Vol. 61 • No. 12

December 2018

Microwave Journal

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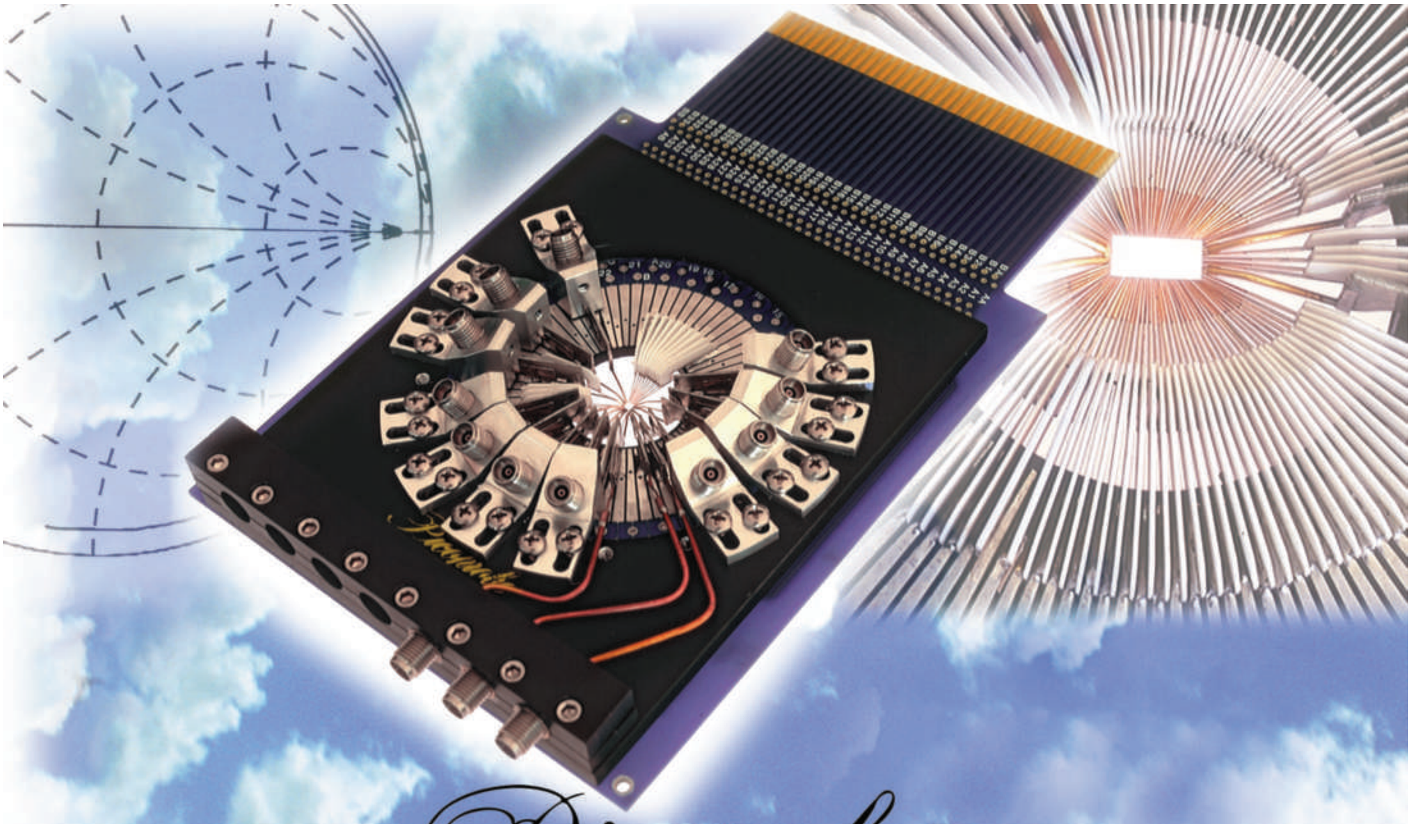

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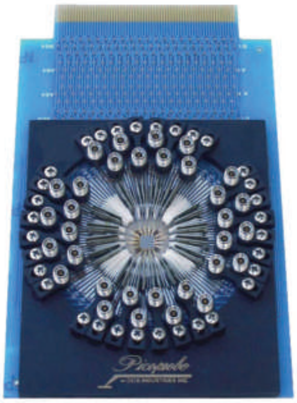

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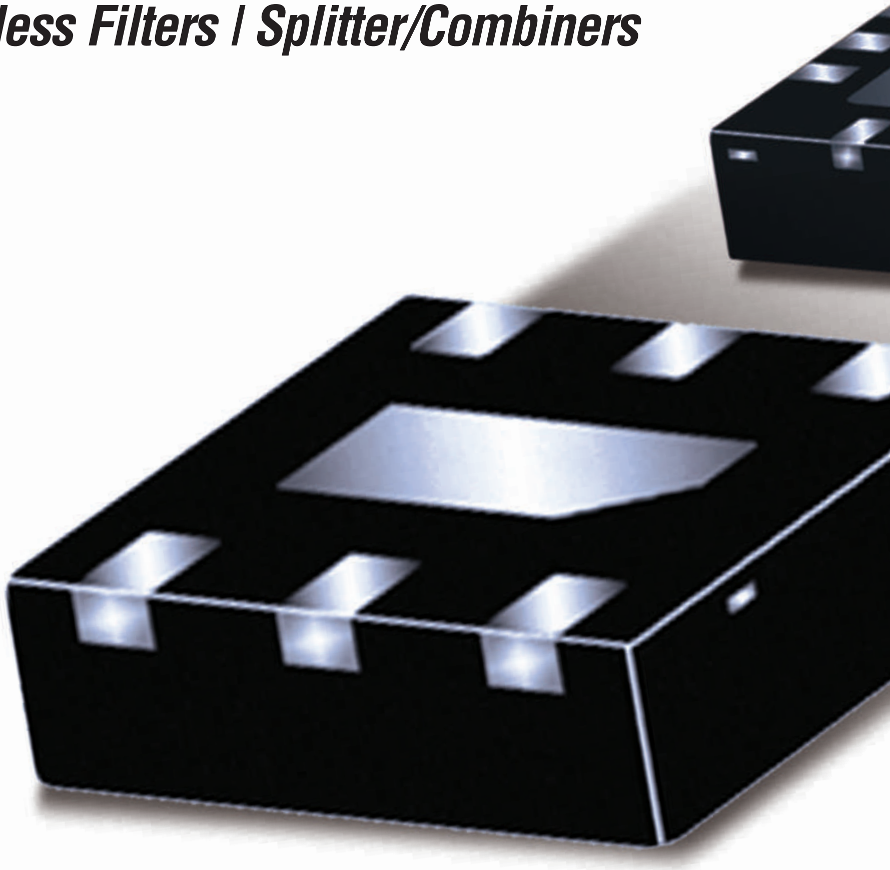

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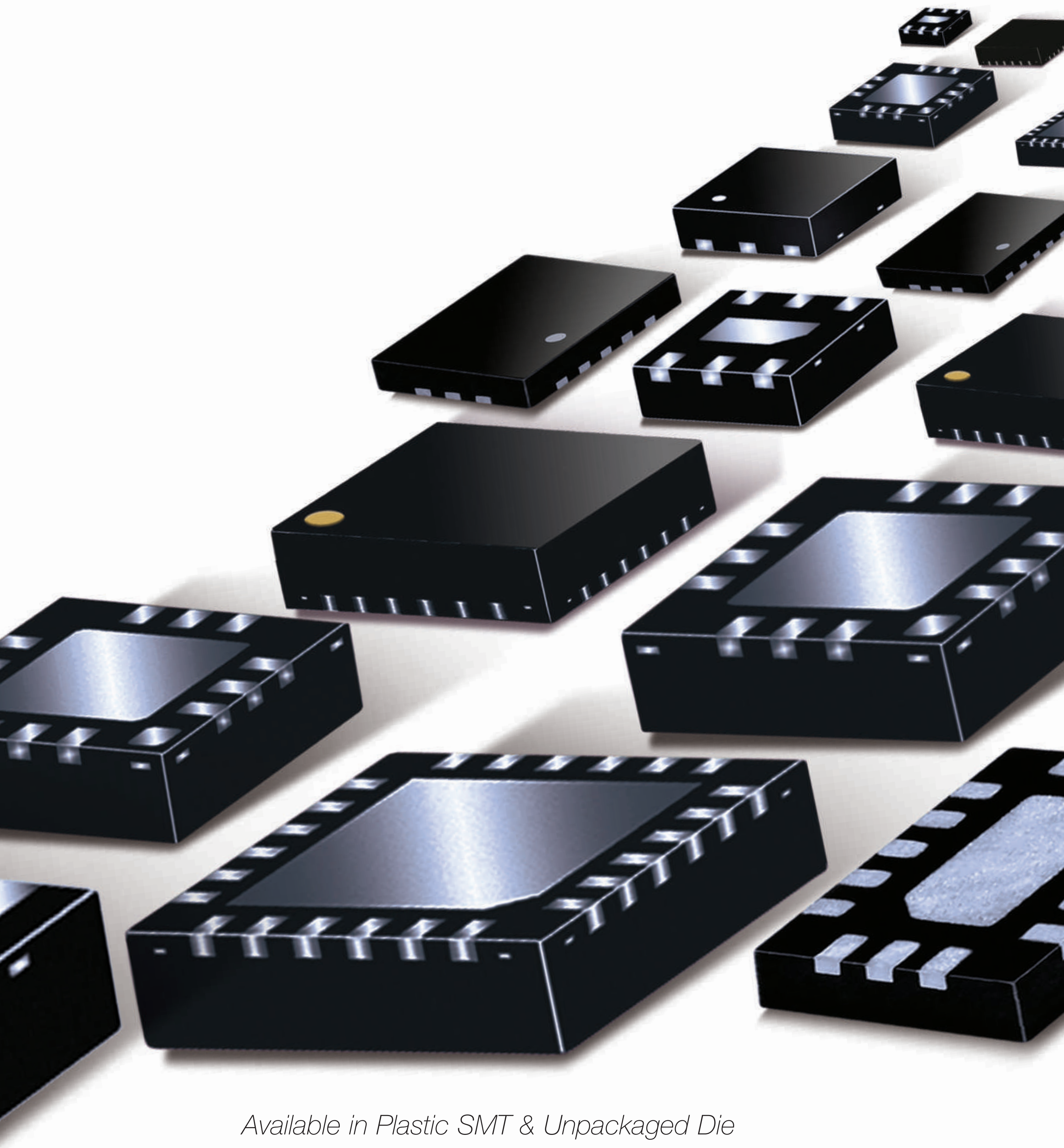

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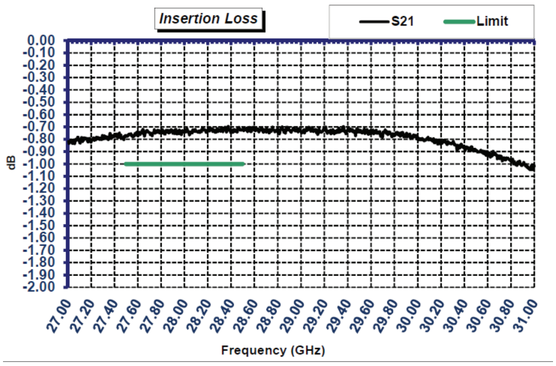

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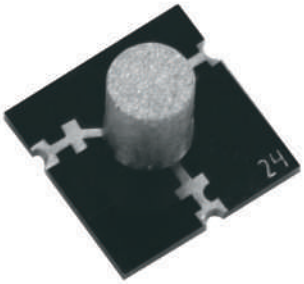

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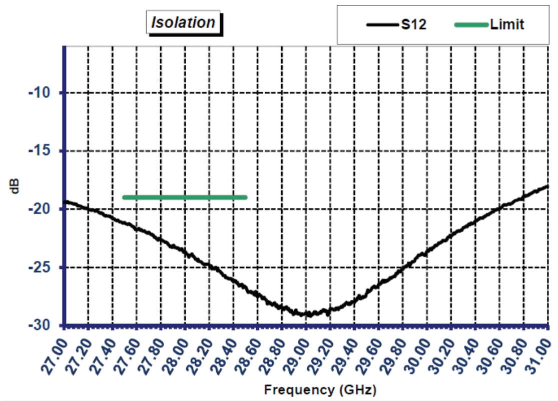

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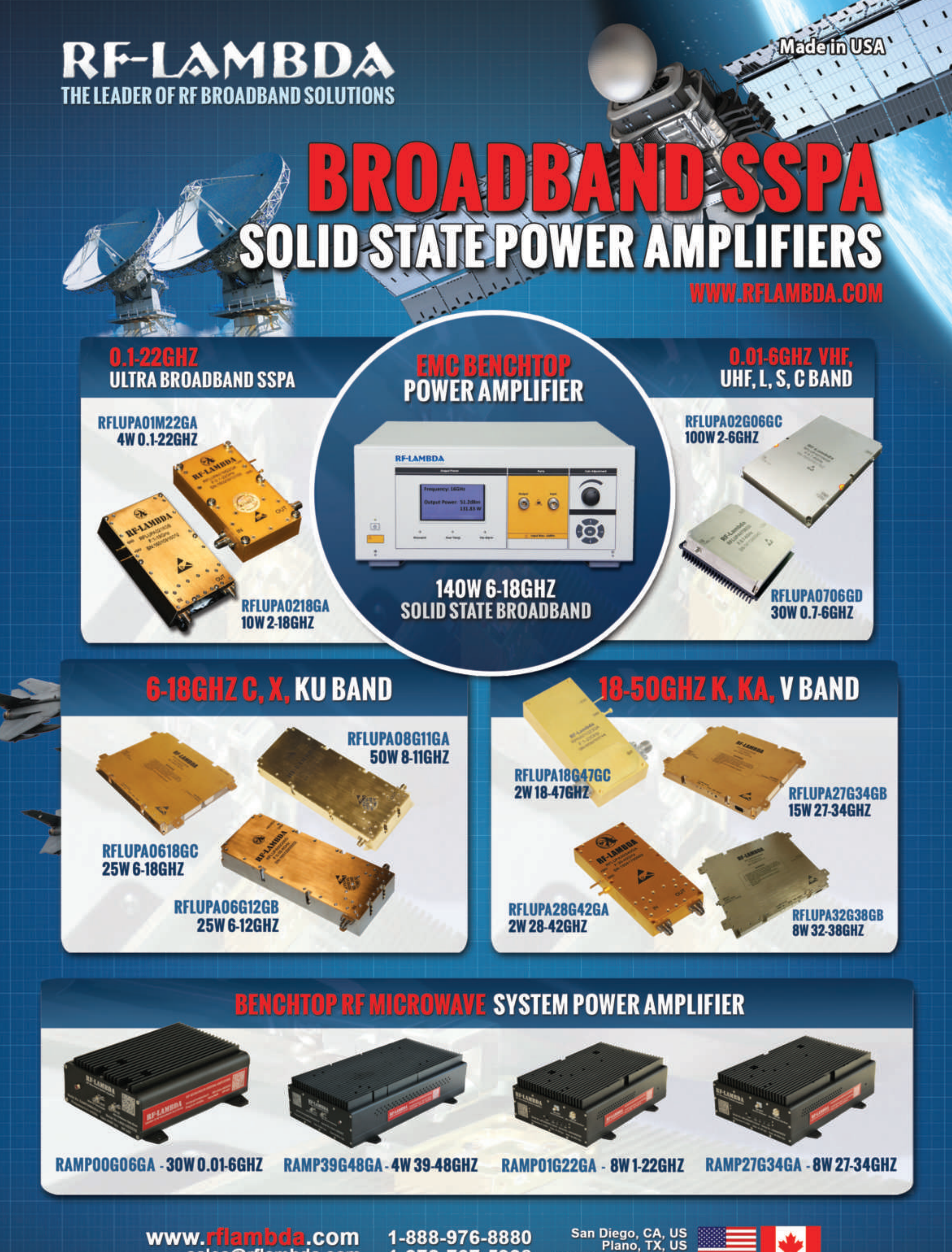
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CONTENTS

December 2018
Vol. 61 • No. 12
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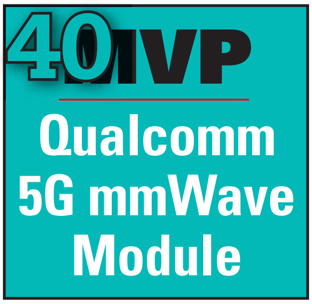

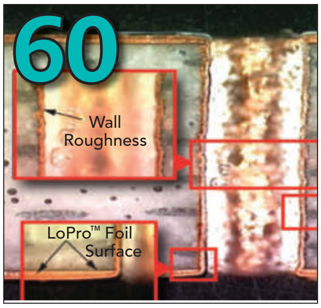

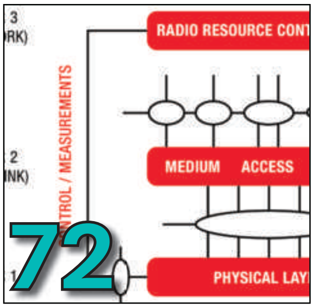

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Microwave Journal CONTENTS

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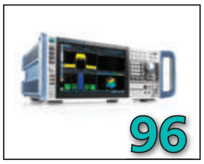

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Tech Briefs

Departments

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EUROPEAN EDITORIAL OFFICE
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Executive Interview

Kailash Narayanan, VP and GM of the wireless devices segment at **Keysight Technologies**, discusses the state of 5G on the eve of deployment, reflecting Keysight's experience with operators, network equipment manufacturers and chip set suppliers since the beginning of 5G R&D.

WHITE PAPERS

Custom MMIC — Realizing the SWaP-C Benefits of Designing with Positive Gain Slope MMIC Amplifiers

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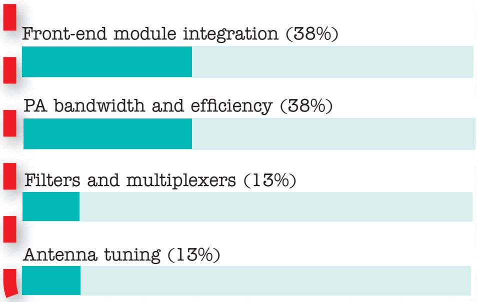

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14

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29-31

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10

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20-23

RWW

Orlando, Fla.

Radio and Wireless Week (RWW2019) consists of five related conferences that focus on the intersection between wireless communication theory, systems, circuits and device technologies. The 92nd ARFTG Microwave Measurement Symposium will also join RWW2019 as a co-located conference from January 19-22.

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EuMCE 2019
January 25, 2019

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February 8, 2019

EuMW 2019
February 11, 2019

PCB West 2019
February 25, 2019

2019 IEEE International Symposium on Phased Array Systems and Technology
March 15, 2019

IEEE COMCAS 2019
April 18, 2019

AMTA 2019
April 26, 2019

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CES 2019
January 8–11, 2019 • Las Vegas, Nev.
https://www.ces.tech/

92nd ARFTG Microwave Measurement Symposium
January 19–22, 2019 • Orlando, Fla.
www.arftg.org

Radio and Wireless Week 2019
January 20–23, 2019 • Orlando, Fla.
https://radiowirelessweek.org/

DesignCon 2019
January 29–31, 2019 • Santa Clara, Calif.
www.designcon.com

Mobile Deployable Communications 2019
January 31–Feb. 1, 2019 • Warsaw, Poland
www.mobiledeployable.com

FEBRUARY

MWC Barcelona 2019
February 25–28, 2019 • Barcelona, Spain
www.mwcbarcelona.com/

MARCH

EMV 2019
March 19–21, 2019 • Stuttgart, Germany
https://emv.mesago.com/events/en.html

RF & Microwave 2019
March 20–21, 2019 • Paris, France
www.microwave-rf.com

GOMACTech 2019
March 25–28, 2019 • Albuquerque, N.M.
www.gomactech.net/2019/index.html

APRIL

EDI CON China 2019
April 1–3, 2019 • Beijing, China
http://ediconchina.com/

WAMICON 2019
April 8–9, 2019 • Cocoa Beach, Fla.
www.wamicon.org/

Expo Electronica 2019
April 15–17, 2019 • Moscow, Russia
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CS Mantech 2019
April 29–May 2, 2019 • Minneapolis, Minn.
http://csmantech.org/

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SATELLITE 2019
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May 13–15, 2019 • Prague, Czech Republic
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Space Tech Expo 2019
May 21–22, 2019 • Pasadena, Calif.
www.spacetechexpo.com/

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June 2–7, 2019 • Boston, Mass.
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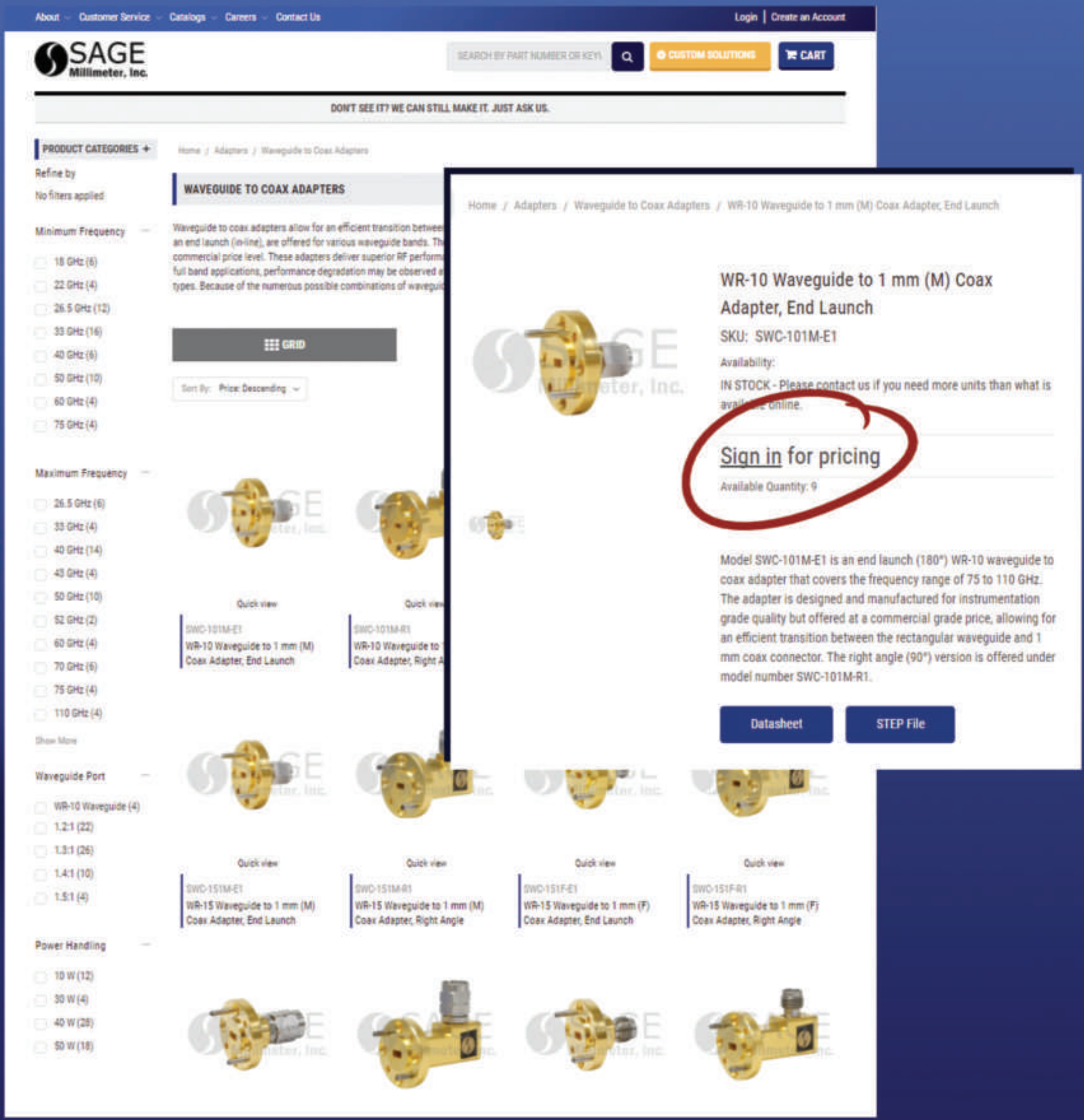

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Let's Talk 6G

Pat Hindle, *Microwave Journal* Editor

In June, the first 5G specification was finalized as 5G NR phase I (Release 15) and next year will see the completion of phase II for the 5G NR specification. 5G started in the U.S. this October, when Verizon released the first commercial 5G service with the deployment of mmWave Fixed Wireless Access service in several cities. AT&T started the deployment of the first standards-based 5G mobile service in November, and T-Mobile plans to start in the first half of 2019. It is surprising that the first two deployments in the U.S. use mmWave technology, which was deemed too expensive and short-range to be viable a few years ago. Although it will be several years before 5G becomes prevalent to consumers around the world, we have to ask what is next?

At September's Mobile World Congress Americas 2018, FCC Commissioner Jessica Rosenworcel suggested that 6G could feature terahertz (THz) frequency networks and spatial multiplexing with multiple simultaneous beams of data transfer with a high level of network densification. This could be accomplished with miniaturized base stations embedded ubiquitously in the environment everywhere. While Rosenworcel said these technologies are far away, spectrum policies need rethinking now in advance of 6G including valuation, auctions and distribution.

Rosenworcel suggested dynamic sharing rather than the binary licensed/unlicensed model. She also proposed a blockchain approach to spectrum management. She said that instead of having a centralized database to support shared access in specific spectrum bands, we could explore the use of blockchain as a lower-cost alternative. With the emergence of blockchain technology being used in wireless applications, we will explore 5G and blockchain as a technology track at EDI CON China 2019 in Beijing in April as it relates to an open wireless network. It will be interesting to see where this technology is headed and the benefits to using it with 5G networks.

As I attended several 5G events this year, a few advanced technologies stood out as potentials for 6G. At the Brooklyn 5G Summit in April, NYU students were performing channel sounding testing using 140 GHz signals produced by Virginia Diodes' sources. NYU led the way for 5G mmWave implementations with some of the first studies to develop propagation models, and seem to be doing the same for 6G with these projects. Nokia was demonstrating a single chip 90 GHz phased array at the Summit as well, so I look for these upper mmWave to lower THz frequencies being potential technologies for 6G.

At the University of Oulu's Center for Wireless Communications, they have €250 million of funding over the next eight years for project 6Genesis: 6G-Enabled Wireless Smart Society & Ecosystem. Their charter is to think outside the box for the wireless vision for 2030. The 6Genesis project is led by the University of Oulu in collaboration with Nokia, the VTT Technical Research Center of Finland, Aalto University, Business Oulu and the Oulu University of Applied Sciences. The low latency of 5G, several milliseconds, may not be good enough for 6G and using 100 to 1000 GHz signals will be needed to handle data rates up to terabit/s speeds so they will explore how these goals might be possible.

