Vol. 63 • No. 2

February 2020

Microwave Journal

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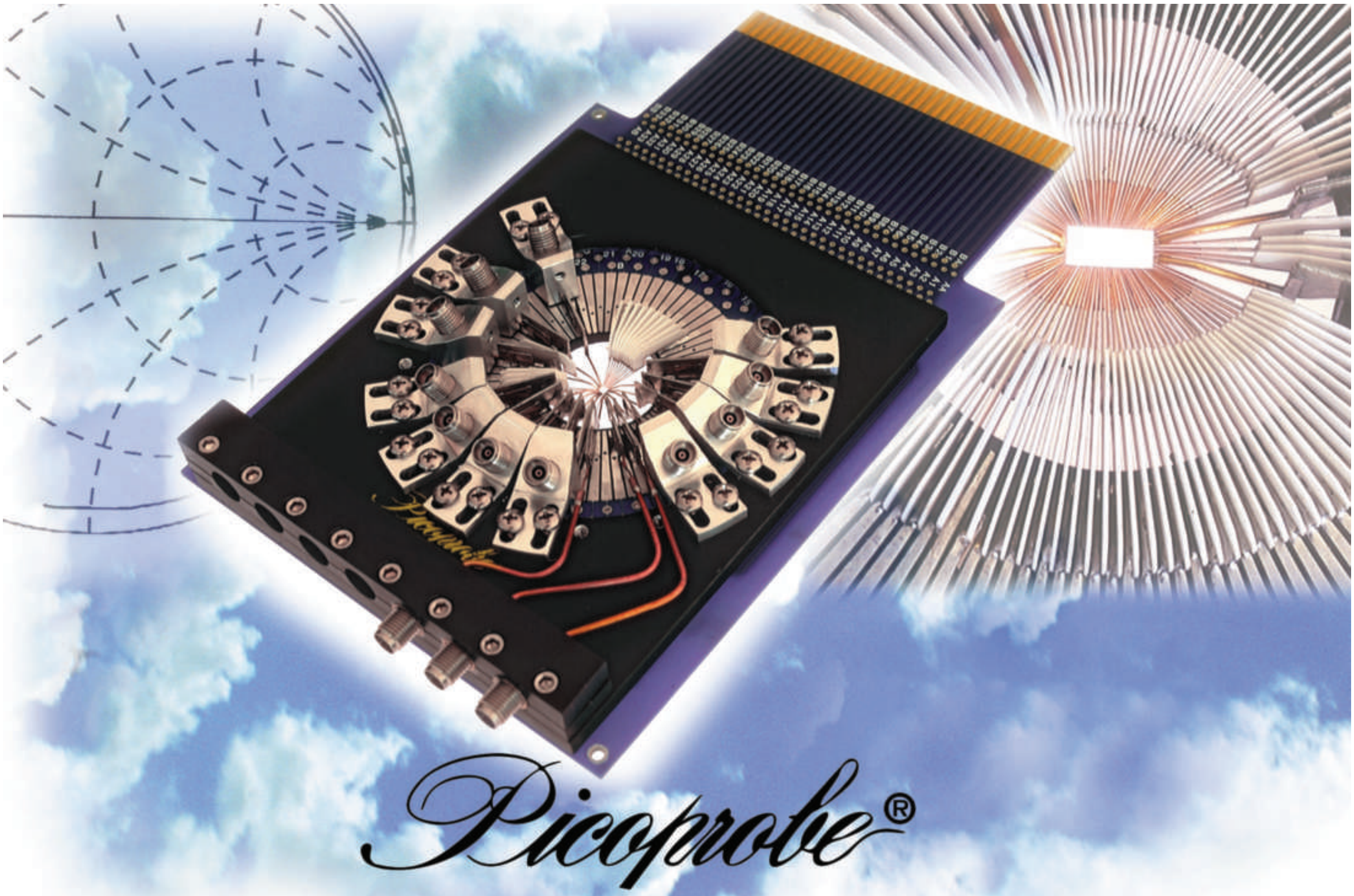

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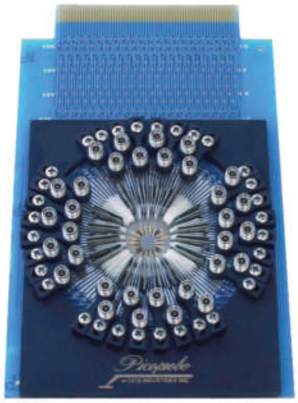

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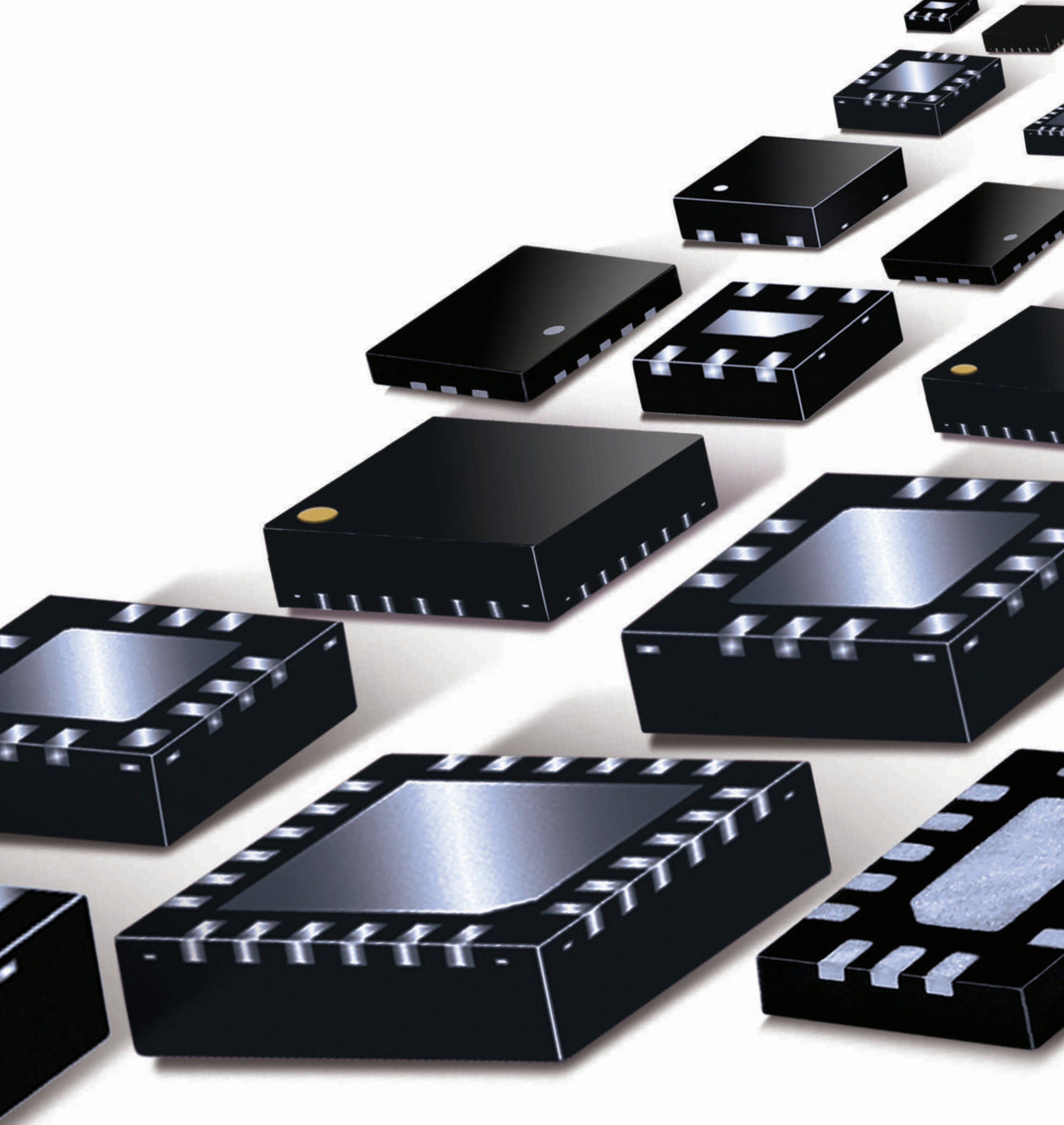


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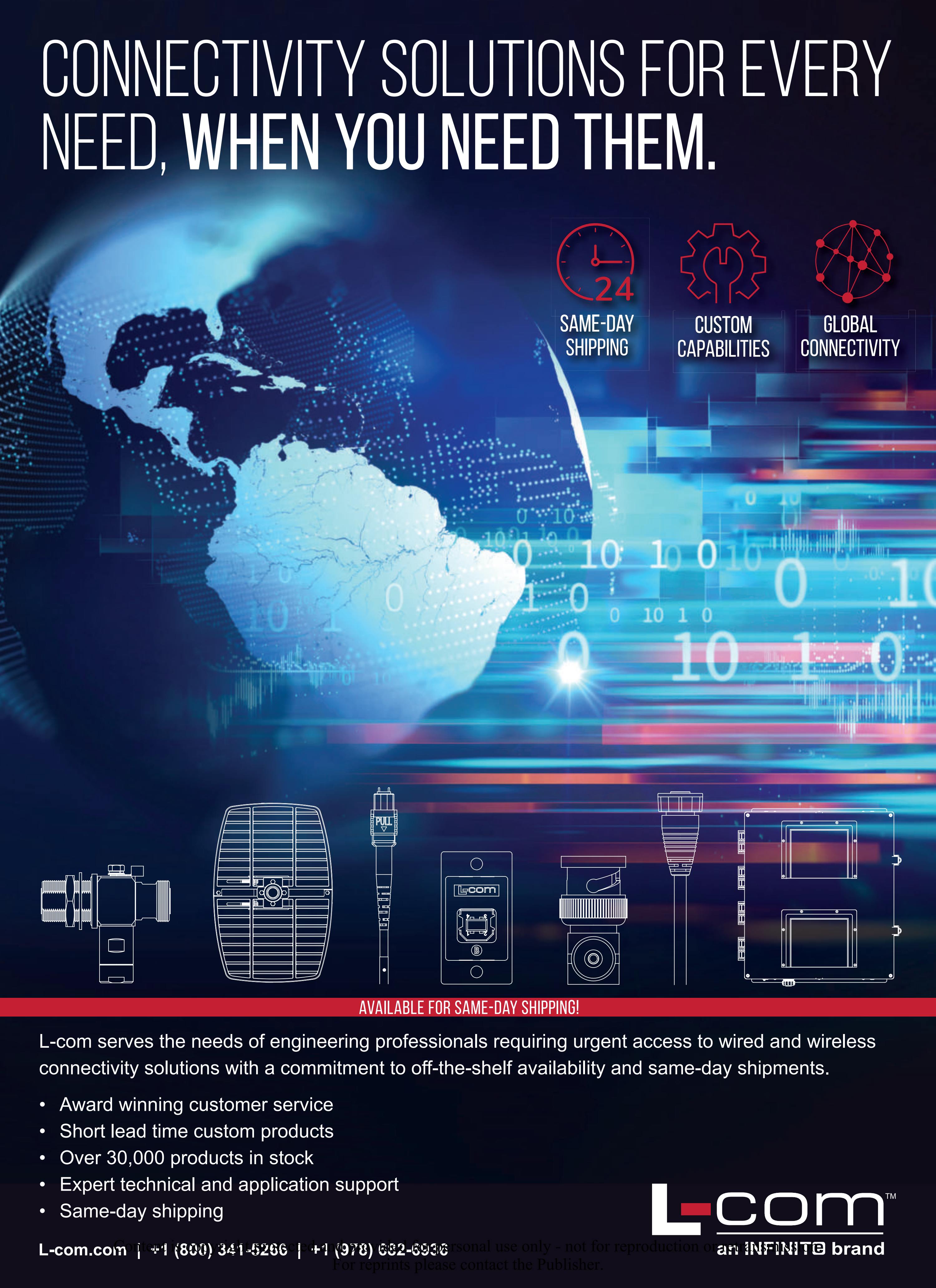
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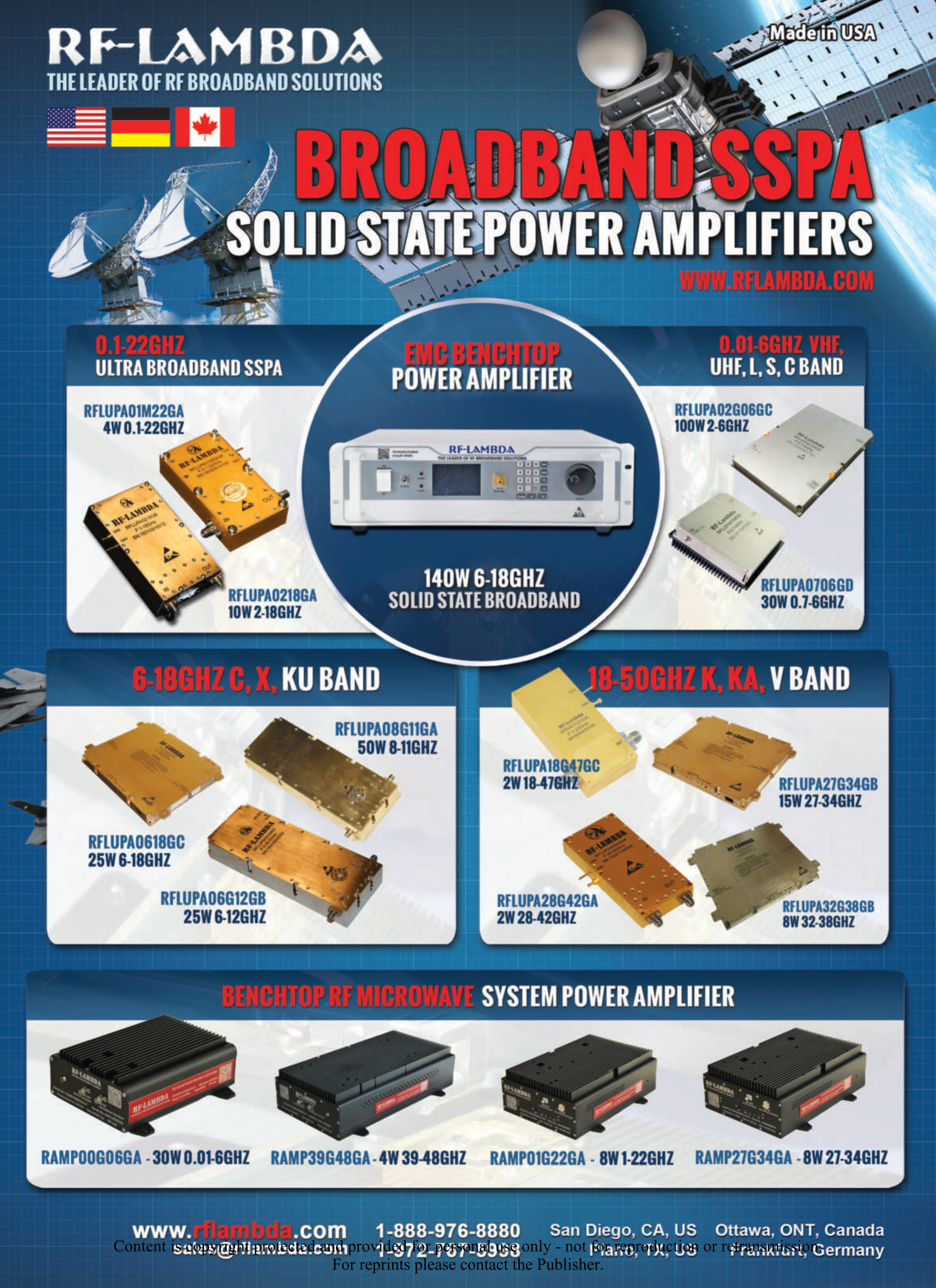
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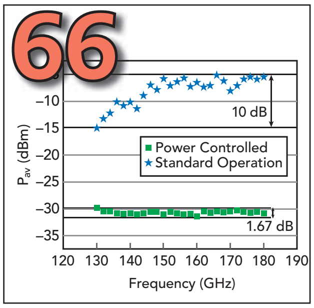

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Paul A. Moakes, CommAgility

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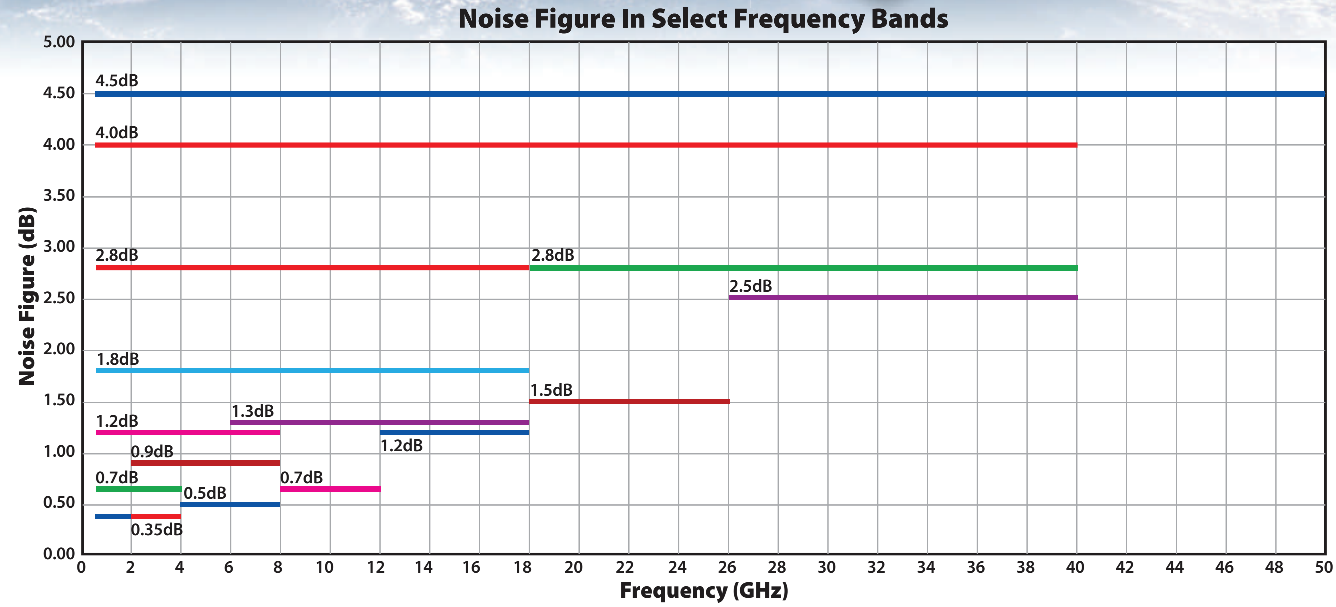

Noise Figure In Select Frequency Bands
Noise Figure (dB)
5.00
4.50
4.00
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1.50
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0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
Frequency (GHz)

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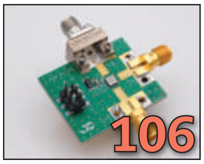

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Executive Interviews

Wendy Shu describes her path to CEO of the company formed by her parents, the decision to rename **SAGE Millimeter** as **Eravant** and how this shapes the vision for the company.

Oren Hagai, founder and CEO of **Interlligent RF & Microwave Solutions**, discusses the firm's unique service offering, the success of its U.K. expansion, attractive growth markets and its upcoming design seminar in Tel Aviv.

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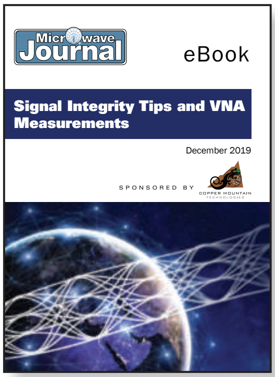

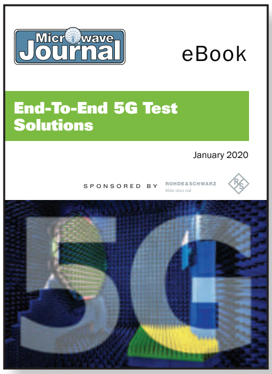

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https://2020.satshow.com/

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ARMMS
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www.armms.org/conferences/

17-18 GOMACTech

Washington, DC

Established in 1968, GOMACTech has focused on advances in systems being developed by the Department of Defense and other government agencies and has been used to announce major government microelectronics initiatives such as VHSIC and MIMIC, and provides a forum for government reviews. GOMACTech and the Space Environment and Effects Working Group (SEEWG) are pleased to announce that SEEWG technical interests will again be integrated into GOMACTech 2020 conference program.

www.gomactech.net/2020/index.html

17-19 emv

Cologne, Germany

The EMV 2020 conference will take place in Cologne and provide a comprehensive overview of the latest trends and developments within electromagnetic compatibility. EMV is changing its location for the 2020 event: the exhibition and conference will stay in North Rhine-Westphalia in the even years and move from Düsseldorf to Cologne.

https://emv.mesago.com/events/en.html

18-19 RF & Microwave

Paris, France

The 9th edition of RF & Microwave 2020 conference will cover topics around RF, microwaves, wireless, EMC and fiber optics. It will consist of over 80 exhibitors and partners and is expected to draw over 1,900 visitors. The trade show will majorly focus upon connected wireless objects, the field of EMC, EMC tests, the EMC connectivity, architectures and technologies of microwave functions applied to drones, backhaul to 94 GHz network for 5G and trends on the RAN 5G.

www.microwave-rf.com

27 Call for Papers Deadline

ITC

ITC 2020, taking place October 26-29, 2020 in Glendale Ariz., is currently accepting papers on topics such as Telemetry Solutions, Spectrum Efficient Technologies and Applications, Application of Wireless Technologies, Time-Space Position Technologies and more.

www.telemetry.org/

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PCB West 2020
February 24

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March 16

ITC 2020
March 27

AMTA 2020
May 1

2020 IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS)
May 9

APMC 2020
May 15

IEEE IMaRC 2020
July 30

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www.mwcbarcelona.com/

MARCH

SATELLITE 2020
March 10-12 • Washington, D.C.
https://2020.satshow.com/

GOMACTech 2020
March 17-18 • San Diego, Calif.
www.gomactech.net/2020/index.html

EMV 2020
March 17-19 • Cologne, Germany
https://emv.mesago.com/events/en.html

Microwave & RF 2020
March 18-19 • Paris, France
www.microwave-rf.com

APRIL

2020 IEEE Texas Symposium on Wireless and Microwave Circuits and Systems
April 2-3 • Waco, Texas
https://texassymposium.org/

Expo Electronica 2020
April 14-16 • Moscow, Russia
www.expoelectronica.ru/en-GB

WAMICON 2020
April 15-17 • Clearwater Beach, Fla.
www.wamicon.org/

ARMMS Spring 2020 Conference
April 27-28 • Thame, U.K.
www.armms.org/conferences/

MAY

CS Mantech 2020
May 11-14 • Tucson, Ariz.
http://csmantech.org/

EDI CON China 2020
May 13-14 • Beijing, China
www.ediconchina.com

Space Tech Expo USA 2020
May 18-20 • Long Beach, Calif.
www.spacetechexpo.com/

IEEE IMBioC 2020
May 25-28 • Toulouse, France
https://imbioc-ieee.org/

JUNE

Military Space USA 2020
June 9-10 • Los Angeles, Calif.
www.smi-online.co.uk/defence/northamerica/milspace-usa

IEEE MTT-S IMS 2020
June 21-26 • Los Angeles, Calif.
https://ims-ieee.org/

MilSatCom USA 2020
June 24-25 • Arlington, Va.
www.smi-online.co.uk/defence/northamerica/MilSatCom-USA

95th ARFTG Microwave Measurement Symposium
June 26 • Los Angeles, Calif.
www.arftg.org

JULY

SEMICON WEST 2020
July 21-23 • San Francisco, Calif.
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	28 GHz	Silicon Core BFIC	AWMF-0108	Tx/Rx Single Pol Quad BFIC
			AWMF-0158	Tx/Rx Single Pol Quad BFIC
			AWMF-0151	new! Tx/Rx Dual Pol Quad BFIC
		Silicon Converter IFIC	AWMF-0153	new! Tx/Rx Up and Down Converter IFIC
	37/39 GHz	Silicon Core BFIC	AWMF-0144	Tx Single Pol Quad BFIC
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			AWMF-0156	Tx/Rx Single Pol Quad BFIC
			AWMF-0159	new! Tx/Rx Dual Pol Quad BFIC
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SATCOM	Ku-Band	Silicon Core BFIC	AWMF-0146	new! Rx Dual Pol Quad BFIC
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	Ka-Band	Silicon Core BFIC	AWMF-0109	Tx Dual Pol Quad BFIC
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			AWMF-0143	Intelligent Gain Block IC
RADAR	X-Band	Silicon Core BFIC	AWS-0101	Tx/Rx Dual Pol Low NF Quad BFIC
			AWS-0103	Tx/Rx Dual Pol High IIP3 Quad BFIC
			AWS-0104	Tx/Rx Single Pol Low NF Quad BFIC
			AWS-0105	Tx/Rx Single Pol High IIP3 Quad BFIC
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	Ku-Band	Silicon Core BFIC	AWMF-0117	Intelligent Gain Block IC

mmW Silicon ICs

Intelligent Array Solutions

mmW Algorithms to Antennas

Editor's Note: As 5G mmWave applications are being implemented, the issues of propagation distance and blocking have limited the success of initial deployments. However, new array beam forming technologies have been developed to help overcome these limitations by enabling higher power/gain, higher efficiency and improved scanning angles. Our cover feature introduces two array beam forming technologies that promise to improve mmWave systems: the first is Holographic Beam Forming from Pivotal Commware, and the other is dielectric resonator antenna technology from Antenna Company. So stay tuned as we address semiconductor technology improvements for 5G mmWave applications in our April issue.

Breaking Down mmWave Barriers with Holographic Beam Forming®

Eric Black, Alex Katko and Andjela Ilic-Savoia
Pivotal Commware, Kirkland, Wash.

mmWave wireless services have been traditionally used in short range wireless transport applications such as fronthaul/backhaul, point-to-point links and SATCOM. 5G in the U.S. will push the role of mmWave beyond simple transport to become a capacity layer for fixed wireless access (FWA) and enhanced mobile broadband (eMBB). Taking mmWave from its fixed beam roots to a dynamic, reconfigurable access layer will depend critically on beam forming techniques to assure link margins without requiring massive capital outlays.

5G mmWAVE BEAM FORMING TECHNOLOGIES

Beam forming uses planar antenna arrays with typical antenna gain ranging from 17 dB (4 square wavelength arrays) to 29 dB (64 square wavelengths). Phased arrays are a classic architecture used for beam forming. A canonical 4-element time division duplexed (TDD) phased array is shown schematically in ***Figure 1***. In such an array, the antenna elements are spaced roughly one-half wavelength apart and every element is backed by a module consisting of a transmit power amplifier (PA), receive low noise amplifier (LNA), phase shifter and switches to swap between the transmit and receive modes. These elements are typically packaged as 4-element modules on a single chip. This distributed architecture is notoriously expensive and power hungry but is well understood by antenna engineers and industry and has been the standard for analog beam forming for decades. At mmWave, phased arrays have seen heavy usage in defense and satellite applications but have not seen widespread use in commercial terrestrial applications.

Phased array beam forming is both named for and enabled by a phase shifter behind every element. In transmission mode, the radio signal is distributed through a corporate feed network, providing the same phase shift to every element in the array. Phase shifters at each element then impart the appropriate delay in carrier phase to cause constructive interference of the radiated fields in desired direction while also causing destructive interference in others. The finite nature of

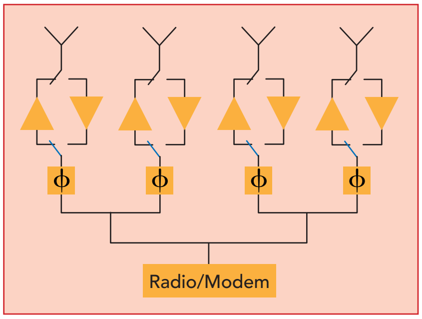
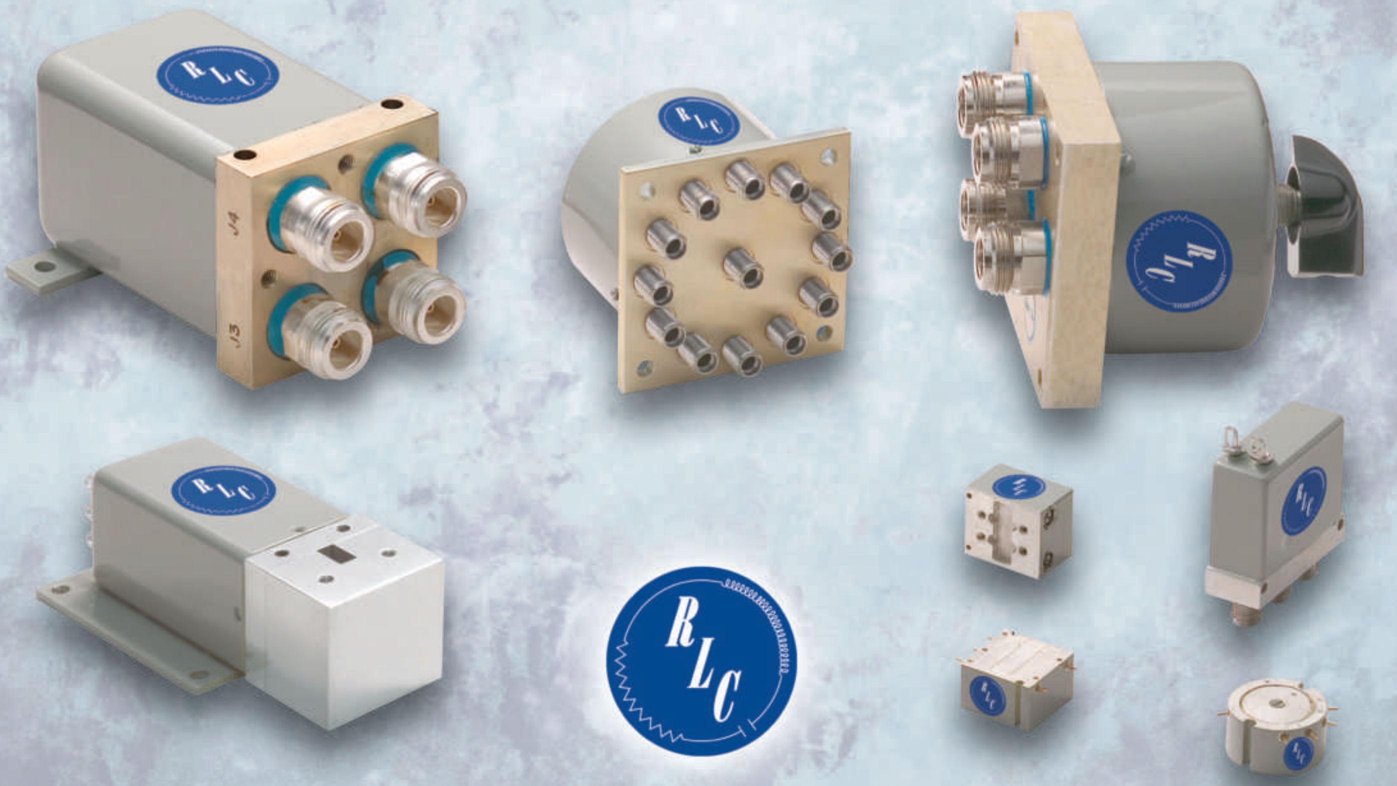


Fig. 1 **A canonical TDD phased array architecture.**



the antenna aperture (radiating area of the antenna surface) gives rise to sidelobes or unavoidable radiation in undesired directions. Sidelobes are usually 13.4 dB or more below the beam peak. Receiving from the antenna array is the reverse of transmission, with the PA and LNA chains swapping for receive mode while the phase shifters align the received signals from the desired direction to constructively add while destructively combining the other directions. In both transmit and receive, the antenna radiation pattern is well defined and is typically measured in anechoic chambers.

