Vol. 66 • No. 8

August 2023

Microwave Journal

EuMW
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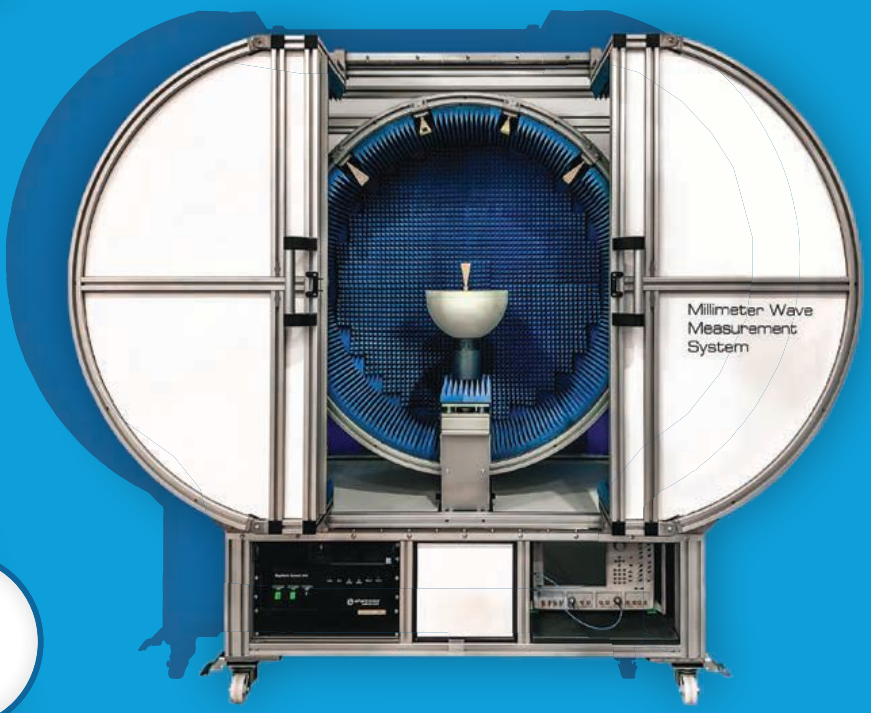
KYOCERA AVX



TYPICAL DYNAMIC RANGE:
50db

MAXIMUM MASS OF DUT:
10kg on the mast

TECHNOLOGY:
Far-field / Spherical with oversampling

FREQUENCY RANGE:
18GHz - 110GHz

MAXIMUM SIZE OF DUT:
45cm

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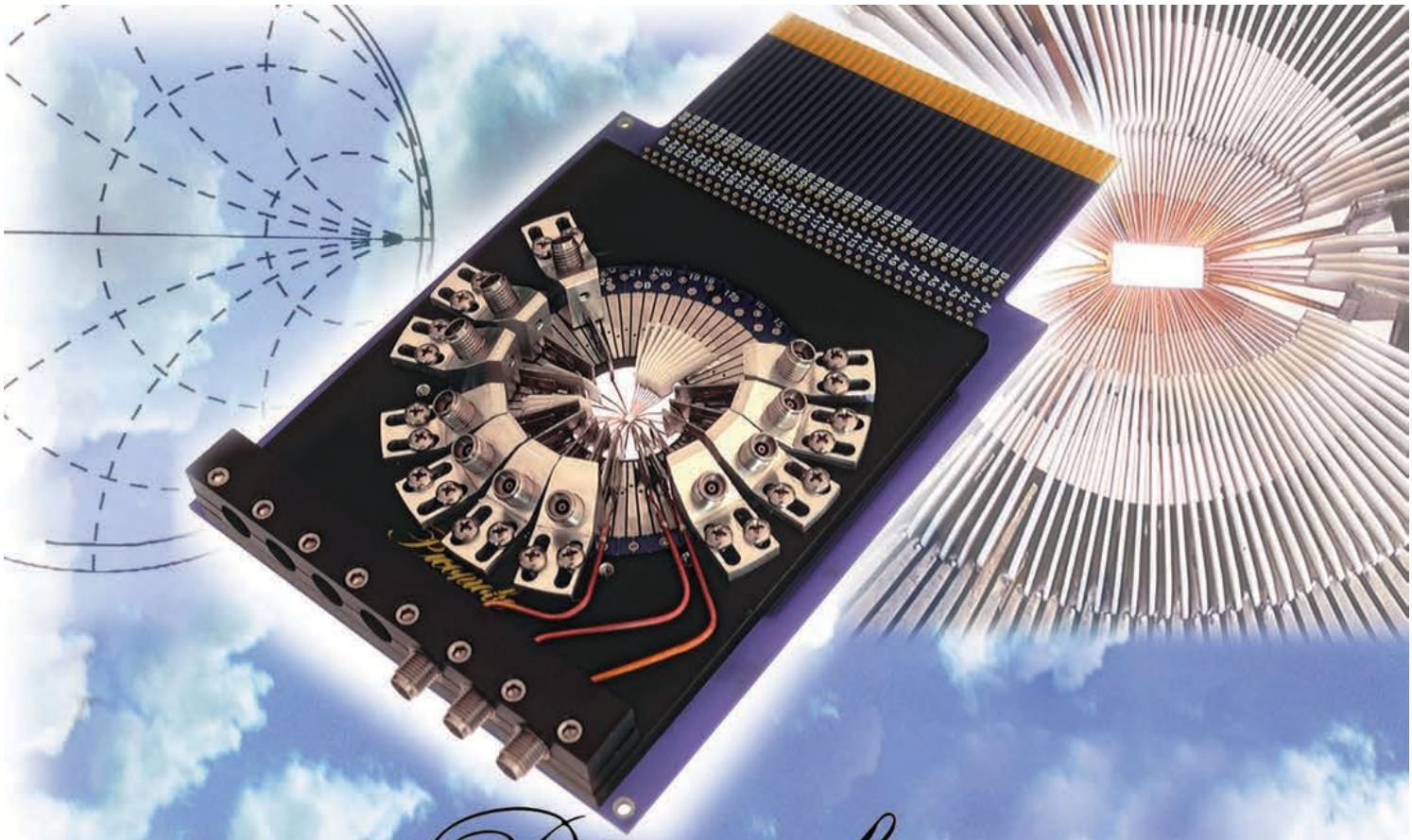
Testing Chamber

The ETH-MMW-1000 is a fully anechoic millimeter wave measurement system capable of testing wireless devices from 18 to 110GHz. The system is self-contained, portable, and compact enough to fit into any laboratory or production environment.