In the 6Genesis promo video, they envision an intelligent personal edge, an augmented reality interface using AI and cloud computing to deliver personalized data to your palm. Sensor to AI fusion would enable smart clothing, ambient measurements and individual health monitoring. Autonomous vehicles and ships, smart materials, holographic interfaces, intelligent cities, smart buildings, bio-centric identity for security and more would all become reality. Pretty cool stuff, but seems more likely 2050 before we reach this level of sophistication in our communication networks and data management systems.

In May, Tektronix/IEMN and Nippon Telegraph and Telephone Corporation (NTT) both announced development of 100 Gbps "wireless fiber" solutions. Each took a different route, with Tektronix and IEMN (a French research laboratory) demonstrating a single carrier wireless link with a 100 Gbps data rate signal at 252 to 325 GHz per the recently published IEEE 802.15.3d standard, while NTT used a new principle, Orbital Angular Momentum (OAM) multiplexing at 28 GHz with MIMO technology.

Editor's Note

The Tektronix/IEMN demonstration used advanced data coding, THz photonics and wideband and linear devices to enable ultra-fast wireless connections in the 252 to 325 GHz band, according to the release. The purpose of the new 802.15.3d standard is to provide for low complexity, low-cost, low-power consumption, very high data rate wireless connectivity among devices and in the future "low THz" bands.

NTT successfully demonstrated for the first time 100 Gbps wireless transmission OAM multiplexing in order to achieve terabit-class wireless transmission to support demand for future wireless systems. It was shown in a laboratory environment that dramatic increases in transmission capacity can be achieved by signals using this new principle of OAM multiplexing in combination with widely used MIMO technology. NTT conducted transmission experiments at a distance of 10 m in the laboratory operating in the 28 GHz frequency band. Eleven data signals each at a bit rate of 7.2 to 10.8 Gbps were simultaneously generated and carried by multiple OAM-multiplexed signals, thereby achieving large-capacity wireless transmission at a total bit rate of 100 Gbps.

Software-defined radio (SDR) has been around for many years but is now starting to become commercialized. The U.S. agency DARPA is running the Spectrum Collaboration Challenge in the world's largest channel emulator test bed called the Colosseum to further this technology. We published a deep technical piece on this effort as the cover feature in our September issue. The project will see how AI and SDR technology can be brought together in a large scale test with 256 radio inputs and outputs. In order to better use our existing spectrum, perhaps our 6G phones will listen to what frequencies are being used in real-time and use unoccupied frequencies to better utilize this scarce resource.

6G is likely to be a combination of higher frequencies (mmWave and perhaps THz), integration of blockchain and AI in SDRs and possibly new modulation schemes and techniques to achieve vast improvements in capacity, throughput and latency. ■

Cover Feature
Invited Paper

Reinventing Radar: The Power of 4D Sensing

Avik Santra, Ismail Nasr and Julie Kim
Infineon Technologies, Neubiberg, Germany

Radar has evolved from a complex, high-end military technology into a relatively simple, low-end solution penetrating industrial and consumer market segments. This rapid evolution has been driven by two main factors: Advancements in silicon and packaging technology are leading to miniaturization, and growth of computing power is enabling the use of machine learning algorithms to tap the full potential of raw radar signals. Radar facilitates localization of targets in 3D space and can be further used for vital sensing or classification, providing a 4D view that enables several industrial and consumer applications. The use and applications of radar technology have grown multi-fold in recent years. Apart from military and defense applications, radars increase safety and facilitate driving in medium- to premium-priced cars, for example. For many industrial and consumer applications, the wide adoption of short-range radar sensors follows reliable system performance at low-power and low-cost. In this article, we explain how radar technology can be used in consumer electronics and industrial applications, bringing benefits to our daily lives.

Radar supports existing applications while providing features that enable completely new use cases. Radar 3D localization in home and industrial applications provides range and angle, both in azimuth and elevation. Radar can also sense velocity for position mapping and tracking. Specialized radars can detect human cardiopulmonary motion, providing a promising approach to overcoming problems of false triggering and dead spots in conventional sensors for occupancy sensing. Radar technology produces a unique signature for any object or material. This feature can be used in systems to recognize different types of liquids—water vs. milk—or materials—silk vs. cotton.

Low-cost sensor solutions are enabling radar's use for industrial testing and automation. They are robust in harsh environments, such as poor lighting, fog or pollution. Additionally, they can be aesthetically concealed without affecting performance, making them suitable for many consumer applications. Radar has been demonstrated to be a powerful sensor for short-range localization and vital sign tracking within consumer electronics, medical care, surveillance, driver assistance and industrial applications.[1-5]

ENABLING TECHNOLOGIES

A radar system consists of two parts: First, the radar hardware, including the RF transceiver, waveform generator, receiver unit, anten-

na and system packaging. Second, the signal processing, which parses the radar return echo to extract meaningful target information.

Since the invention of integrated circuits, the operating frequency of transistors has steadily increased, enabling the realization of circuit blocks that operate at frequencies up to 1 THz.[6] Transistors are also shrinking in size, with more advanced technology nodes enabling further integration.[7] ***Figure 1*** highlights the evolution of radar technology used in automotive applications. SiGe bipolar technology has been the preferred silicon technology for automotive and industrial mmWave radar for the past several years, as its performance, cost and integration fit superbly with application requirements.[8-9] State-of-the-art SiGe technology has reached operating frequencies beyond 300 GHz. For example, Bock et al.[10] describe front-end BiCMOS technology with an F_t of 250 GHz and an F_{max} of 370 GHz for the SiGe transistors. Their technology also has 130 nm CMOS, which can be used for radar building blocks, such as phase-locked loops and digital signal processing. RF CMOS technology has also been shown to be a candidate for mmWave radar.[11] Although RF performance is not as good as SiGe, CMOS offers greater digital integration, attractive for increased signal processing on the radar chip.

Higher operating frequencies and advanced packaging technologies have enabled the integration of antennas into the package and, in some cases, on the silicon die. Antenna integration is essential for reducing radar design complexity and for reducing overall system cost, allowing penetration into industrial and consumer markets. Antenna configurations have been integrated into packaging for different fields of view to cover various system requirements.[12] Operation beyond 100 GHz allows the integration of the antenna on silicon,[13] further reducing radar size and cost.

RADAR TYPES

Small short-range radars can typically be categorized as CW, modulated CW and impulse ultra-wideband (UWB).

CW Radar

CW radars transmit and receive continuously, while impulse radars transmit short pulses while the receiver is not operating and receive in the quiet period between transmit pulses. CW radars require separate transmit and receive antennas with good isolation. The major advantage of CW radars is that signal processing at the receiver is at low frequencies, reducing the sampling rate requirement, which simplifies processing circuitry.

CW radar transmits an unmodulated continuous frequency tone. The received echo is processed to estimate a target's radial velocity by evaluating the change in phase with respect to time of the received signal relative to the transmitted signal. This Doppler frequency shift is from the transmitted signal reflected from a moving target. The disadvantage is range information cannot be obtained from a pure CW signal; it can only be obtained through either pulse-Doppler operation or transmitting two distinct frequency tones, known as frequency shift keying.

Modulated CW Radar

Several patterns are used to frequency modulate the transmit signal. A popular waveform is sawtooth frequency modulation, where the frequency is linearly increased over time (up-chirp) or decreased over time (down-chirp). This is called frequency modulated CW (FMCW). At

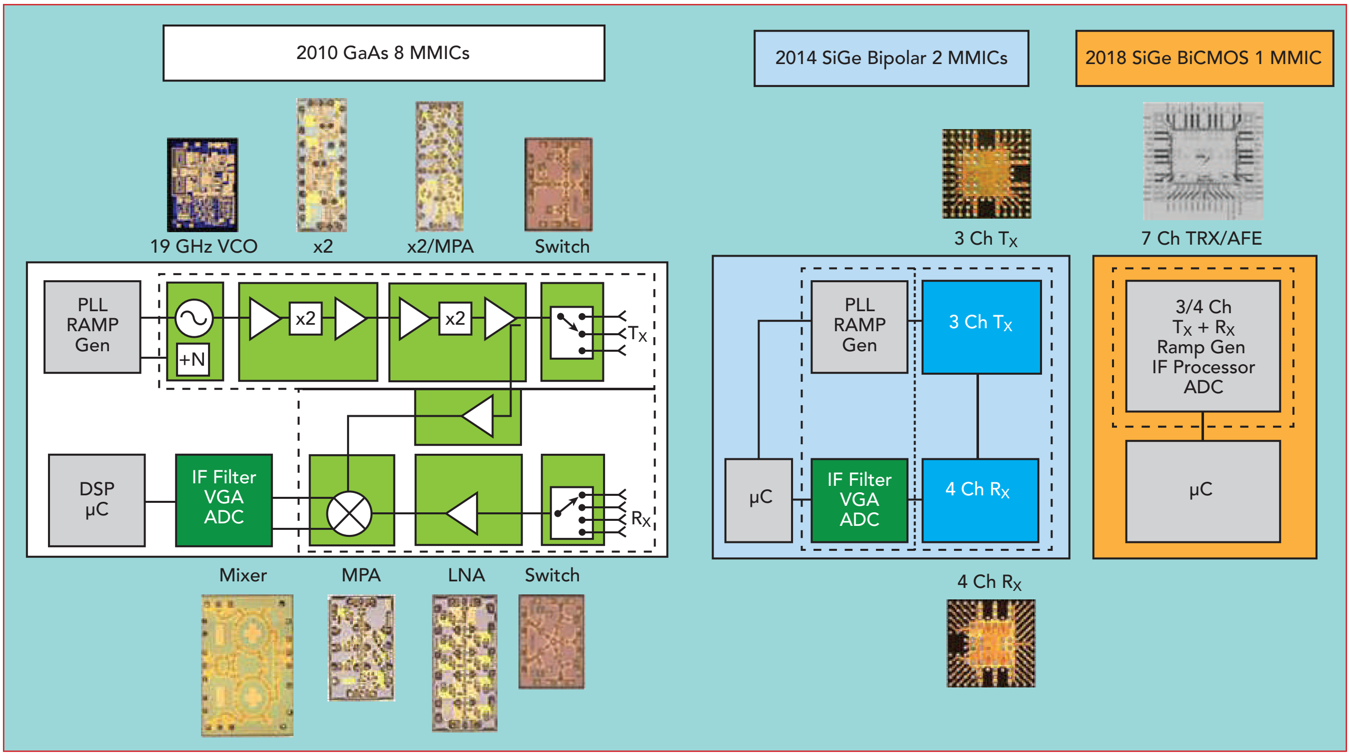

Fig. 1 77 GHz radar transceiver technology and integration trend.

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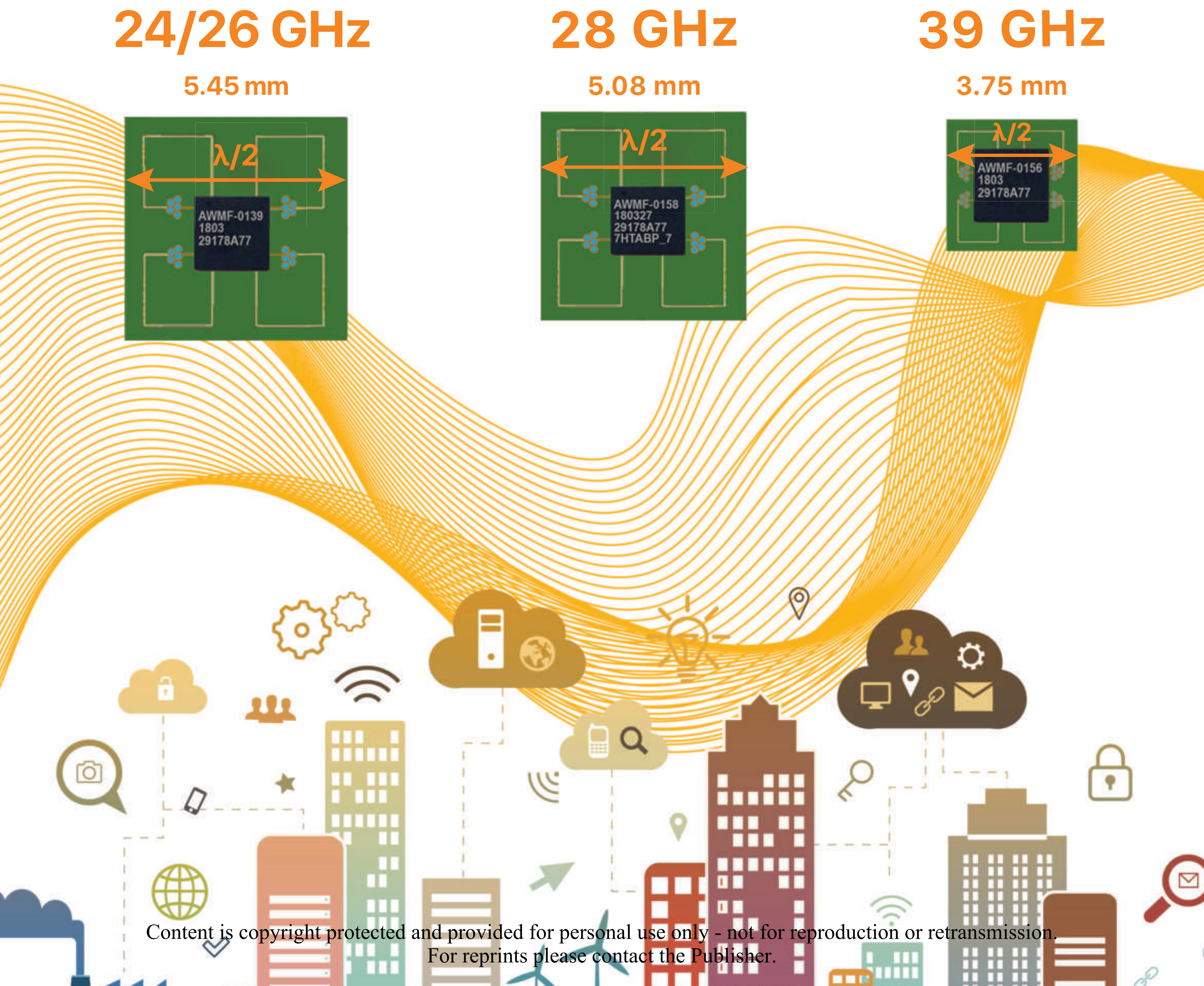


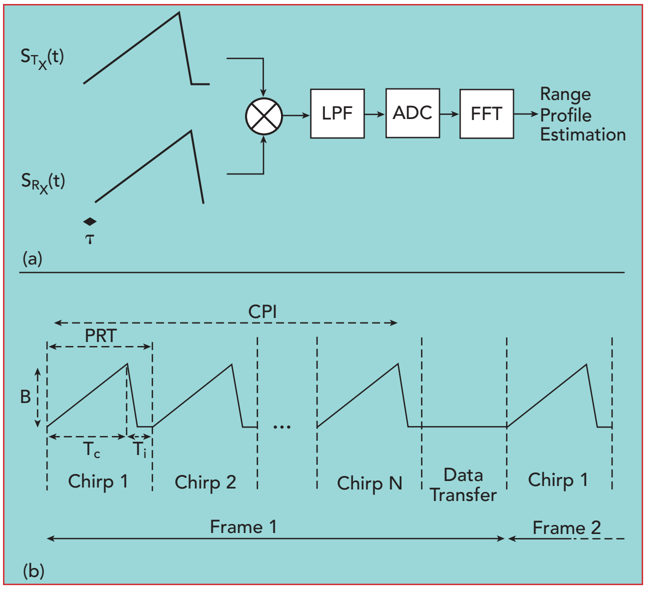


Fig. 2 De-ramping the FMCW signal (a) and radar frame structure (b).

the receiver, the matched filtering operation requires mixing the received chirp with the transmit signal, called "de-ramping" or "de-chirping" (see ***Figure 2a***). $S_{T_X}(t)$ and $S_{R_X}(t)$ refer to the transmit and the received chirp respectively. The round trip propagation delay

$$\tau = \frac{2R_k}{c}$$

is translated to an intermediate frequency after mixing in the receiver. Spectral analysis along the chirp provides range estimates of targets in the radar's field of view. The swept bandwidth, B, determines the range resolution, $\delta R = c/(2B)$. The maximum unambiguous range $R_{max} = N_s \delta R$, where N_s is the number of transmit frequency steps. The analog-to-digital converter (ADC) output along a single chirp is referred to as "fast time."

Figure 2b shows the frame structure of the FMCW radar. The chirp duration T_c determines the maximum detectable unambiguous Doppler, $fd_{max} = 1/(2T_c)$. The time duration between two chirps is referred to as the pulse repetition time (PRT) and is given as PRT = $T_c + T_i$. The velocity content of a target within a range bin causes a phase change across multiple chirps within the target's range bin. The spectral estimation across chirps provides the velocity information. The collection of consecutive chirps used for coherent integration is referred to as the "frame" or "dwell" and represents how often target parameters are estimated or updated. The coherent processing interval (CPI), the time duration of a frame, determines the Doppler resolution $\delta fd = 1/(2CPI)$. The time samples along the chirps within the CPI are referred to as "slow time." Two critical aspects that determine the performance of a sawtooth frequency modulated radar system are the ramp linearity and the transmit-to-receive (T_X-R_X) leakage. Any deviation from a linear ramp results in range estimation errors and the T_X-R_X leakage limits the radar's maximum detection range.

Impulse UWB Radar

Impulse radar transmits short pulses and determines distance by measuring the time delay between the transmitted and returned signal. Impulse radar transmits ultra-wideband, short pulse waveforms and is a non-coherent system. The time difference between pulse transmission and reception determines the range of the target and the peak of the spectrum determines the Doppler velocity. The pulse width determines the range resolution and the Doppler resolution is typically poor in such systems; however, they do not suffer from T_X-R_X leakage, since the transmitter and the receiver do not operate at the same time.

This article introduces the concept of 4D sensing using FMCW radar. However, several aspects are applicable to impulse UWB radar.

3D POSITION LOCALIZATION

To estimate a target in 3D space, a MIMO configuration of at least $N_{T_X} = 2$ transmit elements and $N_{R_X} = 2$ receive elements in an L-shaped linear array with appropriate spacing is required. This results in a virtual 2 × 2 rectangular array sufficient for estimating a target's elevation and azimuth coordinates.

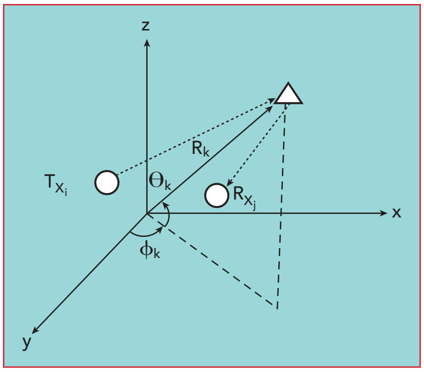


Fig. 3 3D position of the target.

As shown in ***Figure 3***, the 3D coordinates in space of the T_X element are denoted as $d_m^{TX}, m = 1 \ldots N_{T_X}$ and for the R_X element as $d_n^{RX}, n = 1 \ldots N_{R_X}$. Assuming far-field conditions, signal propagation from the T_X element d_m^{Tx} to a point scatterer p and the reflection from p to the R_X element d_n^{RX} can be approximated as $2R_k + d_{mn}$, where R_k is the base distance of the k^{th} scatterer to the center of the virtual linear array and d_{mn} refers to the relative position of the virtual element to the center of the array. The radar views the space in polar coordinates, thus the 3D cartesian position of the k^{th} target can be represented as

$$r_k = \left[R_k \cos(\theta_k)\sin(\phi_k) \;\; R_k \cos(\theta_k)\cos(\phi_k) \;\; R_k \sin(\theta_k)\right] \tag{1}$$

and the directional unit vector is represented as

$$u_k = \left[\cos(\theta_k)\sin(\phi_k) \;\; \cos(\theta_k)\cos(\phi_k) \;\; \sin(\theta_k)\right] \tag{2}$$

where θ_k and ϕ_k are the elevation and azimuth angles, respectively, of the target with respect to the center of the virtual array. The transmit steering vector can be written as

$$a_m^{T_x}(\theta,\phi) = \exp\left(-j2\pi \frac{d_m^{T_x} u(\theta,\phi)}{\lambda}\right); m = 1,\ldots,N_{T_x} \tag{3}$$

while the receiving steering vector is

$$a_n^{R_x}(\theta,\phi) = \exp\left(-j2\pi \frac{d_n^{R_x} u(\theta,\phi)}{\lambda}\right); n = 1,\ldots,N_{R_x} \tag{4}$$

where λ is the wavelength of the transmit signal. The received baseband signal from the k^{th} target scatterer can be expressed as

$$\overline{S_{R_x}}(t) = \rho_k e^{\frac{-j2\pi 2u_k \cdot r_k}{\lambda}} a_n^{R_x}(\theta_k,\phi_k) a_m^{T_x}(\theta_k,\phi_k)^T \, \overline{S_{T_x}}(t) \tag{5}$$

where ρ_k represents the composite amplitude contribution due to propagation path loss, antenna gains and receiver gains. $\overline{S_{T_X}}(t)$ and $\overline{S_{R_X}}(t)$ are the transmitted signal from N_{T_X} transmit antennas and the received signal at N_{R_X} receive antennas, respectively. After having estimated the range R_k of the k^{th} target through spectral analysis along fast time, the angular coordinates of the target—namely azimuth angle θ_k and elevation angle ϕ_k—can be estimated through monopulse, Capon or FFT beamforming algorithms. ***Figure 4*** shows the 3D localization of three targets with different positions (range, azimuth, elevation) in the radar's field of view.

THE FOURTH DIMENSION

Vitals and Occupancy Sensing

The breathing motion of human beings and heart motion from hearts beating have unique signatures that are picked up by radar as position and Doppler information.

A vibrating point scatterer target at base distance R_k from the center of the radar array induces a target re-

sponse along slow time t_s, which can be expressed as

$$R(t_s) = R_k + \sum_{i=1}^{I} \alpha_v^{(i)} \sin\left(2\pi f_v^{(i)} t_s\right) \tag{6}$$

where f_v represents the vibrating frequency, $\alpha_v^{(i)}$ represents the maximum amplitude of the ith vibrating target source and I represents the number of vibrating sources. A quasi-stationary human at a fixed distance from the radar sensor can be modeled as the superposition of two vibrating sources: one from the respiratory motion, the other from heart motion. The human resting respiratory rate is around 12 to 20 beats per minute ($f_v^{(1)} = f_r = 0.2 - 0.4$ Hz), with a maximum displacement for chest wall motion $\alpha_v^{(1)} = 7.5$ mm. The heart rate can be from 50 to 200 beats per minute ($f^{(2)}_v = f_h = 0.8 - 3.3$ Hz), with a maximum displacement $\alpha^{(2)}_v = 0.25$ mm. After lowpass filtering, the received signal can be expressed as

$$s(t_f, t_s) = \rho_k \exp\left(j\overbrace{\left(\frac{4\pi\gamma R(t_s)}{c}\right)}^{\text{1st term}} t_f + j\left(\overbrace{\frac{4\pi f_c R(t_s)}{c}}^{\text{2nd term}} - \overbrace{\frac{8\pi\gamma R^2(t_s)}{c^2}}^{\text{3rd term}}\right)\right) \tag{7}$$

Here, we expand the time index t as a combination of fast time, t_f, and slow time, t_s. The round trip propagation delay

$$\tau = \frac{2R(t_s)}{c}$$

The third term in Equation 7 leads to undesired second-order terms, such as $f_r + f_h$ and $2f_r$, which fall within the vital signal spectra. If not accounted for, these undesired terms lead to an incorrect estimate of the vital signal. This poses a challenge to accurately estimate vital parameters. The other terms in Equation 7 lead to the expression

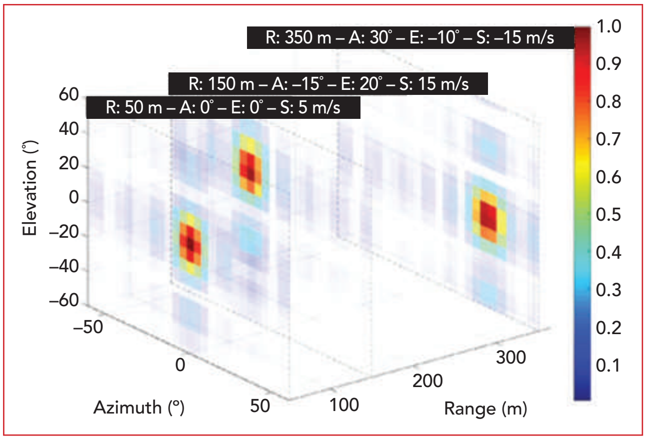


Fig. 4 Estimated 3D position of three targets with different ranges and elevation and azimuth angles.

$$s(t_f, t_s) = \rho_k \exp\left(j\left(\frac{4\pi\gamma R_k}{c} + \frac{4\pi\gamma\alpha_v^{(i)} \sin\left(2\pi f_v^{(i)} t_s\right)}{c}\right) t_f + j\left(\frac{4\pi f_c R_k}{c} + \frac{4\pi f_c \alpha_v^{(i)} \sin\left(2\pi f_v^{(i)} t_s\right)}{c}\right)\right) \tag{8}$$

Considering that $R_k >> \alpha_v^{(i)}$, the second term in Equation 8 can be ignored. The first term is estimated or compensated by the fast time FFT and is proportional to the human's base distance R_k. The change in phase over slow time, given by the fourth term, represents the minute motion generated from the human chest wall. Thus, by monitoring the phase, followed by spectral analysis, one can estimate the non-overlapping heart and respiratory frequencies. However, the estimate of these minute movements is susceptible to random

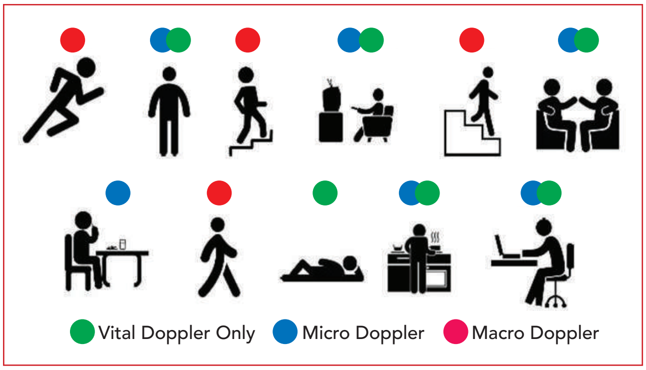


Fig. 5 Human activities with associated Doppler sensed by the radar.

body movement and human motion. This poses another challenge to wide acceptance of the technology, where precise vital measurements are mandatory. Random body movement can be compensated by multiple radar sensors.[14]

The ability of the radar to wirelessly estimate vital signs leads to applications such as sleep apnea detection, patient monitoring, presence sensing, driver monitoring and physiological monitoring in surveillance and earthquake rescue operations.[15-19] Short-range radar systems that are lightweight and low-cost offer good solutions for human presence sensing with efficient energy utilization.[20-21]

We can divide the Doppler components into three categories: macro Doppler induced by major body movement, micro Doppler induced by human gestures and vital Doppler induced by vital motion. ***Figure 5*** illustrates various indoor human activities and their associated Doppler components that can be sensed by the radar. A radar sensor can identify these different Doppler components distinctly, offering a ubiquitous solution for occupancy sensing.[21] Other sensors using passive infrared (PIR) or ultrasound, which detect presence from motion, fail during some daily activities such as sitting, reading or sleeping.