Massive Multiuser MIMO (MU-MIMO) is a newer technique, shown in ***Figure 2***, that replaces analog phase shifters with direct digital conversion of the analog waveform. At low frequencies (sub-3 GHz) high resolution digital to analog (DAC) and analog to digital converters (ADC) are used to directly create the radio waveform with the appropriate phase shift. More interestingly, different phase shifts can be imparted on a per-carrier basis and create beams carrying different information for the same subcarrier. Receiving is similar with the received waveform being digitized at each antenna element. The digital bus-work connects each element to a coordinated radio/baseband system which post-processes the signals into their respective digital streams.

In practice, direct DAC in MIMO is rarely done at mmWave. RF up/down conversion is used to reduce sampling requirements to those of baseband signals. Even so, the DAC/ADC and RF conversion pairs are even more expensive and power hungry than a phased array. For traditional cellular this may prove acceptable as base station densities are modest. At mmWave, deployed densities are expected to be much higher due to the shorter link distances at mmWave rendering MU-MIMO unsuitable for real deployments.

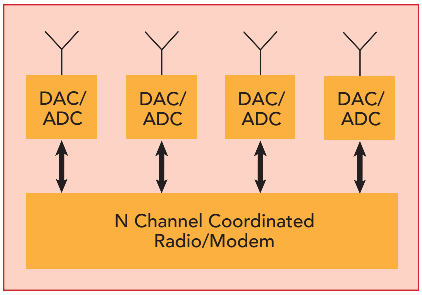


Fig. 2 A canonical MIMO array architecture.

Holographic Beam Forming (HBF)

HBF is a new technique derived from metamaterial concepts. Functionally, HBF is an analog beamformer with performance equivalent to analog phased arrays. As with other planar arrays, the antenna area dictates the achievable beamwidth and maximum realized gain. The HBF technique uses one RF chain that feeds all the elements in the array through a single RF port. Rather than a corporate feed as in phased arrays or digital network in MIMO, HBF uses a series feed that distributes the RF signal along multiple individual antenna elements. Slots, patches, dipoles and other small antenna types have all been shown to work with the HBF technique as radiating elements. A varactor tuned feed coupler transfers energy from the distribution network into the antenna element and this is shown schematically in ***Figure 3***. As shown, each element sees a different progressive phase shift from the feed point. Beam forming is accomplished by using the capacitance shift in the varactor to vary the coupling to selected elements with the proper phase alignment needed to point the beam in the desired direction.

HBF is named for its similarity to conventional optical holography. In optical holography, an external source excites the hologram surface which converts the excitation into an output wave our eyes perceive as an image. In HBF, the radio is the source excitation and the beam is the output wave. The pattern of

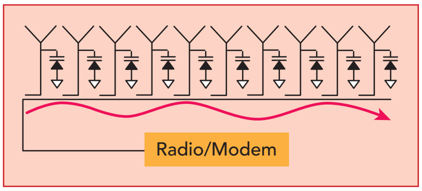


Fig. 3 A canonical HBF architecture.

Testing 5G connectivity in NSA mode

5G NR supports non-standalone (NSA) and standalone (SA) modes. In NSA mode a connection between the user equipment (UE) and base station uses both current LTE (4G) and new 5G technologies. In SA mode the connection is solely 5G based. 5G devices will initially use NSA and, in time, increasingly SA mode as connection technology.

An NSA mode requires LTE as an anchor for exchange of control and signaling information between the LTE network and the UE. A 5G NR capable UE supporting E-UTRA–NR dual connectivity (EN-DC) performs the LTE cell search and selection procedure when switched on, followed by LTE system information acquisition and execution of the LTE initial access procedure. Meanwhile, the UE provides its radio access capabilities to the network for LTE and for 5G NR. Thus the network can add a 5G NR connection to boost for instance data speeds when necessary.

EN-DC enables the UE to connect simultaneously to two different radio access networks, an LTE base station (eNB) and a 5G base station (gNB). The signals of the two base nodes do not need to be time-synchronized and, therefore, are not required to be physically collocated. Dual connection is depicted in ***Fig. 1.***

5G testing requires new test and measurement approaches alongside the familiar LTE ones. Rohde & Schwarz has created the R&S CMX500 radio communication tester that adds 5G NR signaling tests to existing R&S CMW500 LTE solution. As most network operators will implement 5G NR as an extension of an LTE mobile network, the R&S CMX500 can be seamlessly integrated into existing LTE test environment, yet is also ideal for 5G NR testing in standalone (SA) mode. This enables 5G NR RF test, signaling protocol tests as well as data-throughput and application tests (e.g. IMS, VoLTE, VoNR) from R&D to certification tests.

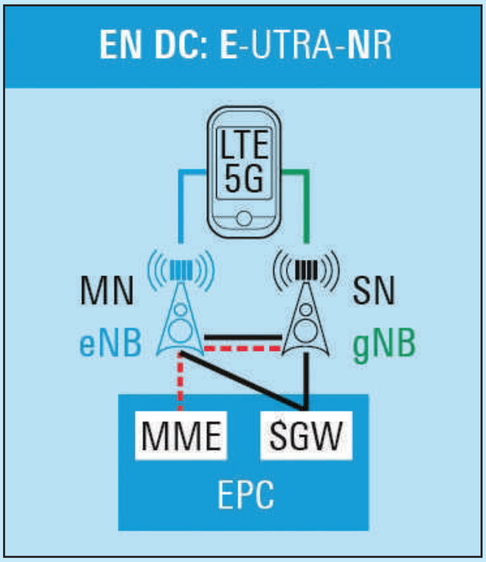


Figure 1. Dual connection in NSA mode

VISIT ROHDE & SCHWARZ AT MOBILE WORLD CONGRESS 2020 HALL 6, BOOTH 6B30

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Is 5G simply another generation of mobile communications technologies? Or something revolutionary? Five Rohde & Schwarz experts for wireless communications technologies give a comprehensive answer to this question. Register now to get access to the 5G New Radio online compendium: **www.rohde-schwarz.com/5g-ebook** element coupling converting the guided excitation into a free space wave is exactly a hologram. As a passive system, the technique is fully reciprocal with reception and transmission using the same hologram. No switching at the antenna level is required. All the amplifiers and baseband components can remain within the radio unit.

Figure 4 shows a typical HBF implemented in a multilayer printed circuit board at 39 GHz. The holographic technique uses a denser lattice than half wavelength along one dimension. As suggested from the schematic view of Figure 3, many of the elements will have the wrong phase for the desired beamshape and are turned off. In order to avoid the efficiency penalty for having significant portions of the array in the "off" state, the elements are packed at more than double the density of a traditional array to allow uniform aperture excitation and efficient beam forming. The element miniaturization along one axis has an additional benefit in that it widens the scanning volume to nearly ±80 degrees with less than 10 dB loss from antenna broadside.

5G mmWAVE SYSTEM DESIGN

Current 4G networks suffer from limited available spectrum to serve ever-increasing data demands from users. As mmWave spectrum is being used to close this gap, more systems showcase the need for cost-effective, low-power beam forming techniques.

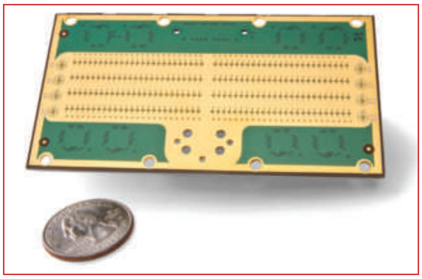


Fig. 4 **39 GHz HBF antenna.**

A high-level cellular network architecture is shown in ***Figure 5***. Perhaps the most challenging link in the above architecture is the radio access network (RAN) link. Fronthaul, backhaul and other transport is generally expected to use fiber as the physical medium. RAN, by its nature, requires wireless connectivity. In the context of 5G, the RAN link can be decomposed into the following node types:

- The Base Station (gNB in 5G): The gNB connects the core network to end user equipment.
- User Equipment (UE): The UE connects to the gNB for access and provides the user with service.
- Repeater: Repeaters are optional components that connect the gNB and UE.

These node types all have mmWave capability. The mmWave requirements differ among node types which drives different architecture decisions for practical implementation of 5G equipment.

A mmWave gNB must comply with requirements standardized by 3GPP, the primary cellular RAN standards development organization. In practical terms, mmWave gNBs are driven to meet the following high-level requirements:

- Hybrid beam forming architecture with 2 or 4 subapertures each capable of an independently steered beam
- Moderate-to-high output power, with effective isotropic radiated power (EIRP) from 50 to 70 dBm
- Beamwidths on the order of 5 to 10 degrees
- Fast switching capable of complying with timing requirements at the slot and symbol level, translating to beam-to-beam switching times of ~4 μs

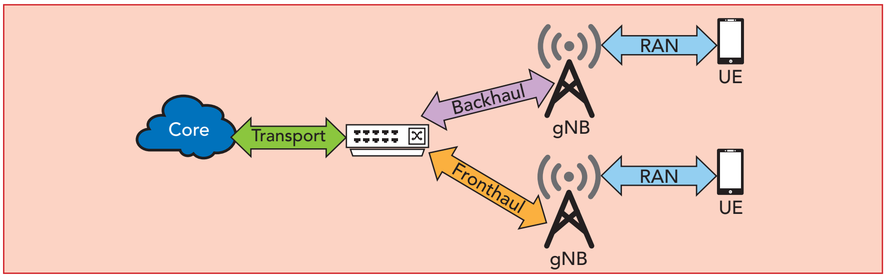
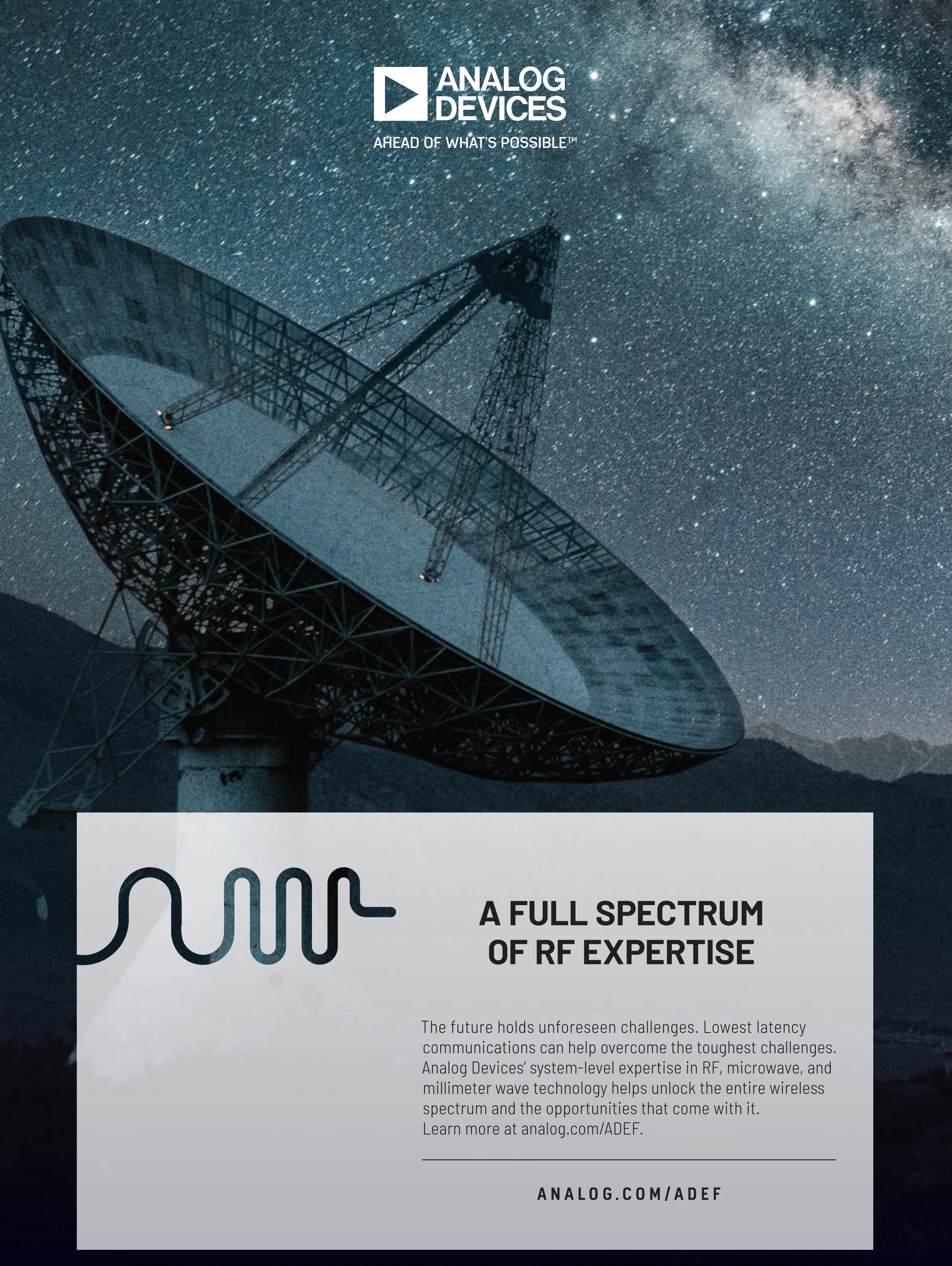


Fig. 5 **A high-level 5G cellular network architecture.**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HBF is well-suited to mmWave gNB designs. Hybrid beam forming with HBF results in low RF and thermal complexity. Phased-array-based hybrid beamformers use monolithic modules to realize the required antenna gain, with each module generating heat due to the phase shifter and amplifier losses. This leads to a thermal design challenge with heat generated throughout the PCB. With HBF beamformers, there is a single RF PA per HBF from which to extract heat. This also allows for digital predistortion (DPD), which enhances efficiency and reduces power consumption. HBF also lends itself to rapid beam-switching implementations, without any RF gain or phase adjustment required at fast time scales.

5G UEs pose a major challenge for device designers. The inherently lower power added efficiency at mmWave, compared to traditional cellular bands, leads to devices operating at higher temperatures while simultaneously reducing battery life. The simplified architecture for DPD with HBF is particularly important in handset UEs for this reason, as early 5G handsets have seen thermal issues with multiple mmWave arrays in a confined physical envelope. Mass-market UEs also have even more stringent cost requirements than gNBs, with a constant "race-to-the-bottom" in price pushing designers to embrace novel technologies if they have a corresponding cost decrease.

As a contrast to 5G gNBs and UEs, 5G repeaters are less defined in standards. Generally, repeaters reproduce an incoming signal with minimal processing, typically limited to L1 (physical layer) or L0 (RF layer) only. Regardless of whether a repeater processes a signal at L0 or L1, beam forming is needed to support mobile network operator (MNO) requirements. The cost, complexity and power draw are expected to be less than a full gNB, allowing repeaters to serve as network extension nodes without the effort of deploying a complete gNB. Cost is a major driver for repeater deployment by MNOs: the lower the cost, the more easily repeaters can be deployed to cover gaps in the network. HBF is thus a natural fit for the beam forming subsystem of a 5G mmWave repeater.

When compared to a full gNB solution, repeaters do not need full-stack processing to operate. The lower the layer of processing, the lower cost of the signal processing chain, as FPGAs and ASICs are not required. A L0 repeater consists primarily of a system controller, power supply and management unit, RF chain(s) and beamformer(s). These modules are required in a L1 repeater with the addition of frequency conversion (to IF or I/Q), ADC/DAC chains and baseband processing. L0 repeaters provide the lowest cost architecture, while L1 repeaters can provide additional signal conditioning in the presence of interference.

Repeaters extend a signal to locations unreachable by the original source. As an example, the free space path loss at 28 GHz is approximately 71 dB 10 ft. from the source. A repeater which extends coverage to an additional 10 ft. (say from a window, inside a home) should have at least 71 dB of gain to compensate. With typical window or wall penetration loss adding at least 5 dB, this example repeater needs 50 dB of electronic gain with an additional 26 dB of gain contributed by the Tx and Rx antennas.

With a restriction to L0-only processing, the repeater must be able to remain unconditionally stable across all deployment environments: this presents the fundamental design issue for repeaters given the large electronic gain required within a single enclosure. Careful RF design is needed to prevent oscillation under any conditions, as stability is affected by temperature, scattering environment and even window material. Pivotal's L0 repeater using HBF has been proven in real-world deployments to effectively extend the coverage of mmWave in both indoor and outdoor settings. The use of low-cost mmWave repeaters is a crucial piece in the 5G deployment puzzle to avoid over-deployment of gNBs, which leads to a node density and cost that is unacceptable for MNOs.

5G mmWAVE HBF REPEATERS IN FIELD TRIALS

Penetration through building material presents a challenge for mmWave deployments. It is not un-

common to encounter over 40 dB of loss when transitioning from outdoor to indoors. Since the channel is reciprocal, the same degradation occurs in the uplink direction, from UE to gNB. To overcome mmWave propagation and outdoor to indoor penetration loss, Pivotal Commware created two mmWave beam forming repeater products: the Echo 5G (see ***Figure 6***), a self-installable, tablet-sized, on-the-window, beam forming repeater for facilitating outdoor to indoor propagation, and the Pivot 5G, a professionally installed network element/repeater for supplementing and, in some cases, replacing gNB in commercial network deployments. This setup has been tested in numerous environments with a U.S.-based carrier and commercial gNBs and has completed interoperability testing with network equipment from three gNB vendors.

Fig. 6 **Pivotal Echo 5G™.**

Apartment Buildings

Pivotal conducted one trial in a suburban apartment building shown in ***Figure 7***. The gNB was located 700 ft. away and a commercial UE was inside the home. The Echo 5G was placed on the patio window (in yellow) with line-of-sight (LOS) to the gNB at 45 degrees from window broadside (parallel arrows). The unobstructed gNB-to-UE link supported peak throughput of 1.5 Gbps. The UE was then moved around the interior and tests run in various locations within the apartment.

The two pictures in Figure 7 depict "before and after" the unit was utilized. Figure 7 summarizes

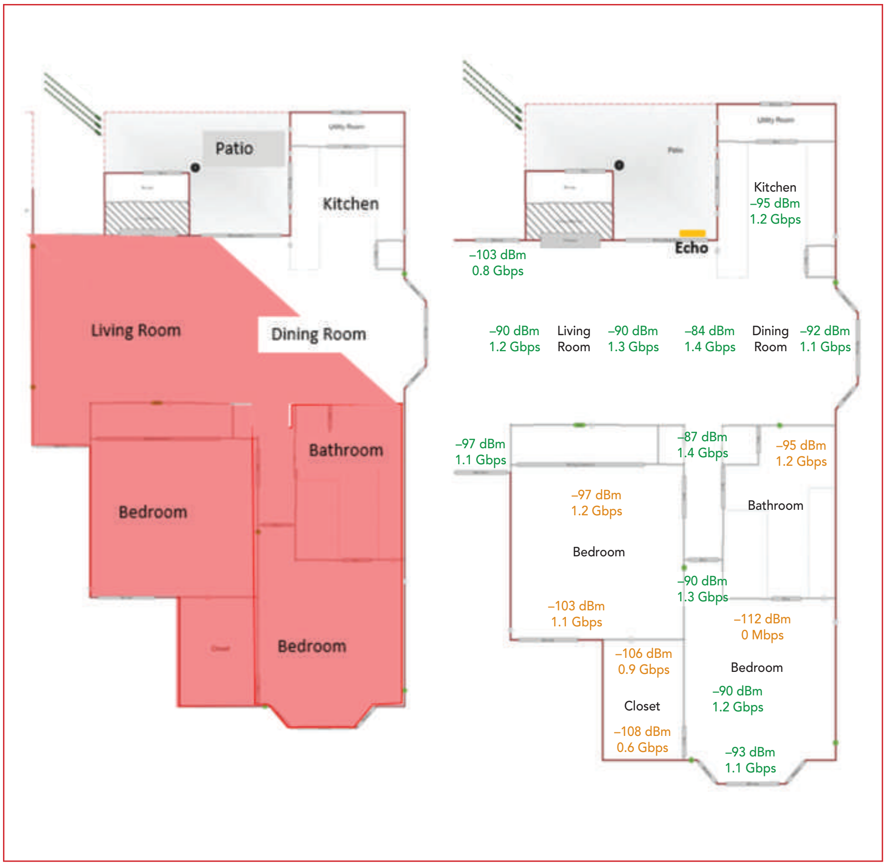


Fig. 7 **Suburban apartment trial results, before and after Echo 5G deployment.**

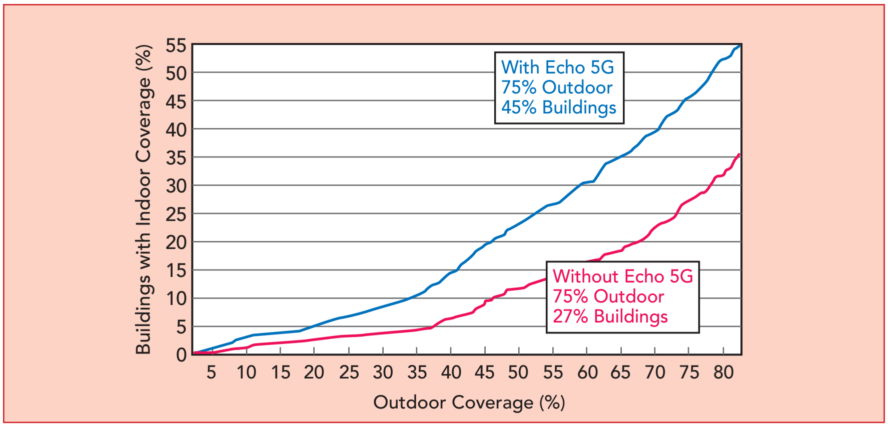


Fig. 8 Outdoor vs. indoor coverage, urban, without Echo (red) and with Echo (blue).

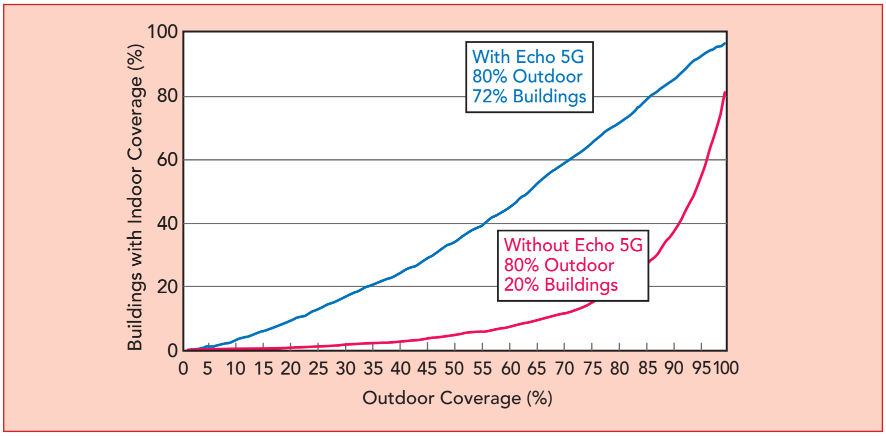


Fig. 9 Outdoor vs. indoor coverage, suburban, without Echo (red) and with Echo (blue).

throughput results. The results printed in green are all LOS locations from the unit. The results in amber are non-LOS locations from Echo that Echo still served very well.

Without this product, full rate was only observed by placing the UE at the balcony door, as most of the interior was mmWave shadowed by the building wall (in red). Only the kitchen area indoors was not in the mmWave shadow, as it had LOS connectivity to gNB through the window. For other test locations, a mostly full rate experience was observed and locations that previously had no connectivity showed substantial throughput. Signal level measurements showed 20 to 30 dB improvement.

The number of gNBs needed to cover an area is the dominant factor in calculations of CAPEX and OPEX associated with a network deployment. This type of unit reduces the number of initially needed base stations dramatically, with 1 km distant LOS links becoming possible even

Fig. 10 Pivot 5G prototype.

with outdoor to indoor penetration challenges.

Modeling suggests the served addressable market (SAM) can be doubled, even quadrupled, if this product is utilized to bring the mmWave signals indoors without adding additional gNBs. ***Figures 8*** and ***9*** show projections for urban and suburban environments, respectively. In both figures, the baseline is achieved outdoor coverage (x-axis). The benefit Echo 5G brings

is the additional indoor coverage (y-axis) depicted with the blue line in each of the plots.

Repeater Applications

Pivot 5G is an outdoor network repeater shown in ***Figure 10***. As a base station proxy, the unit redirects mmWave signals from the gNB around obstacles and extends the range of 5G base stations.

A bring-your-own-device demonstration was set up for MWC Los Angeles 2019. This demonstrated Echo 5G and Pivot 5G in a real-world environment, with commercial gNB and 5G UEs. The demo location was a meeting boardroom near the MWC venue, and the room lacked LOS to the gNB. Echo 5G was deployed on the window facing South Figueroa Street. From this position, the Echo 5G was located 300 ft. away from the gNB but lacked LOS to the gNB. Pivot 5G was deployed in the hotel parking lot to redirect coverage to Echo 5G. The topology is depicted in ***Figure 11***.

Fig. 11 Live demo setup for MWC Los Angeles 2019.

Testing used a standard Samsung S10 5G phone. Each of the demos was benchmarked from inside the boardroom showing that 5G throughput is impossible without the units. In each test, the phone either could not connect to 5G or it connected with low throughput (< 100 Mbps). With Echo 5G and Pivot 5G on, throughput of 1000 Mbps on the 5G network, with the phone positioned 15 to 20 ft. in LOS of the Echo 5G, was consistently observed.

Moving into a hallway behind the boardroom, the phone did not initially connect to 5G. With the Echo 5G and Pivot 5G turned on, throughput of 800 Mbps was shown even with the phone positioned 20 to 30 ft. away and not in LOS of the Echo 5G.

Finally, 150 Mbps was achieved in a second hallway—two boundaries and over 30 ft. away from the window—by the Echo 5G and Pivot 5G. Without them, there was no 5G reception. The layout and the results are depicted in ***Figure 12***.

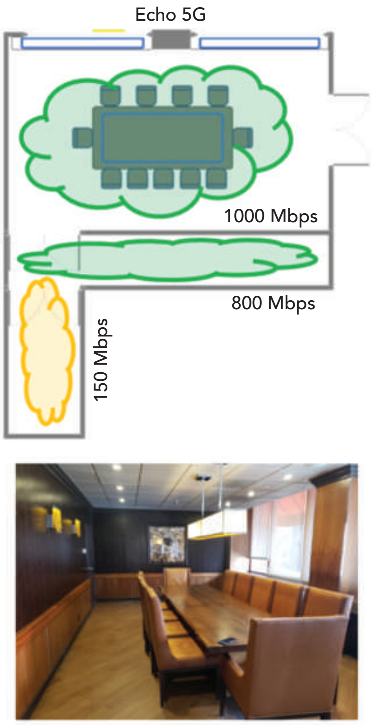


Fig. 12 The layout of the indoor space and photo of the boardroom.

SUMMARY

This article demonstrated the importance of beam forming in 5G mmWave networks and described three beam forming technologies: phased arrays, MU-MIMO and HBF. It claimed that HBF is particularly well-suited to 5G mmWave system designs and explained why, from a systems perspective, the use of low-cost mmWave repeaters is a crucial piece in the 5G deployment puzzle to avoid over-deployment of gNBs. Finally, the article elaborated on field trials and early success stories associated with 5G mmWave repeaters that use HBF.■

Cover Feature
Invited Paper

Dielectric Resonator Antenna Arrays for 5G Wireless Communications

Diego Caratelli, Ali Al-Rawi, James Song and David Favreau
The Antenna Company, Eindhoven, Netherlands

Global deployments of 5G networks are on a rapid pace and are expected to deliver a 100× increase in network capacity compared to 4G. To expand network capacity, the 5G NR air interface enables diverse spectrum in both the sub-6 GHz and mmWave frequency bands. The additional spectrum enabled by 5G brings new challenges for product design and global deployment, particularly in the mmWave frequency range. Customer premise equipment (CPE) solutions that operate in the mmWave frequency band are required to bring 5G fixed wireless access (FWA) to urban and suburban landscapes. To achieve the high data rates and low latencies promised by 5G, the antenna system becomes a crucial component in the overall system design. The Antenna Company is developing mmWave active antenna arrays for CPE applications that utilize novel materials and advanced antenna design strategies to address the performance limitations of conventional printed circuit board (PCB) solutions. This article discusses the performance benefits of utilizing a 64-element dielectric resonator antenna (DRA) array.

DRA BENEFITS FOR 5G

The new generation of 5G wireless communications is designed to provide mobile users with fiber-like data speeds, low latency and high signal fidelity. Industry-wide development efforts to enable these performance breakthroughs include advanced channel coding techniques, massive MIMO and mobile mmWave. Breakthroughs in antenna system design are crucial for the global use of mmWave spectrum. In addition to providing radio coverage, antenna systems must be able to reconfigure the radiation pattern characteristics to meet the dynamics in 5G wireless communications.[1]

Advances in material science and manufacturing make DRA technology a valid solution for the development of commercial array antennas. DRAs share several features with their counterpart, patch antennas; they are compact and are easy to integrate with active electronics. However, DRAs are more efficient than patch antennas at mmWave frequencies due to the high conduction loss. In addition, DRAs can provide more design freedom, compared to patch antennas, in relation to the geometry and materials forming the basic dielectric resonating structure. Different feeding techniques, design procedures and DRA structures can be found in review papers.[2-3] Long et al. systematically studied the radiation characteristics of different DRAs and their potential for mmWave applications.[4] It is shown that DRAs are compact, lightweight, cost-effective and feature broader bandwidth (BW) characteristics and large scanning angles up to ±60 degrees and beyond, as compared to patch antennas.[5-6]

The BW of phased array antennas is mostly determined by the active reflection coefficient during beam steering that affects the scan-loss characteristics of the antenna array. In addition, the shape of the embedded element pattern plays an important role. The mutual coupling can degrade the pattern by modifying the embedded pattern

shape and the realized excitation coefficients.

An 8×8 array of dielectric resonator antennas fed by slot antennas is proposed for mmWave 5G wireless communications. The total radiation efficiency is modeled as a function of frequency and beam steering. It is shown that the total radiation efficiency is higher than 80 percent over the frequency band from 26 to 34 GHz and for scan angles up to 60 degrees. The DRA can perform beam steering over wide BW with a scan-loss comparable to the array factor of an ideal source. In addition, the DRA array is 20 percent smaller in size compared to conventional half-wave-length spaced antenna arrays.

In this article, attention is given to the optimal design of hybrid DRA/slot antennas. It will be shown that the antenna impedance BW can be easily tuned in such a way as to synthesize a wide- or multi-band frequency response.