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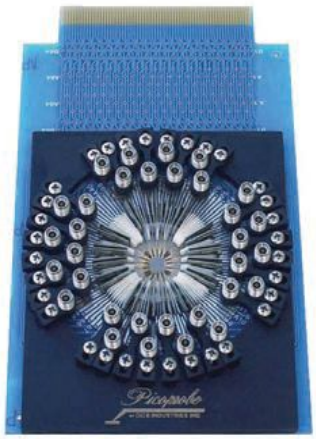

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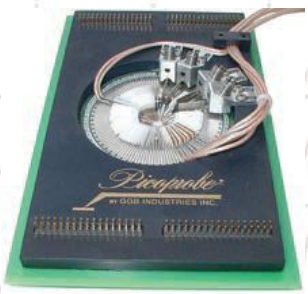

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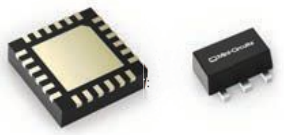

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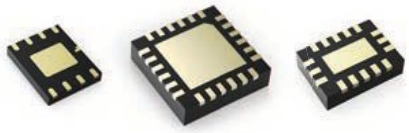

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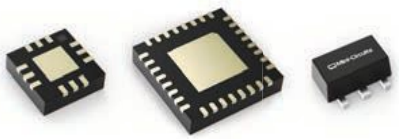

High dynamic range over wide bandwidths up to 45 GHz

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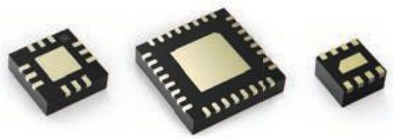

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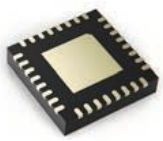

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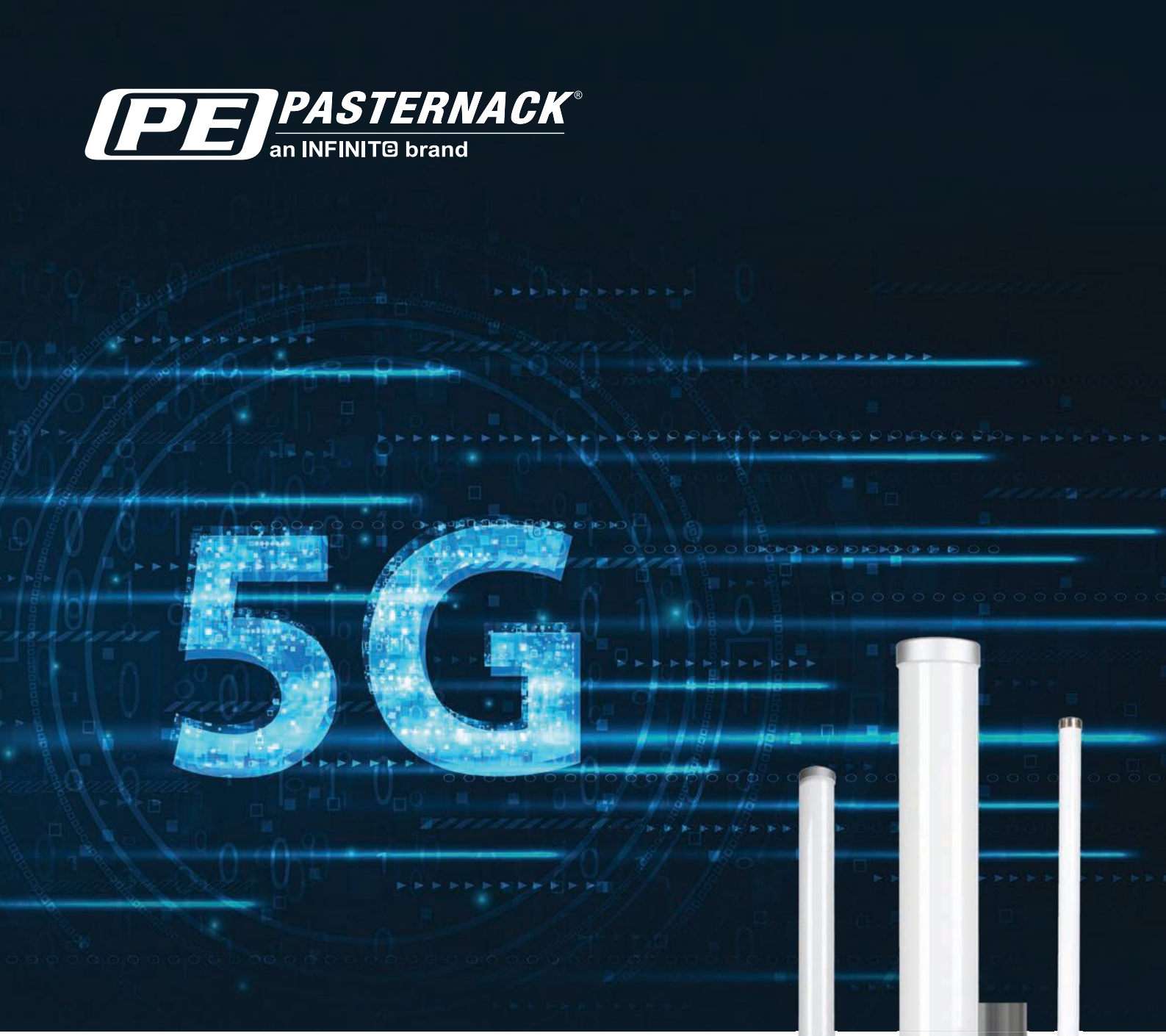

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Microwave Journal

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August 2023
Vol. 66 • No. 8
mmWave Technology+
EuMW Show Issue
mwjournal.com

For this month's cover, we wanted something unique to represent Berlin with EuMW 2023 taking place there. We chose a "Berliner". In Germany, the doughnuts have been referred to as Berliners for over 200 years. The history of this terminology remains blurry, but some sources claim that the pastry was named after a baker from Berlin. In 1756, this baker was allegedly deemed unfit for the Prussian military, but allowed to work as a baker for the regiment. While he was in the field, he would fry doughnuts over an open fire. His comrades named the treats after his hometown, calling them Berliners.

