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August 2022

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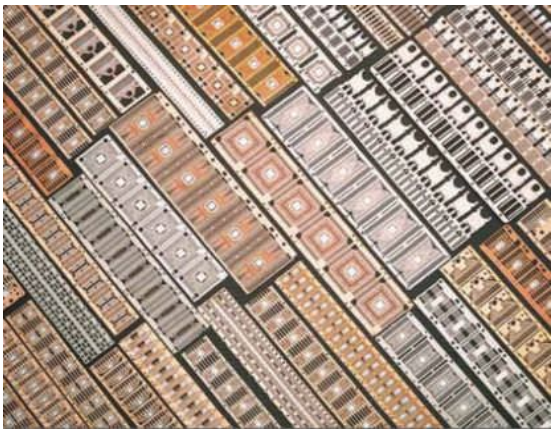

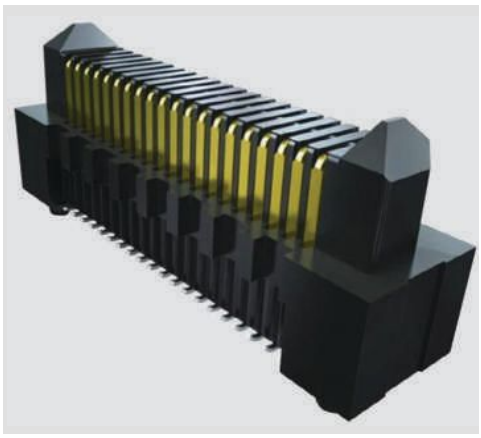

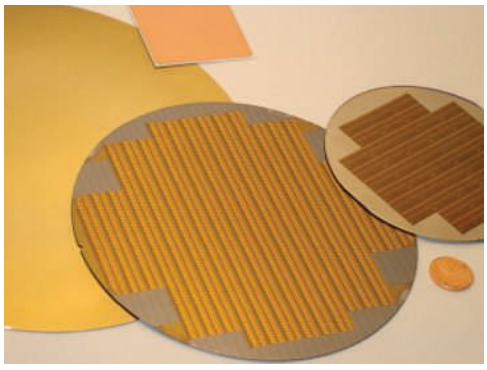

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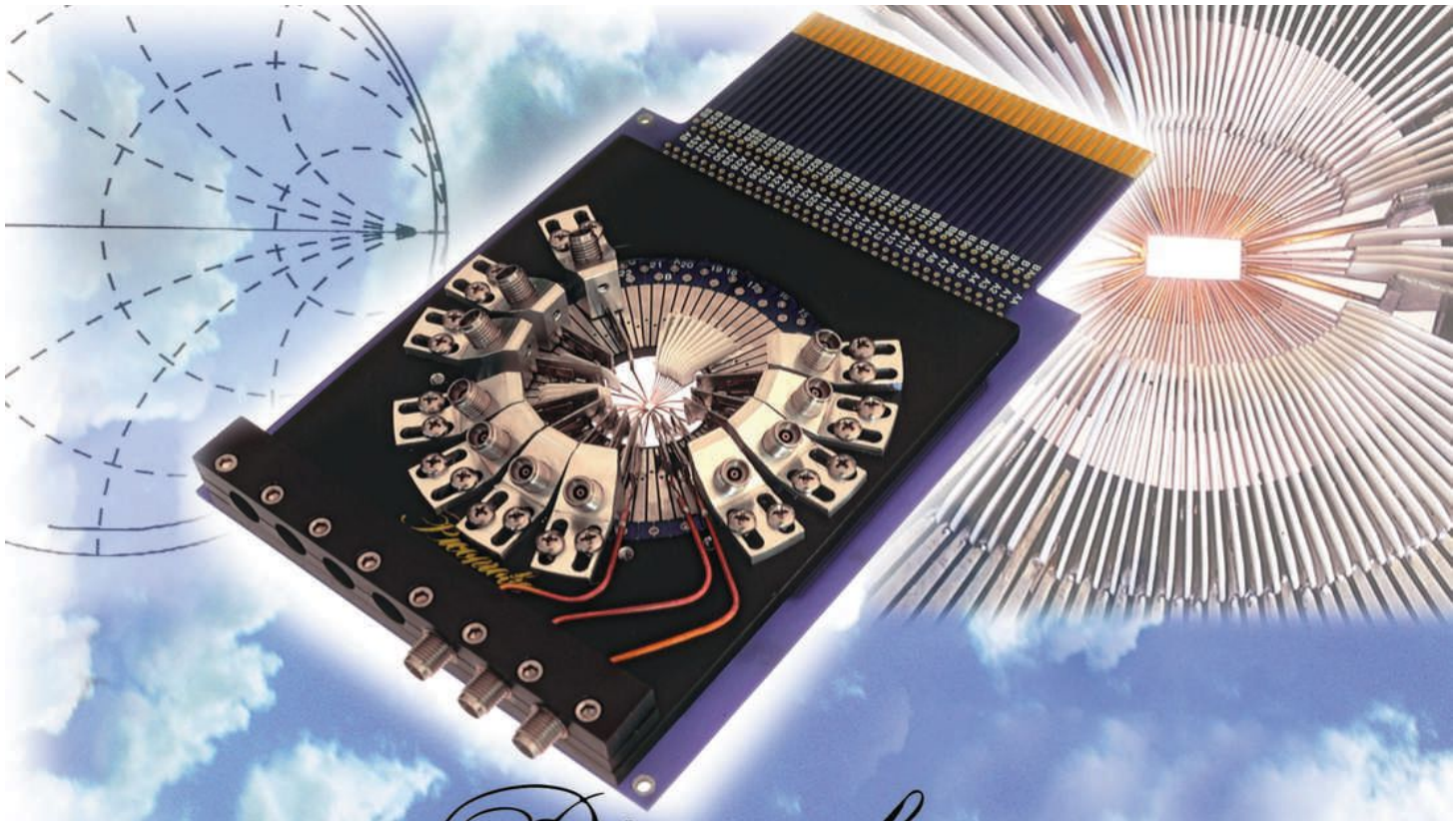

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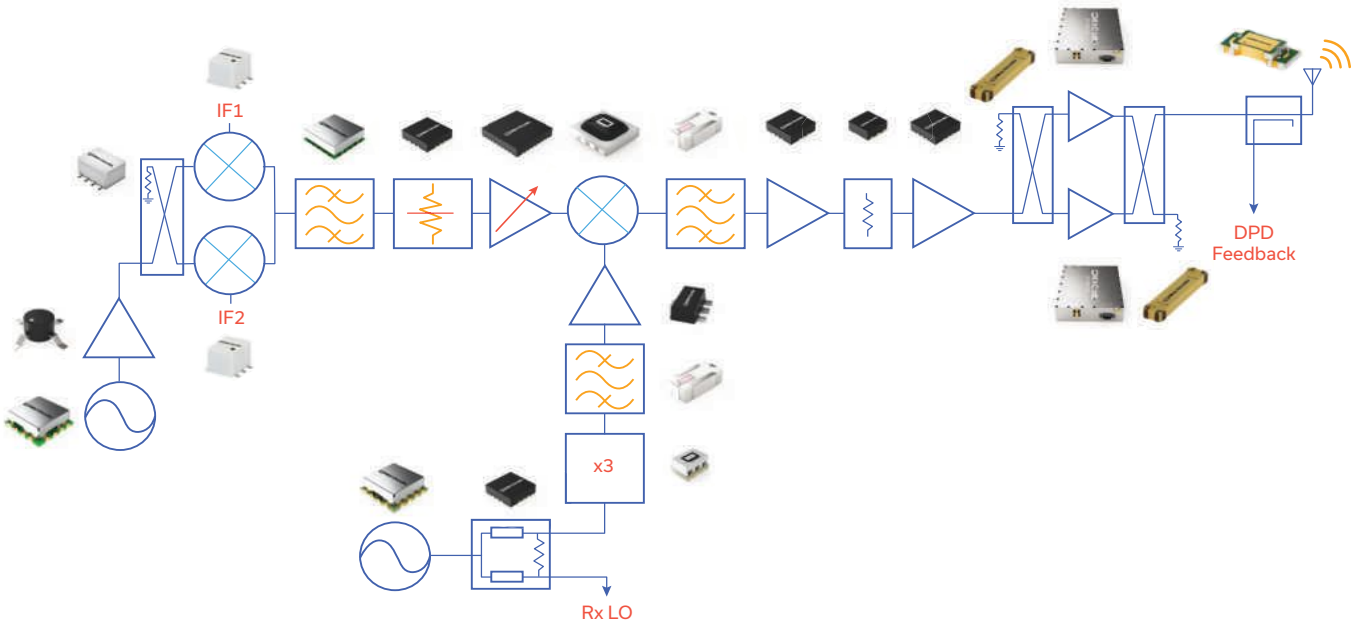

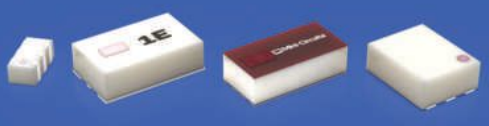

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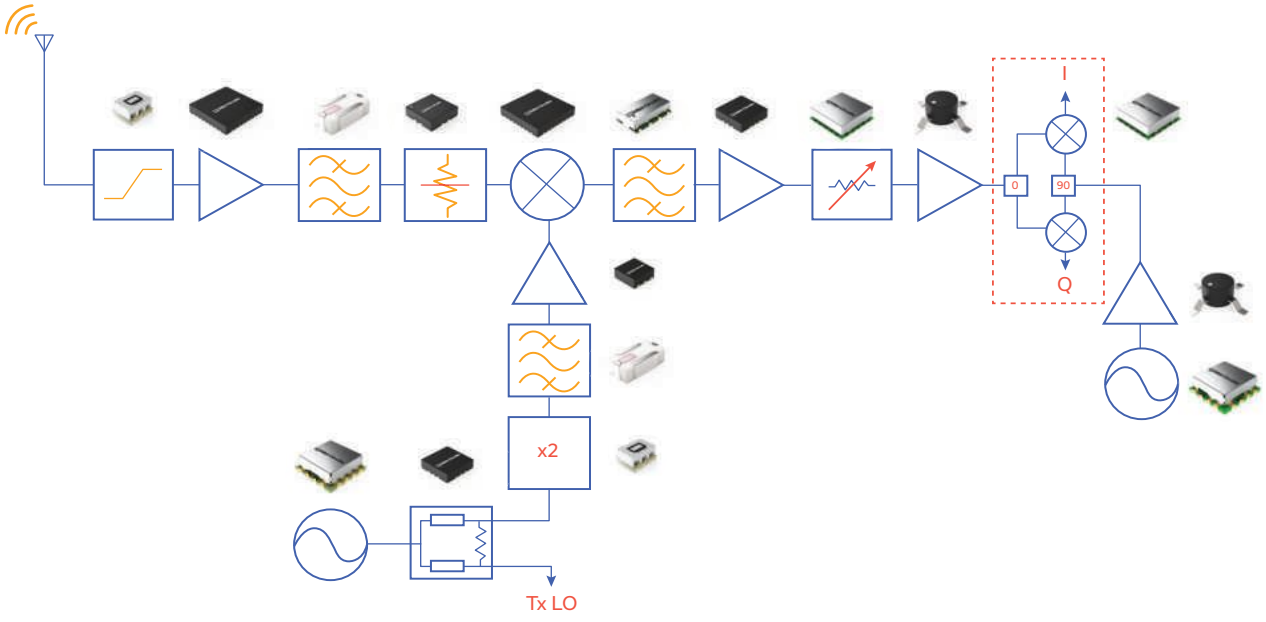

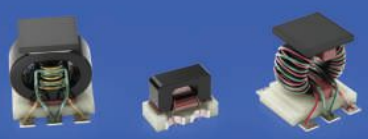

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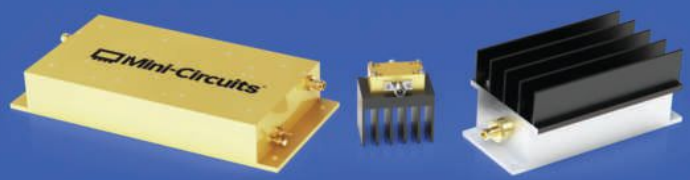

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Reza Rofougaran, Movandi

Marconi's Transatlantic Leap: 12 December 1901

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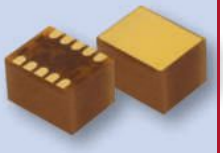

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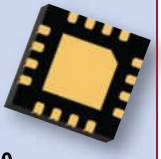

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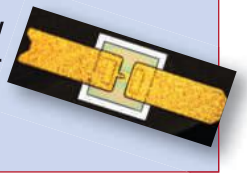

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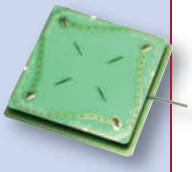

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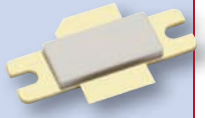

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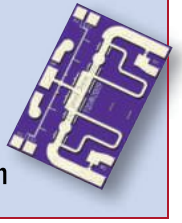

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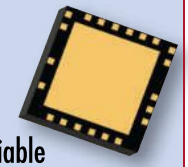

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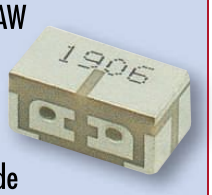

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CEO **Edgar Garay** and CTO **Sanghoon Lee**, co-founders of RFIC start-up Falcomm, share their vision of developing the most energy-efficient mmWave power amplifiers for 5G and how they aim to do it.

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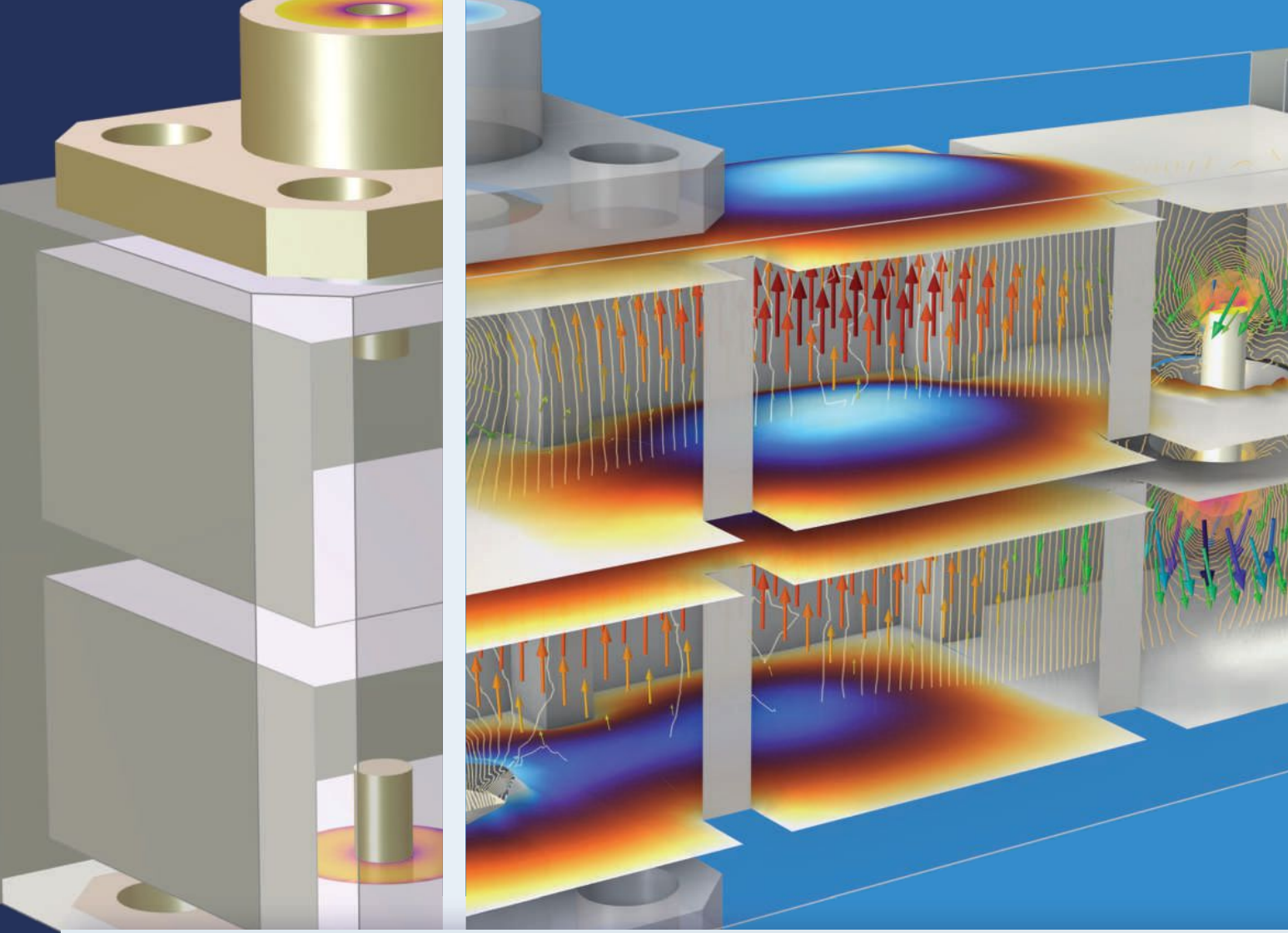

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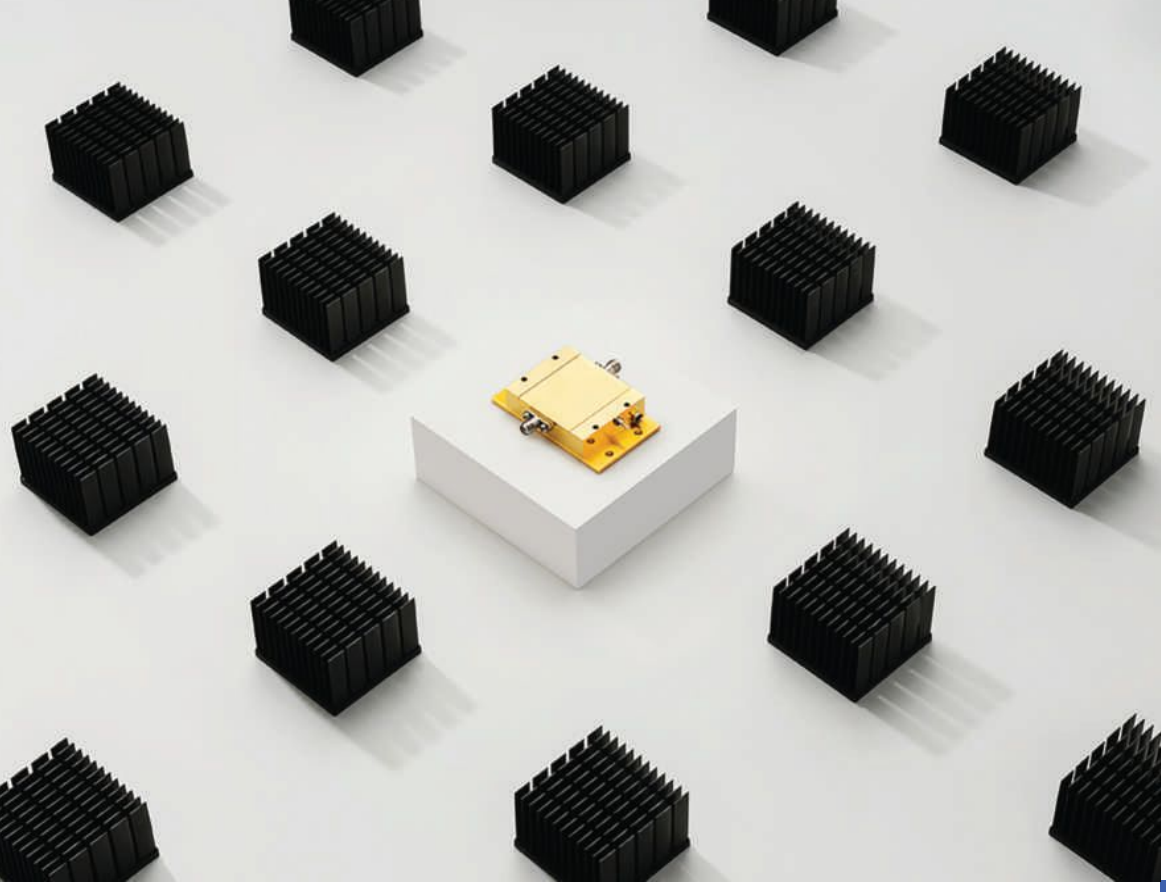

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TIME TRAVEL

Giuseppe Pelosi
University of Florence, Florence, Italy

Marconi's Transatlantic Leap: 12 December 1901

In 1901, Guglielmo Marconi (Bologna, Italy, 1874 – Rome, Italy, 1937) was 27 years old and had been working in radio communications for six years. Fresh from numerous successes and from the foundation of his "Marconi International Marine Communication Company" in 1900, he decided to attempt the leap of radio communication across the Atlantic Ocean, from Poldhu (Cornwall, U.K.) to St. John's (Newfoundland, Canada). Several years after, in 1932, he remembered this feat in an interview (the recording is still available):

On the morning of the 12th of December, everything was ready, and the decisive moment was approaching despite a very strong wind. After many unsuccessful attempts, a kite was flown that raised one end of the antenna to a height of about 120 meters. At 12:30 p.m., on the telephone of the receiver a rhythmic succession of the three points corresponding to the letter "s" of the Morse alphabet reached my ear from Poldhu station on the other side of the ocean, weakly but with such clarity as to leave no room for doubt. Radio telegraphy on the distance of more than 3000 kilometers, that seemed enormous at the time, had been possible despite the alleged obstacle of the Earth's curvature that everyone considered insurmountable (translated by the author).

Transatlantic transmission from the transmitting location (Poldhu, Cornwall, U.K.) to the receiving location (Signal Hill, St. John's, Newfoundland, Canada) on 12 December 1901.

Marconi (far left) witnessing the kite carrying the receiving antenna at Signal Hill, St. John's, Newfoundland, Canada.

Sources:
1. Marconi's speech [in Italian], Web, https://www.teche.rai.it/2015/04/guglielmo-marconi-1901/.
2. G. Bussey, "Marconi's Atlantic Leap," Cambridge University Press, Cambridge (U.K.), 2000.
3. K. Grandin, N. Olander, P. Mazzinghi, G. Pelosi, A Wireless World, One Hundred Years Since the Nobel Prize to Guglielmo Marconi, Contribution to the History of the Royal Swedish Academy of Sciences series, Florence University Press, Vol. 42, 2012.

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From Reconfigurable Intelligent Surfaces to mmWave Beamforming

Geoffroy Lerosey
Greenerwave, Paris, France

Commercializing a disruptive technology that was born in an academic laboratory is not an easy task. Greenerwave, the start-up co-founded by Professor Mathias Fink and Geoffroy Lerosey, is a good example. It originally spun-off in 2016 from our laboratory, Institut Langevin, to develop and sell products based on our findings on the concept nowadays called reconfigurable intelligent surfaces (RIS). Yet the concept was too early. It had no market or business model and, facing a technological barrier, had to pivot. This led to developing a unique beamforming application that was energy efficient and flexible and has significant applications, notably at mmWave.

TIME REVERSAL AND WAVE CONTROL

Wave control is Greenerwave's DNA. Professor Mathias Fink started his career in the 1970s working on novel beamforming approaches for ultrasonic imaging. In the 1990s, fascinated by the physics of waves propagating in multiple scattering media, he proposed the concept of time reversal. Based on the time reversal invariance of the wave equations, it consists in recording the impulse responses between a source and a set of receivers after propagation in or through a complex medium, flipping them in time and sending them back.[1] This results, very strikingly, in the focus of the waves in space and time at the position of the original source, onto a spot whose quality is directly linked to some key parameters of the experiment: number of channels used for time reversal, bandwidth and complexity of the propagation medium.

Generally, due to reciprocity, the operation is realized the other way: an array of programmable sources, named a time reversal mirror, plays the role of a source that can focus on multiple receivers. Time reversal was demonstrated in ultrasonics to be a powerful method to harness the complexity of a multiple scattering medium, enabling wave focusing on much sharper spots than those obtained in homogeneous media.[1,2] Later, time reversal was shown to permit spatial multiplexing onto multiple receivers over the same frequency range in complex media and, subsequently, proposed as an efficient solution for wireless communications—an early demonstration of mMIMO with ultrasound (see ***Figure 1a***).[3]

Between 2004 and 2006, while getting a Ph.D. with Fink, Lerosey transposed the ideas originally developed for ultrasound to electromagnetic waves at microwave frequencies. Recording and digitizing waves at GHz is significantly more challenging than at MHz. Consequently, we introduced the idea of baseband time reversal, recording and flipping in time the impulse response between a source and receiver at baseband.[4-6] This plus a phase conjugation of the carrying frequency results in a time reversal operation that would be realized on the real signals without needing out-of-reach electronics. Using this approach, we showed that time reversal of microwave signals propagating in complex media was feasible and could be a viable so-

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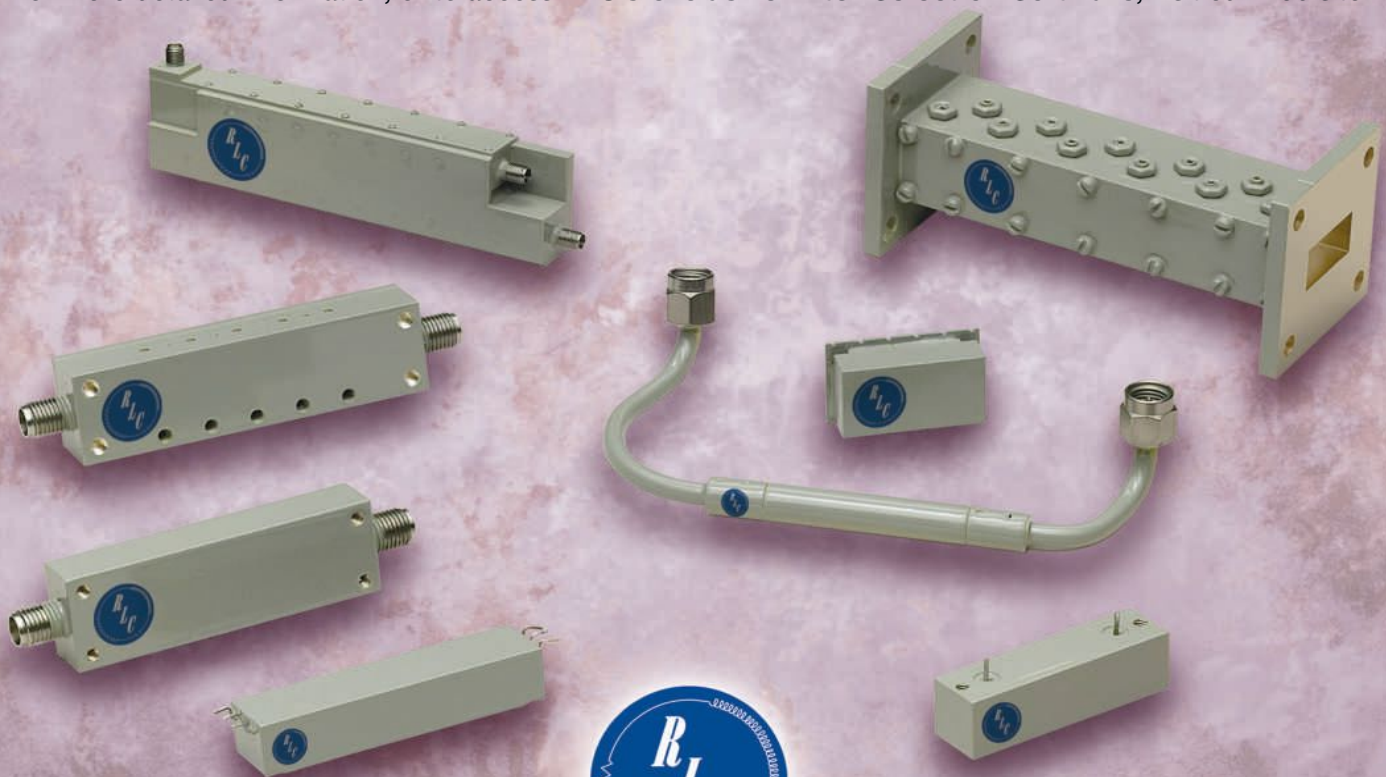

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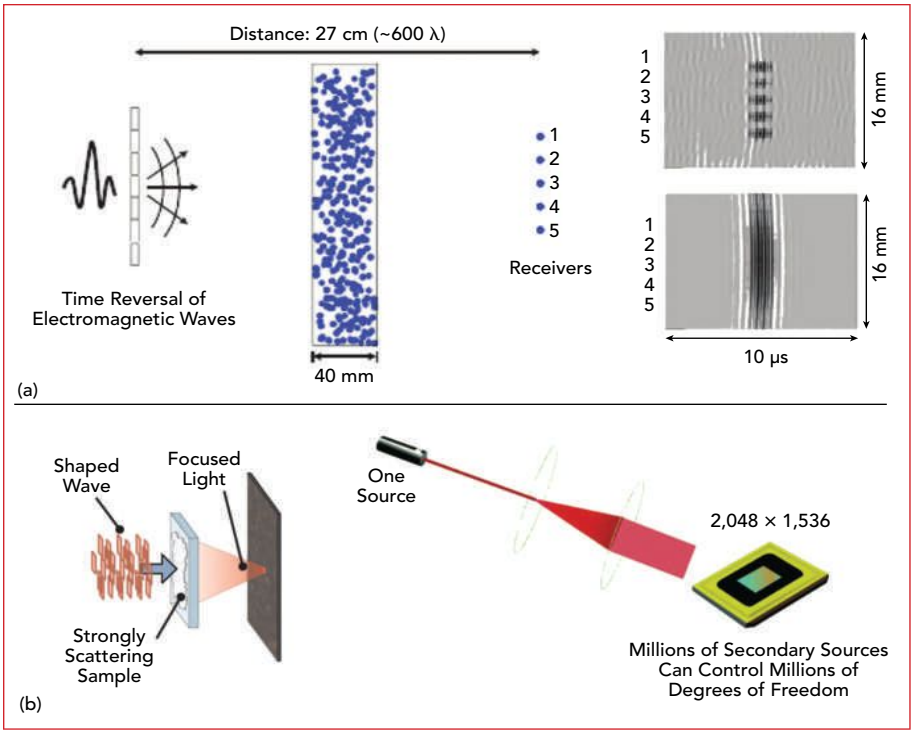

Fig. 1 Time reversal mirror enables spatial multiplexing on several users after propagation through a multiple scattering medium, while it doesn't through water (a). Wavefront shaping with a spatial light modulator focuses light, even after propagation through a thick layer of paint; instead of complex sources, millions of secondary sources in reflection are used (b).

lution for wireless communications, especially with relatively wide bandwidths.[7]

We eventually founded a company, Time Reversal Communications, aimed at turning these concepts into commercially viable products. Yet it turned out to be complex: At this time, fading and multipath in complex environments had found a powerful solution with OFDM, and almost all wireless communications systems went from the time to the frequency domain. Another barrier to the adoption of our technology was its complexity, resulting in expensive and power-hungry systems. A base station would require numerous channels, each with power amplifiers, low noise amplifiers and data converters. We realized that while controlling waves was a "must have" in wireless communications, unlike ultrasonic imaging, cost and efficiency were more important.

