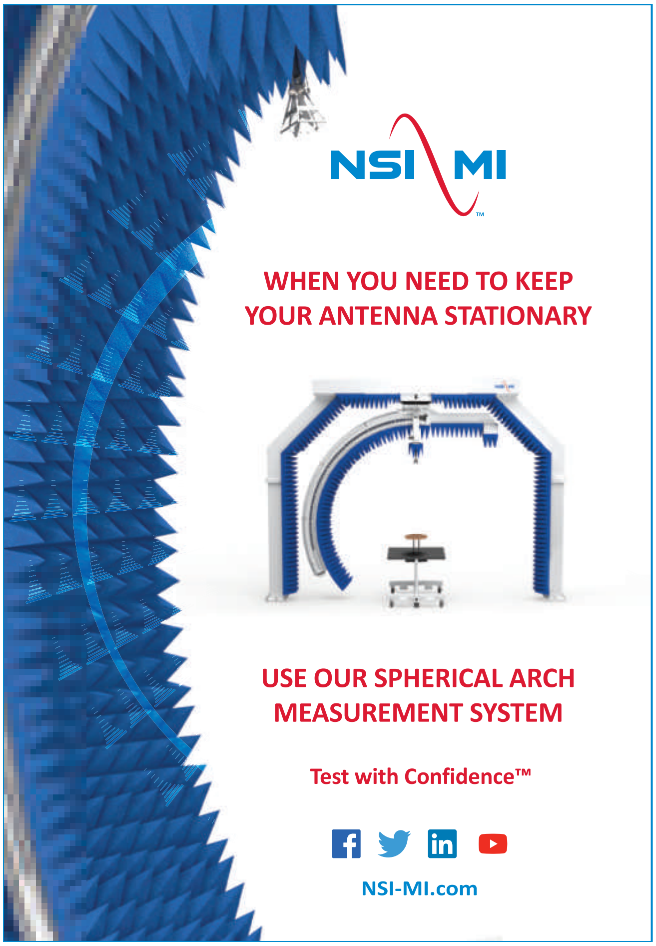
Cellular Band (MHz)	660-720	699-798	824-894	880-960	1710-1785	1805-1910	1920-1990	2110-2170	2500-2700	3400-3800
Part No.	5506	5507	5508	5510	5517	5518	5519	5521	5526	5536
Release	Production Samples Now								Samples in Q4	

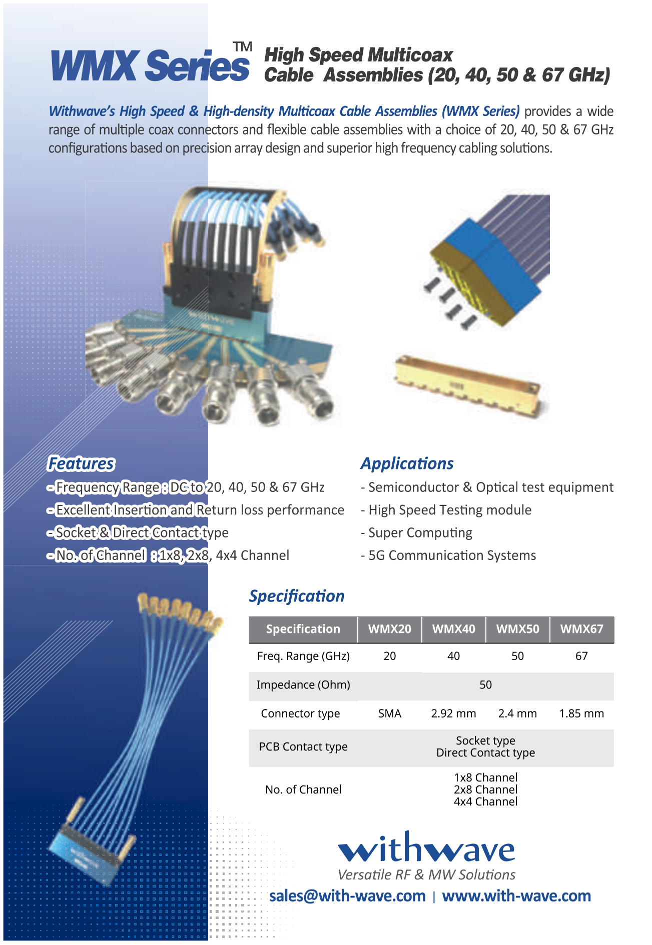
and 5G cellular bands between 660 and 3,800 MHz. When amplifying a 10 MHz LTE waveform, each device delivers 24 dBm of linear power over the entire temperature range while maintaining an adjacent channel leakage ratio (ACLR) better than -45 dBc, error vector magnitude (EVM) less than 1 percent, third-order intermodulation (IMD3) under -20 dBm and power-added efficiency (PAE) greater than 15 percent—without the aid of supplemental linearization schemes like digital predistortion (DPD) or crest factor reduction (CFR). ***Figure 1*** shows the native ACLR, EVM, IMD3 and PAE versus output power of the GRF5507, a PA covering the 699 to 798 MHz cellular band.

The ability to beat the -45 dBc ACLR performance metric without DPD or CFR is critical for cellular systems like home and commercial repeaters and boosters, femtocells, picocells and cable loss compensators that feed automotive "shark fin" antennas. With each of these, the sensitivity to cost, power and size prohibits using elaborate linearization like DPD and CFR. Instead, designers must rely on the power amplifier's native linearity to meet the stringent emissions mask requirements imposed by the 4G and 5G standards.

Although these MMICs are well suited for non-DPD applications, they are also compatible with transmitters where supplemental linearization is available. When used with DPD and CFR, the GRF55xx PAs yield another 2 to 3 dB of output power while maintaining ACLR better than -45 dBc. In such applications, the ¼ W family effectively provides ½ W output power with efficiencies of 25 to 30 percent. ***Figures 2*** and ***3*** show the GRF5510 PA's native ACLR and EVM performance and improvements using DPD and CFR. The GRF5510 MMIC covers the 880 to 960 MHz cellular band.