Cover Feature

Special Reports

online spotlight

Look for this month's exclusive article online at mwjournal.com

A High Gain Reflectarray Antenna for Airborne mmWave Sensing Devices
Jiyeon Jang, Yejune Seo, Yejin Lee, Junghyun Cho and Sungtek Kahng, Department of Information and Telecommunication Engineering, Incheon National University

Technical Features

EuMW 2023 WAVES BEYOND WALLS

EuMW 2023 SHOW COVERAGE

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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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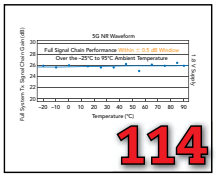

Product Feature

Tech Briefs

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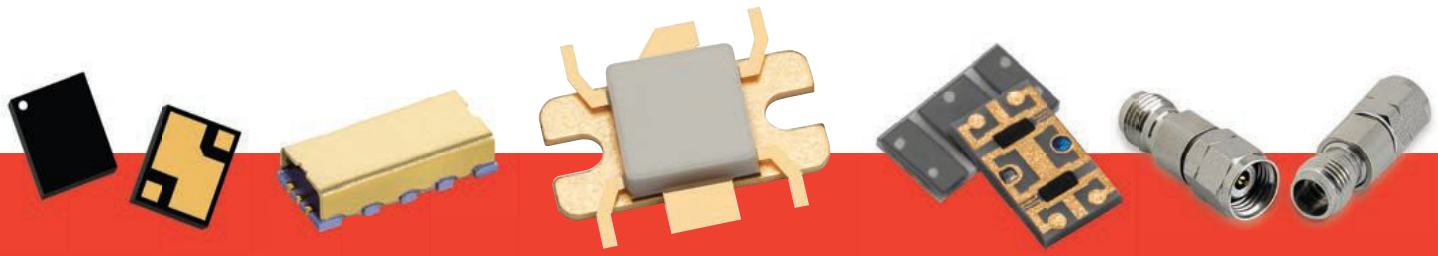

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Executive Interview

Pat Hindle, Media Director at ***Microwave Journal*** and ***Signal Integrity Journal***, talks about the challenges facing print versions of technical magazines as Microwave Journal celebrates its 65th year of publication and Signal Integrity grows its readership, along with how these magazines are adapting to the realities of the digital era to find new opportunities.

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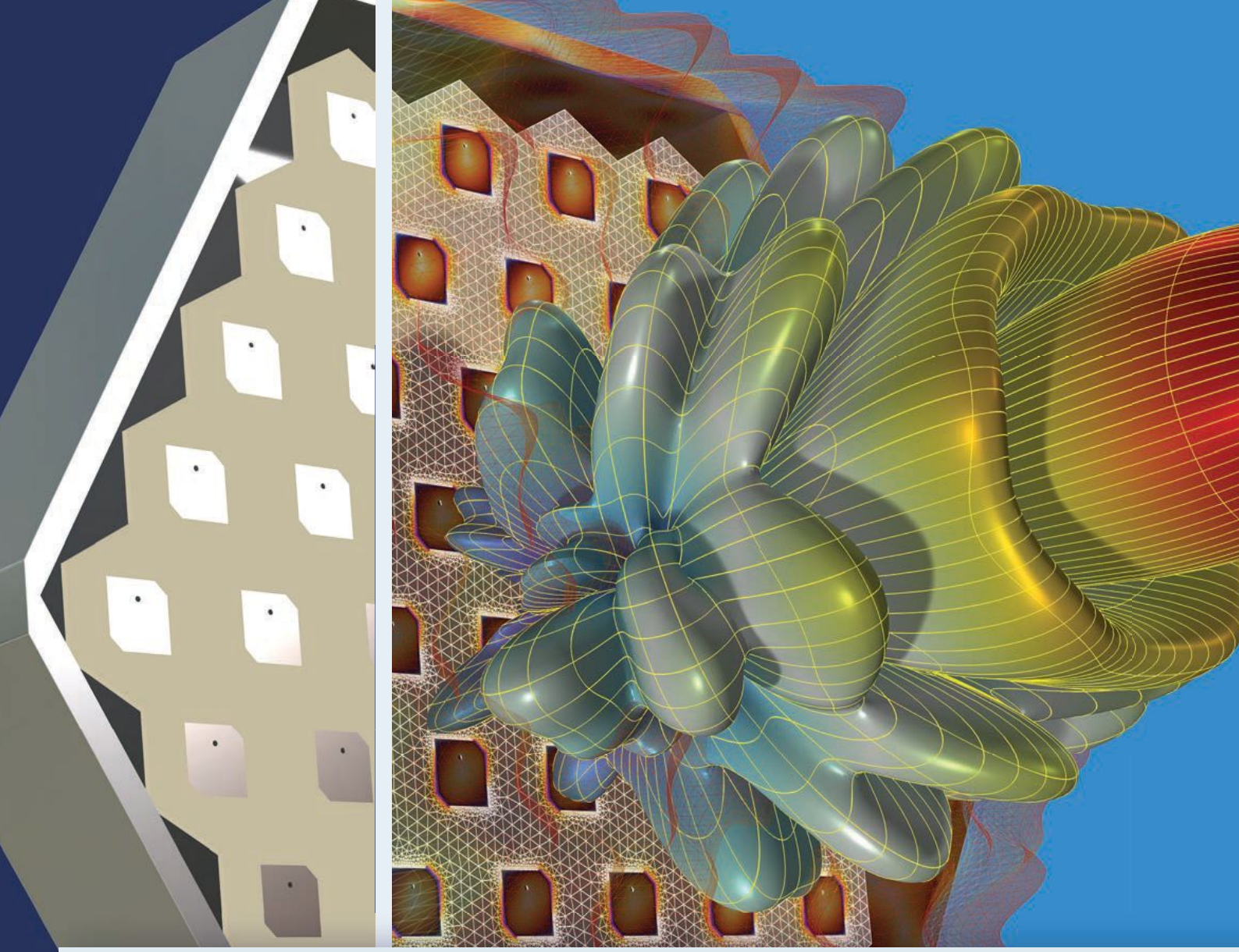

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TIME TRAVEL

By Stefano Selleri

Oliver Heaviside in Music

Electromagnetic researchers are seldom popular among the general public. Maxwell is not second to Einstein or Newton when considering the advancements in our understanding of the physical world due to his theory, yet the average person knows the latter and ignores the former. Tesla is probably the best known in this group, due to his attention to promoting himself, his presence in the media and his name now synonymous with a high-tech company. And we have dozens of movies where Einstein or Tesla are cited!