Classification Sensing

Radar can capture unique signatures of a target based on target velocity, size, shape, smoothness, reflectivity and orientation, as well as horizontal and vertical polarization properties. These properties can be extracted with appropriate feature engineering algorithms developed for classification and sensing.

Consider an example classifying materials such as carpet, tile, laminate and water using a mmWave radar. ***Figure 6*** shows various materials with their range/cross range images generated through Capon-based MIMO imaging principles. One of the challenges to classification sensing for industrial and consumer applications is scalability, due to sensor-to-sensor variability from fabrication uncertainties such as wafer lots and manufacturing artifacts. Classification models trained on one group of sensors do not necessarily work for other groups of similar sensors. The change of sensor casing enclosing the radar can influence the back-scattered signal, introducing variations in classification features that result in classification errors. When the classification model is developed using certain material types and radar orientations, the model fails to scale for a different sensor orientation or type of material, such as one carpet made of nylon and another of olefin. It is impossible to train the sensor system to account for all these variations.

One of the approaches to circumvent these challenges is “one-shot learning,” inspired by the word2vec embedding concept for natural language processing and, lately, for human face classification.[22-24] Instead of using deep neural networks to train as a multi-class classifier, one-shot learning determines similarity between two materials by projecting the input features to a d-dimensional embedding space. Typical values of d are 16 or 32 for use cases such as this.[25] One-shot learning uses a Siamese network trained using two identical neural networks with the same weights; the last layers of the neural network are fed to a contrastive loss function. The network tries to match the anchor (current feature image) with the positive (feature image that is in theory similar with the anchor), as far as possible from the negative (feature image that is different from the anchor). One of the contrastive loss functions that the Siamese network is trained on is

$$\text{Loss} = (1-Y)\frac{1}{2}D_{SN}^2 + (Y)\frac{1}{2}\left(\max\left(0, m - D_{SN}\right)\right)^2 \quad (9)$$

where D_{SN} is the Euclidean distance between outputs of the twin Siamese networks. Y = 1 if inputs are from the same class, and Y = 0 if they are from a different

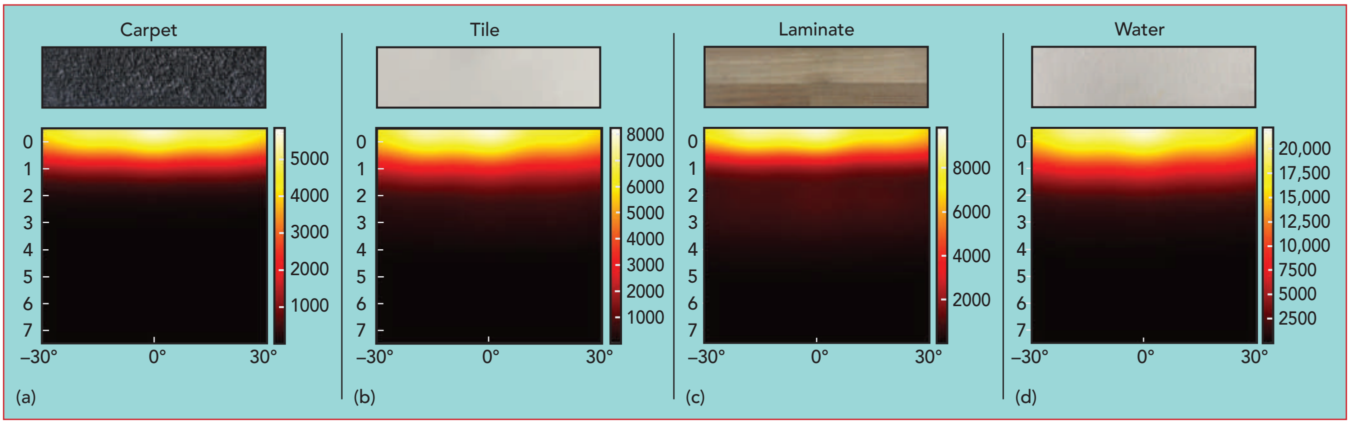
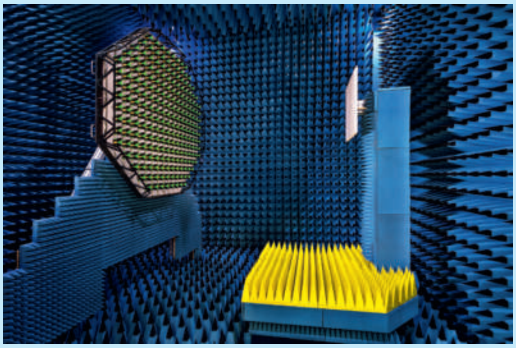


Fig. 6 Materials and their range/cross-range features: carpet (a), tile (b), laminate (c) and water (d). Note differing scales.

Advertorial



The R&S PWC200 plane wave converter (the octagonal array on the left) generates a flat wavefront where the base station under test is located, which will be only 1.50 m away in place of the white reference antenna shown here.

OTA Test System for 5G Base Stations

ROHDE&SCHWARZ

5G base stations will use massive MIMO antenna arrays to achieve both higher capacity and higher energy efficiency. This base station architecture requires a new measurement paradigm – and T&M equipment such as the R&S PWC200 plane wave converter.

Each antenna in the array of a 5G base station will be a self-contained unit consisting of the frontend (RF transceiver, amplifier, upconverter and downconverter) and the actual antenna elements. Thus future base stations will have to be characterized as a whole, using over-the-air (OTA) technology to measure RF parameters. However, it is only possible to obtain conclusive transmitter and receiver measurements under far field conditions at the base station location or with a test setup that simulates the far field. And that is exactly what the R&S PWC200 plane wave converter does.

The R&S PWC200 is a bidirectional phased array consisting of 156 wideband Vivaldi antennas in the near field region of the device under test – a base station, passive antenna, or antenna array. Installed in a compact test chamber, which can also be supplied turnkey, the converter enables real-time transmitter and receiver measurements (radiation pattern, gain, EVM, ACLR, etc.) in the frequency range up to 6 GHz. Such measurements previously required a compact antenna test range (CATR) significantly larger than the R&S PWC200.

Each antenna has a phase shifter and attenuator pad, enabling targeted synthesis of the electromagnetic field where the device under test is located. To feed the signal to the array or to test signal reception, a combiner merges all signal paths to a single port to which the measuring instrument can be connected.

Thanks to their compact dimensions and easy handling, both the R&S PWC200 and the test chamber can be used in development and for calibration in production.

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class. m > 0 is the margin hyper-parameter.

If, for example, there are 100 images of the four classes, then the total possible trainable pair of images are $N = {}^{400}_{2}C = 79{,}800$. The intuitive idea is that the deep network learns a d-dimensional space where similar materials are co-located and dissimilar materials are farther apart. During the inference phase, the input feature image from an unknown material is fed to the trained deep neural network to project the feature map into the d-dimensional embedding space and then classified through a nearest neighbor algorithm.

Radar sensors such as Soli lead to emerging technologies such as gesture sensing.[26-27] This technology is used in wearables and mobile phones to provide a natural and intuitive human-computer interface. Radar sensors such as RadarCat have proven to be extremely accurate in object and material classification of everyday objects and materials, transparent materials and different body parts.[28] Recently, radar sensors have been successfully applied to fingerprint biometric identification. Unique radar signatures are fed through novel signal processing and machine learning models to identify a group of individuals with reliable accuracy.[29]

CONCLUSION

This article provides an overview of advancements in front-end and back-end technologies leading to the use of radar in consumer and industrial applications. Radar not only senses the 3D position of targets in its field of view, it enables sensing of human vital signals or signal classification as the fourth dimension, providing a different view of its environment where other sensors fail. The radar sensor is able to extract subtle information about targets in its field of view, making it suitable for a variety of industrial and consumer applications.■

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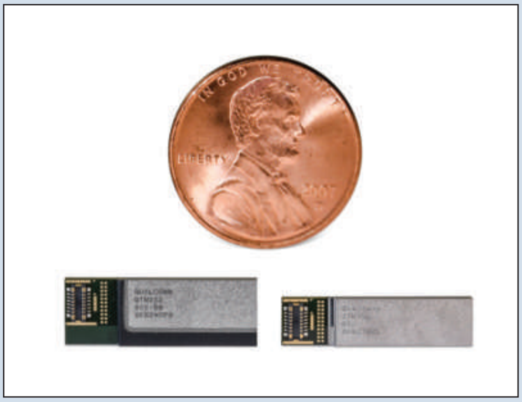

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Qualcomm Technologies Inc.
San Diego, Calif.

Achieving the dramatic jump in data rates for 5G's enhanced mobile broadband service relies on the bandwidth available at mmWave frequencies. Dedicated spectrum in three bands—at 28, 39 and, more recently, 24 GHz—has been proposed, and regulatory authorities in many countries are allocating spectrum.

On the infrastructure side of the link, the development of mmWave base stations has progressed rapidly, enabled by field trials to determine propagation characteristics. Propagation has proven more resilient than many expected, benefiting from scattering and multipath. Using phased array antennas, base stations can provide the necessary EIRP and beam steering to achieve spatial coverage with the necessary link margins.

This early success has enabled companies like Verizon to begin deploying fixed wireless access services to stationary consumers, who mount 28 GHz antennas on windows or along roof lines. In most cases, subscribers can obtain respectable signal levels and data rates, as confirmed by an early independent evaluation in Houston by Signals Research Group.

The next big unknown has been the performance of a mobile *smartphone* at mmWave frequencies. Phone and component manufacturers face numerous technical challenges developing a viable mmWave radio for the phone:

- Ensuring antenna coverage regardless of phone orientation and hand placement.
- Maintaining sufficient link margins during transmit and receive.
- Maximizing phone battery life by minimizing power consumption.
- Minimizing the temperature rise of the module and phone with the thermal design.
- Minimizing the size of the mmWave radio, with a form factor compatible with a smartphone.

In July 2018, Qualcomm Technologies announced the QTM052 family of mmWave antenna modules for the smartphone—a first in the industry. Used with the Snapdragon X50 5G modem, the integrated system provides antenna to baseband processing and meets Release 15 of the 5G New Radio (NR) specification. Then, in October, Qualcomm added a new module design to the QTM052 family, reducing the size by 25 percent. The smaller

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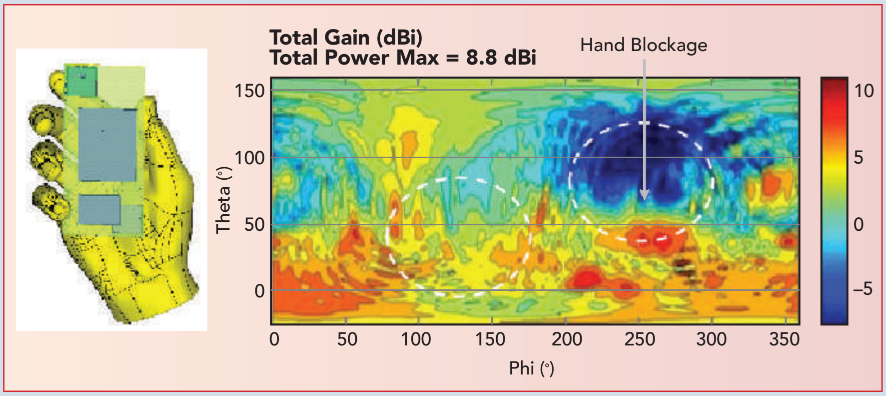

Fig. 1 EM simulation of a mobile phone, showing mmWave signal attenuation caused by a hand holding the phone.

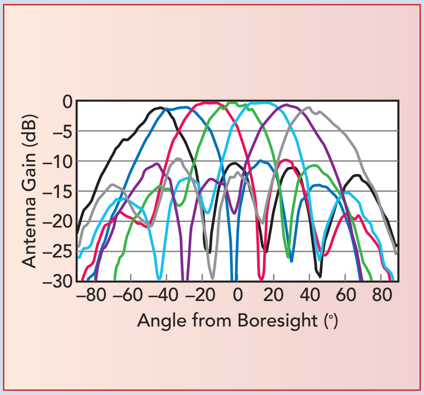

Fig. 2 Antenna patterns of a vertically polarized patch array showing ±45 degree beam steering.

design enables the module to be mounted along the edge of even thinner phones and supports up to four modules in a smartphone.

The QTM052 currently covers three 5G bands, handling up to 800 MHz aggregated carrier bandwidth in the 26.5 to 29.5 GHz band (n257) and covering the entire 27.5 to 28.35 GHz band (n261) and the entire 37 to 40 GHz band (n260). Functionally, the QTM052 comprises a phased array antenna, radio transceiver and power management. It connects to Qualcomm's X50 5G modem, which controls beamforming and beam steering.

ANTENNA ARRAY

Various antenna options are available, supporting either face or edge placement in the phone. Qualcomm's tests show that both orientations have similar performance, so the choice depends on other design trade-offs, such as phone thickness. Whichever configuration is used, several of the antenna modules are placed at different locations in the phone, ensuring coverage regardless of phone orientation and compensating for signal blockage when a hand is holding the phone (see ***Figure 1***).

The arrays use patch and dipole antennas, either single or dual polarization. The arrays provide spherical coverage in each polarization and beam steering of ±45 degrees around boresight (see ***Figure 2***).

TRANSCEIVER

The transceiver RFIC, fabricated with a silicon process, integrates transmit and receive channels for each antenna element, as well as providing frequency conversion between RF and IF. The on-chip up- and down-conversion includes the mixer, voltage-controlled oscillator with multiplier and phase-locked loop (see ***Figure 3***).

The power amplifier can deliver 10 to 15 dBm output power, although it typically operates backed off to 6 to 8 dBm output to meet the 5G NR −25 dB error vector magnitude (EVM) linearity requirement. The transmit/receive (T/R) switch at the antenna is placed in the receive path, so it does not reduce output power. The input receive amplifier has a low noise figure which does not limit the performance of the downlink from base station to handset, even with the loss of the T/R switch. On-chip digital circuitry translates commands from the X50 modem to control the T/R state and the relative amplitude and phase of each antenna element. Beam steering and array taper are set with passive phase shifters and attenuators with 1 dB gain control steps, respectively.

The transceiver RFICs are packaged in flip-chip ball grid arrays, which are mounted to the backside of the board containing the antenna array (see ***Figure 4***).

EIRP AND POWER DISSIPATION

The shorter range of mmWave links, available output power from the power amplifiers and the constrained form factor of the phone challenged the design of the


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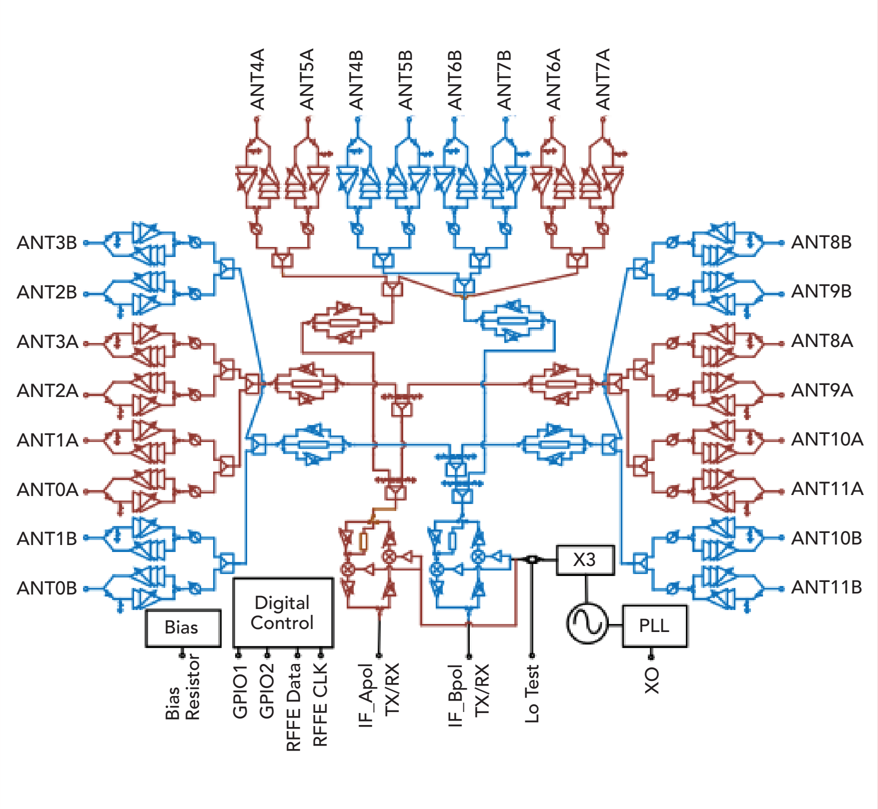

Fig. 3 Notional block diagram of the transceiver RFIC.

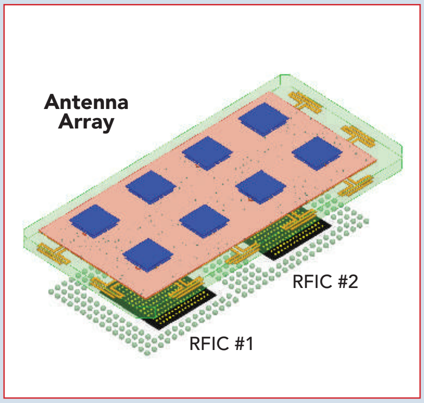

Fig. 4 The transceiver RFICs are mounted to the backside of the board containing the antenna arrays.

QTM052 to achieve the required output power and minimize power dissipation. As noted, the silicon power amplifier can deliver 10 to 15 dBm at 28 GHz. A single $\lambda/2$ patch antenna has a gain of 5 dBi, and a 2 × 2 array provides an additional 6 dB of summation gain and 6 dB beam-forming gain. Using a single polarization adds another 3 dB, netting a total antenna gain of 20 dB, which boosts the radio output to 30 to 35 dBm EIRP.

The thermal design of the board holding the RFIC BGAs must channel the heat without creating "hot spots" in the phone noticeable to the user. For the 2 × 2 array transmitting a 64-QAM OFDM or SCFDM signal at 28 GHz, each power amplifier is backed off to approximately 6 to 8 dBm. At this output, the typical DC power dissipation for four transmit channels is 350 to 380 mW.

5G PHONES COMING SOON

Qualcomm has achieved an amazing engineering feat: developing a mmWave radio using a multi-polarization phased array antenna with beam steering and highly integrated RF transceiver that meets the 5G NR specification—a radio small enough so four modules will fit in a smartphone to ensure coverage while the phone is held. This level of engineering and end-to-end system integration in a commercial product is as impressive as the performance.

Operators and smartphone manufacturers say the first 5G phones will appear on the market in early 2019. Although Qualcomm will not say, no doubt you will find the QTM052 providing the mmWave connection.

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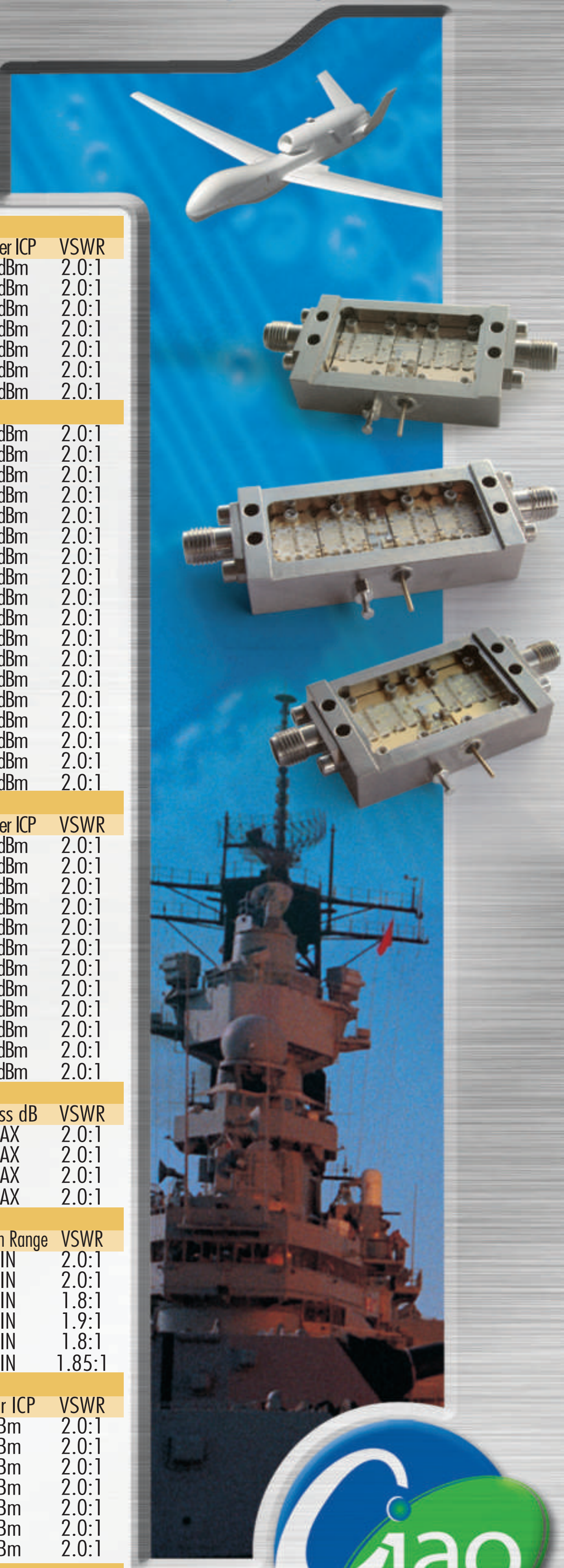

OCTAVE BAND LOW NOISE AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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DefenseNews
Cliff Drubin, Associate Technical Editor

Harris, L3 to Combine to Create Global Defense Technology Leader

Harris Corp. and L3 Technologies Inc. have agreed to combine in an all stock merger of equals to create a global defense technology leader, focused on developing differentiated and mission critical solutions for customers around the world. Under the terms of the merger agreement, which was unanimously approved by the boards of directors of both companies, L3 shareholders will receive a fixed exchange ratio of 1.30 shares of Harris common stock for each share of L3 common stock, consistent with the 60-trading day average exchange ratio of the two companies. Upon completion of the merger, Harris shareholders will own approximately 54 percent and L3 shareholders will own approximately 46 percent of the combined company on a fully diluted basis.

The combined company, L3 Harris Technologies Inc., will be the sixth largest defense company in the U.S. and a top 10 defense company globally, with approximately 48,000 employees and customers in over 100 countries. For 2018, the combined company is expected to generate net revenue of approximately $16 billion, EBIT of $2.4 billion and free cash flow of $1.9 billion.

The combined portfolio brings depth and balance of relationships across a wide range of customers, in both the U.S. and international markets. Increased scale will enable the combined company to be more cost competitive, expand capabilities to provide end-to-end solutions across multiple domains of air, sea, land, space and cyber, enhance leadership in RF and spectrum technologies and establish a leading platform-agnostic supplier and integrator.

Both L3 and Harris are technology driven organizations with significant R&D investment and a combined workforce of approximately 22,500 engineers and scientists. The combined company plans to accelerate investment in select technologies to expand leadership in key strategic domains including national security. By leveraging a common operating philosophy of continuous improvement and operational excellence, L3 Harris Technologies will continue to drive operating margin improvement.

The merger is expected to close in mid-2019.

US Army Awards Contract for Multi-Mission Radar

The U.S. Army awarded Raytheon Co. a $191 million contract for Ku-Band RF (KuRFS) radars. KuRFS, an advanced electronically scanned array system, fills an immediate U.S. Army operational need for a counter-UAV radar.

Already deployed, KuRFS delivers precision fire control as well as "sense and warn" capability for multiple missions including detection of rocket, artillery, mortar and swarming UAS threats.

"Seeing threats—like swarming drones—as soon as possible on the battlefield is essential to protecting critical assets and saving soldiers' lives," said Andrew Hajek, senior director of tactical radars, Raytheon IDS. "KuRFS makes this possible by delivering a unique combination 360-degree situational awareness, precision and mobility."

KuRFS enables defense against multiple threat types through integration with the Land-Based Phalanx Weapon System, 50-caliber guns and 30 mm cannons. The radar also supports high-energy laser and the Coyote weapon system in both a ground mounted or vehicle mounted configuration.

KuRFS is able to quickly address the urgent needs of the Army through a model of rapid-turn development and deployment. This reduces time to fielding, while providing enhanced flexibility to adapt to a quickly-changing threat environment in the drone space.

AFRL Awards Contract to Develop GaN Modeling Capability

Qorvo has been awarded a four-year contract by the U.S. Air Force Research Laboratory (AFRL) to lead a team developing a physics-based, unified GaN modeling framework intended to accelerate the design of GaN devices.

In addition to Qorvo, the program, named Engineering Predictable Behavior into GaN Devices Foundational Engineering Problem (FEP), will comprise Modelithics, the University of Padua, NI AWR, HRL and the University of Colorado-Boulder.

The output of the program will be a single tool that unifies physics and device modeling and will simulate device performance and assess reliability, enabling design trade-offs not currently possible. AFRL sees this simulation capability reducing the number of design-build-test iterations, enhancing device reliability, reducing development time and cost.

Delivery of the final, unified modeling framework is planned during 2022.

"This award enables the Air Force to leverage Qorvo's nearly 20 years of expertise developing the industry's most reliable, highest performing GaN process. We are proud to be selected by the Air Force to develop this new modeling and simulation tool, which will accelerate advanced GaN designs for mission-critical applications, even as it reduces costs,"said James Klein, president, Infrastructure and Defense Products, Qorvo.

For More Information Visit mwjournal.com for more defense news.

GaN's high-power density, leading to high output power and efficiency well into mmWave frequencies has made it the preferred semiconductor technology for radar, EW and communication systems for military applications. These same advantages are enabling it to gain market share for wireless infrastructure power amplifiers as device cost decreases.

General Atomics Tests Airborne Tracking and Targeting System

General Atomics Electromagnetic Systems (GA-EMS) recently participated in the Rim of the Pacific Exercise (RIMPAC) to conduct demonstrations and testing of the Missile Defense Agency's (MDA) Airborne Tracking and Targeting System (ATTS). The ATTS is configured on an MQ-9B remotely piloted aircraft to generate precision tracks and imagery of targets of interest. The system was employed throughout the RIMPAC exercises conducted near the Hawaiian Islands.