During the development of the GRF55xx series, Guerrilla RF consulted with its customers to ensure the devices in the family deliver the best blend of power and linearity to maximize the effective





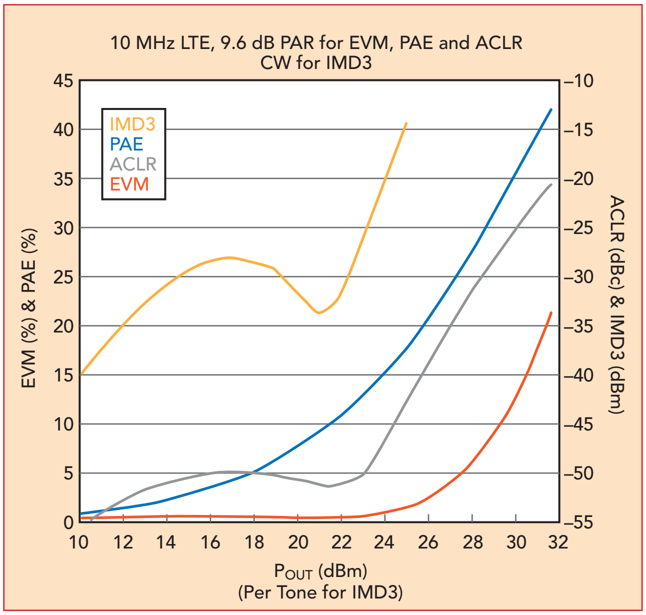


Fig. 1 GRF5507 performance vs. output power at 85°C.

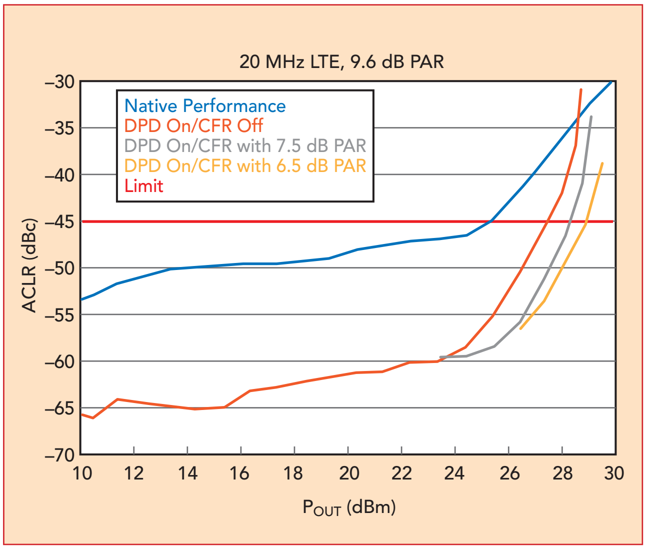


Fig. 2 GRF5510 ACLR performance vs. output power.

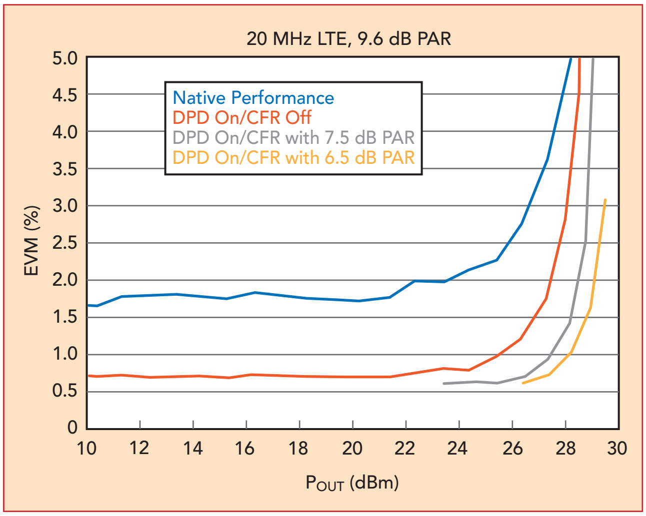


Fig. 3 GRF5510 EVM performance vs. output power.

range and throughput for their cellular systems. The designs tune the internal harmonic terminations of each device to achieve the best native linearity, and these specialized harmonic matches drove the need for a family of amplifiers, each one tuned for a cellular band. Despite the unique tuning, each PA in the family has a common pinout and footprint, enabling coverage of many cellular bands using a single printed circuit board (PCB) layout.

In addition to its excellent native linearity, the GRF55xx series is exceptionally rugged. Design enhancements were implemented on each stage to ensure the devices are resilient to poorly matched loads. This is critical for applications where the load can be inadvertently compromised, like disconnecting an antenna and exposing the final stage to VSWRs much greater than 2:1. Ruggedness testing of each member of the family validated that when the PAs are subjected to extreme 8:1 VSWR loads, they will sustain input drive levels as high as 10 dBm on the sub-1 GHz designs and up to 23 dBm on the mid-band family (see ***Figure 4***). The data points represent survivable operation when the PA is subjected to an 8:1 VSWR load swept through all phase angles and over the full -40°C to +85°C operating temperature range.

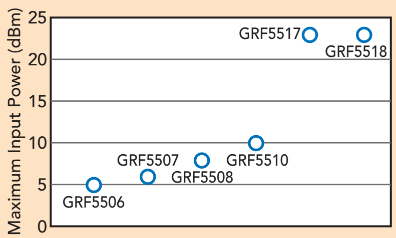


Fig. 4 **Maximum survivable input power with up to 8:1 output VSWR.**

With the previously released 5 W GRF5504/9 PA series, these new ¼ W MMICs serve as the beachhead for Guerrilla RF's expansion into the growing 5G PA market. Production samples and evaluation boards are available now for the low- and mid-band products, with the remaining members of the family coming by year-end. Each PA in the GRF55xx family is assembled in a pin-compatible, 3 mm × 3 mm, 16-pin QFN package. The common footprint enables a single PCB design to address multiple bands simply by swapping the PA MMIC.

Guerrilla RF
Greensboro, N.C.
www.guerrilla-rf.com

PCB Simulation Suite Improves Design Performance, Reduces Development Time and Cost

Avishtech, LLC
San Jose, Calif.

As the industry shifts toward higher speed designs and next-generation wireless communications, insertion loss and the ability to predict it have become constraints to achieving higher speeds. While the industry has been working on increasing data rates through new signaling techniques, loss modeling leaves much to be desired, requiring multiple revisions of signal integrity (SI) test vehicles—a very expensive and time-consuming process that may take many months before completing loss validation. Another pain point is caused by the increasing number of inputs and outputs on devices, yet miniaturizing circuits to be compact. As such, dimensional deformation, coefficients of thermal expansion (CTE) and the moduli play major roles in determining manufacturability and reliability. Products designed solely for optimizing SI may suffer from unintended poor reliability, costing major delays in time to market.

Recognizing this, Avishtech has built tools to help solve these challenges in an integrated, multidisciplinary fashion—not in silos. Avishtech has released two products: Gauss 2D, to address SI issues, and Gauss Stack, for the thermomechanical, manufacturability and reliability concerns.