FROM ACTIVE TO PASSIVE WAVE CONTROL

We developed a solution while working in optics. Colleagues from the Netherlands, fascinated by what time reversal enabled in ultrasound and microwaves, were working to transpose the concept to light. In this domain, building a large array of transceivers capable of acquiring and generating time-varying signals is impossible. So they changed the paradigm, realizing while lacking complex and powerful sources of light, they did have powerful dynamically reconfigurable reflectors of light, used in adaptive optics and astronomy. They used spatial light modulators (SLMs), arrays of millions of unit cells that can control the phase and/or the amplitude of an impinging optical wavefront to control light propagation through complex media. Their seminal contribution was a shock to us, as they demonstrated they could focus a red laser beam through a thick layer of paint by inserting an SLM between the laser and layer of paint and shaping the wavefront of the incident light—introducing the concept of wavefront shaping (see ***Figure 1b***).[8] Their work and the demonstrations we did[9-12] opened

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a new research area in optics that is still active. To Fink and Lerosey, it was a revolution: why would one design very complex arrays of sources to control waves, when a simple reconfigurable reflector would do so?

RECONFIGURABLE INTELLIGENT SURFACES

When Fink came back from vacation in his countryside house in late August 2012, complaining about poor reception with his mobile, we started thinking about improving wireless communication without adding complexity to the base station or the mobile. Inspired by our work in optics, we pursued the idea of making the propagation environment "electromagnetically smart" and using it to enhance and improve the energy efficiency of wireless transmissions. We only needed to design a surface with dynamically reconfigurable electromagnetic properties and to use it, like in optics, as a spatial microwave modulator to shape the incident electromagnetic waves at will. We could make any indoor or outdoor environment "smart" by covering it with these surfaces and dynamically harness the reflections.

Using our knowledge of wave physics and wave control, we decided on the simplest tunable surface: a binary phase tunable surface. Experiments in optics taught us that crude control yields relaxed hardware and faster optimizing algorithms. Similarly, exploiting our metamaterial background, we devised a very simple unit cell. It consisted of a main patch resonator strongly coupled to a parasitic stripline resonator, whose resonance frequency was controlled by a PIN diode. By polarizing the diode, we could change the unit cell phase reflection from 0 to π in real time with extremely low power consumption. The unit cell was fabricated and characterized using inhouse equipment and gave satisfying results: a π phase shift between its two states at Wi-Fi frequencies, with similar dissipation in both states.[13]

We assembled 102 unit cells on a homemade printed circuit board and controlled these elements using two Arduino controllers. To our knowledge, this was the first RIS demonstration, even though the term was coined years later by the wireless communications community. The idea was to show we could shape the electromagnetic waves propagating inside a room after emission by a simple source—a monopole on a ground plane—to maximize the electromagnetic energy received by a remote and non-line-of-sight antenna, mimicking a tunable surface enhanced wireless transmission. To do so, we simply used the same iterative algorithms used in optics, maximizing iteratively the received energy while testing one by one for the best state of each unit cell (see ***Figure 2***). The results were striking: using this relatively small surface of 0.4 m^2 in a typical office room, we managed to increase the energy received by the antenna by about 10 dB while consuming only a milliwatt.[14] Look-

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P3T-500M40G-60-T-55-292FF	0.5 - 40	6	60	50 ns	+5 V @ 35 mA -5 V @ 15 mA	SP3T, Absorptive 1.0" x 1.0" x 0.5" 2.92mm (F)
P4T-100M53G-100-T-RD	0.1 - 53	6	100	50 ns	+5 V @ 200 mA -5 V @ 200 mA	SP4T, Absorptive 1.25" x 1.25" x 0.4" 2.4mm (F)
P5T-500M40G-60-T-55-292FF-5G40G	0.5 - 40	8	60	40 ns	+5 V @ 55 mA -5 V @ 45 mA	SP5T, Absorptive 1.25" x 1.25" x 0.4" 2.92mm (F)
P6T-2G18G-60-T-512-SFF-LV	2 - 18	4	60	50 ns	+5 V @ 121 mA -12 V @ 33 mA	SP6T, Absorptive 1.5" x 2.0" x 0.4" SMA (F)
P7T-0R8G18G-60-T-SFF-SMC	0.8 - 18	4.3	60	75 ns	+5 V @ 300 mA -5 V @ 100 mA	SP7T, Absorptive 1.5" x 1.5" x 0.7" SMA (F)
P8T-100M54G-90-T-RD	0.1 - 54	9	90	50 ns	+5 V @ 400 mA -5 V @ 300 mA	SP8T, Absorptive 1.6" x 1.68" x 0.4" 2.4mm (F)
P9T-500M40G-60-R-55-292FF-OPT1222	0.5 - 40	6.5	60	100 ns	+5 V @ 450 mA -5 V @ 75 mA	SP9T, Reflective 4.5" x 1.5" x 0.4" 2.92mm (F)
P12T-0R5G18G-60-T-SFF	0.5 - 18	5	60	100 ns	+5 V @ 300 mA -5 V @ 100 mA	SP12T, Absorptive 6.0" x 2.0" x 0.4" SMA (F)
P16T-100M52G-100-T-DEC	0.1 - 52	18	100	100 ns	+5 V @ 1100 mA -12 V @ 720 mA	SP16T, Absorptive 8.0" x 3.0" x 0.77" 2.4mm (F)
P20T-7G18G-80-T-515-SFF-SP	7 - 18	7.5	65	250 ns	+5 V @ 500 mA -15 V @ 200 mA	SP20T, Absorptive 4.0" x 4.0" x 0.63" SMA (F)
P32T-0R5G18G-60-T-SFF	0.5 - 18	9.5	60	100 ns	+5 V @ 1450 mA -5 V @ 200 mA	SP32T, Absorptive 8.0" x 3.5" x 1.0" SMA (F)


P6T-2G18G-60-T-512-SFF-LV


P7T-0R8G18G-60-T-SFF-SMC


P8T-100M54G-90-T-RD


P9T-500M40G-60-R-55-292FF-OPT1222


P12T-0R5G18G-60-T-SFF


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ing at the spectrum of the received signal before and after optimization, we clearly saw the 10 dB increase in gain over a frequency range defined by the coherence frequency of the room, about 100 MHz. Scanning the field with an electrooptic probe to avoid perturbations by the measurement, we could demonstrate the field reflected by the room had been focused on the receiving antenna.

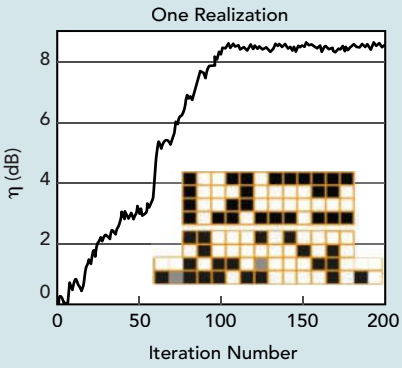

Fig. 2 The first reconfigurable intelligent surface developed at Institut Langevin in 2012, which increased the received signal by almost 10 dB.

THE BIRTH AND ALMOST DEATH OF GREENERWAVE

After filing a seminal patent and publishing a paper, we started to showcase our findings from the Institut Langevin laboratory, which received interest from both internal researchers and external visitors. By limiting the measurement time of the test equipment, we could almost optimize the transmission between two antennas in real time and plot it live. The effect was stunning as people realized that smarter environments could potentially lead to greener and much more efficient wireless communications. The strong enthusiasm, as well as believing that our concept was unique, led us to found Greenerwave early in 2016, aiming to commercialize products based on these ideas. As physicists, we didn't know about business models or product-market fit, and we thought that the technology was self-sufficient enough to start a successful company. After raising half-a-million euros, we hired a CEO to operate the company and make it a success, while we stayed in academia and provided support as consultants. We believed with a proof of concept enhancing wireless communications on a standardized protocol, we would easily raise another round of financing, much larger this time, to make the company a success.

Company efforts went first to realizing industry compatible RIS with the potential for the mass market. Electromagnetic designs and physics-based control algorithms were tackled by the academics on the Institut Langevin side, while the hardware (layout and controller) and embedded software were engineered in the start-up. Exploring various designs and contacting many suppliers verified that the technology had the potential for mass market. The problem came from the control part of the RIS: the algorithms to optimize wireless connectivity on a device using them require feedback quantifying the link quality, which could be obtained from the network or the device. Starting on smart dynamical electromagnetic surfaces for 4G, we quickly realized that proving anything with signals coming from a cellular base station would be extremely challenging: the network can modify many parameters during a session with a device (e.g., frequency, gain). Any optimization would be inefficient without involving the network operator and infrastructure provider.

So we decided to move to Wi-Fi and use device feedback, designing RIS at 2.45 and 5 GHz. Our

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strategy was to develop something close to a product as soon as possible using only the data available from the operating system of the devices as feedback; the received signal strength indication (RSSI) was the only readily accessible parameter. However, optimizing Wi-Fi connections between an access point and laptop was not easy, since we first had to disable all the automatic functions of the access point, such as automatic gain control and MIMO. Like in our 4G trials, the automatic functions would have acted in an asynchronous and uncontrolled manner versus the RIS. Doing this, we were able to show nice RSSI optimization and subsequent data rate improvement in the laboratory (see ***Figure 3***), which almost convinced us that the convincing demonstrator was close.

Using RSSI, the demonstrator proved unstable in many cases and useless in some. Those familiar with such systems know the only good estimators of wireless link quality are secret, deep inside chipsets and obtained with proprietary and unique algorithms. RSSI, which is transmitted to the operating system, is very noisy and unstable, especially when numerous Wi-Fi networks coexist. This explains why the approach failed. We asked the large chipset manufacturers for access to the deep levels of the chipsets, but our emails were unanswered. RIS was not well known and unproven, Regrettably, RIS for infrastructure and networks had no market and no business model, and a consumer device—in laptop covers, for example—would not make it to the market due to the technical barrier. Greenerwave had no convincing demonstrator, could not raise more funds and was going bankrupt.

DISRUPTIVE MMWAVE BEAMFORMING

As the inventor of the technology and founder, Lerosey decided to take a leave from academia to save the company. Besides finding cash, the most urgent matter was finding other applications for our core: electronically reconfigurable surfaces with physics-based algorithms to control them. In academia, we had studied the properties of cavities made reconfigurable with tunable metasurfaces. We used surfaces with controllable electromagnetic properties as reconfigurable boundary conditions in cavities.[15–17] Several ideas emerged that were investigated with a new partner, Timothée Laurent, who brought 10 years of experience as a strategy consultant at Kearney. One of the ideas that made sense was to make the cavity leaky and use it as an electronically steerable antenna for 5G or satellite communications.

The steerable antenna works as follows: waves are injected inside the cavity using a basic source, the tunable metasurface shapes the generated wavefield inside the cavity and the field leaks out through openings in the cavity, forming a beam in a chosen direction. Jean-Baptiste Gros quickly assembled a proof of concept using a 5 GHz

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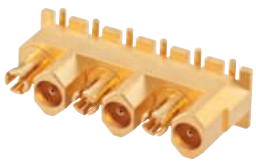

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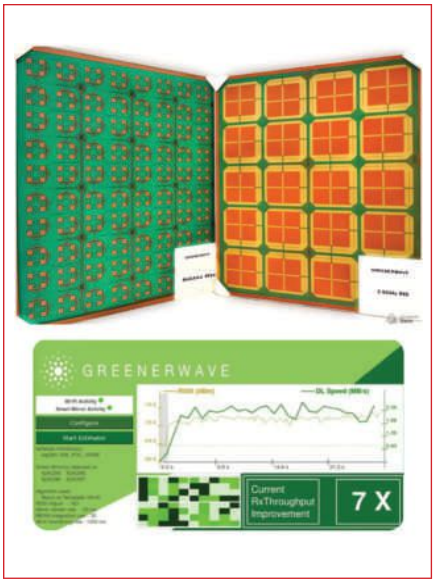

Fig. 3 Greenerwave developed RIS for Wi-Fi to optimize the data transfer from an access point to a laptop, showing a 7x improvement back in 2016.

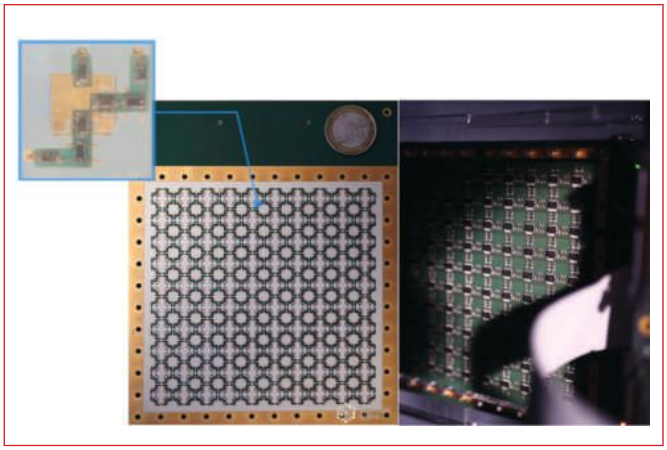

Fig. 5 The first Greenerwave mmWave RIS developed for an electronically steerable antenna.

Going from GHz to mmWave was not easy, but we had our first tunable 27 to 31 GHz electromagnetic surface by the end of 2019 (see ***Figure 5***), which used the simple binary phase shift design with dual polarization control. We assembled our first antenna at the beginning of 2020, a 10 × 10 × 2.5 cm^3 prototype fed by a monopole in one of its corners (see the right hand photo in Figure 4). To realize the leaky part of the cavity, we used a semi-transparent RF mirror made of copper mesh on a substrate, which we spatially tuned to be more transmissive at the center than on the borders, which was intended to taper or apodize the beams.

We only realized the unique potential of the technology after testing it. First, we could verify that despite the small size of the antenna and the very crude binary phase control of the tunable surface, we could form beams in any direction, with directivity only a few dB below the theoretical limit. Second, the antenna could support a bandwidth only limited by the tunable surface, i.e., more than 4 GHz. We

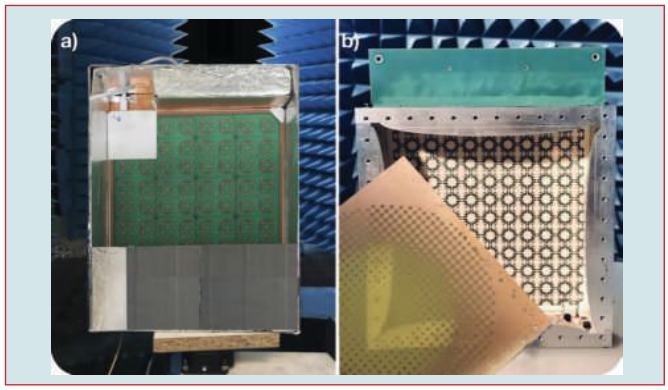

Fig. 4 The proof of concept for an electronically steerable antenna using the 5 GHz RIS developed for Wi-Fi (left) and the equivalent version 2 years later at 30 GHz (right).

tunable surface designed for the Wi-Fi RIS, putting it in a metallized MacBook box with a simple monopole. The result was impressive: using a bunch of Si PIN diodes and a very simple printed circuit board design, we realized an electronically steerable antenna that could be as flat as a conventional active phased array (see ***Figure 4***). Impressed, the French Defense Agency provided funding to apply the concept to demonstrate a beamformer around 30 GHz.

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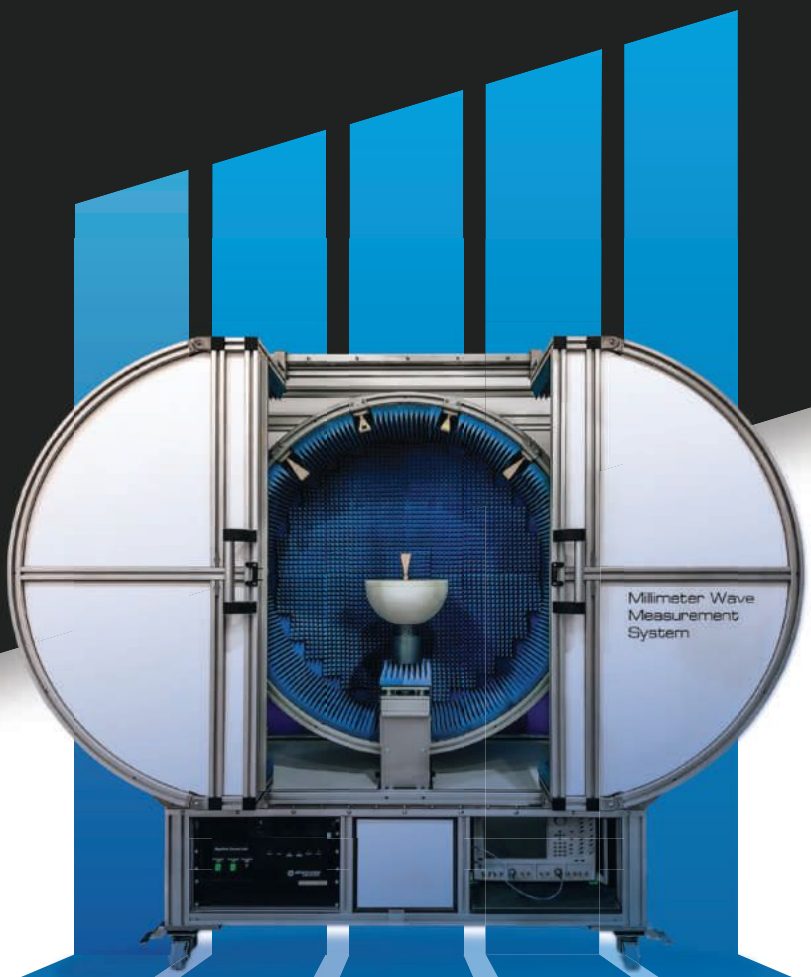

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measured instantaneous bandwidths from 300 MHz to 2 GHz that could be software-controlled (see ***Figure 6a***). Third, the scan range of the antenna was ±70 degrees with the scan loss defined by the cosine law, with control over any polarization and its purity (see ***Figure 6b***). This unique characteristic results from the design of the antenna: the whole field created inside the cavity radiates to the far-field through the very tiny holes of the leaky mask, outperforming phased arrays that are limited by the radiation pattern of their individual radiators. Fourth, we demonstrated the antenna could emit multiple beams at a single frequency, at different frequencies, even on orthogonal polarizations (see ***Figure 6c***). A slightly modified antenna showed that hybrid beamforming is possible with minimal crosstalk, by sending four beams from four feeds at the same frequency. Last, the beamforming proved very robust to reducing the number of diodes inside the cavity; the sidelobes remain well controlled with 25 percent or 50 percent of the unit cells not active (see ***Figure 6d***).

The mmWave prototype convinced us of the advantages of the technology: a flat electronically steerable antenna with hardware nearly as simple as passive phased arrays, very low power consumption and high efficiency. Beam switching is as fast as with an active phased array and has unique features such as multi-beam, multi-polarization and multi-band capabilities, all controlled by software. The antenna is conformable to any shape, compatible with any front-end design and protocol/standard agnostic because it is based on wave control.

SATCOM AND AUTOMOTIVE APPLICATIONS

We scaled the antenna to 30 × 30 × 2.5 cm^3 and engineered a more homogeneous feed consisting of a leaky waveguide around the perimeter of the cavity. The new design, which required a few iterations and was completed mid-2021, covered 27 to 31 GHz, consumed approximately 30 W and had the same properties as the first prototype (see ***Figure 7***). It established a datalink with the French Defense Agency GEO satellite Athena-Fidus, leading the French Defense Agency (AID) and French Space Center (CNES) to fund further development of the

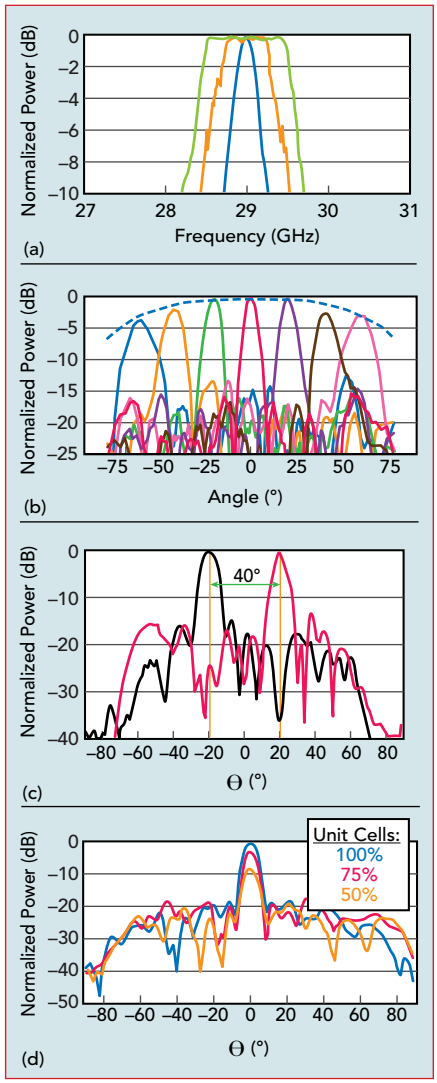

Fig. 6 **Electronically steerable antenna performance: tunable instantaneous bandwidth (a), scan angle and loss (b), multi-beam performance (c) and resilience to loss of unit cells (d).**

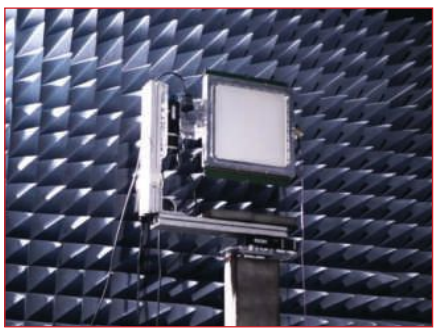

Fig. 7 **Ka-Band transmit antenna prototype, which established a link with the Athena-Fidus GEO satellite.**

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Waveguide Band (GHz)	WR28 26-40	WR19 40-60	WR15 50-75	WR12 60-90	WR10 75-110	WR8 90-140	WR6.5 110-170	WR5.1 140-220	WR4.3 170-260	WR3.4 220-330	WR2.8 260-400	WR2.2 330-500	WR1.5 500-750	WR1.0 750-1,100
Dynamic Range (BW=10Hz, dB, typ)	120	120	120	120	120	120	120	120	115	115	100	110	100	95
(BW=10Hz, dB, min)	110	105	110	110	110	110	110	110	110	105	80	100	80	75
Magnitude Stability (±dB)	0.15	0.15	0.10	0.10	0.10	0.15	0.25	0.25	0.3	0.3	0.5	0.5	0.4	0.5
Phase Stability (±deg)	2	2	1.5	1.5	1.5	2	4	4	4	6	6	6	4	6
Test Port Power (dBm)	13	13	13	18	18	16	13	6	4	1	-10	-3	-16	-23

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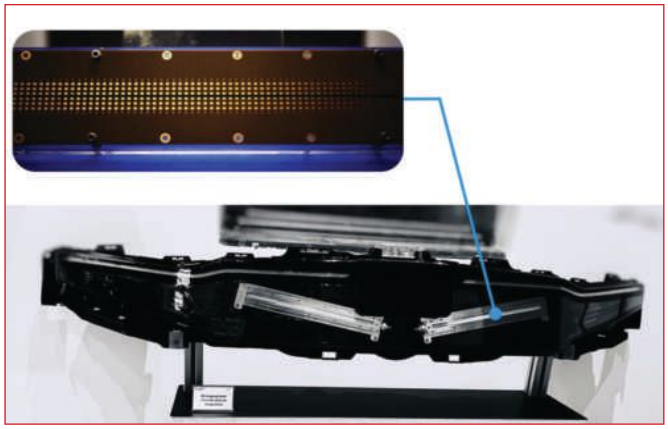

Fig. 8 **Tunable electromagnetic surface at 77 GHz (top) and integrated in a bumper as part of a beamforming radar (bottom).**

Ka-Band antenna. Greenerwave is funding development of a Ku-Band version, which is planned to be commercialized by the end of 2023. Because of the simplicity of the hardware, the antenna solves a significant problem each mega-constellation operator faces: the price of the ground terminal.

Our first 5 GHz proof of concept steerable antenna was also interesting to a French automotive supplier, Plastic Omnium. Its chief innovation officer saw the potential of the simple beamforming technology for mass market automotive applications, turning the conventional 77 GHz radar into a high-resolution 4D imaging radar. Embedded in Plastic Omnium's large vehicle body panels, an antenna built on Greenerwave's experience in ultrasound and optics imaging,[18] could be a game changer in the automotive market. A simple proof of concept at 7 GHz using our beamforming technology with time multiplexing and homemade algorithms turned a 1Tx/1Rx radar chipset into an imaging device. The performance of this prototype led to a more ambitious project to replicate the technology in the automotive radar band at 77 GHz, transforming an off-the-shelf 3Tx/4Rx radar chipset into a 4D imaging radar. The success of the 77 GHz prototype led to our current effort: integrating several beamformers with unique imaging algorithms in a bumper (see ***Figure 8***), intended to transform a conventional radar chipset into a cost effective, low-power, multi-mode 4D imaging radar.

THE FUTURE

Four years after a complete pivot and new start with a single employee, Greenerwave now employs more than 40, has multiple public contracts and private customers and a growing patent portfolio of some 12 patent families on various applications. Our near-term goal is to launch our satcom antennas, which requires a series A fundraising round. Meanwhile, we continue to explore business models from licensing to products, partnering with companies to apply our unique technology to antennas, automotive radar and RFID—an application without technical barriers and worthy of a future article.

Since Greenerwave was created to commercialize RIS, the technology has seen increasing interest for wireless communications, with standardization starting at ETSI and 3GPP.[19–22] Should RIS proceed to commercial deployment, we remain in a good position to re-enter the market. We have seminal patents years older than those of the competition, and they will be hard to bypass. Our RIS activities have been supported by European research grants in collaboration with companies such as NEC,

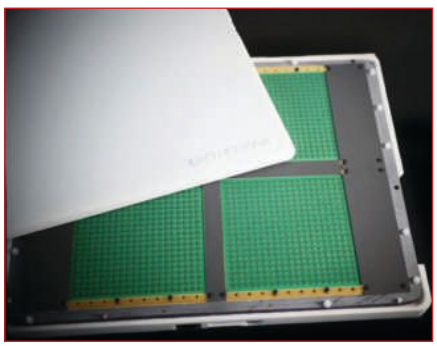

Fig. 9 **mmWave RIS for 5G, demonstrated as a passive access point extender and tested by NTT Docomo on a 5G base station.**

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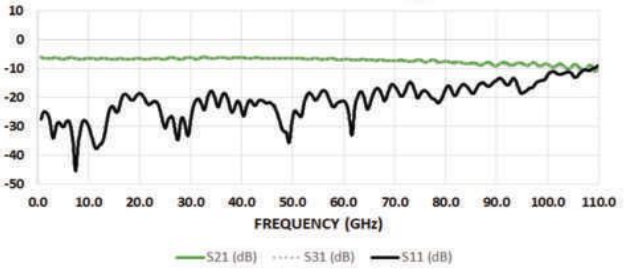

HL9449 Bias Tee

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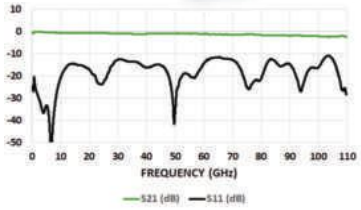

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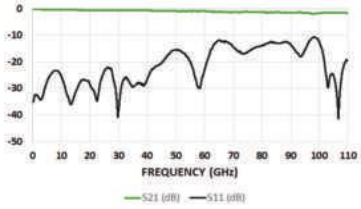

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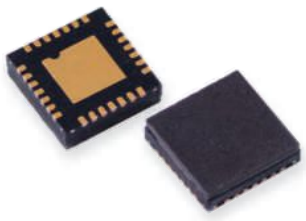
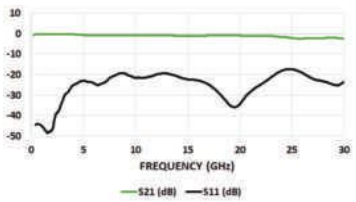
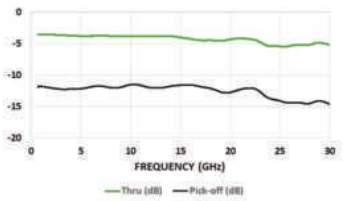


HL7041 SMD BIAS TEE



HL7061 SMD Z-MATCHED PICKOFF TEE



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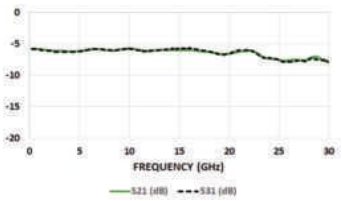

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Telecom Italia and Nokia. Our Ka-Band electronically steerable antennas are based on RIS inside a leaky cavity, so the R&D leading to steerable antennas is aligned with the development of RIS for mmWave 5G. We applied the technology to 5G beginning in 2019 through a collaboration with the Japanese firm AGC (see ***Figure 9***), demonstrated in various experiments.[23,24] AGC and NTT Docomo used our RIS as a passive access point extender for 5G mmWave networks at the end of 2021. Should the RIS market take off, we are ready for it.[25] ■

ACKNOWLEDGMENTS

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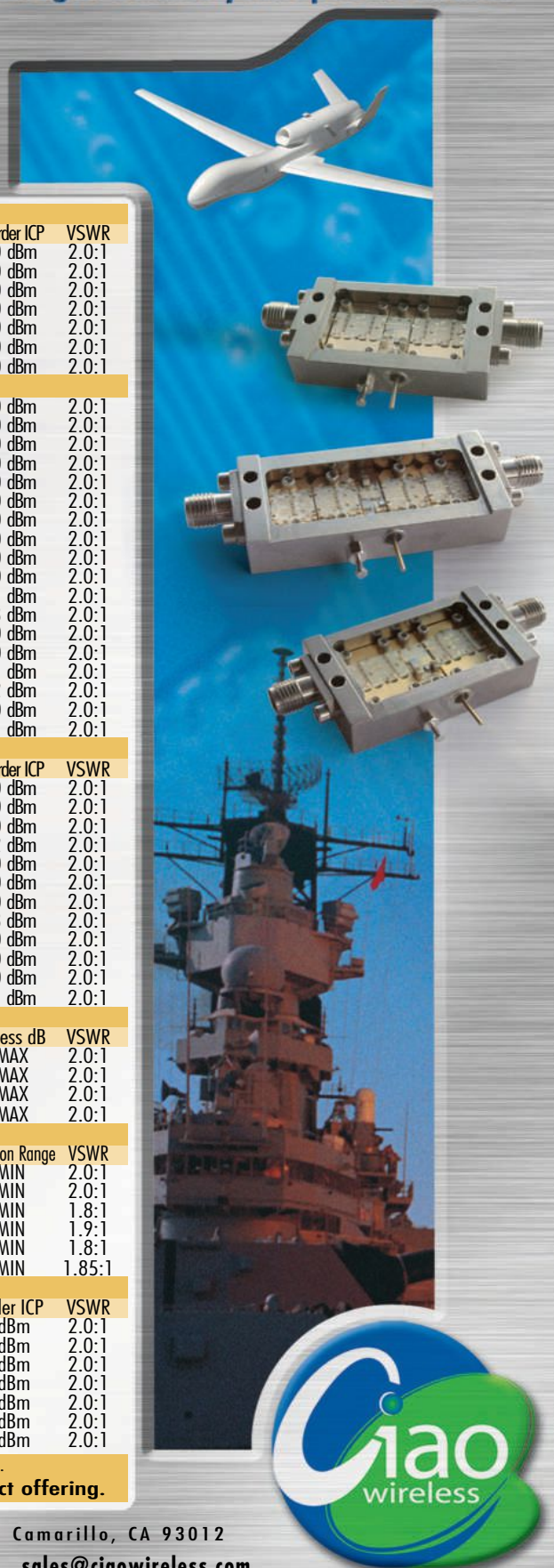

OCTAVE BAND LOW NOISE AMPLIFIERS

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

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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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Next-Generation Atomic Clocks for Civil and Defense Applications

Thales and SYRLINKS have signed an ambitious multi-year contract with the French defense procurement agency (DGA) to develop a new generation of very small, high performance atomic clocks.