ANTENNA ARRAY DESIGN

Individual Antenna Element Design

A single array antenna element consists of a slot antenna fed by proximity coupling via a microstrip transmission line. The dielectric material for the transmission line is RO4308 with relative permittivity (ε_r) of 3.6. The slot then feeds a square dielectric rod, as illustrated in ***Figure 1***. In this design a dielectric material with ε_r = 11.3 is used in the analysis. With a proper selection of dimensions similar to Keyrouz and Caratelli,[5] the slot antenna radiates properly and excites the proper modes in the dielectric rod (Transverse Magnetic modes). A detailed mode analysis can be found in Long et al.[4]

By using a fork-like microstrip line to feed the aperture slot (see ***Figure 2***), the impedance can be well matched to 50 Ω with a broadband reflection coefficient better than −10 dB over the frequency range from 26 to 30 GHz (see Figure 1). In particular, the antenna element is fitted with a suitable mini-SMP connector, as shown in ***Figure 3***. Notice that the considered DRA element displays a radiation pattern that is mostly confined in the half-sphere above the relevant ground plane.

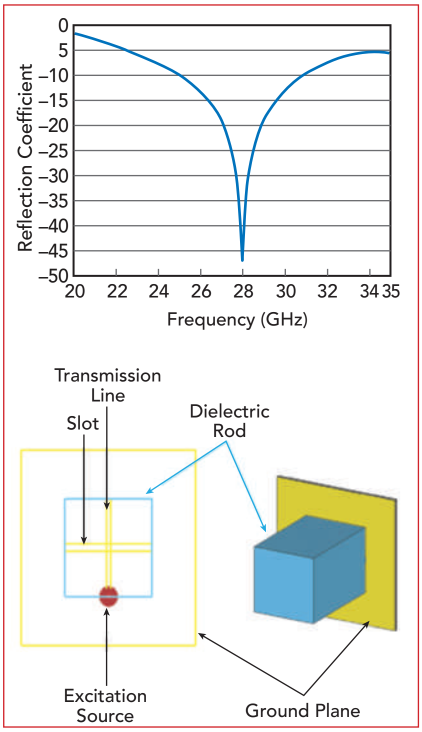
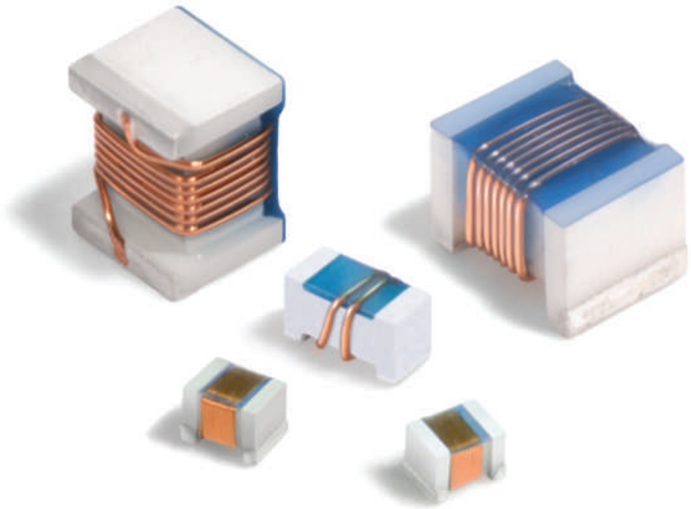


Fig. 1 Magnitude of the input reflection coefficient of the individual DRA element (the illustration shows the configuration of the radiating structure).

Blue Chip Performers



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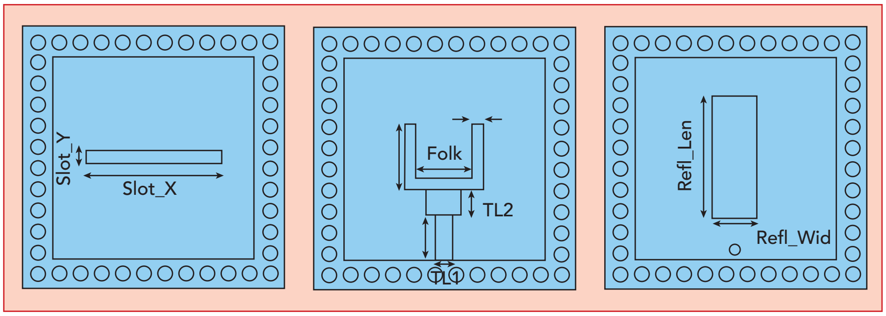

Fig. 2 Antenna element feeding structure.

Antenna Array Scan Properties

The aperture-fed DRA detailed in the previous section is placed in a uniform 64-element array consisting of 8×8 elements, as shown in ***Figure 4***. The inter-element spacing is about half-wavelength at 28 GHz. The objective is to examine the array performance while beam steering over the operational range of frequencies.

For a two-dimensional planar array, the beam steering angle (θ, φ) can be controlled by setting certain phase values at the (m, n)th port according to Equation 1, in which m and n stand for row and column, d_x and d_y stand for the spacing in x- and y- direction, respectively.[9]

$$\phi_{m,n}(\theta,\varphi) = k_0\left[\begin{matrix}\left(m+\frac{1}{2}\right)d_x \sin\theta\cos\varphi + \\ \left(n+\frac{1}{2}\right)d_y \sin\theta\sin\varphi\end{matrix}\right] \quad (1)$$

As shown in ***Figure 5***, the phased DRA array features wideband characteristics. The total radiation efficiency is better than 80 percent over the frequency band between 26 and 34 GHz along the H-plane. Also, the DRA array displays nearly flat efficiency characteristics over a wide scan range. Such high performance is related to the fact the

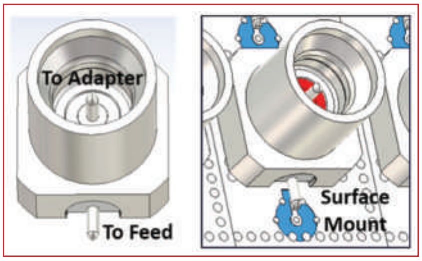

Fig. 3 Integration of mini-SMP connector to the individual DRA element.

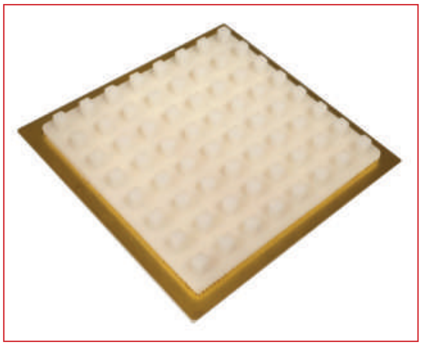

Fig. 4 Three-dimensional view of an 8×8 array of uniformly spaced DRA elements.


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DRA radiating elements are wideband and the electromagnetic field is confined within the relevant dielectric rod. As a result, the inter-element coupling is much smaller as compared to patch array antennas. A comparable patch array antenna with equivalent aperture and inter-element spacing displays a much narrower band performance with a poor efficiency away from the central resonant frequency, as it appears from ***Figure 6***. The patch array elements are fed via slots. The dielectric laminate on which the patch antenna elements are printed is RO4308 with relative permittivity of $\varepsilon_r = 3.6$.

The active reflection coefficient of the array is significantly more complicated to evaluate as it requires the evaluation of the mutual coupling data between the activated array element and the adjacent elements. Based on the derivation in Pozar,[7] for a two-dimensional planar array, the active reflection coefficient Γ can be calculated by Equation 2, where $S_{m,n}$ stands for the mutual coupling coefficient between the m-th and n-th ports. As shown in ***Figure 7***, the broadband characteristics of the proposed DRA array, as compared to the equiva-

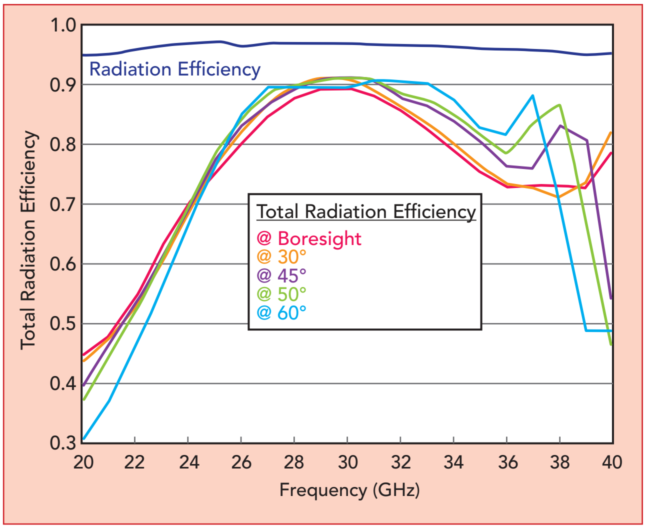


Fig. 5 **Total radiation efficiency of the 8×8 DRA array shown in Figure 4 as a function of scan angles and frequency along the H-plane.**

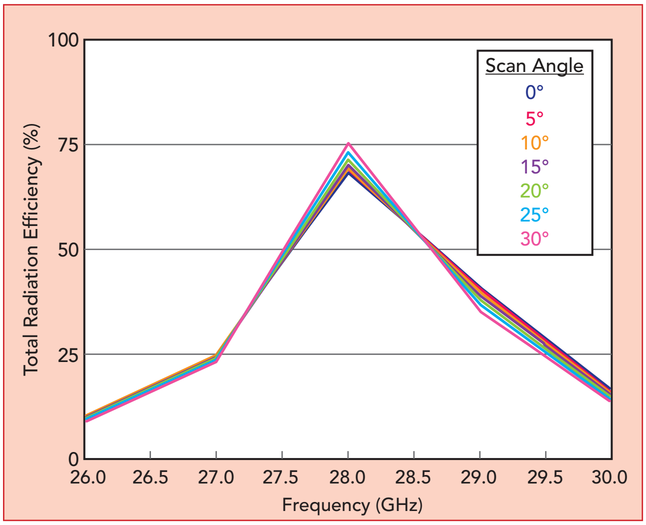
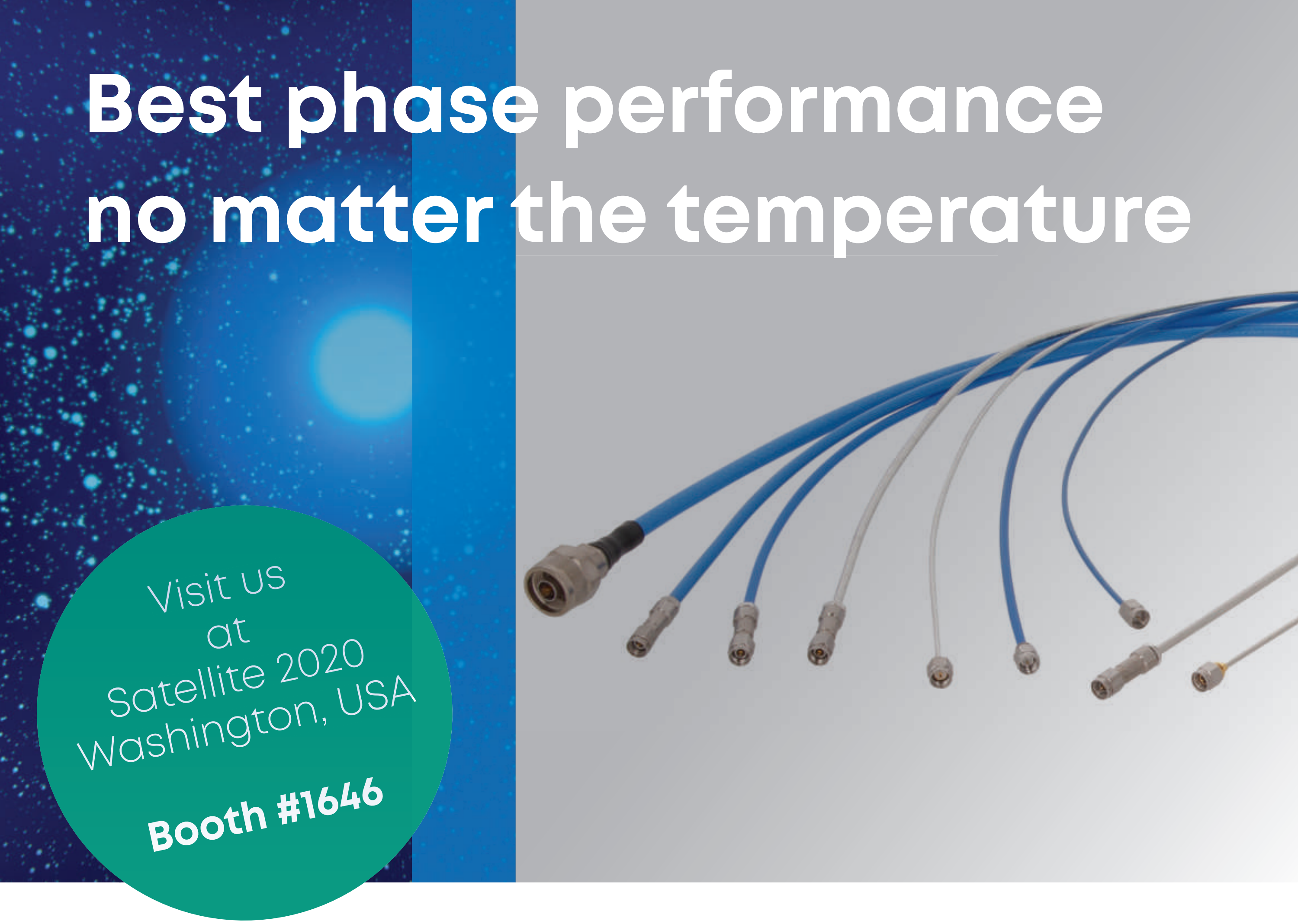


Fig. 6 **Total radiation efficiency of a patch array antenna as a function of frequency and scan angle.**



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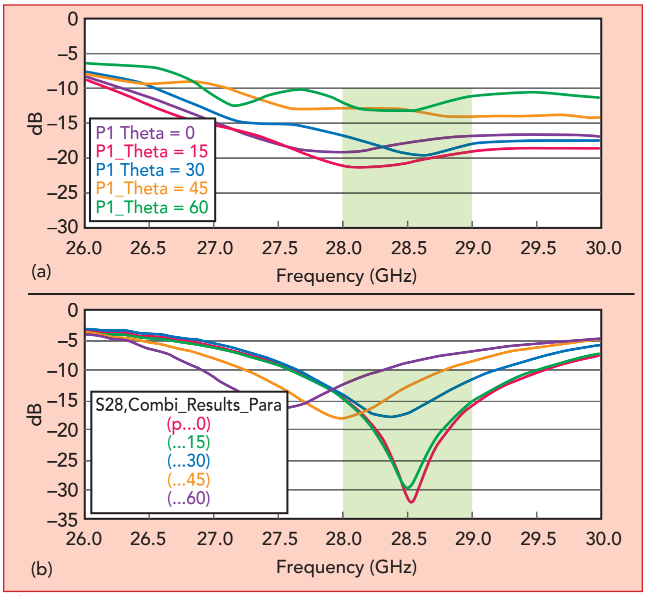

Fig. 7 Frequency-domain behavior of the magnitude of the active input reflection coefficient displayed by an 8×8 array of DRA (a) and patch antennas (b) for $\varphi = 0°$ and $\vartheta = 0°, 15°, 30°, 45°, 60°$.

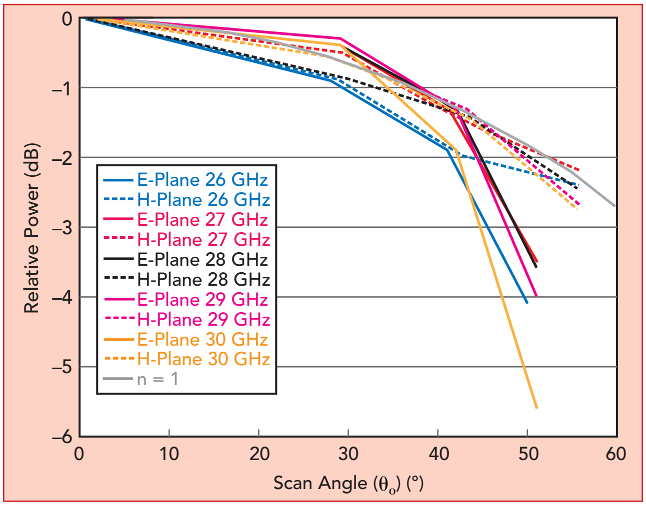

Fig. 8 Beam steering scan loss displayed by the 8×8 DRA array with scan loss evaluated as a function of frequency along the relevant E- and H-planes.

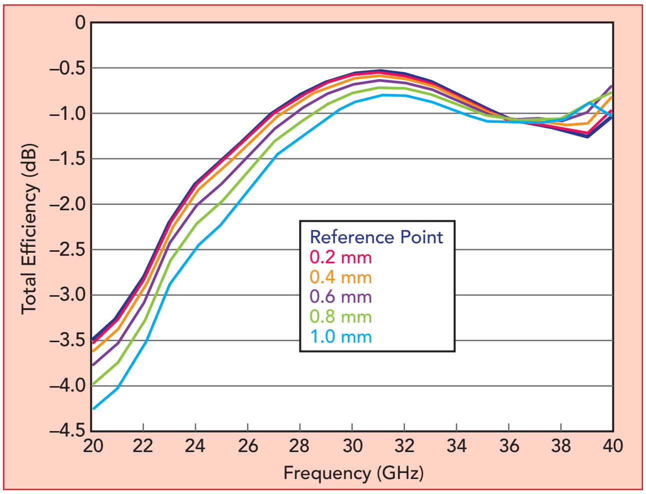

Fig. 9 Total efficiency of the 8×8 DRA array as a function of the misplacement of the radiating structure on the circuit board containing the relevant feeding network.

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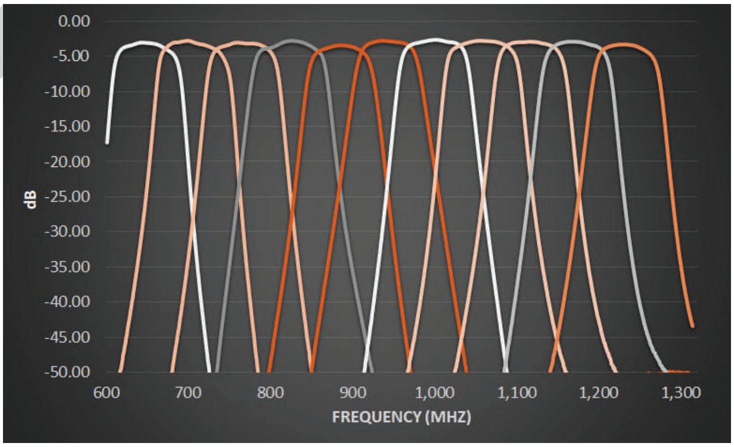

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lent structure based on patch antenna elements, are also validated in active mode, that is while beam scanning. The considered array structures feature equivalent interelement spacing and aperture.

$$\frac{V_{m,n}}{V_{0,0}} = e^{-jk_0\left[md_x \sin\theta\cos\varphi + nd_y \sin\theta\sin\varphi\right]}$$

$$\Gamma = \sum_m \sum_n S_{m,n}\left(\frac{V_{m,n}}{V_{0,0}}\right) \qquad (2)$$

In **Figure 8**, the scan-loss characteristics along both the H- and E-plane are evaluated. From the obtained results, it can be inferred that the scan loss along the H-plane follows the array factor of an ideal cosine source. The performance is just slightly degraded along the E-plane. This difference is mainly due to the asymmetry of the average embedded pattern of the array. On the other hand, a significant advantage is related to the fact that the array performance is stable over a very large frequency band.

As it appears in **Figure 9**, the proposed DRA array displays robust performance also against manufacturing tolerances related to the misalignment or misplacement of the radiating structure on the circuit board containing the relevant feeding network. This is important to ensure reduced sensitivity of the array to non-idealities typically encountered in mass-production assembly lines.

CONCLUSION

The antenna impedance bandwidth can be easily tuned in such a way to synthesize a wide- or multiband frequency response by the combination of DRAs and radiating slots. The proposed DRA array achieves a total radiation efficiency better than 80 percent in the band from 26 to 34 GHz and large scanning angles compared to a conventional half-wavelength spaced patch antenna array. With the advances in material science and manufacturing techniques, DRA technology can become a cost-effective, high performance solution for 5G wireless communications. ■

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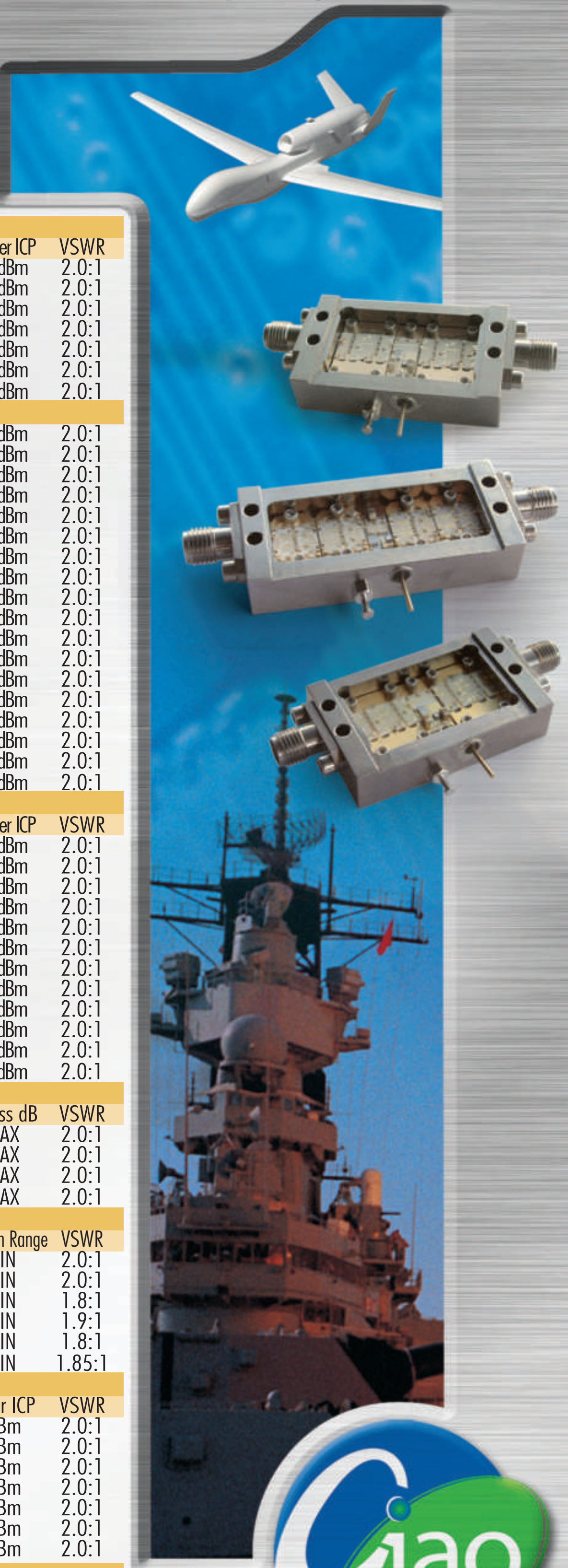

OCTAVE BAND LOW NOISE AMPLIFIERS

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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Air Force, Navy, Army Conduct First 'Real World' Test of ABMS

In the first field test of a novel approach to warfighting, communicating and decision-making, the Air Force, Navy and Army recently used new methods and technology for collecting, analyzing and sharing information in real-time to identify and defeat a simulated cruise missile threat to the U.S.

A three-day long exercise of the Advanced Battle Management System (ABMS) tested technology being developed to enable the military's developing concept called Joint All-Domain Command and Control (JADC2). When fully realized, senior leaders say JADC2 will be the backbone of operations and deterrence, allowing U.S. forces from all services as well as allies to orchestrate military operations across all domains, such as sea, land, air, space and cyber operations. The technology under development via ABMS enables this concept by simultaneously receiving, fusing and acting upon a vast array of data and information from each of these domains—all in an instant. The Air Force expects to receive around $185 million this fiscal year for this effort and intends to bolster these resources over the next five years, underscoring both its importance and potential. This initial exercise focused on defending the homeland. This demonstration was the first of its kind in a series of exercises scheduled to occur roughly every four months. Each new exercise will build on the one before and include responses to problems and lessons learned.

Aircraft from the Air Force and Navy, a Navy destroyer, an Army air defense sensor and firing unit, a special operations unit, as well as commercial space and ground sensors came together to confront—and defeat—a simulated threat to the U.S. homeland. Upon detection of a potential cruise missile threatening the U.S. simulated by QF-16s, the information was relayed in quick succession using new software, communications equipment and a "mesh network" to the USS Thomas Hudner, an Arleigh Burke-class destroyer deployed in the Gulf of Mexico. The same information was passed to a pair of Air Force F-35s and another pair of F-22s. Also receiving the information were commanders at Eglin AFB, a pair of Navy F-35s, an Army unit equipped with a mobile missile launcher known as HIMARS and special forces on the ground.

Events culminated when senior leaders from across the DoD arrived at the test's command and control hub for an ABMS overview and abbreviated exercise. In a well-secured room, they watched real-time data pour in, and out of, the command cell. They observed information from platforms and people flowing instantly and simultaneously across air, land, sea and space that provided shared situational updates as events occurred whether the information originated from jets or passing satellites or from sea and ground forces on the move. Then, the group transitioned to outdoor tents to continue the exercise in a rugged environment.

"Today's demo is our first time demonstrating IoT connectivity across the joint force," Air Force Acquisitions Lead Dr. Will Roper said. "Cloud, mesh networking and software-defined systems were the stars of the show, all developed at commercial internet speeds." He also spoke to the necessity of industry partnership and leveraging their expertise. "Our four-month 'connect-a-thon' cycle unlocks industry's ability to iterate with testers, acquirer and warfighters. For example, the insights from connecting the F-22 and F-35 for the first time will help our industry partners take the next leap," Roper said. The intent is to move much faster than before to conceive, build and test new technologies and strategies despite complexity or technical challenges.

An equally important goal is to demonstrate the real world value of the hard-to-describe effort in tangible, understandable ways. JADC2, previously named multi-domain operations command and control, relies on ABMS to develop software and algorithms so that artificial intelligence and machine learning can compute and connect vast amounts of data from sensors and other sources at a speed and accuracy far beyond what is currently attainable. ABMS also includes hardware updates including radios, antenna and more robust networks that enable unimpeded data flow to operators. Aside from tools and tech, JADC2 also demands a cultural change among service men and women that embraces and responds to multi-faceted battlespaces driven by information shared across the joint force.

The critical difference going forward is to create a failsafe system that gets—and shares—real-time information across multiple spaces and platforms simultaneously, that removes barriers that keep information from personnel and units that need it. For example, once in place, the new command and control ability will allow F-16 and F-35 pilots to see the same information at the same time in the same way along with a submarine commander, a space officer controlling satellites and an Army Special Forces unit on the ground.

IBCS Simultaneously Intercepts Multiple Threats During Flight Test

The U.S. Army and Northrop Grumman Corp. (NGC) recently conducted simultaneous engagement of two incoming target cruise missiles during a flight test using the Army's Integrated Air and Missile Defense (IAMD) Battle Command System (IBCS). Including Sentinel, Patriot and Marine TPS-59 radars and Patriot Advanced Capability-2 (PAC-2) Guidance Enhanced Missile-TBM (GEM-T) interceptors, the test demonstrated successful interoperability and the

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end-to-end performance of the IBCS system to detect, track and simultaneously engage multiple threats.

The test was conducted at White Sands Missile Range, N.M. by a test detachment of soldiers from the 30th Brigade 3rd Battalion 6th Air Defense Artillery Regiment who manned the workstations and executed the engagement plan presented by IBCS. The friendly forces defense laydown consisted of a battalion, two battery IBCS engagement operations centers, a Patriot radar, two Sentinel radars and two PAC-2 launchers. Also contributing to the test were a U.S. Marine Corps AN/TPS-59 joint radar connected to an external Link 16 network and F-35 fighter aircraft with sensors adapted to IBCS. All these systems were connected to the IBCS Integrated Fire Control Network (IFCN).

Designed to emulate potential real world events, the flight test began when two cruise missile surrogate threats were launched. The cruise missiles flew in a maneuvering formation until they neared their targets, and then split off to attack two separate defended assets. IBCS fused data from the various participating sensors and external networks into accurate composite tracks of both threats. Then it developed the engagement plan employed by the soldiers to successfully launch two PAC-2 missiles and intercept both cruise missile targets.

"Today's successful flight test further demonstrates the maturity of the IBCS and its capabilities in support of multi-domain operations," said Maj. Gen. Rob Rasch, Army Program executive officer, Missiles and Space. "The inclusion of Marine Corps and Air Force sensor systems in the test architecture validate the system's open architecture and the potential for IBCS to operate seamlessly with joint services, as well as foreign partners in the future, to extend battlespace and defeat complex threats."

"IBCS is the Army's #1 air and missile defense priority and will fundamentally change our air and missile defense force and capability, maximizing the combination of sensors and shooters in a completely different way than ever before," said Brig. Gen. Brian Gibson, Army Futures Command and director of the Air and Missile Defense Cross Functional Team. "Successful execution of this mission-critical test validates that IBCS is well prepared for the upcoming limited user test in Q2 2020."

IBCS is the cornerstone of the Army's IAMD modernization program. Designed to connect the force for unified action against evolving threats, IBCS is a net-centric command and control system for the air and missile defense mission. IBCS enhances battlefield survivability by creating a resilient self-healing network of all available sensors that can reduce and eliminate vectors of attack while providing operators with a single integrated air picture of unprecedented accuracy and expanded area of protection.

2020 Will See Cities Develop Advanced Urban Strategies

Already in 2019, cities had developed deeper insights into high-priority challenges and approaches to address those. According to ABI Research, many have started to develop a narrative centered around five holistic focus areas: digital twins and urban modeling, resilience, circularity, electric micro-mobility and micro-transit and smart urban spaces. "In 2020, these concepts will be integrated into a comprehensive urban agenda and strategy, defining the character of smart cities of the future. But they also help address short-term challenges. The adoption of micro-mobility in the form of electric bike, scooter and motorcycle sharing significantly reduces both air pollution and traffic congestion, arguably the two biggest issues cities are grappling with today," says Dominique Bonte, Smart Cities & Smart Spaces VP.

This represents a short-term solution awaiting widespread adoption of electric driverless vehicle sharing by 2030. It does, however, prompt city governments to reorganize public space to accommodate these new smart mobility modes. The wider safety and sustainability questions are starting to be approached in a more structural and fundamental way, respectively focused on resilience (readiness and responsiveness) and an approach based on circular economy concepts (resource self-sufficiency and recycling maximization). "Finally, the digital twin and wider urban modeling concepts will provide a fertile environment for the mass adoption of basic IoT connectivity technologies, informing and enhancing static 3D models to become real-time replicas of the cities' physical assets, in turn, enabling further efficiency and resource utilization improvements, scenario analysis, generative design and preventive and real-time maintenance," Bonte adds.

"Translating these high-level paradigms into practical technology implementations, however, will continue to elude all but the most advanced cities, such as Singapore and Dubai. Issues include technology life cycle uncertainty—if or when to adopt new technologies like 5G, LPWA, AI, blockchain and driverless mobility—anticipating upgrade cycles, repurposing systems across multiple verticals and use cases and learning how to efficiently implement open IoT platforms," Bonte explains.