Yet Oliver Heaviside (1850-1925), to whom we owe our current vector form of Maxwell's equations, making them so much easier to use than their original quaternions form[1], curiously made his name appear in probably the most successful musical of all times: Cats by Andrew Lloyd Webber.[2] Webber drew his inspiration for Cats from T.S. Eliot's poems. Thomas Stearns Eliot (1888-1965), a winner of the Nobel Prize for Literature in 1948, did not cite Heaviside in his book,[3] but it is rumored that unpublished material by Eliot did. Webber stated, in an interview on the making of Cats, "What Valerie (Eliot's widow) unearthed next…some sort of entertainment which ended with the animals getting into a big balloon that took them up, up, up past the Russell Hotel, up, up, up, to the Heaviside Layer."[4]

Screenshot of the theatrical representation of the ascension to the Heaviside Layer in Cats.
(Blue Ray Edition, 1998)

Oliver Heaviside (left), Thomas Stearns Eliot (middle) and Andrew Lloyd Webber (right).
(Courtesy of Wikipedia and Creative Commons CC0 1.0 Universal Public Domain Dedication)

So, Eliot was indeed figuring that the afterworld for cats was up in the sky in the Heaviside Layer. The term "Heaviside Layer" was proposed by William Eccles (1875-1966) in 1910 and rapidly gained acceptance.[5] It describes the ionospheric layer extending from roughly 90 to 150 km above sea level. This layer was hypothesized, independently, by Arthur Edwin Kennelly (1861-1939) and Heaviside in 1902 to explain how Guglielmo Marconi (1874-1937) managed to obtain a beyond-the-horizon transatlantic radio link in 1901. Indeed, the world had to wait until 1924 for proof of its existence, thanks to Edward V. Appleton (1892-1965). We should note that Appleton won the Nobel Prize in 1947 for his discovery of the ionosphere. This was the year before Eliot wrote Cats and this might explain the placement of the afterworld for the cats!

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2. A.L. Webber, "Cats," May 1981, New London Theatre, London, U.K.
3. T.S. Eliot, "Old Possum's Book of Practical Cats," London, U.K., Faber & Faber, 1939.
4. A.L. Webber, "The Making of Cats," Broadway revival souvenir program, 2016.
5. A. Russel, "The Kennelly-Heaviside Layer," Nature 116, 1925, p. 609.

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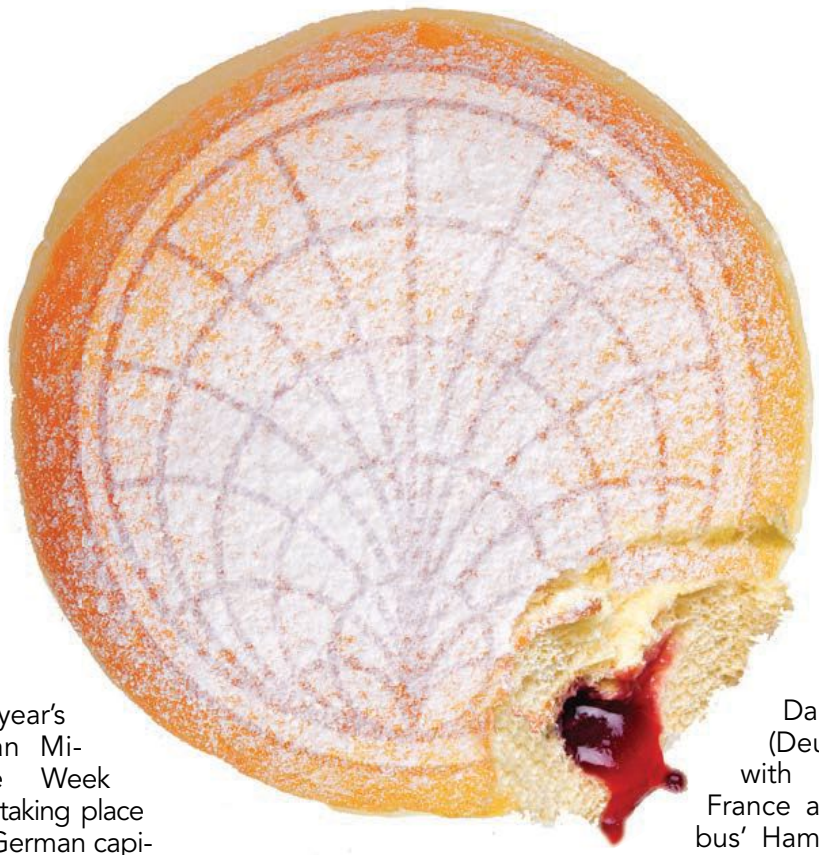

With this year's European Microwave Week (EuMW) taking place for the first time in the German capital, Berlin, whose Brandenburg Gate is shown in ***Figure 1***, we turn the spotlight onto the German RF and microwave industry. Berlin holds a unique place in Europe's history and that of the world. June 24, 2023, marked the 75th anniversary of the start of the Berlin airlift (in German, *"Berliner Luftbrücke"*). This was a heroic year-long operation carried out by the U.S., the U.K. and France, along with several other countries. This effort delivered food and supplies to the people of West Berlin who had been cutoff from land-based routes due to a Soviet Union blockade. This was only one episode in a remarkable history that includes the momentous toppling of the Berlin Wall[1] in November 1989 and the reunification of Germany the following year.

PLANES AND AUTOMOBILES

Germany is the largest economy in the EU and the fifth largest globally by GDP per capita. It has strengths across several sectors, particularly in automotive, where the Volkswagen Audi Group, BMW and Mercedes are all world-leading brands. Aerospace is also a strong sector, with multinational manufacturer Airbus having sizable operations in 27 locations across Germany, including Hamburg, Ulm and Manching. Airbus was formed as EADS in 2000 by the merger of DaimlerChrysler Aerospace (Deutsche Aerospace/DASA) with Aérospatiale-Matra of France and CASA of Spain. Airbus' Hamburg facility is the third largest site in the global aviation industry, overseeing the A320 jet aircraft program.