"We tested MDA's ATTS under operational conditions to help further characterize its tracking performance against real-world targets of interest," stated Dr. Michael Perry, VP for lasers and advanced sensors, GA-EMS. "Exercises like RIMPAC provide us with a unique opportunity to shake out and stretch the system's capabilities. We can now take the test data we've obtained and analyze it to further improve ATTS' ability to effectively track and target a variety of threats at long-range and in real-time."

MQ-9 (U.S. Air Force Photo)

"GA-EMS continues to develop and advance its portfolio of missile defense weapon systems and technologies to support air, sea and land platforms," said Scott Forney, president, GA-EMS. "In an increasingly more complex, multi-layered warfare environment, systems like ATTS will enhance our military forces ability to improve tracking and targeting accuracy to protect lives and achieve mission success."

Held every two years, RIMPAC is the world's largest multinational maritime warfare exercise. RIMPAC 2018 exercises included 25 nations, 46 ships, approximately 200 aircraft, five submarines and 25,000 personnel.

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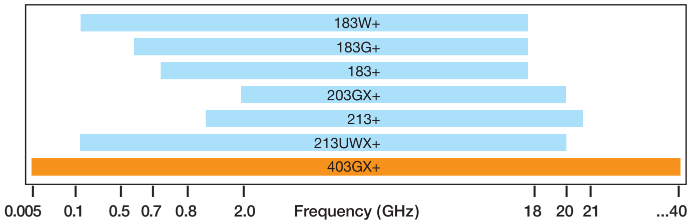
	ZVA-183GX+*	0.5-18	27±2	27	36	3.0	1479.95
	ZVA-183X+*	0.7-18	26±1	24	33	3.0	935.00
NEW!	**ZVA-203GX+**	**2.0-20**	**29±1**	**13.5**	**27.5**	**3.0**	**1295.00**
	ZVA-213X+*	0.8-21	26±2	24	33	3.0	1039.95
	ZVA-213UWX+	0.1-20	15±1	15	30	3.0	1795.00
NEW!	**ZVA-403GX+**	**0.005-40**	**11±1.5**	**11**	**21**	**4.0**	**1995.00**

* Heat sink must be provided to limit base plate temperature.To order with heat sink, remove "X" from model number and add $50 to price.

Wideband Performance



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5G Americas Report Details 3GPP Releases 14 to 16 Standards

The publication of "Wireless Technology Evolution: Transition from 4G to 5G," which details the extensive standards work by the global organization 3GPP in the development of 5G wireless technology, was recently announced by 5G Americas.

3GPP's robust past of standardizing the technologies that drive the largest mobile wireless ecosystems from GSM to LTE and now to 5G creates the backbone for this unique whitepaper by 5G Americas. LTE and its advanced evolutions, currently deployed on 613 commercial networks worldwide, is expected to be the dominant mobile wireless technology well into the next decade. Now, Release 15 begins the first phase of 5G of wireless technologies.

While 3GPP Release 14, which was frozen by mid-2017, produced LTE-Advanced Pro features, it also focused on the study items towards 5G mobile wireless technology and architecture including Cellular Vehicle to Everything (C-V2X) communications. However, in Release 15, the first phase of normative specifications for 5G provides specifications for a wider range of spectrum bands, from below 6 GHz to mmWave bands up to 100 GHz enabled by a New Radio (NR) access technology.

> 3GPP Release 15 marks the start of a new era; technology enablers for the IoT, autonomous vehicles and URLLC.

"5G Americas expects that the four U.S. national carriers will have launched 5G networks based on the 3GPP standards in the next nine months, building on their global leadership in LTE technology," commented Vicki Livingston, head of communications, 5G Americas and a contributing author to the report. "If appropriate regulatory policies, at the local, state and federal levels, are in place and adequate spectrum resources are allocated in low, mid and high bands, the U.S. could be well-positioned to continue in a leadership role."

The progress on Release 15 has been significant; responding to requests by numerous leading companies, 3GPP escalated their timeline for Rel-15 Non-Standalone (NSA) 5G NR specifications which were completed in December 2017. The 5G NSA specifications have an LTE anchor for the control plane communications with a 5G NR cell to boost user data. The Rel-15 Standalone 5G NR specification will work without any reliance on LTE and those specifications were completed in June 2018 along with specifications of the new core network. The new core network specified in Rel-15 will provide interaction with the Evolved Packet Core (EPC) 4G system with orchestration, virtualization, a clearly separate control and user plane, and signaling architecture. Network slicing and Service Level Agreement (SLA) for groups of devices of new vertical industries and services will be provided for by the 5G core specification.

To meet the timeline and full compliance with ITU IMT-2020 requirements, the standardization in Release 16 continues to progress. Definition of work study items was completed in July 2018, on schedule, with the option of adding additional study and work items in the future, as needed. Release 16, or phase 2 of 5G, will primarily address any outstanding issues in Rel-15, expansion of 5G NR based on C-V2X capabilities, Industrial IoT, enhancements to ultra-reliable low latency communication (URLLC) and 5G in operation in unlicensed spectrum and above 52.6 GHz. 5G efficiency improvements in Rel-16 will include enhancements to 5G self-organizing networks (SON) and big data capabilities, MIMO enhancements, improved power consumption, support for device capabilities exchange and a study of support for non-orthogonal multiple-access (NOMA). The Release 16 standards will be completed before the end of 2019 to target the ITU IMT-2020 submission.

Global Connectivity Reliant on Bluetooth, Wi-Fi and RFID, Even as LPWA Catches Up

In a new report, ABI Research shows how the Internet of Everything (IoE) represents the practical aggregation of three domains: the Internet of Digital, the Internet of Things (IoT) and the Internet of Humans (IoH). These are three separate addressable markets served by the same single Internet and the same variety of connectivity technologies. When industry commentators talk about the connected world, very large numbers are discussed. Numbers so large that it is hard for an individual organization to apply them in any meaningful way to their own businesses.

Jamie Moss, research director of M2M, IoT and IoE, explains, "Organizations need to be able to identify the segment of the connected world that is relevant to them, namely the endpoints that their products and services can address. This requires an understanding of how the connected world breaks down, by technology, application, device type and end-user channel. This level of segmentation can only be built from the bottom up, by understanding individual device markets, the application for which they are suitable and the technologies that enable them. The IoE must not be considered as a market but as the aggregation of all markets."

At the end of last year, there were nearly 22.5 billion connected devices worldwide; in 2022, there will be more than 40 billion. Of the nine vertical markets that

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ABI Research aggregates connected devices into, by far the most significant are PCs and digital home, mobile devices and retail, advertising and supply chain. This will not change between now and 2022.

Typically, the installed base of mobile devices runs on the powerhouse of the mobile phone industry—at first feature phones and since 2012 smartphones, specifically. PCs and digital home is a rich melting pot of important device markets from routers, to laptops and desktops, to TVs and set-top boxes. Retail, advertising and supply chain is an industry propelled by the growth of connected devices in retail and advertising, as well as in asset and inventory management.

Turning to the connectivity technologies that are used in devices that constitute a longer-term portion of the installed base before being replaced, Bluetooth and Wi-Fi were the most prevalent at the end of 2017, with 8.7 and 8.4 billion devices active worldwide, respectively. Cellular technologies used for non-M2M purposes were close behind with nearly five billion active connections. There is considerable overlap between Bluetooth, Wi-Fi and cellular with many devices featuring more than one or all three. The total number of connections by technology differs from the total number of devices by a ratio of 5:3. For example, there are only 60 percent as many devices as there are total connections active across all technologies.

Connections for Cellular M2M and for proprietary low-power wide-area (LPWA) networks will have by far the greatest CAGR over the next five years. Between 2017 and 2022, M2M and LPWA connections will double their representation, from eight percent of all cellular connections to more than 16 percent. By 2022 the total number of active cellular M2M and LPWA connections will be 1.5 billion. Although this is only four percent of all connected devices, it represents those that will be the most individually valuable enterprise assets.

> Cellular M2M and LPWA networks will have by far the greatest CAGR over the next five years.

Moss concludes, "Unlike more common, less secure connectivity technologies such as Bluetooth and Wi-Fi, IoT-specific technologies are not bundled into a product as a generic differentiator, on the vague premise that an end user might find a use for them. They are built into products shipped to order after careful upfront calculations have determined that they will generate a specific return on investment (ROI). The growth of IoT connections is therefore organic, occurring naturally when the technology fits and the business case is right. The growth of IoT connections is immune to hype, it exists for practical pre-calculated outcomes."

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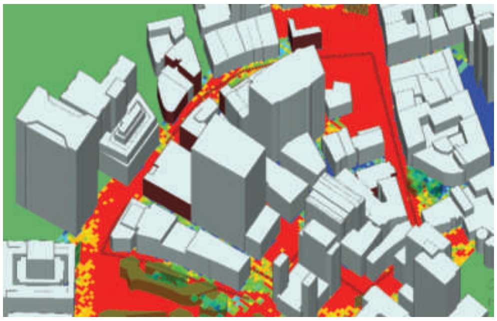

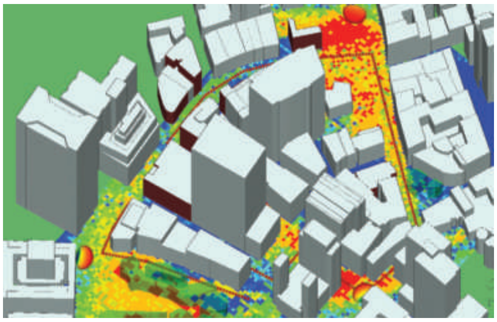

Beamforming with massive MIMO (top) shows significant improvement to throughput over links between single antennas (bottom)

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

SemiGen Inc., an ISO and ITAR registered provider of RF and microwave contract assembly, automated PCB assembly, foundry services, semiconductor devices and RF supplies, announces the acquisition of **Ion Beam Milling** of Manchester, N.H. Ion Beam Milling is a 35 year old manufacturing company who pioneered several thin film circuit processing techniques using innovative ion beam milling approaches.

Samtec Inc. announced the recent acquisition of the assets and going-forward business relationship of **Precision Connector Inc. (PCI)**. PCI specializes in the design and manufacture of precision RF and microwave coaxial connectors and brings over 25 years of design experience in the RF/microwave industry to the Samtec team. The additional engineering support and product offering of precision interconnects—such as 3.50 mm, 2.92 mm, SMP, 2.40 mm, 1.85 mm, SMPM and 1.0 mm—will further strengthen Samtec's RF portfolio and accelerate Samtec advancements into the precision RF sector.

COLLABORATIONS

Rohde & Schwarz and **Huawei** have successfully tested the interoperability of LTE-V connected vehicles with the R&S CMW500 wideband radio communication tester using the embedded Huawei Balong 765 IC as an LTE-V UE. The solution verified multiple test scenarios for Internet of Vehicles (IoV) communications based on 3GPP Release 14 Mode 4. LTE-V is a cellular IoV technology standard based on device to device (D2D) and existing LTE technologies. In the R&D phase, interoperability testing between terminals from different providers verifies connectivity and compliance with the standard. Testing the conformance of LTE-V terminals based on an authoritative third-party test platform is a crucial foundation for successful commercial deployment of LTE-V.

Keysight Technologies Inc. announced that it has been selected as the sole supplier of 5G network emulation solutions by **Xiaomi Corp.**, a Chinese electronics company, to accelerate development of its 5G NR mobile devices. 5G devices operating on mmWave frequencies rely on phased array antenna and beamforming technologies to address higher data throughput requirements. Keysight's 5G RF DVT Toolset supports the latest 3GPP 5G New Radio (NR) Release 15 specifications, including beamforming and beam management across sub-6 GHz and mmWave frequencies. This comprehensive set of capabilities allows Xiaomi to validate the performance of 5G mobile devices, with easy-to-use tools for test case creation, execution and analysis in a controlled laboratory-based environment.

DuPont Sustainable Solutions (DSS) has announced a partnership with **Guardhat**, an industrial safety technology company specialized in developing wearables, infrastructure and software platforms, to provide a safer and more productive work environment. Through this partnership, DSS and Guardhat will work together to develop advanced, scaleable solutions that provide actionable, real-time data for industrial companies seeking to better safeguard their employees. These breakthrough technologies allow companies to capture data about where and when employees face risks and hazards.

ACHIEVEMENTS

The **American Council of Independent Laboratories (ACIL)** recently announced recipients of the nationwide ACIL Customer Quality Service Award for 2018-2019, and, once again, **D.L.S. Electronic Systems** received this award. Developed in 1996 to address the industry's quality issues and recognize those laboratories with exemplary quality performance, the program provides laboratory data users with a mechanism to evaluate testing laboratories. Participants commit to ensuring data integrity, meeting customers' quality needs and setting performance standards for the testing laboratory industry. No other evaluation program ranks customer satisfaction with laboratory services and requires laboratory management to commit to a data integrity program.

Richardson RFPD announced that it has become an adopter member of the **LoRa Alliance™**. The nonprofit technology association promotes and collaborates on an open, global standard (LoRaWAN™) for low-power wide-area network (LPWAN) IoT connectivity. As an adopter member, Richardson RFPD will support the LoRa Alliance, participate in member meetings and continue its global leadership role in delivering tailored, end-to-end IoT solutions to its customers. Richardson RFPD extensive IoT offering includes modules, gateways and components for LPWA/cellular, as well as Bluetooth, Wi-Fi and GNSS applications.

Several of **Skyworks**' innovative solutions have received top honors from **Mobile Breakthrough**. Mobile Breakthrough recognizes the world's best mobile and wireless companies, products and people based on selections from an independent panel of experts within the wireless industry. Skyworks' family of advanced GNSS low-noise amplifier front-end modules were named "GPS-based Solutions of the Year," and their family of small cell PAs, were named the "Small Cell Technology Innovation of the Year."

CONTRACTS

L3 Technologies announced that it has been selected for a $36 million demonstration of existing technologies (DET) contract award for the **U.S. Navy's Next-Gener-**

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ation Jammer Low Band (NGJ-LB) program. The DET program encompasses a period of performance of 20 months, culminating in a demo at Naval Air Station Patuxent River, Md. The Next-Generation Jammer will augment, and eventually replace, the ALQ-99 tactical jamming system currently integrated on the EA-18G Growler aircraft. Over the past few years, L3 Technologies has conducted successful Navy technology demonstrations that operate cooperatively in electronic attack and electronic sensing.

HRL Laboratories LLC was awarded a $9.1 million CPFF completion contract for a **DARPA** mmWave GaN maturation project. Work will be performed in Malibu (97 percent) and Huntington Beach, Calif. (3 percent), with an expected completion date of April 2020. Fiscal 2018 research, development, test and evaluation funds in the amount of $1.2 million are being obligated at time of award. This contract was a competitive acquisition off the Microsystems Technology Office office-wide broad agency announcement HR001116S0001, with 138 offers received. DARPA is the contracting activity (HR0011-19-C-0006).

ORBCOMM Inc. and **Savi®** announced that the **U.S. DoD** has placed a significant multi-million dollar order with Savi for ORBCOMM telematics products and Savi services, which will enable the DoD to track and monitor nearly 24,000 high-value military assets. This order from the Defense Logistics Agency (DLA) is part of the active RFID-IV contract to provide government agencies and allied partners with state-of-the-art hardware, software and integration services for worldwide asset tracking and in-transit visibility.

Fairbanks Morse has been awarded a contract to build and deliver the four main propulsion diesel engines (MPDE) that will power LPD 30, which will be the **U.S. Navy**'s first LPD Flight II class ship. The newly designed ship will be based on the San Antonio-class hull, but the LPD Flight II is fitted with a fully capable flight deck and hangar, a well deck and the vehicle and cargo capacities to support and sustain more than 500 combat-equipped Marines for up to 30 days. Each engine will feature common rail (CR) fuel injection technology.

Harris Corp. has provided **Lockheed Martin** with its sixth of 10 advanced navigation payloads contracted for the U.S. Air Force's GPS III satellite program. The GPS III navigation payload features a Mission Data Unit (MDU) with a unique 70 percent digital design that links atomic clocks, radiation-hardened processors and powerful transmitters—enabling signals 3× more accurate than those on current GPS satellites. The payload also boosts signal power, which increases jamming resistance by 8× and helps extend the satellite's lifespan. Harris is committed to delivering a seventh navigation payload by the end of 2018.

Triumph Group Inc. announced that its Integrated Systems business has been selected by **Huntington Ingalls Industries** to supply remote valve actuation (RMVA) systems as part of the scheduled overhaul of the USS George Washington (CVN73) nuclear powered aircraft carrier. Under terms of the agreement, Triumph's Mechanical Solutions facility in Shelbyville, Ind. will produce 165 RMVAs for the carrier. RMVA systems provide mechanical backup push/pull control, which allows for remote opening and closing of critical valves throughout the ship. Valued for their high level of reliability, even in harsh environments, the Triumph RMVAs have a low-cost of ownership and unique adaptability, making the system ideal for rapid configurations and installations aboard ship.

PEOPLE

▲ *Penny Cotner*

Infinite Electronics Inc. announced the appointment of **Penny Cotner** as president and CEO. Current CEO Terry Jarnigan will be transitioning to the role of executive chairman. The changes are effective immediately. Under Jarnigan's leadership, Infinite Electronics has experienced explosive growth driven by major expansion of product lines, deep investments in technical resources and multichannel marketing to communicate with engineers worldwide.

▲ *Casey Krawiec*

StratEdge Corp. announced it has selected **Casey Krawiec** as VP of global sales. Krawiec will be responsible for the global sales of StratEdge's high speed, high frequency semiconductor packages and assembly and test services. Krawiec has worked for companies involved with wafer preparation, microelectronic assembly and packaging for almost 25 years. After earning a B.S. degree in mechanical engineering from the University of Kentucky and a MBA from the University of Louisville, Krawiec was a design engineer for the DoD for several years.

▲ *Mark Griffin*

XMA-Omni Spectra® announced the promotion of **Mark Griffin** to director of sales and marketing. He will spearhead all sales and marketing efforts in alignment with XMA's vision of advancing future technologies through disruptive RF design, manufacturing and support initiatives. Griffin joined XMA in early 2018 as a regional sales manager. He holds a degree in business management from Franklin Pierce College, as well as Electronics Technician "A" School certification from the U.S. Coast Guard. Prior to joining XMA, Griffin held positions with MACOM, Arrow Electronics, SkyWorks and most recently Microwave Components Inc.

The Radio Club of America (RCA) announced that **Professor Ted Rappaport**, founding director of NYU WIRELESS and a professor of electrical and computer

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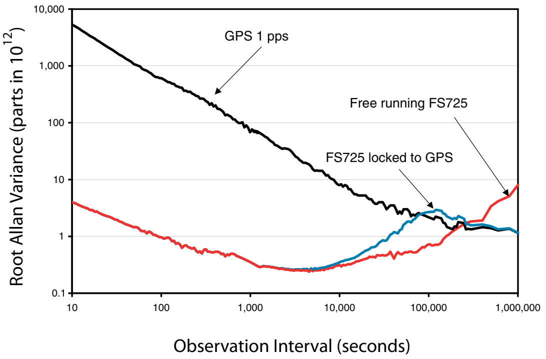

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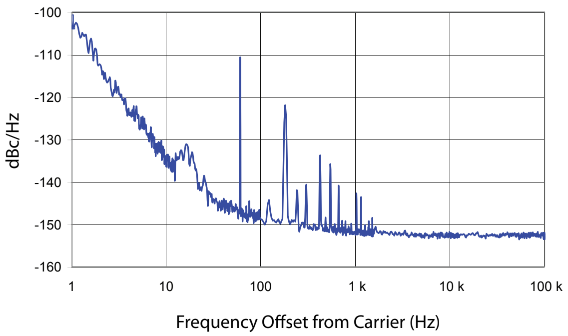

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engineering at the NYU Tandon School of Engineering, will receive the Armstrong Medal for demonstrated excellence and lasting contributions to radio arts and sciences. Rappaport conducted seminal research, most recently in the mmWave radio spectrum. He advanced commercialization of this 5G technology that will bring broadband speeds to wireless communication—thereby potentially revolutionizing medicine, enabling autonomous vehicles and inexpensively connecting rural communities to the digital world, and more.

▲ *Ted Rappaport*

Modine Manufacturing Co. congratulated **Gina Janke**, one of seven members, given the Fellow Grade award at the Society of Women Engineers (SWE) annual WE18 event, the world's largest conference and career fair for women engineers. The Fellow Grade award recognizes continuous service to the advancement of women in the engineering profession. Janke, principal manufacturing engineer in the Vehicular Thermal Solutions (VTS) segment, has been with Modine for 21 years, and is currently responsible for cost estimating activity for products manufactured at the Trenton, Mo. facility and aluminum welded tube products at Nuevo Laredo, Mexico.

REP APPOINTMENTS

M Wave Design Corp. announced that it has signed **Third Wave Electronics** to represent it for the Mid-Atlantic region—Maryland, Washington, D.C., Delaware and Virginia—for its Passive Microwave Components line. This compliments the other regional sales organizations. A full list can be seen at their website.

PLACES

NAI has established several new facilities within their plants in Hermosillo, Mexico and Suzhou, China. These operations are dedicated to the design, prototyping and testing of cable assemblies, harnesses, box builds and panel builds. There are separate facilities for fiber optic interconnects and copper. Referred to as "Centers of Excellence" (CoE) or as New Product Introduction departments (NPI), these specialized operations include dedicated teams of engineers who design, analyze and qualify assemblies, as well as box or panel builds, before they go into production.

INVITED PAPER

Evaluating PCB Plated Through Holes For 5G Applications

John Coonrod
Rogers Corp., Chandler, Ariz.

The broad range of frequencies covered by 5G wireless networks places added requirements on circuit materials operating through mmWave frequencies. This article explores the RF performance effects of plated through hole (PTH) surface-wall roughness on signal transitions from top to bottom copper layers of high performance printed circuit board (PCB) materials for 5G applications.

5G wireless networks are being touted as one of the greatest technology advancements to reach modern electronic communications, making use of signal carrier frequencies below 6 GHz, as with earlier wireless communications generations, but also reaching well into mmWave frequencies for short-haul, high speed data links. Printed circuits for such a wide range of frequencies require special circuit laminates. RO4730G3™ laminates from Rogers Corp., for example, offer outstanding performance from RF through mmWave frequencies.

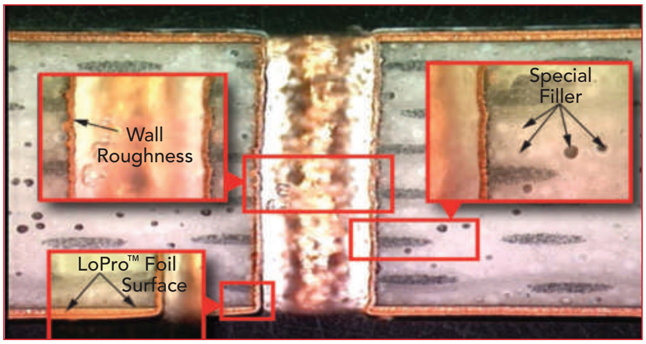

Fig. 1 **Circuit laminates using hollow microsphere fillers may form PTHs with rough wall surfaces.**

However, a difference between this type of laminate and more traditional circuit materials, and a cause for concern among some circuit designers, is the use of hollow microspheres in substrate fillers. Because of the microspheres, the appearance of micromachined circuit features, such as PTHs from one conductive copper layer to another, can appear much rougher than PTHs in more traditional circuit materials without these fillers. Are looks deceiving or is the concern warranted? Extensive testing, summarized in this article, has shown that the impact of microsphere fillers on PTH surface roughness is purely cosmetic and does not affect circuit performance.

PTH COMPARISON TEST

The wall surfaces of all PTHs can vary in texture, even when comparing the roughness of wall surfaces in the same laminate. Wall surface roughness varies from hole to hole simply due to multiple factors involved in the drilling process. In a material with microsphere fillers, for example, a drill may or may not impact a microsphere. When the drill impacts and fractures a hollow sphere, copper plating for that PTH follows the contour of the opened sphere and the PTH wall is not smooth and flat (see ***Figure 1***). It is only natural to question whether the roughness translates to compromised electrical performance or reliability compared to a more traditional circuit laminate in which PTHs are smoother in appearance. In general, and for traditional high frequency circuit materials not using microsphere fillers, a rough wall surface can indicate a problem in the PCB fabrication process, with a concern for PTH reliability. For circuit materials with hollow microsphere fillers, however, PTHs with rough surfaces are normal and are not indicative of poor performance.

Prior to evaluating the impact of PTH wall surfaces on high frequency circuit performance, RO4730G3 circuit laminates with their microsphere fillers were extensively evaluated under different operating conditions. This included, for example, 10 layer highly accelerated thermal shock, double-sided PTH reliability, double-sided PTH-to-PTH conductive-anodic-filament (CAF) resistance, plane-to-plane CAF resistance, maximum operating temperature and surface-mount technology testing, insulation resistance and PTH quality. The material and its microspheres passed these tests under industry standard testing conditions. Additional information regarding these tests can be found online at the Rogers Corp. Technology Support Hub.

RF tests were performed to compare circuit material with glass reinforcement and microsphere fillers (i.e., 20.7 mil thick RO4730G3 circuit laminate) with a circuit laminate without glass reinforcement and with much smaller solid fillers (i.e., 20 mil thick RO3003G2™ laminate), both from Rogers. The two materials have similar dielectric constants (Dk) or relative permittivities (ε_r) of approximately 3, and the same thickness. The main difference is that the RO3003G2 material produces a relatively smooth PTH wall surface and the RO4730G3 PTH wall surface is rougher. The texture of a circuit PTH wall surface is usually considered to be more of a circuit fabrication issue than a material issue. Still, material characteristics can make a difference, including circuit material filler type, filler size, glass reinforcement and resin type. Comparing the RO4730G3 laminate and its hollow microsphere fillers with the RO3003G2 laminate, which has no glass reinforcement and extremely small fillers, smoother PTH wall surfaces might be expected for the latter, assuming that optimum PCB fabrication methods were used for both materials. In fact, as ***Figure 2*** shows, RO3003G2 circuit laminates can produce relatively smooth PTH wall surfaces.

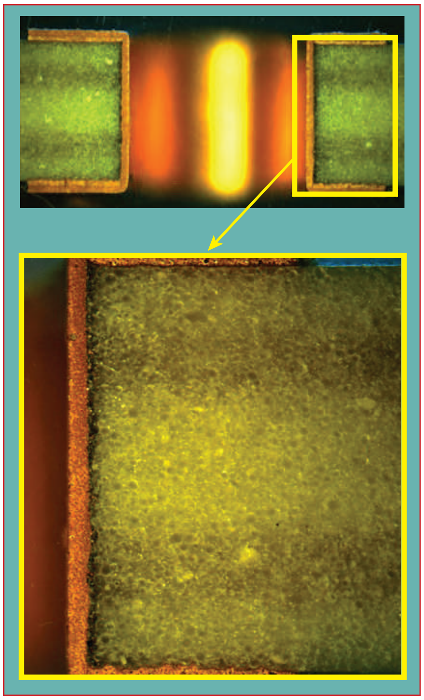

Fig. 2 Microscopic image of a relatively smooth PTH wall in 20 mil RO3003G2.