Gauss 2D is an electromagnetic (EM) field solver that goes beyond other offerings by providing extremely high accuracy and granularity, coupled with additional features. Gauss 2D provides more than basic impedance information for a printed circuit board

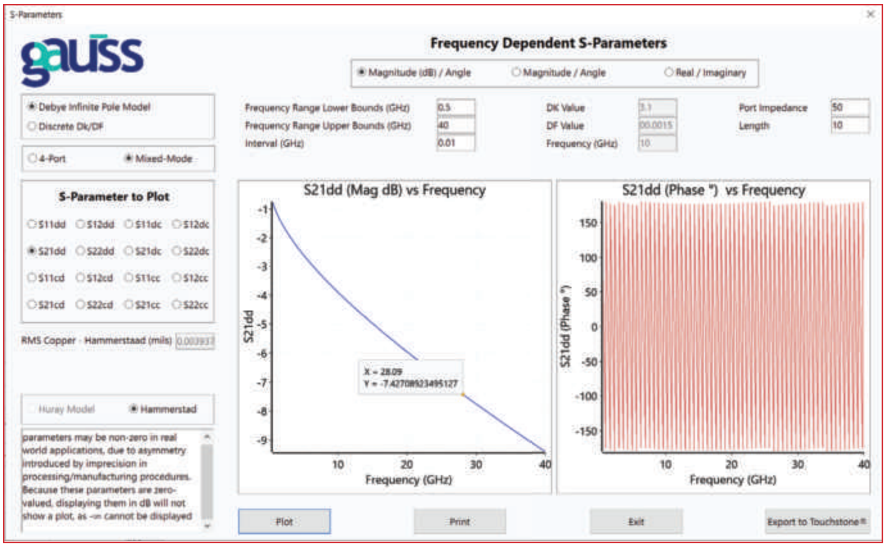


Fig. 1 Gauss 2D S-parameter interface, showing a 10 in. long differential stripline.

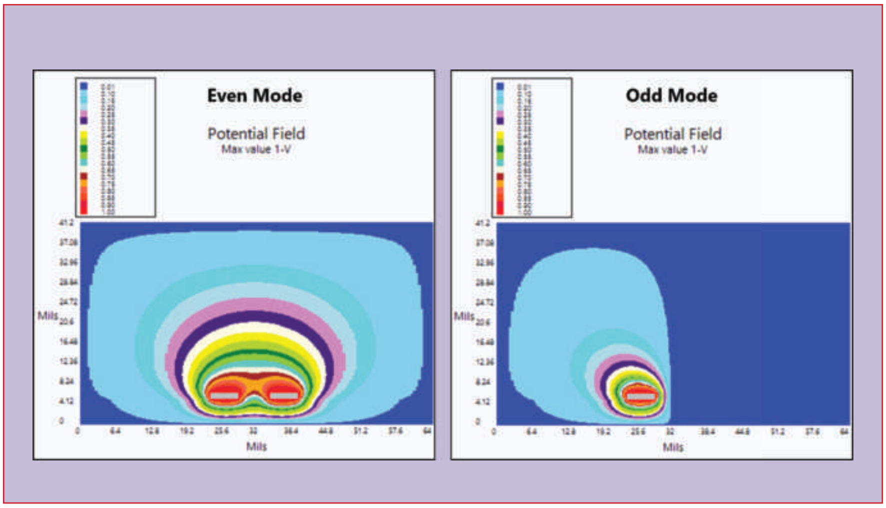


Fig. 2 Electric potentials for even and odd modes of a differential microstrip trace.

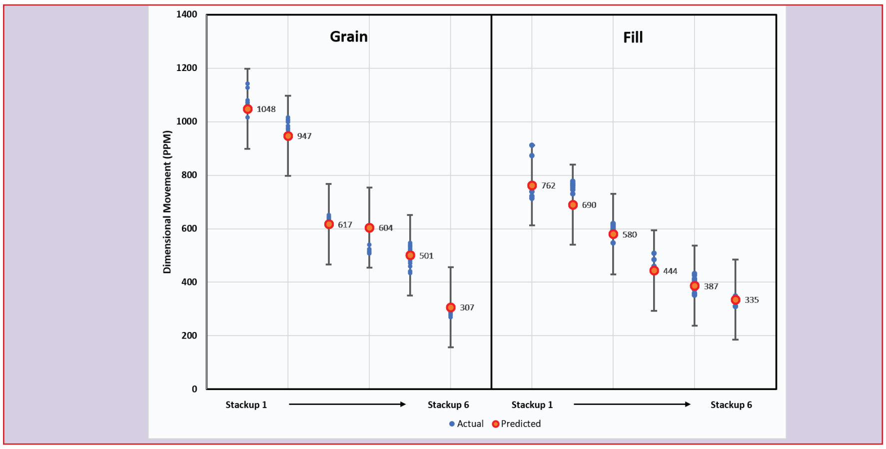


Fig. 3 Gauss Stack predictions vs. measurements of test vehicle boards. The bars represent 150 ppm from the Gauss Stack predictions and contain all the measurements.

(PCB) transmission line:

- Detailed loss information, including accurate conductor loss to account for the proximity effect
- Full RLGC parameters, including matrices for multiconductor configurations
- Frequency-dependent modeling and projection of these properties, including frequency-dependent S-parameters (see ***Figure 1***)
- Crosstalk calculations for differential and multiconductor configurations
- Dielectric property extraction

Gauss 2D also provides visualization of the electric potentials and fields, giving deeper granularity and further insight into concerns like coupling and interference (see ***Figure 2***). The ability to predict losses accurately helps avoid multiple iterations of test vehicles on different material sets and different copper types.

Gauss Stack is the industry's first and only complete simulation environment for PCB stackups, enabling users to rapidly design a stackup and conduct high fidelity thermomechanical and electromagnetic simulations. The thermomechanical simulations address dimensional stability and reliability, among other issues. Gauss Stack is the only tool that predicts dimensional movement for the grain and fill directions for each core layer in a stackup. Anyone who has worked in a PCB shop can attest that manufacturing PCBs is a complex process, in part from iterating through compensation factors to achieve successful circuit registration between layers. Gauss Stack's highly accurate predictions enable a board shop to bypass this expensive and lengthy process of compensating through scout lots and databases. Boards can be built correctly the first time—a key enabler of quick-turn capabilities benefiting both board shops and customers, as well as improving yield.

Figure 3 compares the predictions from Gauss Stack with measurements of test vehicle boards.

Lam. Temp. (°C)	205	Panel Size X (mm)	400	Resin Density (g/cm³)	1.45	Alpha X (PPM/°C)	20.06	Ex (GPa)	21.957	Gxy (GPa)	8.864	vxy	0.239
Bond. Temp. (°C)	155	Panel Size Y (mm)	350	Tg (°C)	160	Alpha Y (PPM/°C)	20.13	Ey (GPa)	21.875	Gxz (GPa)	8.410	vxz	0.305
Flow Factor	0.005	Resin Mod (GPa)	5.50	Resin Poisson Ratio	0.33	Alpha Z1 (PPM/°C)	73.71	Ez (GPa)	7.803	Gyz (GPa)	8.372	vyz	0.306
Resin System	170 Tg Filled Low	GS Tol (mils)	0.1	Resin CTE (PPM/°C)	55	Alpha Z2 (PPM/°C)	271.91	Warp (mm)	0.00				

Fig. 4 Material properties for a resin system used in a stack (left) and Gauss Stack thermomechanical outputs (right).