Code-named CHRONOS, these new quantum clocks will meet the requirements of numerous civil and military applications. Thanks to their very high stability (error of less than 1 second in tens of thousands of years), defense electronics equipment will be able to operate when a GNSS signal is unavailable, for example due to hostile jamming.

Working with the procurement agency, the partners will help safeguard France's technological sovereignty in GNSS-denied positioning, guidance, navigation and ECCM-protected, encrypted military communications. In civil applications (5G network synchronization, transport, energy, etc.) the CHRONOS quantum clocks will deliver unprecedented price/performance to French and international customers.

Source: Thales

GNSS technology provides the precise time reference for critical infrastructure such as 4G/5G networks, Internet, air and rail transport, energy networks, global banking transactions, high frequency trading and satellites, which would quickly fail if the signal were unavailable. In view of this high level of dependency, back-up systems are needed to ensure that civil and military infrastructures can continue to operate even if the GNSS timing signal is unavailable.

Thales's industrial facility in Vélizy-Villacoublay and the Thales Research & Technology center in Palaiseau, both near Paris, have the right combination of industrial capabilities and talent to manufacture the atomic and optical core of these future quantum clocks.

SYRLINKS, based in Rennes, Brittany, specializes in satellite radiocommunications, radio navigation systems and miniature atomic clocks, and its products were selected to equip 650 satellites for the American operator OneWeb. The company will develop the electronic brain of the CHRONOS clock and guarantee its high precision timing function.

The Centre national de la recherche scientifique (CNRS) will provide critical scientific support for this project via its SYRTE (Observatoire de Paris) and Femto-ST (Université de Franche-Comté) joint research units.

The Israel MoD to Begin Testing a Robotic Unmanned Combat Vehicle

The Israel Ministry of Defense (MoD) will begin testing a robotic unmanned vehicle (M-RCV Medium Robotic Combat Vehicle), developed by the Ministry's Directorate of Defense Research and Development (DDR&D), the Tank and APC Directorate and Israeli security industries.

The vehicle includes a new robotic platform type BLR Mk2 made by BL, a 30 mm autonomous turret developed by the Tank and APC Directorate for the "Eitan" APC, Elbit's "Iron Fist" Active Protection System, fire control and mission management systems and a robotic autonomous kit, in addition to situation awareness systems. The vehicle also features a capsuled drone for forward reconnaissance missions and a passive sensing kit developed by Elbit Systems and Foresight.

The technology demonstrator, led by the MoD's DDR&D and the Tank and APC Directorate, integrates several cutting-edge technologies including advanced maneuvering capabilities, the ability to carry heavy and varied mission loads and a built-in system for transporting and receiving UAVs.

The vehicle will also incorporate sights, an IAI missile launcher and Rafael Advanced Defense Systems' "Spike" missiles. The M-RCV's capabilities include a highly autonomous solution for forward reconnaissance, and controlled lethality in all-terrain conditions. It is operational day and night in all-weather scenarios, while emphasizing operational effectiveness, simplicity, minimum operator intervention and integration into heterogeneous unmanned arrays.

Source: Israel Ministry of Defense

The system was developed as part of the autonomous battlefield concept led in the DDR&D in collaboration with the Tank and APC Directorate while implementing an open architecture for integrating future capabilities and integrating the robot alongside other tools and capabilities.

The system is a joint product of many years of investment by the DDR&D and the Tank and APC Directorate and is expected to start field tests during 2023 in representative scenarios.

Successful Troposcatter Communications Demo for the U.S. Army

Raytheon Intelligence & Space (RI&S), a Raytheon Technologies business, successfully demonstrated the next-generation,

For More Information

Visit mwjournal.com for more defense news.

Source: Raytheon Intelligence & Space

transportable beyond-line-of-sight (BLOS), Troposcatter communications system establishing high bandwidth, high stability communication links for the U.S. Army.

The wireless, point-to-point communications system delivers voice and command and control information to decision makers when tactical satellite communications are denied, degraded or unavailable—a critical communications capability that supports the Department of Defense's Joint All Domain Command and Control vision to connect the battlespace across every domain.

"The modernized Troposcatter system delivers more capability with increased throughput performance and low latency at a significantly lower cost," said Denis Donohue, president, Communications & Airspace Management Systems, RI&S. "The solid-state power amplifier technology reduces overall size and weight, while increasing performance. With our enhancements, this system is a force multiplier, delivering key links over vast distances, much greater than any line-of-sight communications system available to our soldiers today."

As the program of record for the U.S. Army, the AN/TRC-244(V)1 Troposcatter system is designed for broadband communications at long range BLOS links. The system can be configured with a single antenna, or additional antennas for diversity, combining to extend system performance. The system is automated for self-alignment of the antenna and will achieve link connectivity in less than 40 minutes, once emplaced.

The Troposcatter system uses radio-scattering effects in the lowest part of the atmosphere, allowing for BLOS communication, eliminating the need for multiple, expensive line-of-sight relays and limited satellite resources, to cover the range of a single Troposcatter link. The Troposcatter system offers a lower latency, cost-efficient solution compared to satellite communications. The small, portable system is designed to be set up quickly to set up a communications link—furthering transport capacity of the military's tactical network.

The RI&S team tested several Troposcatter systems in multiple operational environments at seven different locations across various distances, including some in mountainous terrain at distances approaching 120 miles. The results were successful, and transmissions were received at all locations with low latency. This testing will support U.S. Army fielding decisions for the initial lot of 19 systems and is the first step of an iterative test series.

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WBA Report Sets Out How Wi-Fi 6/6E Enables Industry 4.0

The Wireless Broadband Alliance (WBA) published "Wi-Fi 6/6E for Industrial IoT: Enabling Wi-Fi Determinism in an IoT World." This paper explores how Wi-Fi's latest features are ideal for meeting the demanding requirements for a wide variety of existing and emerging IIoT applications. This includes manufacturing/Industry 4.0 and logistics, involving autonomous mobile robots, automated ground vehicles, predictive maintenance and augmented/virtual/mixed reality (AR/VR/MR).

For example, manufacturers are increasingly using IIoT sensors for vibration, temperature and lubricant viscosity to catch emerging equipment problems before they result in extensive, expensive downtime. Other IIoT sensors provide real-time insights about production output, inventory levels and asset locations.

Source: Wireless Broadband Alliance

Produced by the WBA's Wi-Fi 6/6E for IIoT working group, led by Cisco, Deutsche Telekom and Intel, the white paper provides an overview of Wi-Fi 6 and 6E capabilities that are ideal for sensors and other IIoT applications, such as:

- Scheduled access enabled by trigger-based uplink orthogonal frequency domain multiple access in Wi-Fi 6 provides the ability to reduce or eliminate contention and bound latency (e.g. 99 percentile).
- Wi-Fi 6 provides many deterministic QoS capabilities, such as the traffic prioritization that is a key component of time-sensitive networking for Industry 4.0 applications.
- The Fine Timing Measurement protocol specified in IEEE 802.11-2016 enables time-synchronization but also precise indoor range and position/location determination.
- The target-wake-time feature added to Wi-Fi 6 provides more efficient power-save and scheduling enhancement. This capability is a good fit for battery-powered IIoT nodes that need to transmit only infrequently.
- Wi-Fi 6E supports up to 1.2 GHz of spectrum, making it ideal for use cases that require both multi-Gb/s throughput and determinism, such as industrial AR/VR/MR and sensor fusion.

The 52-page report also includes RF/network deployment guidelines for factory, warehouse, logistics and other use cases.

5G to Top 1B Subscriptions in 2022 and 4.4B in 2027

North America is forecast to lead the world in 5G subscription penetration in the next five years with nine-of-every-ten subscriptions in the region expected to be 5G in 2027. The forecast is contained in the latest edition of the Ericsson Mobility Report, which also predicts that current global 5G subscriptions will pass the one billion milestone by the end of 2022.

The 2027 timeline includes projections that 5G will account for: 82 percent of subscriptions in Western Europe, 80 percent in the Gulf Cooperation Council region and 74 percent in North-East Asia.

In India, where 5G deployments have yet to begin, 5G is expected to account for nearly 40 percent of all subscriptions by 2027. In global terms, 5G is forecast to account for almost half of all subscriptions by 2027, topping 4.4 billion.

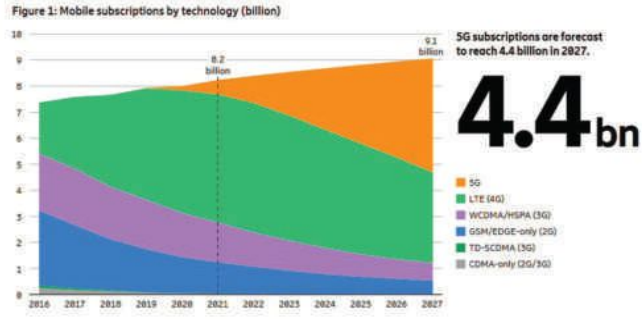
The report reveals that global mobile network data traffic doubled in the past two years. This traffic growth was driven by increased smartphone and mobile broadband usage, as well as the digitalization of society and industries. The recent statistics and forecasts highlight the strong demand data connectivity and digital services have, and are expected to have, despite the global COVID-19 pandemic and geopolitical uncertainties. Several hundred million people are becoming new mobile broadband subscribers every year.

The report verifies that 5G is scaling faster than all previous mobile technology generations. About a quarter of the world's population currently has access to 5G coverage.

The report highlights the increasingly important role that fixed wireless access (FWA) is playing in the delivery of broadband services. Ericsson predicts that the number of FWA connections will exceed 100 million in 2022, a figure that is forecast to more than double by 2027, reaching almost 230 million.

The report also contains four in-depth articles:

- Unleashing the power of IoT connectivity
- The evolution of MTN's connectivity platform
- Enabling use cases with CSP edge computing
- Securing 5G networks in evolving threat landscapes.



Source: Ericsson Mobility Report

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Increasing Demand for Human-Drone Collaboration and the Maturity of 5G to Spur Growth in the Drone Market

The market of small unmanned aerial systems (sUAS), commonly known as drones, continues to grow. ABI Research predicts total worldwide shipments of sUAS ecosystems to reach 3 million by 2025, increasing at a 25 percent CAGR. The maturity of drone hardware and complementary technology such as 5G allows more countries to relax their drone regulations and build up their domestic drone supply chain due to heightened techno-geopolitics disputes.

"Even though COVID-19 had a significant negative impact on the drone industry and worldwide consumer sales have decreased markedly, shipments for civil and commercial use cases have been growing. Moreover, the end of restrictions in most places, except in China and some Asian countries, has accelerated sUAS adoption," explained David Lobina, Industrial, Collaborative and Commercial Robotics analyst at ABI Research. "The demand for drones has never been higher before in various use cases, such as aerial data collection, infrastructure inspection, disaster response, network assurance and last-mile delivery."

Zipline is helping authorities deliver COVID-19 vaccines in Ghana and Nigeria, with a plan to expand medical supplies delivery service into Japan. In addition, employees of large industrial companies are using drones with the help of service providers, such as DroneBase, DroneDeploy and PrecisionHawk to scan and monitor valuable assets.

sUAS shipments to Reach 3 million by 2025

5G is another critical factor that will spur the growth of drone adoption. Qualcomm launched the Flight RB5 platform in August 2021, bringing down the barrier to developing 5G-connected drones. While most recent 5G applications focus on ultra-reliable low latency communications, 5G is expected to provide edge AI, integration with satellite communication, inter-robot mesh or swarm communications, and most importantly, support for beyond visual line of sight (BVLOS). In January 2022, the Northeast UAS Airspace Integration Research Alliance and the New York UAS Test Site received authority from the Federal Aviation Administration to test and fly drones BVLOS across 35 miles of airspace within the New York Drone Corridor. At the same time, Verizon Robotics developed software that integrates drones into the U.S. National Airspace System, helping drones can operate safely and seamlessly together.

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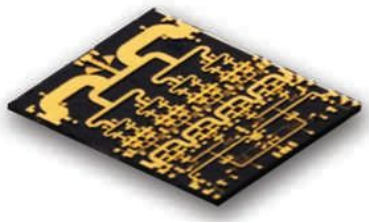

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Qualcomm Technologies Inc. announced that it has acquired **Cellwize Wireless Technologies Pte. Ltd.**, a leader in mobile network automation and management, to further accelerate Qualcomm Technologies as a leader in 5G Radio Access Networks (RAN) innovation and adoption. Cellwize's 5G network deployment, automation and management software platform capabilities further strengthen Qualcomm Technologies' 5G infrastructure solutions to fuel the digital transformation of industries, power the connected intelligent edge and support the growth of the cloud economy.

Quantic™ Electronics, a portfolio company of Arcline Investment Management, announced the acquisition of **Microwave Dynamics**, a leader in high precision microwave and mmWave components. Founded in 1993, Microwave Dynamics designs and manufactures free running and phase-locked oscillators, amplifiers, frequency converters and frequency multipliers for aerospace, defense and industrial markets. With applications for land, sea, air and space, 100 percent of Microwave Dynamics' products are produced in the U.S. and designed to perform under extreme environmental conditions, such as intense shock vibration and high temperature variance. The company's products are geared to maximize stability and minimize noise.

Sivers Semiconductors has completed the integration of **MixComm**, creating a strong global challenger in 5G, satcom and radar. Along with broadening Sivers' portfolio and increasing Siver's presence in the U.S., the integration entails synergies of approximately SEK 10 million per year. Sivers writes down intangible assets of approximately SEK 22 million due to overlapping product development areas. Sivers is also introducing a new role in the U.S., making Mike Noonen, former CEO of MixComm, U.S. president. Sivers has found large synergies in development tools and some personnel which gives a total saving of approximately SEK 10 million per year compared with if MixComm and Sivers had been two autonomous units.

Trive Capital has announced that it has acquired **Custom Microwave Inc. (CMi)**, which will join the Vitesse Systems platform. Vitesse Systems was launched in 2018 following the acquisition of California Brazing. The platform is focused on mission-critical assemblies that enable the advancement of communication, radar and electronic warfare systems. CMi is a provider of high performance passive antennas that are engineered for critical space and ground applications. CMi's engineering and testing expertise combined with advanced manufacturing processes will enable Vitesse to support a complete range of complex high performance RF applications.

COLLABORATIONS

Modelithics welcomed **Microwave Technology Inc.** into the Modelithics Vendor Partner (MVP) Program at the Sponsoring level. Microwave Technology is a recognized leader in the design, manufacturing and marketing of GaAs and GaN based MMICs, discrete devices and hybrid amplifier products for commercial wireless communication, defense, space and medical applications. As a Sponsoring MVP, Microwave Technology and Modelithics are in collaboration to develop new models for five of Microwave Technology's new GaAs FET devices to be included in the Modelithics COMPLETE Library™ for multiple simulators.

Ansys has collaborated with **TSMC** on the TSMC N6RF Design Reference Flow for TSMC's N6 process technology. The Reference Flow uses the Ansys multiphysics simulation platform, including Ansys RaptorX, Ansys Exalto, Ansys VeloceRF and Ansys Totem to provide a low-risk and proven solution for designing RF chips. The TSMC N6RF Design Reference Flow provides RF designers with a workflow that accelerates design times and reduces wasteful over-design. It enables higher performance and reliability for chips used in 5G radio communication, Wi-Fi connectivity and IoT networks.

UScellular and **Ericsson** announced that they have begun 5G testing at altitude using drone technology. These tests are the first of their kind with UScellular's 5G network and lay the groundwork for future use cases of cellular-connected drones in a variety of industries. Initial visual line of sight trials were conducted in Beloit, Wis., using a drone that was flown between two of UScellular's commercial 5G towers. The drone was outfitted with a 5G smartphone and RF measurement equipment designed to capture performance metrics such as signal strength and quality, upload and download speeds and latency throughout the flights at various altitudes.

Avnet Inc., a global technology solutions provider, is working with **Fujikura** to develop a leading-edge 5G FR2 phased array antenna development platform for mmWave frequency bands. This platform enables customers to quickly develop and prototype advanced 5G mmWave systems using AMD-Xilinx's Zynq® UltraScale+™ RFSoC Gen3 and Fujikura's FutureAccess™ Phased Array Antenna Module (PAAM), controlled by Avnet's proven RFSoC Explorer® software. This combination of leading-edge components and software will enable customers to quickly prototype with Fujikura's compact PAAM and AMD-Xilinx's RFSoC.

Purdue University's College of Engineering has partnered with **MediaTek Inc.**, a global fabless chipmaker, to open the Midwest's first semiconductor chip design center, to be housed on Purdue's campus. The center marks another piece of Purdue's commitment in addressing society's increasing semiconductor demands and the needed talent pool. In May, the university an-

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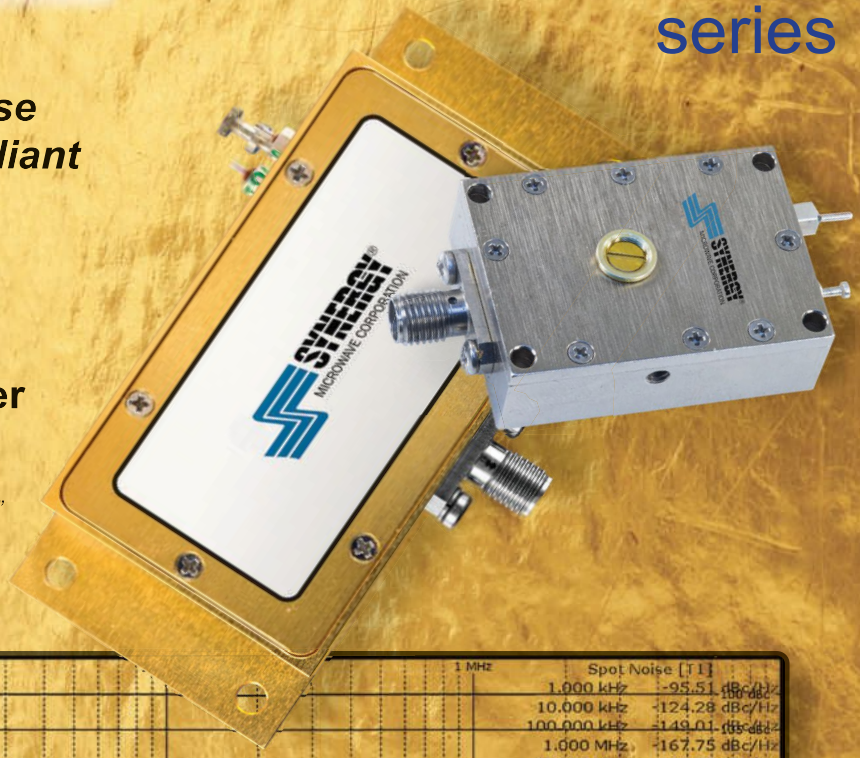

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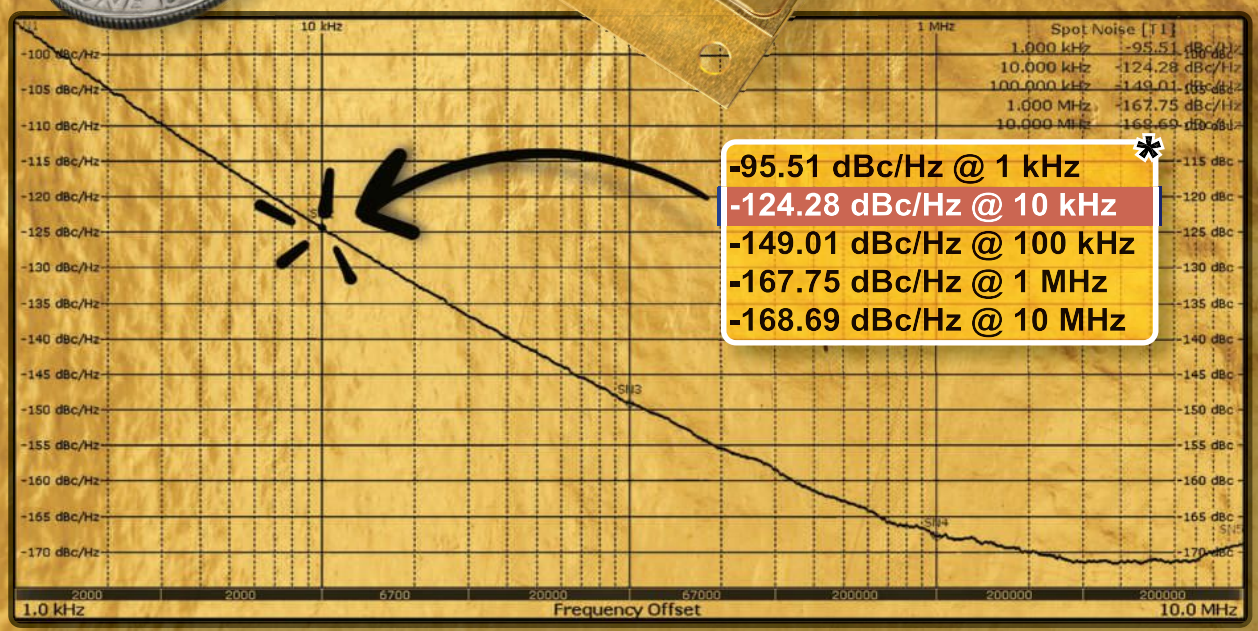

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nounced the launch of its Semiconductor Degrees Program, a comprehensive set of innovative, interdisciplinary degrees and credentials in semiconductors and microelectronics.

Renesas Electronics Corp. announced a strategic partnership with **Tata Motors Ltd. (TML)** and **Tejas Networks Ltd.**, both Tata Group companies, on the design, development and manufacturing of Renesas' semiconductor solutions for enhancing innovation across electronics systems for the Indian and emerging markets. These joint endeavors extend the companies' longstanding relationship as technology and business partners, including the recently announced next-generation EV Innovation Center jointly established by Renesas and Tata Group's Tata Elxsi in March 2022.

Horizon House Publications announced the formation of the **High Frequency and High-Speed Media and Events Group**, made up of *Microwave Journal* and *Signal Integrity Journal* magazines plus EDI CON China, EDI CON Online events and managed exhibitions for IEEE MTT-S International Microwave Symposium, on behalf of IEEE, and European Microwave Week, on behalf of European Microwave Association. The High Frequency and High-Speed Media and Events Group at Horizon House Publications provides comprehensive, integrated marketing opportunities for the electronic design industry. *Microwave Journal* and *Signal Integrity Journal* offer advertising opportunities in the print/digital magazines, web sites and a full host of digital marketing vehicles, including emails, banner ads, white papers, videos, webinars, sponsored content, eBooks, podcasts and online panels. *Microwave Journal* also includes the popular video/podcast series, *Frequency Matters*.

ACHIEVEMENTS

Raytheon Technologies has recognized Mini-Circuits with a Premier Award for performance in 2021 and overall excellence in Business Management/Customer Service and Collaboration. The Premier Award is an annual recognition platform under the Raytheon Technologies Performance+ Program to recognize suppliers with superior performance and provide exceptional value to Raytheon Technologies.

Qorvo® has been selected by the **U.S. Department of Defense (DoD)** to proceed with the Advanced Integration Interconnection and Fabrication Growth for Domestic State-of-the-Art (SOTA) RF GaN program, also known as STARRY NITE, as part of the Office of Undersecretary of Defense Research & Engineering's microelectronics roadmap. The STARRY NITE program seeks to develop and mature domestic, open SOTA RF GaN foundries in alignment with the DoD advanced packaging ecosystem. The Qorvo team will leverage over 30 years of technology development and a long record of successfully establishing high performance and reliable GaN manufacturing technology.

Ignion, a global provider of ground-breaking IoT antenna solutions, has been recognized by the **European Commission's European Innovation Council (EIC) Accelerator** for their innovation and high business potential. The win was awarded for the first miniaturized multi-radio chip antenna component tailored to the Internet of Things (IoT) applications and the cloud-based digital twin platform called Antenna Intelligence Cloud (AIC). Ignion was among 74 winners out of 1000 who were considered from 18 countries. The awards were based on a range of criteria including excellence, scale-up potential, level of risk and implementation.

CONTRACTS

Mercury Systems Inc., a leader in trusted, secure mission-critical technologies for aerospace and defense, announced it received a three-year basic ordering agreement worth up to $50 million from the **Naval Air Systems Command (NAVAIR)** for engineering services and products relating to Mercury's Advanced Data Transfer System (ADTS) for deployment across multiple rotary-wing and tilt-rotor platforms.

Akoustis Technologies Inc., an integrated device manufacturer of patented bulk acoustic wave (BAW) high band RF filters for mobile and other wireless applications, announced that it has entered into a new multi-year, multi-million dollar contract from the **Defense Advanced Research Projects Agency (DARPA)** to pursue new materials and device manufacturing methods. As a result of the expected advances, the program could extend the company's patented and proprietary XBAW® technology to 18 GHz, opening up significant new commercial and defense applications to Akoustis.

PEOPLE

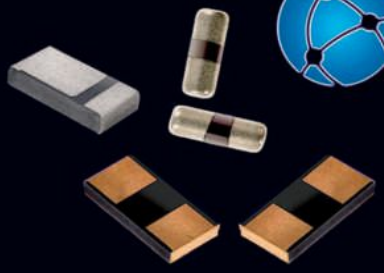
▲ ***Mark Twaalfhoven***

Trexon, a portfolio company of Audax Private Equity, announced the appointment of **Mark Twaalfhoven** to the position of President and CEO, effective immediately. Mark Twaalfhoven has an extensive technology and operations background. He was most recently the CEO of Pulse Electronics, where he led significant enhancement and expansion of the company. Prior to that, he served as CEO of Teleplan International, currently known as Reconext, a company servicing electronic devices. He also led the development of Amphenol in Asia as well as the computer and communication devices markets.

▲ ***Jim Nevelle***

Prose Technologies, a leader in wireless antenna and coverage solutions, announced leadership and focus for the North American market with the appointment of **Jim Nevelle** as president and a concentration on its manufacturing in the U.S. In January 2022, the Rosenberger Group announced the spinoff of its base station antenna, microwave antenna, indoor and outdoor coverage solutions, Open RAN sub-systems and related services business to create a new, private company called Prose.

5G and Beyond!



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- Resistors
- Terminations
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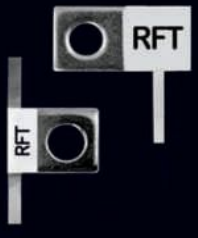

Brazed:
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- Terminations
- Attenuators

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- Isolators
- Circulators

STAR MICROWAVE

MIL and HI-Rel:
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Around the **Circuit**

Jim Nevelle was selected to lead the business in North America to continue offering market-leading technologies to the U.S. market.


▲ *Ryan Jennings*

Anokiwave Inc. announced the appointment of **Ryan Jennings** as vice president of Satcom and Systems. In this role, Jennings will be responsible for growing the satcom customer base as well as defining and leading the architecture for future satcom products. This appointment comes at a strategic time for Anokiwave, as the satellite communications industry is poised for growth with multiple high capacity systems either already on-orbit or planned for the near future as operators aim to provide broadband service to every corner of the world.


▲ *Brian Rundell*

Indium Corp. announced that **Brian Rundell** has joined the company as a technical support engineer based at the company's headquarters in Clinton, NY. Rundell is responsible for providing technical assistance to current and potential customers to resolve soldering process-related issues. This includes assisting with the optimization of Indium's soldering materials in addition to providing product and process training. Rundell brings more than 19 years of industry experience to Indium.


▲ *Rick Madormo*

Wolfspeed Inc. announced the promotion of **Rick Madormo** to senior vice president of Sales and Marketing, succeeding Thomas Wessel. Madormo has led Wolfspeed's Americas Sales organization since 2018, focused on the business development strategy, pipeline growth and organizational structure, supporting the company's most recent quarterly revenue growth of 37 percent. An industry veteran, Madormo has more than 25 years of semiconductor experience with sales leadership roles at Intel, Altera and others. In anticipation of Madormo's promotion, Wolfspeed has hired **Owen DeLeon** as the company's new vice president of Sales for the Americas.

REP APPOINTMENT

Richardson Electronics Ltd. announced a global sales distribution agreement with **Altum RF**, a supplier of high performance RF to mmWave semiconductor solutions for next-generation markets and applications. With amplifiers, switches and other products working up to 100 GHz, Altum RF will further expand Richardson Electronics' portfolio to support continually rising frequencies in the market, including 5G/6G, satcom, test and defense applications.