At the same time, the wider ecosystem dynamics toward which smart cities and the overall government technology sector are gravitating are increasingly defined by technology marketplaces (Geotab), open data sharing platforms (Transport for London, HERE's Open Location Platform), vendor accelerator programs (Qualcomm), public-private partnerships (SharedStreets), sharing economy leverage and a long tail of smart city technology startups and system integrators. This represents a major challenge for cities in terms of aligning internal organizational structures to enable efficient participation in this new market constellation.

Against a background of a continuing challenging economic climate, cities will put more emphasis on ROI or, at the very least, will want to optimize where their investments are going. This will require vendors to provide detailed information on what their solutions can achieve in terms of cost savings and tangible benefits for citizens and enterprises alike through both general awareness building and quantitative tools. More concretely, vendors will have to tailor their business models toward CAPEX-free "as-a-Service" offers, while at the same time providing financing support, either directly through their own financing or venture capital divisions or indirectly, helping discover new funding mechanisms and opportunities.

2020: The Year of Cooperative Mobility

Driving is a multi-agent problem, with many of today's accidents and inefficiencies due to poor communication and coordination between the various road users. The year 2020 will see the advent of more cooperative forms of mobility, with 107 million connected cars on the road starting to share data messages about road and traffic conditions to allow other connected vehicles to anticipate hazards and improve traffic flow," says Maite Bezerra, Smart Mobility & Automotive analyst.

The first phase will take the form of low-bandwidth, high-latency communication via the LTE network between connected cars and data ingestion platforms to enable applications like ice and oil hazard warnings and lane-level traffic assistance.

It will also see the first large-scale deployment of 802.11p V2X technology on the Volkswagen Golf in Europe, a model that typically ships in volumes of 450,000+ every year. This will enable low-bandwidth and low-latency broadcast communications between a growing number of connected cars to enable safety-critical collision avoidance.

"At one point, 2020 seemed a distant target, a long-term horizon over which the technology trends that have dominated the automotive scene for the last 10 years—electrification, connectivity, autonomous driving—would all have harmonized to deliver safer, more efficient transportation for all. It's not going to happen in 2020, or much before 2025," according to James Hodgson, Smart Mobility & Automotive principal analyst.

The world goes into 2020 with road accident casualties increasing, OEM spending on autonomous technologies contracting, connectivity enabling the same legacy infotainment applications and ride-hailing operations facing serious questions over profitability. The overall Connected, Autonomous, Shared and Electric

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(CASE) vision remains compelling, and most OEMs are targeting 2025 or 2030 for the transition to connected, autonomous and electrified mobility.

GSA Identifies 23 Countries Setting the Pace for 5G C-Band Spectrum Auctions

The Global mobile Suppliers Association (GSA) identified 23 countries that have auctioned or allocated C-Band spectrum for mobile broadband. C-Band refers to spectrum in the 3300 to 4200 MHz frequency range offering an optimal balance between coverage and capacity. 5G applications suited to C-Band spectrum support include AR/VR, ultra-high definition (UHD) video, smart home, smart manufacturing, health care and drones. The 3300 to 4200 MHz band will also provide both mobile connectivity "on the go" and FWA for domestic and business applications.

The prices paid for the C-Band spectrum have varied widely, with the amount operators are prepared to spend in each market being influenced factors such as competition, spectrum licensing terms, existing spectrum holdings and the amount spent by mobile customers in the country concerned.

The first 23 countries to auction or allocate C-Band spectrum for 5G include Australia, Austria, Czechia, Finland, Germany, Hong Kong, Hungary, Ireland, Italy, Latvia, Norway, Romania, Slovakia, South Korea, Spain and the U.K.

"C-Band spectrum has historically been made available around the world for fixed wireless services using legacy technologies, or has been allocated for satellite or government/military use," commented Joe Barrett, president, GSA. "While a few countries have made portions of C-Band spectrum available for LTE, with the advent of 5G, access to C-Band spectrum is being opened up to support mobile broadband services, often specifically including 5G."

The GSA 5G Spectrum Auction Tracker is a new information database and is available to all GSA members. Coming in Q1 2020, it will be integrated into the GSA Analyser for Mobile Broadband Devices (GAMBoD) database, which is a unique search and analysis tool to enable searches of LTE and 5G devices and new global data on Mobile Broadband Networks, Technologies and Spectrum (NTS). The new 5G Spectrum Auction Tracker database contains details about spectrum auction and allocation trends, including data about the prices of spectrum sold at auction or allocated to operators through administrative proceedings.

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IN MEMORIAM

▲ *Mojgan Daneshmand*

Mojgan Daneshmand and **Pedram Mousavi**, professors at the University of Alberta, along with their daughters Daria and Dorina, were among those killed when a Ukrainian passenger jet crashed early on Wednesday, January 8. All 167 passengers and nine crew members were killed when the plane, which was destined for Kyiv, crashed shortly after takeoff from Tehran. Daneshmand and Mousavi were award-winning professors who worked in wireless communication technology. The pair were travelling home with their two daughters Daria, 14, and Dorina, 9. Daneshmand was an electrical engineering professor and Canada Research Chair holder, and won a prestigious international award for her exceptional research and for establishing herself as a role model in engineering from the IEEE in 2016. She held the Canada Research Chair in Radio Frequency Microsystems for Communication and Sensing and won the IEEE Lot Shafai Mid-Career Distinguished Achievement Award. The honor recognizes her pioneering contribution to microwave and mmWave technologies and being a role model for women in engineering. Daneshmand and her colleagues in the Department of Electrical and Computer Engineering were first to establish modern microwave characterization labs at the University of Alberta.

MERGERS & ACQUISITIONS

Altair has acquired **newFASANT**, a software company based in Spain. newFASANT's products address a range of electromagnetic problems, supporting antenna design and placement, radar cross section analysis, automotive applications (V2V and ADAS) and infrared/thermal signatures. Originally a spin-off from the University of Alcalá, near Madrid, newFASANT's portfolio contains full-wave and high frequency asymptotic electromagnetic solvers. Combining newFASANT's portfolio with Altair Feko™ will strengthen Altair's competitive position and the solutions it offers for IoT, cellular networks, mobile phones and other connected devices, V2V and radar.

Abracon has announced the successful acquisition of **ILSI America**, a privately held market leader of frequency control devices, and its subsidiaries. Abracon will continue supporting ILSI America and its ILSI, MMD, Ecliptek and Oscilent brands for new and existing customers. The ILSI America product portfolio complements Abracon's existing product offerings and provides Abracon's global customer base with a broader range of solutions.

COLLABORATIONS

Keysight Technologies Inc. announced an extended collaboration with **AAC Technologies (AAC)** to accelerate validation of new antenna designs for 5G new radio (NR) devices. Keysight's 5G solutions help accelerate the market introduction of high performance 5G products in nearly any form factor. AAC, a provider of solutions found in smartphones and portable electronic devices across the world, cooperates closely with partners to create differentiated and innovative products in both global and localized markets.

Septentrio has collaborated with **Analog Devices Inc. (ADI)** to provide customers with easy access to optimized integrated GNSS inertial solutions. The two companies are combining ADI's high-quality Inertial Measurement Units (IMU) with Septentrio's multi-frequency, multi-constellation GNSS receivers. The resulting high performance GNSS/INS systems deliver centimeter-level accurate positioning together with 3D orientation (heading, pitch and roll), ideal for applications such as automotive ADAS and industrial automation. Septentrio's GNSS technology provides a unique combination of accuracy and robustness which is aligned well with the capabilities of ADI's sensors.

Plastimo and **Sigfox** have joined to provide total geolocation search and rescue capability across all oceans, beginning in 2020. The new service will be supported by data from the ELO nanosatellite constellation operated by Eutelsat, Sigfox's partner. The first two nanosatellites will be operational in 2020. Plastimo, with more than 50 years expertise designing and manufacturing safety equipment for the boating market, was seeking an innovative solution to quickly and reliably locate seafarers in the ocean. It turned to Sigfox's 0G network to improve and broaden the application of the digital technologies integrated into its safety equipment.

Oculii and **Infineon** have collaborated on radar software solutions that scale performance for cost-effective single-chip solutions tailored for Level 1 ADAS, all the way to multi-chip high performance solutions for Level 4 Autonomous Driving. Oculii's patented Virtual Aperture Imaging Software Technology significantly increases the angular resolution of a radar phased array—dramatically improving the safety, reliability and efficiency of autonomous vehicles in a cost-effective way. This partnership will enable automotive OEMs and Tier-1 customers to leverage Infineon's best in class chipset containing AURIX™ MCUs, MMIC and power supply hardware platform along with Oculii's Virtual Aperture Imaging software to deliver high-resolution performance at an attractive price point.

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Around the **Circuit**

Amazon, **Apple**, **Google** and the **Zigbee Alliance** have announced a new working group that plans to develop and promote the adoption of a new, royalty-free connectivity standard to increase compatibility among smart home products, with security as a fundamental design tenet. Zigbee Alliance board member companies such as IKEA, Legrand, NXP Semiconductors, Resideo, Samsung SmartThings, Schneider Electric, Signify (formerly Philips Lighting), Silicon Labs, Somfy and Wulian are also on board to join the working group and contribute to the project. The goal of the Connected Home over IP project is to simplify development for manufacturers and increase compatibility for consumers.

ACHIEVEMENTS

Qualcomm Technologies Inc., a subsidiary of Qualcomm Inc., and **ZTE Corp.** together achieved a 5G-enabled Voice over New Radio (VoNR) call. The call was performed in compliance with 3GPP Release 15 specifications over the 2.5 GHz spectrum band (n41) by utilizing a ZTE's 5G NR base station and a 5G smartphone form factor test device powered by a Qualcomm® Snapdragon™ 5G Modem-RF System. Voice services are a fundamental offering for mobile operators, and when performed using a 5G network, it is called VoNR.

The first laparoscopy to be performed in Russia with the use of 5G technology was recently undertaken in the 5G pilot zone located in Skolkovo. Telecommunications company **Beeline**, with **Huawei** and **GMS Hospital** partnered together to complete two such surgical procedures. The 5G pilot zone was rolled out in the operational block of the innovation center at Skolkovo, with the support of the Moscow Department of Information Technologies. Thanks to the work of all those involved, a cancer tumor was successfully removed with the use of a laparoscope and 4K camera connected to the 5G network, an anesthesiology console, several additional cameras and the Huawei 5G multimedia white board.

Advantech Wireless Technologies Inc. has received over $2 million in orders of its Engage™ Class 1.2 and 2.4 m FlyAway SATCOM Terminal from a NATO member country. The Engage™ Class Flyaway Terminal Solution includes the most advanced SATCOM technology. This flexible and transportable satellite terminal is a fully integrated tri-band system designed for strategic applications, easy deployment and operation under harsh environmental conditions. The terminal is based on high efficiency, ruggedized tri-band ready 1.2 and 2.4 m Flyaway Antennas which can cover X-, Ku- or Ka-Band by replacing the feed only. The antenna is fully motorized with an integrated satellite finding controller.

CONTRACTS

The **U.S. Air Force** has awarded the Common Computing Environment (Cloud One) contract to **Science Appli-**

cations International Corp. (SAIC). The $727 million contract is for application modernization for the DoD. SAIC will migrate approximately 800 Air Force and U.S. Army mission applications into the cloud. The contract consists of firm fixed price, labor hour and cost reimbursement elements with a nine-month period of performance and four one-year options. Though awarded by the Air Force, the contract will also serve Army applications, as part of the Army's cloud strategic framework. SAIC's solution leverages proven success and capabilities in cloud, IT modernization, software, cyber and data analytics.

Raytheon will build two additional shipsets of SPY-6 radars under a $250 million contract for the **U.S. Navy**. The SPY-6 is a family of next-generation, integrated air and missile defense radars that scale to meet mission requirements of any ship. The company is now contracted to deliver a total of nine radar shipsets to DDG-51 Flight III destroyers. SPY-6 delivers significantly enhanced range and sensitivity (compared to legacy sensors), and gives geographically dispersed ships the ability to share and act on sensor data in ways never before possible. This radar gives the Navy unprecedented operational flexibility to defend against ballistic and cruise missiles as well as advanced surface and air threats.

BAE Systems has received a $175 million contract from the **U.S. Navy** to modernize the guided-missile cruiser USS Vicksburg (CG 69). The Vicksburg will undergo approximately 18 months of work at the company's shipyard in Norfolk, Va., the ship's homeport. The modernization period (MODPRD) contract includes options that, if exercised, would bring the cumulative value to $175.1 million. BAE Systems initiated the first phase of Vicksburg's modernization program in May 2017.

Comtech Telecommunications Corp. announced that during its second quarter of fiscal 2020, its Orlando-based subsidiary, **Comtech Systems Inc.**, which is part of Comtech's Government Solutions segment, was awarded a 10-year, $211 million IDIQ contract by the Cubic Mission Solutions business division of **Cubic Corp.** to provide next-generation troposcatter systems in support of the U.S. Marine Corps. In connection with this contract award, Comtech received an initial $13.4 million order to supply next-generation terminals to Cubic. Delivery of the first units will support test and evaluation for the U.S. Marine Corps.

L3Harris Technologies has received a $50 million follow-on delivery order for Falcon III AN/PRC-160 HF radios and related equipment from the **U.S. Marine Corps** as part of its High Frequency Radio II modernization program. The order is part of the Navy Portable Radio Program five-year IDIQ contract received in 2017. The Marine Corps selected the AN/PRC-160 to replace legacy L3Harris HF radios. The AN/PRC-160 is a modern solution for beyond-line-of-sight communications in

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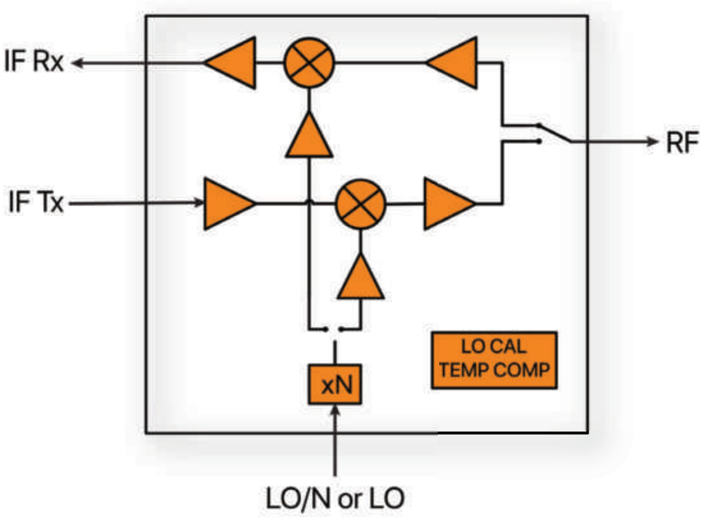

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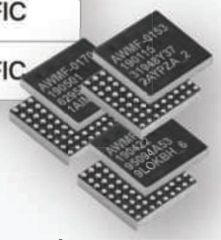

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Elbit Systems Ltd. announced that it was awarded an initial contract from the **Production and Procurement Directorate of the Israeli Ministry of Defense (IMOD)** valued at approximately $31 million (NIS 109 million), to provide Iron Fist Active Protection Systems (APS) for the Eitan Armored Fighting Vehicles (AFV) of the Israeli Defense Forces (IDF). The contract will be performed over a five-year period. Under the contract Elbit Systems will equip the IDF's new wheeled AFVs with the Iron Fist Light Decoupled (IFLD) systems. The Iron Fist system uses optical sensors, tracking radar, launchers and countermeasure munitions to defeat threats at a safe distance.

Kratos Defense & Security Solutions Inc. announced that it has received an approximate $24 million single award contract for microwave electronics products in support of missile system programs. This contract award is the initial production award for what is expected to be long term, multi-year missile system platforms. Kratos is a leading provider of microwave electronic products in support of missile, radar, guided munitions, EW, communication and other programs and systems.

Robotic Research LLC announced receipt of a $16.5 million order for its warfighter localization sensor units, also known as WarLoc®, for the **U.S. Army Product Manager Sets, Kits Outfits and Tools (PM SKOT)** to support forward-deployed U.S. military personnel. Robotic Research will deliver WarLoc units to equip four deployed U.S. Army Brigade Combat Teams in various locations. The first batch of systems has already been shipped. WarLoc provides superior localization and positioning data for teams of warfighters or first responders in GPS-denied environments, including underground facilities and inside buildings and mega-cities.

PEOPLE

▲ *Jim Cable*

pSemi Corp., a Murata co., has announced the retirement of former CEO and esteemed executive **Jim Cable**. After more than 20 years with the company, Cable has retired from his position as chairman and CTO of pSemi and as a global semiconductor R&D director for parent company Murata Manufacturing. Cable joined pSemi (formerly Peregrine Semiconductor) in October 1996 and held positions as COO and VP of technology and engineering before becoming CEO in 2002. From 2002 to 2017, he served as CEO, leading the team through explosive growth,

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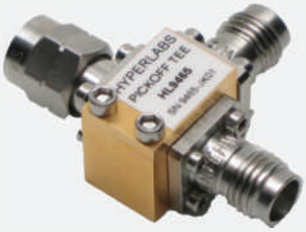

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REP APPOINTMENTS

Modelithics has appointed the **Nearson Marketing Group** to support and sell its Modelithics' high frequency simulation model libraries and precision RF, microwave and mmWave measurement and modeling services in Taiwan. Nearson Marketing Group is an electromagnetic simulation technology consulting company based in Taiwan with customers across various industries as well as academia. The addition of Nearson Marketing Group as a new Modelithics sales representative provides Modelithics customers and potential customers in Taiwan with a local contact for information regarding Modelithics' products and capabilities. In addition, Nearson Marketing Group will now be able to support its customers with RF and microwave simulation models and measurement services, complementing the company's line of electromagnetic simulation tools and related products.

Richardson RFPD, an Arrow Electronics co., announced that it has entered into a global franchise agreement with **ERZIA Technologies S.L.** Headquartered in Santander, Spain, ERZIA is a leading specialist in the design and manufacture of solid-state amplifiers using the latest technologies available to provide rugged and high-reliability solutions for a range of applications, including communications, test & measurement, radar and EW. The agreement covers ERZIA's commercial off-the-shelf products, including high-power/driver amplifier (HPA) modules and low noise amplifier (LNA) modules. ERZIA's broad product offering covers DC to 100 GHz, with connectorized and wave guide interfaces. All of ERZIA's COTS products are ITAR-free designs and offer a high degree of customization.

PLACES

Smiths Interconnect has opened a qualification and test laboratory at its site in Dundee, Scotland. The lab will provide complete qualification testing for Smiths Interconnect products in Europe. The Dundee facility can replicate deep space vacuum and heat with high-power amplifiers and vacuum systems. This capability supports analyzing high-power devices planned for space applications, such as device breakdown voltage behavior in a vacuum or near-vacuum environment. This effect, called multipaction, can render a device useless and degrade the reliability of a satellite.

INVITED PAPER

Frequency Scalable Power Control and Active Tuning for Sub-THz Large-Signal Measurements

Luca Galatro and Raffaele Romano
Vertigo Technologies, The Netherlands

Carmine De Martino and Marco Spirito
Technische Universiteit Delft, The Netherlands

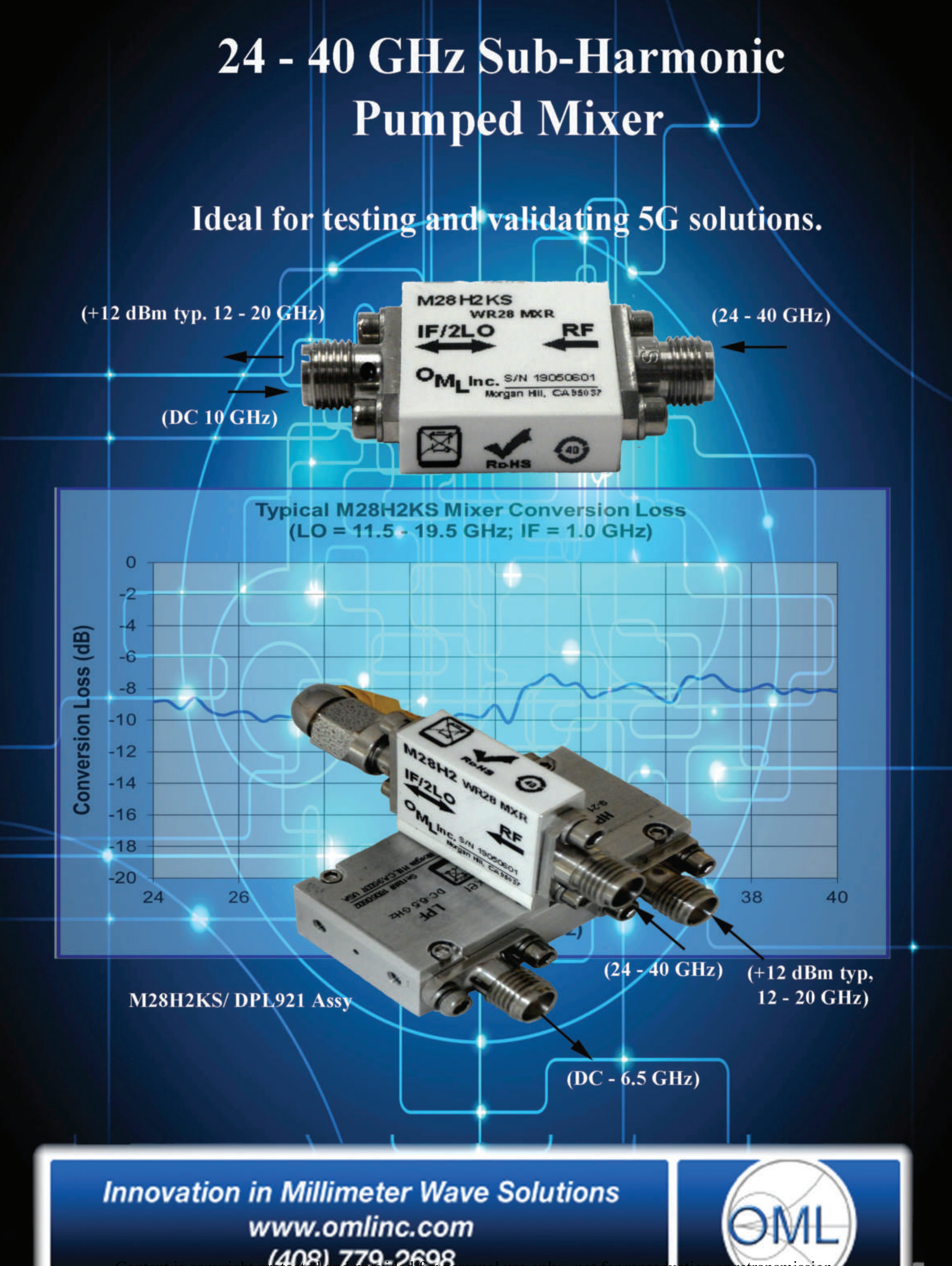
Characterizing electronic devices and MMICs at sub-THz frequencies presents several challenges for the instrumentation. While S-parameter measurements can be performed using vector network analyzers (VNA) with mmWave extenders, large-signal measurements require dedicated measurement setups. A novel approach, described here, expands the capabilities of conventional VNA sub-THz S-parameter setups to achieve refined power control, power sweeps and active load-pull.

The increasing performance of semiconductor technologies in terms of f_t and f_{max} is fostering the development of new commercial applications in the mmWave frequency range. Examples can be found in the development of 5G communication with frequencies up to 80 GHz, automotive radar at 77, 94 and 140 GHz, SATCOM, imaging and home entertainment.

Development for commercial applications inevitably includes characterization of single active devices (i.e., transistors) as well as the testing of ICs such as power amplifiers, detectors and radiometers. The first is to extract and verify the device compact model for frequencies as high as f_t or f_{max}. The latter is to verify IC compliance with the requirements of the final application. Regardless of the scope, the availability of accurate and reliable test instrumentation is fundamental for technology development.

Active device small- and large-signal characteristics must be determined. The first step is typically the measurement of the S-parameters, which can be achieved using VNAs. Broadband VNAs with coaxial extenders are commercially available up to 220 GHz, while waveguide-banded solutions are available up to 1.5 THz. Limitations of these setups are primarily related to available power, losses in interconnections with increasing frequency (especially for broadband coaxial setups) and the difficulty of controlling power delivered to the device under test (DUT) when waveguide-banded extender modules are used.

For large-signal measurements, one of the most popular techniques is load-pull. Passive tuners are available commercially for frequencies as high as 110 GHz,[1] but performance is generally limited by increased losses at mmWave frequencies, which limits the reflection coefficient that can be presented to the DUT load. Commercial active load-pull systems are currently only available for frequencies lower than 40 GHz.[2] Few examples of active load-pull systems exist in the literature at higher frequencies,[3-4] and they are all based on dedicated implementations that are generally not scalable.



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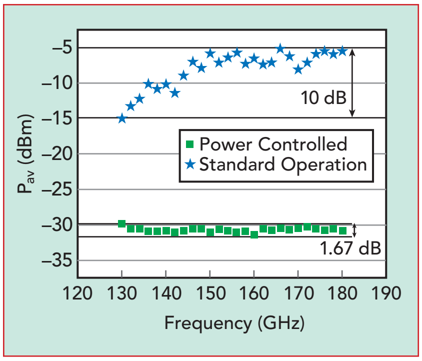

Fig. 1 Output power of a commercial WR5 waveguide extender module showing the nominal output power and a constant –30 dBm set with MMW-STUDIO.

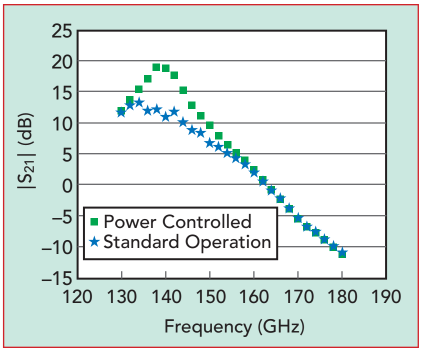

Fig. 2 Measured gain vs. frequency of a two-stage, 130 nm SiGe BiCMOS amplifier using waveguide extenders, comparing nominal power from the extender to power control.

This article describes a measurement approach employing a conventional mmWave VNA with waveguide-banded extenders that has refined power control and power sweep capabilities at any frequency bandwidth covered by the waveguide extenders. With small modifications, the setup can be enhanced to include active tuning capabilities, becoming the first scalable active load-pull setup for sub-THz frequencies.

POWER CONTROL LIMITATIONS

For conventional VNA measurements, dynamic range is maximized through power control, which is achieved with the hardware using a feedback architecture called automatic level control (ALC). When mmWave waveguide extenders are used, ALC is implicitly excluded from the measurement loop. Due to the absence of an ALC within the extenders and the nonlinear nature of the internal components, the power available from the source can vary significantly within the waveguide band. An example is shown in ***Figure 1***, where the output power (P_{av}) of a commercially available WR-05 VNA extender is displayed, with a nominal fixed power at the RF input port of the module. In the figure, the power fluctuation is on the order of 10 dB. Similar values can be expected at all bandwidths, depending on the manufacturer.

This lack of power control to the DUT has different implications on the measurement accuracy of active devices. When performing small-signal measurements, if the power level at the input of the DUT fluctuates and cannot be properly controlled, the risk is to either drive the device into an incorrect operating regime—compromising the small-signal characterization—or to reduce the input power level to ensure proper operation and restrict the dynamic range of the measurement.

An example related to reduced power control capability is illustrated by De Martino et al.[5] in the characterization of a 140 GHz power amplifier. When the DUT, a two-stage 130 nm SiGe BiCMOS amplifier, is characterized using waveguide extenders with a nominal output power, the S-parameters are incorrectly represented in the frequency range between 135 and 160 GHz (see ***Figure 2***).

COMPUTER-AIDED POWER CONTROL AND SWEEPS

The absence of ALC when using mmWave waveguide extenders can be circumvented using a dedicated software control loop. Consider the simplified schematic of a conventional VNA setup for mmWave measurements employing extenders, shown in ***Figure 3a***, with the addition of an external computer and a power sensor for power calibration. As described by Galatro et al.,[6] power control can be achieved with the following steps (see ***Figure 3b***):

1. S-parameter calibration at the waveguide reference planes.
2. Power calibration by connecting a power sensor to waveguide port 1 and measuring the absolute power during a frequency sweep.
3. Power leveling: nonlinear power responses of the extender modules are characterized over large

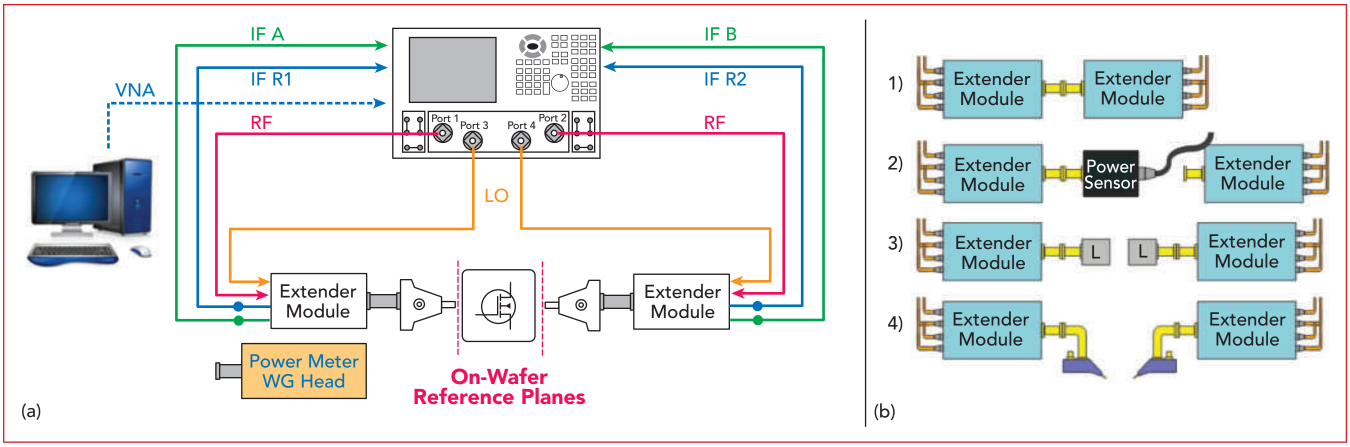

Fig. 3 **Conventional mmWave measurement using waveguide extenders with a 4-port, two-source VNA (a) and the four-step calibration procedure (b).**

sweeps of input power and frequency while measuring the power delivered at the waveguide test port directly using the VNA receivers. This uses the power calibration performed in Step 2.

4. On-wafer calibration shifts all the calibration reference planes (S-parameter, power and leveling) to the desired on-wafer reference plane.

After this four-step procedure, it is possible to accurately control and measure the power provided to the DUT using the high dynamic range and speed of commercial VNAs, as the use of slower and low dynamic range power meters is limited to the power calibration in Step 2.

IMPACT OF POWER CONTROL

The capability of controlling power during S-parameter measurements alleviates measurement inaccuracies related to improper device driving. For example, the device described by De Martino was tested using the power control procedure described above and embedded in MMW-STUDIO, a software platform developed by Vertigo Technologies and TU Delft for accurate sub-THz measurements. In this case, the power is maintained at −30 dBm over the entire frequency range (see Figure 1) to ensure small-signal operation. This ensures correct measurement of the S-parameters as shown in Figure 2, where S_{21} is accurately characterized over the entire bandwidth.