ProductFeature

The bars in the plots show a 150 ppm range around Gauss Stack's predictions, which includes all the measured data. The overwhelming majority of the data points are within a small fraction of the 150 ppm bounds. This confirms aggressive registration targets can be met using Gauss Stack's predictions, eliminating scout lots.

With Gauss 2D, simulation is easy using its extensive set of predefined geometric configurations with detailed information and accuracy—literally seconds to set up a problem. These include the traditional microstrip and stripline configurations, as well as coplanar waveguide, multiconductor and dual dielectric configurations. Gauss 2D accounts for dielectric anisotropy, which enables the user to input Dk and DF properties in both perpendicular and parallel directions. Gauss 2D can also synthesize, enabling a user to "flip the problem," i.e., obtain the trace width corresponding to a target impedance. This capability is built on a nonlinear Newton solver that searches for the desired field solver solution.

Reliability is a critical consideration in PCB design. From an SI standpoint, many "ideal" PCB designs can have low reliability, due to high stresses or significant mismatches in material properties. An extremely low loss design with perfect SI behavior means nothing if the board fails during assembly. Gauss Stack enables designers to obtain key board properties in all three dimensions: CTE, elastic and shear moduli and Poisson's ratios, all at board level. These properties cannot be calculated by any other tool, and they are the primary inputs—with or without a separate CAD model—for granular reliability simulations of cycles to failure. Gauss Stack calculates X and Y stresses for each material layer, providing insight into the reliability of a design and the impact of changing resin content, glass style, number of plies and other stackup parameters.

To illustrate, the screenshot in ***Figure 4*** shows the material properties for a chosen resin system in a stackup (on the left), with Gauss Stack's thermomechanical outputs (on the right). These outputs enable reliability simulation by accurately accounting for the bulk properties of the PCB. In addition to the comprehensive thermomechanical data, the built-in Gauss 2D engine calculates impedance and can synthesize the entire stackup—up to three single-ended and three differential traces per signal layer. All the transmission lines for an entire stackup can be designed with a single click after specifying the target impedances. This paired with Gauss Stack's extensive vendor-specific materials library make designing a PCB stackup a breeze.

The Gauss suite of products provides deep insights not available with other simulation programs, combining extreme accuracy with ease-of-use. As important, Gauss 2D and Gauss Stack enhance design productivity by reducing complex steps—which can take days, weeks or longer—to simple tasks that take just minutes. The result: reduced time, cost and risk.

Avishtech, LLC
San Jose, Calif.
www.avishtech.com

Low Loss, Highly Stable Cable Assemblies for Probe Stations

Probe stations allow a user to position electrical, optical or RF probes on a silicon wafer and connect them to a vector network analyzer so that the device can be tested. Using high-end cabling in a probe station is crucial: cables must be low loss, lightweight and both phase and amplitude stable against temperature, flexure and vibration. This is because once calibrated, the cable must function accurately for a long period of time. If the cable is not phase stable, it can quickly degrade a system, producing inaccurate data and requiring regular re-calibration. A further important consideration is the connectors, which help to keep the probe tip (which requires micrometer accuracy) stable.

Junkosha's MWX001 cable assembly features the lowest insertion loss among any cables for measuring applications requiring flexibility and, as a result, is increasingly becoming the system of choice for probe stations. Cable insertion loss is minimized due to its cable structure, which is optimized for measurement up to 110 GHz. MWX001 also exhibits excellent phase stability, high quality signal transmission and strong form-sustainability. A safety-lock mechanism is available to preserve the 1.0 mm connector's central pin.

Alongside radar, space and defense sectors, the key application area for MWX001 is 5G. Bringing reduced latency and improved data rate, 5G is designed to interconnect devices, machines and people closer than ever before—known as the Internet of Things. This enables a future of advanced technology including autonomous vehicles, smart cities and virtual reality, each bringing more sophisticated chipsets and thus increasing the requirement for efficient probe station testing and high-end cabling. It is here that Junkosha is innovative in delivering an optimized solution for these applications.

Junkosha
Irvine, Calif.
www.junkosha.co.jp/english
Tel: +1-949-825-6177

mmWave Component Library Aims to Improve 5G Design Success

The Modelithics® mmWave & 5G Library is a collection of models developed for the next generation of cellular communications. All models in the library are validated to 30 GHz—some to 125 GHz—so all can be used for designs in the latest mmWave 5G frequency bands. Modelithics' models are available for six RF/microwave simulation software platforms: Keysight Technologies' PathWave Advanced Design System, Keysight Technologies' PathWave RF Synthesis (Genesys), Cadence AWR Design Environment, Ansys HFSS, Sonnet Suites and Cadence Virtuoso Spectre RF.

The models in the Modelithics mmWave & 5G Library are measurement-based, developed from multiple, specialized measurements at test conditions tailored for each device. Most of the capacitor, inductor and resistor models are Microwave Global Models™, meaning the models scale with the part value, substrate and solder pads, making them well-suited for tuning and optimization. Every model comes with a datasheet showing the parameters, recommended model validity, test fixture and measurement details and model-to-measured data plots.

Many suppliers are represented in the Modelithics mmWave & 5G Library, including AVX, Coilcraft, Mini-Circuits, Piconics and Presidio. For example, the CAP-MUR-0201M-103 is a Microwave Global Model for the Murata 939118492510 silicon capacitor, which has been validated from DC to 110 GHz. The CAP-PPI-0201BB-001 model for the Passive Plus 0201BB surface-mount chip capacitor family features substrate scalability and has been validated from DC to 65 GHz.

A free evaluation of the Modelithics mmWave & 5G Library is available.

VENDORVIEW

Modelithics Inc.
Tampa, Fla.
www.modelithics.com
sales@modelithics.com

1 MHZ TO 40 GHZ

Programmable Attenuators

High-Accuracy Level Control

- Attenuation ranges up to 120 dB
- Step size as small as 0.25 dB
- Single-channel and multi-channel models
- USB, ethernet, RS232 and SPI control options
- Plug and play GUI and robust API included
- Designed and manufactured in-house

8-Channel Attenuator Ready for Wi-Fi 6E Testing

As Wi-Fi 6E quickly follows Wi-Fi 6, device manufacturers are gearing up to provide the many benefits it will offer. The new IEEE wireless standard adds non-overlapping channels and access to the 6 GHz band with 1200 MHz of contiguous spectrum. This has the potential to vastly improve network efficiency and increase throughput per user 4x in signal-congested areas. Wi-Fi 6E also consumes less power, which should prolong battery life in mobile devices.