Airbus' predecessor, DASA, was also responsible for much of the early development of 77 GHz automotive radar for adaptive cruise control in vehicles that allowed Mercedes-Benz to introduce Distronic onto the S-Class (W220) in 1998-99.[2]

We must mention Holger Meinel, one of the leading figures in the microwave industry, not only in Germany but worldwide. Meinel was one of the founders of the European Microwave Association and in the mid-1990s was instrumental in setting up EuMW in its current form.[3] At EuMW in Milan in 2002, Meinel

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was awarded the Certificate of Appreciation by EuMA for his contributions to EuMC and EuMW. Meinel is shown in ***Figure 2*** at IMS2023 after receiving the prestigious IEEE Transportation Technologies Award for developing and promoting the application of mmWave technology in transportation systems. His work in automotive radar dates to the 1970s, when as a young research and development (R&D) engineer at AEG-Telefunken, a forerunner to DASA, he started to design components for a 35 GHz collision avoidance radar.

Fig. 1 **Brandenburg Gate in Berlin. (*Source:* Getty Images)**

DEFENSE AND AEROSPACE

HENSOLDT is a multinational corporation headquartered in Taufkirchen, near Munich. They originally spun out of Airbus in 2017, acquiring British radar manufacturer Kelvin Hughes later that year. HENSOLDT focuses on sensor technologies for protection and surveillance in defense, security and aerospace applications. Among its products are radar systems for surveillance, reconnaissance, air traffic control and air defense, with HENSOLDT radars being deployed on platforms including the Eurofighter Typhoon, the German Navy's F125 frigates and the U.S. Navy's littoral combat ships and ground-based systems. Its ground-based air defense sensors include TRML-3D and TRML-4D.

In May 2023, it was reported that HENSOLDT Sensors had successfully modernized the core test systems of COBRA, an artillery location radar used by several NATO armies. Under a multi-million-euro contract, HENSOLDT replaced the radar target generator and the COBRA Radar Environment Simulator, both key elements of the radar's test environment.[4]

Dassault Systèmes, a French aerospace company, acquired Darmstadt-based CST AG in 2016. CST Studio Suite is now under Dassault Systèmes' SIMULIA brand, and has been integrated into its 3DEXPERIENCE platform. The 2023 release introduces enhanced capabilities for its modeling, meshing and high-frequency solver technologies, including improved antenna array design and placement, hybrid solutions, filter design automation, and non-parametric optimization for high-frequency applications, as well as improved radar response analysis and channel impulse response.

TEST AND MEASUREMENT

No review of the German microwave market would be complete without mentioning Rohde & Schwarz, Europe's leading manufacturer of RF and microwave test and measurement equipment. The company was founded in 1933 with its headquarters in Munich, as well as an R&D center in Berlin. Over the past three decades, Rohde & Schwarz has been a leader in developing the standards for successive

Fig. 2 **Holger H. Meinel with Boeing Technical Fellow Timothy Lee at IMS2023.**

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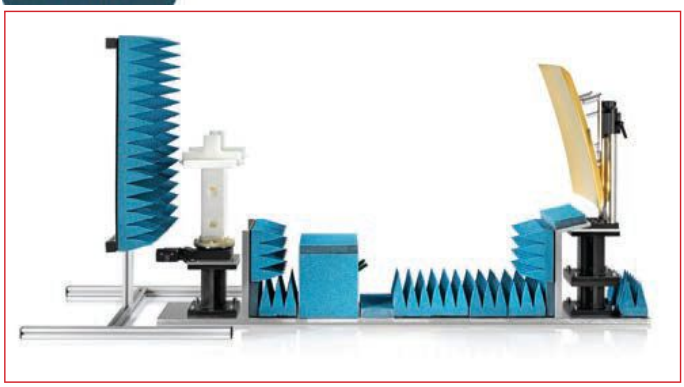

Fig. 3 R&S ATS800B benchtop CATR OTA test system.

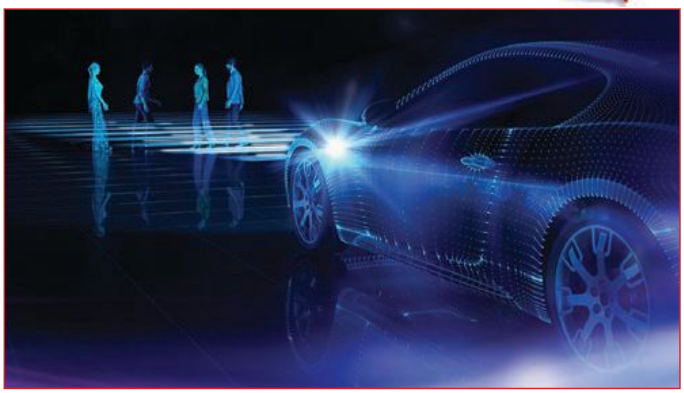

Fig. 4 The dSPACE DARTS 9040-GT simulation.

generations of mobile communications and participating in standards bodies from GSM to 5G. Its product range includes testers for all the main wireless standards including Wi-Fi. Rohde & Schwarz is developing new waveforms for 6G, including characterizing how they perform in real environments.

Their latest announcement, at MWC Shanghai, was a collaboration with Qualcomm to test GSO and GEO satellite chipsets to 3GPP Release 17.[5] In June, Rohde & Schwarz also described a joint project, carried out with Fujikura and Avnet to validate CATR OTA systems for testing 5G mmWave phased array antennas in an R&D environment. The validation used the R&S ATS800B benchtop CATR OTA test system shown in ***Figure 3*** to measure EIRP and EIS in addition to traditional radiation patterns.

In addition to being the leading provider of RF drive testing equipment and services, along with measurement systems for 4G and 5G mobile handsets and infrastructure, Rohde & Schwarz manufactures mmWave airport security scanners. The R&S QPS Quick Personnel Security Scanner will be familiar to frequent air travelers. It operates at 70 to 80 GHz at a power level around 1 mW and automatically detects potentially dangerous items carried on the body or in clothing with data acquisition times less than 32 msec. The scanner is used for airport security checks, security at high threat potential public events and access control at security-related facilities.