The four-step procedure described enables doing more than just controlling power during S-parameter measurements. The capability of controlling and measuring power can also be used to perform power sweeps to derive large-signal characteristics such as gain compression. ***Figure 4*** shows measurement results for power sweeps at different frequencies of the PA described above. Note that the measurement of approximately 250 data points took only about 4.5 minutes, compared to 2 hours to properly perform all the measurements using a power meter setup.

SUB-THz ACTIVE LOAD-PULL

As shown in the previous section, using a four-step calibration and the aid of external computation enables large-signal measurements at mmWave frequencies by employing off-the-shelf equipment designed for small-signal measurements, i.e., the same equipment commonly used

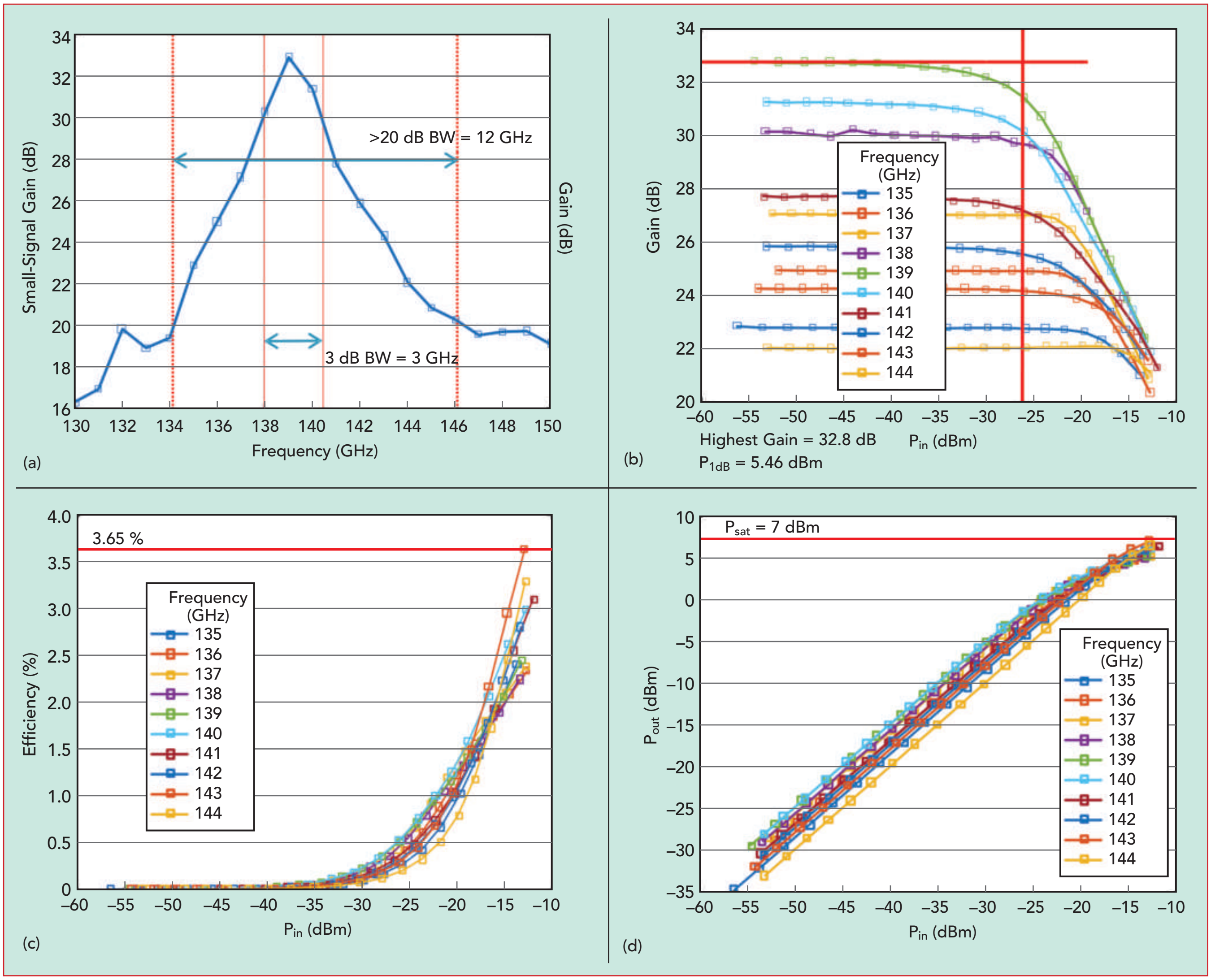

Fig. 4 Measured performance of a two-stage, 130 nm SiGe BiCMOS amplifier, showing the small-signal gain vs. frequency (a), gain vs. P_{in} (b), efficiency vs. P_{in} (c) and P_{out} vs. P_{in} (d).


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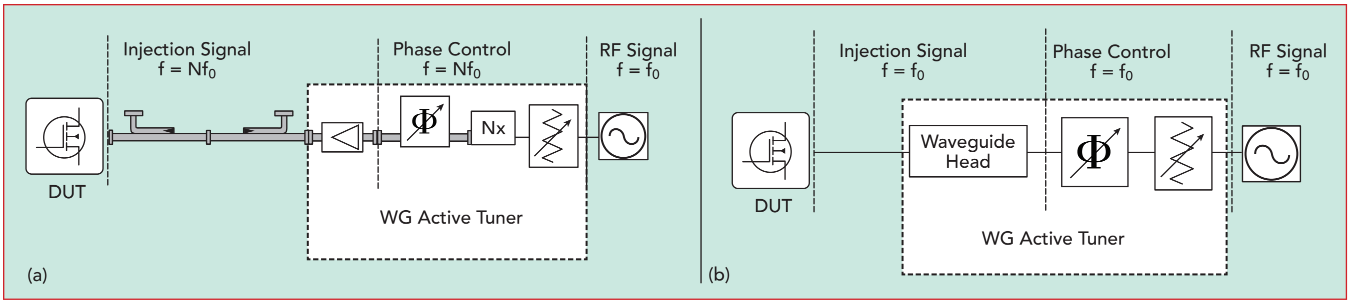
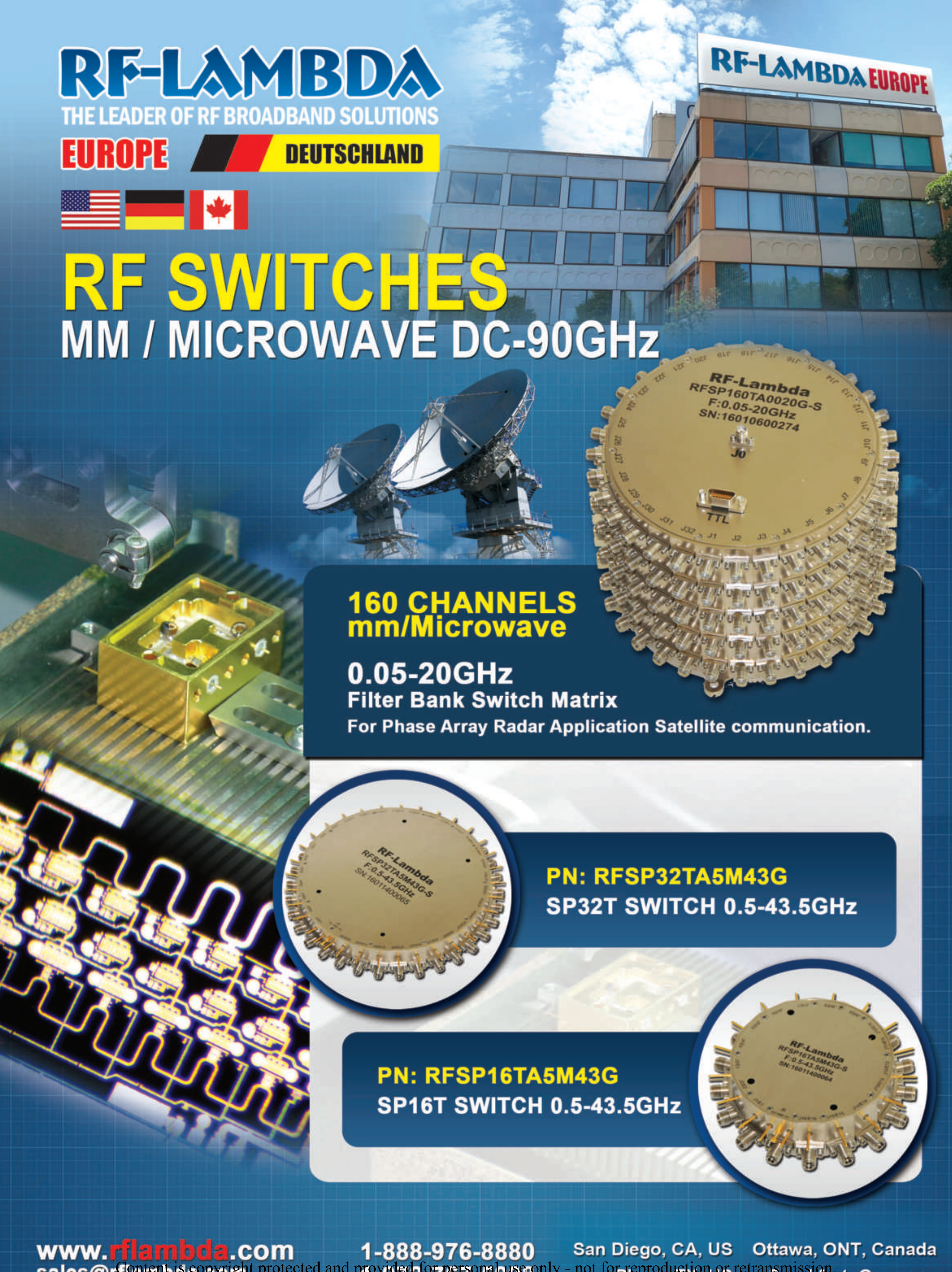


Fig. 5 Two active tuner implementations: modulating the injected signal after (a) and before frequency multiplication (b).

for simple, non-power controlled, S-parameter measurements. The large-signal capabilities of the setup, however, are limited, and only matched measurements can be performed, since the load or source impedance presented to the DUT cannot be changed with respect to the system intrinsic impedance.

To perform more advanced measurements (i.e., active load-pull), the hardware setup needs improvement. The realization of an active load-pull setup requires an active tuner, which changes the impedance condition by properly injecting a defined signal, controllable both in phase and amplitude, into the DUT terminal. Considering the system previously described, while it is possible to modulate the power injected into the DUT, no phase control is available.

To incorporate phase control, a programmable phase shifter must be inserted into the signal injection path. The intuitive solution is to place the phase shifter just before the reflectometer, enabling phase modulation directly on the frequency-multiplied signal (see ***Figure 5a***). This implies modification of the mmWave extender by employing a mmWave phase modulator. While suitable from a measurement perspective, the high cost of such a component with the complexity of a hardware modification inside a mmWave extender makes this solution unrealistic. If, however, the phase shifter is placed before the mmWave extender (see ***Figure 5b***), phase modulation is performed on the RF signal before frequency multiplication, thus at a lower frequency with respect to the measurement. This allows more flexibility and a lower cost, since lower frequency components are used for the phase shifter and the waveguide extender need not be modified.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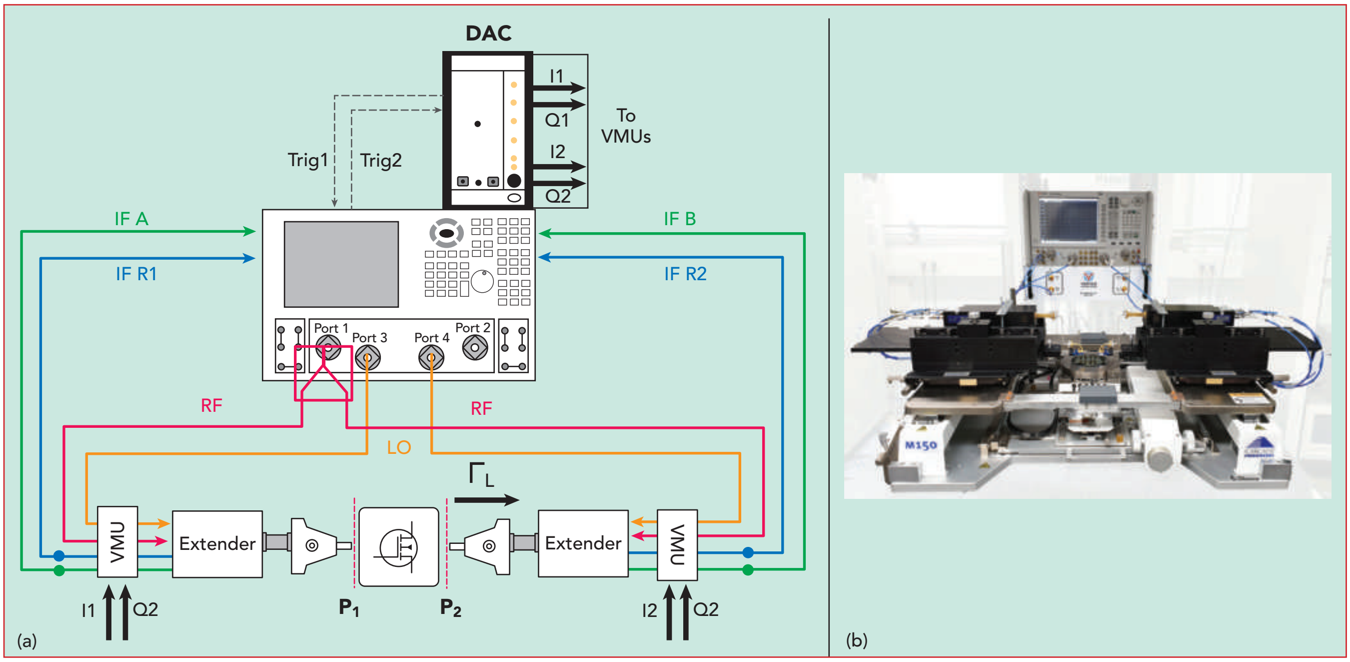

▲ Fig. 6 The scalable active load-pull test bench for measurements at sub-THz frequencies (a) and view of the complete on-wafer active load-pull system (b).

FREQUENCY SCALABLE ACTIVE TUNER

Once the topology of Figure 5b is chosen, the actual implementation must be defined. The choice of the waveguide head is defined by the specific frequency range, which, in principle, is arbitrary, as it does not affect the lower frequency hardware. For the amplitude and phase modulation, appropriate components must be chosen. In the case of MMW-STUDIO, amplitude (power) modulation of the injection signal is obtained directly from the RF source of the VNA, while power control is achieved by means of calibration.

For an open loop active load-pull architecture, one of the main requirements is phase coherence between the injected waves at the input and the output of the DUT: the two injected signals must share the same time base. The easiest and most reliable approach is for the two injected waves at the test ports to share the same RF source.[7] If that is the case, and it is desired to use just one RF source of the VNA to control both injections, it is not possible to independently control the power at each port with the same source. If independent power modulation at the two ports is required, another solution must be used. The use of I/Q modulators, as in mixed signal active load-pull[8] at mmWave frequencies,[6] could allow both power and phase modulation for each port, independently. The main difference with mixed signal active load-pull is that signal modulation is performed at a different frequency than the measurement frequency.

Using these considerations, the classical schematic of Figure 3a is modified in ***Figure 6a*** to achieve active load-pull capabilities. Figure

6a is a simplified block diagram of the implementation realized by Vertigo Technologies, where the I/Q modulators are embedded in general vector modulation units (VMU). The VMUs are both driven by port 1 of the VNA through a power splitter, to ensure total phase coherence, at a fixed power. The I/Q modulators are used as phase/amplitude modulators with DC signals (I and Q) generated through a high bit count (24-bit) digital-to-analog converter that is synchronized with the VNA through a handshaking loop to ensure high speed. The frequency at which the VMUs operate is the same as the RF input frequency of the extender modules, typically in the range between 5 and 20 GHz for most commercially available extenders for output frequencies to 1.1 THz. The signal modulated by the VMU is presented to the extenders and is up-converted to the desired frequency. The up-converted signal becomes the injection signal for the active tuner; using an iterative procedure, it is possible to perform active load-pull measurements.

Figure 6b shows a practical implementation of a complete on-wafer active load-pull system working in the WR6.5 waveguide band (110 to 170 GHz). The VMUs for both the input and the output are conveniently assembled in a single rack-mount case for ease of mounting and signal distribution. The system of Figure

TABLE 1

LOAD CONTROL STABILITY VS. FREQUENCY

Frequency (GHz)	Stability of |ΓL| (Standard Deviation)	Stability of ∠ΓL (Standard Deviation – Phase)
96	0.002	0.05
140	0.0035	0.33
180	0.0016	0.17
288	0.001	0.29
500	0.0046	0.57

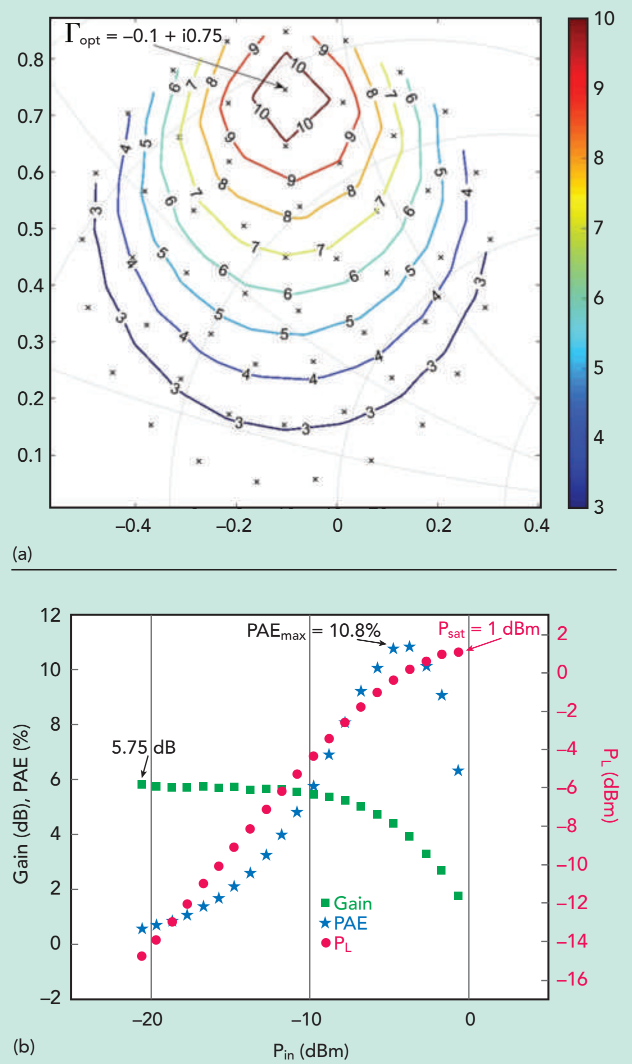

Fig. 7 Active load-pull measurements of a two-fingered, 130 nm SiGe BiCMOS HBT at 125 GHz, showing the PAE contours (a) and the gain, PAE and power delivered to the load at the optimum PAE load (b).

6b, together with the MMW-STUDIO LP software, can perform active load-pull measurements at any desired load impedance (depending on the DUT and the extender specifications), ideally at every frequency covered by mmWave extenders. This setup has been tested up to 500 GHz with stability better than 0.01 in magnitude and 0.6 degrees in phase. ***Table 1*** shows a summary of load control stability at different measured frequencies.

Figure 7 shows the large-signal characterization of a commercial, double-finger 130 nm SiGe BiCMOS HBT. The test was performed at 125 GHz with more than 54 different loading conditions and an input power sweep from −21 to −1 dBm. ZC140 extender modules from Rohde & Schwarz were used, featuring a nominal available power of 8 dBm. Figure 7a shows the power-added efficiency (PAE) contours, identifying the optimum loading condition for peak PAE: Γ_{opt} = −0.1 + i0.75. Figure 7b shows the measured gain, PAE and power delivered to the load (P_L) versus the input power, P_{in}, at Γ_{opt}. To the authors' knowledge, the results of Figure 7 represent the first published active load-pull measurements of an active device at frequencies higher than 110 GHz.

CONCLUSION

With the aid of software, dedicated calibration and small hardware modifications, it is possible to expand the capabilities of conventional waveguide extender-based VNA setups to perform accurate power control, power sweeps and active load-pull measurements in the sub-THz frequency range. The described approach is scalable to every frequency band covered by mmWave waveguide extenders and has been tested to 500 GHz. Measurements of commercial BiCMOS devices at 125 GHz show the capability of this approach to fully characterize realistic devices using off-the-shelf equipment.■

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INVITED PAPER

Pillars of 5G: Spectral & Energy Efficiency

Corbett Rowell
Rohde & Schwarz, Munich, Germany

5G deployment is driven by two key factors that are typically in conflict with each other: system capacity (spectral efficiency) and system cost (energy efficiency). Spectral efficiency describes how much capacity can be provided and is typically measured in bps (bits per second) per Herz of frequency, whereas energy efficiency characterizes how much it costs to run the network for a given capacity.

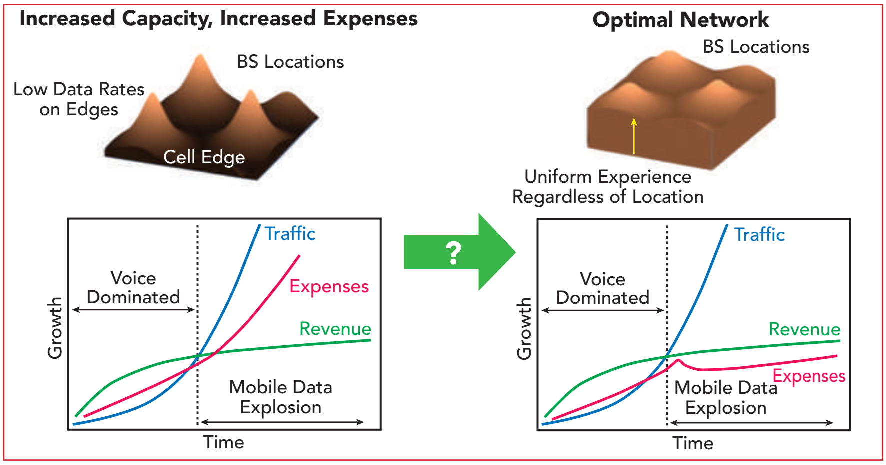
In the past generations of mobile technology, the cost of the provision of higher capacity was almost directly proportional, as this involved building more base stations or increasing the spectral bandwidth (BW) inside the network. While this was roughly sustainable in the past, the demands for 10 to 100× the capacity of 4G networks make this approach a path to bankruptcy, as it is unlikely the consumers of the increased capacity are willing to increase their expenditure by 10 to 100×. As illustrated in ***Figure 1***, in order to advance the mobile networks, the industry needs to solve the problem of how to increase capacity across the entire network while simultaneously decreasing the costs of running the network.

HOW MUCH DOES IT COST TO RUN A CELLULAR NETWORK?

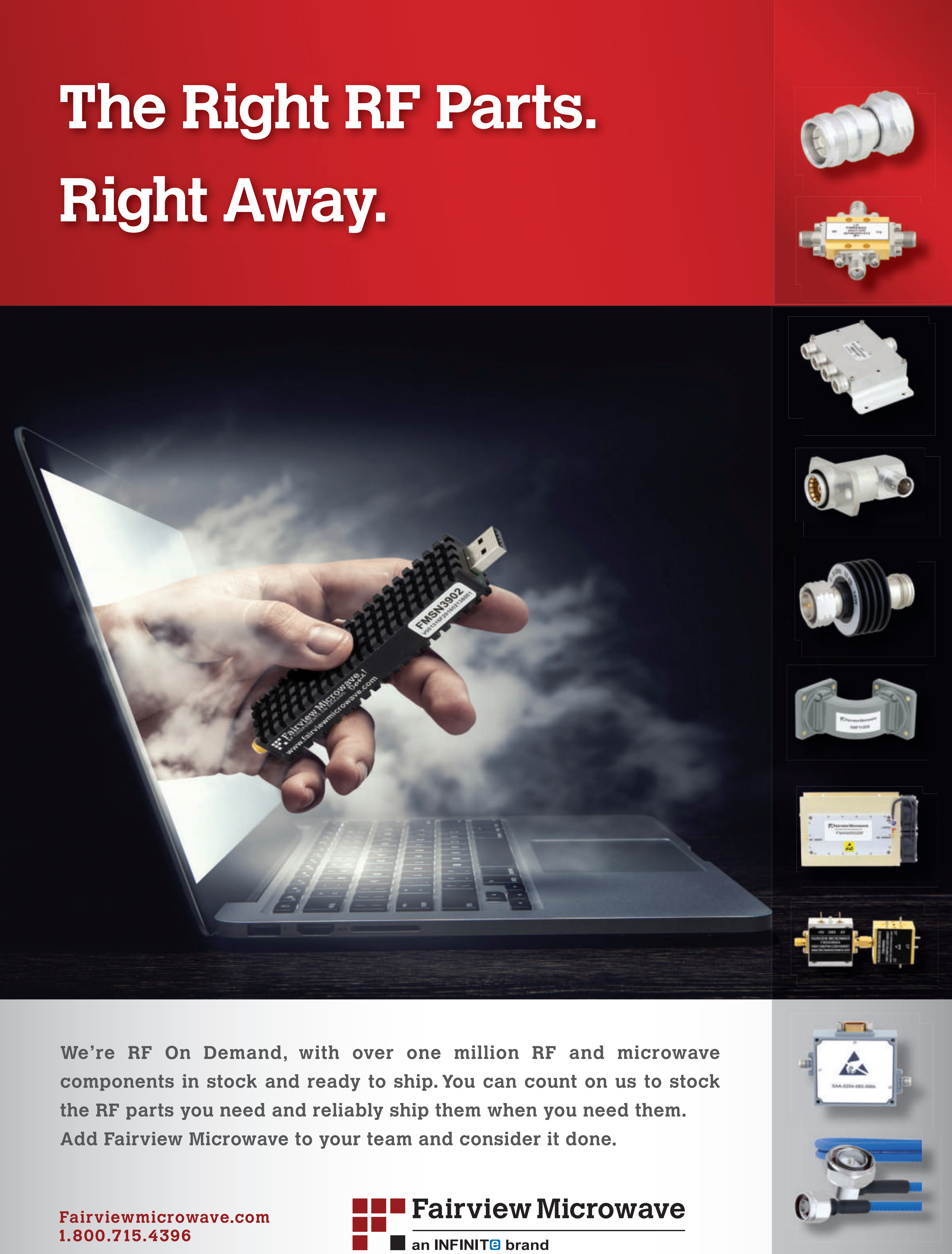
Although the base stations have become more energy efficient from 2G to 4G, the costs of providing more capacity through network densification have increased significantly (see ***Figure 2***). Most of the cost of setting up and operating a cellular network is in the remote provision of air conditioning and site rental for the base stations.[1-2] In terms of the initial CAPEX, the air conditioning is over 50 percent, leaving the remaining for the base station equipment. Similarly, in terms of recurring OPEX, electricity is almost 50 percent of the costs. Most of the electricity is for the operation of the remotely distributed air conditioning network used to cool the baseband processors (radio units are typically air-cooled and do not require additional air conditioning). The actual transmission of energy is only 7 percent of the OPEX. If more base stations are deployed, the 30 percent of site rent scales accordingly, making it unattractive to simply deploy more base stations (this could become a problem for 5G FR2 with reduced cell sizes compared to 5G FR1).

From the analysis of the power consumption, it is clear that most of the costs are due to the distributed and remote deployment of air conditioning for the baseband processing portion of a base station. China Mobile proposed to centralize the baseband processing in a manner similar to data storage facilities for the internet. ***Figure 3*** illustrates the architecture of the baseband cloud where each baseband for a base station becomes a virtual machine inside the cloud (C-RAN). Even traditionally separate network appliances such as gateways can be integrated into the cloud as virtual machines. By centralizing the baseband processing, the remote air conditioning becomes centralized, thereby significantly decreasing both OPEX and CAPEX. In addition, it is easier to realize CoMP where separate base stations transmit to a mobile phone (network MIMO) with a centralized control, increasing the spectral efficiency at the same time. This architecture is independent of the Radio Access Network and can be used to control a mixed generation cellular network.

The type of information being transmitted also influences the energy efficiency of the network. As shown in Figure 2, different types of data have different data packet to signaling packet ratios (DSR). A



▲ **Fig. 1** **5G business case. Drive profit by reducing expenses (energy efficiency).**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low DSR represents a low usage of the channel to transmit data; for example, text messages which represent 60 percent of all network traffic have a DSR between 1 to 3 whereas photos and videos are more energy efficient as this data requires fewer signaling packets. 5G FR1 addresses this problem by adjusting the subcarrier spacing to allow different types of data to more efficiently use the available channel capacity.

Cellular Network Energy Consumption (China)

2G GSM
830,000 Base Stations
80 GWH (96 KWH per BTx)

↓

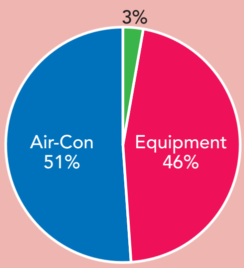
3G TD-SCDMA
350,000 Base Stations
13 GWH (37 KWH per BTx)

↓

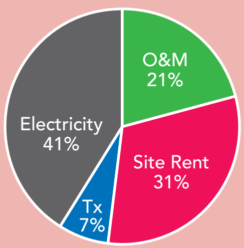
4G TD-LTE
800,000 Base Stations
16 GWH (20 KWH per BTx)

Service Type	Ratio (%)	Packet Size (kB)	Data to Signaling Ratio (DSR)
Text/IM	60	1	1 to 3
Voice	35	10	65 to 375
Photo	4	150	
Video	1	1500	

Radio Access Network Energy Consumption



CAPEX



OPEX

Biggest CAPEX/OPEX Expense is Air Conditioning
Source: CMRI, "C-RAN: The Road Towards Green RAN", Dec. 2013

Example: China Mobile Network in 2013 Consumed Over 15 Billion KWH
Source: IEEE Communications Magazine, Feb. 2014

Fig. 2 Power consumption in a cellular network.

WHAT DETERMINES THE CAPACITY OF A NETWORK AND HOW CAN IT BE INCREASED?