With these advantages in mind, AdauraTech developed its eight-channel programmable attenuator for high performance RF design and testing. From 50 MHz to 8 GHz, the AD-USB8AR38G95 provides 95 dB attenuation with a resolution of 0.25 dB and greater than 120 dB of interchain isolation. The frequency range exceeds the 7.125 GHz upper threshold of the unlicensed 6 GHz band recently approved by the FCC for Wi-Fi 6E, making the programmable attenuator well suited for the latest generation of Wi-Fi MIMO testing, as well as sub-6 GHz cellular (3G, 4G, 5G) and IoT.

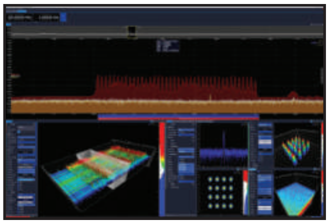
Each of the eight channels can be controlled discretely, with control and power via a built-in USB connection or integrated power over Ethernet port. AdauraTech's "zero software" platform streamlines setup and control using a browser-based graphical interface, with HTTP REST commands and direct Telnet connections requiring no additional software or drivers. The R3 series is agnostic of the operating system, working equally well with Windows, Linux or macOS.

Housed in a single, custom-machined, aluminum enclosure, the compact AD-USB8AR38G95 eight-channel programmable attenuator is the standard bearer in the company's new R3 series product line.

Adaura Technologies
Roseville, Calif.
www.adauratech.com

RTSA-Suite Pro Software Now Available

VENDORVIEW



The new RTSA-Suite Pro is a powerful real-time spectrum analysis software which is available for the new SPECTRAN® V6 X USB-RealTime Spectrum Analyzer for free. It can display and analyze any received or recorded data from a nearly unlimited number of SPECTRAN analyzers. The software is being updated and expanded with new features almost daily. Furthermore, the integration of various hardware components allows optimal settings for drone detection, especially in the area in which Aaronia's AARTOS system is to be used.

Aaronia AG
https://aaronia.com/software/

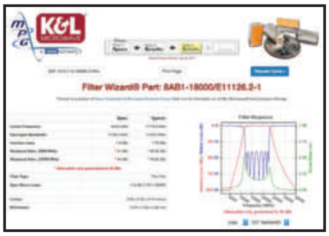
HUBER+SUHNER EMP Protector Tool Box

VENDORVIEW

The EMP Tool Box allows an easy selection of the best product considering the individual requirements, by filtering various parameters. Finding the right EMP protectors and appropriate gas discharge tube or calculating the transient response of a HEMP. In addition to these features, the connector and RF power section demonstrates a graph of the admissible RF (CW) power versus frequency of the nine most common interfaces used for surge protectors. Find the best products for your needs: http://empselector.hubersuhner.com.

HUBER+SUHNER AG
www.hubersuhner.com

K&L Microwave's On-Line Filter Synthesis Tool



K&L Microwave's Filter Wizard® filter synthesis and selection tool streamlines identification of filter products meeting customer specifications across a large portion of K&L's standard product offerings. Filter Wizard® accelerates user progress from specification to RFQ for RF and microwave filters spanning an ever-increasing range of response types, bandwidths and unloaded Q-values. Provide the application with your desired specifications and the software will return a list of products that match, placing response graphs, outline drawings and downloadable S-parameters at your fingertips.

K&L Microwave
www.klfilterwizard.com

Microwave Calculator App

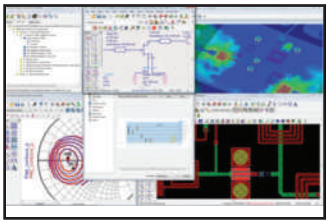
VENDORVIEW

Mini-Circuits is excited to announce the newest version of their Microwave Calculator app for iOS and Android devices. Designed specifically for RF and microwave engineers, the newly renovated app now includes 31 calculations and an improved user interface to make calculations more accessible for engineers in the lab, in the field or on the fly. Mini-Circuits is pleased to offer this tool for FREE as part of their commitment to support industry peers with innovative resources to make your job easier.

Mini-Circuits
www.minicircuits.com/applications/microwave_calculator.html

Modelithics' COMPLETE Library v20.5 for Keysight ADS

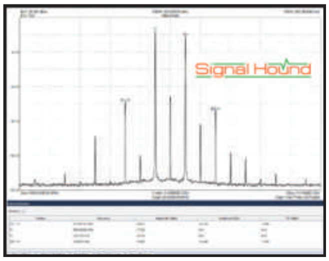
VENDORVIEW



Modelithics has released the newest version, version 20.5, of the COMPLETE Library for use with Keysight Technologies' PathWave Advanced Design System (ADS) software platform. Version 20.5 includes 23 new circuit simulation models, representing over 3,850 components and adds compatibility with Keysight PathWave ADS 2021. The Modelithics COMPLETE Library is comprised of a large selection of highly scalable Microwave Global Models™ of passive and active components. The library is an indispensable collection of simulation models for all types of passive and active RF and microwave devices engineered to enable designers to go from concept to product faster and easier.

Modelithics Inc.
www.Modelithics.com

Signal Hound's Spike™ Spectrum Analysis Software



Intermodulation distortion causes unwanted interference in RF systems, occurring when multiple signals pass through a nonlinear system and modulate each other. Signal Hound's Spike™ spectrum analysis software includes a new intermod distortion panel which allows engineers to measure and continuously monitor problematic artifacts with the click of a button. With the measurement enabled in Swept Analysis Mode, special markers are placed on the active trace so critical information can be absorbed at a glance.

Signal Hound
https://signalhound.com

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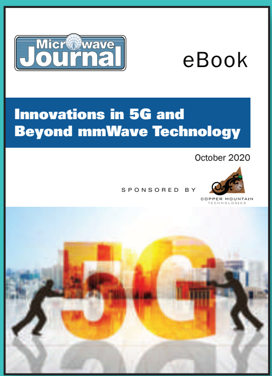

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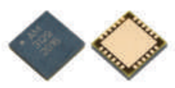


AM3129 is a miniature voltage-tunable notch filter bank covering the 1 to 6 GHz frequency range in a 9 mm QFN package. Six notch filters and two bypass paths with SP8T switches on the input and output are contained in the multichip module. Separate tune voltages provide precise control of center frequency and notch bandwidth. AM3129 provides an excellent filtering solution for receivers or transceivers requiring flexible frequency rejection, high dynamic range, low insertion loss, small size, weight and power consumption.