VALIDATING ELECTRIC VEHICLE TECHNOLOGY

Spanning the gap between the test and measurement and automotive markets is dSPACE, which specializes in simulation and validation for networked, autonomous and electrically powered vehicles. Its product range targets automotive manufacturers and their suppliers for testing both software and hardware components. The key systems requiring microwave testing, particularly as self-driving vehicles evolve, are the radar sensors that capture height, distance and speed information. The dSPACE Automotive Radar Test System (DARTS) 9040-GT, introduced in December 2022 and represented in ***Figure 4***, is the latest in a product family of radar target simulators for testing automotive 4D sensors. It offers precise simulation with high resolution of two separate radar targets that approach from different angles, or are located at different distances but at the same angles, with an instantaneous bandwidth covering the entire 5 GHz of the automotive E-Band. This replaces the previous test

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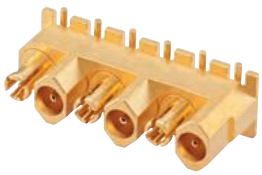

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method that required two separate target-generating instruments and it supports the development of radar systems that need to meet strict separation capability requirements.

RESEARCH AND DEVELOPMENT

Germany benefits from a strong R&D infrastructure with world-class universities and organizations like the Fraunhofer-Gesellschaft, a world-leading applied research organization. Founded in 1949 and named after Munich researcher and inventor Joseph von Fraunhofer, the organization runs 76 institutes and research units throughout Germany. It employs 30,800 people, mostly scientists and engineers and has an annual research budget of around €3.0 billion. A recognized non-profit organization, much of Fraunhofer's €2.6 billion research income is generated from industry contracts and publicly funded research projects, with additional funding from the German federal and state governments.

The Fraunhofer Institute for High Frequency Physics and Radar Techniques (FHR), based in Wachtberg, will be exhibiting at EuMW 2023. Earlier this year, FHR restructured into three new divisions to better tailor research and development services to the needs of its customers and partners. These divisions are multifunctional RF and radar systems; radar for space situational awareness and industrial high frequency systems.

TERAHERTZ AND SUB-MILLIMETER

Fraunhofer Institute for Applied Solid State Physics (Fraunhofer IAF), based in Freiburg, is the main location for the organization's work on compound semiconductors. At this year's EuMW, Fraunhofer IAF will present its ICs for terahertz (THz) frequencies up to 670 GHz, as well as sub-mmWave circuits and modules with potential applications beyond 5G and precise distance measurement. THz waves can penetrate obstacles like smoke, dust, fog and clothing, even from several hundreds of meters. This presents a wide range of potential applications for the ICs, including high data rate communications, avionics and satellite earth observation, along with security applications like concealed weapons detection. The chips are based on InAlAs/InGaAs mHEMT transistors with cutoff frequencies over 1 THz. They are grown on 4 in. GaAs substrates with gate lengths of 20 nm. They will display metamorphic InGaAs-based MMICs and amplifier modules with a noise figure of 2 dB in W-Band and 6 dB at 340 GHz. In addition, mmWave directional radio links operating between 30 and 300 GHz based on Fraunhofer MMICs offering transfer rates of over 100 Gbit/s over distances of more than 30 km will be shown.

ACST is a specialist THz company, spun out of Technische Universität Darmstadt (TUD) in April 2006 to commercialize Schottky diodes for mmWave and THz applications. During the past decade, it has been involved in more than 20 R&D projects supported by the European Space Agency, the EC (FP7 & H2020), the German government and industrial partners. With core competencies in component fabrication technology and RF engineering, the company specializes in the development of custom products and services.

The Leibniz Institute for High Performance Microelectronics (IHP) in Frankfurt was founded in 1983 as an institute of the Academy of Sciences but became a limited company in 1992. It is now focused on the integration of SiGe BiCMOS technologies and developing prototype devices with 500 GHz f_{max} for applications like wireless and broadband communication, security, medical technology, aerospace, mobility and industrial automation.

TELECOMS RESEARCH AND DEVELOPMENT

Another Fraunhofer site, the Heinrich-Hertz-Institut (HHI) near Berlin, launched F5G OpenLab at MWC in Barcelona in March. F5G OpenLab is a test and experimentation facility aimed at making data communications more sustainable by promoting optical fiber-based fifth generation fixed networks and advancing the validation of technol-

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ogies defined by ETSI. Fraunhofer HHI is also involved in 6G research, including how 6G services can improve healthcare by providing functions like telehealth monitoring, robotics, augmented reality and responsive exoskeletons.

Last year, Fraunhofer HHI instituted a real-time-capable communication infrastructure for testing industrial applications in one of the first operational 5G standalone campus networks in Germany. It is intended to be a test environment for future edge cloud applications in Industry 4.0. Research teams will also use the infrastructure to develop network technologies enabling 6G and a future open 5G/6G ecosystem.

Germany also has a significant presence in the mobile infrastructure OEM market. Although headquartered in Finland, Nokia Networks was formed in 2006 as a joint venture between Nokia and Germany's Siemens. It originally traded as Nokia Siemens Networks before shortening to its current name when Nokia bought out the Siemens stake in 2013. It subsequently acquired another European rival, Alcatel-Lucent, in 2015.

Nokia retains the large former Siemens telecoms site in Munich. The Nokia Digitalization & Technology hub there has employees belonging to almost all the Nokia business units, including a team of scientists and experts from Bell Labs. The main research activities at Bell Labs Munich center on 6G mobile networks, security, data analytics and network architectures, with close collaboration with the local Nokia Standards team that is working on leading-edge network technologies and systems research.

EUROPEAN INITIATIVES

In June 2023, the European Commission approved a new Important Project of Common European Interest (IPCEI) to "support research, innovation and the first industrial deployment of microelectronics and communication technologies across the value chain." This latest €8.1 billion project, called IPCEI ME/CT, follows from the original IPCEI, set up to support research and innovation in microelectronics and approved by the Commission in December 2018. Germany is a major participant in both projects, along with 13 other EU member states.

The IPCEI ME/CT projects aim at creating innovative microelectronics and communication solutions and energy-efficient manufacturing methods to enable digital and green transformation. They address several sectors, including 5G and 6G communications, autonomous driving, artificial intelligence and quantum computing. The new IPCEI involves 68 projects from 56 companies, closely cooperating through more than 180 envisaged cross-border collaborations.

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SEMICONDUCTOR FABS

Unique in Europe, Germany is exceptionally strong in semiconductor manufacturing. Germany's automotive industry was badly affected by the chip shortage of the past two years and securing the supply chain is of national importance.

Global Foundries has its Fab 1 in Dresden, Saxony, which was its first chip foundry after spinning out of AMD in 2008. It is now just one of a growing cluster of large-scale fabs in the Dresden area.