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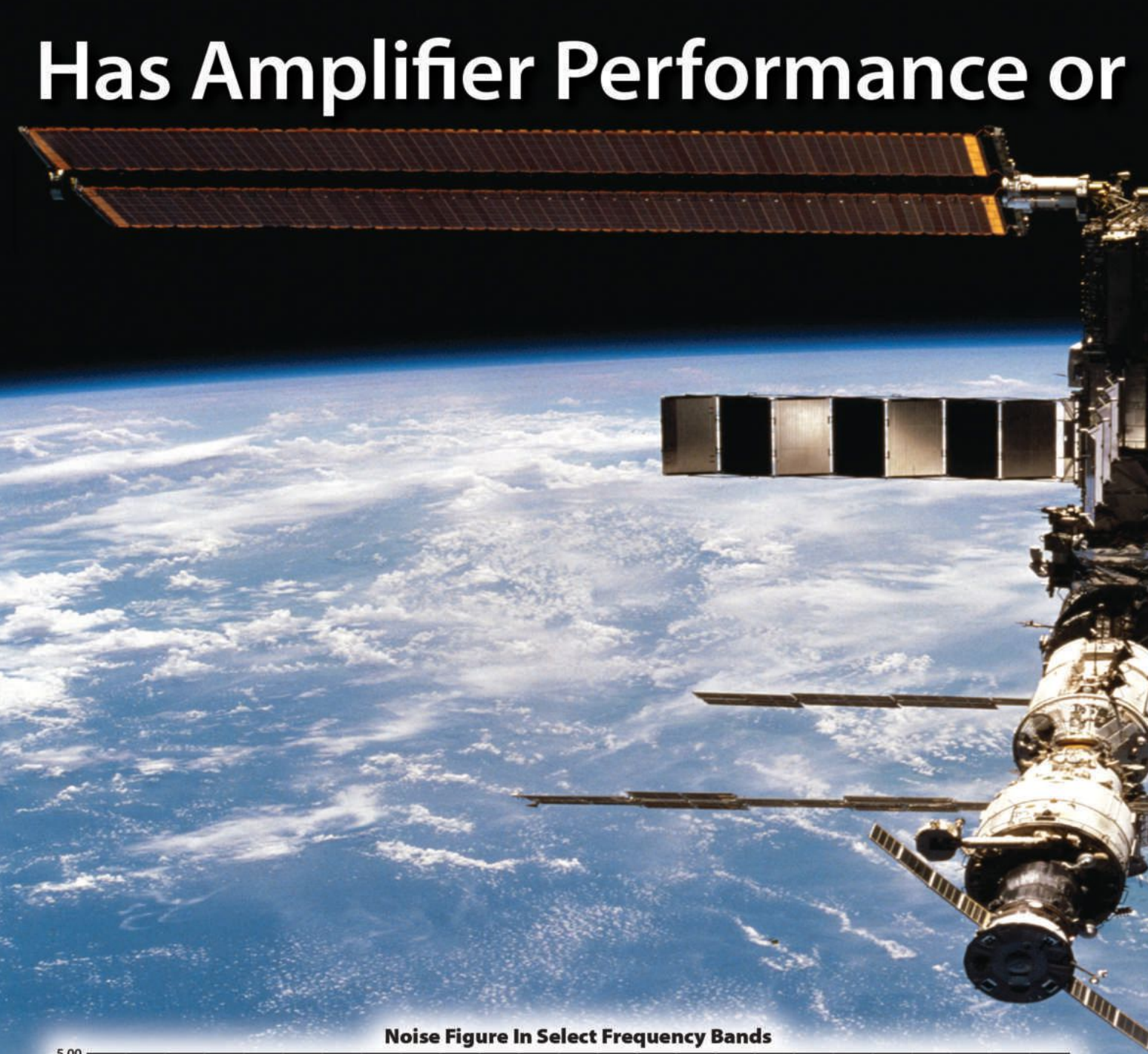

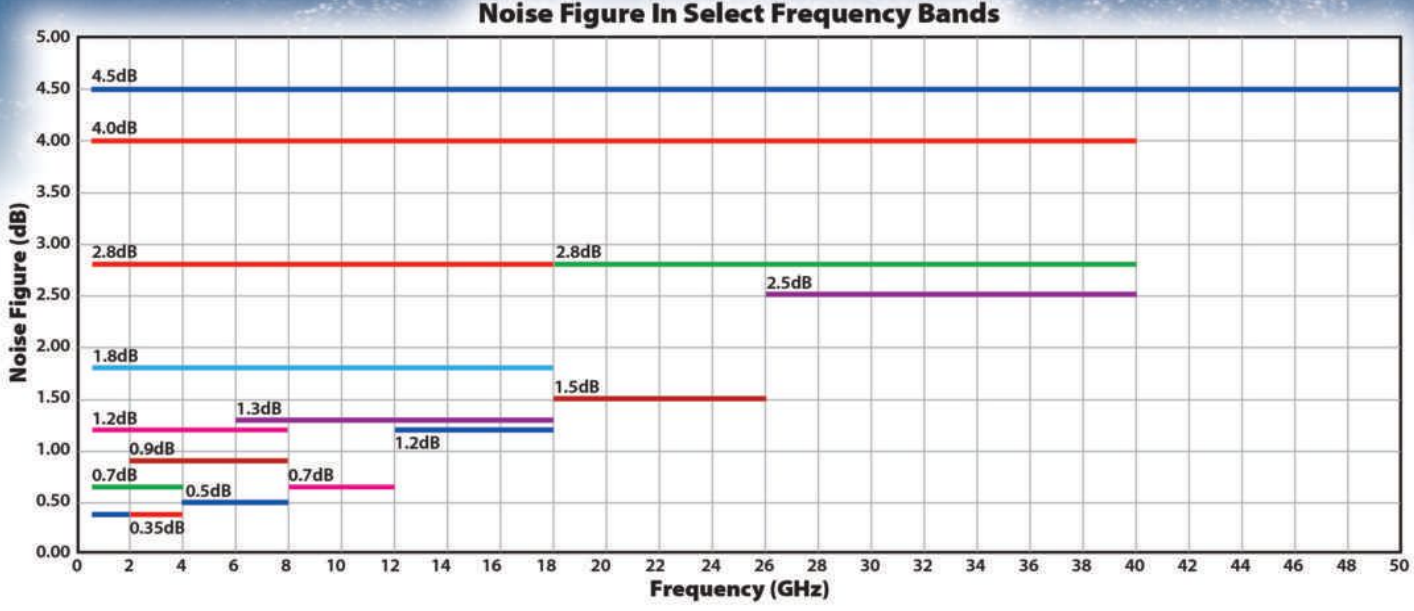

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Welcome to the 25th European Microwave Week

Luca Perregrini
EuMW General Chair
University of Pavia, Italy

Luciano Tarricone
EuMW General Co-chair
University of Salento, Italy

For complete coverage of the EuMW 2022 conference, event news, exhibitor product information and special reports from the editors of *Microwave Journal*, visit our online show daily at mwjournal.com/eumw2022.

It is our great pleasure to welcome you to the European Microwave Week (EuMW) 2022, which has come back to Milan after 20 years.

Milan is a vibrant, fast-developing European city and wealthiest in Italy, which hosts the headquarters of national and international banks and companies. The surrounding area is one of the most industrialized regions of Europe, and many universities and research centers are located there. Milan is conveniently served by three international airports. The well-developed and very efficient public transportation allows to easily visit all the tourist attractions in the city. Moreover, Milan is well connected to the main Italian cities by high speed trains, making possible one-day visits to Venice, Florence, Turin, Bologna and even Rome. Milan has many attractions such as the famous Gothic Cathedral, the Sforza Castle and world's most famous opera house La Scala Theater. Moreover, the city hosts many prominent museums. Among them, it is worth remembering the Pinacoteca di Brera, featuring one of the foremost collections of Italian paintings, including masterpieces by Piero della Francesca; the Pinacoteca del Castello Sforzesco, with an art collection including Michelangelo's last sculpture Pieta Rondanini and Leonardo da Vinci's Codex T rivulzianus manuscript; the church of Santa Maria delle Grazie, hosting the Last Supper of Jesus, the famous mural painting by Leonardo. More information is on the official city website: https://www.yesmilano.it/en.

Leonardo da Vinci spent more than ten years in Milan, leaving some of his major masterpieces. This is the main reason to choose the Vitruvian Man for the logo of the Week, and a motto inspired by Leonardo, i.e., "Creative Microwaves," to remind all of us that the progress of science and technology comes only from curiosity and creativity.

EuMW 2022 is held at the Milano Convention Centre (MiCo), a completely renewed venue in the business district of CityLife, at walking distance of many must-see attractions.

This is the 25th anniversary of EuMW. The whole microwave community is indebted to the founders of the European Microwave Association (Eu*M*A), which in 1998 started the "Microwave Week." EuMW steadily grew up with a year-by-year addition of technical activities and exciting events, becoming one of the largest worldwide events and the perfect venue to meet colleagues, share ideas and make friends. EuMW 2022 includes the European Microwave Conference (EuMC), the European Microwave Integrated Circuits Conference (Eu-

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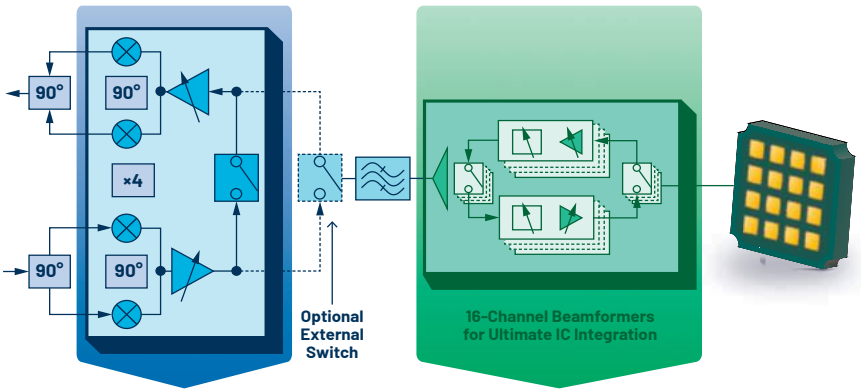

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MIC), the European Radar Conference (EuRAD), the Defence, Security and Space Forum, the Automotive Forum, the Beyond 5G and 6G Forum and more than 30 workshops covering topics spanning from theory to application, from devices to systems. The event also features the largest RF and microwave trade show in Europe. The opening and closing plenary sessions of each of the three conferences feature keynote lectures by internationally renowned leaders in their fields. Participation to EuMW of students and young professionals is strongly encouraged. We organized many activities specifically for them, namely two doctoral schools, a Three Minutes Thesis competition, an IEEE Young Professional technical session, the Career Platform, prizes and grants, student helpers program and networking event.

The Women in Microwave, co-sponsored by the IEEE MTT-S, will be in the beautiful location of Pinacoteca Ambrosiana, and includes a technical session followed by a visit to the museum.

Our thanks go to many colleagues who have volunteered to organize this event and have spent a lot of time and tireless effort putting together an excellent technical program. Eu*M*A and Horizon House are also gratefully acknowledged for their continued support and help. At the time of writing, the pandemic situation is under control and many restrictions have been relaxed. We really hope that in September we can safely travel and meet freely. Socialization is the nature of human beings and meeting and networking are vital for our community to exchange ideas, make connections, mentor younger colleagues, meet old friends and make new ones. To this aim, we organized many social activities, such as EuMIC dinner, students and young professionals get-together, Automotive Forum Dinner, Welcome Reception, Gala Dinner, TPC lunch and EuRAD lunch.

We look forward to hosting you in Milan. The city will surprise you, and we are sure you will enjoy EuMW 2022. ■

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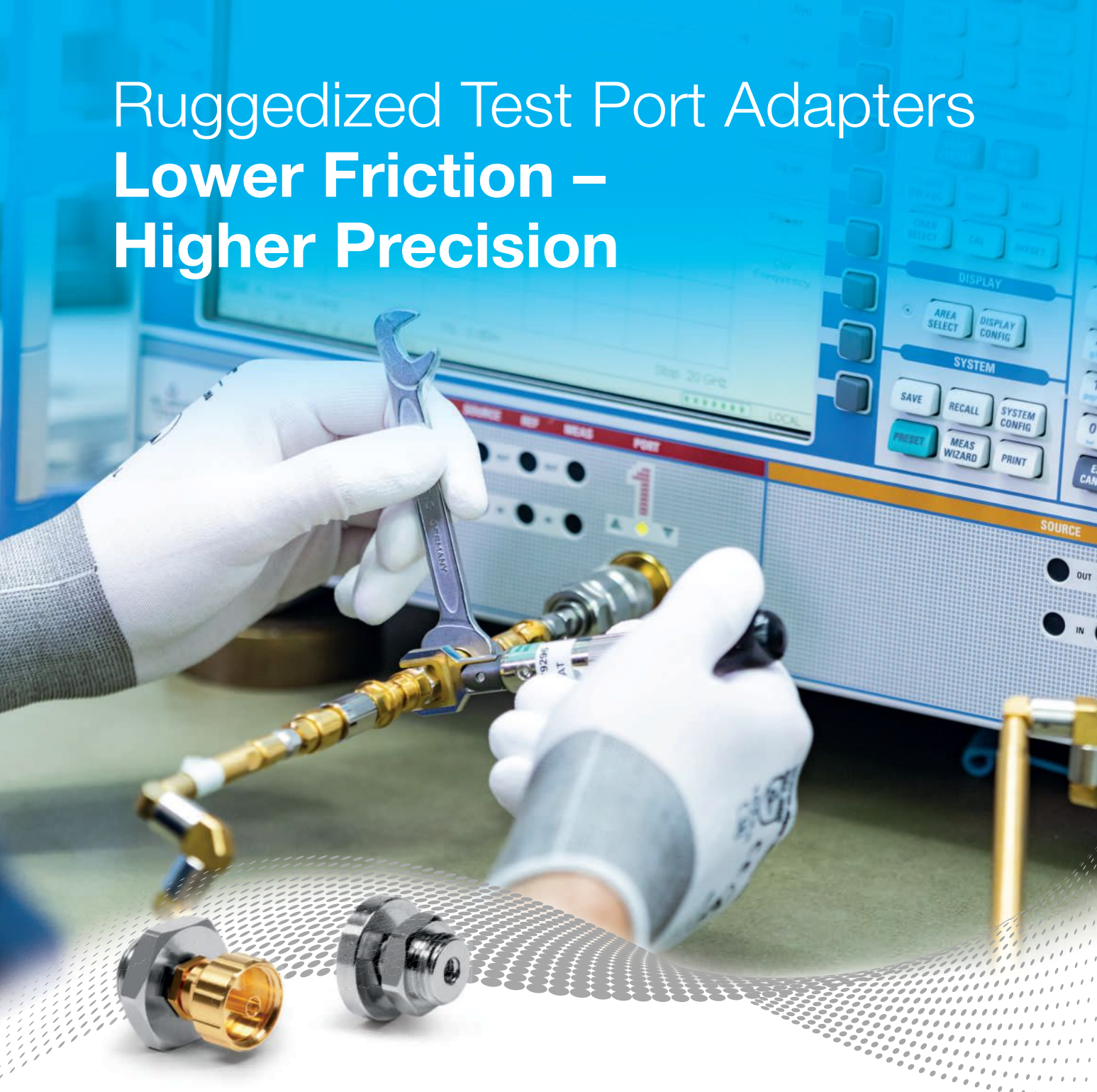

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Pasta, Pizza and "Parlando di Microonde"*

Helen Duncan
MWE Media, Ltd., U.K.

Italy has a unique place in the history of microwaves. Not only the birthplace of radio pioneer Guglielmo Marconi, the country was also first to use "microonde" (microwave) in literature to describe the high frequency waves we all know and love.[1] This year, EuMW 2022 takes place in Milan, returning to that city for the first time since 2002. This latest article in our series about the microwave industry in Europe takes a closer look at Italy—the key players in this market, as well as its historical contributions to advancing microwave technology.

Fig. 1 **Guglielmo Marconi with the wireless telegraphy equipment he invented and patented.**

Much of the country's manufacturing industry is concentrated in the northwest region, known as the "Industrial Triangle." The Triangle joins the cities of Milan, Turin and Genoa, housing the automotive industry and production of defense and aerospace equipment. This area is also home to some of the microwave companies that serve these sectors. There is also a concentration of microwave expertise further south, around Rome and Perugia—both cities having universities that specialize in microwave and mmWave technology.

A BIT ABOUT MARCONI

Guglielmo Giovanni Maria Marconi was born in Bologna in 1874, the son of an Italian aristocrat father and an Irish mother who came from the Jameson family of whiskey

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Industry 4.0 makes new industrial systems more complex than before. The IoT ("Internet of Things") refers to the networking of objects (e.g., cars or production machines) with the Internet. By installing microchips, these can collect and process data directly with other objects and computers, via the Internet - without human intervention.

RFID SYSTEMS POSE CHALLENGES FOR PRODUCT DEVELOPERS

There are many challenges to overcome with an RFID (Radio Frequency Identification) system. Signals must be transmitted smoothly from the reader to the chip on the RFID tag and back again. However, the chip is also supplied with energy from the received signal. For this purpose, both the energy harvester system as well as the transmitting and receiving system must be analyzed with the modulation of the signal. Of particular importance is the field coupling between the antennas. This should be as favorable as possible in a well-defined region around the reader and with the maximum number of tag alignments.

ANALYZE AND OPTIMIZE SENSORS AS VIRTUAL PROTOTYPES

Condition monitoring as a prerequisite for condition-based maintenance of systems, as well as for autonomous negotiation of manufacturing processes, must not only take the condition of the process and machine into account, but also possible sensor failures and the current manufacturing accuracy. This includes an extended consideration of the measurement uncertainty for statistical or general data-based evaluation models, since these use correlations in complex systems, among other things, in order to be able to evaluate the condition of individual components. With electromagnetic multiphysics simulation, important decisions - with a comprehensive understanding of the physical behavior of the sensor design gained through simulation - can be made in a well-founded manner at a very early stage of development.

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distillers. Despite having no formal education, he began experimenting with electromagnetic waves as a young man, and patented a radio wave-based wireless telegraphy system (see ***Figure 1***).[2] In 1897, he moved to the U.K. and founded The Wireless Telegraph & Signal Company, which later became the Marconi Company. In 1901, he achieved the remarkable feat of transmitting a radio signal more than 2,000 miles across the Atlantic, from Poldhu in Cornwall, England, to Newfoundland in Canada. He shared the 1909 Nobel Prize in Physics with Karl Ferdinand Braun "in recognition of their contributions to the development of wireless telegraphy," and was later ennobled as a Marchese by the King of Italy.

TELECOMMUNICATIONS

True to Marconi's heritage, Italy retains a strong telecoms industry. Its main mobile network operators are Wind Tre, TIM and Vodafone. A newcomer, Iliad, took on frequency bands abandoned by Wind Tre after the merger between Wind and 3 Italy, then launched as an operator in February 2018. Iliad grew at a phenomenal rate, acquiring 2 million subscribers in the first seven months of operation. The fifth operator is Fastweb, owned by Swisscom, which was initially a provider of fiber-optic broadband. Fastweb became a mobile virtual network operator in 2015, then acquired a 5G operator license in July 2019.

Most recently, Fastweb began rolling out 26 GHz 5G for fixed wireless access (FWA), to provide ultra-broadband connectivity at Gbps data rates as an alternative to fiber to the home. Samsung has been announced as the end-to-end supplier of core and radio units and, in February, Fastweb announced plans to use Qualcomm's 5G "gen 2" FWA platform to commercialize its 5G standalone (SA) mmWave offering, featuring Snapdragon X65 and X62 5G modem-RF systems. This will enable Fastweb to rapidly scale its 5G mmWave FWA deployments, with a plan to connect 12 million homes and businesses in Italy by the end of 2025.

SIAE Microelettronica in Milan has been a key player in microwave point-to-point telecommunications links since before the advent of the earliest mobile networks, with a history going back 69 years. Its current product portfolio includes a complete range of microwave radios, including split mount, full outdoor and all-indoor systems across traditional licensed microwave bands and mmWave frequencies, supporting MEF, IP/MPLS and SDN protocols. Also in the portfolio are microwave radio products for licensed and unlicensed frequencies from 4 to 80 GHz, E-Band radios, multiplexers, cell site gateways, network switching devices and network management systems. The company designs and produces its own RF components from semiconductors to system level and boasts in-house RF laboratories, clean room facilities and complete product assembly lines.

In May 2022, SIAE Microelettronica announced it had become a member of the O-RAN Alliance, the worldwide technology community of over 300 telecom operators, vendors, research and academic institutions working to define and build an open and interoperable ecosystem for virtualized mobile networks, supporting the specifications of 3GPP and other standardization bodies.

SPACE AND DEFENSE

Italy has a particularly strong space and defense industry. One of Europe's largest manufacturers in this sector is Leonardo, headquartered in Rome. Leonardo was founded under its original name of Finmeccanica in 1948, the same year the Italian Constitution was established. The name change to Leonardo officially occurred at the beginning of 2017, inspired by the famous Italian polymath Leonardo da Vinci. Over the years, the company has absorbed several famous brands in these market sectors, including Alenia, SGS Thomson (now ST Microelectronics), AgustaWestland, DRS Technologies and SELEX. Through a partnership with BAE Systems and Airbus, Leonardo owns a 25 percent stake in European missile systems manufacturer MBDA, and it is also a partner in the Eurofighter consortium that manufactures the Typhoon aircraft. In collaboration with Thales, it is a partner in both Thales Alenia Space and Telespazio. These latter two companies together make up the Space Alliance, a strategic partnership

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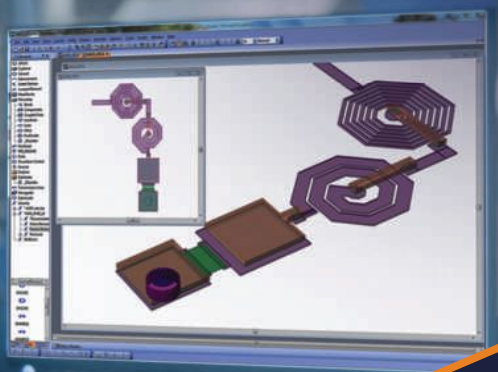

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formed in 2005. Combining Thales Alenia Space's expertise in satellite systems with the capability of Telespazio in satellite services means the Space Alliance can readily address the needs of the space market, which are increasingly focused on applications and the space technologies themselves.

CONTRACTS

Thales Alenia Space is a European leader in both active electronically scanned array development and satellite navigation. The company recently signed a new contract with the EU Agency for the Space Program (EUSPA) to develop, qualify and deploy the European Geostationary Navigation Overlay Service (EGNOS). Under this contract, the company will provide EUSPA and the EU navigation community with a new version of EGNOS (V243), underpinned by a state-of-the-art Navigation Land Earth Station (NLES) technology being developed to transmit the EGNOS data to the geostationary satellites. This will be integrated with a new geostationary satellite, GEO3, to enhance the end-to-end performance of the EGNOS system. Thales Alenia Space additionally announced the integration of a new satellite (GSAT0223) into the ground mission segment of Galileo, which has increased the operational constellation to 23 satellites for positioning and 25 for search and rescue; this will improve the service to the 3.3 billion Galileo users.

Earlier this year, Leonardo signed a €260 million contract with German aerospace manufacturer Hensoldt[3] that will give Leonardo responsibility for developing key components of the European Common Radar System (ECRS) Mk1 E-scan radar (see ***Figure 2***). ECRS Mk1, which will be fitted to the Eurofighter Typhoon models ordered by Germany and Spain, adds a digital multi-channel receiver and wideband transmit/receive modules to enhance the capabilities of the existing ECRS Mk0, for which Leonardo is the design authority. Leonardo will design and produce core antenna, APSC and processor components and will develop wideband capabilities to improve the ECRS Mk1's detection range and accuracy. Leonardo will also be the design authority for the new U.K.-led ECRS Mk2 radar variant, which will feature a multi-function array. The modules for the ECRS Mk1 will be produced at Leonardo's sites in Nerviano near Milan, Campi Bisenzio in Florence, Palermo in Sicily and Edinburgh, U.K.

Another major defense equipment manufacturer with headquarters in Rome is the Elettronica Group, along with its subsidiary ELT-Roma. Founded in 1951 and once partially owned by Finmeccanica, Elettronica specializes in the design

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Fig. 2 **Leonardo is developing key components of the ECRS Mk1 radar fitted to the Eurofighter Typhoon.** ***Source:*** **Hensoldt AG/Stefan Petersen.**

and production of electronic warfare equipment and systems, electronic support measures, electronic counter measures, signals intelligence, radar warning receiver, cyber warfare and homeland security.

In 2019, Space Engineering—already a wholly-owned subsidiary of Airbus—changed its name to Airbus Italia S.p.A. At the time of the change, the Tiburtina, Rome-based company had 120 employees at its 1,200 m^2 facility and was focused on satellite communications. This included the validation and qualification of on-board and ground components, equipment and subsystems such as antennas and repeaters. Its activities also extended to the development of IoT applications, mobile terminals for airborne, train and land applications, RF components and ground modems. In addition to working on several large Italian and international space programs, it holds several international patents related to antennas, radar, scientific software and digital signal processing. Airbus Italia's assembly, integration and test facility benefits from a 12 × 8 × 7 m anechoic chamber and environmental and thermal vacuum chambers, as well as a 250 m^2 ISO-8 clean room and it has test facilities for measurements up to 70 GHz.

SPACE ECOSYSTEM

The dominance of the Italian market by the large defense and aerospace equipment manufacturers Elettronica and Leonardo, along with its two joint ventures in the Space Alliance, has led to the emergence of a cluster of smaller space-focused companies in Italy.

Marco Lisi, who led the systems engineering activities for Galileo at the European Space Agency, and was previously chief scientist at Telespazio, observed: "Since the COVID-19 pandemic, Italy is experiencing a 'renaissance period' in RF and microwaves, with the flourishing of small and medium enterprises that are very dynamic and innovative."

Among the young companies highlighted by Prof. Lisi are Qascom, which has developed the open service authentication service for Galileo and specializes in the detection of jamming and spoofing of global navigation satellite system (GNSS) signals. One of Qascom's latest projects is building a software-defined radio receiver payload for the Lunar GNSS Receiver Experiment (LuGRE). LuGRE is a collaboration between the Italian Space Agency (Agenzia Spaziale Italiana) and NASA that aims to test lunar navigation based on existing satellite navigation signals, with a view to developing navigation approaches for Artemis astronauts and robotic missions' exploration of the Moon. The payload that is being developed by Qascom will fly on a NASA Commercial Lunar Payload Services mission in 2023. ***Figure 3*** shows an artist's impression of LuGRE on the moon's surface, with the Earth-based GNSS constellations tak-

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Fig. 3 **Artist's impression of LuGRE on the moon and the GNSS constellation orbiting the Earth.** ***Source:*** **NASA/Dave Ryan.**

ing up less than 10 degrees of the lunar sky.

Argotec, based in Turin, produces microsatellites (CubeSats), managing all the stages in the process from research, design and assembly through integration test and operation. The ArgoMoon is a microsatellite that will be the only European payload aboard Artemis 1, the first mission of the NASA Space Launch System. The ArgoMoon will take photos during the mission to confirm that the other CubeSats have been successfully released. It will also be a platform to validate autonomous tracking of specific targets in a deep space environment.

Leaf Space, founded in 2014 in Lomazzo, Lombardy, operates a distributed ground station network to connect with small satellites, based on a "ground segment-as-a-service" model. This enables their clients to access a complete set of satellite operations services, including time-shared access to ground, customized telecommunication solutions, ground station procurement and microwave system consultancy. This method can reduce the cost and development time for SmallSat operators, whose ground segment becomes a predictable recurring cost.

UNIVERSITY SPIN-OFFS

Many of Italy's microwave manufacturers began as spin-offs from leading universities. Aresys, for example, is a spin-off of Politecnico di Milano and targets customers in the space, aerospace, defense and oil and gas markets. Founded in 2003, the company specializes in remote sensing, focusing on research and development activities to deliver customized solutions and services in airborne and spaceborne synthetic aperture radars (SARs), ground-based SAR, radar and ground-penetrating radar, pipeline acoustic monitoring systems and seismic and geophysical prospecting systems.

In April this year, Aresys was announced as a sub-

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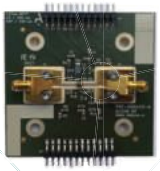

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contractor for a technology demonstration mission called SATURN, which is short for Synthetic AperTure radar cUbesat foRmation flyiNg. The mission will define the technical requirements and assess the critical technologies needed for a constellation of microsatellites equipped with miniaturized SAR instruments. The prime contract is with the Italian Space Agency, while Aresys is responsible for the SAR payload, MIMO SAR data processing and the payload ground segment. The subcontractors are Politecnico di Milano, responsible for the mission requirements and data scientific exploitation, and Airbus Italia, which will provide the payload antenna design and carry out manufacturing.

The SATURN mission is aimed at demonstrating the technology of coordinated swarms of MIMO SAR microsatellites for low-cost Earth observation. By distributing the key resources among small-sized, simpler systems—rather than concentrating them in a single large satellite—and assuring the correct combination of signals from each single node of the swarm, the swarms can be deployed on different orbital planes, enabling high revisit time and optimum performance, irrespective of the available daylight and cloud cover.

RF Microtech is a company originally spun out of the University of Perugia by the late Professor Roberto Sorrentino, who was one of the founders of the European Microwave Association (Eu*M*A) and was Eu*M*A president from 1998 to 2009. RF Microtech develops and manufactures custom products for equipment manufacturers and system integrators, supporting projects with technical assistance, consultancy, RF design and simulation and RF test and characterization. Its product expertise includes antennas and phased arrays, microwave filters, passive components and microwave sensors and systems—addressing telecoms and satcoms, space and avionics and industrial control and sensing applications.

Active Technologies, based in Ferrara in Northern Italy, manufactures a range of high performance arbitrary waveform generators and pulse generators. The company emerged out of the University of Ferrara in 2003.

PASSIVE COMPONENTS AND INTERCONNECT

Italy has several independent component and subsystem manufacturers, which support its indigenous aerospace and telecoms corporations and export to customers across the world. It is particularly strong in manufacturing passive components, waveguide and coaxial connectors and adapters.

Pasquali Microwave Systems, located in Florence, has been operating since 1958, specializing in precision mechanical machining to produce waveguide devices and assemblies. The microwave components and as-

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semblies it manufactures are used in high reliability applications worldwide, including civil and military radars and the space, telecommunications and security sectors. Genex RF, in Rome, manufactures a range of passive components, waveguide components and coaxial connectors, adapters and assemblies up to 40 GHz.

Würth Elektronik Stelvio Kontek is the Italian subsidiary of the German Würth Elektronik Group and manufactures electromechanical components, including terminal blocks, connectors, fuse-holders and sensors in its Oggiono facility in Lombardy. MTR, based in Naples, manufactures waveguide parts, including filters and couplers.

CPE Italia is based in Milan and manufactures cables, connectors and assemblies for frequencies to 65 GHz, as well as a series of microwave and RF resistors, attenuators and power loads. Products for military and other applications requiring stringent environmental qualification are a specialty. Multiple coaxial contacts within a single standard MIL 38999 series III circular connector are featured, offering the advantage of a rapid blind-mate connection where space is limited. Phase-matched coaxial cable sets are also offered. Leanfa designs and manufactures solid-state OEM microwave and RF generators and power amplifiers (PAs) for industrial, scientific and medical applications. Its generator designs feature highly accurate parametric control, with modular and scalable architectures that run from a single low voltage DC supply.

Microwave Filters & TVC was founded in Rome in 1979 and designs and produces passive components from 10 MHz to 90 GHz for applications including microwave and mmWave backhaul links, cellular repeaters, satcom, broadcasting and test and measurement. The product range includes filters, diplexers, waveguide isolators and circulators, loads, couplers, OMTs, adapters, seamless and flexible/twistable waveguide, cables, connectors and cable assemblies. Filter technologies include hairpin and combline, RC lumped component and helical filters.

Intech Microwaves in the Tecnopolo Tiburtino area just outside Rome serves the large aerospace and defense companies nearby. It specializes in the design and production of microwave components and subsystems and the design and development of automatic test equipment. With a 300 m^2 clean room area out of a total of 600 m^2, the company has microelectronic assembly equipment with chip-and-wire capability, RF testing to 50 GHz and environmental test. Its products encompass both its own and custom designs for specific customers. The standard product range includes passive components such as filters, power dividers and combiners, MMICs and active components (low noise amplifiers and receivers, PAs and transmitters, microwave sources), digital components, subsystems and assemblies and antennas.