Atlanta Micro Inc.
www.atlantamicro.com

Fixed Waveguide Attenuators

Eravant is introducing a new line of precision fixed waveguide attenuators. They are manufactured with wire EDM to ensure high accuracy and a smooth internal finish. The attenuators feature anti-cocking flanges to reduce misalignment errors and sandblasting treatment to provide a durable, aesthetically appealing outer finish. WR-15 through WR-10 models are in stock right now. Other models (WR-42 through WR-06) are in development and scheduled to be released throughout the rest of the year.

Eravant
www.eravant.com

RF Hybrid Couplers

VENDORVIEW

Fairview Microwave Inc., an Infinite Electronics brand and a leading provider of on-demand RF, microwave and mmWave components, has extended its RF hybrid coupler product line with new models to meet high frequency component demands. These high performance hybrid couplers are ideal for RF applications requiring an equal split of input and output ports with 90-degree or 180-degree phase shifts while maintaining high isolation between ports. Fairview's 21 new RF hybrid coupler models feature a coaxial design with SMA and 2.92 mm connectors.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Ultra-Broadband Bias Tees

HYPERLABS Inc. has developed a line of ultra-broadband bias tees with bandwidths extending from 35 kHz to over 67 GHz that can be used to apply or monitor a DC voltage on high speed data or RF signaling. Model number HL9447 has a maximum insertion loss of 1.25 dB and offers a 175 mA current rating on the DC port. The HL9547 is a higher power offering with a current rating of 1000 mA and a typical 2.0 dB insertion loss.

HYPERLABS Inc.
www.hyperlabs.com

26 to 34 GHz, 20 dB Directional Couplers

VENDORVIEW

MECA expanded offering of 5G mmWave products. Featuring 10 dB couplers covering 26 to 34 GHz with 2.92 mm interfaces. Typical specifications of 1.5:1 VSWR, 15 dB directivity, 1 dB insertion loss and .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 U.S. and 36-month warranty.

MECA
www.e-MECA.com

Digitally Controlled Analog Phase Shifter

VENDORVIEW

Model number PS-12-360-QQ1470 Option 107 is a 1.7 GHz, digitally controlled analog phase shifter with capability for phase shifting from 0 to 360 degrees. The unit consists of an analog phase shifter and a digital-to-analog converter. Eight logic input lines allow 256 discrete values of phase. This particular unit operates at 1.7 GHz with 360-degree minimum phase shift. An eight-bit digital control sets the phase with 1.41-degree resolution and switching time is 200 nS. Insertion loss is typically 4 dB and worst case insertion loss is 6 dB.

Planar Monolithics Industries Inc.
www.pmi-rf.com

Low ESR Capacitor Assemblies

VENDORVIEW

RFMW announced design and sales support for Knowles - Novacap SV Series capacitor assemblies. SV series capacitors offer high capacitance-to-volume ratio, low equivalent series resistance and low equivalent series inductance while reducing overall circuit board footprint. Vertical stacking of ceramic capacitors provides far superior performance than either aluminum or tantalum electrolytic capacitors. Up to ten, same size chips, may be stacked with various lead configurations to safeguard against thermal and mechanical stresses as with the SV2220BB476M101LNW-10R, 47uF 100V (VDCW) assembly.

RFMW
www.rfmw.com

5G Dual-Channel Receiver Front Ends

Richardson RFPD, an Arrow Electronics company, announced the availability and full design support capabilities for a family of RF and mmWave front-end modules from Analog Devices Inc. These dual-channel receiver front-end multichip modules are designed for time division duplexing applications that operate from 2.4 to 4.2 GHz (ADRF5545A), 3.7 to 5.3 GHz (ADRF5547) and 1.8 to 2.8 GHz (ADRF5549). The devices are configured in dual channels with a cascading two-stage LNA and a high-power silicon SPDT switch.

Richardson RFPD
www.richardsonrfpd.com

CABLES & CONNECTORS

High Performance Cable Assemblies

Withwave offers high performance cable assemblies with 0.047"cable diameter (flexible, semi-rigid and semi-flexible) for various kinds of interconnection solutions such as high speed testing, short range and telecommunication applications. Features include DC to 26.5, 40, 50 and 67 GHz, standard and custom cable options available and available interface: SMA, 2.92 mm, SMPM, 2.4 mm

NewProducts

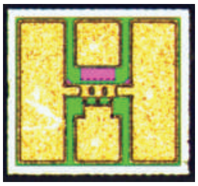
and 1.85 mm types. Applications include telecommunication systems, high speed testing and short range interconnection.
withwave co. ltd
www.with-wave.com

AMPLIFIERS

Broadband Amplifier
VENDORVIEW

The model 1000A400 is a solid-state, self-contained, air-cooled, broadband amplifier designed for applications where instantaneous bandwidth, high gain and linearity are required. The model 1000A400, when used with a sweep generator, will provide a minimum of 1000 W of RF power. Included is a front panel gain control which permits the operator to conveniently set the desired output level. The 1000A400 is protected from RF input overdrive by an RF input leveling circuit.
AR RF/Microwave Instrumentation
www.arworld.us

Low Noise Enhancement Mode PHEMT



The BeRex BCL015 is a GaAs super low noise enhancement mode PHEMT in an industry standard, bare die product. For commercial, military/Hi-Rel and test and measurement applications, this broad frequency range 1,000 MHz to 26 GHz super low noise PHEMT features 12 dB typical associated gain and 0.43 dB NF at 12 GHz, with a single positive voltage operation.
BeRex
www.berex.com

Solid-State Power Amplifier Module

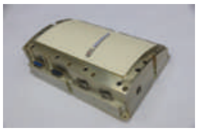
COMTECH PST introduced its latest development for the TWT replacement market covering the full 2,000 to 6,000 MHz band providing 75 W linear power in a small, compact, lightweight, ruggedized form factor, ideally suited for UAV, fixed wing, rotary wing applications. This SSPA features built-in protection and monitoring circuits, low voltage prime power input, high efficiency and reliable solid-state technology. Unit will self-protect under fault conditions and automatically return to normal operation when fault conditions are removed.
Comtech PST
www.comtechpst.com

TWT Replacement
VENDORVIEW

Exodus AMP2085D is a rugged SSPA replacing aging TWT technology. These SSPAs offer an ultra-broadband, class A/AB design for all industry standards. 2 to 8 GHz, 300 W minimum, 400 W typical and 55 dB gain. Excellent P1dB power/gain flatness compared to TWT's.