Differences in PTH surface roughness of the two materials shown in Figures 1 and 2 are clear, but will this affect RF performance? For a test vehicle, a microstrip trans-

mission line provides an effective means of comparing the effects of smooth and rough PTH wall surfaces on otherwise similar circuit materials, since PCB fabrication variables for microstrip have less impact on RF performance than for other high frequency transmission line formats. The microstrip circuits for these tests (see ***Figure 3***) were designed with the goal of achieving good results up to 40 GHz.

The "standard" microstrip transmission line, shown in Figure 3a, has grounded coplanar waveguide (GCPW) structures at the ends to launch to the 2.4 mm coaxial connectors (model #1492-04A-5 from Southwest Microwave). Figure 3b shows the top and bottom layers with a PTH in the middle to provide a transition between layers. The 2 in. test circuit is a loosely coupled GCPW transmission line to have similar RF performance to the microstrip "standard" transmission line. Loose coupling enhances performance at higher frequencies and is a good fit for this test vehicle through 40 GHz.

A number of circuits of the same design were fabricated from the same material panel to evaluate RF performance differences resulting from normal material variation and the effects of PCB fabrication process uncertainties. The original panel, measuring 24 in. × 18 in., was cut into two panels, each measuring 12 in. × 18 in., so that material consistency was maintained across the different test circuits. The same fabrication and test process was used for both circuit materials, the 20 mil thick RO3003G2 circuit material with smooth PTHs and the 20.7 mil thick RO4730G3 circuit material with rougher PTHs.

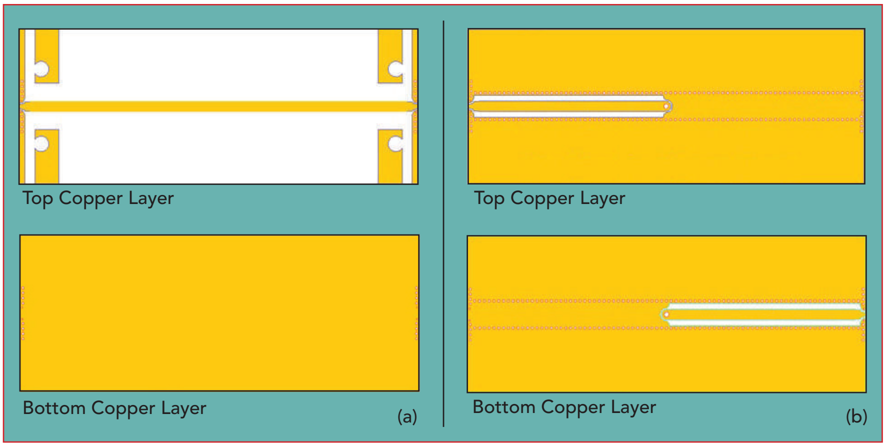

Fig. 3 Standard microstrip transmission line (a) and test circuit with PTH transition (b), used to evaluate the effect of PTH surface roughness on RF performance.

TABLE 1

S_{21} PHASE MEASUREMENTS

RO3003G2 (Smooth PTH Via Hole Wall)						
	Phase Angle (°)			Phase Angle Difference (°)		
Circuit ID	24 GHz	28 GHz	39 GHz	24 GHz	28 GHz	39 GHz
No via	–3189	–3728	–5237	Reference	Reference	Reference
P1 C1	–3167	–3708	–5237	22	20	0
P1 C2	–3169	–3711	–5241	20	17	–5
P1 C3	–3165	–3706	–5233	24	23	3
P1 C4	–3163	–3704	–5231	26	24	6
P1 C5	–3165	–3706	–5234	23	22	3
P1 C6	–3166	–3707	–5236	23	21	0
No via	–3186	–3725	–5233	Reference	Reference	Reference
P2 C1	–3167	–3707	–5233	19	18	0
P2 C2	–3165	–3706	–5231	21	19	2
P2 C3	–3164	–3704	–5227	22	22	6
P2 C4	–3163	–3703	–5226	23	23	7
P2 C5	–3165	–3705	–5229	21	20	4
P2 C6	–3161	–3701	–5223	25	25	10

PANEL 1

PHASE ANGLE DIFFERENCE (°)

	24 GHz	28 GHz	39 GHz
Average	22.93	21.13	1.11
Std Dev	1.91	2.32	3.56
Range	5.64	6.76	10.13

PANEL 2

PHASE ANGLE DIFFERENCE (°)

	24 GHz	28 GHz	39 GHz
Average	22.00	21.20	4.83
Std Dev	2.13	2.40	3.62
Range	5.93	6.70	9.97

TEST RESULTS

A large amount of data was collected including insertion loss, return loss, impedance, group delay and phase angle. ***Figure 4*** shows vector network analyzer screen shots of a sample of the test circuit in Figure 3b, with results in both the frequency and time domains. From Figure 4a, $|S_{21}|$ is 3.93 dB at 39 GHz, per marker 2. In Figure 4b, marker 1 shows that $|S_{11}|$ and $|S_{22}|$ at 40.7 GHz are better than 14.83 dB. Using time domain reflectometry, Figures 4c and d show the impedance in the body of the test circuit: approximately 48 Ω at markers 1, 2 and 3 in the PTH transition. Small impedance anomalies can be seen in the transition areas, although these are less than 2 Ω and have little impact on RF performance. This circuit is considered to have a good transition from top to bottom signal layers.

These through measurements show the effects of a PTH transition from one copper layer to another. Microstrip and loosely coupled GCPW circuit impedances are influenced most by substrate thickness versus conductor width, variations

in copper thickness and substrate Dk. The impedance in the PTH area is impacted more by these variables than any variation in the wall surface. For this reason, impedance was not used to gauge the effects of PTH wall surfaces on RF performance, although the data was collected.

Since surface roughness of a conductor along a microstrip transmission line affects the phase angle of a signal passing through it,[1-2] through measurement phase is a sensitive measure of the RF signal path through the PTH. Repeatabil-

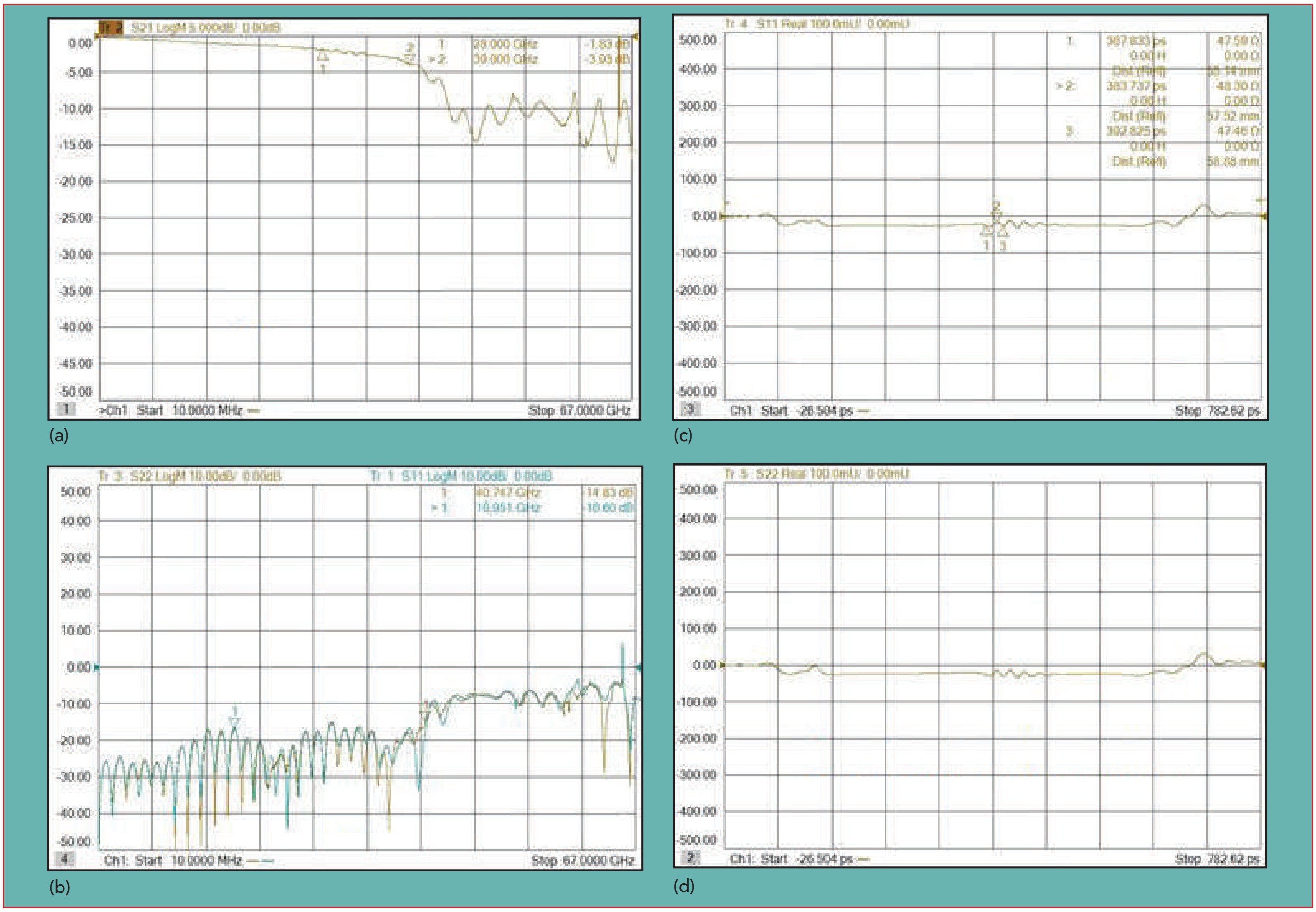

Fig. 4 Measured PTH test circuit: $|S_{21}|$ (a), $|S_{11}|$ and $|S_{22}|$ (b); real impedance vs. distance, as S_{11}, i.e., looking into the circuit from port 1 (c), and as S_{22}, i.e., looking into the circuit from port 2 (d).

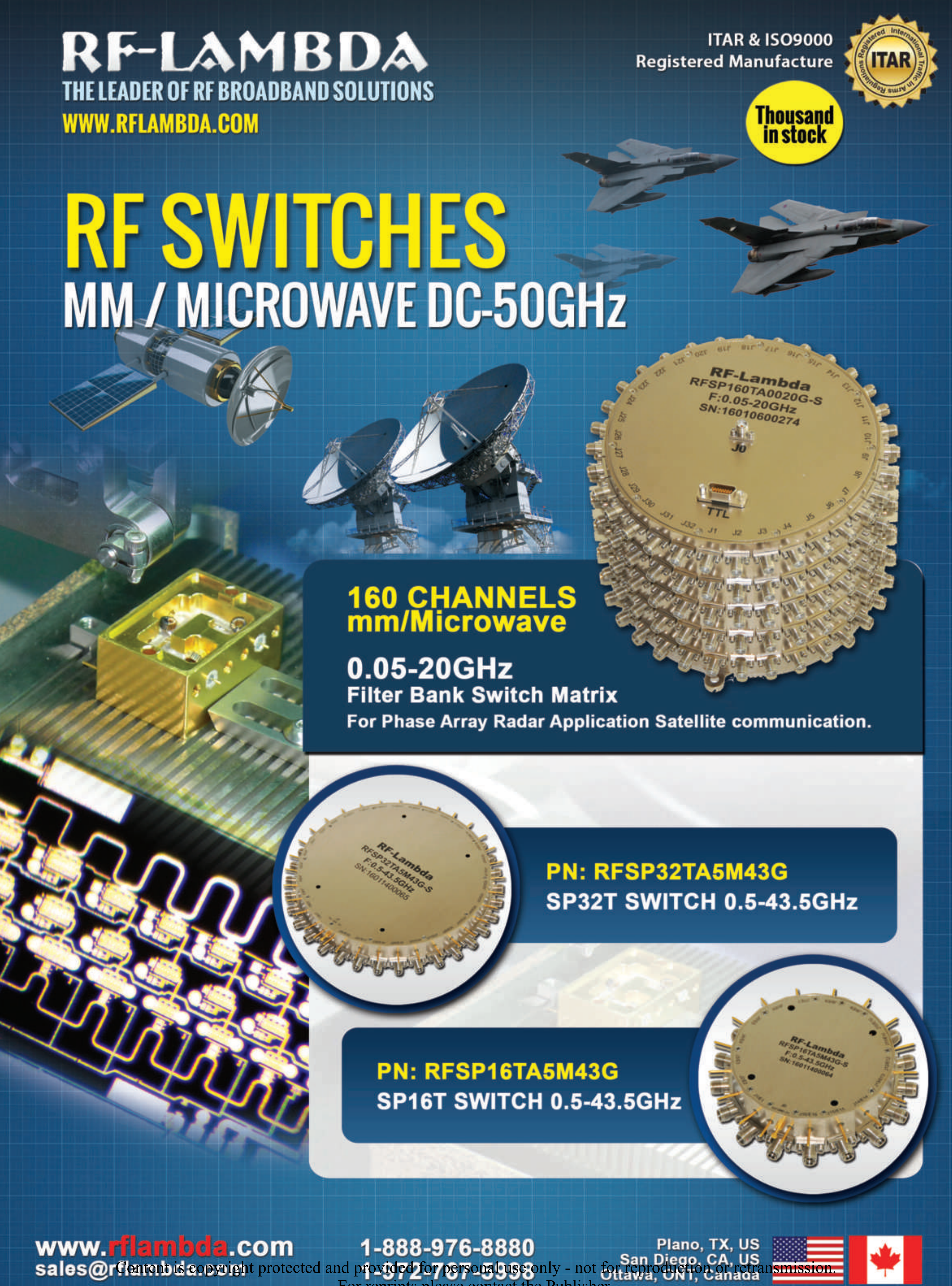
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TABLE 2

S_{21} PHASE MEASUREMENTS

RO4730G3 (Rough PTH Via Hole Wall)			
Panel 1 Phase Angle Difference (°)			
	24 GHz	**28 GHz**	**39 GHz**
Average	23.85	24.03	7.70
Std Dev	2.28	2.73	3.29
Range	6.06	6.89	7.60
Panel 2 Phase Angle Difference (°)			
	24 GHz	**28 GHz**	**39 GHz**
Average	19.68	18.61	–4.16
Std Dev	2.23	2.74	4.05
Range	6.83	8.31	10.47

TABLE 3

PHASE ANGLE (°)

Circuit ID	24 GHz	28 GHz	39 GHz
P2 C1	–3192	–3738	–5279
P2 C2	–3193	–3738	–5282
P2 C3	–3192	–3738	–5277
P2 C4	–3188	–3733	–5273
P2 C5	–3195	–3742	–5283
P2 C6	–3193	–3740	–5283
Average	–3192	–3738	–5279

ity measurements on one test circuit determined the S_{21} phase angle within a standard deviation of ±1.2 degrees at 39 GHz. For this measurement, S_{21} phase angle is the unwrapped phase angle, an absolute value summation of the −180 to ±180 degree phase. This is meaningful resolution for 5G frequencies at 39 GHz, where lower frequencies are less sensitive to phase variations. For a 2 in. long microstrip transmission line on a substrate with a Dk of about 3, the phase angle range is thousands of degrees at 39 GHz, so that suitable phase resolution is provided by the test circuits and this measurement approach.

Summarizing the results, ***Table 1*** shows data for six different circuits of the same design fabricated using one panel of RO3003G2 substrate material and compared, for reference, to a microstrip transmission line without a PTH. The table also shows data for six different circuits of the same design fabricated on a second panel of substrate material, where the two panels were originally cut from the same piece. The circuit ID indicates which panel the circuit came from and the circuit ID on that panel. For example, P1C4 is from panel 1, circuit number 4. To ensure consistency, circuits were separated from each other and evenly covered the panel. Some differences, due to factors such as conductor width variation, copper plated thickness variation and drilled hole quality were from PCB fabrication tolerances rather than PTH wall roughness. In addition, tight gaps around transitioning PTHs exhibited some variation due to normal PCB fabrication tolerances. Also, there were minor material variations across each panel, such as slight differences in Dk. Considering these uncertainties, repeatability of the phase data is within ±1.2 degrees at 39 GHz.

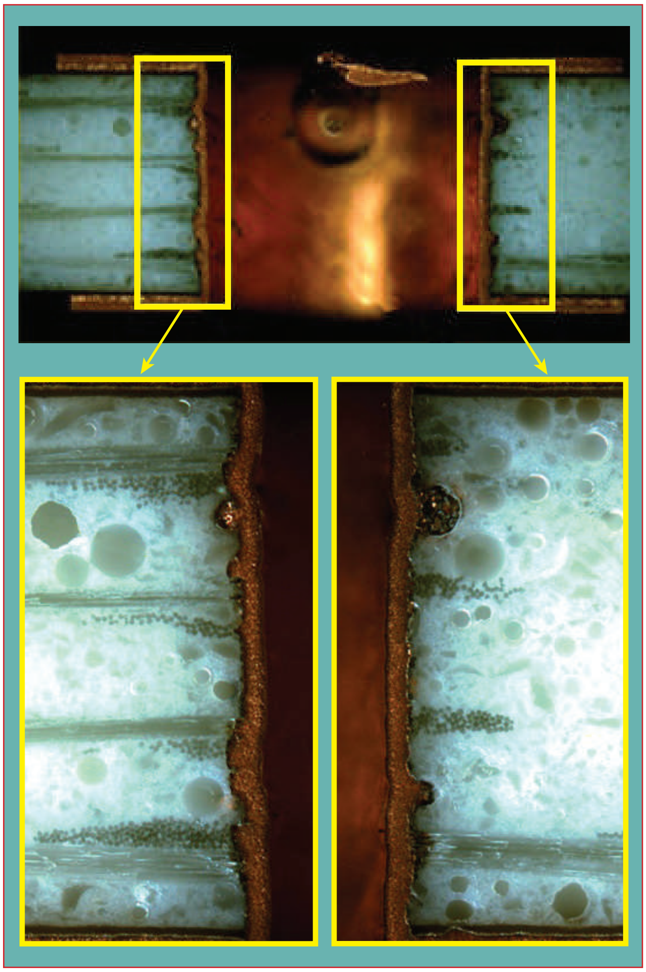
Although not a factor in these measurements, the Dk tolerance of the RO4730G3 circuit material is within ±0.05. At higher frequencies, however, even slight Dk variations can sometimes be noticeable: at 39 GHz, for example, a Dk shift of 0.05 will cause a change in phase of about 15.3 degrees. For a tolerance of ±0.05 or total Dk shift of 0.10, the phase angle at 39 GHz could change by as much as 30.6 degrees due to Dk variation alone. This is good to keep in mind when considering the phase angle variation shown in Table 1. Because the same original panel of material served as the source of panels for the PTH evaluations, variations in phase angle due to Dk variations can be expected to be minimal.

Table 2 shows the phase difference average, standard deviation


VDi
WR 3.4
220 - 330 GHz

and range from the circuits fabricated with the RO4730G3 laminate, which has the rougher PTHs. The statistical differences between the RO3003G2 and RO4730G3 laminates can be seen by comparing Tables 1 and 2. As noted, every attempt was made to minimize variations due to the material, with material panels 1 and 2 in each case coming from the same starting panel. Comparisons of phase angles and any differences are principally due to circuit fabrication effects. When analysis of the results is restricted to a single panel, phase angle differences are minimally influenced by PCB material variations. Each panel exhibits some variation in S_{21} unwrapped phase angle, but the variations are not significant between the two different materials.

Visibly, using microphotographs, the PTH surface walls appear quite different. For example, Figure 2 shows the PTH of ID P1 C1 fabricated on 20 mil thick RO3003G2 laminate, with a smooth PTH wall surface. ID P2 C6 (see ***Figure 5***), fabricated on 20.7 mil thick RO4730G3 circuit material, has a rougher PTH wall surface. Judging by appearance alone, there might be some cause for concern regarding PTH wall surface roughness on RF performance; however, these and other tests have shown that, with respect to the test vehicles considered, differences between rough and smooth PTH side walls are only cosmetic, with no apparent impact on RF/microwave/mmWave performance, at least through 40 GHz (see ***Table 3***).



▲ Fig. 5 Close-up photographs of the side walls of a PTH fabricated with 20 mil RO4730G3 laminate.

CONCLUSION

The information reported in this article is a small sample of the data collected testing circuit materials with smooth and rough PTH transitions. The purpose of these tests was to demonstrate the effects of PTH surface-wall roughness on RF performance at mmWave frequencies; they demonstrated that the different appearance between rough and smooth PTH side walls is only cosmetic and has no adverse effect on RF, microwave and mmWave performance through 40 GHz.■

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Navigating the 5G NR Standards

Sheri DeTomasi
Keysight Technologies, Santa Rosa, Calif.

Approximately once each decade, wireless communications standards have marched forward, advancing through 2G, 3G, 4G and now moving into 5G. The 5G New Radio (NR) standard creates a whole new era of wireless communications. The promise of everything connected, all the time, with extremely fast download speeds and ultra-low latency will require massive changes across the 5G ecosystem.

The 5G NR standard adds new operating bands with advanced ways to package and transmit signals. mmWave operating bands, wider modulation bandwidths, scalable numerologies and new initial access procedures introduce many changes to understand and implement in new infrastructure and mobile designs. Chipsets and devices will operate at higher frequencies. Devices and base stations will use new technologies to make connections and networks will evolve to handle more data, more users and different levels of service. 4G and 5G NR networks must initially work in harmony to provide seamless service for users. To fully capture 5G opportunities through new use cases and new business models, it is important to understand the 5G NR standard and develop techniques for successful implementation.

TABLE 1

IMT-2020 VISION USE CASES

Enhanced Mobile Broadband (eMBB)	Ultra-Reliable and Low Latency Communication (URLLC)	Massive Machine-Type Communication (mMTC)
All data, all the time	Ultra-high reliability	30 billion "things" connected
2 billion people on social media	Ultra-responsive	Low cost, low energy
500 km/h mobility	< 1 ms air interface latency	10^5 to 10^6 devices/km^2
20 Gbps peak data rate (downlink)	5 ms end-to-end latency	1 to 100 kbps/device
10 Gbps peak data rate (uplink)	99.9999% reliability	10-year battery life
	50 kbps to 10 Mbps	

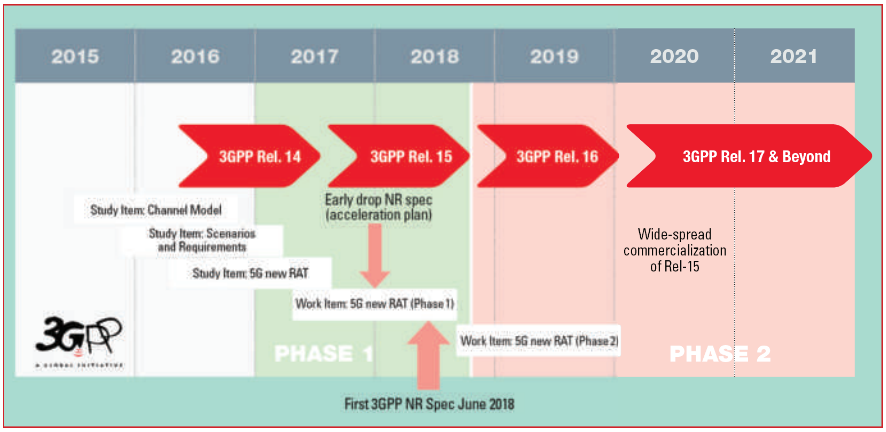


Fig. 1 3GPP timeline for 5G NR releases.

WHO DEVELOPED THE 5G NR STANDARDS?

The International Telecommunications Union (ITU) worked with operators, network equipment manufacturers (NEM) and standards organizations to define the International Mobile Telecommunications 2020 (IMT-2020) vision. The 5G NR standard specifies new features that require the development of new technologies to meet the aggressive goals shown in ***Table 1***. The Third-Generation Partnership Project (3GPP) is responsible for the development of the 5G NR access technology specifications to meet the recommendations of IMT-2020.

The ITU and 3GPP are using a phased approach to enable widespread commercialization of 5G NR by 2020. In phase 1, 5G NR Release 15 focuses on setting the foundation for the enhanced mobile broadband (eMBB) and ultra-reliable and low latency communications (URLLC) use cases. Phase 2 will continue the evolution of 5G NR, optimizing new features like unlicensed spectrum access and connected vehicle-to-everything (V2X) communication, beginning in 5G NR Release 16, which is projected to be completed by the end of

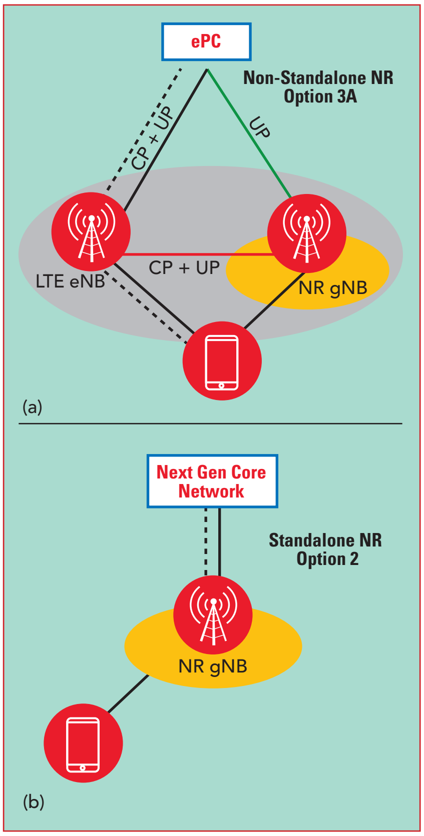
2019. 5G NR Release 15 is forward compatible with NR Release 16 but not backward compatible with 4G Release 14. 3GPP will also continue to define enhancements to LTE-Advanced Pro (initially specified in Releases 13 and 14) in Releases 15 and 16 (see ***Figure 1***).

The expectation is that 5G NR will operate alongside 4G LTE and deliver enhanced services. 5G NR Release 15, approved in June 2018, specifies the 5G radio access network (RAN) that will operate with both the 5G NR next-generation NodeB (gNB) and LTE evolved NodeB (eNB) base stations. 5G NR supports both standalone (SA) and non-standalone (NSA) modes of operation in phase 1. In NSA mode, the user equipment (UE) requires a legacy eNB base station with a connection to the evolved packet core (EPC), so the control plane can support 5G NR communication. In SA mode, the 5G network operates independently from the 4G core network (see ***Figure 2***). Seven different connectivity options are defined in the 5G NR specifications, enabling different upgrade paths to the next-generation core network for NEMs.

While 5G NR Release 15 is considered complete, there is a NR late drop freeze planned for December 2018 and an abstract syntax notation (ASN) drop in March 2019 to address NR architecture connectivity options not completed in September 2018. Conformance test definitions, one of the biggest areas still in development, have a target completion date of May 2019. Release 16 will begin identifying new types of services, devices, deployment models and spectrum bands with an emphasis on URLLC enhancements for industrial IoT, utilization of unlicensed bands, V2X, UE positioning and UE power efficiency.