Bosch is a major supplier of chips to the automotive industry with semiconductor fabs in Reutlingen and Dresden, with Dresden shown in ***Figure 5***, opening in June 2021. Products planned for the €1 billion Dresden fab include systems-on-a-chip for 360-degree radar sensors for automated driving. Both the Bosch Dresden fab and the latest upgrades to the Reutlingen fab are being supported by funds from the IPCEI.

Three of X-Fab's six fabs are in Germany. Erfurt, in the central state of Thuringia, manufactures digital as well as RF and analog ICs on its 12-in. 1.0 µm, 0.8 µm and 0.6 µm CMOS mixed-signal processes. Dresden has a 350 nm analog/mixed-signal CMOS process (XH035) running on 8-in. wafers alongside earlier generation standard and customer-specific mixed-signal CMOS processes and an RF-MEMS foundry making variable capacity RF switches is located in Itzehoe, near Hamburg.

Franco-German collaboration UMS, originally formed in 1996 as a collaboration between DASA and Thales of France, has a site in Ulm that houses GaAs and GaN technology development and production. In June, UMS launched its CHA6262-99F, a three-stage GaN PA operating in the 17.3 to 21.5 GHz range with 4 W typical output power and 36 percent PAE, designed for space applications and a range of other microwave systems.

NEW SEMICONDUCTOR INVESTMENTS

Taiwanese semiconductor giant TSMC is in advanced negotiations to build a new fab in Dresden, which is expected to cost up to €10 billion ($10.7 billion).[6] TSMC has been attracted by assistance available under the EU Chips Act, under which Europe plans to spend €43 billion ($46.07 billion) to subsidize a doubling in chipmaking capacity by 2030. Also in Dresden, Infineon has approval[7] to begin building a €5 billion semiconductor plant scheduled to start production in 2026, which the company says would be the largest single investment in its history and would create around 1,000 jobs.

On the western side of Germany, Wolfspeed is reportedly planning a €3 billion SiC plant in Saarland[8] mainly for use in electric vehicles, making this the biggest SiC produc-

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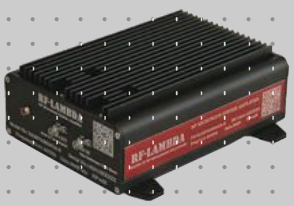

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REMC02G06GE 2-6GHZ 500W

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Fig. 5 **Production clean room at the Dresden Bosch semiconductor plant. (*Source:* Bosch)**

tion facility in the world. Meanwhile, Intel is spending more than €30 billion to develop two fabs in Magdeburg, central Germany, for which it will receive €10 billion of subsidies from Germany, creating 3,000 jobs at the company as well as tens of thousands more jobs with suppliers and partners.[9]

COMPONENTS AND SOFTWARE ROUNDUP

Other German vendors exhibiting at EuMW 2023 include:

AFT Microwave, based in Backnang, specializes in custom ferrite-based microwave components such as circulators, insulators and loads, ferrite material, thin film circuits and passive components and subsystems.

AXTAL GmbH, a German manufacturer of low phase noise frequency control products was founded 20 years ago and acquired at the start of this year by Q-Tech Corporation, a U.S.-based supplier of high-reliability crystal oscillators. The combined product portfolios offer a range of crystal oscillators including XO TCXO, MCXO and OCXO quartz oscillators, including crystal oscillators designed for space applications from LEO, MEO and GEO to deep space.

Becker Nachrichtentechnik GmbH in Asbach specializes in the development and manufacturing of modules, devices and systems including wideband amplifiers and signal distribution for broadcast, trunked radio, air traffic control and satellite navigation and air interface emulation for mobile and wireless networks up to 10 GHz.

Biconex GmbH in Radeberg offers metal-plated polymers for shielded housings, RF antennas, filters and other components requiring strong resistance to wear.

IMST GmbH is an engineering company and system house in Kamp-Lintfort, specializing in radio systems technology, chip design, antennas and EDA software for customer-specific developments. It also offers an accredited test laboratory for product approvals.

Kuhne Electronic GmbH is a manufacturer of power amplifiers (PAs), LNAs, signal sources and antennas for amateur radio.

KVG Quartz Crystal Technology GmbH is a manufacturer of crystal oscillators based in Neckarbischofsheim.

LPKF Laser & Electronics AG manufactures laser manufacturing and printed circuit board (PCB) prototyping solutions with headquarters in Hanover.

Mician GmbH in Bremen sells the μWave Wizard, a full wave 3D electromagnetic design automation suite for the development of passive microwave systems and components, including antennas.

Micro Systems Technologies is a group of companies, based mostly in Germany, with a range of LTCC substrate and packaging technologies, PCBs and hermetic feedthroughs.

Rosenberger Hochfrequenztechnik GmbH is the main company of the Rosenberger Group with its headquarters in Bavaria, Germany and other manufacturing locations around the world. It provides a range of standard and custom RF, high voltage and fiber optic con-