In the early 1900s, two researchers working independently derived a relatively simple equation that serves as a Moore's Law for the wireless industry: the Shannon-Hartley theorem. This theorem gives an upper bound to the amount of information that can be transmitted over the wireless channel where the individual channel capacity is dependent on only two parameters: channel BW and the signal-to-noise-ratio (SNR). While the capacity scales linearly with the channel bandwidth, it only scales at log2 for the signal to noise ratio:

$$C_j = BW\log_2(1 + SNR)$$

From the Shannon-Hartley theorem, there are three basic methods to increase network capacity (see ***Figure 4***):

1. Increase the channel BW: In 4G, carrier aggregation is used to increase the available signal bandwidth and 5G FR2 uses the mmWave frequencies to obtain larger capacities.
2. Increase the number of channels: MIMO utilizes the multipath scattering inside the network to concurrently transmit on several channels at the same time. Similar to the channel BW, network capacity also scales linearly with this effect, but with an upper limit determined by the correlation (or similarity) of the multipaths inside the network. 5G FR1 relies on scaling up MIMO to provide increased data rates.
3. Increase the output power of the network: Due to the presence of the noise in the SNR, the asymptotic log scaling of the SNR, and health/safety concerns of high electromagnetic energy, this method has its limits. One safer method of increasing the SNR throughout the network is the use of femtocells in areas of decreased coverage. If too many omnidirectional femtocells are deployed in a single area, however, the interference between the femtocells provides

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Designation (WRD)	Waveguide Code	Frequency (GHz)
200 - D24	D200	2.00 - 4.80
350 - D24	D350	3.50 - 8.20
350 - D36	D351	3.50 - 12.40
475 - D24	D475	4.75 - 11.00
500 - D36	D500	5.00 - 18.00
650 - D28	D650	6.50 - 18.00
750 - D24	D750	7.50 - 18.00

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Designation			Wave-guide Code	Frequency (GHz)
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650	6	14	R650	1.12 - 1.70
510	7	18	R510	1.45 - 2.20
430	8	22	R430	1.70 - 2.60
340	9 A	26	R340	2.20 - 3.30
284	10	32	R284	2.60 - 3.95
229	11 A	40	R229	3.30 - 4.90
187	12	48	R187	3.95 - 5.85
159	13	58	R159	4.90 - 7.05
137	14	70	R137	5.85 - 8.20
102			R102	7.00 - 11.0
112	15	84	R112	7.05 - 10.0
90	16	100	R090	8.20 - 12.4
75	17	120	R075	10.0 - 15.0
67			R067	11.0 - 17.0
62	18	140	R062	12.4 - 18.0
51	19	180	R051	15.0 - 22.0
42	20	220	R042	18.0 - 26.5
34	21	260	R034	22.0 - 33.0
28	22	320	R028	26.5 - 40.0
22	23	400	R022	33.0 - 50.0

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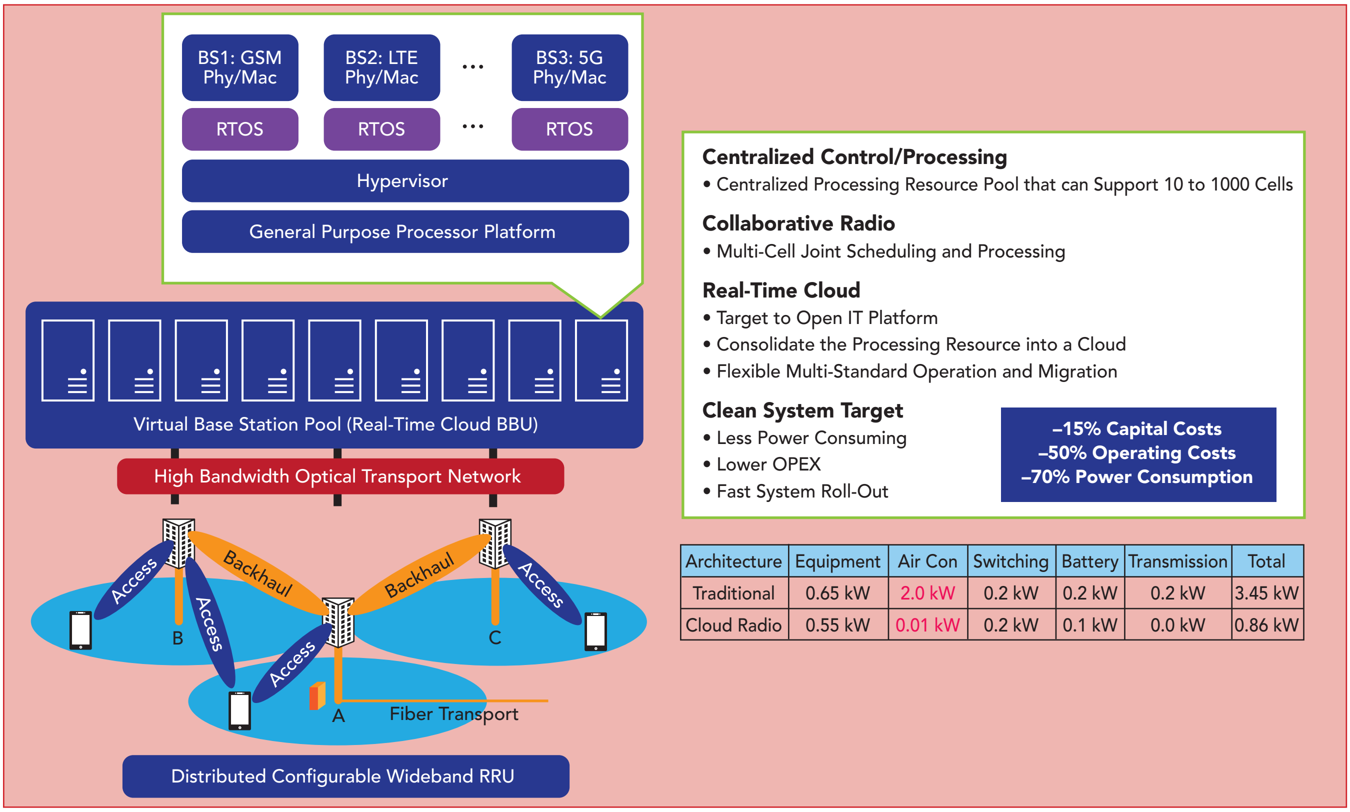
an upper limit to the capacity gain of the network. By targeting the energy to a specific user, however, the energy efficiency of the network can be increased—this is referred to as "beamforming" and it is a key technology for both 5G FR1 and FR2 base stations.

IMPROVEMENT OF ENERGY EFFICIENCY WITH BEAMFORMING

In a traditional cellular network, a cell is associated with a base station that transmits energy throughout a wide area (typically 120 degrees angular arc in front of the base station). While some of this energy is received by users within the base station's cell, the vast majority of this energy is absorbed into the environment (buildings, people, trees, cars, etc.). This wasted power represents a reduced energy efficiency and higher network OPEX (see ***Figure 5***). If the single base station antenna is replaced by 120 antennas that target the energy to individual users, the required base station power is decreased to 0.1 percent of the original output power.[3] This reduction, however, is theoretical. Practically, the output power for the same capacity only decreases to 30 percent of the original power due to the efficiency and losses of the RF components inside the base station.



Architecture	Equipment	Air Con	Switching	Battery	Transmission	Total
Traditional	0.65 kW	2.0 kW	0.2 kW	0.2 kW	0.2 kW	3.45 kW
Cloud Radio	0.55 kW	0.01 kW	0.2 kW	0.1 kW	0.0 kW	0.86 kW

Fig. 3 Centralized baseband processing.

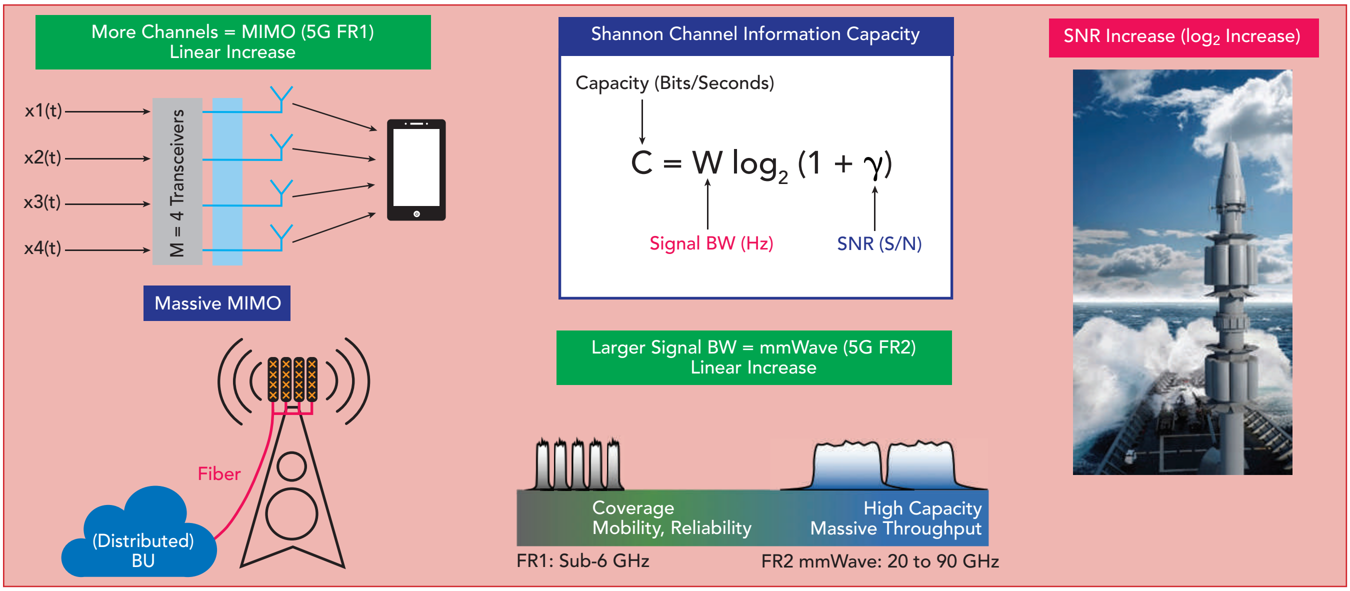


Fig. 4 Spectral efficiency.

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MV389 10 MHz

Low Phase Noise Miniature OCXO with Low G-sensitivity

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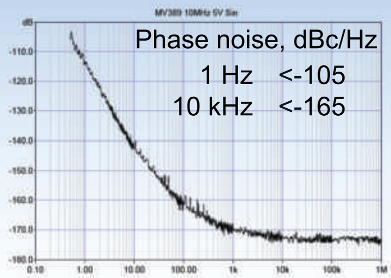
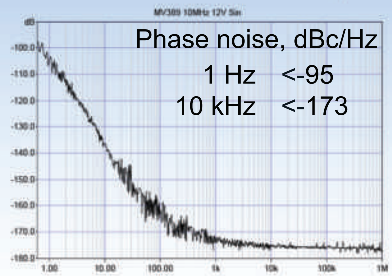
- √ low G-sensitivity <6E-10/G (typical), options up to <3E-10/G
- √ package 25.8x25.8x12.7 mm





MV317 100 MHz

Miniature High Frequency Precision Low Phase Noise OCXO

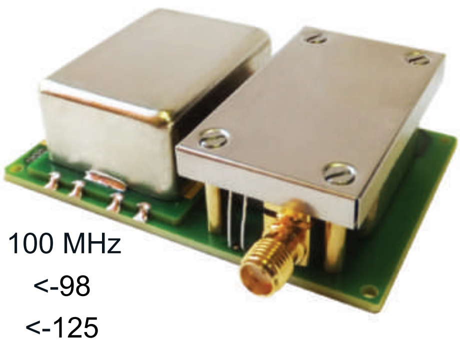
- √ low G-sensitivity <1E-9/G (typical), options up to <2E-10/G
- √ package 25x25x10.3 mm

Phase noise (typical), dBc/Hz, for	100 MHz
10 Hz	-102
100 Hz	-135
1 kHz	-164
10 kHz	-185
100 kHz	-190

MV359 10 and 100 MHz

Ultra Low Noise Dual Frequency OCXO

- √ Allan Deviation 5E-13 per sec.
- √ temperature stability ±1E-9
- √ package 67x44x18 mm



Phase noise, dBc/Hz, for	10 MHz	100 MHz
1 Hz	<-120	<-98
10 Hz	<-145	<-125
100 Hz	<-160	<-135
1 kHz	<-165	<-160
10 kHz	<-170	<-175
100 kHz	<-170	<-180

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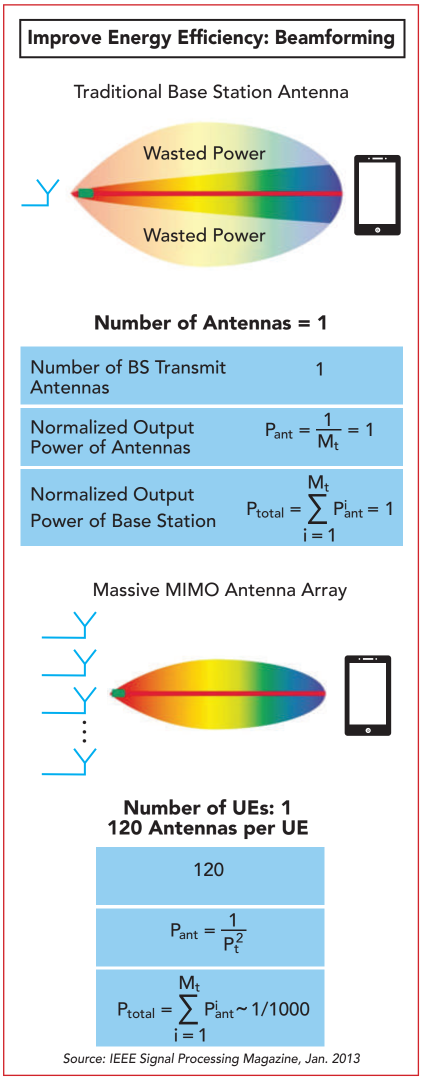
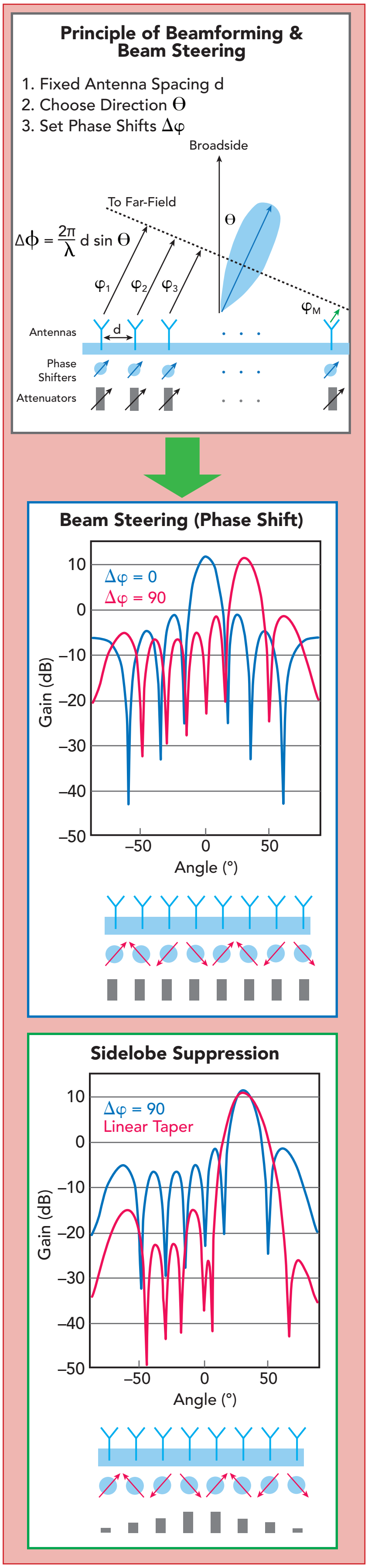
In order to form a beam, a set of periodically spaced antennas can form a beam in any direction by only changing the phase differences between the antennas (see ***Figure 6***). Typical antenna array spacing is half wavelength, leaving the beam angle (θ) directly related to the phase difference between the antennas: $\theta \propto \sin^{-1}(\Delta\varphi)$. While the beam can focus its energy in a desired direction, there is also energy going in other directions (sidelobes and backlobes). This additional energy represents interference to other users inside a base station cell. This effect can be mitigated by either ensuring the adjacent users are in the nulls of the main beam or by weighting the individual antennas with an amplitude distribution to lower the energy in the sidelobes (see Figure 6).

There are three types of beamforming architecture that have di-



▲ **Fig. 5** Beamforming and energy efficiency.



▲ **Fig. 6** Principles of beamforming.

Bringing Microwave & Millimeter-wave Products To Market

New Millimeter-wave Applications Drive Demand & Generate New Challenges: Microwave and millimeter-wave applications beyond 6 GHz have garnered extensive interest in the last few years, largely due to growth in 5G cellular, micro-satellite constellations, millimeter-wave backhaul, radar, and Internet-of-Things (IoT) applications where increased bandwidth and reduced spectrum congestion are critical. Additional technology trends that embrace increased frequencies include active electronically steered arrays (AESA) for military radar, V-band automotive radar, and V-band/E-band backhaul.

5G and IoT wireless applications are moving to 20 ~ 60 GHz frequency bands to overcome atmospheric attenuation and enhance throughput in the millimeter-wave spectrum. Advanced active antenna systems (AAS) are being developed that incorporate beamforming, multi-input-multi-output (MIMO), and carrier aggregation (CA) technologies, requiring greatly advanced and complex antenna systems than previous cellular or wireless IoT.

All of these new technologies come with new challenges for industries that are traditionally familiar with sub-6 GHz technology. There is a new realm of expertise, equipment, and range of physical considerations for development of competitive technology that meets both customer and user requirements and expectations.

Manufacturing Success In The Millimeter-wave Era

Big Opportunity Means Big Stakes: Years of producing a 77GHz Frequency Converter Module, RFE's engagement with a large OEM led to the development of new Automotive Radar Test Systems with a complete range of capabilities with > 100 fielded systems achieving 100% satisfaction and reliability.

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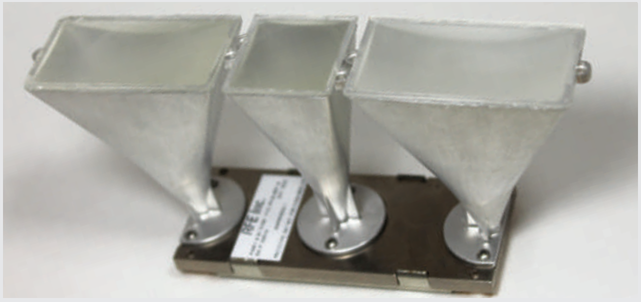
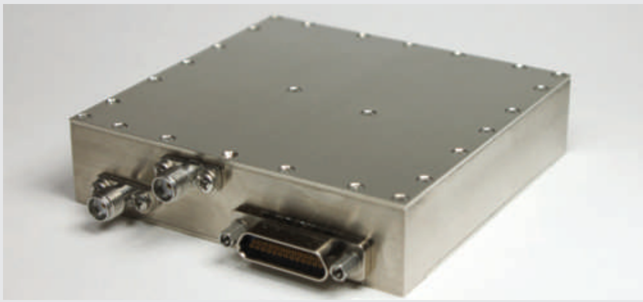


77 GHz FMCW Radar Warning Receiver: Today's automotive and transportation systems rely on high-reliability / high-performance radar. Target tracking, collision threat prediction, configurability and cost along are critical. In conjunction with Mobile Technology Solutions (MTS), RFE developed a 77 GHz frequency-modulated continuous wave (FMCW) radar system that exceeds the standards in the marketplace. With over 150 meters of range, RFE's automotive radar platform is unaffected by vehicle glass and a custom designed antenna/lens system eliminates the alignment issues common with strip-line configurations.



Broadband Fast Tuning Miniature Synthesizer: Microwave and millimeter-wave radar, radios, and instruments are built using frequency synthesizers. With more high frequency applications, synthesizers are now needed that exhibit wide bandwidth in smaller form factors than previous technologies. Predicting this emerging need, RFE has developed a broadband fast tuning miniature synthesizer that operates from 0.1 ~ 20 GHz with < 50µs tuning speed in a tiny 3 x 3 x 0.7" package with spurious content down to -60 dBc, phase noise below -65 dBc/Hz at 10 kHz and rugged operating temperature range of -45 to +85 deg C.

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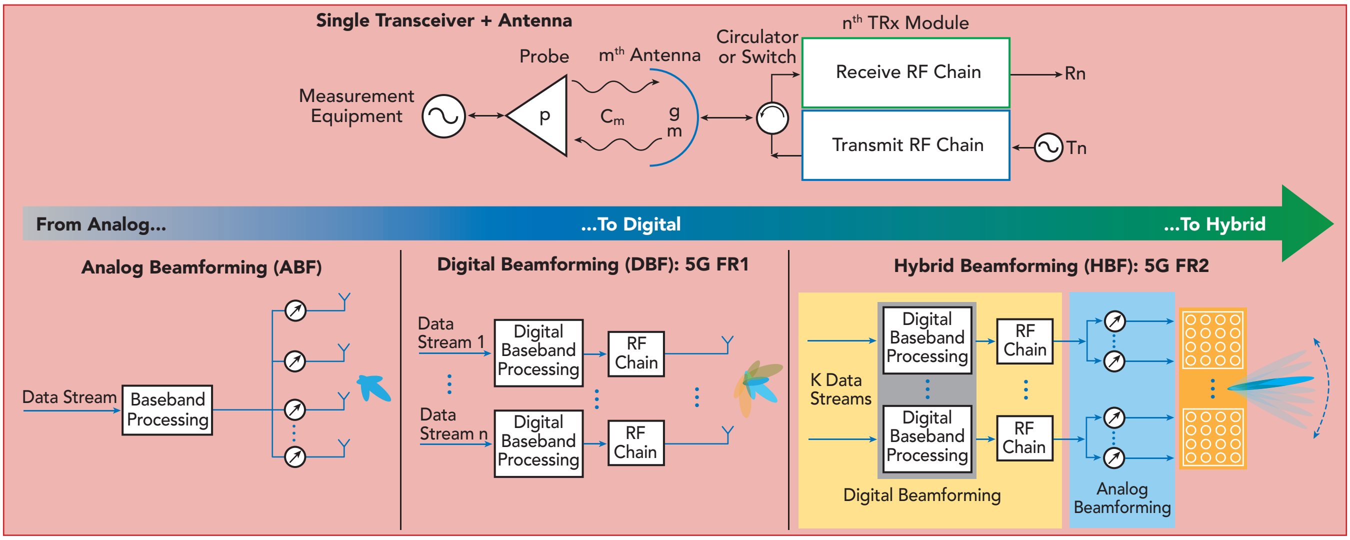

Fig. 7 Beamforming architectures.

rect impact on the energy efficiency of the base station and the UE (see *Figure 7*):

- Analog Beamforming (ABF): The traditional way to form beams is to use attenuators and phase shifters as part of the analog RF circuit where a single data stream is divided into separate paths. The advantage of this method is that there is only one RF chain (LNA, filters, switch/circulator) required. The disadvantage is the loss from the cascaded phase shifters at high power.
- Digital Beamforming (DBF): DBF assumes there is a separate RF chain for each antenna element. The beam is then "formed" by matrix-type operations in the baseband where artificial amplitude and phase weighting is performed. For frequencies lower than 7 GHz in 5G FR1, this is the preferred method since the RF chain components are comparatively inexpensive and can combine MIMO and beamforming into a single array. For frequencies of 28 GHz and above, the PAs and ADCs are very lossy for standard CMOS components. If exotic materials, such as GaAs and GaN are used, the losses decrease at the expense of higher cost.
- Hybrid Beamforming (HBF): HBF combines DBF with ABF in order to allow the flexibility of multiple radio transceivers plus beamforming while reducing the cost and losses of the beamforming unit (BFU). Each data stream has its own separate analog BFU with a set of M antennas. If there are N data streams, then there are N×M antennas. The analog BFU loss due to phase shifters can be mitigated by replacing the adaptive phase shifters with a selective beamformer such as a Butler matrix. One proposed architecture uses the digital BFU to steer the direction of the main beam while the analog BFU steers the beam within the digital envelop.

OPTIMAL NETWORKS: SPECTRAL AND ENERGY EFFICIENCY

The combination of C-RAN, MIMO, new spectrum and beamforming allows 5G to both increase capacity while decreasing costs compared to traditional and current cellular networks. The Shannon-Hartley theorem can be reformulated to take into account the energy efficiency of the channel.[2] Using the constraints in the performance of the base stations and the network, the joint optimal spectral-energy efficiency of 2G and 4G networks can be calculated at 4 bps/Hz for GSM and 8 bps/Hz for LTE. Note, in real networks, these values are often lower at 4 bps/Hz for LTE.

The combination of MIMO and digital beamforming in 5G FR1 can lead to an increase of capacity of over 3× compared to an LTE network while decreasing costs by a factor of 10 (assuming that there are eight transceivers per user with beamforming). While 5G FR1 has limited frequency spectrum available, 5G FR2 uses large amounts of spectrum above 24 GHz. The spectral efficiency of 5G FR2 (assuming HBF with eight transceivers per antenna array) is comparable to LTE at 10 bps/Hz, but with higher energy efficiency compared to LTE[4] (see *Figure 8*).

In conclusion, the combination of spectral and energy efficiency allows operators to deploy new networks that can simultaneously boost capacity while lowering OPEX. Networks of the future will combine the different solutions of FR1 and FR2 into

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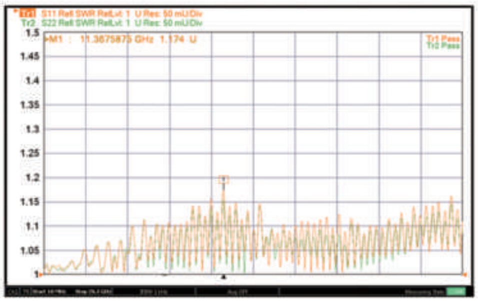
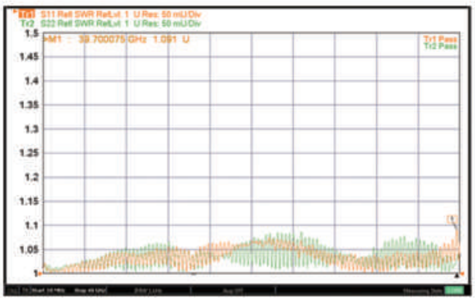
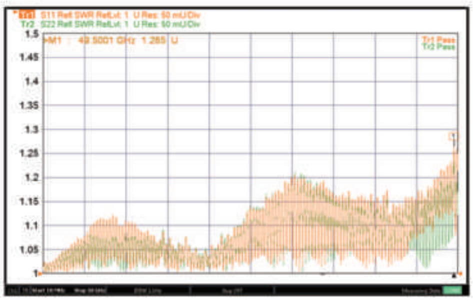


26.5GHz



40GHz



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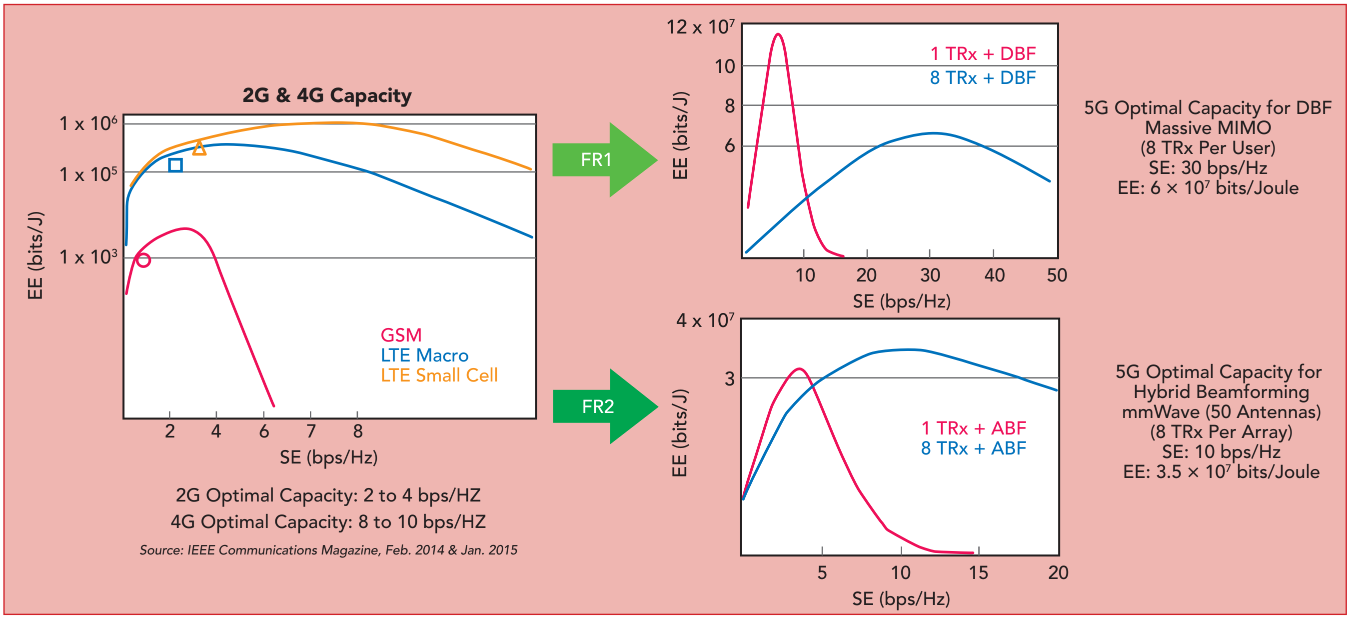

Fig. 8 Optimized networks: spectral and energy efficiency.

single networks, allowing the FR1 to deliver high dates in a wide area network with in-building penetration while FR2 serves as data off-loading, hotspots and extreme network densification. This network deployment will not only affect consumers and equipment vendors, but also has a fundamental impact on the entire test & measurement industry.

IMPACT ON TEST & MEASUREMENT INDUSTRY

The new base stations required for 5G result in a new measurement paradigm with the use of over-the-air (OTA) testing for both antenna and transceiver performance characterization.