WHAT IS IN THE 5G NR 3GPP SPECIFICATIONS?

RAN working groups define the 5G NR specifications. The workgroup outputs are public: all documents, meeting reports and pub-



▲ Fig. 2 **5G NR phase 1 non-standalone (a) and standalone (b) modes.**

lished specifications are available on the 3GPP website.[1] The 5G NR specifications appear in the 38.xxx series documents. The 5G NR RAN study items and specifications define the functions, requirements and interfaces of the networks. RAN study items are followed by work items that are followed by the release of specifications.

The radio interface between the UE and the network consists of layers 1, 2 and 3 of the communications stack, commonly known as the physical layer, the data link layer and the network layer. The physical layer, defined in TS 38.200, represents the interface to the "real world" and includes the hardware and software to control this linkage. The physical layer provides a transport channel and specifies how information is transferred over the radio interface. Layers 2 and 3, defined in the TS 38.300 series (see ***Figure 3***), work in conjunction with the physical layer.

The data link layer, also known as the medium access control (MAC) layer, enables data transfer between the different networks. The MAC layer provides different logical channels to the radio link control (RLC) in the network layer. Layer 3, the radio resource control (RRC) layer, connects with the nodes in the network so that the UE can travel seamlessly throughout the network.

The RAN working groups are responsible for developing the 5G NR specifications in certain areas, such as the 5G NR physical layer. TR represents a technical report or study, and TS represents a technical specification. The 5G NR RAN working groups and technical specifications are:

- **RAN1 (radio layer 1, TS 38.201–38.215)** is responsible for the physical layer (layer 1) of the UE and the data transport to the radio interface protocol architecture (layers 2 and 3). It includes specifications of the physical channel structures, mapping of the transport channels into physical channels, multiplexing, modulation and channel coding, as well as the physical layer procedures, such as cell search, power control and beam management.
- **RAN2 (radio layers 2 and 3, TS 38.300–TS 38.331)** is responsible for the radio interface architecture and protocols. This includes interfaces between the 5G NR and the 5G core network. It covers the network interfaces, the physical layer and connections to MAC, RLC and the packet data convergence protocol (PDCP). RAN2 is also responsible for the RRC protocol, the strategies of radio resource management (RRM) and the services provided by the physical layer to the upper layers.
- **RAN3 (radio network, TS 38.401–38.474)** is responsible for the overall architecture and the protocol specifications. TS 38.2xx and TS 38.3xx in RAN1 and RAN2 define the radio interface protocols, and RAN3 defines the next-generation interface protocols.
- **RAN4 (radio performance and protocol, TS 38.101–38.307)** is responsible for the RF aspects of the communications and the

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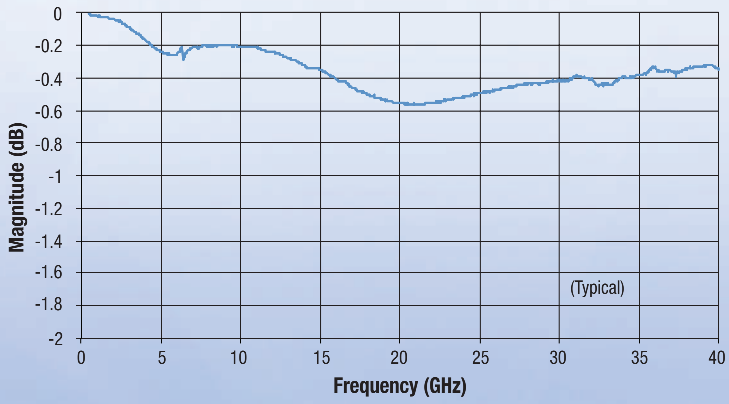

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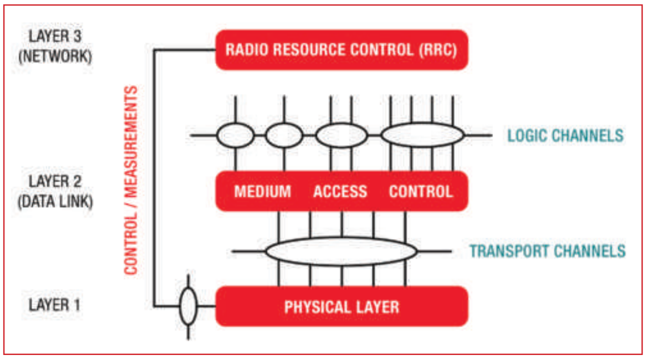


Fig. 3 Radio interface protocol architecture around the physical layer (from 3GPP document TS 38.201).

development of the minimum requirements for 5G NR transmission and reception, as well as the parameters for channel demodulation. RAN4 also provides test procedures for base station conformance and specifications for electromagnetic compatibility (EMC), radio link, cell selection/reselection and performance supporting RRM.

- **RAN5 (mobile terminal conformance tests, TS 38.508–38.533)** is responsible for the specifications of conformance testing at the radio interface for the UE, based on the specification defined in RAN4 for signaling and protocol test cases. RAN5 has the responsibility for RF and signaling subgroups, including RF conformance and inter-radio access technology (RAT) procedures.

The RAN specifications introduce new frequencies and techniques for 5G NR signal creation, transmission and reception:

- Operating bands extend into mmWave: frequency range 1 (FR1) from 450 MHz to 6 GHz and frequency range 2 (FR2) from 24.25 to 52.6 GHz.
- Wider channel bandwidths up to 100 MHz for FR1 and 400 MHz for FR2, which can be aggregated to produce even wider transmission bandwidths.
- Scalable numerology with flexible allocation of resources to support many use cases and services (e.g., subcarrier spacing that scales, enabling variable slot duration for low latency, time-sensitive applications).
- Dynamic time-division duplex (TDD) and bandwidth, which deliver flexibility in resource assignments and better spectrum utilization.

5G NR signals are more complex than 4G signals. A signal's modulation properties can be evaluated by viewing IQ constellation diagrams and error vector magnitude (EVM), EVM per symbol and EVM by subcarrier. This analysis provides some insight into the signal's performance. The radio layer protocol tests ensure a device is performing as expected. A network emulator can provide the protocol messages with specific numerologies and frame structures to test the key performance indicators (KPI) and vali-

date the performance of a device prior to commercial deployment.

Equally important, the 5G system architecture must evolve to keep pace with the radio access changes. Key to success are supporting the variety of 5G services, the many different types of devices and the varied traffic loads. Many network operators are moving to software-defined networking (SDN) and network functions virtualization (NFV). Distributed cloud, network slicing and self-optimizing networks (SON) are key enabling technologies. These new technologies help virtualize the network architecture and management plane to create enhanced communication capability. In parallel with 5G NR, the 3GPP system architecture (SA) work identifies the features and functionality needed to deploy a services-based operational network for 5G. These specifications are contained in 3GPP TS 23.xxx documents.

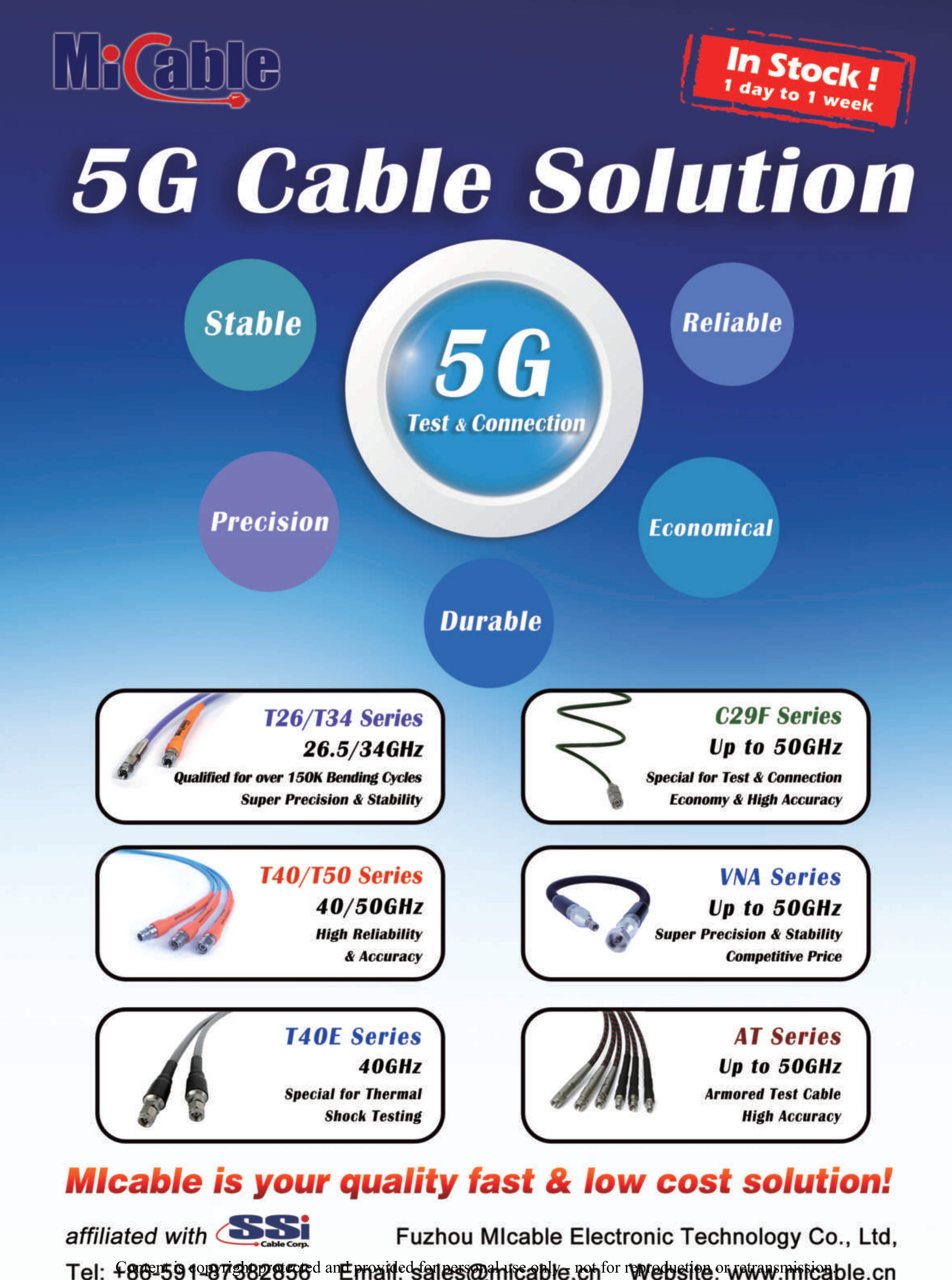
CONFORMANCE, PRE-CONFORMANCE AND DEVICE ACCEPTANCE TESTING

A major milestone in the development of devices and base stations is passing the conformance and compliance tests outlined in the 3GPP RAN4 and RAN5 specifications. All UEs and base stations must pass the required conformance tests before being released to the market. Conformance tests, however, only provide a minimum pass/fail result, offering no indication of how the device will perform when integrated into a wireless communications system. Device and base station manufacturers will test a wider set of parameters using verification and regression testing to ensure quality and sufficient margins. Pre-conformance testing is also done to check the confidence of a "pass" before conformance testing. This reduces the time and expense of rework in case the device fails official conformance tests (see ***Figure 4***).

UE conformance tests involve connecting a device to a wireless test system and performing the required 3GPP tests:

- RF transmission and reception to a minimum level of signal quality.
- Demodulation to determine data throughput performance.
- RRM to assure initial access, handover and mobility.
- Signaling to assess the upper layer signaling procedures.

Even though 5G NR Release 15 is complete, most of the 5G NR conformance tests will not be defined until May 2019. One of the key challenges will be testing the radiated performance of the device antenna. The use of mmWave multi-element antenna arrays integrated into RFIC requires over-the-air (OTA) testing to validate beam steering and performance. It is important to validate designs using OTA test methods approved by 3GPP. To date, 3GPP has approved three RF performance OTA test methods for UE devices (see ***Table 2***). Base station tests are still in development. An OTA test solution typically includes an anechoic chamber, probing and the test equipment to perform a wide range of RF, demodulation and functional performance tests at sub-6 GHz and mmWave frequencies. Third party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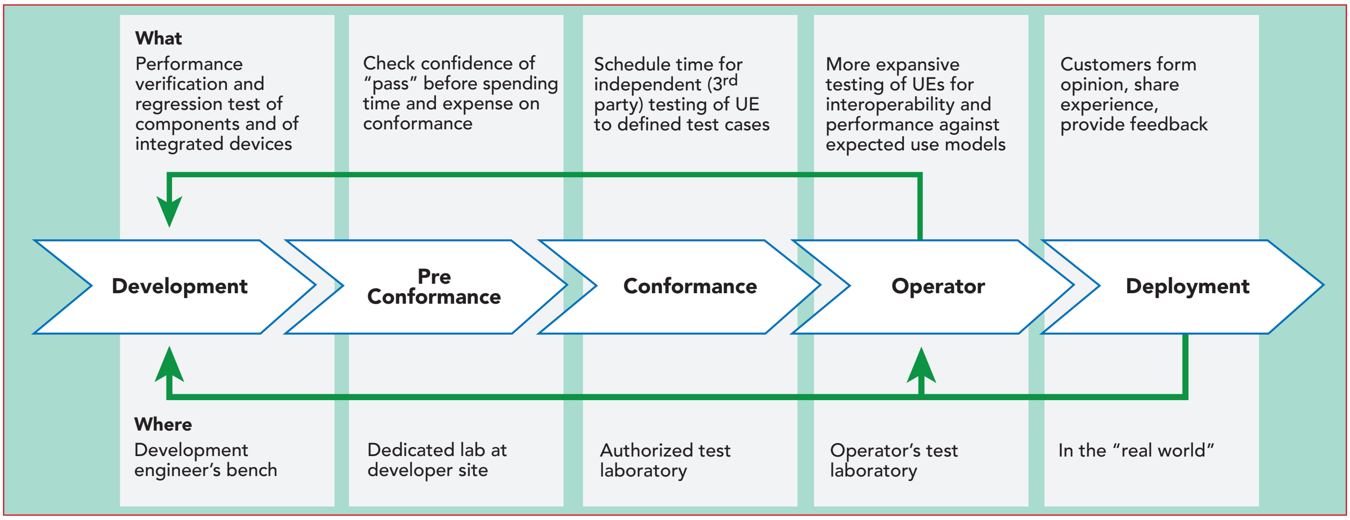

Fig. 4 Typical test flow from development to deployment.

TABLE 2

3GPP OTA TEST METHODS FOR UE DEVICES

Direct Far Field (DFF)	*Indirect Far Field (IFF)*	*Near Field to Far Field Transformation (NFTF)*
Simple and comprehensive	Near field to far field conversion enables compact antenna test range	Compact approach, can be lower cost
Can be very large with greater path for mmWave devices	Suitable for testing mmWave devices; not well suited for spatial RRM	Limited application: transceiver only; no receiver or RF parametric tests yet

labs conduct conformance tests to ensure equipment vendors do not influence the results. Test systems used to perform conformance tests must be validated and calibrated to ensure they perform the tests under controlled conditions with known uncertainties.

Once a UE passes conformance testing, the device is validated on a specific network. Device acceptance testing is operator specific and used to evaluate whether the device has sufficient performance to meet the goals set by the operator. For example, some networks make claims such as the "fastest network" or the "most reliable" network. In these cases, the operator acceptance tests include performance and functional tests to ensure the device will deliver the promised service on their network. Many operators expect to have 5G NR acceptance tests available in 2019.

It will be especially important for device and base station manufacturers to test the radiated RF performance of their designs early in the design cycle. Multi-element antennas will need validation of their 3D beam performance and measurements such as EVM and adjacent channel power ratio (ACPR) during movement to ensure performance across the antenna range. Initial access and beam management tasks like handovers and 4G fallback procedures evaluated early in the design cycle will help ensure proper operation across the wireless network.

NEXT STEPS?

5G NR promises everything connected, all the time, with extremely fast download speeds. With 5G NR Release 15 approved, developers are working on 5G NR devices and base stations. 5G NR expanding into higher frequencies and using new technologies adds complexity in the way signals are built, transmitted and processed. As the standard continues to evolve, more features are added and conformance and acceptance tests are completed, 5G NR designs need to be flexible and ready to adapt to the higher mmWave frequencies with wider bandwidths, denser waveforms and a growing number of test cases.■

Reference

1. 3GPP Specifications Groups, www.3gpp.org/specifications-groups.


360° @ 1 GHz
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770° @ 18 GHz
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INVITED PAPER

5G or Wi-Fi 6 (.11ax)?

Cees Links
Qorvo, Greensboro, N.C.

5G versus Wi-Fi (802.11ax). This is an antinomy that we hear often these days, as wireless data communication technology and standards are still in development, and new proprietary technologies are popping up every once in a while, looking for attention. How do we separate the noise from what really matters? Should consumers care about any of this?

It can be helpful to remind ourselves how we got to where we are today.

STANDARDS DEVELOP DIFFERENTLY

The standardization body for wireless phone communication is 3GPP. The roots of 3GPP are with the telephone operators and their governmental sponsors, since operators were originally governmental bodies—and still are in some countries. For wireless computer data communication, it is IEEE 802.11, which is rooted in the computer industry. In addition to academics and regulators, IEEE 802.11 has a large engineering membership, most of whom are sponsored by their employer companies.

The IEEE 802.11 and 3GPP have another complete and fundamental difference: The government-sponsored 3GPP works with licensed spectrum, spectrum that is acquired for a certain amount of time to provide communication services. The government, as licensor of the spectrum, is responsible for making sure that the spectrum can only be used by the licensee. On the other hand, the IEEE 802.11 standards group has developed standards in the "unlicensed" bands, bands that have been set aside by the government for "free usage" based on a set of rules, such as limited power so the interference range for realistic applications stays local. These bands are called ISM (industrial, scientific and medical) and can be found at 2, 5 and 60 GHz.

The companies that sponsored their engineers to develop IEEE 802.11 needed to enforce compliance to the IEEE 802.11 standard, as the IEEE 802.11 itself does not regulate compliance. So the Wi-Fi Alliance was founded by these interested companies for enforcing and promoting the IEEE 802.11 standard under the Wi-Fi brand. 3GPP, on the other hand, never really focused on a cohesive brand strategy aimed at consumers. This makes sense because 3GPP was the interest group of operators, who always had a certain control of the market. So instead of bothering with brand consistency, whole sets of ever-improving standards migrated from GSM/GPRS to 3G, Edge, 4G, LTE—now 5G, which will likely involve a new set of implementations.

	Wearables	Home	Phone
Typical Range	< 10 m/30 ft	< 100 m/300 ft	Outdoor (Km/miles)
Content	Bluetooth	WiFi	lte, 5G
Sense & Control	Bluetooth SMART	zigbee	NB-IoT
Typical Applications	Personal Appliances (Wristband, Smart Watch, Step Counter, Keyboard, Mouse, Pointer)	Indoor Networks (Internet, Email, Phone, Security, Energy Management, Home Monitoring)	Outdoor Networks (Phone, Chat, Internet, Smart City, Industry 4.0, Agriculture, Smart Logistics)

Fig. 1 Today's wireless data communications technologies have evolved to serve different needs.

WHY DO COMPUTERS HAVE TWO RADIOS?

When Wi-Fi was emerging in the late 1990s, the general tendency in "3GPP land" was to ask "Why do you need Wi-Fi?" At that time, the standardization of 3G was progressing well and promising high data rates, and 3G modems connected to or integrated in laptops were envisioned to provide ubiquitous connectivity. The general opinion was that this "unlicensed technology" would disappear, probably sooner than later, because the lack of oversight in the unlicensed bands would bring performance spiraling down quickly.

Of course, we know today that things turned out differently (see *Figure 1*). Wi-Fi has found a way to properly operate in the unlicensed ISM bands and satisfy the needs for wireless connectivity indoors, i.e., in-home or in-building, where 3G was not able to penetrate well. Also, Wi-Fi rapidly increased its data rate and expanded its capabilities by moving from the 2.4 GHz band into the 5 GHz band, and it is expected to further increase data rate by going to 60 GHz. Range extender technologies and, more recently, the concept of distributed Wi-Fi (Wi-Fi Mesh) have also supported Wi-Fi's success.

A significant part of the reason that Wi-Fi was successful was that data communications via 3G required a paid subscription from telephone operators and a data plan that initially led to quite hefty bills, not to mention roaming charges. By comparison, Wi-Fi was almost free, as the incremental cost for Wi-Fi via a fixed telephone, ISDN and, later, ADSL was limited. So now we had wired operators directly competing with the wireless operators, which ultimately stimulated worldwide acceptance of Wi-Fi. The wireless operators helped this along by initially discouraging the use of 3G for data—and therefore encouraging the use of Wi-Fi—due to concern for a voice service collapse if 3G were "overused" for data.

This answers the question of why most computers and tablets have only two radios: Wi-Fi and Blue-

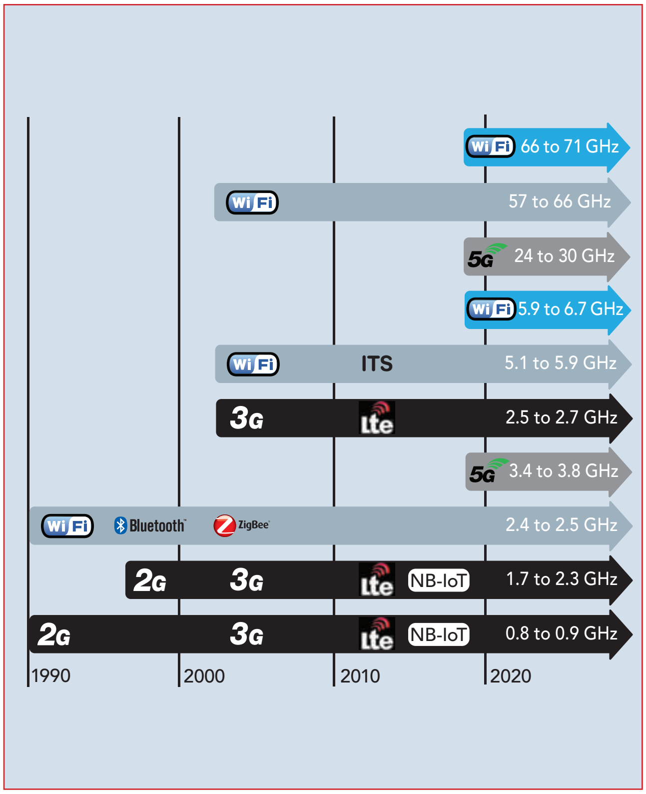


Fig. 2 Approximate frequency bands and dates of spectrum availability for the main wireless technologies.

tooth. 3G-licensed radios and their successors were rarely integrated in computers or tablets because Wi-Fi offered a cost-effective and versatile internet connection. An integrated 3G radio, plus SIM card subscription, was just too expensive by comparison. When a mobile solution is needed, users have turned to devices like 3G dongles or, more commonly today, using their mobile phone as a hotspot.

The evolution of wireless technologies was made possible by growing amounts of radio spectrum made available by the world's regulatory authorities. ***Figure 2*** gives a rough indication of the major technologies and frequency bands involved. At the 2019 World Radio Conference, significant new allocations are expected for Wi-Fi and 5G to support the increasing demands for wireless data communications.

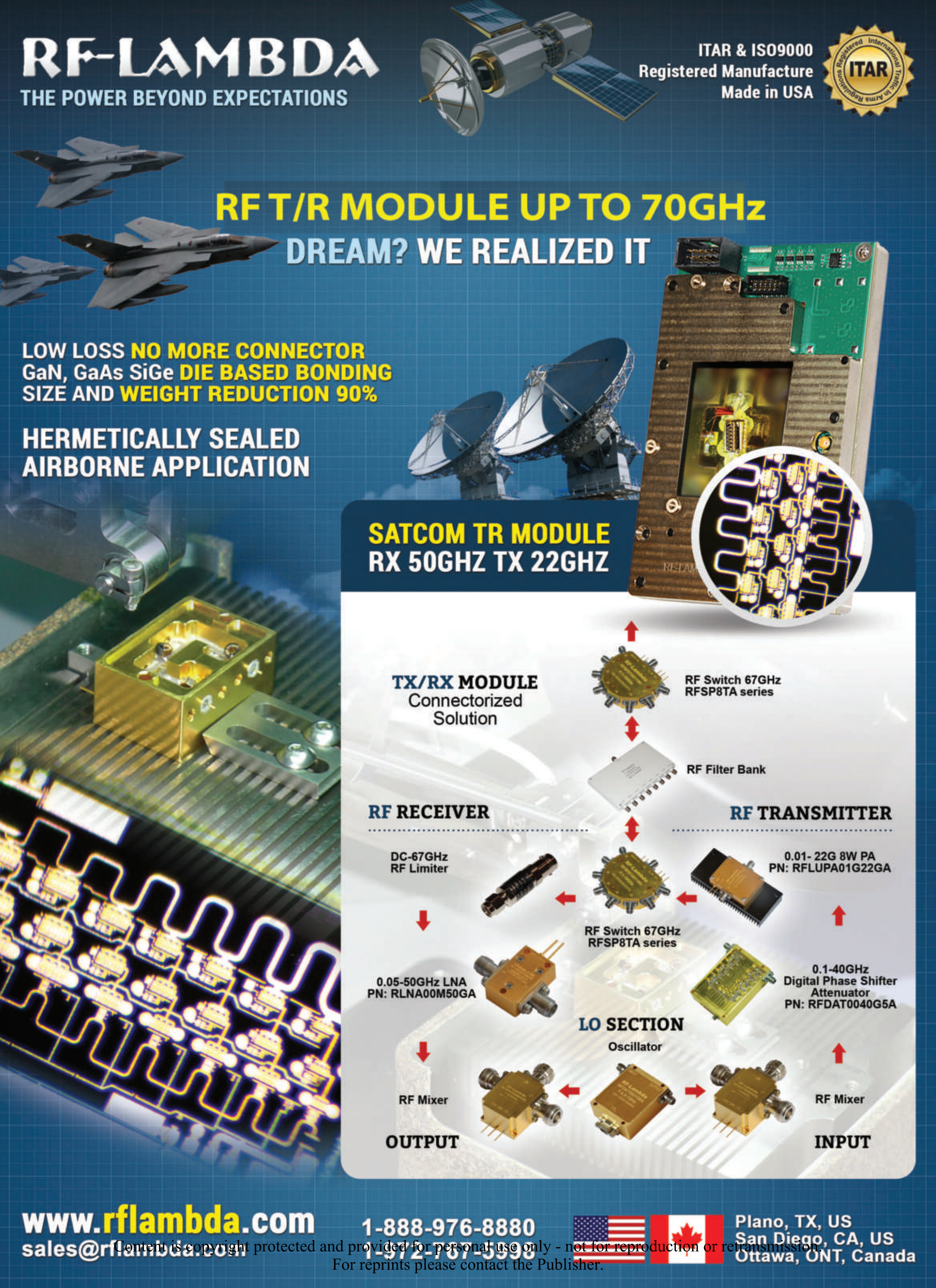
WORKING TOGETHER?