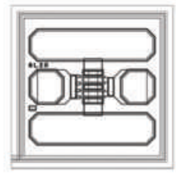
Forward/reflected power monitoring, VSWR, voltage/current/temperature sensing for superb reliability and ruggedness. The nominal weight is 75 lb. in a compact 6U chassis.
Exodus Advanced Communications
www.exoduscomm.com

X- & Ku-Band Solid-State Power Amplifiers



Kratos General Microwave's cutting-edge, field proven SSPAs are designed and built for the harshest environment conditions, including hostile temperatures, shock, vibration, moisture, altitudes and G-forces. The custom and off-the-shelf SSPAs in X-Band and Ku-Bands, utilize the latest GaN and GaAs technologies and provide high-power density in a compact footprint to meet critical space and weight requirements in high frequencies. All of its SSPAs can be supplied to meet the most stringent environmental requirements.
Kratos General Microwave
www.kratosmed.com

E-PHEMT Transistor
VENDORVIEW



Mini-Circuits' model TAV2-14LN-DC+ is a low noise E-PHEMT transistor in die form for applications from 50 MHz to 12 GHz. It features low noise and high gain when externally impedance matched and externally biased. The RoHS-compliant transistor draws typical drain-source current of 20 mA from +2 V DC and 40 mA from a +4 V DC. Matched to 50 Ω and biased at +4 V DC and 40 mA, the typical gain is 23.4 dB at 50 MHz, 16.4 dB at 6 GHz and 10.2 dB at 12 GHz. The typical output power at 1 dB compression and the same operating conditions is +17.7 dBm at 50 MHz, +19.1 dBm at 6 GHz and +19.1 dBm at 12 GHz. The noise figure at +4 V DC is typically 2.5 dB at 50 MHz, 0.7 dB at 6 GHz and 1 dB at 12 GHz, and typically 0.7 dB at 50 MHz, 0.6 dB at 6 GHz and 0.8 dB at 12 GHz for a +2 V DC supply. The transistor die is designed for drain-source voltage as high as +5 V DC and operating temperatures from -40°C to +85°C.
Mini-Circuits
www.minicircuits.com

SYSTEMS

Modular Rapid Prototyping Platform

Micram USPA is a new modular rapid prototyping platform, integrating 72 GS/s Micram VEGA ADC & DAC signal converters

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h. Total (Sum of 15f and g)		30,177	28,167
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PS Form 3526, September 2007 (Page 2 of 3)

with a broad range of Xilinx and Intel FPGAs. USPA is a flexible, programmable real-time environment for extremely high speed signal processing, a powerful toolset for telecom research, ultrafast data generation and acquisition and ASIC/SoC design applications. USPA delivers both ultrafast performance and remarkable cost effectiveness compared with custom platforms, cutting development time and cost.

Micram
www.micram.com

SOURCES

SMT Noise Sources

VENDORVIEW

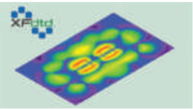
Pasternack, an Infinite Electronics brand and a leading provider of RF, microwave and mmWave products, has just released a new series of miniature SMT packaged noise sources that are ideal for built-in test equipment, dithering for increased dynamic range of A/D converters and as a source for bit error rate testing. Applications include communication systems, microwave radio, military and commercial radar, test and measurement, base station infrastructure and telecom data links. Pasternack's new noise sources include nine models with industry standard SMT gullwing pin and dual in-line pin surface mount packaging options.

Pasternack
www.pasternack.com

SOFTWARE

XFdtd Electromagnetic Simulation Software Update

VENDORVIEW



Remcom announced an update to XFdtd® 3D EM Simulation Software, with new features to address 5G mmWave antenna design challenges including support for high performance tuners and singularity correction. In addition, PCB import enhancements save time in the design workflow. As mobile devices continue to grow in complexity, engineers are challenged to include more antennas in less available space within the device while maximizing efficiency. Multi-port RF devices such as tuners and switches can be utilized to optimize band coverage.

Remcom Inc.
www.remcom.com

TEST & MEASUREMENT

6 GHz USB Real-Time Spectrum Analyzer

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Aaronia AG
www.aaronia.com/v6

Q/V-Band RF Upconverter

VENDORVIEW

The Q/V-Band offers larger bandwidths for feeder links to satellites, making it ideal for the implementation of upcoming data links with high bit rates. This includes future communications and cellular backhaul networks that can provide end users with large volumes of data. Operators of conventional geostationary satellites as well as LEO satellites in the new space environment are discovering the advantages of these new satellite bands. High demands are placed on microwave components in the Q/V-Band, which means they must undergo extensive testing during development and verification.

Rohde & Schwarz
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TotalTemp Technologies expands its offerings to include more products such as custom wide range temperature chambers. Featured here is the model C230 temperature chamber with custom apertures on four sides and +325°C to -160°C temperature range. It features time tested designs and the award winning synergy Nano temperature controller. Meet your custom requirements in a better way than with off-the-shelf solutions. Two year warranties and accessible knowledgeable support before and after the sale.

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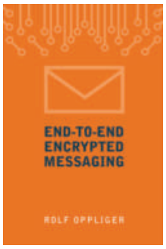

End-to-End Encrypted Messaging

Rolf Oppliger

This exciting resource introduces the core technologies that are used for Internet messaging. The book explains how Signal protocol, the cryptographic protocol that currently dominates the field of end-to-end encryption (E2EE) messaging, is implemented and addresses privacy issues related to E2EE messengers. The Signal protocol and its application in WhatsApp is explored in depth, as well as the different E2EE messengers that have been made available in the last decade are also presented, including SnapChat. It addresses the notion of self-destructing messages (as originally introduced by SnapChat) and the use of metadata to perform traffic analysis.

A comprehensive treatment of the underpinnings of E2EE messengers, including Pretty Good Privacy (PGP) and OpenPGP as well as Secure/Multipurpose Internet Mail Extensions (S/MIME) is given to explain the roots and origins of secure messaging, as well as the evolutionary improvements to PGP/OpenPGP and S/MIME that have been proposed in the past. In addition to the conventional approaches to secure messaging, it explains the modern approaches messengers like Signal are based on. The book helps technical professionals to understand secure and E2EE messaging on the Internet, and to put the different approaches and solutions into perspective.

To order this book, contact

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96th ARFTG
Microwave Measurement Conference
January 2021

The theme for the 96th ARFTG Conference is "Measurement Techniques for Accelerating the Design of 5G Circuits and Systems."

Out of an abundance of caution amid the ongoing COVID-19 pandemic, the ARFTG Microwave Measurement Symposium scheduled for 17th-20th January 2021 (Co-located with Radio and Wireless Week RWW-2021) was to be held in San Diego, CA, USA, will be a virtual event.