THE ITALIAN MICROWAVE LANDSCAPE

In conclusion, defense and aerospace are the dominant factors in Italy's thriving microwave community. The advent of small satellites has provided a significant boost to the industry and enabled smaller companies to enter the market, many supported by close ties with academia. Italy now has a rich ecosystem of component and subsystem vendors supporting larger equipment manufacturers. Prospects for the future look very promising.■

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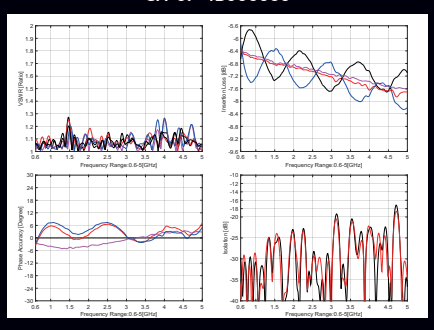
SA-07-4B006050	4x4	0.617~0.821	1.4	8.2	±1.1	±0.8	±10	16
		0.832~0.96	1.4	8.2	±1.1	±0.7	±9	16
		1.427~1.71	1.5	8.3	±0.9	±0.7	±9	15
		1.71~2.2	1.5	8.5	±0.9	±0.8	±10	14
		2.496~2.69	1.5	8.7	±0.9	±0.7	±9	13
		3.3~4.2	1.6	8.9	±1	±0.7	±12	13
		4.4~5	1.6	9.2	±1	±0.8	±12	13
SA-07-4B020080	4x4	2.4~2.5	1.4	7.3	±0.5	±0.3	±4	14
		5.18~5.83	1.5	7.7	±0.6	±0.4	±5	13
		5.9~7.25	1.5	7.8	±0.7	±0.5	±6	13
SA-07-8B020080	8x8	2.4~2.5	1.5	11.2	±0.6	±0.4	±8	13
		5.18~5.83	1.5	11.6	±0.8	±0.5	±10	12
		5.9~7.25	1.55	11.8	±0.9	±0.7	±12	12
SA-07-4B240430	4x4	24~43	2.0	12.4	±1.2	±2.0	±15	10

*Theoretical 6dB Included

Note: The connected components are available from MIcable which include the phase matched assemblies & low loss high isolation phase matched switches.

Typical Test Curve**

SA-07-4B006050



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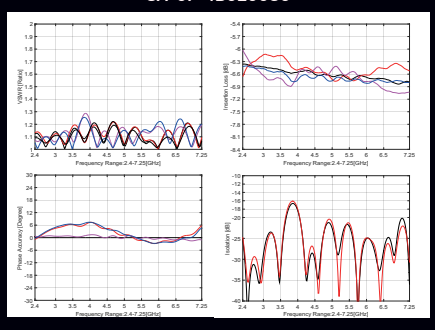

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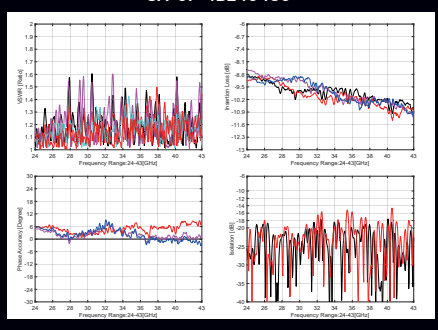

**Corresponding Channels: A1B1、A1B2、A1B3、A1B4

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INVITED PAPER

The Ideal Band for 6G

Joe Madden
Mobile Experts, Silicon Valley, Calif.

The 'killer app' for 5G and 6G systems has been a major question for the mobile industry, so when we talk with various players, we get a range of viewpoints. Will AR/VR drive 5G and 6G markets like email drove 3G? Or like Google Maps/Uber/Facebook drove 4G?

So far, it appears that 5G is different. The operators are not deploying 5G for higher speeds to support apps at gigabit speeds. Instead, operators are deploying 5G to boost capacity in the network, where the higher speeds/wider bandwidths of 5G channels are useful.

The business challenge for the operators is that revenue has stopped growing quickly, but data demand is continuing to grow at 30 to 50 percent per year. This means that the operators need to add capacity while dropping their cost/GB at least 30 percent per year.

A brief study of history shows us that such rapid cost reduction is possible, if we can use wider blocks of spectrum and techniques like massive MIMO to drive much higher throughput in each radio (see ***Figure 1***). Through this lens, it seems obvious that sub-THz is the next step for mobile technology.

But there's a problem; signals over 100 GHz won't penetrate a wet paper bag or the windshield of a car. The propagation of this signal means that huge capacity will be available, but only in a tight space (see ***Figure 2***).

We can imagine applications where short propagation and huge bandwidth can be useful. Try to watch a video at an NFL stadium on game day. Try to equip an automotive manufacturing plant with thousands of 8K resolution cameras for automation and inspection, using a wireless network. Yes, it is believed that we will add a layer of capacity in sub-THz bands for these applications, but we must recognize that they will be niche opportunities. Sub-THz will only work in places where poor propagation and penetration are acceptable, or helpful because they enable us to re-use spectrum.

In addition to sub-THz spectrum, mobile operators will push for better use of any band they can get below 15 GHz. They need RF channels that can penetrate through brick, wood and glass so that indoor customers can use the capacity that they provide—remember that 80 percent of mobile traffic happens indoors, so doubling the outdoor capacity with poor pen-

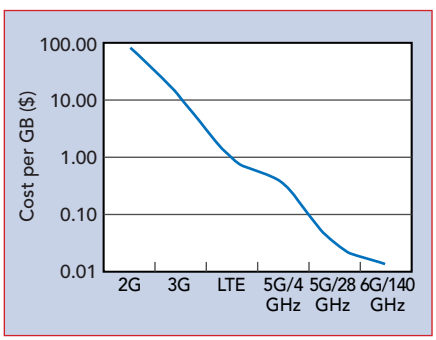

Fig. 1 **Cost per GB of data by cellular generation, historic and projected.**

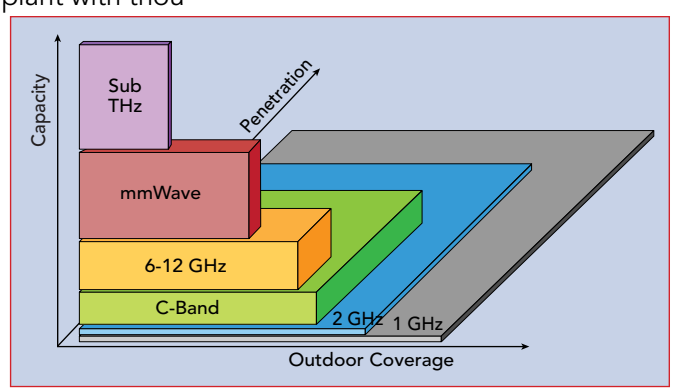

Fig. 2 **Trade-off between frequency spectrum data capacity and coverage.**

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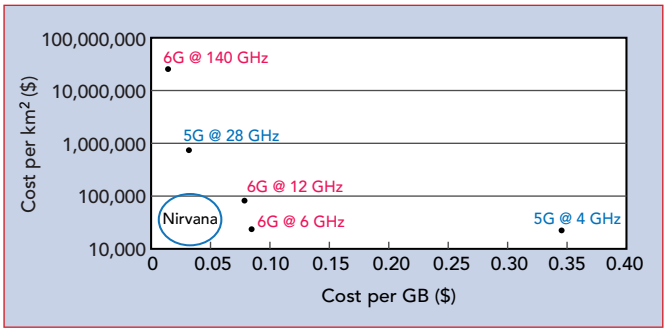

Fig. 3 Cost per GB of data vs. cost per km² of coverage.

etration is useless.

Leading up to the 6G cycle, we can identify a few bands that will be interesting:

The U.S. has allocated the 6 to 7 GHz spectrum for unlicensed operation, with some strict power limitations. But China appears likely to use this band for licensed 5.5G or 6G services…roughly 300 to 400 MHz could be allocated to each of the three major operators there. DISH, RS Access and a few other companies hold spectrum licenses at 12 GHz. The 12 GHz MVDDS band can be re-purposed from television to wireless broadband, with a fat block of 500 MHz.

Many other bands below 6 GHz are under-utilized. Radionavigation, broadcast, radar and other systems have been deployed for 80 years with spectrum set aside 100 percent of the time. Is this necessary in our connected world? Imagine a radionavigation system that only transmits on a 10 percent duty cycle. Ships are not likely to go off course if they get updates on their backup system every 900 milliseconds. Looking over the FCC chart of spectrum usage, it seems that more than 2 GHz of bandwidth could be liberated, by shifting to a spectrum-sharing strategy similar to CBRS.

So, we need to pursue two goals with 6G: we must reduce cost per GB so that the mobile operators can make a profit, but we must also achieve reasonable coverage so that the capacity is available where it's needed.

During the 2G/3G cycles, we said that the 800 to 900 MHz band was "beachfront property" because the propagation is excellent. LTE networks at 2 GHz were ideal because of their combination of coverage and capacity. For 5G, we call the 2.5 to 3.5 GHz bands the "Goldilocks zone." Do you see the trend? As data demand grows, our concept of the 'best' spectrum is moving higher.

The most compelling band for 6G may be the 6 to 7 GHz band (see ***Figure 3***), where cost per GB and cost per square kilometer of coverage are both optimized, with fairly good penetration of walls. The U.S. has already given away this band, but operators in China and a few other countries will achieve an excellent cost profile this way. American operators and others will need access to wide blocks at 12 GHz or below to succeed. ■

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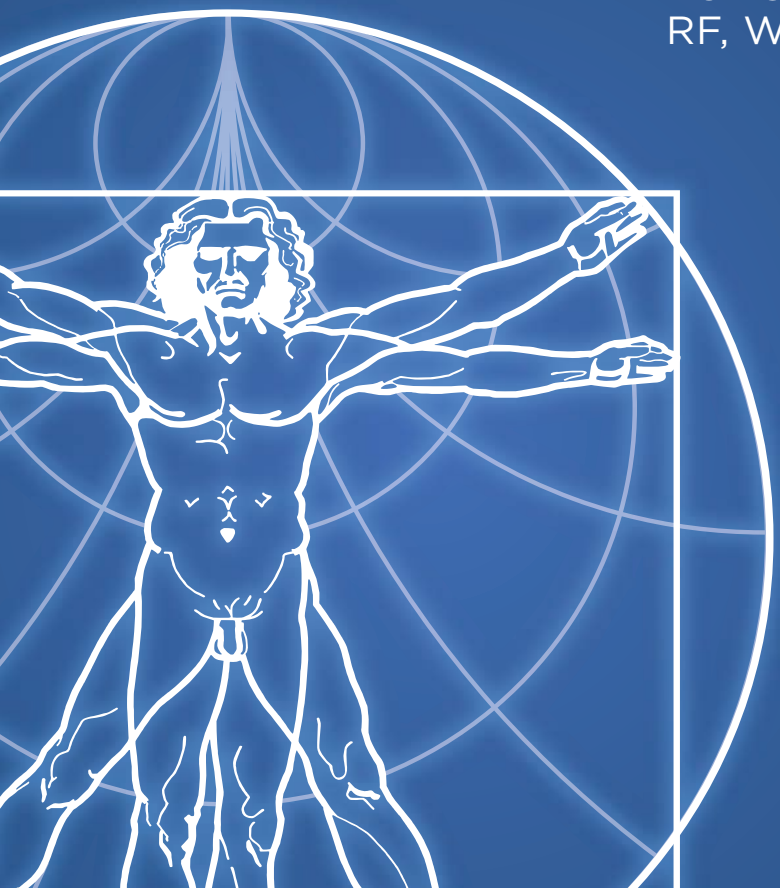

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Tuesday 27th September 2022	09:00 - 18:00
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Thursday 29th September 2022	09:00 - 16:30

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- European Microwave Integrated Circuits Conference (EuMIC) 26th - 27th September 2022
- European Microwave Conference (EuMC) 27th - 29th September 2022
- European Radar Conference (EuRAD) 28th - 30th September 2022
- Plus Workshops and Short Courses (From 25th September 2022)
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Registration opening times:

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- Sunday 25th - Thursday 29th September 2022 (08:00 - 17:00)
- Friday 30th September 2022 (08:00 - 10.00)

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1 Conference	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 520	€ 140	€ 730	€ 200	€ 730	€ 200	€ 1,020	€ 280
EuMIC	€ 400	€ 130	€ 560	€ 190	€ 560	€ 190	€ 780	€ 260
EuRAD	€ 360	€ 120	€ 500	€ 170	€ 500	€ 170	€ 700	€ 240
2 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC	€ 740	€ 270	€ 1,030	€ 390	€ 1,030	€ 390	€ 1,450	€ 540
EuMC + EuRAD	€ 700	€ 260	€ 980	€ 370	€ 980	€ 370	€ 1,380	€ 520
EuMIC + EuRAD	€ 610	€ 250	€ 850	€ 360	€ 850	€ 360	€ 1,190	€ 500
3 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC + EuRAD	€ 900	€ 390	€ 1,250	€ 560	€ 1,250	€ 560	€ 1,760	€ 780
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	Date	Delegates*	All Others**	Delegates*	All Others**
Automotive Forum	26th September 2022	€ 280	€ 390	€ 350	€ 450
5G and Beyond Forum	29th September 2022	€ 60	€ 90	€ 80	€ 100
Defence, Security & Space Forum	28th September 2022	€ 30	€ 60	€ 30	€ 60
Tom Brazil Doctoral School: Build a Frequency -Modulated Continuous Wave Radar in 1-day	25th September 2022	€ 40	€ 40	€ 40	€ 40
Doctoral school: Microwaves for emerging medical technologies	26th/27th September 2022	€ 40	€ 40	€ 40	€ 40

* those registered for EuMC, EuMIC or EuRAD ** those not registered for a conference

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Despite the organiser's best efforts to ensure the availability of all listed workshops and short courses, the list below may be subject to change. Also workshop numbering is subject to change. Please refer to www.eumweek.com at the time of registration for final workshop availability and numbering.

Sunday 25th September 2022			
SC1	EuMIC	Full Day	Fundamentals of Microwave PA Design
WS1	EuMIC	Full Day	140GHz: Where radar meets 6G
WS2	EuMC/EuMIC	Full Day	Latest Digital Predistortion Solutions for 5G and Beyond: from Handsets to MIMO Arrays.
WS3	EuMC/EuMIC	Full Day	Millimeter-Wave GaN Power Amplifiers
WS4	EuMC	Half Day	New On-Chip and Scalable RF Packaging Solutions with Integrated Antennas for 5G mmWave and 6G Applications
WS5	EuMIC	Half Day	RF and mmW reliable ICs: characterization, test and security challenges
WS6	EuMC/EuMIC	Full Day	Technological needs for future SatCom connectivity
WS7	EuMC	Full Day	Microwave Design and Metrology for Quantum Computing
WS8	EuMC	Full Day	Reconfigurable radiofrequency circuits based on ferroelectric materials
WS9	EuMC	Half Day	Advances in Nonlinear Component Modeling and Digital Predistortion under Modulated Signal Conditions
WS10	EuMC	Half Day	Electromagnetic Waves in Daily Life: Research Insights from Young Professionals
WS11	EuMC	Full Day	Additive Manufacturing Technologies for Microwave and Millimeter-Wave Applications

Monday 26th September 2022			
WM1	EuMC	Half Day	Recent Advances in Topologies, Technologies and Practical Realizations of Microwave Sensors dedicated to biomedical applications
WM2	EuMC	Full Day	Cryogenic RF-mmW Technology and circuit platforms: a path toward Quantum-Computing
WM3	EuMC	Full Day	mmWave Front Ends: Challenges and Advances
WM4	EuMC	Full Day	Wireless Power Transmission
WM5	EuMC	Full Day	Substrate Integration Technologies for High-Density Hybrid and Monolithic Integrated Circuits, Antennas and Systems
WM6	EuMC	Full Day	Reconfigurable intelligent surfaces for smart electromagnetic environment: an integrated vision towards industrial applications
WM7	EuMC	Full Day	Recent developments in millimetre-wave measurement: S-parameters and material properties
WM8	EuMC	Full Day	New techniques and foundations for microwave and mm-wave RF filtering devices for emerging communication systems
WM9	EuMC	Full Day	Nanoparticles in medicine: from diagnosis to treatment
WM10	EuMC	Half Day	RF Reliability Status and Challenges for 5G mmWave and 6G Applications

Friday 30th September 2022			
WF1	EuRAD	Half Day	Ubiquitous Radar
WF2	EuRAD	Half Day	Future individual mobility based on automotive radar sensors and more ...
WF3	EuMC	Half Day	Design and optimization of mmWave wideband radios for 5G and Satcom
WF4	EuMC/EuRAD	Half Day	Metasurfaces
WF5	EuRAD	Full Day	Applications for advanced passive radar systems
WF6	EuRAD	Full Day	Radar for Medical and Biological Applications and Bioinspired Radar
WF7	EuMC	Half Day	Dosimetry and microdosimetry applied to emerging wireless technologies: from human to cell level
WF8	EuRAD	Full Day	Integrated Sensing and Communications for 6G Systems
WF9	EuMC	Full Day	Reconfigurable Intelligent Surfaces and Smart Skins for B5G/6G Communications: Recent Advances, Current Trends and Vision

WORKSHOPS AND SHORT COURSES	IN COMBINATION WITH CONFERENCE REGISTRATION				WITHOUT CONFERENCE REGISTRATION			
	Society Member*		Non-Member		Society Member*		Non-Member	
	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
Half Day	€ 110	€ 80	€ 140	€ 110	€ 140	€ 110	€ 190	€ 140
Full Day	€ 150	€ 110	€ 200	€ 150	€ 200	€ 150	€ 270	€ 200

INVITED PAPER

mmWave Power Amplifier MMIC Design and Modeling Challenges

David Farkas
Nxbeam Inc.

Improved simulation accuracy is demonstrated using a hybrid electromagnetic (EM) device model, which includes EM wave interaction and coupling effects, versus a piecewise model for a power amplifier (PA) MMIC design.

The use of mmWave frequencies has surged in recent years due to the increased demand for wireless data. Both terrestrial and satellite communication systems continue to push higher into this frequency range to take advantage of the large available bandwidth. While both terrestrial and satellite communication systems will play a key role in our future wireless communication infrastructure, designing the MMICs to support these systems is often challenging. A key component of these wireless systems, and the most challenging to design, is the PA.

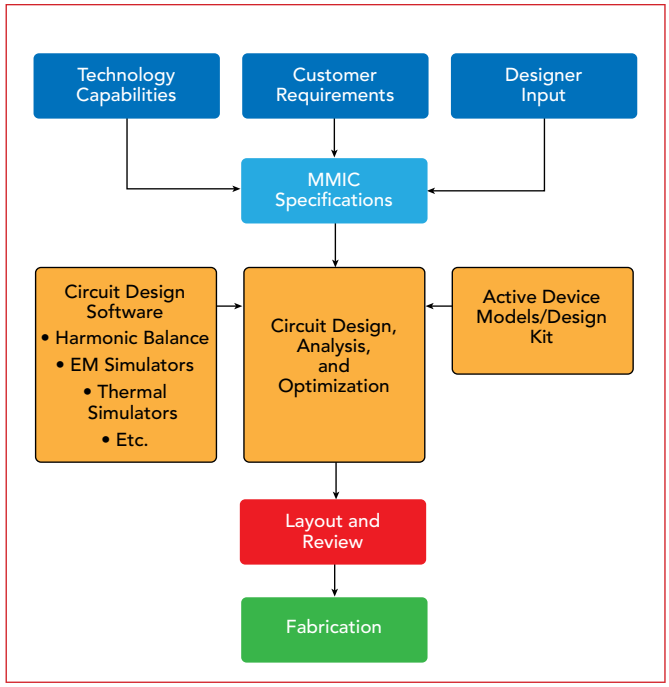

Fig. 1 **MMIC design flow.**

For high-power applications at mmWave frequencies, GaN has quickly become the semiconductor technology of choice due to its superior power, and more importantly, linear power performance. This technology also provides high gain and high efficiency while being extremely reliable. While there are many challenges to designing mmWave GaN PA MMICs, this article focuses on the growing challenge of supporting multi-system specifications and how to partition MMICs in simulation for accurate modeling.

MMIC DESIGN FLOW

The common design flow for developing a MMIC is shown in ***Figure 1***. A design starts with collecting information from customers to understand their MMIC needs and system requirements. At this stage, the MMIC designer provides design input, and various semiconductor technologies

are assessed to determine the best technology. The goal of this initial stage is to finalize the semiconductor technology and MMIC design specifications.

After these are finalized, circuit design software, which contains various types of simulators (e.g., harmonic balance, EM, thermal and others), is used. Passive and active models for the semiconductor technology are also obtained, most commonly from the semiconductor foundry in the form of a design kit. With these tools in hand, the MMIC designer performs analysis and optimization, in which circuit topologies are analyzed and optimized to achieve the design specifications.

Once the design is completed, it goes through various reviews before the start of fabrication. The cycle time to develop a MMIC typically ranges from six to nine months for design, fabrication and test, but this can vary greatly due to various factors such as circuit complexity and semiconductor foundry lead time. Given the time and cost to develop a MMIC, it is essential for designers to do everything possible to achieve first-pass design success.

SUPPORTING MULTI-SYSTEM SPECIFICATIONS

PA MMIC suppliers develop products to satisfy market demand for a specific frequency band and application. An example is the 27 to 31 GHz Ka-Band used for satellite communications. A portion of this band is also used for 5G mmWave applications.

Within the satellite communications market itself, the requirements for Ka-Band PA MMICs can differ greatly due to the variety of system architectures and designs. One of the main MMIC specifications that varies between systems is the maximum linear power specification, which relates to the linearity of the amplifier.

Linearity requirements are highly dependent on several system-level factors such as the modulation scheme, number of carriers and bandwidth. When different satellite systems have different specifications for PA linearity, it creates a unique and more complicated multi-system specification for the PA. The challenge is to create a MMIC that can support multiple systems, which is more cost effective and profitable for the MMIC supplier.

To illustrate this challenge, consider, for example, the linearity requirements for a QPSK modulation scheme versus a 512 QAM modulation scheme. For QPSK modulation, the maximum output power of a MMIC is commonly specified in terms of a spectral regrowth limit, most typically around -30 dBc. By rule-of-thumb, this would approximate to a two-tone third-order intermodulation distortion (IMD3) specification of -24 dBc. For 512 QAM modulation, the IMD3 specification will be around -45 dBc or possibly lower. Designing a single PA MMIC that provides optimum performance for both these cases is a challenge for the MMIC designer.

Designing PA MMICs to multi-system specifications requires flexible design approaches. One way is to design for multiple biasing schemes. By keeping individual stages of a PA MMIC biased independently and adjustable by the end user, performance can be tailored for different uses. Designing for different biasing schemes requires complex analysis and design work from the onset to determine the best transistor size and total periphery for each stage of the amplifier.

The purpose is to take advantage of the nonlinear effects, namely AM-to-AM and AM-to-PM, of individual stages where the nonlinear effects from one stage of a design can compensate for the nonlinear effects from another stage. This will change based on biasing; and the more gain stages used in a design, the greater the flexibility to accommodate multiple specifications. There are limitations, however, to the number of stages in a PA design, because too much gain can cause stability issues.

An example of a MMIC designed

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to operate with different biasing schemes is Nxbeam's NPA2003-DE. The NPA2003-DE is a 27 to 31 GHz 32 W GaN PA MMIC. ***Table 1*** shows the performance of this PA MMIC with the biasing scheme indicated in the figure. To showcase how this MMIC was designed for multi-system specifications, ***Figure 2*** shows the IMD3 results for two different biasing schemes, specifically a QPSK modulation and a 512 QAM modulation.

Figure 2a is the biasing scheme for QPSK modulation. This biasing provides a nulling effect at around 42 dBm output power in which the nonlinear behavior of the second stage of the design compensates for the nonlinear effects from the third stage. By creating this nulling effect, higher output power can be achieved with a smaller output power back-off. From this curve, a power level of greater than 22 W can be achieved for a -24 dBc IMD3.

Figure 2b shows the IMD3 performance for the 512 QAM biasing scheme which is designed to provide a more traditional 3:1 IMD3-to-carrier ratio. It should be noted that the ratio for this MMIC is closer to 2.5:1 in the range of -45 dBc. The figure shows achievable IMD3 levels of -45 dBc or better required for this type of higher-order modulation. At an IMD3 level of -45 dBc, this MMIC provides 4 W of output power.

TABLE 1

MEASURED CW PERFORMANCE OF THE GaN PA MMIC AT 25°C

Parameter	Units	NPA2003-DE
Frequency Range	GHz	27–31
Saturated Pout (Average)	dBm	45.1
Small Signal Gain (Average)	dB	24.9
Power-Added Efficiency (Average)	%	30.2
Input Return Loss	dB	> 11
Output Return Loss	dB	> 8
Bias Voltage	V	24
Bias Current	A	2.0
Bias Voltage Range	V	20–28

MMIC PARTITIONING FOR ACCURATE MODELING AND SIMULATION

Once the PA MMIC topology, device sizes and stage

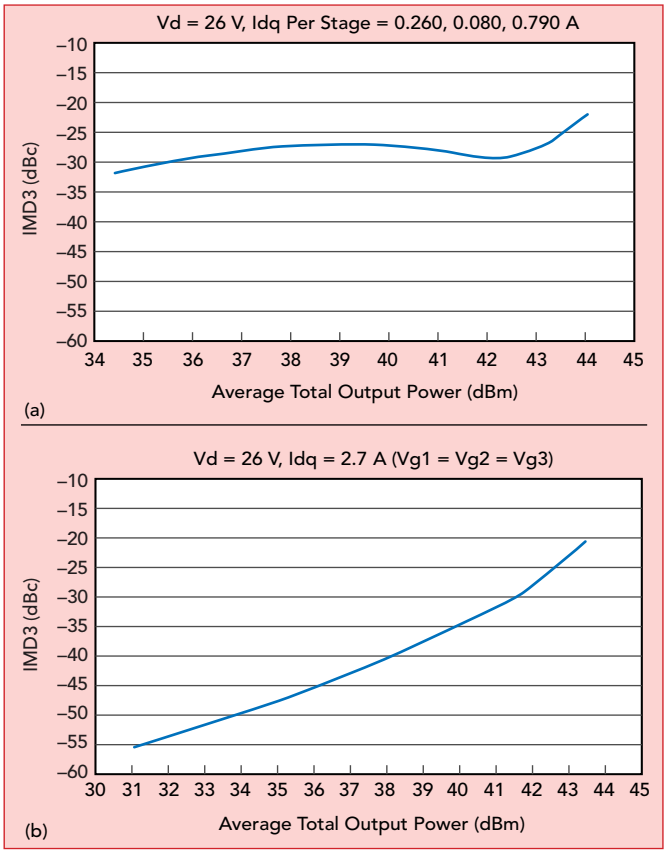

Fig. 2 Measured IMD3 with 10 MHz tone spacing at 29 GHz, comparing the PA biased for QPSK (a) and 512-QAM (b) modulation and operating at 25°C.

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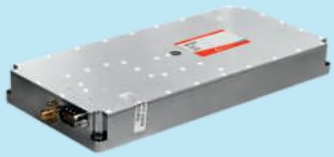

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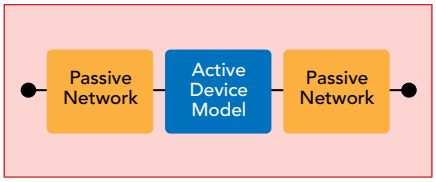

Fig. 3 Piecewise MMIC design approach.

periphery ratios have been determined, the challenge moves to accurately modeling and simulating the circuit, which becomes more difficult at mmWave frequencies. Accurate modeling and simulation are critical to achieving first-pass design success. As previously mentioned, MMICs are designed using circuit design software that contains a variety of simulators. Passive components of a MMIC are typically modeled using EM simulators, while the active devices are independently modeled using a variety of different linear and nonlinear models. Some nonlinear model examples include Angelov, Materka and EEHEMT.

Since active device models are independently created, a piecewise design approach is usually taken to design a MMIC. ***Figure 3*** shows an illustration of a piecewise design approach, in which different parts of a MMIC are modeled separately and connected within the circuit design software to simulate the combined circuit performance.

During the initial phase of a design, lumped or distributed models may be used for the passive components but by the end of the design, EM simulation software is used as it has the capability to capture the true passive network behavior more accurately. With the speed and accuracy of today's EM simulation software, the entire passive portions of a MMIC can be EM simulated. The final MMIC design will then consist of EM simulated networks of passive components connected directly to the active device models in this piecewise fashion.

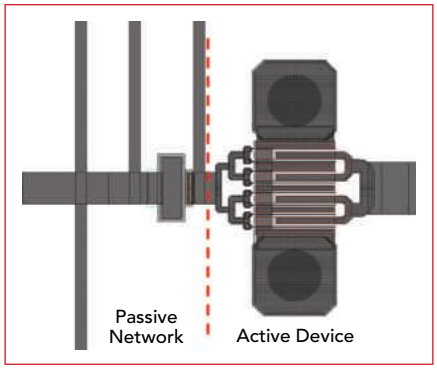

Fig. 4 Section of the PA MMIC showing the connection between the passive network and active device.

To be successful with the piecewise design approach, it is important for the designer to understand how and where to partition a MMIC so that when connected in a piecewise fashion, the correct performance of the circuit is predicted. This partitioning is crucial at mmWave frequencies as passive and active components are moved closer together. ***Figure 4*** illustrates this as it shows a portion of a circuit where an active device is connected to a passive network. The red dashed line represents a common plane to partition this circuit, however, understanding the effects of this partition can affect the outcome.

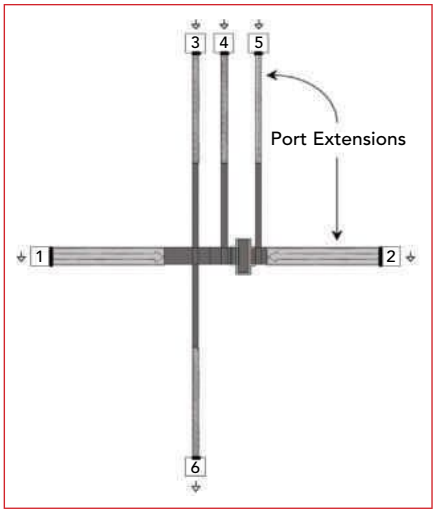

Fig. 5 Passive network from Figure 4 used in the piecewise simulation.

To understand circuit partitioning, it is important to look at how these individual piecewise circuit models are created, as well as the assumptions used. ***Figure 5*** shows the passive network from Figure 4. It should be noted that much of the

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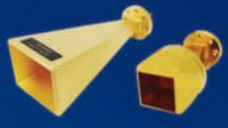

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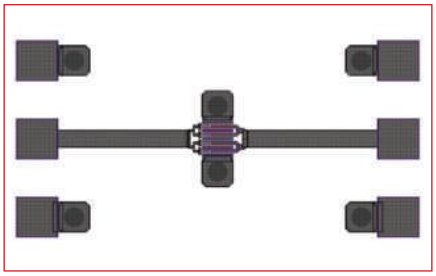

Fig. 6 **Active device measurement test structure.**

passive network has been removed to simplify this explanation. When simulating a passive structure such as this, it is important to understand what the excitation signal looks like on each port.