One would think that after 3G and Wi-Fi fought their battles, the demarcations between the two technologies would be clear: Wi-Fi for private areas such as home and office and 3G everywhere else. But, no.

Initially, the telephone operators in 3GPP were naturally quite suspicious about the development of so-called "hotspots," public places where people could get access to high speed internet without needing a subscription. Fortunately for the telephone operators, it turned out that running a large number of hotspots was not trivial, particularly for large retail and hotel chains, cities and trains. Public hotspot companies have been slowly absorbed by the telephone operators, who started to further embrace Wi-Fi and learned that "unlicensed" was not as bad as it sounded. Operators even developed strategies to use public hotspots with private routers to "off load." In other words, they used Wi-Fi connected hotspots for traditional phone services.

At the same time, consumers and companies are learning that running Wi-Fi networks is becoming more complex, and telephone operators—recently including cable operators—are finding that private Wi-Fi networks are business opportunities: helping consumers and smaller companies run their Wi-Fi networks.

Finally, with the rapid growth of data traffic, especially via video applications like YouTube, the operators need increased capacity. But getting more frequency bands is not easy. A faster way of getting this capacity, next to leveraging Wi-Fi, was realizing that the successor of 3G, 4G or LTE technology can also run in the ISM band. This realization gave rise to the concept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of LTE with licensed assisted access (LAA). The 3GPP specifications allow both Wi-Fi and LTE-LAA to be used in the same 5 GHz spectrum. The first installations of LTE-LAA are being planned now, but we will have to wait and see if LTE-LAA is a hit.

WHAT HAPPENS NEXT?

Now that we understand history, we can see a new battle looming. The IEEE 802.11 has been working diligently on higher speed versions, 11n and .11ac, and is in the process of completing .11ax. At the same time, the 3GPP is moving on from 4G/LTE and investing heavily in 5G. In any case, it should not come as a surprise that the talk is (again) about which technology is going to win: 5G or IEEE 802.11ax. Both will be in the high data rates (Gbps) and quite power intensive to get good range, while trying to infringe on each other's territory. 5G is claiming that it will have "way better indoor penetration," and .11ax is throwing out the slogan, "5G has arrived and it is called Wi-Fi 6."

Wi-Fi 6 is an evolution of Wi-Fi 5, but it offers new, additional capabilities that greatly improve its capacity and ability to share spectrum efficiently and without any dramatic "hang-ups" that sometimes occur in high density, high load situations. These improvements show that Wi-Fi technology has reached a level of maturity that increases its attraction for consumers, enterprises and service providers.

IEEE 802.11ax has a clear path worked out, although with the increased data rate the range is definitely reducing. Interestingly, Wi-Fi has turned this disadvantage into an advantage by focusing this new IEEE 802.11ax standard on distributed Wi-Fi (Wi-Fi Mesh) and enabling the use of multiple channels at the same time to connect multiple access points in different rooms to the main router. The focus of IEEE 802.11ax is on full indoor coverage—every nook and cranny in a home or office building covered with the same high data rate, creating an experience that will not easily be replaceable with 5G.

However, 5G is facing its own serious challenges, including delays. 5G's higher data rates also create a penalty on its range and, for cellular base stations, coverage goes "by the square." The expectation is that the range for 5G will probably decrease by less than half, forcing the number of base stations to more than quadruple. In dense urban areas, where finding real estate to place base stations is expensive, this will mean rolling out 5G infrastructure will be a significant expense, at the same time many operators are still recovering from their 4G investments.

Though it varies a bit by country and the financial structure of the telephone operators, the belief is that higher data rates will be needed to sustain the consumer and business appetites for higher data rates, particularly in dense population settings where the use of licensed spectrum can be better controlled than unlicensed.

A BATTLE AFTER ALL?

In the end, who is going to win?

Both 5G and Wi-Fi have very particular characteristics that will be beneficial for connecting computers—including all the devices that can now be classified under this term—to the internet. The operator that can best exploit both technologies to its advantage and define and execute a strategy that leverages both will become the winner. This operator will make a worry-free and seamless experience for the consumer, allowing fluid transitions between the two standards when necessary. Seen from this perspective, the ultimate winner of this technology battle will be the end user.■

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STANDARDS WEEK

For a number of years, Working Groups for EMC Society sponsored standards projects have met in parallel with the Technical symposium. This year, many standards related activities will take place as part of the Technical program. Proposals for standards related sessions are invited focusing on all aspects of standards contributions, including tutorial material, workshops on existing standards, novel contributions to standards projects or appraising the need for new standards.

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- Notification of Acceptance: January 6, 2019
- Preliminary Papers Due: February 16, 2019
- Final Papers Due: April 19, 2019

For more information, contact:
Alistair Duffy – apd@dmu.ac.uk

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Ultra-Low Noise MMIC Amplifiers Improve Receiver Dynamic Range

Custom MMIC
Chelmsford, Mass.

Modern system requirements placed on a microwave receiver design are often difficult to achieve, because small size, low-cost and high performance are often at odds. First and foremost, any new design will typically need to offer a performance advantage over existing systems. For example, in a superheterodyne system (see ***Figure 1***), an engineer may be asked to design for wider bandwidth, lower system noise figure and higher linearity. Often, the limiting component for all of these specs is the low noise amplifier (LNA) immediately following the antenna.

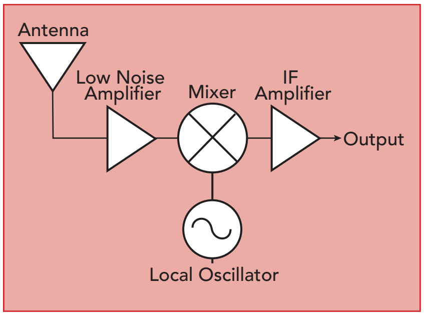


Fig. 1 **Simplified block diagram of a superheterodyne receiver.**

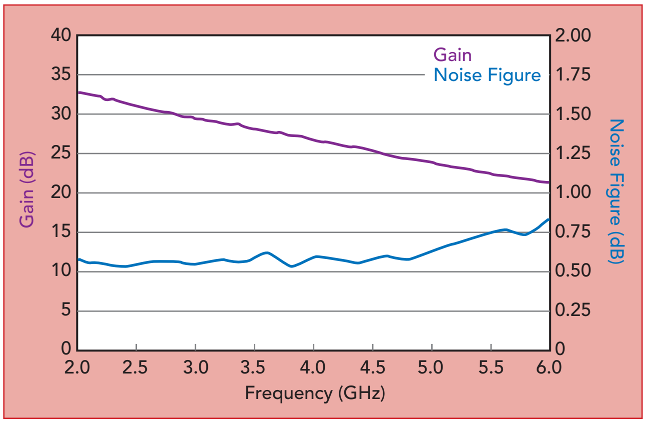
When deciding how to implement the LNA, a designer has several options. Typically, the best performing solutions are hand-tuned amplifiers, which require considerable board space and are both costly and time consuming to manufacture. MMIC LNAs, on the other hand, offer the smallest size and easiest manufacturing solution. A compromise between these two is a design using discrete transistors, but without hand tuning. This approach is relatively easy to manufacture, yet still requires large board area.

Obviously, if performance were the only metric, a hand-tuned discrete solution would be used in most applications. This is rarely the case, however, and the need to reduce size, weight, power and cost (SWaP-C) requires the designer to consider the other two options. The final consideration is often which is more important: meeting a difficult size requirement or having the best possible noise figure.

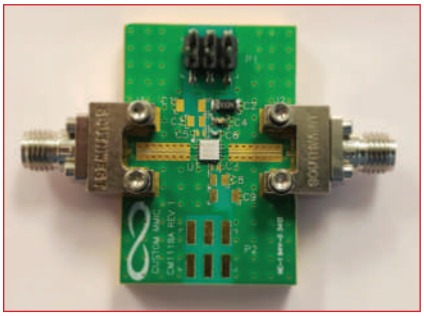
ULTRA-LOW NOISE AMPLIFIERS MEET BOTH

Custom MMIC now offers a MMIC solution that solves both challenges. The CMD283C3 is the first in what will be a series of ultra-low noise amplifiers. This off-the-shelf packaged MMIC features performance previously achievable only with discrete solutions. Operating from 2 to 6 GHz, the LNA has a typical noise figure of 0.6 dB with greater than 20 dB gain across the band (see ***Figure 2***).

Fabricated with an enhancement mode PHEMT process, the CMD283C3 has many



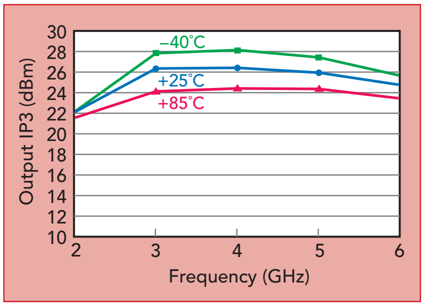
▲ Fig. 2 Typical gain and noise figure of the CMD283C3.



▲ Fig. 3 Evaluation board shows the small size of the LNA, with few external components.

features in addition to the world-class noise figure, making it an ideal solution in a receiver front-end. One key benefit is the all positive bias, which means no negative power supplies or sequencing voltages. The CMD283C3 is self-biased and provides input and output DC blocking capacitors on-chip. Eliminating the external components needed with a depletion mode LNA without on-chip capacitors reduces size and off-chip circuit complexity when implementing the CMD283C3 in a system. The evaluation board in ***Figure 3*** shows the small package size—just 3 mm × 3 mm—and the minimal external circuitry.

The LNA has very low power consumption yet maintains a high output third-order intercept point (OIP3): The nominal bias current is just 42 mA at 3 V, and the typical OIP3 is +26 dBm (see ***Figure 4***). This combination of extremely low noise and high linearity enables a system designer to achieve very high dynamic range, a critical requirement in many receiver applications.



▲ Fig. 4 Output IP3 vs. temperature.

The LNA's wide operating temperature range, from −40°C to +85°C, make it well-suited for all applications, whether military, aerospace or commercial.

BUILDING ON HERITAGE

Custom MMIC's existing portfolio of LNAs includes a broad range from S- through Ka-Band, many offering the best noise figure available. The CMD283C3 is the first product in Custom MMIC's new ultra-low noise amplifier line, offering a step-change improvement over the current portfolio. The low noise performance surpasses what was previously achievable in a fully-matched, wideband MMIC. Additional LNAs will be released during the coming year, as Custom MMIC brings this combination of discrete LNA performance and small footprint to frequencies through Ka-Band.

The unique combination of industry-leading performance and small board footprint allows receiver designers to take system designs to a new level of performance and SWaP-C—enabling the next generation of low noise, high linearity receivers.

VENDORVIEW

Custom MMIC
Chelmsford, Mass.
www.custommmic.com

New Spectrum Analyzer Family Ideal for 5G NR Signal Analysis

Rohde & Schwarz
Munich, Germany

With the advance of 5G NR technology in R&D and production, engineers need to analyze wireless communication signals with test solutions supporting 5G bandwidth and RF requirements. Rohde & Schwarz supports these users with a new family of midrange signal and spectrum analyzers: the R&S FSV3000 and the R&S FSVA3000, available with up to 400 MHz analysis bandwidth and up to 44 GHz input frequency, which cover all relevant 5G NR frequency bands. Their common user interface includes new features for fast setup of measurements and capturing rare events.

Fig. 1 Screenshot of a measured 5G NR signal at 28 GHz with EVM below 1 percent.

The R&S FSV3000 is designed to help users set up complex measurements in the easiest and fastest way. With its usability and high measurement speed, it is the right instrument in both the lab and on a production line. It provides up to 200 MHz analysis bandwidth, enough to capture and analyze two 5G NR carriers at once.

The R&S FSVA3000 has up to 400 MHz analysis bandwidth, a high dynamic range and an outstanding phase noise of −120 dBc/Hz, delivering performance which was reserved for high-end instruments until recently. Users can perform more demanding measurements, such as linearizing power amplifiers, capturing short events and characterizing frequency agile signals.

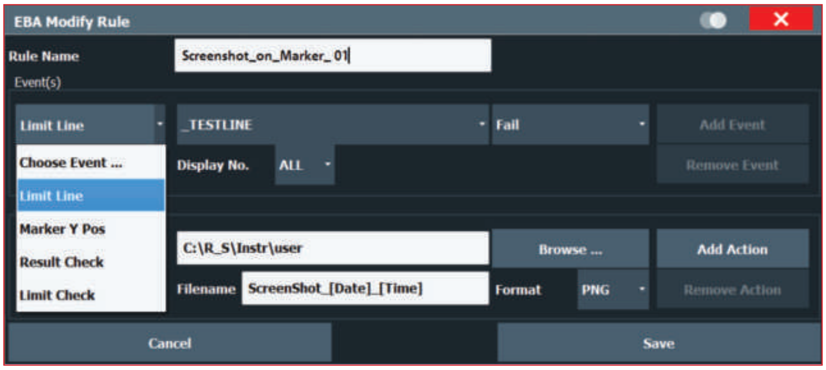


Fig. 2 To help with troubleshooting, the event-based action feature enables users to define events that trigger actions like screenshots or recording data in a log.

Both the R&S FSV3000 and R&S FSVA3000 can measure error vector magnitude (EVM) values better than 1 percent for a 100 MHz signal at 28 GHz (see ***Figure 1***), making the analyzer family an ideal fit for analyzing 5G NR signals.

NEW, INNOVATIVE USER INTERFACE

Troubleshooting rare events or setting up complex measurements is easy with both the R&S FSV3000 and R&S FSVA3000 spectrum analyzers. An event-based graphical user interface makes it easy to trigger on rare events (see ***Figure 2***). The user only has to select an event, like a limit line failure, from a drop-down menu and add a corresponding action, like a screenshot or saving I/Q data. Whenever the event occurs, the corresponding action is performed, and the event is recorded for later in-depth analysis.

A one-button measurement feature shortens the setup of the instrument. At the press of a button, the most important parameters like center frequency, span or amplitude reference are automatically set based on the applied signal. In case of a pulsed signal, the gate sweep parameters are also set. For standard conformance measurements on communication signals, like adjacent channel leakage ratio (ACLR) or spectrum emission mask (SEM), the one-button measurement feature selects the corresponding standard parameter table.

When setting up complex measurement plans on an automated production line, external PCs take over the control of measurement instruments via standard commands for programmable instruments (SCPI) programs. The embedded SCPI recorder in the new analyzers makes the programming of such executable control scripts much faster and easier. All manual user input is translated into SCPI commands, which can be exported as plain SCPI or in the syntax of common programming languages

or tools such as C++, Python or MATLAB.

With many RF measurements, an additional signal generator is required. The smart signal generator control of the new analyzer family goes far beyond what a classic generator control can do: with the coupling manager, users can control the generator with the analyzer. Changing frequency or level on the analyzer directly controls the generator. The analyzer can even display the user interface of the generator, so the user can operate the complete setup from only one screen. The SCPI recording function of the analyzer and the generator can also be coupled.

HIGH SPEED ANALYSIS

Rohde & Schwarz designed the R&S FSV3000 and the R&S FSVA3000 for high speed performance in automated test systems. They perform spectral measurements, signal demodulation and switching between measurement modes in the shortest time, enabled by fast synthesizer technology. FFT-based ACLR and SEM measurements are faster than swept spectrum measurements, while showing the same dynamic range. The analyzers' signal analysis options include most modern communication standards like 5G NR, LTE and IEEE 802.11ac and 11ax wireless LAN. Engineers can use them for general-purpose measurements like noise figure, gain, phase noise and vector signal demodulation.

In classic production systems where the analysis takes place on the instrument, an enhanced computer power option provides a faster CPU to accelerate digital signal demodulation. In cloud-based test systems, the signal analysis is done on external CPUs and requires the transfer of huge amounts of I/Q data. The new Rohde & Schwarz analyzer family perfectly interacts with cloud-based processing. The optional 10 Gbps LAN interface enables I/Q data transfer toward the network side at high sample rates, which is required for wideband signal analysis such as 5G.

The R&S FSV3000 and R&S FSVA3000 will be available from Rohde & Schwarz in March 2019.

VENDORVIEW

Rohde & Schwarz
Munich, Germany
www.rohde-schwarz.com/fsv3000

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Visit the Rohde & Schwarz Video Channel
at
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Radio and Wireless Week Highlights

Keynote Speakers
G. Michael Lester, Technical Transfer Partnership Manager, Kennedy Space Center
Alanson Sample, Associate Professor, University of Michigan

2nd IEEE IoT Summit on "The Internet of Things Meets the Internet of Space"
Sunday, 20 January 2019 and Monday, 21 January 2019
Organizers: Multi-Society IEEE IoT Initiative and MTT-S

Workshops
5G New Radio: The Prospects for GaN from Devices to Systems
Organizers: Pere L. Gilabert, Universitat Politècnica de Catalunya and Spyros Pavlidis, North Carolina State University, and Neil Braithwaite, Consultant

RF Transceiver Imperfections in Wideband and Millimeter Wave Systems
Organizer: Tomas Gotthans, Brno University of Technology and Genevieve Baudoin, Université Paris-Est, ESIEE Paris

Microwave Power Amplifier Design and High Performance Innovative Passives
Organizers: Howard Hausman, President/CEO, RF Microwave Consulting Services, Adjunct Professor, Hofstra University

Distinguished Lecturers
Terahertz Communications at 300 GHz: Devices, Packages and System
Ho-Jin Song, Pohang University of Science and Technology, Korea

Nonresonating Modes Do It Better!
Simone Bastioli, RS Microwave Company Inc., USA

Energy Efficient Future Wireless Communications
Nuno Borges Carvalho, Universidade de Aveiro, Portugal

Everything You Can Do With Vector Nonlinear Microwave Measurements
Patrick Roblin, Ohio State University, USA

Young Professionals Forum and Networking Event
Monday, 21 January 2019

Student Contest Elevator Pitches and Poster Session
Monday, 21 January 2019

Demos
Tuesday, 22 January 2019

Exhibits
Monday, 21 January 2019 and Tuesday, 22 January 2019

All accepted papers will be published in a digest and will be included in IEEE Xplore Digital Library.

Digital Equalization for mmWave Analog Up-/ Down-Converters

Time-interleaving of analog-to-digital converters (ADC) is used to increase the sampling rate of high performance digitizers. The new 10-bit digitizers from Guzik use Keysight ADCs, where 160 individual ADCs are interleaved to sample up to 64 GSPS—160 "slices" each sampling at 400 MSPS—to form two analog channels, each at 32 GSPS. Time-interleaving that many ADCs makes it challenging to achieve high spurious-free dynamic range. Guzik's patented digital equalization technology reduces mismatch between slices, non-flatness of the frequency response and group delay of the digitizer to create a calibrated baseband receiver covering DC to 10 GHz with an input signal range from −32 to +22 dBm.

This same technology has been used to equalize the frequency response and group delay of up- and down-converters, working with the digitizer to create a "reference calibration plane" at the down-converter input (i.e., an RF reference plane) and the up-converter input (i.e., an IF reference plane). The equalization de-embedding technology significantly reduces the linear distortion of the external frequency converters. Non-flatness of the frequency response of the up- and down-converters was reduced from ±1.5 dB to ±0.1 dB, and non-flatness of group delay was reduced from ±1.25 ns to ±100 ps. At 28 GHz, the resulting residual error vector magnitude through the up- and down-converters was reduced from ~11 percent (−20 dB) to ~1 percent (−40 dB) for a 16-QAM, 625 Msymbol per second signal with a root-raised-cosine filter factor of 0.35. For signals with up to 2.5 GHz bandwidth, on the output of the mmWave down-converter, the equalization is performed real-time inside the Intel FPGA-based digital processor of Guzik's ADP7000 series digitizers, using the patented digital down-converter.

Guzik Technical Enterprises
Mountain View, Calif.
www.guzik.com

50 GHz Terminated SP4T and SP6T Coaxial Switches

Radiall is expanding its family of 50 GHz coaxial switches with new terminated SP4T and SP6T models where the unconnected ports are automatically terminated with 50 Ω loads. All of the RF paths in each switch have the same electrical length, and all ports use 2.4 mm female connectors.

These new switches offer excellent performance: At 50 GHz, the maximum insertion loss is 1.2 dB, with at least 50 dB isolation between any two ports and 3 W average incident power handling at room temperature. VSWR at any port does not exceed 2.2:1. At 20 GHz, the insertion loss is 0.7 dB maximum, with ≥ 55 dB isolation and 1.7:1 VSWR maximum. The switches require a nominal 28 V bias voltage, and switching is actuated by either a TTL or BCD signal, with a nominal switching time of 15 ms.

Radiall's 2.4 mm electromechanical switches use Radiall's Modular System for Electromechanical Switches (RAMSES). This patented mechanical and electrical design approach improves the consistency of contact resistance and extends the lifetime of Radiall switches. Switch life span is rated at two million cycles over the operating temperature range of −25°C to +70°C.

These two new terminated switches complement Radiall's previously released un-terminated SP4T and SP6T designs. All of the 50 GHz models are well-suited for 5G test systems operating in the 24, 28 and 39 GHz bands, as well as the 28 GHz military and commercial satellite bands.

Radiall
Tempe, Ariz.
www.radiall.com


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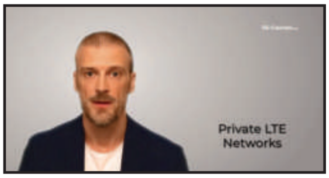


5G-Courses.com has released a new course into its portfolio: Private LTE Networks. This course covers technical, practical and business-related aspects of private wireless networks in unlicensed and lightly licensed frequency bands. Radio standards such as MulteFire, LAA, LWA and private LTE are described and compared with traditional standards (Wi-Fi) in an easy-to-understand style. Leading the class is Oscar Bexell, a subject matter expert in the convergent area of Wi-Fi and cellular networks.

5G-Course.com

www.5g-courses.com/courses/private-lte-networks

New Online Store

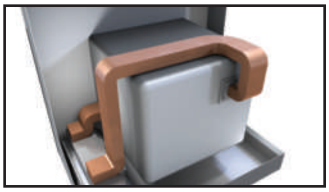
Centerline Technologies has launched an online store providing a variety of precision-finished substrate materials in small quantities. For those seeking quantities of less than 10 pieces or adhering to a tight deadline, the web store is an excellent opportunity for sourcing affordable materials. All products are processed by Centerline to achieve optimal surface finish, size and tolerance.

Centerline Technologies

https://shop.centerlinetech-usa.com/

Connectivity for RF-Energy Video

VENDORVIEW



Using solid-state generated and amplified RF-power for applications, including cooking, warming and lighting, RF-Energy brings a completely new user experience to the respective applications. This is mainly due to the better controllability of amplifiers, when compared to magnetrons. RF-power amplifiers in RF-Energy applications have a lot of similarities with amplifiers used in communication industries. The main differences however are the additional higher power levels and the focus on power use instead of signal quality and linearity.

Huber+Suhner

www.hubersuhner.com/en/solutions/rf-energy

DIY Vector Network Analyzer Kit

VENDORVIEW

The first of the University Project kits, UVNA-63, includes all the elements students need to build a fully functioning vector network analyzer, develop S-parameter algorithms and perform real-time measurements of 2-port RF devices. The kit comprises Vayyar's high performance transceiver chip with a variety of RF components from Mini-Circuits, along with control software and a development environment for Python and MATLAB®.

Mini-Circuits

www.minicircuits.com/WebStore/uvna_63.html

Impressive Comparison Test Video

How do the best handheld spectrum analyzers match up in a direct comparison test? Which device finishes ahead in key parameters such as sensitivity and harmonics, intermodulation and dynamic range? Narda STS has put up a video comparison on its YouTube channel. In it, Narda's SignalShark challenges the established reference instruments. Pitted against the newcomer in the field of real-time handheld analyzers are the Anritsu Spectrum Master, Tektronix H500/600 and the PR100/DDF007 from Rohde & Schwarz.

Narda Safety Test Solutions (STS)

https://youtu.be/Ry0tKoAEeG8

Strategies for Using Xilinx's RFSoC

Xilinx's new RFSoC brings a powerful and unique solution for addressing some of the most demanding requirements of high bandwidth and high channel count system. This website provides a look at how RFSoC compares to the current trends in A/D and D/A converters and the strategies for getting the most performance out of this new family of FPGAs.

Pentek

www.pentek.com/go/rfsocmj

Web&VideoUpdate

New E-Commerce Website with Expanded Capabilities

PolyPhaser, an Infinite Electronics brand, has launched a completely updated website with online purchasing capabilities and same-day shipping for many of its most popular surge protection solutions. PolyPhaser's new ecommerce website allows customers to place and track orders, access expanded product specifications, check product inventory levels, engage in live online chat support and much more. The updated website makes it easier for the company's global customer base to purchase and receive industry-leading RF surge protection devices and other key PolyPhaser products.

PolyPhaser
www.polyphaser.com

Easily Find the Perfect Product

VENDORVIEW

With the industry's widest range of over 500 digitizers and AWGs, Spectrum Instrumentation will have the perfect fit solution for your project that comes with the company's unique five year warranty. Just use the "Parameter Search" and choose your platform, number of channels, resolution and speed—and the website will show the perfect fit solution. Visit the company's website and just click on "Products" to begin.

Spectrum Instrumentation
www.spectrum-instrumentation.com

New Website

VENDORVIEW

The Teledyne Defense Electronics Group, representing about 15 consolidated Teledyne companies, has launched a new website. The "TDE" Group specializes in advanced RF/microwave systems, hi-voltage interconnects and components, comprehensive space-qualified offerings and a one-stop shop for microelectronics packaging and circuit card assembly. Among TDE's business units are Teledyne Microwave Solutions, Teledyne Labtech, Teledyne Defence & Space, Teledyne Reynolds, Teledyne Relays, Teledyne Storm, Teledyne AES, Teledyne e2v HiRel, Teledyne Energetics and Teledyne Paradise Datacom.

Teledyne Defense Electronics Group
www.teledynedefelec.com

NEW PRODUCTS

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

COMPONENTS

Super Low Insertion Loss High Power Waveguide Filters

VENDORVIEW

The WZ-Series bandpass filters are narrowband (< 2 percent BW) filters designed with very sharp rejection slopes while maintaining low insertion loss and very high-power handling (kW range). Popular uses are at the output of a high-power amplifier or at the input of a receiver for low noise figure. WZ-Series are available as filters or as multiplexers.

Exceed Microwave
www.exceedmicrowave.com

mmWave Controlled Components

General Microwave offers a wide range of mmWave products operating in the 18 to 40 GHz frequency range including catalog attenuators, switches and phase shifters as well as integrated microwave assemblies. If it is a standard catalog unit or a highly customized mmWave product designed specifically for high performance, General Microwave can provide products to support your requirements.