5G BASE STATION ARCHITECTURE

The combination of beamforming and MIMO into a single array leads to a massive MIMO base station as multiple sets of antennas are required for both beamforming (same data vector for each antenna) and MIMO (different data vectors for each set of beamforming antennas). Designing these base stations so that both spectral and energy efficiency can be increased is complex and requires very tight integration of all the components (see ***Figure 9***):

- Beamforming Architecture: This depends on the availability of components both in terms of losses (energy efficiency) and cost.
- Wideband Power Amplifier and Filter Banks: The increase of the number of frequency bands, carrier aggregation across wide frequency bands will require large numbers of both filters and power amplifiers. The power amplifiers will require pre-distortion or exotic materials to operate at higher efficiencies.
- Antenna Mutual Coupling: Simply packing more antennas into a space will decrease the capacity and increase the losses in the base station.
- Clock Synchronization: For a large massive MIMO array, the clocks will

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ERDLVA-218-CW-LPD

PMI Model No.	Frequency Range (GHz)	TSS	Log Slope (mV/dB)	Dynamic Range Log (dBm)	Size (Inches) Connectors
DLVA-50M18D5G-40-LIN-LOG-CD-1 https://www.pmi-rf.com/product-details/dlva-50m18d5g-40-lin-log-cd-1	50 MHz - 18.5	-40 dBm	50 ± 5	-40 to 0	4.0" x 3.0" x 1.0" SMA (F)
SDLVA-100M18G-CW-70-MAH https://www.pmi-rf.com/product-details/sdlva-100m18g-cw-70-mah	0.1 - 18	-70 dBm	10 ± 1	-65 to +5	2.3" x 2.2" x 0.40" SMA (F)
SDLVA-2020-70 OPT.0518-A03-A07-50OHM https://www.pmi-rf.com/product-details/sdlva-2020-70-opt-0518-a03-a07-50ohm	0.5 - 18	-65 dBm	20 ± 10%	-65 to +5	3.0" x 3.5" x 0.5" SMA (F)
SDLVA-1G20G-55-12-SFF https://www.pmi-rf.com/product-details/sdlva-1g20g-55-12-sff SDLVA-1G20G-58-12-SFF https://www.pmi-rf.com/product-details/sdlva-1g20g-58-12-sff	1 - 20	-55 dBm -58 dBm	50	-55 to +5	1.08" x 0.71" x 0.29" SMA (F)
SDLVA-218-65-16MV-12DBM https://www.pmi-rf.com/product-details/sdlva-218-65-16mv-12dbm	2 - 18	-64 dBm	16 ± 2	-55 to +10	4.24" x 0.994" x 0.38" SMA (F)
ERDLVA-218-CW-LPD https://www.pmi-rf.com/product-details/erdlva-218-cw-lpd	2 - 18	-64 dBm	77 ± 5	-60 to +4	2.04" x 1.67" x 0.472" SMA (F)
SDLVA-2D5G4D9G-60-50MV https://www.pmi-rf.com/product-details/sdlva-2d5g4d9g-60-50mv	2.5 - 4.9	-70 dBm	50.5 ± 5%	-60 to 0	2.3" x 1.0" x 0.4" SMA (F)
DLVA-8G10G-75-50-SFF https://www.pmi-rf.com/product-details/dlva-8g10g-75-50-sff	8 - 10	-78 dBm	50 ± 4	-75 to 0	2.0" x 1.5" x 0.4" SMA (F)
SDLVA-8G18G-40-5-SFF https://www.pmi-rf.com/product-details/sdlva-8g18g-40-5-sff	8 - 18	-45 dBm	50 ± 6	-40 to 0	1.2" x 0.85" x 0.4" SMA (F)
DLVA-18G40G-42-50-CD-1 https://www.pmi-rf.com/product-details/dlva-18g40g-42-50-cd-1	18 - 40	-34 dBm	50	-32 to +10	1.86" x 1.69" x 0.4" 2.92mm (F)
SDLVA-18G40G-65-CD-292FF https://www.pmi-rf.com/product-details/sdlva-18g40g-65-cd-292ff	18 - 40	-65 dBm	25	-63 to +2	2.37" x 1.8" x 0.42" 2.92mm (F)


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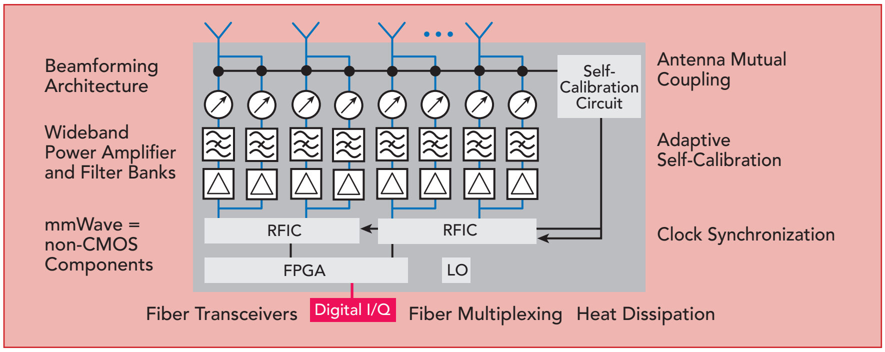

Fig. 9 Massive MIMO architecture.

require synchronization over separate PCB boards. Clock drift will lead to uncertain phase changes (due to frequency drift) between the antennas and decrease the effect of beamforming.

- Adaptive Self-Calibration: Due to the large numbers of components, chipsets, clocks and amplifiers, together with the dependency of phase on temperature conditions inside the base station, the output phase at each antenna can vary significantly from the desired phase. Therefore, an adaptive self-calibrating circuit is required where the phase and amplitude offset of each signal is measured and is then pre-distorted so that optimal beamforming can be achieved.
- Fiber Transceivers: The output of the massive MIMO base station is typically baseband that is then transmitted through fiber to either a local baseband unit or into the C-RAN. Consequently, a real-time FPGA is required to translate the output baseband data from the RFIC to the baseband protocol for fiber.
- Heat Dissipation: The combination of up to hundreds of antennas, thousands of components and dozens of RFICs/FPGAs within a confined space leads to significant heat and thermal issues. As these units are deployed without externally provided air cooling in areas of large temperature variation, large heatsinks are required, significantly increasing the weight of the massive MIMO unit.

TEST & MEASUREMENT OF 5G BASE STATIONS AND DEVICES

Traditionally, the performance of a base station was measured by separating the antenna portion from the radio/RF portion. The modulated performance of the RF transceivers could be measured directly with cables between the RF test ports and the measurement instruments (i.e., vector signal analyzer and signal generators). The antenna performance was typically measured OTA using CW waveforms with a vector network analyzer.

Due to the highly integrated architecture of the massive MIMO base station, there is no longer direct access to the individual RF paths. This implies a fundamental

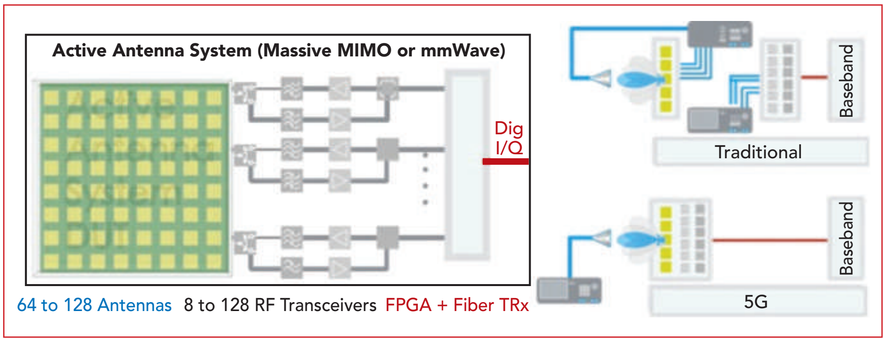

Fig. 10 New measurement paradigm for 5G.

change of measurement philosophy by moving away from highly predictable cable measurements of the RF transceivers to a more chaotic environment consisting of OTA measurements (see ***Figure 10***).

OTA measurements are significantly more complex than cable measurements due to the different physical properties of the radiated fields (see ***Figure 11*** (p. 98)) in the near-field and far-field regions of the device under test (DUT). Due to both the time and spatial-varying properties of the modulated signals, measurements must be performed in the far-field of the DUT (planar waves), resulting in either very large anechoic antenna chambers or indirect far field chambers such as the plane wave converter (PWC) or compact antenna test range (CATR). A CATR uses a reflector to convert a spherical wave to a planar wave distribution in the near field of the reflector and the PWC uses an array to generate a planar wave distribution in the near field of the array (see ***Figure 12*** (p. 98)).

Due to the elimination of RF test ports and the use of frequencies in the millimeter region, OTA will become an essential tool for characterizing the performance of not just the antenna arrays of an active antenna system of a massive MIMO array, but the internal transceivers as well. For this reason there will be a high demand for OTA chambers and measurement equipment to not only measure the strict radiative properties of antennas, but substituting traditional conducted transceiver measurements as well. Rohde & Schwarz, with its wide range of anechoic chambers and measurement equipment expertise, is well situated to deliver solutions even for future customer requirements.[5] ■

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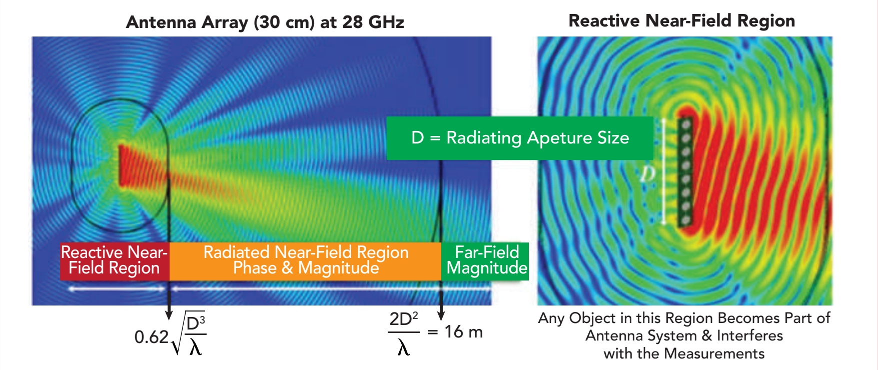

Fig. 11 Antenna electromagnetic fields.

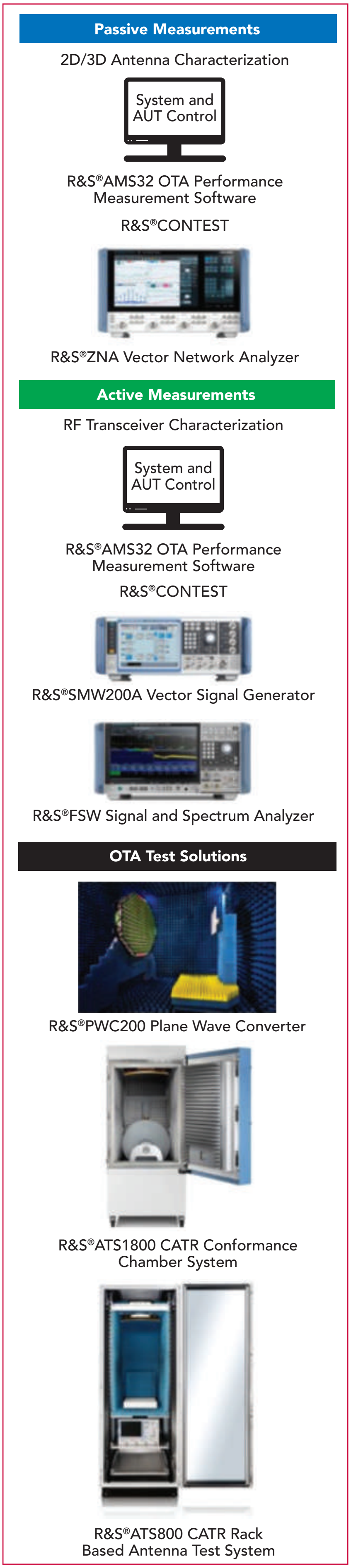

Fig. 12 Plane wave converter and CATR.

INVITED PAPER

5G: Crossing the Dreaded Trough of Disillusionment to the Plateau of Productivity

Sarah Yost
National Instruments, Austin, Texas

In 2019, 5G went mainstream. The first commercial deployments were rolled out, and mobile users in select markets began to get the first taste of 5G technology. Looking at the Gartner Hype Cycle (see ***Figure 1***), 5G is at the peak of inflated expectations and should reach a plateau of productivity in two to five years. After the peak of inflated expectations, a period of disillusionment is anticipated, and it seems 5G will be no exception. The promises that 5G made cover numerous applications with numerous technological challenges. The first 3GPP release to cover 5G, release 15, only covered a small subset of the technology needed to fully realize the key performance indicators (KPI) of 5G: enhanced mobile broadband (eMBB), massive machine type communications (mMTC) and ultra-reliable low latency communications (URLLC). Release 15 focuses primarily on eMBB; only the subsequent releases will address mMTC and URLLC, with substantial work to complete these efforts.

Fig. 1 Gartner Hype Cycle, August 2019. Source: Gartner.

5G PHASE 2

When 5G was first defined, there was a recognition that it was more complex and ambitious than previous generations, and development was split into two phases. The first phase, corresponding to release 15, was intended to address a subset of features for the first commercial deployments in 2019. The second phase, release

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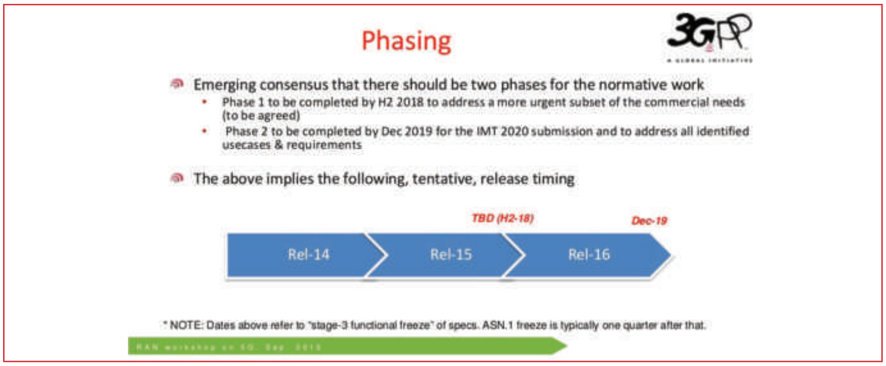

Fig. 2 5G phased plan. Source: 3GPP.

16, was intended to be a follow up to "address all identified usecases (sic) and requirements," according to a 2015 3GPP RAN document (see ***Figure 2***). Trying to address all additional uses cases in release 16 has proven to be unrealistic; features and use cases are being pushed into release 17 and beyond.

Some of the topics that release 16 is addressing include integrated access and backhaul, side link enhancements for V2X, and New Radio Unlicensed (NR-U). Some of the topics that have been pushed for consideration in release 17 include non-terrestrial networks, positioning enhancements and spectrum above 52.6 GHz. Completing study items and work items for mmWave frequencies above 52.6 GHz is one of the noticeable technologies pushed into future releases, compared to the plan several years ago. The reason for this is that mmWave is hard. It is hard from a technology perspective to address the challenges with building and testing mmWave products that function indoors, outdoors and while moving. It is hard from a business perspective to create the right financial models for deploying this expensive new technology.

PUSHING HIGHER AND HIGHER

Much work remains to make mmWave successful for large commercial deployments. Yet, there is a desire from some in the research community to continue exploring how and if higher frequencies can be used for wireless communications. The 3GPP has only documented plans to look into frequencies at 114 GHz and below, but frequencies around 140 and 300 GHz —even up to 1 THz—are being explored, technology that is likely 10 years or more from commercialization. These higher frequencies have some unique properties because of their shorter wavelengths compared to lower frequency mmWave signals. For example, THz signals can be used for sensing applications like air quality detection or to implement touchless gestures for interacting with machines. There are even wider swaths of bandwidth available in the THz range, so much higher data rates are theoretically

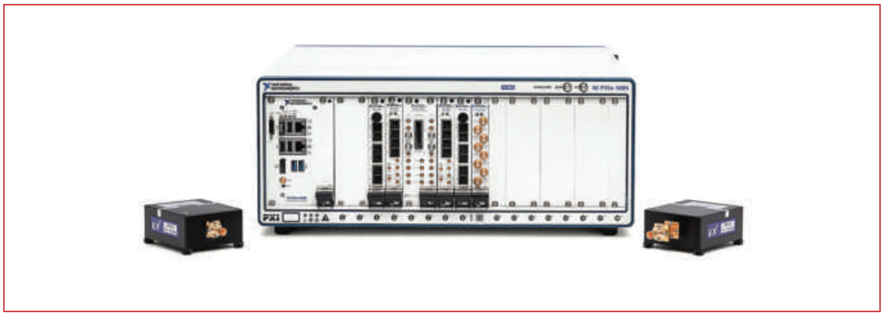

Fig. 3 Combining a mmWave transceiver with extenders enables measurements from 110 to 170 GHz.

possible. With wavelengths smaller than 1 mm, using THz frequencies for location and positioning could provide centimeter accuracy.

These are promising aspects of THz technology, but there are challenges as well. Transceivers covering these frequency ranges are expensive, and there are few products on the market. ***Figure 3*** shows one example of hardware that is available to enable THz research: a software-defined testbed comprised of the mmWave Transceiver System (MTS) from National Instruments (NI) with up- and down-converters, or frequency extenders, from Virginia Diodes (VDI). Another challenge for THz is the significant signal loss, which is even greater than at mmWave frequencies. The distances for which THz communications will be useful needs to be assessed, in addition to how these signals behave in different channel environments. Limited channel models exist today, and more measurements are needed to create robust models. As THz research is at a similar phase as mmWave technology 10 to 15 years ago, it seems clear that THz will not be included in 5G, while it is a promising candidate for 6G.

LOOKING FORWARD

Over the next five years, with any luck, 5G will move beyond the dreaded trough of disillusionment and into the plateau of productivity. For this to happen, mmWave research must continue. Beam tracking algorithms will improve. Chipsets will become more widely available and prices will begin to drop. As mmWave technology becomes more affordable, more researchers will have access to higher frequency equipment and applications like mmWave massive MIMO can be more widely explored. Breakthroughs in THz equipment, for research, commercialization and test, will also be needed to bring the technology out of research and solidify it as a 6G technology.

The next five years will be full of advancements in wireless communications. The list of use cases and applications 5G can support will expand, and the technologies that will shape 6G will become clearer.■

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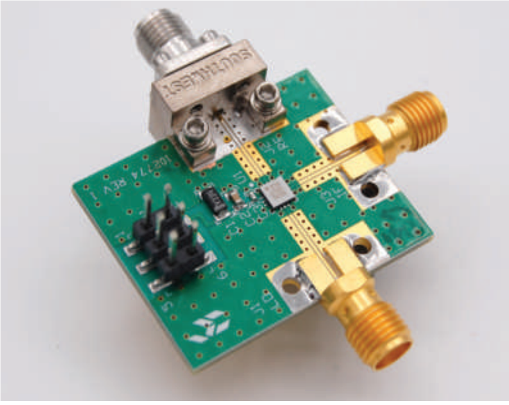

Ku- and Ka-Band Subharmonic Mixers Improve System Performance

Custom MMIC
Chelmsford, Mass.

Since enabling the superheterodyne receiver some 100 years ago, mixers have been a constant in RF/microwave systems, while the circuit topologies and technologies used to build them have been constantly optimized to improve performance, shrink size and reduce cost. The most common topology has been the fundamental mixer, where the mixing generates IF frequencies at the sum and difference of the RF and local oscillator (LO) frequencies, i.e., $f_{LO} + f_{RF}$ and $f_{LO} - f_{RF}$ if $f_{LO} > f_{RF}$. The LO signal is typically much higher in power than that of the RF signal since the

TABLE 1
SUBHARMONIC MIXER PERFORMANCE

Parameter	Unit	CMD303	CMD310	CMD310C3
RF Frequency	GHz	13 to 21	20 to 32	20 to 32
LO Frequency	GHz	6.5 to 10.5	10 to 16	10 to 16
IF Frequency	GHz	DC to 3	DC to 7	DC to 6
Minimum LO Drive	dBm	0	–4	–2
Conversion Loss	dB	8.5	9.5	8.5
2LO to RF Isolation	dB	28	36	33
2LO to IF Isolation	dB	48	53	60
Input IP3	dBm	12	10	11

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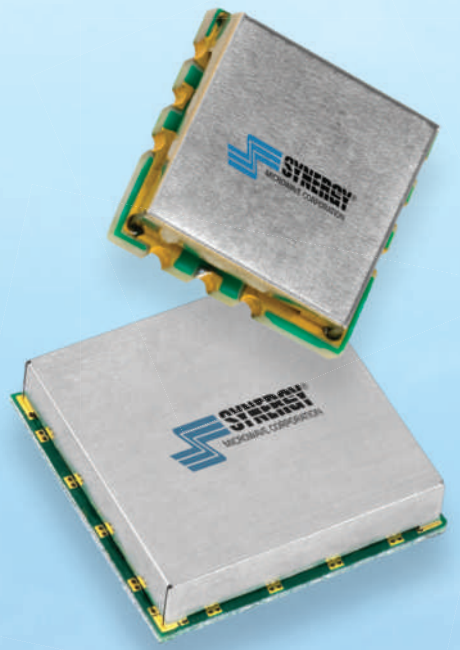
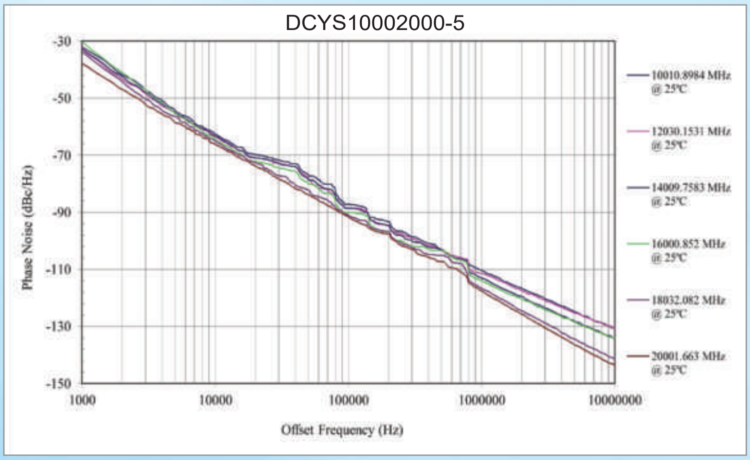
Voltage Controlled Oscillators

Model Number	Frequency	Phase Noise @ 10 kHz offset	Phase Noise @ 100 kHz offset	Tuning Voltage	Output Power
	(GHz)	(dBc/Hz)	(dBc/Hz)	(V)	(dBm)
DCO100200-5	1 - 2	-95	-117	0 - 24	+1
DCYS100200-12	1 - 2	-105	-125	0 - 28	+4
DCO200400-5	2 - 4	-90	-110	0 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0 - 18	0
DCO300600-5	3 - 6	-75	-104	0 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0 - 16	+2
DCO400800-5	4 - 8	-75	-98	0 - 15	-4
DCO5001000-5	5 - 10	-80	-106	0 - 18	-2
DCYS6001200-5	6 -12	-70	-94	0 - 15	> +10
DCYS8001600-5	8 - 16	-68	-93	0 - 15	> +10
DCYS10002000-5	10 - 20	-65	-91	0 - 18	> +10





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LO is used to turn on the diodes and drive the mixing process. In a practical mixer, unwanted signals such as LO and RF leakage and spurs will appear at the IF port. One of the challenges faced by system designers is minimizing these unwanted signals to achieve the spurious-free dynamic range required by the system.

A fundamental mixer is an efficient solution at lower frequencies, where it is relatively easy to generate a low phase noise LO signal. At higher frequencies—say above 15 GHz—generating such a signal can be difficult and expensive, which makes fundamental mixers a non-optimal choice in many applications. One alternative is to generate the LO at half the required frequency and use a ×2 multiplier to double the frequency. A passive multiplier topology is one approach, although it can be quite lossy and require a buffer amplifier at the output to increase the LO power. Alternatively, an active multiplier topology will provide higher output power, although it requires DC bias and may still require an output buffer amplifier. Whether passive or active, a discrete multiplier topology requires additional components between the LO source and the mixer, increasing circuit complexity and consuming additional board area.

Custom MMIC has developed an elegant solution to this problem by releasing three GaAs MMIC subhar-

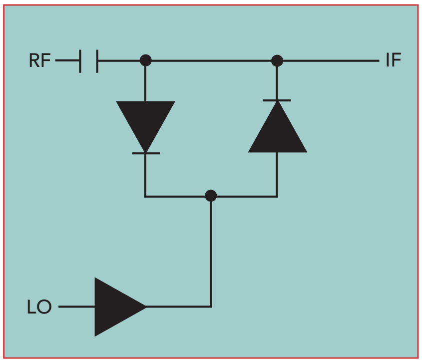


Fig. 1 Simplified block diagram of the Custom MMIC subharmonic mixer.

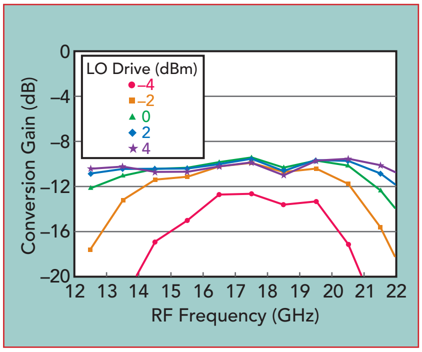


Fig. 2 Conversion gain vs. RF frequency and LO drive for the CMD303 used as an up-converter.

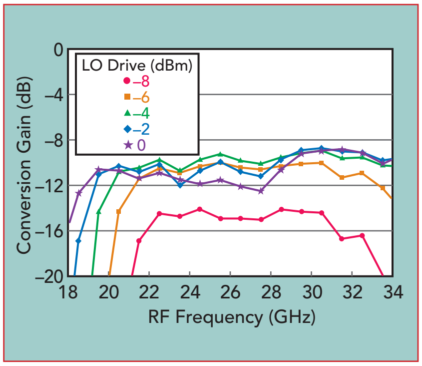
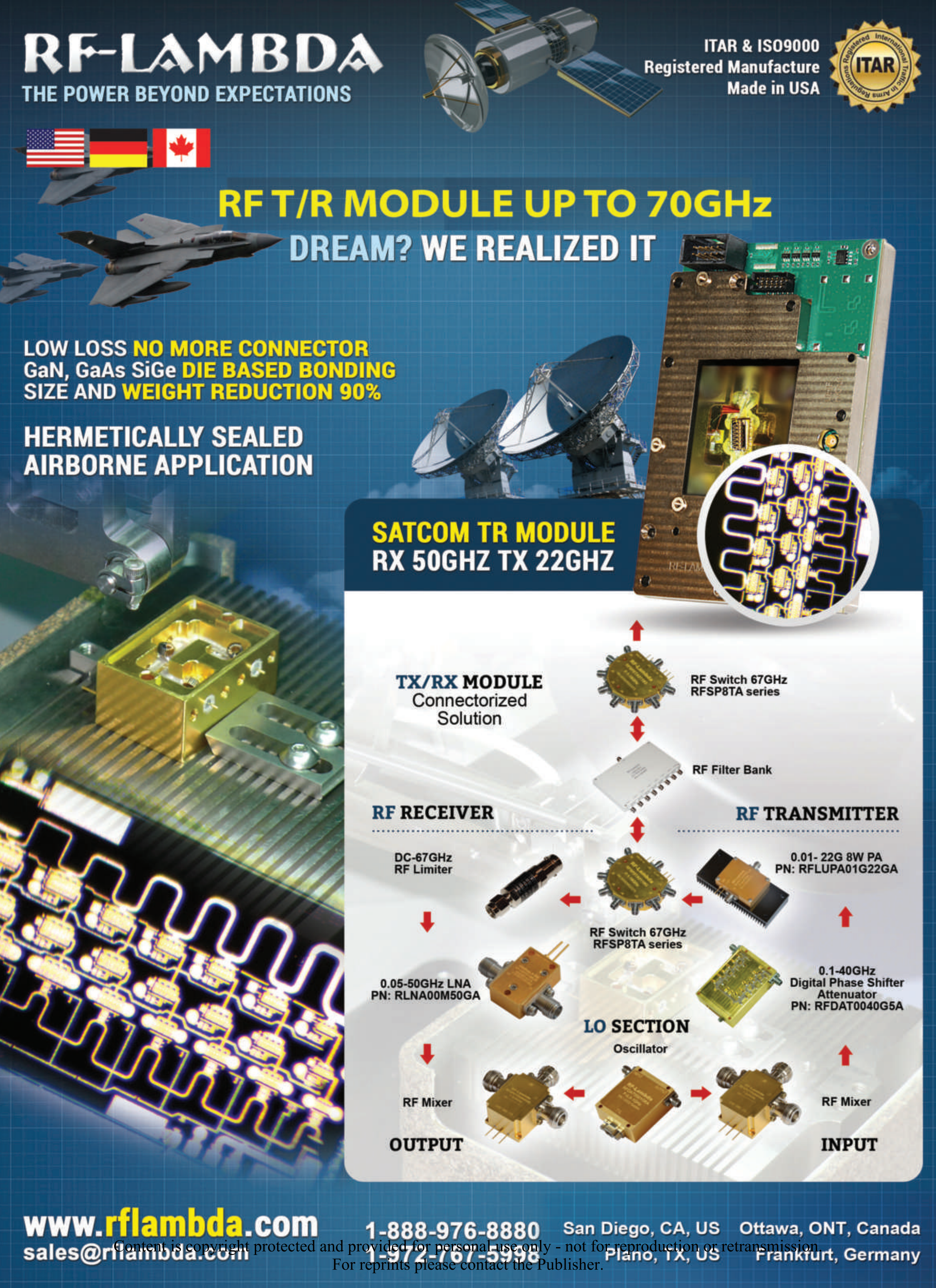


Fig. 3 Conversion gain vs. RF frequency and LO drive for the CMD310 used as an up-converter.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Ottawa, ONT, Canada
Frankfurt, Germany

monic mixers, the first in a new family, which can be used as down-converters in a receiver or up-converters in a transmit chain. In Custom MMIC's designs, the LO is input at half the desired LO frequency and an anti-parallel diode pair creates the desired effect of mixing at twice the provided LO frequency (see ***Figure 1***). The integrated buffer amplifier also reduces the required input LO power considerably below that needed to drive a passive fundamental mixer. Another benefit of a subharmonic mixer is high rejection of the even LO harmonics at the RF and IF output ports (i.e., $2f_{LO}$, $4f_{LO}$, etc.), which reduces the required LO filtering.

Fabricated with GaAs MMIC technology, Custom MMIC's subharmonic mixers are a new MMIC category for the company. Two of the three mixers are available as die, with RF frequency ranges covering 13 to 21 GHz (CMD303) and 20 to 32 GHz (CMD310); the latter design is also available in a ceramic 3 mm × 3 mm QFN package (CMD310C3). The performance of the three products is summarized in ***Table 1***. All operate from a single supply voltage, nominally +3 to +4 V, and typically require approximately 30 mA.

Figure 2 shows the conversion loss performance of the CMD303 used as an up-converter. Over the specified RF frequency range of 13 to 21 GHz, the conversion loss is approximately 10 dB with LO drive at or above the rated minimum of 0 dBm. Similar performance is achieved with the higher frequency CMD310 used as an up-converter (see ***Figure 3***). Across the specified RF frequency range of 20 to 32 GHz, the conversion loss is approximately 10 dB with the LO drive at or above −4 dBm.

These highly integrated GaAs subharmonic mixers only require external bypass capacitors to achieve the performance shown on the datasheet, making them easy to design in and minimizing circuit area. The die versions are rated for operation from −55°C to +85°C, while the packaged version is rated from −40°C to +85°C. Mixer performance is stable with temperature variation, with conversion loss changing less than 1 dB over the full operating temperature range.

In addition to these subharmonic mixers, Custom MMIC offers products for the entire RF signal chain—from the CMD283C3 low noise amplifier with 0.6 dB noise figure to the CMD304 DC to 67 GHz distributed amplifier. Constantly developing products to meet tough technical requirements, Custom MMIC introduced 39 high performance GaAs and GaN MMICs in 2019, a record for the company.

Read more about Custom MMIC's history and capabilities in the Fabs and Labs profile published in the June 2019 issue of *Microwave Journal.*

VENDORVIEW

Custom MMIC
Chelmsford, Mass.
www.custommmic.com

≥ 300 W Rack-Mount TWTAs Cover 2 to 6 and 6 to 18 GHz

dB Control offers two rack-mount traveling wave tube amplifiers (TWTA) for electronic warfare simulation, RFI testing and other applications requiring 300 to 325 W power in the 2 to 18 GHz range. The dB-4345 TWTA provides 325 W CW output power with 55 dB minimum gain across 2 to 6 GHz, and the companion dB-4311M covers 6 to 18 GHz, providing 300 W CW output with 55 dB minimum gain. Using a wideband, periodic permanent magnet focused, conduction-cooled TWT, the amplifiers support CW and constant envelope, AM, FM and pulse-modulated signals. The TWTA power supply is a low noise, high efficiency design that minimizes any interference to the RF signal path. Both models operate from single phase, 220 VAC power, although the prime power can be customized.

Each TWTA has an embedded microcontroller with an Ethernet interface for control and protection. However, the fault diagnostics and status indicators are integrated in the amplifiers, so outside controllers and interconnect cabling are not required. The TWTAs can be configured with standard or custom interface protocols rather than Ethernet. Another available option is RF gain control.