ARFTG is the premier conference focused on RF, microwave, and millimeter-wave measurements, calibration, and uncertainty. It has been the birthplace of many notable papers on advanced techniques, measurement standards, and linear and nonlinear device characterization and modeling. ARFTG holds two conferences a year, which include IEEE archived, technical papers, workshops, and the ARFTG/NIST short course on microwave measurements.

The Measurement Short Course, held on the first two days of the conference, is organized in cooperation with the National Institute of Standards and Technology (NIST). This course is taught in a seminar style and provides both an excellent grounding in the fundamentals as well as exposure to the latest in RF and microwave test and measurement techniques taught by the experts. Basic measurements are covered on Day 1, while additional in-depth topics are covered on Day 2. This course is not only for young engineers just starting out but also for experienced engineers who want to broaden their expertise.

The Automatic Radio Frequency Techniques Group (ARFTG) is a technical organization interested in all aspects of RF and microwave test and measurement. ARFTG was created in 1972 to help end-users get the most from the latest generation of test and measurement equipment. In the early years, the primary focus was on instrumentation, automation, and calibration. In the meantime, measurement techniques have evolved greatly, and now include such diverse topics as nonlinear measurements, production testing, temporal measurements, high-frequency fixturing and probing, multi-port network analysis, mixed-signal measurements, millimeter-wave and terahertz measurements. The broad range of interests is reflected in the themes of our conferences.

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FABS and LABS

NXP's 150 mm GaN Wafer Fab — Most Advanced RF GaN Fab in the US

NXP, the world's largest supplier of LDMOS power transistors for cellular infrastructure, has built and qualified a 150 mm wafer fab to produce its GaN on SiC power transistors. The $ 100 million investment in a dedicated GaN wafer fab in Chandler, Arizona, reflects NXP's belief in GaN's market potential in 5G.

GaN is not a new technology to NXP. Motorola—which became Freescale Semiconductor in 2004 and then merged with NXP Semiconductors in 2015—began researching GaN as an RF semiconductor technology nearly 20 years ago, when only 2-in. wafers were available. As the technology matured, the company transferred its GaN process to a foundry partner to serve its nascent production needs, with initial products shipping in 2014.

While LDMOS has been the dominant base station power transistor technology for three decades, GaN adherents have long argued its potential to eventually supplant LDMOS: higher power density and efficiency, higher frequency coverage and wider bandwidth. Like any new technology, GaN faced the challenges of demonstrating these performance advantages in producible, reliable devices and reducing manufacturing cost to meet the expectations of base station equipment manufacturers. The launch of 5G, with its higher frequency bands, wider channel bandwidths, massive MIMO architectures and need to minimize energy consumption shifted the power amplifier trade space enough to give GaN a beachhead, leading to widespread adoption.

With its power transistor heritage rooted in the base station market, NXP focused its GaN development on the performance needs of the base station, especially linearity. In contrast, the U.S. GaN device industry focused on maximizing power and efficiency, driven by radar and electronic warfare applications. This led to devices with "memory" effects caused by electron trapping, which makes the device harder to linearize with digital predistortion (DPD). NXP's development treated linearity as co-equal with power and efficiency, yielding a material structure and device that is "DPD friendly."

The decision to build its own GaN fab gives NXP more control over production capacity and cost, with tighter integration between the process and device designers—both in Chandler. Nonetheless, it will retain its external GaN foundry to ensure sufficient capacity as 5G volumes ramp, as well as redundancy in its supply chain. NXP's GaN products will be assembled and tested at its facility in Malaysia, which also serves as the back-end for LDMOS.

Built within an existing building in Chandler, the fab was a "greenfield" construction using the traditional bay/chase design: the operators work in the bays, i.e., the clean room, and the back of the equipment and electrical and plumbing connections are in the chase. The fab, NXP's sixth, uses best practices from its silicon fabs: automation, SPC and machine learning. However, unlike silicon, SiC wafers are optically transparent, which posed a challenge requiring unique wafer handling and processing.

On September 29, NXP virtually cut the ribbon at the fab and plans for it to be at full capacity, shipping product by the end of the year. NXP's $ 100 million investment should eliminate any lingering doubts about GaN's future in the base station market. However, NXP's commitment to GaN does not mean it is retiring LDMOS. Rather, its strategy is to offer a full suite of technologies for wireless infrastructure: LDMOS, GaN and SiGe for mmWave applications.

www.nxp.com/RFGaN

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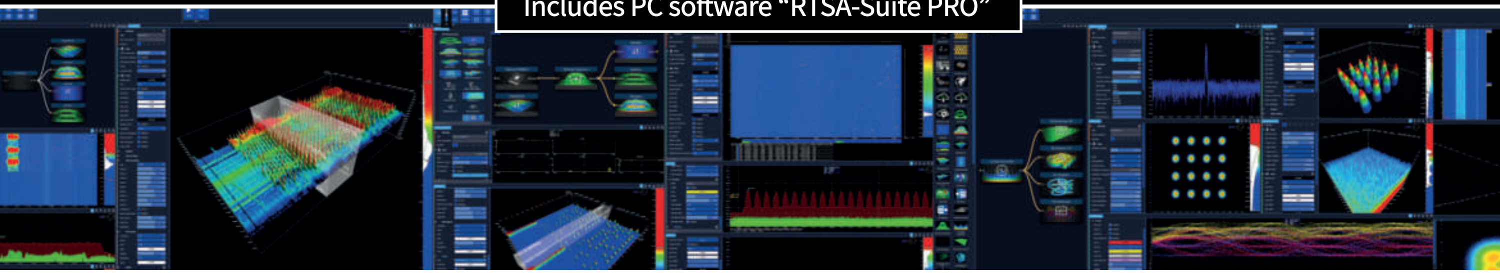

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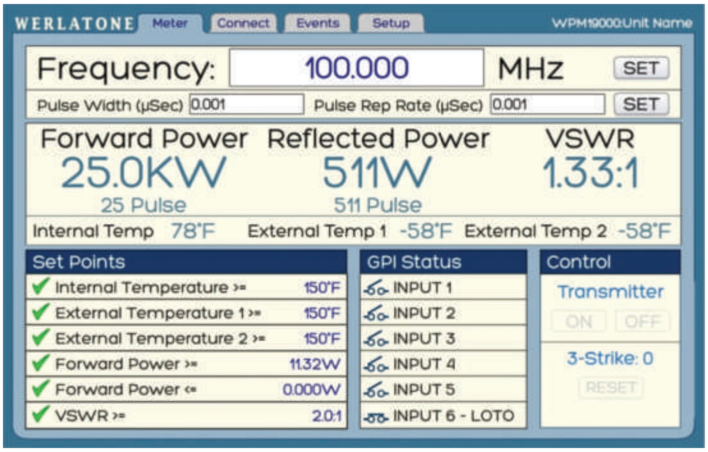

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