General Microwave Corp.
www.kratosmed.com

Broadband Isolators & Circulators

VENDORVIEW

MECA Electronics' latest new product offering: broadband (SMA) isolators and circulators covering 2 to 6 GHz encompassing S- and C-Bands with VSWRs of 1.45:1 typ., isolation 15 dB typ. and insertion loss of 0.7 dB typ. in a 1.58 × 1.62 × 0.70 in. package. This is in addition to the family of isolators and circulators ranging from 700 MHz thru 40 GHz. Made in the U.S. with 36 month warranty.

MECA Electronics
www.e-MECA.com

3 GHz, 75 Ω Balun for DOCSIS 3.1 and Beyond

VENDORVIEW

MiniRF has taken its broadband Wireless expertise (50 Ω) and applied to its CATV product line. The MRFXF9703 is a 1:1 transformer with 18 dB RL and < 1 dB of

loss to 1.8 GHz. This part is future proof with excellent performance out to 3 GHz. The MRFXF9703 is offered in a mini 0.15 × 0.15 SMD package. MiniRF: Passives with a Passion for Performance.

MiniRF
www.minirf.com

LRUs

Norden Millimeter announced an expanding product line of LRUs. Pictured is a LRU for airborne application which includes multiple frequency converters, local oscillators and control modules. Norden has extensive experience in the design, development and manufacturing of custom microwave products and sub-systems. Norden can provide custom designed and tested products with additional non-standard features to meet stringent military environments or test requirements. Norden products cover bands from 500 MHz to 110 GHz.

Norden Millimeter
www.nordengroup.com

Diplexer

Response Microwave Inc. announced the availability of a new diplexer for use in specific telecom antenna applications. The new RMDU.0-25004310f offers Tx band of DC to 1 GHz and Rx band of 1.5 to 2.5 GHz, with typ. electrical performance of 0.5 dB max insertion loss, 14 dB min. return loss and 35 dB min. rejection over the band. Power handling is 50 W CW and PIM is –150 dBc. The unit is operational over the –10°C to +85°C range and mechanical package is 2.4 × 7.3 × 1.3 in., plus 4.3/10 female connectors.

Response Microwave Inc.
www.responsemicrowave.com

Multiplexers

RLC Electronics' multiplexers are available in 2, 3 or 4 channel versions. Adjacent passbands may be designed for a contiguous or non-contiguous response. For passband frequencies below 2 GHz, lumped element designs will often achieve the desired response in the smallest package. At higher frequencies (up to 40 GHz), distributed coaxial structures are employed to realize the lowest possible loss. The unit pictured is a diplexer that covers both L-/S-Band frequencies, as well as Ku frequencies, and exhibits low loss (< 0.5 dB per channel).

RLC Electronics
www.rlcelectronics.com

Broadband Bandpass Filter

Spacek Labs Fc2-625-9 is a WR-15 broadband bandpass filter. This series is offered from 18 to 110 GHz with bandwidths from 30 to 100 percent of the band. These waveguide filters combine its exceptional performance lowpass filter and highpass filter technologies. Model Fc2-625-9 has a passband from 48 to 72 GHz. Lower and upper 20 dB rejection is 45 and 74 GHz respectively, rejecting > 30 dB out to 110 GHz. Insertion loss is 1 dB typ., 2 dB max.

Spacek Labs
www.spaceklabs.com

CABLES & CONNECTORS

40 GHz Skew Matched Cable Pairs

Fairview Microwave Inc. has released a new line of 40 GHz skew matched cable pairs designed for bit-error-rate testing, eye diagrams and differential signals at data rates of 10 to 28 Gbps. Fairview's new line of skew matched cables consists of three extremely flexible models that are 100 percent tested for skew match. Performance specs include an impressive VSWR of 1.4:1 and 1 ps delay match. These cable pairs cover 2 channels with 50 Ω nominal impedance and a bandwidth of DC to 40 GHz.

Fairview Microwave Inc.
www.fairviewmicrowave.com

3.5 and 7 mm Precision Adapters

VENDORVIEW

RF Superstore recently announced the addition of 3.5 and 7 mm precision adapters to its extensive inventory of in-stock RF adapters and connectors.

RF Superstore
www.rfsuperstore.com

NewProducts

AMPLIFIERS

0.7 to 18 GHz CW Dual Band Amplifiers

AR put two of their state-of-the-art Class A CW amplifiers in a single chassis, and now you can go from 0.7 to 18 GHz with the reliability of solid-state designs and have freedom like never before. With up to 60 W in the first 0.7 to 6 GHz band split and up to 40 W output power in the 6 to 18 GHz split, AR put it together for you in one package that costs less, weighs less and takes up less space than two separate amplifiers.
AR RF/Microwave Instrumentation
www.arworld.us/html/ps-dual-band-amplifiers.asp

High-Power Solid-State Amplifier

The AMP2128 0.7 to 6 GHz high-power solid-state amplifier system produces a min. of 125 W of CW power with a gain of 52 dB. This state-of-the-art power amplifier features instantaneous wideband operation with built-in protection circuits for superb reliability and ruggedness. It is packaged in a 5U (8.75 in.) chassis and is nominally 80 lb. This system is manufactured as standard with local/remote monitoring and control circuitry interfaces. They are suitable for all modulations. Applications include EMI/RFI, EW, communications, high-power testing and TWTA replacements.
Exodus Advanced Communications
www.exoduscomm.com

0.3 to 20 GHz, Low Noise Amplifier

PMI Model No. PE2-16-300M20G-1R7-15-12-SFF is a low noise amplifier (LNA) that works from 300 MHz to 20 GHz. This amplifier has a very low noise figure over this broad frequency range. This LNA provides 16 dB of small signal gain while requiring only a single supply of +12 V. The P1dB output power of 15 dBm allows this LNA to function as a LO driver for balanced, I/Q or image reject.
Planar Monolithics Industries Inc.
www.pmi-rf.com

Low Current MMIC Amplifier

Mini-Circuits' EHA-163L+ is a low-current, wideband gain block that operates from DC to 16 GHz with 15 dB gain and ±0.75 dB flatness up to 12 GHz. This model is well matched to 50 Ω with input/output return loss of 10 dB or better up to 16 GHz without the need for any external matching components. Operating on a single 5 V supply with just 20 mA typ. current consumption, the amplifier provides +6.5 dBm P1dB and +15.6 dBm IP3 at midband. Fabricated using a highly reliable HBT process on GaAs, the amplifier has repeatable performance from lot to lot and comes housed in a tiny 2 × 2 mm QFN package.
Mini-Circuits
www.minicircuits.com

Solid-State Power Amplifier

RFMW Ltd. announced design and sales support for an ultra-broad bandwidth, GaN, solid-state power amplifier (SSPA) from Aethercomm. Model number SSPA 0.2-2.5-200 operates from 200 to 2500 MHz and delivers a typical, saturated output power of 200 W. Designed and tested to withstand MIL-STD-810 high shock and vibration requirements, small signal gain is ~60 dB and operating voltage is 50 VDC. The SSPA 0.2-2.5-200 is offered in a modular housing that is approximately 5 × 9 × 1.5 in.
RFMW Ltd.
www.rfmw.com

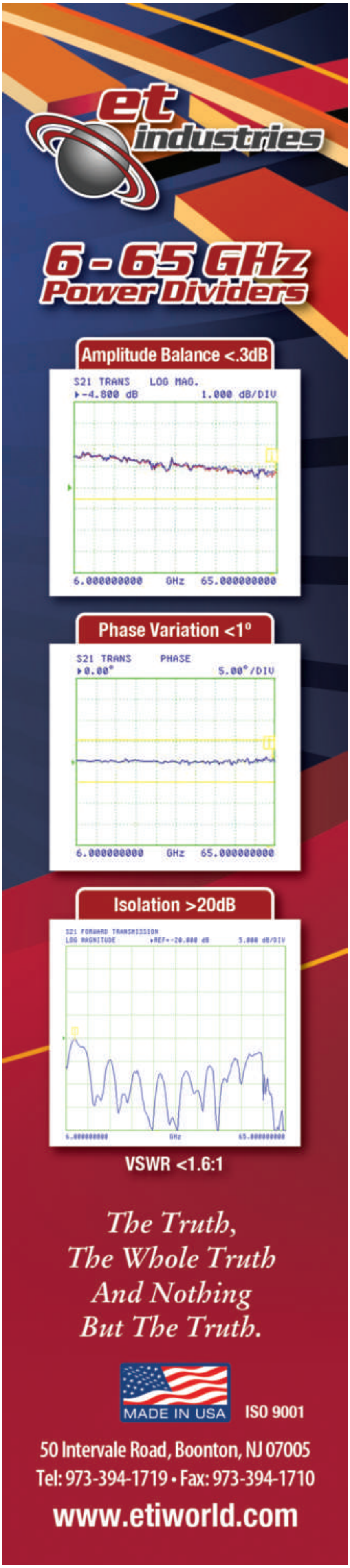
Power Amplifiers

Richardson RFPD Inc. announced the availability and full design support capabilities for two new evaluation boards from GaN Systems Inc. The new power amplifiers are designed for the growing wireless charging market and feature GaN technology that enables smaller, lighter, lower-cost and more efficient power systems. The 100 W power amplifier (GSWP100W-EVBPA) is ideal for applications in the consumer market, including items such as laptop computers, recreational drones, domestic assistant robots, power tools and fast-charging of multiple smartphones.
Richardson RFPD Inc.
www.richardsonrfpd.com

SYSTEMS

Up-Converters

Norsat's MEDIAN series of Ku-Band block up-converters are designed with both performance and value in mind. This series provides reliable, durable and strong linearity, making them ideal for VSAT, broadcast, maritime and portable terminal applications. The MEDIAN series is available in 16, 25 and 40 W options and is guaranteed by Norsat's two-year warranty. Norsat can also customize these BUCs to meet your needs.
Norsat International
www.norsat.com



NewProducts

SOURCES

PCIe4 Compliant Oscillator

The Pletronics HC5544DEV-100.0MHz oscillators have received expanded PCIe V4.0 base reference clock (Refclk) compliance testing, meeting all compliancy testing performed by an independent third-party lab. This HCSL oscillator is certified for all four generations of PCI Express from 2.5GT/s to 16GT/s. PCI Express Technology is considered to be the standard internal interface allowing high bandwidth between the device and the motherboard. The HC5544DEV-100.0M product is a differential HCSL output oscillator manufactured with a high precision quartz crystal.

Pletronics
www.pletronics.com

50 to 115 MHz High Performance Frequency Synthesizer

The surface mount synthesizer model FSW511-10 delivers a powerful performance over a frequency bandwidth of 50 to 115 MHz. With its factory preset step size of 100 kHz, this model has low “close-in” phase noise of –102 dBc/Hz at 1 kHz, –105 dBc/Hz at 10 kHz offset and –132 dBc/Hz at 100 kHz while locked to a 10 MHz external reference. The buffered output power is +6 dBm min. This product requires +5 and +15 V supplies to operate. All communications are managed via an easy plug-n-play programmable format. The practical small package of 0.94 × 0.94 × 0.23 in. makes it easy to fit on any project.

Synergy Microwave Corp.
www.synergymwave.com

Low-Power Clock Modules

SGTM™ based on EWOS Syrlinks OCXOs are offering unparalleled performances with power consumptions 10 to 20× lower than other available solutions. The modules are built around a fast electronic and high precision EWOS OCXOs allowing a clock synchronization of less than 20 ns, and excellent short-term and medium term stabilities (resp. 6.10-12 and 1.10-11). They are ideal for battery powered application requiring high precision timing when GNSS time is no longer available (like underwater devices or GNSS denied areas).

Syrlinks
www.syrlinks.com

Voltage Controlled Oscillator

VENDORVIEW

The SMV5550B-LF features wideband tuning from 5000 to 6000 MHz within a tuning range of 0 to 10 VDC, while offering a small footprint measuring 0.3 × 0.3 × 0.08 in. This unparalleled VCO features phase noise performance of –80 dBc/Hz at 10 kHz offset and covers the band with an average sensitivity of 135 MHz/V, while delivering to the end user a nominal 3 dB of output power into a 50 W load.

Z-Communications
www.zcomm.com

SOFTWARE

PIM Finder Software

Kaelus has debuted PIM finder, software designed to accurately identify and locate external PIM sources outside antenna infrastructure. Used in combination with the Kaelus iVA cable and antenna analyzer and the iPA portable PIM analyzer, PIM finder is a software option available through Kaelus Unify, used to pinpoint and detect external PIM sources such as loose mounting and cable brackets, fasteners, parapet walls and more, while allowing for the elimination of key causes of PIM interference.

Kaelus
www.kaelus.com

ANTENNAS

Antennas

KP Performance Antennas has debuted its new ProLine antennas, a series of high performance parabolic and sector antennas that are perfectly suited for high density, point-to-point, point-to-multipoint and backhaul applications. KP’s new ProLine parabolic antennas are engineered to deliver high, stable gain over wide bandwidths with side-lobe and back-lobe suppression for mitigating inter-sector interference. These 5 GHz antennas are available in 1 and 2 ft. diameters with gain performance of 24 dBi and 29 dBi, respectively.

KP Performance Antennas
www.kpperformance.com

ESP Antenna Line

RadioWaves has released the enhanced standard performance series parabolic line. The ESP series offers a full portfolio covering all unlicensed bands, providing the highest gain in the industry. ESP antennas are available in 2, 3 and 4 ft. configurations and come fully assembled from the factory. Boasting excellent side lobe performance that exceeds industry standard, the ESP series requires minimal post installation maintenance, needing only a single tool for mounting.

RadioWaves
www.radiowaves.com

TEST & MEASUREMENT

Coaxial RF Probes

VENDORVIEW

Pasternack has expanded their line of RF coaxial probes into the 40 GHz operating frequency range for use in microwave components, high speed communications and networking. Pasternack's extended line of coaxial RF probes now includes 4 models that deliver 10 dB maximum return loss over the broad frequency range of DC to 40 GHz. These probes are offered in GS and GSG configurations with a pitch of 800 or 1500 µm and a 2.92 mm interface.

Pasternack
www.pasternack.com

R&S QAR

VENDORVIEW

The unique R&S QAR from Rohde & Schwarz visualizes and characterizes signal penetration of radomes. Automotive radars are often located behind bumpers and brand emblems. The materials of these covers (radomes) should allow the radar signals to pass through as uniformly and unhindered as possible. With the imaging R&S QAR automotive radome tester from Rohde & Schwarz, users in development and production environments can now check this easily, reliably and under automated control.

Rohde & Schwarz
www.rohde-schwarz.com

VNA Waveguide Calibration Kit

VENDORVIEW

Model STQ-TO-12-U3-CKIT1 is a E-Band waveguide vector network analyzer (VNA) calibration kit designed to work with industry standard network analyzers in the frequency range of 60 to 90 GHz. The calibration kit consists of two straight waveguide sections, one fixed short, one fixed matching load, one sliding load, one ¼ wavelength offset, two waveguide quick connects, 10 3/32 hex head waveguide screws, a 3/32 in. hex waveguide screw driver and one calibration data USB drive.

Sage Millimeter
www.sagemillimeter.com

MICRO-ADS

5G and Satellite Spectrum, Standards and Scale

Geoff Varrall

"This book provides a refreshing analysis of the many factors that will affect the success of 5G. I would highly recommend this book to all levels of professionals involved in the development of 5G from engineers through to CEOs."

— Moray Rumney, Keysight Technologies

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This resource provides key insight into future 5G radio systems and the technical and economic impact on industries, communities and end-users. The book offers a comprehensive understanding of the options available for teams tasked with bringing 5G products and services to market or developing supporting standards and regulatory frameworks.

Readers find contemporary examples of millimeter band radio hardware including 60 GHz and V- and E-Band point-to-point radio. This book demonstrates the profound progress with 4G radio signal processing and RF hardware to reveal its potential applicability to 5G radio systems. It shows how 5G systems are capable of delivering data rates that are 10 to 100× faster than 4G systems. Developments in spatial processing and beamforming in local area radio networks are presented and the challenge of scaling these systems to wide area radio is explored. This book reviews military and space radio and automotive radar innovation with direct relevance to 5G radio design.

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Jaime Leger
Northeast Reg. Sales Mgr.
(New England, New York, Eastern Canada)
685 Canton Street
Norwood, MA 02062
Tel: (781) 619-1930
FAX: (781) 769-5037
jleger@mwjournal.com

Michael Hallman
Eastern Reg. Sales Mgr.
(NJ, Mid-Atlantic, Southeast, Midwest, TX)
4 Valley View Court
Middletown, MD 21769
Tel: (301) 371-8830
FAX: (301) 371-8832
mhallman@mwjournal.com

Pacific and Mountain Time Zones
Brian Landy
Western Reg. Sales Mgr.
(CA, AZ, OR, WA, ID, NV, UT, NM, CO, WY, MT, ND, SD, NE & Western Canada)
144 Segre Place
Santa Cruz, CA 95060
Tel: (831) 426-4143
FAX: (831) 515-5444
blandy@mwjournal.com

International Sales
Richard Vaughan
International Sales Manager
16 Sussex Street
London SW1V 4RW, England
Tel: +44 207 596 8742
FAX: +44 207 596 8749
rvaughan@horizonhouse.co.uk

Germany, Austria, and Switzerland (German-speaking)
WMS.Werbe- und Media Service
Brigitte Beranek
Gerhart-Hauptmann-Street 33,
D-72574 Bad Urach
Germany
Tel: +49 7125 407 31 18
FAX: +49 7125 407 31 08
bberanek@horizonhouse.com

Korea
Young-Seoh Chinn
JES Media International
2nd Floor, ANA Bldg.
257-1, Myungil-Dong
Kangdong-Gu
Seoul, 134-070 Korea
Tel: +82 2 481-3411
FAX: +82 2 481-3414
yschinn@horizonhouse.com

China
Shenzhen
Michael Tsui
ACT International
Tel: 86-755-25988571
FAX: 86-755-25988567
michaelt@actintl.com.hk

Shanghai
Linda Li
ACT International
Tel: 86-021-62511200
lindal@actintl.com.hk

Beijing
Cecily Bian
ACT International
Tel: +86 135 5262 1310
cecilyb@actintl.com.hk

Hong Kong, Taiwan, Singapore
Mark Mak
ACT International
Tel: 852-28386298
markm@actintl.com.hk

Japan
Katsuhiro Ishii
Ace Media Service Inc.
12-6, 4-Chome,
Nishiiko, Adachi-Ku
Tokyo 121-0824, Japan
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FAX: +81 3 5691 3336
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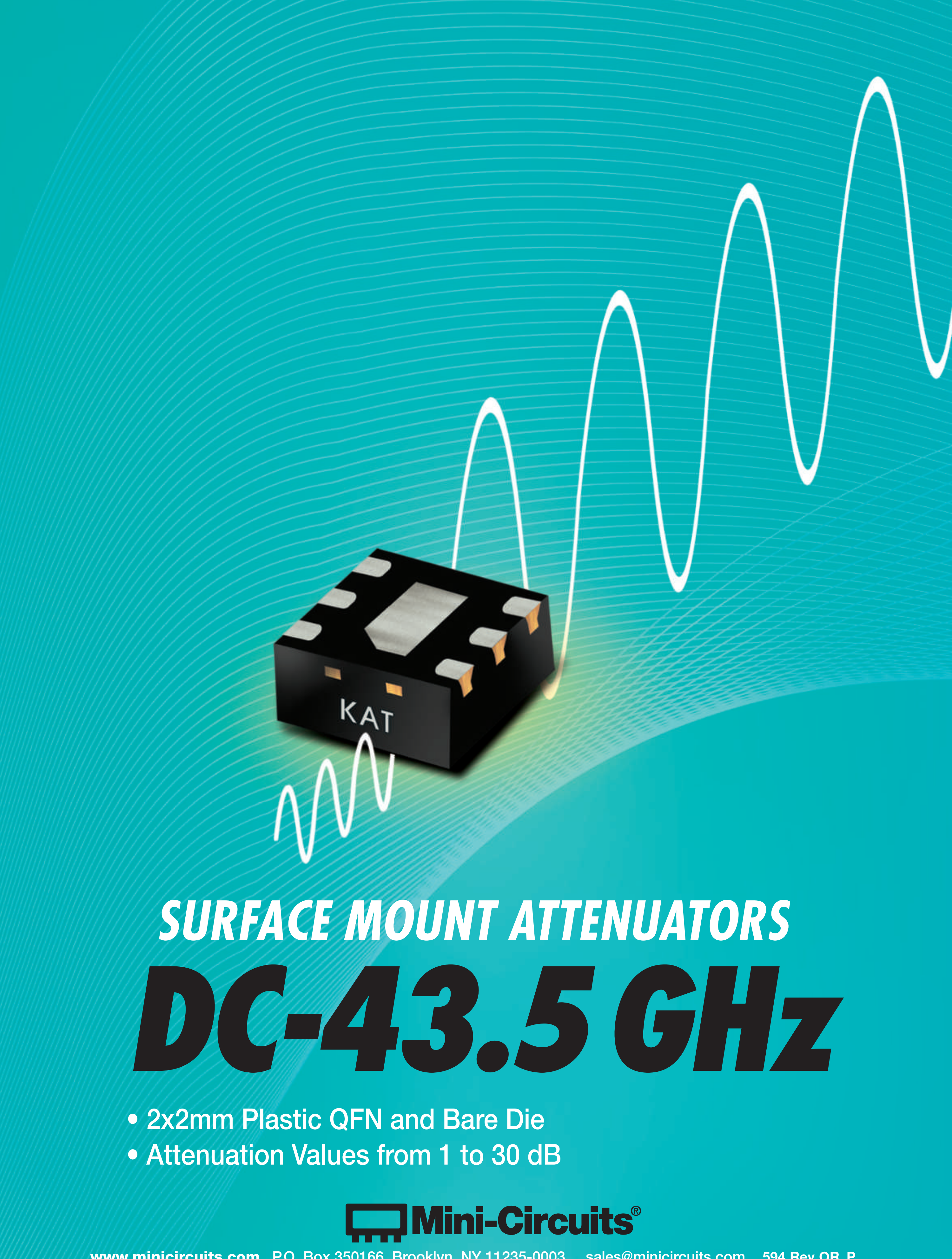
Ed Kiessling • Traffic Manager/Inside Sales • 685 Canton Street, Norwood, MA 02062 • Tel: (781) 619-1963 FAX: (781) 769-6178 • ekiessling@mwjournal.com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FABS and LABS

A Passion for Dielectric Materials

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

Beginning with materials, MCV Microwave offers proprietary dielectric resonators operating in TE, TM or TEM mode, with dielectric constants from 6 to 190 and Q•f up to 300,000 at 10 GHz. The resonators, suitable for microstrip and stripline networks, are widely used in voltage controlled oscillators, dielectric resonator oscillators and microwave filters from 6 to 100 GHz.

Competence with high Q materials naturally leads to designing high performance filters. MCV's filter and multiplexer products encompass cavity, ceramic and LC designs, including ultra-narrowband—down to 0.03 percent passband bandwidth—and wideband filters from 2 MHz to 70 GHz and in all configurations: bandpass, band rejection, lowpass, highpass and multiplexers. Products have been developed that meet the most stringent requirements of defense, aerospace and wireless systems. MCV is recognized for ultra-low passive intermodulation (PIM) filters and duplexers for wireless communications, including a line of cavity-based duplexers with better than –173 dBc PIM levels for the standard communications bands from 350 MHz to 3.5 GHz. Using frequency selective surface metamaterials, the company's designers are developing filters and multiplexers to cover the 5G mmWave bands.

MCV has also applied its dielectric materials capability to develop patch antennas for GPS, Wi-Fi and cellular, including a patented hybrid antenna for six LTE bands. The rectangular microstrip antennas have strict dimensional accuracy and use the company's proprietary dielectric materials with tight dielectric constant tolerance and temperature stability, yielding excellent antenna sensitivity and stability.

Because PIM is such a critical performance parameter in wireless communications and PIM problems are very challenging to identify and solve—particularly sites with co-located services—MCV offers engineering consulting to carriers and in-building operators to identify and mitigate sources of frequency interference, whether in cellular networks or Wi-Fi hot spots.

To meet the company's high standards, MCV is largely vertically integrated, from dielectric materials produced in Japan through product design and manufacturing. Design teams are located in Delaware and at MCV's headquarters in San Diego, where the filter and antenna products are manufactured. MCV has machining and plating operations in San Diego, with additional machining and plating capacity in China, when needed for high volume production. The comprehensive test capability supports the development and production of all products, as well as the "PIM hunting" services. MCV's staff has grown to around 300, with some 25 in engineering and 250 supporting production.

Reflecting its vision of being "customer centric," MCV Microwave strives to understand each customer's unique needs and to respond quickly with a customized solution at a competitive price, always with exceptional quality and delivery. MCV is ISO 9001:2015 and AS9100D certified and ITAR registered. The firm's many customers include well-known Fortune 500 companies and start-ups, an endorsement of its strong technical capabilities and commitment to quality and responsiveness.

www.mcv-microwave.com

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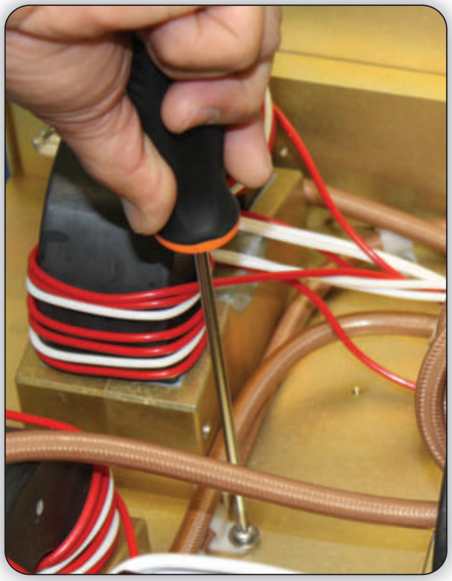

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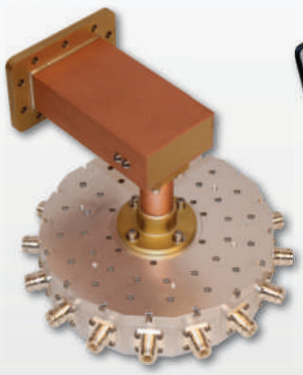

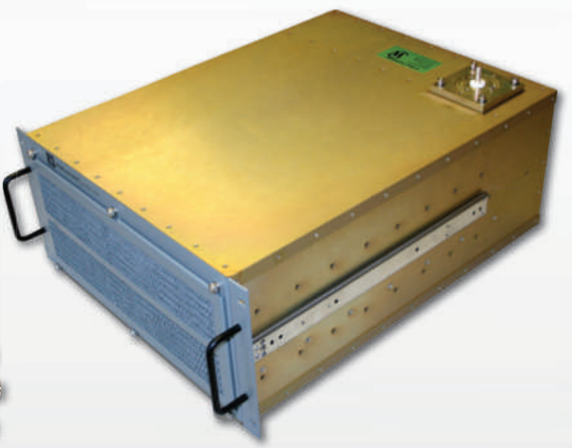

DECADES AHEAD®

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