In this case, standard port extensions are used on each port. The purpose of port extensions is to enable any higher-order modes developed from the port excitation method to decay before interacting with the passive structure being characterized. In this way, the resulting S-parameter file will be for a particular excitation mode, mainly the fundamental mode for each port transmission line. When developing a model using this approach, the MMIC designer must understand that the resulting S-parameter model is accurate only for this excitation mode.

Similarly, the development of active device models usually involves taking measurements of a device test structure, like the one shown in ***Figure 6***. As can be seen from the test structure, relatively long transmission lines are used to feed the active device. In this way, the active device is also excited by fundamental mode excitation. Like the EM simulation, the active device model is accurate only for this mode of excitation.

The difficulty with mmWave circuits is that the distance between active devices and the passive structures is short, such that the mode excitation assumed when cascading individual models together may no longer be valid. This is the case shown in Figure 4. The proximity of the discontinuities from the shunt transmission lines close to the input of the active device will generate higher-order modes in that region of the circuit which includes the input of the active device. In this case, there is not enough distance between this discontinuity and the active device to develop a clean fundamental mode excitation. This will be referred to as EM wave interaction and this EM wave interaction must be account-

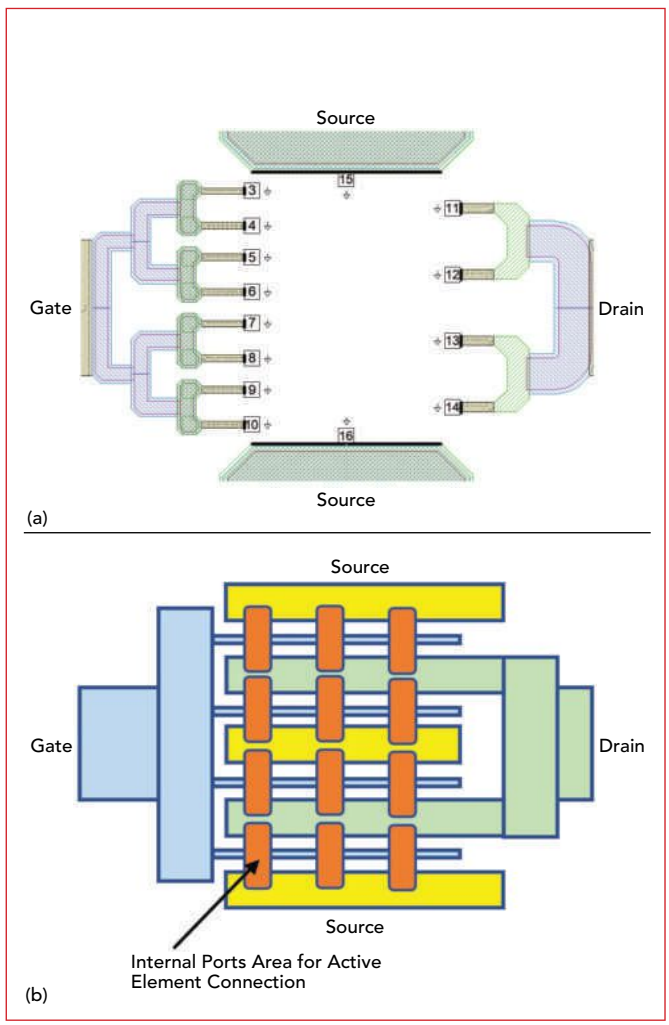

Fig. 7 **Hybrid EM active device model using grounded port (a) and internal distributed port (b) implementations.**

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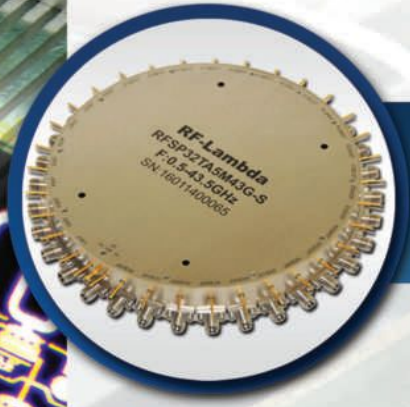

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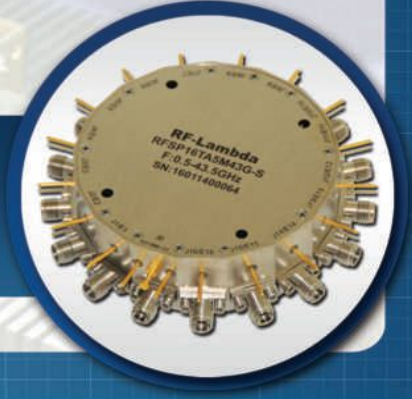

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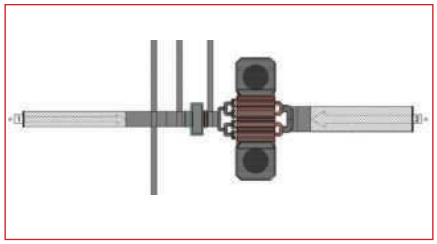

Fig. 8 EM simulation of the passive network and hybrid EM device model.

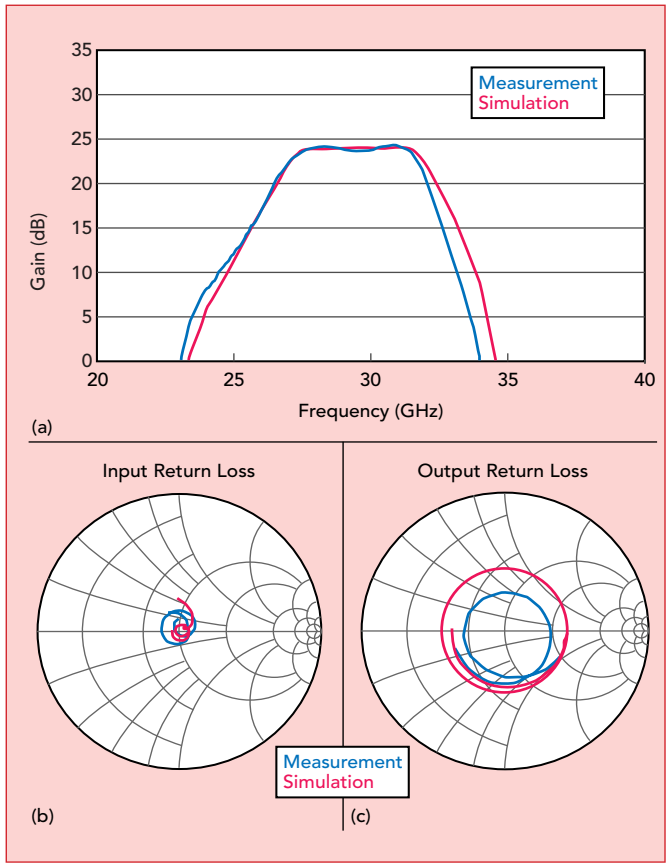

Fig. 9 Measured vs. simulated performance, using the hybrid EM device model for the MMIC PA: gain (a) input return loss from 27 to 31 GHz (b) and output return loss from 27 to 31 GHz (c).

ed for in the simulation for accurate circuit prediction.

In addition to EM wave interaction, there are also EM coupling effects that must be considered when partitioning a circuit for piecewise simulation. If elements of the passive EM network are near the active device, this EM coupling may also need to be accounted for in the simulation. An example of this from Figure 4 is the close proximity of the top active device via to the nearest vertical transmission line of the passive network.

A well-documented method to account for this EM wave interaction and coupling effect has been to include more of the active device into the EM simulation.[1-3] This is referred to as a hybrid EM device model. Hybrid EM device models have been around for over 20 years with many different styles and implementations. An example of two are shown in ***Figure 7***. The goal of these models is to accurately capture the voltage and current waveform distributions on the active device manifolds or within the active portion of the device.

In hybrid EM device models, internal ports are used within the active device that provide the terminals to connect to a core intrinsic device model, such as an Angelov model. Figure 7a shows an example where just the extrinsic device manifolds and source vias are included in the EM simulation. This EM simulation makes use of grounded ports to connect the active device model, while Figure 7b illustrates the use of internal distributed ports for connection to the intrinsic device model.[1,2]

The challenge with these hybrid EM device models lies in the implementation of the internal ports, which are not true to the real device and will cause their own inaccuracies. The goal however is to develop an internal port method that reduces these inaccuracies such that they have a negligible effect on the surrounding circuitry, or at least less of an effect relative to the EM wave interaction and coupling effects.

With the development of a hybrid EM device model, the EM simulation consists of both the passive structure and the passive portion

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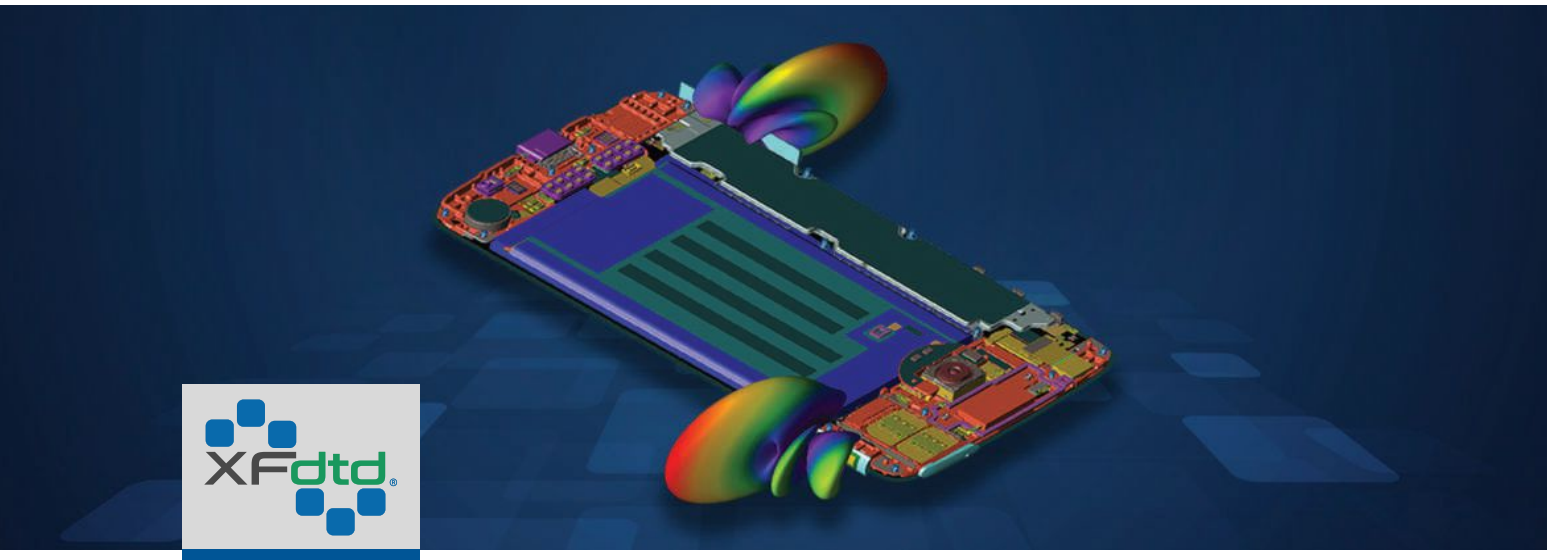

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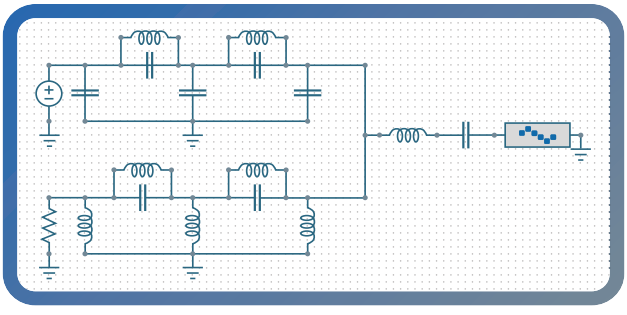

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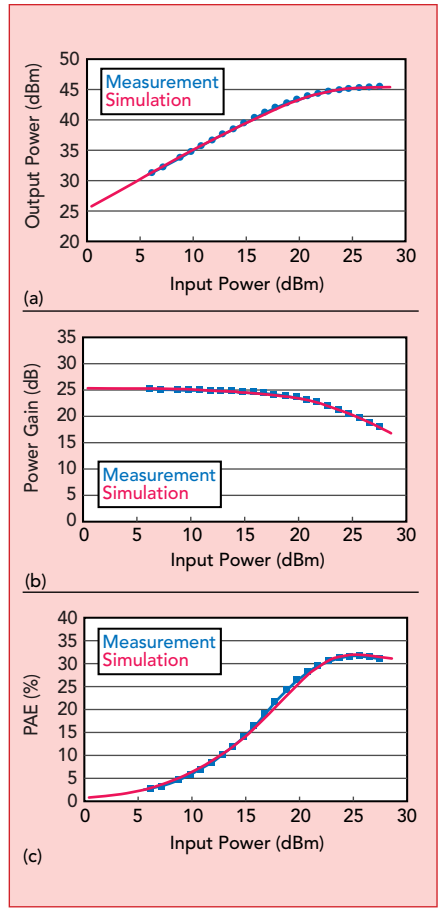

Fig. 10 Measured vs. simulated performance at 29 GHz, using the hybrid EM device model for the MMIC PA: output power (a), power gain (b) and PAE (c).

of the active device model. An example of how the circuit structure presented in Figure 4 would be simulated using a hybrid EM device model is shown in ***Figure 8***. Note that the other ports of the input passive network are not being shown for simplicity.

COMPARISON OF SIMULATION VERSUS MEASUREMENT

To demonstrate improved simulation accuracy using the hybrid EM device model and to show the effect of EM wave interaction and coupling effects, measurements of Nxbeam's NPA2003-DE are compared with simulations using the hybrid EM device model approach versus the piecewise model design approach. It should be noted that this MMIC was designed using the hybrid EM device model approach. All simulations are done using Cadence's Microwave Office Design

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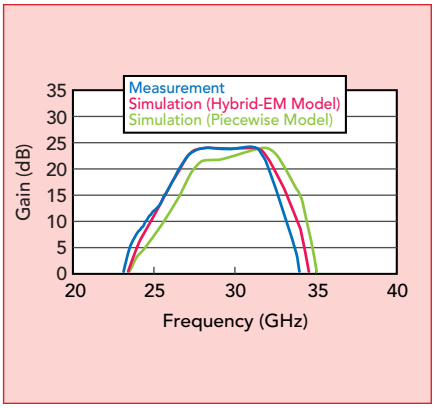

Fig. 11 **Measured gain vs. simulations using the hybrid EM device model and piecewise device model for the MMIC PA.**

Suite including AXIEM for the EM simulator. All active devices models are developed by Nxbeam.

Figure 9 shows small-signal measurement of the NPA2003-DE versus simulation for just the hybrid EM device model approach. As can be seen from the gain in Figure 9a, the hybrid EM device model accurately predicts the gain and bandwidth of the MMIC with a slight exception in the high-end roll-off. The return loss comparisons in Figures 10b and c are included for completeness.

Achieving good agreement between measured and simulated return loss is much more difficult as the measurements are taken on a test module which contains additional substrates and transitions between the measurement reference planes and the MMIC. This can mask the true accuracy of the simulation methods. Calibration error can also play a role in comparing simulated to measured return loss at mmWave frequencies as measurement error typically increases with frequency.

Measured versus simulated performance using the hybrid EM device model for power is shown in ***Figure 10***. The hybrid EM device model approach achieves close agreement in power, power gain and power-added efficiency.

To compare simulation accuracy between the hybrid EM device model approach and the piecewise model design approach, ***Figure 11*** shows the small-signal gain result from Figure 9 compared with the piecewise simulation result. The gain from the piecewise approach is shifted approximately 1 GHz higher in frequency. In addition, the gain shows an upward slope across most of the band. If the piecewise design approach was relied upon for this design, the measured result would likely have been the mirror image of this, namely the gain shifted down in frequency from the desired band by approximately 1 GHz with the gain sloped downward in frequency.

CONCLUSION

The ever-increasing demand for wireless data will continue to push wireless communication systems to higher mmWave frequencies. Designing PA MMICs for these systems will continue to be challenging as many systems will have different MMIC specifications.

Designing MMICs for multi-system specifications will require more flexible design approaches. In addition, it has never been more critical to obtain first-pass design success due to the time, resources and cost. The hybrid EM device model approach, as well as other new models and methods, will be needed to support more accurate MMIC development in the future. ■

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INVITED PAPER

Radar Target Simulation Using Directional Antennas

Andrew Laundrie
Eravant, Torrance, Calif.

Since the earliest days of radar, many techniques have emerged for simulating radar targets for a variety of applications.[1,2] Recently, there is renewed interest in simulated radar targets for the development of new applications at mmWave and THz frequencies.[3,4,5] There is also a growing need for low-cost target simulators to support radar system tests during manufacturing and when calibrating or servicing radar systems in the field.[6] This article presents some basic concepts that may be applied to the design and operation of low-cost radar target simulators using directional antennas.

A single directional antenna may be used as a radar target by terminating its I/O port in a manner that causes some, or all, of the received power to be radiated back toward the radar system. In the simplest case, the antenna is terminated with a short circuit or another fixed impedance that is intentionally mismatched to the antenna impedance, thereby generating a reflected radar signal (see ***Figure 1***).

Assuming negligible backscattering from the antenna structure itself, the effective radar cross-section (RCS) is a function of the gain of the antenna used to simulate the radar target, as well as the fraction of received power reflected back to the antenna port and transmitted toward the radar. By analyzing the signals involved, the effective RCS of the target antenna is readily determined.

The well-known Friis transmission equation[7] describes the RF power exchanged between a transmitter and a receiver. It states that the ratio of the received power, P_{rx}, to the transmitted power, P_{tx}, is equal to the product of the effective areas of the transmit and receive antennas divided by the distance squared and the wavelength squared:

$$P_{rx} / P_{tx} = A_{rx} A_{tx} / d^2 \lambda^2 \quad (1)$$

where A_{tx} and A_{rx} are the effective areas of the transmit and receive antennas, d is the distance between the antennas and λ is the wavelength.

The effective area of an antenna, A_{eff}, is given as:

$$A_{eff} = G\lambda^2 / 4\pi \quad (2)$$

where G is the antenna gain.

Substituting antenna gains for the effective areas in the Friis transmission equation produces another familiar equation:

$$P_{rx} / P_{tx} = G_{rx} G_{tx} (\lambda / 4\pi d)^2 \quad (3)$$

For the case of an antenna used to simulate a radar target, the fol-

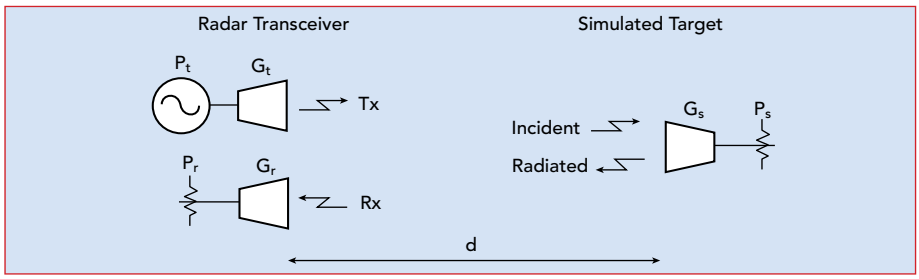

Fig. 1 **Monostatic radar with a reflecting antenna simulating a target.**

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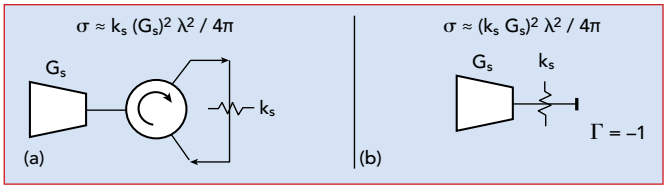

Fig. 2 Radar target simulator with adjustable RCS: three-port circulator functioning as a signal diplexer (a) and adjustable attenuator between the reflecting antenna and a short-circuit termination (b).

lowing equation applies:

$$P_s / P_t = G_s G_t (\lambda / 4\pi d)^2 \quad (4)$$

where P_s is the power received by the target simulator antenna, P_t is the power transmitted by the radar, G_s is the gain of the target simulator antenna and G_t is the gain of the transmit antenna.

If all the power received by the target simulator antenna is reflected and retransmitted back toward the radar, the reflected power received by the radar, P_r, is given as:

$$P_r / P_s = G_r G_s (\lambda / 4\pi d)^2 \quad (5)$$

where G_r is the gain of the radar receiver antenna.

Combining Equations (4) and (5) yields the fraction of transmitted power received by the radar:

$$P_r / P_t = G_t G_r (\lambda / 4\pi d)^4 (G_s)^2 \quad (6)$$

The fraction of transmitted power received by a radar system is also commonly expressed in terms of the target's RCS, which is usually denoted using the symbol σ:[8]

$$P_r / P_t = G_t G_r \sigma \lambda^2 / (4\pi)^3 d^4 \quad (7)$$

Combining Equations (6) and (7) produces the effective RCS of the simulated target in terms of the gain of the target antenna, assuming total reflection of the received signal:

$$\sigma = (G_s)^2 \lambda^2 / 4\pi \quad (8)$$

Equation (8) indicates that an antenna configured for total reflection of the received signal back toward the radar has an RCS equal to the antenna's effective area multiplied by its gain:

$$\sigma = A_s G_s \quad (9)$$

where A_s is the effective area of the reflecting antenna.

The analysis thus far assumes that the radar is responsive to co-polarized reflections. If the radar responds to cross-polarized signals or some other transformation of the transmit polarization, separate receive and transmit antennas may be used to achieve the desired response polarization.

If the power retransmitted by the target antenna is not equal to the received power, but instead is reduced by an attenuation factor, k_s, the RCS of the reflecting antenna is reduced by that factor:

$$\sigma = k_s (G_s)^2 \lambda^2 / 4\pi \quad (10)$$

Two possible configurations for a simulated target with adjustable RCS are shown in ***Figure 2***. In Figure 2a, a three-port circulator functions as a signal diplexer. It passes the received signal through an adjustable attenuator and routes the attenuated signal back to the antenna. The range of RCS that is achievable using such a configuration may be limited by the performance of the circulator. Imperfect impedance matching or signal leakage between ports will determine the minimum reflected signal. In practice it may be difficult to achieve both a wide range of RCS and a flat frequency response using this configuration.

In Figure 2b an adjustable attenuator is placed between the reflecting antenna and a short-circuit termination. If the antenna impedance is well-matched to the attenuator impedance, a wider range of RCS may be realized with this configuration; however, the antenna structure itself produces some backscattering that may determine the lower limit for the effective RCS of the simulated target.

The attenuator in Figure 2a may be replaced with an amplifier to increase the RCS of the simulated target. Signal leakage through the circulator, as well as various imped-

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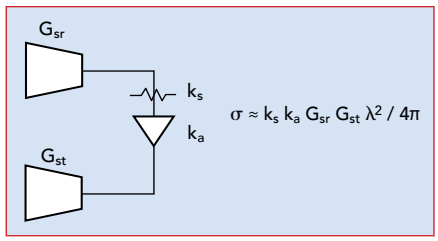

Fig. 3 **Radar target simulator with adjustable RCS and two antennas.**

ance mismatches in the system, will limit how much amplifier gain can be supported while avoiding oscillation.

Improved performance may be achieved using separate transmit and receive antennas for the simulated target (see ***Figure 3***). For such a configuration, the RCS may be estimated as:

$$\sigma = k_a k_s G_{sr} G_{st} \lambda^2 / 4\pi \qquad (11)$$

where k_a is the amplifier gain, G_{sr} is the gain of the target simulator receive antenna and G_{st} is the gain of the target simulator transmit antenna.

A target simulator that employs either one or two antennas can include a delay function to control the target's effective distance from the radar. RF-over-fiber systems based on various technologies are readily available, making it possible to implement range delays equivalent to 100 miles or more at frequencies as high as 60 GHz.[9]

DOPPLER TARGET SIMULATORS

A moving target may be simulated by generating a frequency-shifted copy of the received signal and transmitting it back to the radar system. Such a frequency-shifted signal may be produced using a single-sideband (SSB) modulator and a signal diplexer (see ***Figure 4***). Typically a SSB modulator is realized using a balanced quadrature mixer that provides good suppression of the input carrier signal as well as the unwanted sideband.

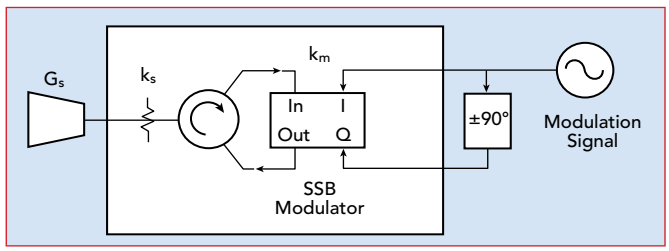

Fig. 4 **Doppler radar target simulator with adjustable RCS.**

To achieve effective suppression of the unwanted sideband, the in-phase (I) and quadrature-phase (Q) modulation signals must be offset in phase by 90 degrees at the modulation frequency. Either the upper or lower sideband is selected by providing either a positive or negative phase difference between the I and Q modulation signals. By selecting the upper sideband, the signal returned to the radar is higher in frequency and simulates decreasing distance between the radar and the target. Conversely, selecting the lower sideband produces a lower frequency return signal that simulates increasing distance.

Assuming negligible signal loss in the signal diplexer and negligible impedance mismatches, the RCS of a single-antenna Doppler target simulator may be estimated as:

$$\sigma = k_m (k_s)^2 (G_s)^2 \lambda^2 / 4\pi \qquad (12)$$

where k_m is the conversion loss of the SSB modulator.

The modulation frequency determines the frequency shift applied to the received radar signal. For an actual moving target, the Doppler frequency shift is twice the closing velocity divided by the wavelength of the radar signal. For example, a radar frequency of 35 GHz and a target velocity of 80 mph (36 m/s) result in a Doppler frequency shift of 8.3 kHz. At 77 GHz the Doppler frequency shift at 80 mph would be 18.4 kHz.

To simulate a single target with fixed velocity, the I and Q modulation signals can be obtained from a function generator that provides a phase-offset adjustment for two output channels operating at the same frequency. If the modulation signals have low harmonic content and the modulator is operated within its linear range, harmonic sideband content may be negligible. Otherwise, the target simulator may produce significant sideband harmonics that could be interpreted as

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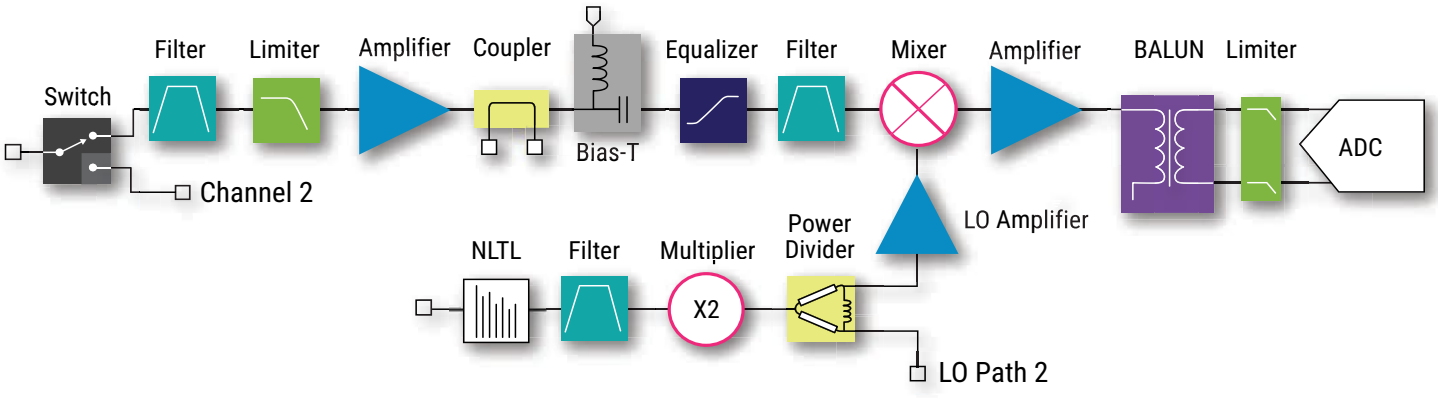

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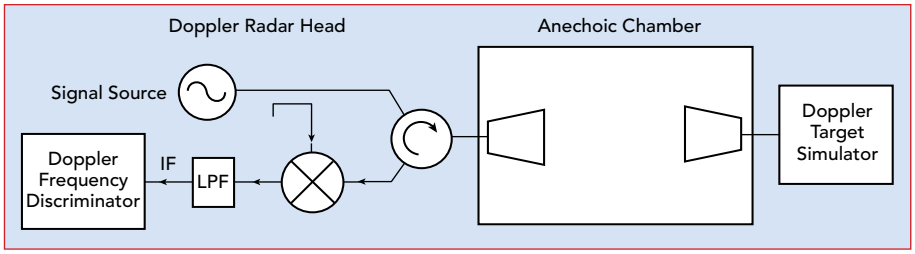

Fig. 5 **Doppler radar test setup.**

additional moving targets.

The magnitude of the frequency-shifted signal can be controlled over a wide dynamic range by adjusting a variable attenuator positioned between the antenna and the signal diplexer. The lower limit of the Doppler signal amplitude does not depend on impedance mismatches or signal leakage. As a result, the Doppler radar target simulator can measure the sensitivity of a Doppler radar system over a dynamic range of 60 dB or more.

DOPPLER RADAR TRANSCEIVER TESTS

In a manufacturing environment, Doppler radar heads can be quickly tested relative to a "golden" unit that has been field-tested and certified as providing adequate sensitivity to a moving target with a known RCS. A typical setup includes an antenna test range or an anechoic chamber with a fixture on one end for mounting the radar head under test (see ***Figure 5***). The target simulator antenna is positioned at the other end of the test range.

Calibration of the Doppler radar test system is straightforward. With the "golden" (calibration) radar head installed and the target simulator activated, the apparent Doppler signal produced by the radar head is fed to a frequency discriminator that computes the target velocity. When the signal-to-noise ratio is sufficient, the frequency discriminator produces a valid measurement of the target velocity. During calibration of the test setup, the attenuation value is adjusted upward to a level where the calibration radar unit becomes unable to produce an accurate velocity measurement. The attenuation value is then decreased slowly until a valid velocity measurement is obtained. The attenuation value may be adjusted further to set the minimum level of performance necessary to pass the sensitivity test. The setup is then used to test production units on a pass/fail basis.

The margin by which a radar transceiver passes or fails can be optionally determined by adjusting the variable attenuator. The sensitivity of the radar head, relative to that of the calibration unit, is determined by the amount of attenuation needed to reach the measurement threshold of the radar head being tested. For example, if the Doppler radar head being tested can measure the target velocity with 6 dB of additional attenuation relative to the calibration unit, it will have approximately twice the measurement range of the calibration unit for a given RCS. This is because the Doppler signal returned to the unit under test is reduced by 12 dB when the attenuator setting is 6 dB greater, and 12 dB attenuation corresponds to target that appears to be twice as far away from the radar head.