Established in 1990, dB Control designs and manufactures reliable, high-power TWTAs, microwave power modules, transmitters, high voltage power supplies and modulators for radar, electronic countermeasures and datalinks. The company also performs contract manufacturing and repair depot services from its 40,000 sq. ft. facility, including transformer winding and testing, full vacuum encapsulation, pressure cure and conformal coating. A subsidiary of HEICO Corp., dB Control specializes in mission-critical—often sole-source—products to military organizations, defense contractors and commercial manufacturers.

dB Control Corp.
Fremont, Calif.
www.dBcontrol.com
info@dBControl.com

Platforms Speed 4G/5G/ Network Development

CommAgility has a new reference platform for LTE mobile device or user equipment (UE), enhanced its existing LTE eNodeB platform and released a new graphical LTE Management Tool. The reference platforms provide an integrated, fully tested solution combining CommAgility processing hardware and 3GPP LTE software, delivering a low-cost starting point for system development and deployment useful for 4G/5G researchers, product developers and LTE network engineers. The new platforms help build LTE solutions, particularly private and custom networks, reducing the time to market and lowering development cost. To support system deployment, CommAgility can provide fully customized hardware and software for the particular LTE or 5G application.

As an example, LTE is well-suited to SATCOM, with low-cost equipment available due to economies of scale, mission-critical traffic handling and the end-to-end security built into the 3GPP specifications. 5G satellite applications are already being studied while the standard is evolving, with requirements such as delivery optimization and high availability being considered. However, developers creating satellite communications systems must extend beyond the LTE standard or early 5G specifications, which requires flexible hardware and expertise with the physical layer (PHY) and protocol stack, for which these new platforms are ideal.

CommAgility's industry-leading LTE PHY and stack software is provided in binary format, including the recently-announced 3GPP Release 15 version of the SmallCell-STACK protocol stack. The LTE Management Tool provides an easy-to-use graphical user interface, which enables straightforward system evaluation, configuration and monitoring. The CA-D8A4-RF4 UE reference platform provides a high performance LTE UE with up to 300 Mbps download and four integrated transceiver channels supporting any frequency between 410 MHz and 6 GHz. The platform's software-defined ability to alternatively function as an LTE eNodeB or UE with different software and firmware loads highlights its flexibility.

CommAgility, A Wireless Telecom Group Company
Loughborough, U.K.
www.commagility.com/products/systems/lte-ref-ue

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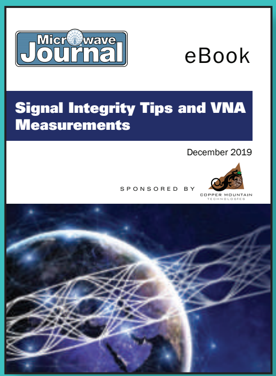

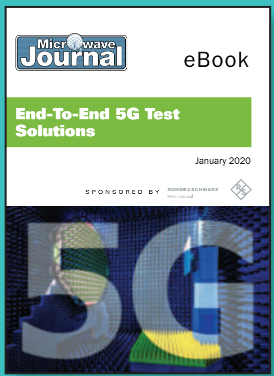

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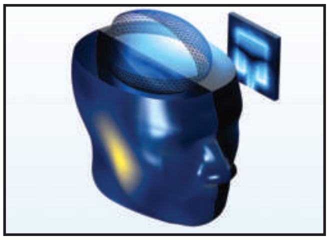
Software and Mobile Apps

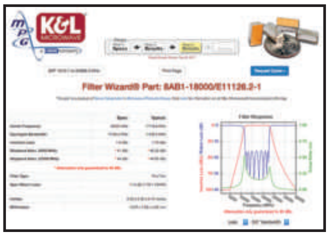
COMSOL Updates RF Module



The RF Module, an add-on to the COMSOL Multiphysics® software, analyzes RF, microwave, mmWave, and THz designs in various multiphysics scenarios. The RF Module optimizes impedance matching and far-field gain pattern of antennas, and insertion loss and coupling effects of passive circuits in the application area of 5G and IoT. The EM simulation can be extended to perform multiscale modeling with ray tracing. It is possible to include other physics phenomena, such as temperature increase with absorbed radiation, and structural deformation induced by heat expansion.

COMSOL
www.comsol.com/rf-module

On-Line Filter Synthesis Tool



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

K&L Microwave
www.klfilterwizard.com

COMPLETE+3D Library™ v19.6

VENDORVIEW

Modelithics has released Version 19.6 of the Modelithics COMPLETE+3D Library for use with ANSYS HFSS. The update adds 117 full-wave 3D electromagnetic models to a large selection of highly scalable models for capacitor, inductor and resistor families from many popular suppliers, with an expanding collection of Modelithics' 3D geometry models for Coilcraft and TDK inductors and a connector model for SV Microwave. Through the MVP Program, free model use for 90 days is sponsored by Coilcraft, TDK and Würth Elektronik; 30-day trials are offered by Exxelia, Vishay and Knowles for the DLI and Syfer models.

Modelithics Inc.
www.modelithics.com/

RF Tool App

VENDORVIEW

The "RF Tools" app is useful not only for customers but also to sales people, engineers and technicians. It shows the relation between RF specific values like impedance, wavelength, return loss (VSWR) and signal delay, including their conversion. On top of this, the app includes the RF cable assembly calculator which allows an easy comparison of up to three out of more than 320 HUBER+SUHNER RF cables. The iPhone app is available for free in English and Chinese.

HUBER+SUHNER
www.hubersuhner.com/en/services/apps

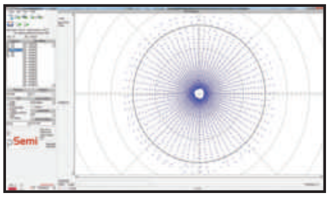
MCL Microwave Calculator App

VENDORVIEW

The MCL Microwave Calculator, developed by Mini-Circuits, performs 21 calculations commonly needed by RF and microwave system designers in a wide range of applications. Quickly compute the effect of VSWR or return loss on transmitted power; cascaded gain and noise figure for up to five amplifier stages; and power-to-voltage conversion. It is the perfect tool to help you solve problems and save time, whether you are working in the lab or in the field.

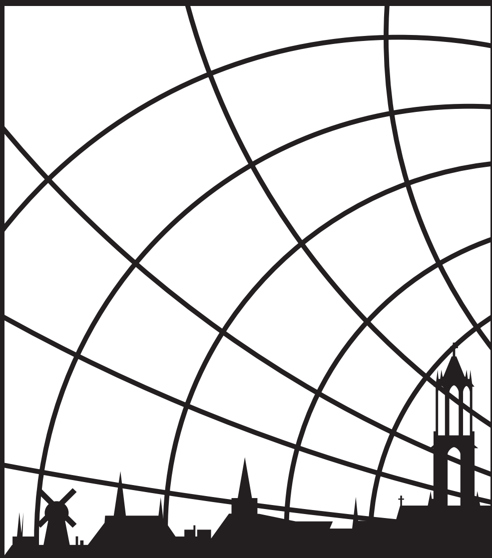
Mini-Circuits
www.minicircuits.com/applications/microwave_calculator.html

sNpViewer to Assist 5G and RF Measurements



pSemi Corp. (formerly Peregrine Semiconductor), a Murata company, is offering the industry free beta software for viewing S-parameters. The pSemi sNpViewer allows for in-depth S-parameter viewing graphically. This comprehensive viewer includes Smith, polar, magnitude, phase and phase vs. amplitude charting. Time-domain analysis is also available. The pSemi sNpViewer allows you to perform searches through thousands of S-parameter files to determine and record optimal performance. The LUT feature can be especially useful for 5G beamforming or for any other device where a phase and/or amplitude LUT is required.

pSemi Corp.
www.psemi.com/snpviewer



NEW PRODUCTS

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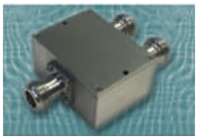
COMPONENTS

Resistive Power Divider

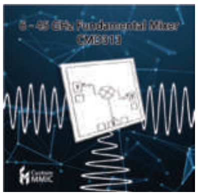


BroadWave Technologies unveiled a new resistive power divider featuring an operating frequency range of DC to 6 GHz. Model 152-215-002 is a 50 Ω, 2-way power divider. This unit has an average power rating of 2 W with 1.5:1 max VSWR. The insertion loss is 6 dB ±1.5 dB nominal, the operating temperature range is 0°C to +70°C and RF connectors are N female. BroadWave Technologies manufactures a wide variety of resistive power dividers in 2-, 3-, 4-, 5-, 6- and 8-way configurations.

BroadWave Technologies Inc.
www.broadwavetechnologies.com

Wideband Double Balanced Mixers

VENDORVIEW



Custom MMIC continues the rapid expansion of its standard product portfolio with three new additions to its GaAs MMIC mixer portfolio. The CMD312, CMD313 and CMD253 are wideband GaAs double balanced mixers, operating from 4 to 28, 6 to 45 and 6 to 14 GHz, respectively. These new MMICs are intended to support emerging wide bandwidth applications in test equipment, instrumentation, aerospace and defense. All three mixers feature low conversion gain and high isolation performance.

Custom MMIC
www.CustomMMIC.com

RF Surge Protectors

Fairview Microwave Inc., an Infinite Electronics brand, has unveiled a new line of coaxial surge protectors created to guard valuable communications equipment from power surges and indirect lightning strikes. Fairview's new RF surge protectors are offered with either male-to-female or male-to-male 4.3-10 connectors. This product line features low insertion loss, max input power as high as 500 W and multi-strike capability.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Dual Directional Coupler

VENDORVIEW

KRYTAR announced the continued expansion of its line of dual directional couplers with the addition of a new model offering 10 dB of coupling over the broadband frequency range of 10 to 46 GHz, in a single, compact and lightweight package. KRYTAR's new dual directional coupler expands the family of superior performance products offering ultra-broadband coverage in compact packages. Model 510046010 is a multi-purpose, stripline design that exhibits excellent coupling over the 10 to 46 GHz frequency band.

KRYTAR Inc.
www.krytar.com

IQ Mixers

Marki Microwave introduced three new IQ mixers. The MMIQ-0218H offers an impressive 2 to 18 GHz RF/LO, DC to 3 GHz IF, IIP3 of +25 dBm and is also available in L-diode. The MMIQ-1040S has a 10 to 40 GHz bandwidth, DC to 12 GHz IF, IIP3 of +27 dBm and is also offered in L-diode. The MMIQ-1865S is an 18 to 65 GHz mmWave IQ mixer with a wide DC to 23 GHz IF, IIP3 of +27 dBm and available in L-diode and H-diode as well.

Marki Microwave Inc.
www.markimicrowave.com

26 to 34 GHz mmWave 2-Way Power Divider

MECA expanded offering of 5G mmWave products. Featuring 2-way power dividers covering 26 to 34 GHz with 2.92 mm interfaces. Typical specifications of 1.3:1 VSWR, 22 dB isolation, 1.5 dB insertion loss and 0.4 dB amplitude balance. Also available are attenuators, terminations, bias tees, DC blocks and adapters. Additionally octave and multi-octave models covering up to 50 GHz built by J-Standard certified assemblers and technicians. Made in U.S. and 36-month warranty.

MECA Electronics
www.e-meca.com

18 to 40 GHz Ultra-Wideband & High Precision Programmable Attenuators

Mitron has developed ultra-wideband and high precision programmable attenuator covering 18 to 40 GHz. The user can control the attenuation via USB and Ethernet with 0.1 dB step, 50 dB attenuation dynamic range, 0.2 dB attenuation accuracy over whole band. Custom designs are available over 0.5 to 40 GHz frequency range, 50 to 120 dB dynamic range. Built-in AC-DC power module with small size 227 × 114 × 50 mm. It can support DLLs.

MiCable
www.mitron.cn

Comprehensive 5G Solution Portfolio

VENDORVIEW

Pasternack, an Infinite Electronics brand, announced a comprehensive portfolio of 5G RF solutions serving the urgent needs of engineers and technicians around the world with high-grade RF components and cable assemblies shipped same-day to support 5G innovation, testing and deployments. The "RF Components for the Next Generation" suite is comprised of thousands of active, passive, interconnect and antenna products supporting global sub-6 GHz and mmWave frequency band applications.

Pasternack
www.pasternack.com

Bi-Phase Modulator

VENDORVIEW

PMI Model No. BPM-2640-180-292FF is a bi-phase modulator operating over the 26 to 40 GHz frequency range. This model offers insertion loss of 8 dB typical while maintaining a typical amplitude balance of ±4 dB, VSWR of 2:1 typ., 3:1 max, switching speed of 100 ns max, phase variation of ±40° typ. and power handling up to 20 dBm operational. Compact housing measures 1 × 1 × 0.5 in. and has 2.92 mm female connectors.

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

New**Products**

Pickoff Tees

RLC Electronics manufactures pickoff tees which offer excellent through-line insertion loss and pickoff stability rise times of < 10 picoseconds (at 40 GHz). Units are offered in standard frequency ranges from DC to 18, DC to 26 and DC to 40 GHz, with the option to customize the pickoff insertion loss value to meet customer specific requirements. The units provide extremely broadband signal monitoring in a very small package (0.54 × 0.39 × 0.32 in.). RLC offers both catalog options and customized options, and can provide form factor drop-in replacement/obsolescence assistance as needed.

RLC Electronics Inc.
www.www.rlcelectronics.com

Passive Multiplier

Model SFP-08215-S2 is a F-Band, ×2 passive multiplier that utilizes GaAs Schottky, beam-lead diodes and a balanced circuit configuration to generate second order harmonics with good harmonic and fundamental suppression. This multiplier requires an input frequency range of 45 to 70 GHz at +16 dBm RF power to yield typical 90 to 140 GHz at +2 dBm typical output power.

SAGE Millimeter
www.sagemillimeter.com

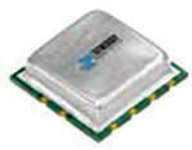
Front-End Modules

VENDORVIEW

Skyworks introduced the SKY85772-11, a new addition to their family of front-end modules (FEM) that are designed for growing retail, carrier and enterprise Wi-Fi 6 applications. The 5 GHz FEM offers best-in-class power and linearity for devices such as access points, routers and gateways. The module's logarithmic power detector allows for wide dynamic power range and its harmonics are FCC compliant, reducing filtering requirements. The solution also delivers 2 dB higher gain, improving linearity when compared to system-on-chip (SoC) architectures.

Skyworks
www.skyworksinc.com

6-Way Power Divider



DFS-9B1 is a 6-way power divider, capable of splitting a signal in the frequency range of 1 to 100 MHz with less than ±0.2 dB of amplitude unbalance across the band. The small surface mount RoHS compliant package measures 0.945 × 0.945 × 0.33 in. with ENIG finished termination. Features include an input power handing of 1 W max when used as a power splitter, isolation of 25 dB min. across the band, insertion loss of 0.9 dB max above the theoretical split loss, phase balance between outputs of 3° and a VSWR of 1.2:1 typical across the band.

Synergy Microwave Corp.
www.synergymwave.com

CABLES & CONNECTORS

Multi-Position Coaxial and Signal Cable Assemblies

Response Microwave Inc. announced the availability of multi-position D38999 coaxial and signal cable assemblies for lab and both military and telecom specific product platform use. Assemblies can be supplied with up to 24 individual cable inserts with connectors and cable types specific to signal or power requirements and frequencies between DC to

18 GHz. Multiple header connector and back-shell options available as well as varied interface for inserts. Custom variants available upon request. Suitable for lab or field environments.
Response Microwave Inc.
www.responsemicrowave.com

Unique Cable Offers Flexibility to 40 GHz

VENDORVIEW

RFMW announces design and sales support for RF cable assemblies capable of small radius bends near the connectors. The P1CA-29M29M-ST085-12 cable assembly is part of P1dB's Tight-Flex™ cable assembly series. With a minimum bend radius of 0.2 in., the cable allows bends at the connector end eliminating the need for a right-angle connectors in some applications. The P1CA-29M29M-ST085-12 measures 12 in. with 2.92 mm male connectors on each end. The ST085 Tight-Flex cable is triple shielded coax with 0.104 in. (2.6 mm) diameter.
RFMW
www.rfmw.com

AMPLIFIERS

Power Amplifier Module

COMTECH PST introduced a new ultra-wideband high-power solid-state RF module. Comtech's latest development continues to expand on its proven innovative integrated RF GaN power amplifier designs by further increasing the bandwidth and power density. Consistent with its planned technology development roadmap, Comtech introduced the latest in GaN-based 4 to 18 GHz RF amplifier. This highly integrated design is ideal for use in communication, EW and radar transmitter systems where space, cooling and power are limited. This unit is ideal for UAV/airborne, ground mobile, surface and shipboard applications.
Comtech PST
www.comtechpst.com

Pulse Amplifier

VENDORVIEW

Exodus Advanced Communications' pulse amp is designed for pulse/HIRF mil-std 461/464 and radar applications. Other frequency ranges and power levels available all providing superb pulse fidelity. It covers 4 to 8 GHz, produces 5000 W pulse, 100 usec pulse width up to a 6 percent duty cycle. A min. gain of 67 dB, monitoring parameters for forward/reflected power, voltage, current and temperature sensing for outstanding reliability and ruggedness. Rack integrated for ease of application integration.
Exodus Advanced Communications
www.exoduscomm.com

High Dynamic Range MMIC Amplifier

VENDORVIEW

Mini-Circuits' TSS-13LN+ ultra-high dynamic range MMIC amplifier provides industry-leading noise figure and IP3 from 1 MHz to 1 GHz. An internal shutdown feature protects the amplifier in the presence of pulsed signals while keeping the power supply at constant voltage to minimize DC power consumption. This model provides 1.1 dB noise figure and +39.2 dBm IP3, making it ideal for maximizing sensitivity and dynamic range in high performance receiver applications. It delivers 22.8 dB typical gain with ±3 dB flatness and +19 dBm output power at 1 dB compression. The amplifier is fabricated using E-PHEMT technology with excellent repeatability. It operates on a single 8 V supply and comes housed in a tiny 12-pad 3 × 3 mm QFN package.
Mini-Circuits
www.minicircuits.com

All-in-One 5G mMIMO RF Power Amplifiers

Richardson RFPD Inc., an Arrow Electronics co., announced the availability and full design support capabilities for the comprehensive RF power multi-chip module (MCM) portfolio for 5G mMIMO from NXP Semiconductors. These devices are part of NXP's 5G Airfast solutions product family and include LDMOS power amplifier modules, GaAs pre-driver modules and receiver modules for cellular frequency bands from 2.3 to 3.8 GHz, with output power from 3 to 5 W.

Richardson RFPD Inc.
www.richardsonrfpd.com

Common-Drain Dual N-Channel 60 V MOSFET

Vishay Intertechnology Inc. introduced a new common-drain dual n-channel 60 V MOSFET in the compact, thermally enhanced PowerPAK®1212-8SCD package. Designed to increase power density and efficiency in battery management systems, plug-in and wireless chargers, DC/DC converters and power supplies, the Vishay Siliconix SiSF20DN offers the industry's lowest RS-S(ON) in a 60 V common-drain device. The dual MOSFET released today provides RS-S(ON) down to 10 mΩ typical at 10 V, the lowest among 60 V devices in the 3 × 3 mm footprint.

Vishay Intertechnology Inc.
www.vishay.com

PACKAGING

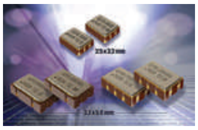
Assembly Services

StratEdge Corp. announces its assembly services for attaching GaN and other high frequency, high-power devices using gold-tin (AuSn) and gold-silicon (AuSi) onto copper-molybdenum-copper (CMC) tabs. StratEdge's proprietary eutectic die attach method maximizes the power output a chip can achieve, optimizing its performance and providing an efficient way to dissipate heat to avoid overheating and failures during normal operation.

StratEdge Corp.
www.stratedge.com

SOURCES

Crystal Oscillators



Q-Tech Corp. introduces the QT723 and QT735 Series of space qualified crystal oscillators, offering satellite and spacecraft designers exceptional performance in the industry's smallest surface-mount packages. These new space, Low-Earth Orbit (LEO) oscillators are 50 kRad (Si) total dose ionization radiation hardened, high shock (20,000 g) resistant and screened per MIL-PRF-55310, Level B with PIND.

Q-Tech Corp.
www.q-tech.com

Direct Synthesizer

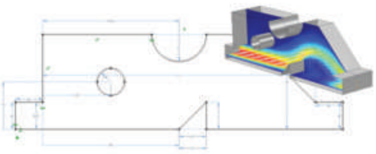
VENDORVIEW

RFE's 0.1 to 20 GHz high speed wideband direct synthesizer with 300 nsec tuning speed features DDS based tuning and has a phase coherent option. For EW/SIGINT, radar test equipment, microwave radio and instrumentation module applications.

RFE
www.rfe-mw.com

SOFTWARE

Version 5.5 of COMSOL Multiphysics®



COMSOL announces the latest version of its COMSOL Multiphysics® software. In version 5.5, the design module provides an entirely new sketching tool for easier creation and more versatile parametric control of geometry models. New and updated solvers speed up a wide range of simulations. Two new add-on products, the Porous Media Flow Module and the Metal Processing Module, further expand the product suite's multiphysics modeling power.
COMSOL Inc.
www.comsol.com

3D Geometry Model

VENDORVIEW

Modelithics has introduced a new set of full-wave EM capable 3D geometry models for Coilcraft's 0603CS surface mount air coil inductor series. The model is now available within Modelithics COMPLETE+3D Library for ANSYS HFSS™. Individual 3D models are available from 1.6 to 390 nH and are validated against multi-substrate measured S-parameters through 20 GHz and equivalent series resistance (ESR), as well as against the corresponding Modelithics CLR Global Circuit model. As Coilcraft is a Sponsoring Modelithics Vendor Partner (MVP), free 90-day trials of all available Modelithics Coilcraft models are available to qualified customers by request.
Modelithics
www.Modelithics.com/MVP/Coilcraft

ANTENNAS

GPS Timing Antennas and UHF Antenna

L-com has introduced a new line of GPS timing antennas and a 118 to 174 MHz tunable, telescopic antenna to address the need for mobile wireless, portable instrumentation and wireless monitoring applications. L-com's new GPS/GLNSS antennas provide accurate reception of satellite timing signals and reference frequencies for use in advanced network applications. The new HG110TEL-BNC portable UHF antenna provides high performance in the UHF frequency range of 118 to 174 MHz, is field tunable and features a telescopic radiator and flexible support mast.
L-com
www.l-com.com

COMMUNICATIONS

Ultra-Performance Receiver

The SIR-4000 uses the latest DSP technologies to meet the specific needs of the end user. Elcom recognized that in today's real-time threat environment one size does not fit all. The company's goal was to provide the end user a tool that could cover a wider frequency range (up to 40 GHz) and instantaneous bandwidth (up to 2 GHz) critical to RWR applications.
FEI-Elcomtech
www.fei-elcomtech.com

MICRO-ADS

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Diplexers
Delay Equalized
Surface Mount
Lowpass
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Root Cosine
Equalizers
Linear Phase
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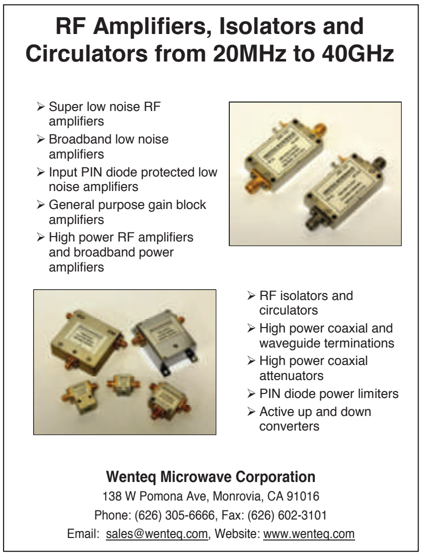

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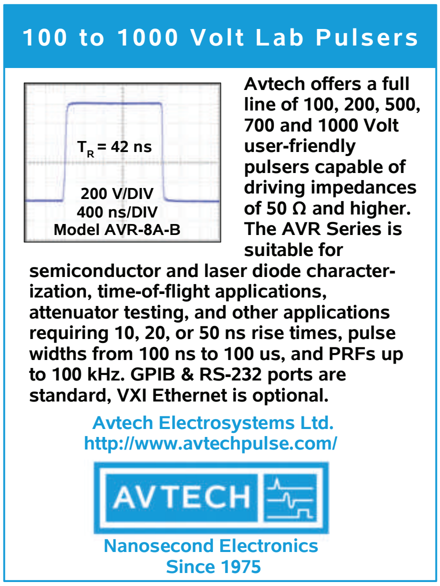

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5G and Satellite Spectrum, Standards, and Scale

Geoff Varrall

This resource presents the emerging role of Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geostationary satellites (GSO) as a delivery option for backhaul and wide area rural and urban mobile broadband and fixed access. The book offers insight into recently established Non Terrestrial Network standards. Readers learn which bands will need to be supported in next-generation 5G and satellite devices and networks and how the bands will be characterized. Channel spacing, guard bands, FDD or TDD, out of band emission limits and in-band performance requirements are discussed. The book discusses what interference issues will arise from new band allocations including co-shared allocations and how interference will be mitigated in and between next-generation terrestrial and satellite 5G networks. Readers learn how modulation choices will affect co-existence issues.

The book discusses the design, performance, cost and test implications of integrating next-generation satellite physical and MAC layers with Release 16 and 17 5G standards and explores how these emerging spectrum and standards map on to IoT and MTC use cases in specific vertical markets. Readers learn how new active and passive antennas in the K-, V- and W-Band (E-Band) impact the satellite link budget and satellite delivery cost economics.

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FABS and LABS

MVG Upgrades Testing Labs To Meet 5G Requirements

Since its creation in 1986, The Microwave Vision Group (MVG) has developed a unique expertise in the visualization of electromagnetic waves. These waves are at the heart of our daily lives: smartphones, computers, tablets, cars, trains and planes—none of these devices and vehicles would work without them. Year after year, the Group develops and markets systems that allow for the visualization of these waves, while evaluating the characteristics of antennas and helping speed up the development of products using microwave frequencies. The Group's mission is to extend this unique technology to all sectors where it will bring strong added value. MVG is structured around three departments: AMS (Antenna Measurement Systems), EMC (Electro-Magnetic Compatibility), EIC (Environmental & Industrial Control). MVG is present in 10 countries and generates 90 percent of sales from exports.

MVG has upgraded and extended its measurement labs for customers who do not have their own facility, and has relocated seven of its 15 sites to fuel innovation and accommodate more efficient, customer-centric testing methods. New locations have been established by MVG teams in San Diego, Philadelphia and Atlanta in the U.S., plus Manchester, Munich, Paris and Brest across Europe. Also, the company's Paris headquarters now boasts a sizable production area with a 12 m ceiling height, specifically for the assembly and testing of large multiprobe arches is a world class facility. This was a result of a 36 month program of investment into MVG's testing, engineering and consulting sites across the globe.

The Paris facility is the jewel in the crown, with a production area capable of assembling and testing some of MVG's largest measurement equipment, in highly controlled, industry-leading conditions. This site is now home to six carefully designed testing labs for customers who do not have their own facility but want access to market-leading technologies for product development testing, measurement and certification.

MVG has a unique product; their StarLab 50 GHz is made to meet the high frequency testing challenge operating from 650 MHz to 50 GHz. Because it is compact and portable, it frees up space in laboratories and production environments and saves costs. This new version is a true revolution inside and out delivering ultra-fast and accurate test results, StarLab 50 GHz provides a future-proof turnkey solution for 5G system development and validation.

Stating that the time was right to invest in its infrastructure, MVG will continue to invest further in its other sites throughout 2020 and beyond to ensure its teams are best placed to serve customers from the aerospace and defense, automotive, consumer electronics, telecommunications and research and academic industries.

These strategic changes in MVG's portfolio of infrastructure assets will be used as a blueprint for further improvements over the coming years, to ensure that the Group is continually evolving their business in line with the specific requirements of their industry.

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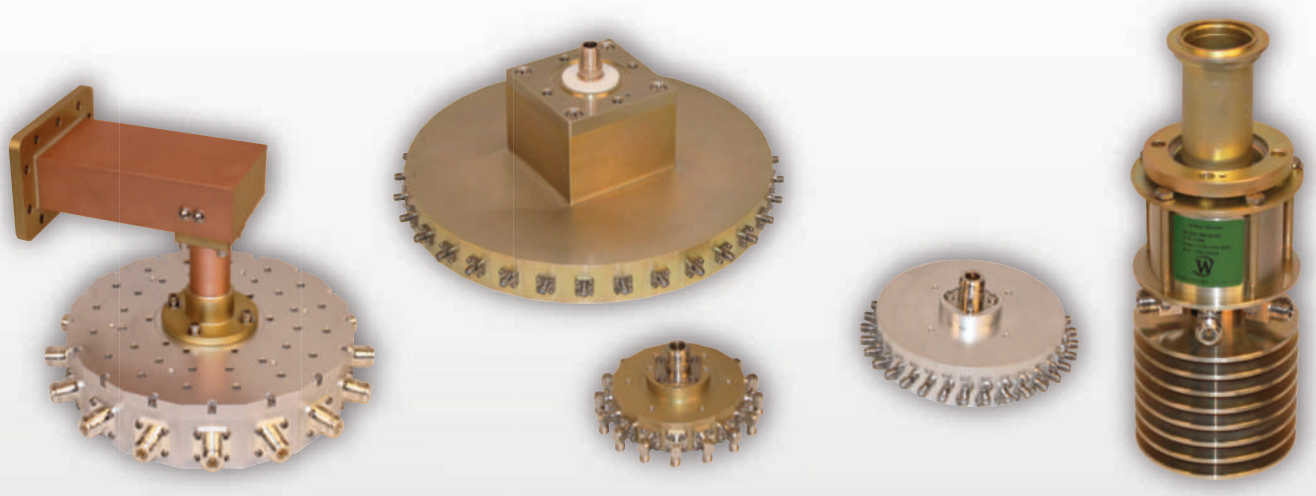
D8454	8-Way	370-450	10,000	50,000	0.25	1.30	3 1/8” EIA, N-Female
D5320	12-Way	470-860	500	5,000	0.3	1.30	All N-Female
D10119	4-Way	700-4200	2,000	15,000	0.3	1.35	13-30 DIN-Female, N-F
D10603	32-Way	900-925	50,000	150,000	0.15	1.25	WR975, 7/16-Female
D10795	32-Way	900-930	25,000	150,000	0.25	1.20	WR975, 4.3-10-F
D9710	8-Way	1000-2500	2,000	10,000	0.3	1.40	1 5/8” EIA, N-Female
D8182	5-Way	1175-1375	1,500	25,000	0.4	1.35	1 5/8” EIA, N-Female
D6857	32-Way	1200-1400	4,000	16,000	0.5	1.35	1 5/8” EIA, N-Female
D9529	8-Way	2305-2360	1,000	6,000	0.2	1.15	7/16-Female, N-Female
D9528	8-Way	2305-2360	2,000	12,000	0.2	1.15	7/8” EIA, N-Female
D11028	16-Way	2305-2360	2,000	20,000	0.2	1.15	1 5/8” EIA, N-Female
D10851	8-Way	2400-2500	8,000	50,000	0.2	1.25	WR340, 7/16-Female
D11433	16-Way	2700-3500	2,000	20,000	0.3	1.35	WR284, N-Female
D11815	16-Way	2700-3500	6,000	40,000	0.3	1.35	WR284, N-Female
D9582	16-Way	3100-3500	2,000	16,000	0.25	1.50	WR284, N-Female
D11839	16-Way	5300-5900	8,000	50,000	0.15	1.40	WR159, 7/16-Male



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