The major factors affecting the sensitivity or detection range of an unmodulated CW Doppler radar sensor include the transmit power, the mixer conversion loss and the sideband noise in the radar signal that is down-converted to the IF channel. Either reduced transmit power or greater mixer conversion loss can reduce the Doppler signal power. Increased AM or FM sideband noise in the radar signal can generate more broadband noise at the mixer output. If a frequency discriminator fails to accurately measure the Doppler frequency, it may be due to poor signal strength, high mixer conversion loss, excessive sideband noise or a combination of these factors.

If a pulsed or FMCW radar is used with a Doppler radar target simulator, and the radar is sensitive to stationary objects (zero Doppler shift), the target simulator may be detected as a stationary object as

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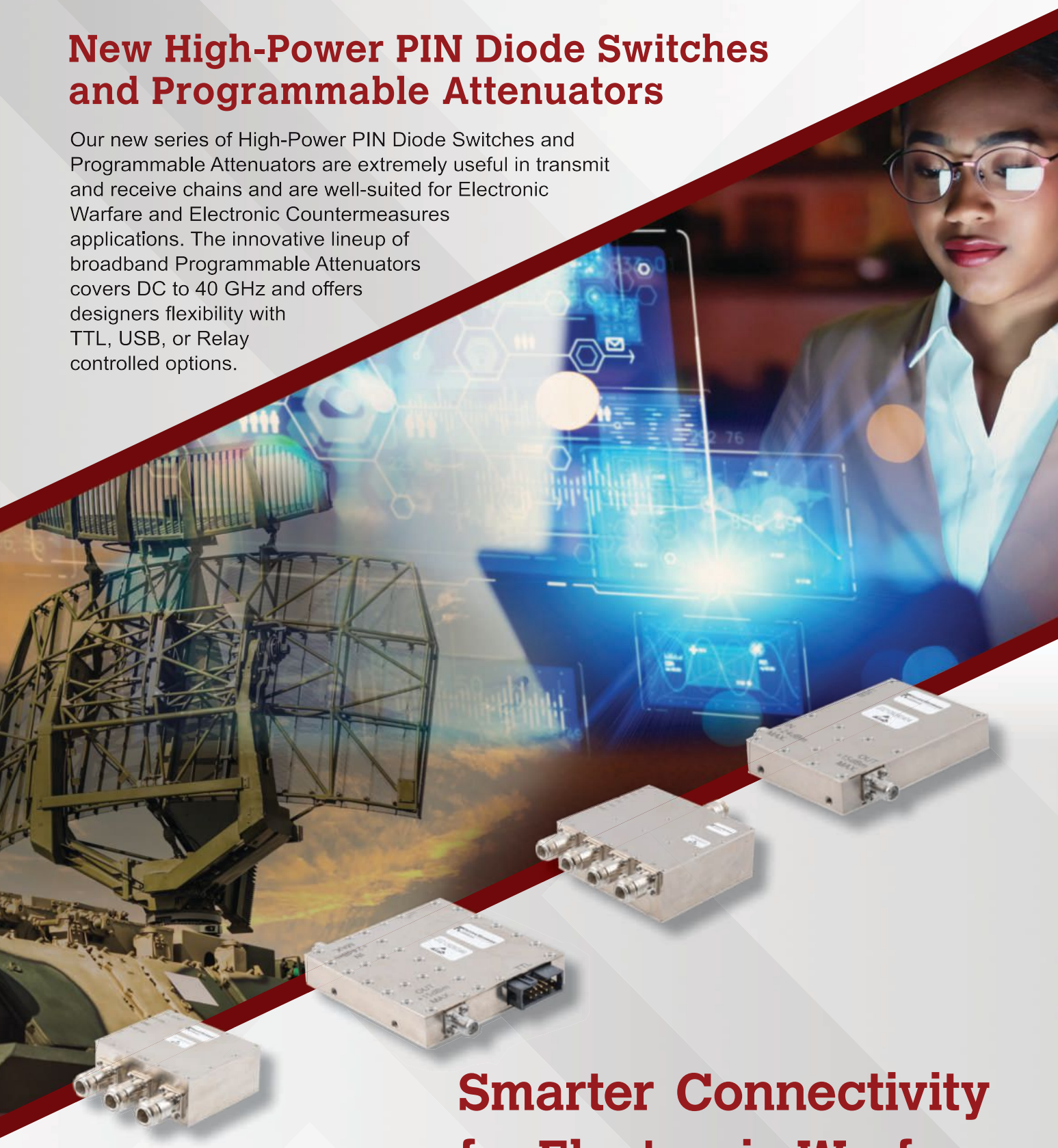

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well as a moving target. A return signal without a Doppler frequency shift may result from backscattering by the antenna structure, impedance mismatch effects, imperfect suppression of the carrier signal in the SSB modulator or signal leakage through the diplexer.

DESIGN EXAMPLES

A typical rectangular horn antenna, Eravant model SAR-2309-28-S2, operates at 35 GHz and provides 23 dBi gain with linear polarization. If its waveguide port is terminated with a short circuit, the antenna can be used to simulate a target with an estimated RCS of approximately 0.2 m^2. A pair of horn antennas with 23 dBi gain operating at 35 GHz and connected to an amplifier with 10 dB gain can be used to simulate a target having an estimated RCS of 2 m^2, a factor of 10 higher than without an amplifier. Alternatively, a single lens-corrected horn antenna, Eravant model SAL-3333732905-28-S1, provides 29 dBi gain at 35 GHz and could provide an RCS as high as 3.5 m^2 without using an amplifier.

Estimating the effective RCS of a Doppler radar target simulator involves more variables. A typical waveguide circulator, Eravant model SNF-22-CA, provides about 0.5 dB insertion loss at 35 GHz. A quadrature mixer, such as Eravant model SFQ-30340310-2828SF-N1-M, exhibits 10 dB conversion loss. If waveguide sections are used to connect the mixer and circulator ports, an additional 1 dB of insertion loss may be expected, resulting in an estimated total conversion loss of 12 dB. If the antenna provides 29 dBi gain, the apparent RCS of the simulated moving target is estimated to be roughly 0.25 m^2. The RCS can be adjusted downward by inserting a variable attenuator between the target simulator antenna and the circulator. Each 6 dB of additional attenuation reduces the effective RCS of the simulated target by a factor of 16.

For an FMCW or pulsed radar system, the present design example can be expected to produce a return signal with zero Doppler frequency shift. The circulator, for example, has a typical input return loss of 12 dB which implies that about 1/16 of the received power would be reflected back toward the radar system with no Doppler shift. Hence the radar system could detect a stationary object with an RCS of about 0.25 m^2 in addition to a moving target with an RCS approximately equal to 0.25 m^2 when the attenuation value is set to 0 dB.

Preconfigured Doppler target simulators are also available, such as Eravant model STR-793-12-D1 which operates from 77 to 81 GHz

Fig. 6 Integrated Doppler radar target simulator.

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(see ***Figure 6***). It includes a direct-read attenuator and a WR-12 interface for connection to a user-specified antenna. Carrier and sideband suppression are 30 dB and 20 dB, respectively. Doppler frequencies up to 250 MHz are supported. The realized RCS depends on the antenna used and any additional insertion loss if a connecting cable is used.

For an unmodulated (CW) Doppler radar system, the distance to the target is ambiguous. Adjustment of the return signal amplitude may be interpreted as either a change in RCS or a change in distance from the radar system. For an FMCW or pulsed radar system, the distance to the target is generally determined by evaluating the effects of signal delay. For these systems valid interpretations of a change in signal level, when everything else is held constant, include a change in the RCS, a change in the target's position in the radar beam or a change in the propagation loss.

CONCLUSION

A directional antenna that is intentionally mismatched can be used as a simulated radar target. The expected RCS of the target can be estimated from the antenna gain. By controlling the mount of received power that is reflected back to the antenna, the RCS of the target can be varied. Separate antennas may be used for receiving and retransmitting the received signal to achieve more flexibility in the polarization response.

By frequency-shifting the received radar signal using a SSB modulator, and retransmitting the frequency-shifted signal back to the radar system, it is possible to effectively simulate a moving target using stationary equipment. A variety of configurations are possible using either one or two antennas. A low-cost single-antenna system that includes only a signal diplexer, a SSB modulator and an adjustable attenuator can be used to measure the effective range of Doppler radar heads in a production environment or when servicing radar systems in the field. ■

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FCTS1000-10-5	1000	-141	-158	
FCTS1000-100-5	1000	-141	-158	
FSA1000-100	1000	-145	-160	
FXLNS-1000	1000	-149	-154	
KFCTS1000-10-5	1000	-141	-158	
KFCTS1000-100-5	1000	-141	-158	
KFSA1000-100	1000	-145	-160	
KFXLNS-1000	1000	-149	-154	
FCTS2000-10-5	2000	-135	-158	
FCTS2000-100-5	2000	-135	-158	
KFCTS2000-100-5	2000	-135	-158	
KSFLOD12800-12-1280	12800	-122	-123	
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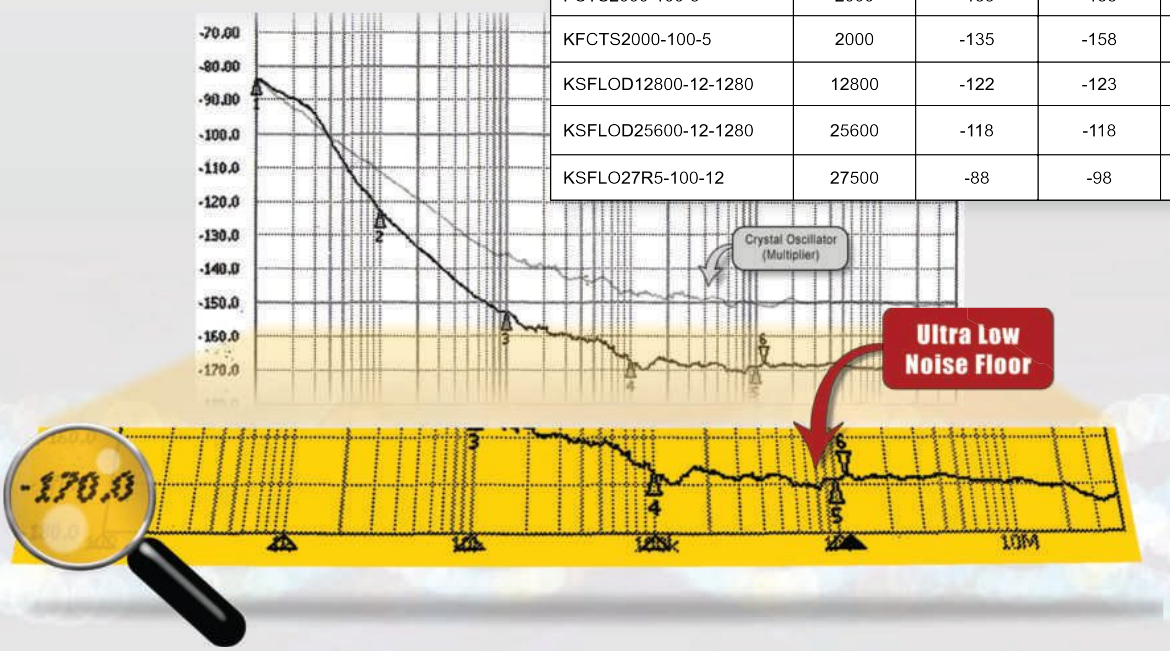

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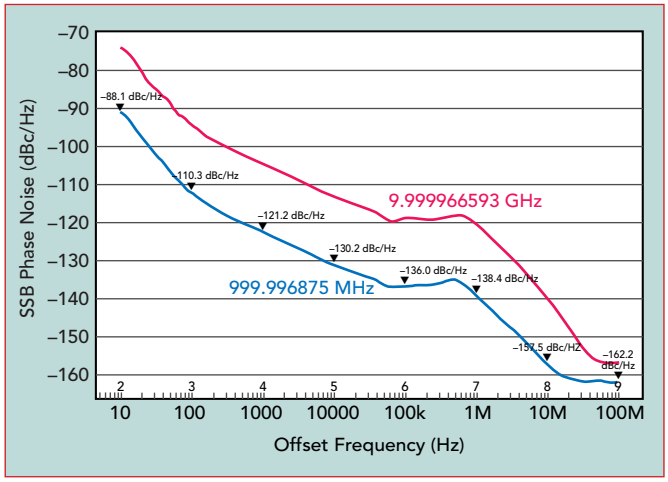

Fig. 1 **SSB phase noise measurement.**

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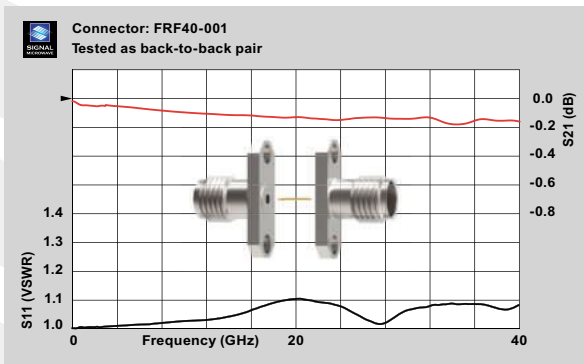

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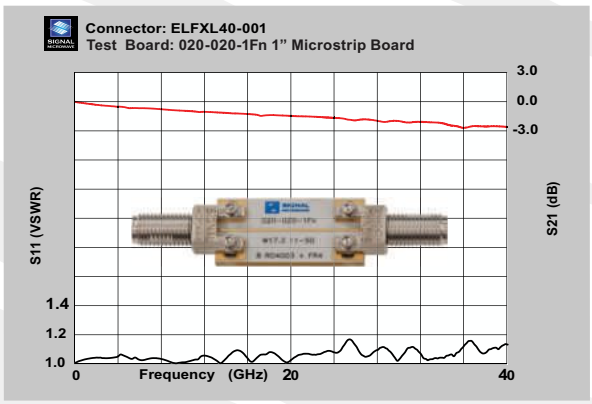

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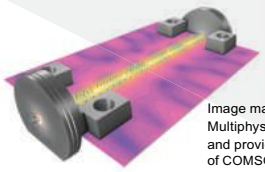

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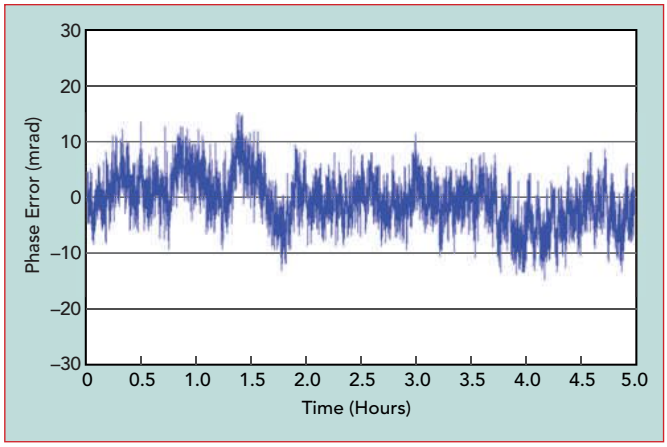

▲ Fig. 2 **Time stability of channel-to-channel phase difference, with both channels set to 5 GHz.**

The synthesizer is well-shielded in a compact flange-mountable module measuring 134 × 95 × 25 mm. It weighs under 0.5 kg and consumes only 17 W, which enables it to use passive heat sinking, with easy and flexible mounting to a heat sink. Internal temperature monitoring is available to prevent the synthesizer from exceeding the recommended operating temperature range; if that occurs, the RF output stage will turn off.

The synthesizer has a standard Ethernet port for connecting to a PC and controlling the unit with AnaPico's graphical interface software or using SCPI commands.

MULTI-CHANNEL AND PHASE-COHERENT

The synthesizer supports an external reference, both 100 MHz and 1 GHz with a relatively wide frequency lock range of ±10 ppm, and it provides a 1 GHz reference output. Using this reference output, multiple units can be connected to implement phase-coherent sources. The first unit acts as the reference, with its 1 GHz reference frequency looped through the other units. To reduce cost, the APMSYN22 modules can be ordered without the internal OCXO when planned to be used with other APMSYN22 modules or an external reference.

Phase-coherence can be characterized by the relative phase difference variation between channels set to the same frequency. ***Figure 2*** shows the phase-coherence measurement with two APMSYN22 modules daisy-chained in a phase-coherent configuration, with both set to 5 GHz. The relative phase difference variation measured in a non-airconditioned room is about ±0.5 degree over 10 hours.

The synthesizer uses a low noise amplifier between the 1 GHz reference input and output. The additive phase noise of the amplifier is low and does not appreciably degrade the phase noise, enabling up to at least 16 channels to be configured as phase-coherent sources.

APPLICATIONS

The APMSYN22 synthesizer is suitable for many applications. It can be used as an RF/microwave system clock, particularly when multi-channel, phase-coherent local oscillators are needed. The individual channel phase adjustment enables accurate timing alignment. The multi-channel, phase-coherent configuration is useful for design and testing of radar receivers, phased array beamforming networks, quantum computing instrumentation (as the RF local oscillators for the I/Q modulators), MIMO receivers and as sources in heterodyne spectroscopic systems. Also, the combination of phase-coherence and fast switching supports fast frequency hopping for agile electronic warfare systems.

AnaPico AG
Zurich, Switzerland
www.anapico.com

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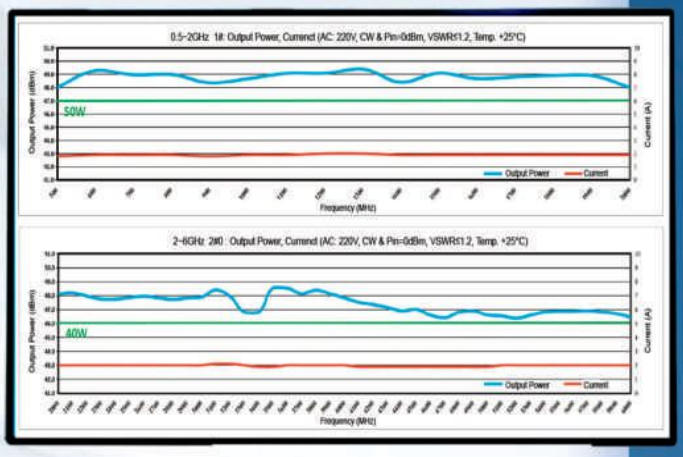

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MIcable announced the latest solid state high gain broadband power amplifier MPAR-005060P44 which covering 0.5~6GHz with output power 40W. It uses state-of-art GaN design technology and can reach higher saturated output power while keeping higher P1dB and better linearity.
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It is designed for applications, such as 5G/ LTE, WIFI and other related system & EMC test.

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Tel: +86-591-87382856 Email: sales@micable.cn Website: www.micable.cn

54 GHz Vector Signal Generator Simplifies Testing to Industry Standards, Can Be Extended to 110 GHz

Keysight Technologies
Santa Rosa, Calif.

Advanced wireless communications systems are driving increasingly complex performance requirements and standards, reflected in each generation of mobile devices, base stations, satellites and electromagnetic spectrum operations (EMSO). Design and test challenges include wider bandwidth, higher frequency, complex modulation and multiple antenna systems.

To address these challenges, Keysight's M9484C VXG vector signal generator (VSG) covers up to 54 GHz with 2.5 GHz modulation bandwidth—5 GHz bandwidth with channel bonding—in a single instrument. Adding the V3080A frequency extender, frequency coverage reaches 110 GHz, and using the Keysight PathWave Signal Generation software enables testing to the latest standards and test requirements for wireless and EMSO applications.

FEATURES AND FLEXIBILITY

The M9484C VXG covers all the 5G NR frequency bands, as well as V- and W-Band for satellite communication links. It generates the complex wideband signals used for carrier aggregation and digital predistortion and delivers excellent RF performance: low phase noise, error vector magnitude (EVM) and adjacent channel power ratio (ACPR). With up to four synchronized and phase-coherent channels in one instrument and more than 32 phase-coherent channels available by daisy-chaining multiple instruments, the VXG greatly simplifies MIMO and beamforming testing. With the capability to simultaneously generate up to eight virtual signals per RF channel, it streamlines complex receiver test scenarios.

Because many of the new standards and applications require multi-channel functionality, higher frequencies and wider bandwidth, the VXG was designed to provide multi-channel setups with one, two or four channels in a single instrument and more than 32 channels using multiple instruments. The VSG has the capability to create any standards-based waveform with up to 2.5 GHz modulation bandwidth per channel. A four-channel instrument supports intra-band and inter-band aggregation up to 10 GHz.

With some applications using frequency bands above 54 GHz, the compatible 110 GHz frequency extender (V3080A) moves the connection close to the device under

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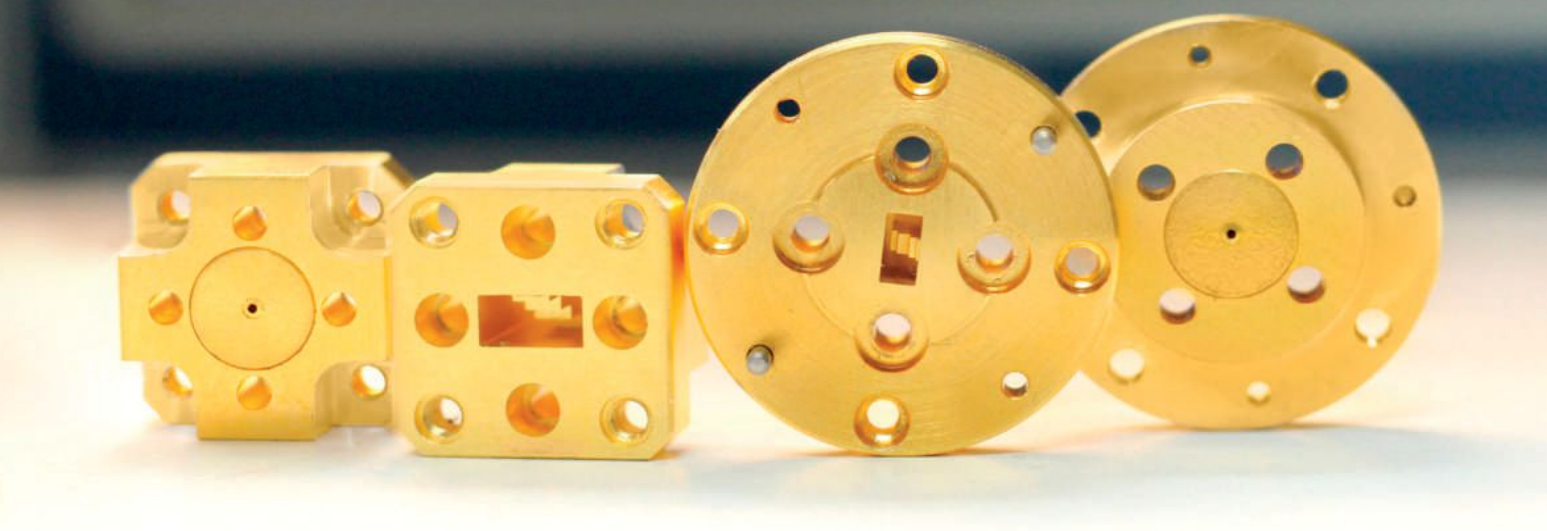

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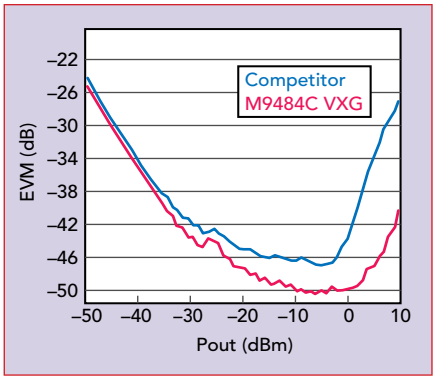


Fig. 1 **VXG EVM vs. output power for a 100 MHz bandwidth 5G NR signal at 39 GHz.**

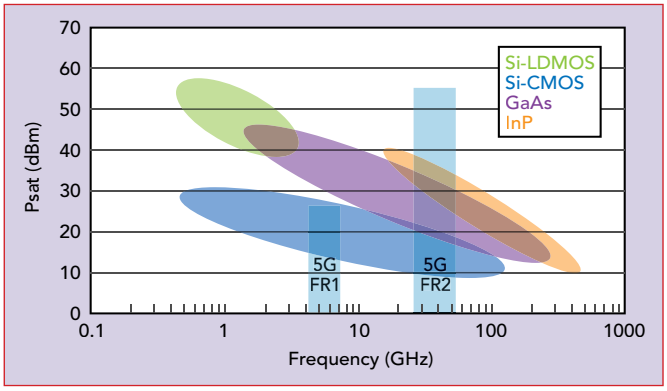


Fig. 2 **Semiconductor process capability: output power vs. frequency.**

test (DUT), reducing path loss and providing high output power to improve the dynamic-range for accurate ACPR and EVM measurements.

CUSTOM ICS

The M9484C was designed to have excellent single-sideband phase noise, signal purity and high power. It delivers the lowest EVM and highest output power in the industry (see ***Figure 1***), achieved with custom MMICs that are used throughout the signal path to ensure measurements reflect the DUT rather than artifacts generated by the instrument. Keysight's custom MMICs use GaAs and InP processes, which deliver higher output power at the frequencies covered by the VSG (see ***Figure 2***). These custom MMICs combined with the novel signal path architecture provide both high output power and low noise, enabling engineers to both test devices driven into compression and measure device sensitivity close to the noise floor.

The Si used in the instrument is equally impressive, including 14-bit digital-to-analog converters running at an 8.5 GHz clock rate and 3 GSPS DSPs with eight real-time processing paths.

GENERATING COMPLEX SIGNALS

Complementing the VXG, Keysight PathWave Signal Generation software simplifies testing to the latest standards and test requirements defined for wireless and EMSO applications. Predefined applications for compliance test setups and auto-configuring signal analysis simplify test workflows. For example, to test the conformance of a 5G NR receiver to the 3GPP 5G NR base station requirements, the software includes 3GPP MIMO fading models and supports the real-time hybrid automatic repeat request. For satellite, automotive radar, new wireless system and aerospace and defense applications, the software can generate custom OFDM and I/Q waveforms.

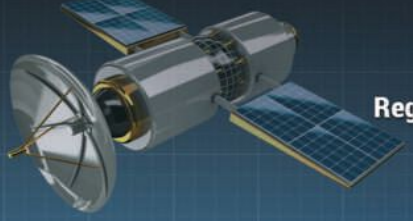
Keysight's new graphical interface makes the VXG easy to use, with quick characterization and troubleshooting. PathWave provides "smart" linkages to Keysight's X-Series signal analyzers, reducing the time spent setting up measurements.

The M9484C VXG is available in seven frequency ranges, from 9 kHz to 6 GHz, to 9 kHz to 54 GHz. The V3080A frequency extender option extends the upper frequency to 110 GHz. The optional PathWave Signal Generation software provides a suite of signal creation tools for the VXG that reduces the time developing test signals for characterizing and verifying compliance with industry standards. The software's reference signals are validated by Keysight.

Keysight Technologies
Santa Rosa, Calif.
www.keysight.com

RF-LAMBDA

THE POWER BEYOND EXPECTATIONS



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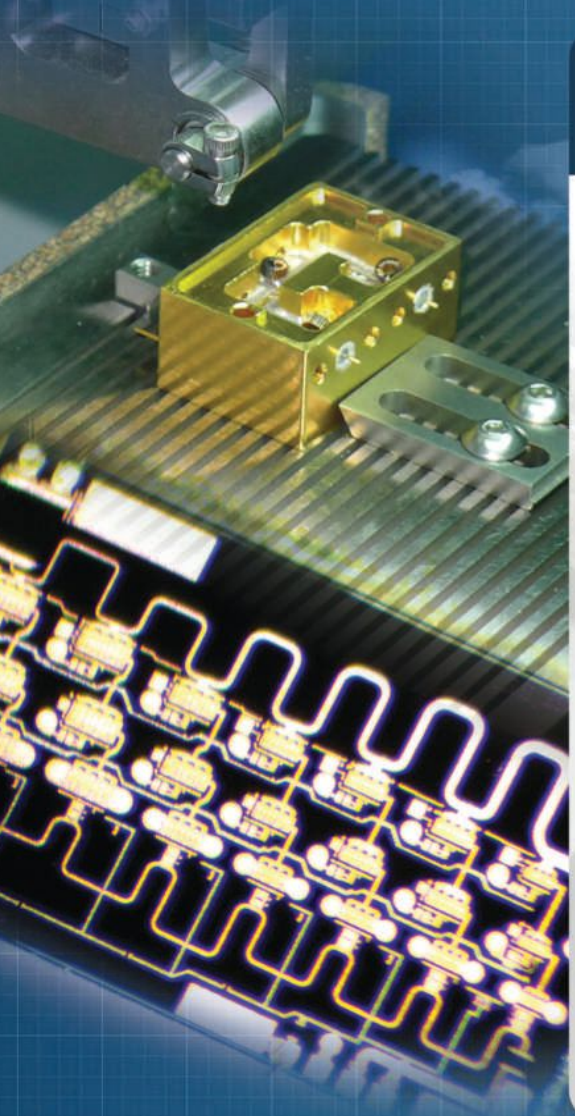

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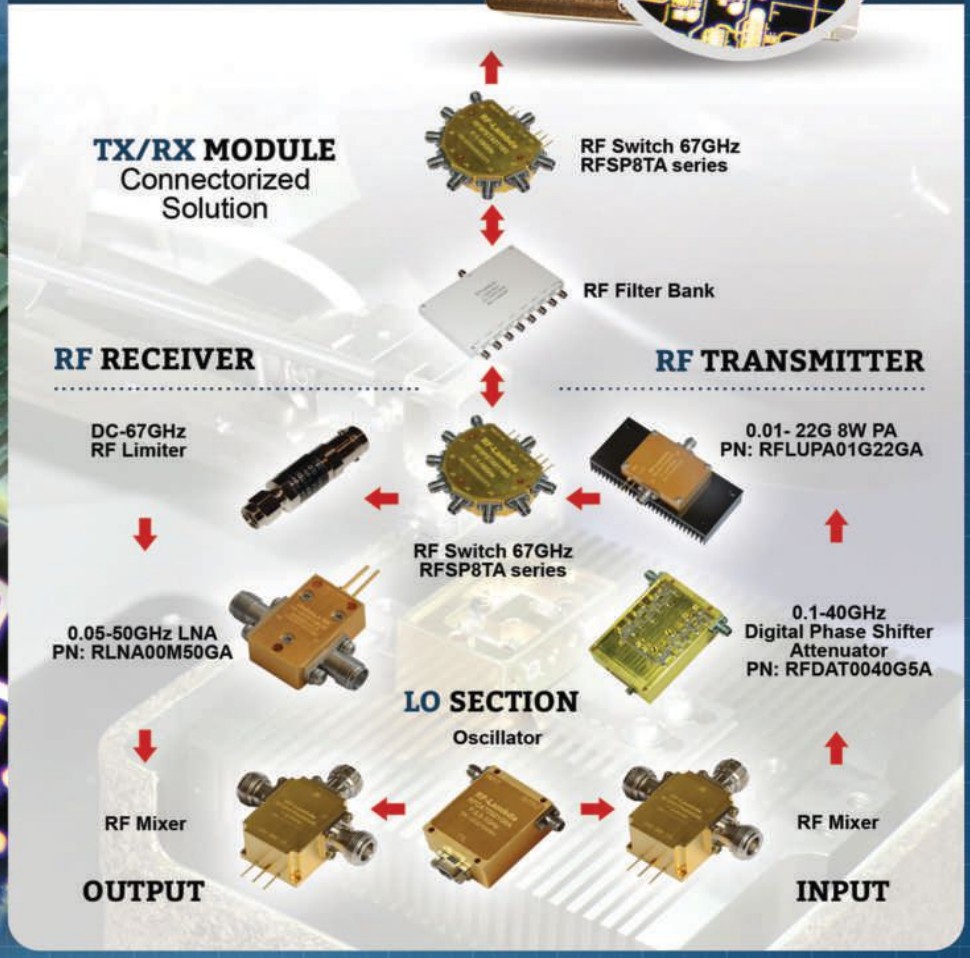

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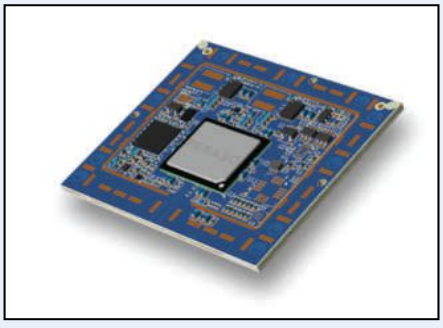
Making 5G Small Cells RF Transparent Yet Visibly Concealed

Designed for 5G networks, RF Industries' TruField™ is a patent-protected technology for "concealment solutions," meaning visibly hidden but transparent to RF. TruField has been tested by independent labs and wireless carriers and shown to have superior RF transparency compared to traditional concealment shrouds that also limit coverage and degrade the network's performance. TruField is agnostic to the frequency—low band, mid band (C-Band) and mmWave—and has less than 0.2 dB transmission loss at any angle of incidence up to 60 degrees.

To maintain the RF signal strength and angular coverage, the TruField shroud uses a proprietary outer shell material developed by Saint-Gobain, an exclusive strategic partner to RF Industries. This unique, lightweight fabric is made of a self-cleaning, hydrophobic material that repels water, mold and droppings or other RF disturbing materials, which keeps the shroud virtually maintenance free and lowers the total cost of ownership. The TruField product line is a customizable, future-proof solution engineered and designed by RF Industries to fit the exact needs of customer antennas.

Founded in 1979, RF Industries designs and manufactures interconnect products for many applications, including RF connectors and passive components, RF coaxial cable assemblies, data cables, wire harnesses, fiber optic cable assemblies, custom cabling, energy-efficient cooling systems and integrated small cell enclosures.

RF Industries
San Diego, Calif.
rfindustries.com/trufield/



5G Beamforming RFIC Supports All FR2 Bands

Peraso developed the PRS1520 mmWave beamformer IC to meet the needs of 5G users, for equipment such as customer equipment, laptops, tablets and hotspots. The integrated RFIC has two independent, 16-channel beamforming arrays for dual polarization or dual-stream MIMO, and multiple RFICs can be used in tiled configurations for larger arrays. The PRS1520 covers all the 5G NR FR2 bands: 24.25 to 29.5 GHz for the n257, n258 and n261 bands and 37 to 43.5 GHz for the n259 and n260 bands. Each beamforming channel has a 5.6-degree phase resolution and the internal processor employs a unique approach for phase and amplitude adjustment that supports dynamic beam tables with thousands of entries. In transmit, the linear output power per element is 17 to 18 dBm, and the RFIC is biased with a single 5 V supply.

To support evaluation of array performance, Peraso is developing an evaluation module, the EVK-PRS1520, which integrates the beamforming RFIC with a printed circuit board containing a dual polarized antenna, supporting circuitry and a USB-C control interface. Including the antenna array, the module measures 50 x 92 mm. Sampling of the evaluation module is planned to begin during the third quarter of 2022. Each antenna polarization has 16 elements, enabling a total EIRP (both polarizations) of approximately 47 dBm in the n261 band. This demonstrates the PRS1520 is suitable for fixed wireless access customer equipment, small cell nodes and personal mobile hotspots.

Peraso is a fabless semiconductor company that has focused on mmWave since 2008. In addition to supporting the 5G FR2 bands, Peraso manufacturers 60 GHz RFIC products for wireless infrastructure and consumer electronics.

Peraso Inc.
San Jose, Calif.
www.perasoinc.com

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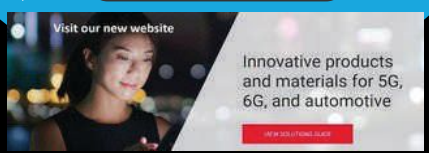
Analog Devices has a rich history of delivering system-level solutions to enable the warfighter and protect critical missions in the unforgiving vastness of space. Leverage our competitive edge to create your own. ADI executives, Bryan Goldstein, Yasmine King and Sean D'Arcy explain ADI's distinct technical and system-level experience which enables manufacturers to get to market faster.

Analog Devices
www.youtube.com/watch?v=RM4xqU4eykk

AGC Multi-Materials Division's New Website Officially Launched

AGC Multi-Materials Division's new website has been officially launched, featuring material solutions for high frequency and high speed applications for 5G/6G, automotive radar, aerospace & defence and more.

AGC Multi-Materials Europe
www.agc-multimaterial.com



Importance of Mismatch Tolerance for Amplifiers Used in Susceptibility Testing

Read to learn about the overlooked issue of mismatch in RF systems and how to properly select an amplifier that can mitigate ill effects of mismatch.

AR RF/Microwave Instrumentation
https://bit.ly/3mvOa1d

A Cadence Cloud Update 2022 from Mahesh Turaga

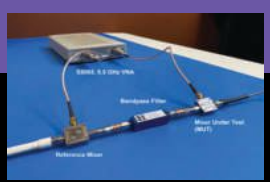
Evelyn Puchta interviews Mahesh Turaga about the history and progress of EDA in the cloud, the latest Cadence Design System innovations, the status of SaaS for EDA and the key considerations for companies considering a move from on-prem to hybrid or even cloud-first software strategies.

Cadence
www.youtube.com/watch?v=ARo8kqBmj9A

mmWave Measurements with a Low Frequency VNA

Learn how to use a lower frequency VNA to measure a mmWave mixer. This provides a more affordable, accessible measurement setup for high frequency measurements.

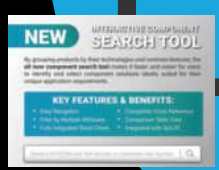
Copper Mountain Technologies
https://bit.ly/3y5QYI3



Kyocera AVX Launches New Interactive Component Search Tool

Available as a fixed navigation menu option on the KYOCERA AVX website, the new component search tool allows users to quickly and easily explore an extensive selection of the company's proven portfolio of antennas, capacitors, circuit protection devices, filters, couplers and inductors, as well as view and purchase available stock from its authorized distributor network.

KYOCERA AVX
https://search.kyocera-avx.com



Modelithics Releases the COMPLETE Library v22.2

This version adds nearly 50 new models for various components to the Modelithics COMPLETE Library. With these additions, the Modelithics COMPLETE Library now includes over 825 models that represent over 25,000 passive and active RF/microwave component

Modelithics

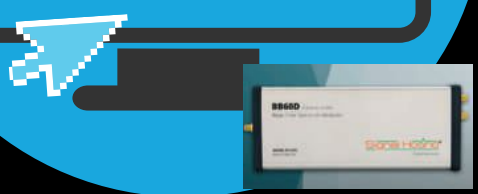
www.modelithics.com/model

IMS2022 Show Highlights

Signal Hound had a fantastic time at IMS2022. Check out what attendees were excited about and view some incredible new products on the company's website on its IMS2022 webpage.

Signal Hound

https://signalhound.com/ims-2022/



WilsonPro Makes 5G Better

Customers easily reap the benefits of the entire 5G spectrum with WilsonPro's innovative indoor and outdoor cellular technology. Check out the 5G webpage for more information.

Wilson Electronics

www.wilsonpro.com/5g

NEW PRODUCTS

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FEATURING VENDORVIEW STOREFRONTS

COMPONENTS

Analogue Die Phase Shifters

Arralis announced their advanced K- and Ka-Band analogue die phase shifters are ready to order. Operating at 17 to 21 or 25 to 33 GHz, the phase shifters enable up to 350-degree and > 360-degree smooth phase variation across the band, respectively. These bare die phase shifters are currently in stock and available to order. Arralis analogue phase shifters are an alternative to digital phase shifters where any required phase delay is achievable with the phase set by varying the control voltage in the range of -0.5 to 0.7 V.
Arralis
www.arralis.com

SSB Modulator Encodes 77 to 82 GHz

VENDORVIEW

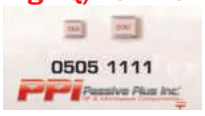
Model SFM-77382312-1212SF-N1 is an E-Band single-sideband modulator operating from 77 to 82 GHz. Quadrature modulation signals are nominally 6 V peak-to-peak and are applied to both IF inputs. The IF range is DC to 1 GHz. Carrier and sideband suppression are both nominally 20 dB. Typical conversion loss is 25 dB. An LO signal can be applied to one of the RF ports to yield a quadrature detector.

Eravant
www.eravant.com

mmWave Control Components and Integrated Assemblies

General Microwave Corp. is a key partner with major OEMs and primes, having been chosen for its broad and comprehensive understanding of mmWave technologies. The company offers catalog mmWave phase and amplitude control modules, which includes IQ modulators, phase shifters, switches, attenuators, as well as custom integrated assemblies operating in the 18 to 50 GHz frequency range. If it is a catalog unit or a highly customized mmWave assembly designed specifically for your high performance system needs, contact General Microwave.
General Microwave Corp.
www.kratosmed.com

High Q/Low ESR - Capacitors



PPI offers traditional high Q low ESR 0505 (0.055" × 0.055") and 1111 (0.110" × 0.110") multi-layer ceramic capacitors for UHF/microwave RF power amplifiers, mixers, oscillators, filter networks, low noise amplifiers, timing circuits and delay lines. These capacitors are available in two dielectrics (P90 or NP0); three different terminations: magnetic (100 percent Sn - solder over nickel plating), non-magnetic (100 percent Sn - solder over copper plating) and tin/lead (90 percent Sn 10 percent Pb - solder over nickel plating). Designed and manufactured to meet the requirements for MIL-PRF-55681 and MIL-PRF-123.
Passive Plus Inc.
www.passiveplus.com

SEE US@ EUMW

mmWave Beamformer IC

The PRS1520 is a mmWave beamformer IC supporting 5G NR mmWave bands from 24 to 43.5 GHz. With 32 high-power RF chains, configured to operate with two streams, the PRS1520 provides RF power to enable CPE, small cell and portable applications with a single device. With a total output EIRP (H and V polarization) of up to 47 dBm, the EVK-PRS1520 is suitable for applications such as fixed wireless access customer premise equipment, small cell nodes and personal mobile hotspots.
Peraso Inc.
www.perasoinc.com

8 to 22 GHz Variable Attenuators

RLC Electronics is manufacturing broadband 8 to 22 GHz variable attenuators, intended for panel mounting into customer systems. The frequency can be extended to approximately 24 GHz, as needed. These attenuators have 20 dB minimum attenuation range, exhibit low loss (< 0.5 dB) and are stable over MIL-STD-202 environment. RLC is also offering similar variable attenuators that cover the 4 to 18 GHz band and will support custom frequency requirements as well.
RLC Electronics
www.rlcelectronics.com

CABLES & CONNECTORS

Microwave Cable Assemblies

VENDORVIEW

The product is composed of internally swept, right angle SMA connectors and low loss phase stable cable (Ø4.9 mm) with highly reliable soldering process and rugged configuration design. The typical 1 m length assembly has 2 dB insertion loss and 1.30:1 VSWR up to 26.5 GHz.

Fujian MIcable Electronic Technology Group Co. Ltd.
www.micable.cn

RPC-1.00 Connector Series

The portfolio of the precision connector series RPC-1.00 has been significantly expanded. Flexible and semi-rigid cable assemblies are offered in the various RPC-1.00 to other interface configurations. Low-cost "economical" versions are also available. Inter-Series adapters are now also available in the RPC-1.00 - WSMP version, test port adapters and launcher jacks are also new. The standard program is rounded off by in-series adapters, PCB connectors, waveguide coaxial adapters and gauge kits. Customized cable assemblies with or without armouring are available upon request.
Rosenberger Hochfrequenztechnik GmbH & Co. KG
www.rosenberger.com

SEE US@ EUMW

SSBB Multi-Pin Board-to-Board Connector

Southwest Microwave's new SSBB multi-pin board-to-board connector is freely configurable to meet PCB requirements. The connector assembly is available in surface or edge-mount configurations for parallel and perpendicular board mating. SSBB technology allows a high number of connections due to its lowest-in-the-industry mating and de-mating forces. The connector assembly supports the engineering need for miniaturization without sacrificing performance. Contact Southwest Microwave for support of board layouts and simulations (HFSS).
Southwest Microwave
www.southwestmicrowave.com

SEE US@ EUMW

IMS

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Join Us in San Diego and Experience the Coolest Ideas Under the Sun!

IMS2023 is the centerpiece of Microwave Week 2023, which includes the RFIC Symposium (www.rfic-ieee.org) and the ARFTG Microwave Measurement Conference (www.arftg.org). It is the world's largest technical symposium and industry exhibition for MHz through THz professionals. IMS2023 will feature an exciting Technical Program that compliments this year's theme of Coolest Ideas Under the Sun — think high efficiency, thermal management, model-based design, space and aerospace systems, and so much more!

The Coolest Ideas Under the Sun

SAN DIEGO 2023

IMS2023 Conference Themes

At IMS2023 we will have several focus themes to highlight a number of areas of RF and microwave engineering that are of topical interest or impact. These themes are:

- **Systems & Applications**
- **Space**
- **Biomedical Applications**
- **RF & Microwaves in Latin America**

Interested in participating in IMS2023 as a speaker, attendee or exhibitor? Scan the QR code to sign up for updates.

IEEE

MTT-S
IEEE MICROWAVE THEORY & TECHNOLOGY SOCIETY

For more information: ims-ieee.org/ims2023

New**Products**

1.00 mm RF Cable Connector

VENDORVIEW

The new 1.00 mm RF cable connector from SPINNER is especially suitable for use with UT-47 semi-rigid cable and are provided in standard or custom configurations with cable entries and soldering sleeves as well as a bulkhead, D-hole or four-hole panel-mount version. SPINNER RF cable connectors are found in a wide range of applications such as communication infrastructure, medical, research, industrial, aerospace and defense, automotive and consumer products and must operate reliably even under the most difficult conditions.

SPINNER GmbH
www.spinner-group.com

SEE US@ EUMW

AMPLIFIERS

Solid-State Broadband Amplifier

VENDORVIEW

Exodus AMP2073BDB-LC, a rugged compact dual-band 700 MHz to 10 GHz, solid-state broadband amplifier. Class A/AB design for all applications and industry standards. This amplifier produces 200 W, 700 MHz to 6 GHz and 100 W, 6 to 10 GHz with 53 dB gain. Unprecedented performance as

compared to TWTs with forward/reflected power monitoring in dBm and Watts, VSWR, voltage, current and temperature sensing for extreme reliability. In a compact 5U chassis of 8.75"H × 19" W × 27" D, it weighs 30 kg.

Exodus Advanced Communications
www.exoduscomm.com

Coax Amplifier

VENDORVIEW

Mini-Circuits' model ZHL0G60G7100+ is a high-power coaxial amplifier capable of 100 W typical saturated output power (at 3 dB compression) and 49 dB power gain from 600 to 700 MHz. Ideal for communications and test applications, the Class AB amplifier delivers 71 W (+49 dBm) output power at 1 dB compression and 50 dB small-signal gain. The 50 Ω power amplifier is equipped with a female SMA input connector and a female Type N output connector, available with or without a heat sink and fan.

Mini-Circuits
www.minicircuits.com

42 dB Gain Amplifier Module

VENDORVIEW

RFMW announced design and sales support for a high power amplifier module from Elite

RF. The MB.106.0G404050 incorporates advanced, state-of-the-art, GaN on SiC technology to deliver 10 W of saturated power from 100 to 6000 MHz with a P1dB of 5 W. Biased Class AB, the amplifier provides 42 dB of gain and works in CW mode to support applications including EW, commercial and military radar, jammers, mobile infrastructure, scientific, medical and laboratory use.

RFMW
www.rfmw.com

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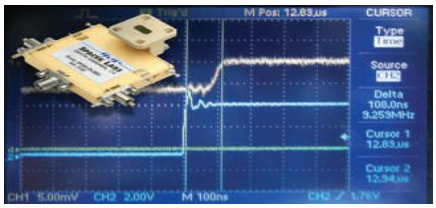
Ka-Band Power Amplifier



The high power amplifier, SP352-25-38W, is designed for use from 32 to 38 GHz. 100 nSec switching speed is controlled using TTL. Saturated output power is 6 to 7 W typical, suited for communication and radar applications. Nominal gain is 35 dB with VSWR < 2:1 at both ports. Bias voltage is +8 VDC with 4.5A quiescent current, 8A at saturated output. Switching speed shown; 100 nSec includes propagation delay of trigger cabling.

Spacek Labs
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IQ Signal Master

Anritsu Co. introduces the IQ Signal Master MX280005A vector signal analysis software that delivers expanded post processing measurements and analysis of IQ data files captured on the Anritsu Field Master Pro™ MS2090A, remote spectrum monitor MS27201A and remote spectrum monitor MS2710xA spectrum analyzers. Designed for challenging field environments, the software assists government regulators inspect the RF spectrum, security agencies track illegal or nefarious signals, spectrum owners protect their licensed spectrum and defense electronics companies analyze radar and electronic warfare signals.
Anritsu Co.
www.anritsu.com

µWave Wizard

Mician is recognized as a leading developer of software tools for rapid development of passive RF components in aerospace and telecommunications. Mician's µWave Wizard products combine the flexibility of 2D/3D FEM with the speed and accuracy of mode matching techniques. Typical applications include waveguide and combline filters, multiplexers, couplers, horn and reflector antennas and more. At EuMW, Mician will preview µWave Wizard 2022 which will be released later in 2022. The new release comes with an all-new user interface, new features and new building block elements.
Mician GmbH
www.mician.com

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TEST & MEASUREMENT

TDEMI G Series

The new TDEMI G is a full-compliance receiver capable of performing measurements in the frequency ranges 30 MHz through 1, 3, 6, 9, 18, 26, 40 and 44 GHz. The core models of the instrument feature both traditional and FFT-based measurement modes by default. HF performance and measurement dynamics were greatly improved upon since the original TDEMI G series through replacement of old components with high-resolution ADCs and FPGAs.
GAUSS INSTRUMENTS International GmbH
www.gauss-instruments.com

Vector Signal Generator

VENDORVIEW

Rohde & Schwarz has introduced not just one but two new maximum frequencies for the R&S SMW200A vector signal generator, bringing previously impossible high performance to digitally modulated signals up to 67 GHz and beyond. The R&S SMW200A is first to enable flat frequency response and 2 GHz modulation bandwidth above 44 GHz. In addition to all applications already supported up to 44 GHz, the 100 kHz to 56 GHz option covers all currently used 5G frequencies, plus Earth-to-satellite applications.
Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

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Real-time Spectrum Analyzer

The BB60D 6 GHz real-time spectrum analyzer offers a bit more dynamic range than the BB60C and preselector filters—for not much more money. Specs includes preselector filters from 130 MHz to 6 GHz, 10 dB more dynamic range than the BB60C, frequency range from 9 kHz to 6 GHz, selectable streaming bandwidth from 4 kHz up to 27 MHz, exceptionally clean spurious and residual responses and sweeps at 24 GHz/second.
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Bookend

A Hands-On Guide to Designing Embedded Systems

Adam Taylor, Dan Binnun and Saket Srivastava

"A Hands-On Guide to Designing Embedded Systems" offers technical depth on FPGAs, firmware, electrical engineering, hardware strategy and new product introduction (NPI) for electrical and firmware engineers. It also provides NPI product manager (called NPI PM) techniques via a scenario-centric framing that may be particularly useful for hobbyists or those endeavoring to begin a hardware start-up. This text may also be useful to new engineers looking to obtain a high-level overview of how engineering enterprises function.

Given that few individuals have relevant experience or hold positions across all these domains, it does leave the reader wondering for which audience the authors are writing. To elaborate, a manager with more than 10 years of experience likely doesn't need NPI PM information, and a high-level manager or group lead likely has ample electrical engineering and firmware experience. Additionally, some of the text feels too abstract for those learning how to design an embedded system — as the specificity of the examples pulls you away from the bigger picture — and is a bit too detailed for someone with a deep academic background looking for a perspective on industry, business, strategy and NPI.

The authors might benefit from splitting the text into three books: electrical engineering basics + FPGA, firmware and new product integration, as doing so would enable them to further develop the FPGA component of their text. In its current form, this section leaves the reader wanting more detail and, at the same time, it may be only relevant to a subset of readers given the complexity, cost and time of FPGA design.

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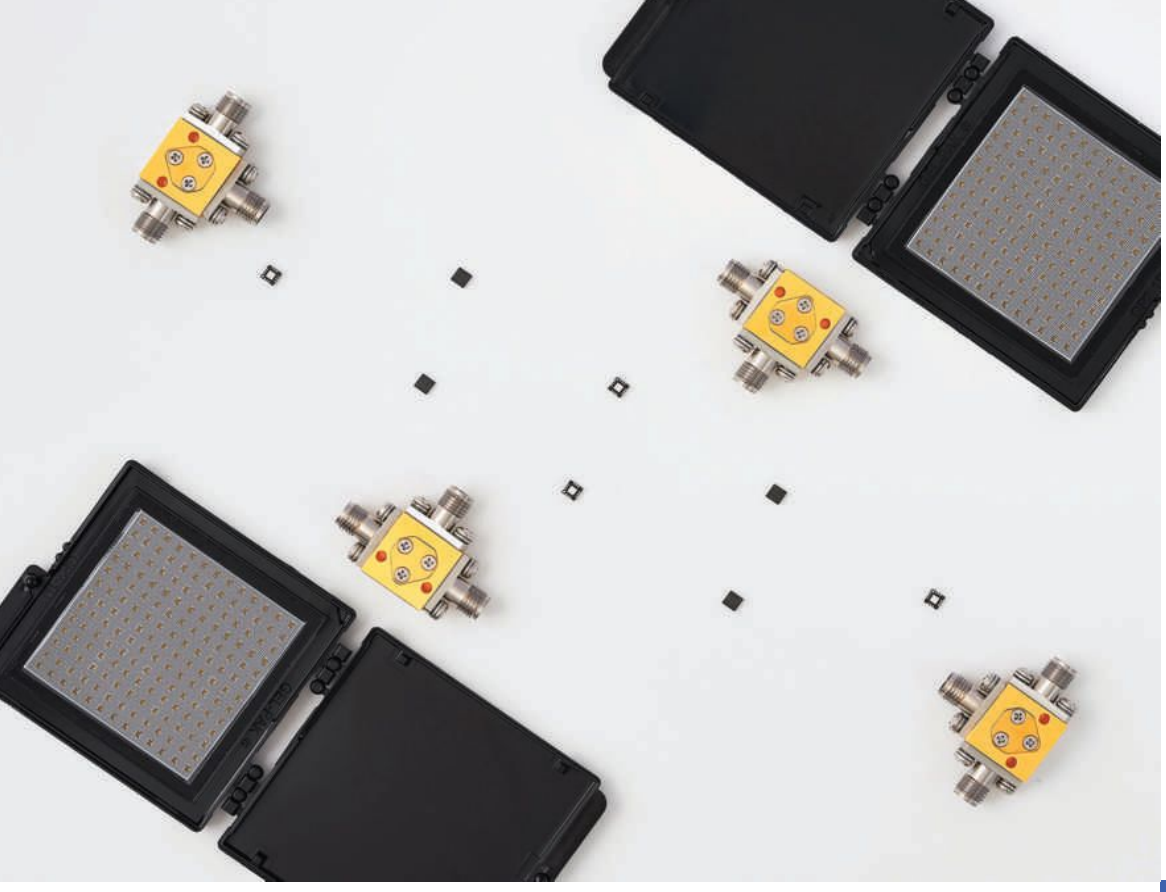

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Mini-Circuits' Deer Park Technology Center: 95 GHz and Rising

Mini-Circuits has long been known for its commanding portfolio of RF/microwave components. Historically, most have been below 6 GHz. Over the last decade or so, that's expanded with many products reaching 18 GHz and some as high as 40 GHz. With commercial and defense applications pushing into the mmWave bands, Mini-Circuits is responding by extending the frequency coverage of its products even higher.

To do so, the company transformed the second floor of its Deer Park, Long Island, shipping facility into a state-of-the-art design and manufacturing center dedicated to high frequency connectorized products. Completed this spring (2022), the 10,000 square-foot, Class 100k cleanroom houses a team of designers, manufacturing staff and an assembly and test line for production. The line also prototypes chip-and-wire products for the other Mini-Circuits' product lines.

The design team at Deer Park is equipped with a complete suite of software tools for developing new products, including system analysis, RF circuit simulation, full-wave electromagnetic analysis, thermal and structural analysis. Specialized software is used for digital circuit design and software development.

The 3,500 square-foot assembly area contains epoxy die attach (using paste and film epoxies), ribbon and wire bonding (both wedge and ball with various sizes of gold wire) and micro soldering. To ensure tight feedback, process development, process verification and quality assurance are performed in the same assembly area, which has bond pull, die shear and high magnification microscopes for inspection.

RF testing encompasses small- and large-signal measurements over temperature to 110 GHz, from noise figure to additive phase noise, to third-order intercept. Mini-Circuits' proprietary test software archives and analyzes the data. Burn-in is performed at Deer Park, while more extensive environmental testing used for qualification—temperature shock, vibration and mechanical shock and others—are performed at the facility in Brooklyn.

With a mix of new recruits and staff from other Mini-Circuits' sites, the team at Deer Park reflects the company's diversity of talent and its family culture: commitment, accountability and a willingness to challenge each other. Engineers feel responsible for the performance and manufacturability of their products. If there's a problem on the manufacturing line, they step up to help solve it.

The products designed and manufactured at the Deer Park Technology Center comprise the full range of circuits, from amplifiers to switches, variable attenuators, equalizers and other supporting products. Released catalog products extend to 95 GHz, with 110 GHz designs being developed. All the current products have coaxial interfaces — 2.92, 2.4, 1.8 or 1 mm connectors — with waveguide versions on the roadmap.

The ZVA-50953X+ is a good example of the portfolio. It's a wideband amplifier with 1 mm coaxial connectors that spans 45 to 95 GHz and provides 15 to 16 dB gain, 14 dBm output power at 1 dB compression and 17 dBm saturated output power. The amplifier is biased with a single supply between 10 and 15 V and typically draws 140 mA.

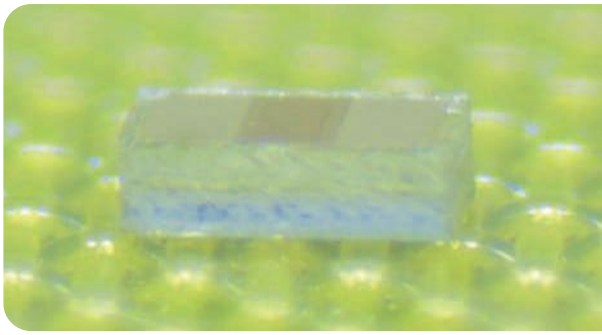
You'll find these Mini-Circuits products in the lab and in the field. The customers using them are enabling the evolution of commercial communications and other applications: 5G networks in the FR2 bands, 60 GHz fixed wireless access, E-Band for high data rate links and, soon, 6G research at D-Band.

www.minicircuits.com

Dielectric Varactor

New

Tecdia's SMT analog varactors, made with unique voltage controlled dielectrics, are designed for controlling impedance inside analog phase shifters operational up to 100GHz.



- Low ESR
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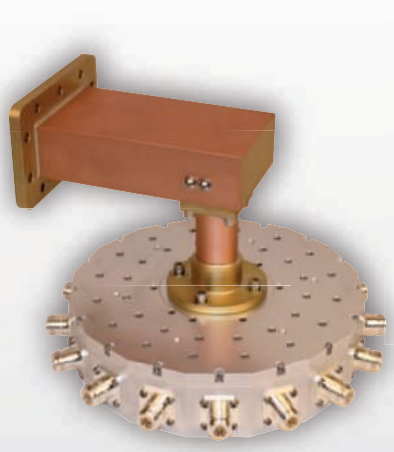
Model	Type	Frequency (MHz)	Power (W CW)	Peak Power (W) 10% DC	Insertion Loss (dB)	VSWR	Connector Type
D9816	8-Way	330-530	10,000	50,000	0.25	1.30:1	3 1/8" EIA, N-Female
D8454	8-Way	370-450	10,000	50,000	0.25	1.30:1	3 1/8" EIA, N-Female
D5320	12-Way	470-860	500	5,000	0.30	1.30:1	All N-Female
D10119	4-Way	700-4200	2,000	15,000	0.30	1.35:1	13-30 DIN-Female, N-F
D10603	32-Way	900-925	50,000	150,000	0.15	1.25:1	WR975, 7/16-Female
D10795	32-Way	900-930	25,000	150,000	0.25	1.20:1	WR975, 4.3-10-F
D9710	8-Way	1000-2500	2,000	10,000	0.30	1.40:1	1 5/8" EIA, N-Female
D8182	5-Way	1175-1375	1,500	25,000	0.40	1.35:1	1 5/8" EIA, N-Female
D6857	32-Way	1200-1400	4,000	16,000	0.50	1.35:1	1 5/8" EIA, N-Female
D11896	4-Way	2000-2120	4,000	40,000	0.25	1.40:1	WR430, 7/16-Female
D11828	4-Way	2400-2500	3,000	25,000	0.20	1.25:1	WR340, 7/16-Female
D10851	8-Way	2400-2500	8,000	50,000	0.20	1.25:1	WR340, 7/16-Female
D11433	16-Way	2700-3500	2,000	20,000	0.30	1.35:1	WR284, N-Female
D11815	16-Way	2700-3500	6,000	40,000	0.30	1.35:1	WR284, N-Female
D12101	6-Way	2750-3750	2,000	20,000	0.35	1.40:1	WR284, N-Female
D9582	16-Way	3100-3500	2,000	16,000	0.25	1.50:1	WR284, N-Female
D12102	6-Way	5100-6000	850	4,500	0.35	1.35:1	WR159, N-Female
D12484	6-Way	8200-8600	600	700	0.35	1.25:1	WR112, SMA-Female
D12485	6-Way	9000-11,000	500	700	0.40	1.35:1	WR90, SMA-Female

Specifications subject to change without notice.



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