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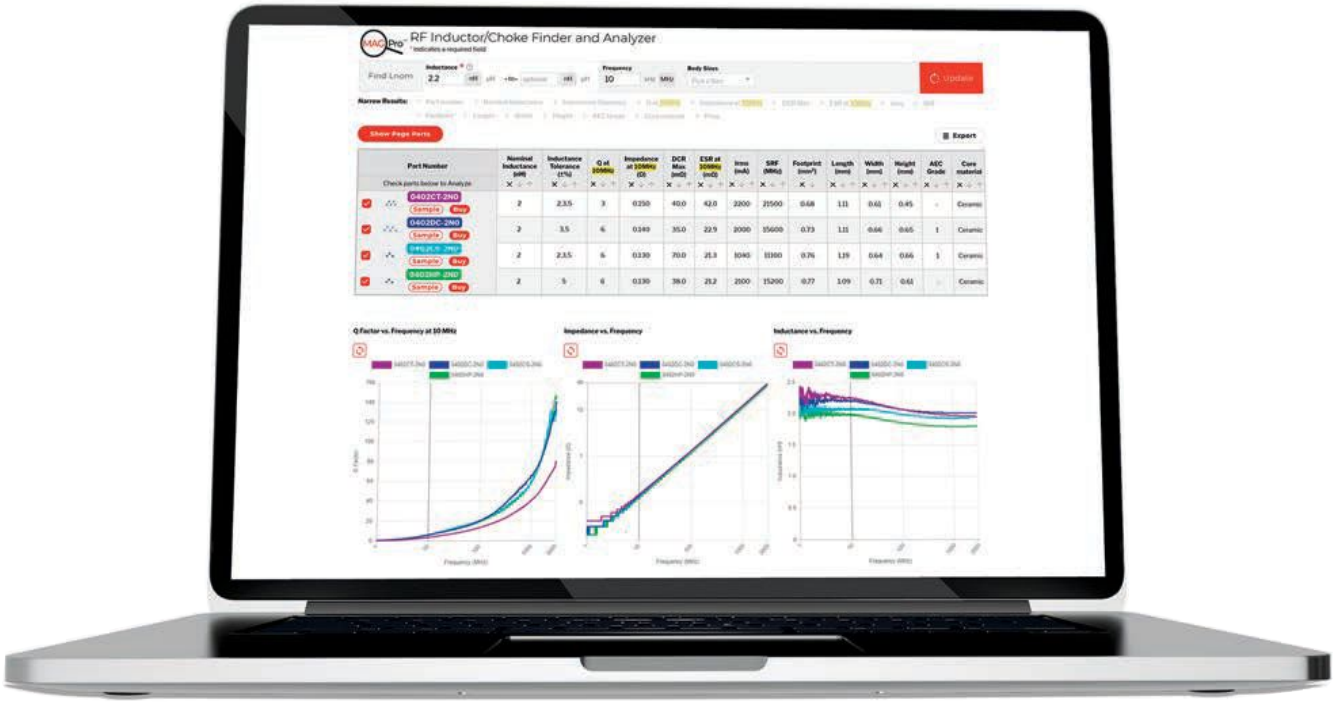

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Siglent Technologies GmbH in Augsburg manufactures a range of test and measurement equipment, including waveform generators, spectrum analyzers, vector network analyzers, oscilloscopes and RF generators.

Silicon Radar GmbH, based in Frankfurt, develops standard and customer-specific MMICs for a wide range of radar applications, including a 24 GHz radar front-end. It has recently been acquired by Indie Semiconductor.

SPINNER GmbH is headquartered in Munich, with a 75-year history of making RF products. With manufacturing facilities around the world, its products include cables, connectors and rotary joints for applications such as communications, broadcast, measurement, satellite, space and radar.

Würth Elektronik Group, with its headquarters in Waldenburg, comprises companies in Germany and around the world that manufacture RF electromechanical components, PCBs and intelligent power and control systems.

Via Electronic GmbH in Hermsdorf manufactures high performance LTCC substrates. ■

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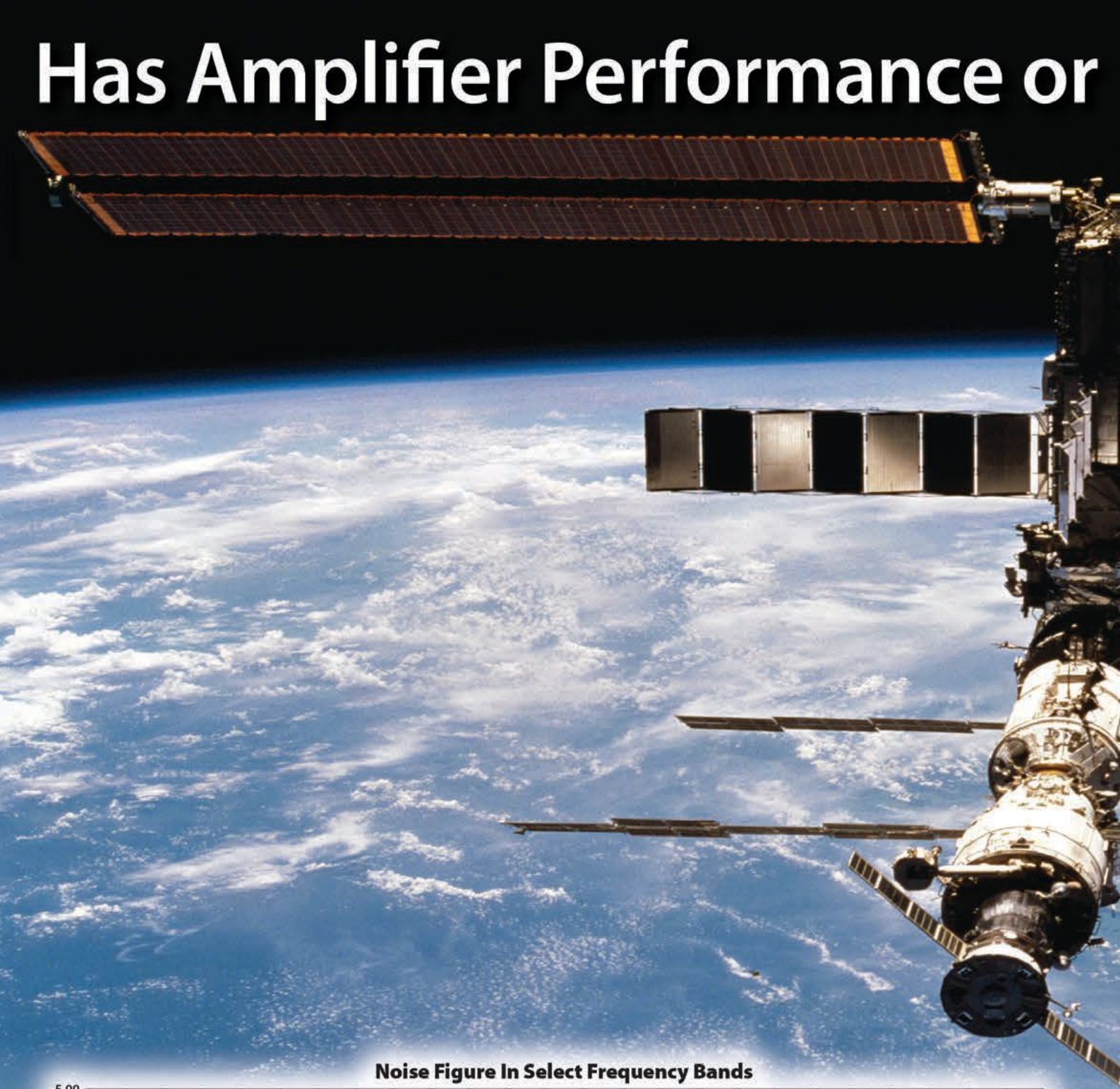

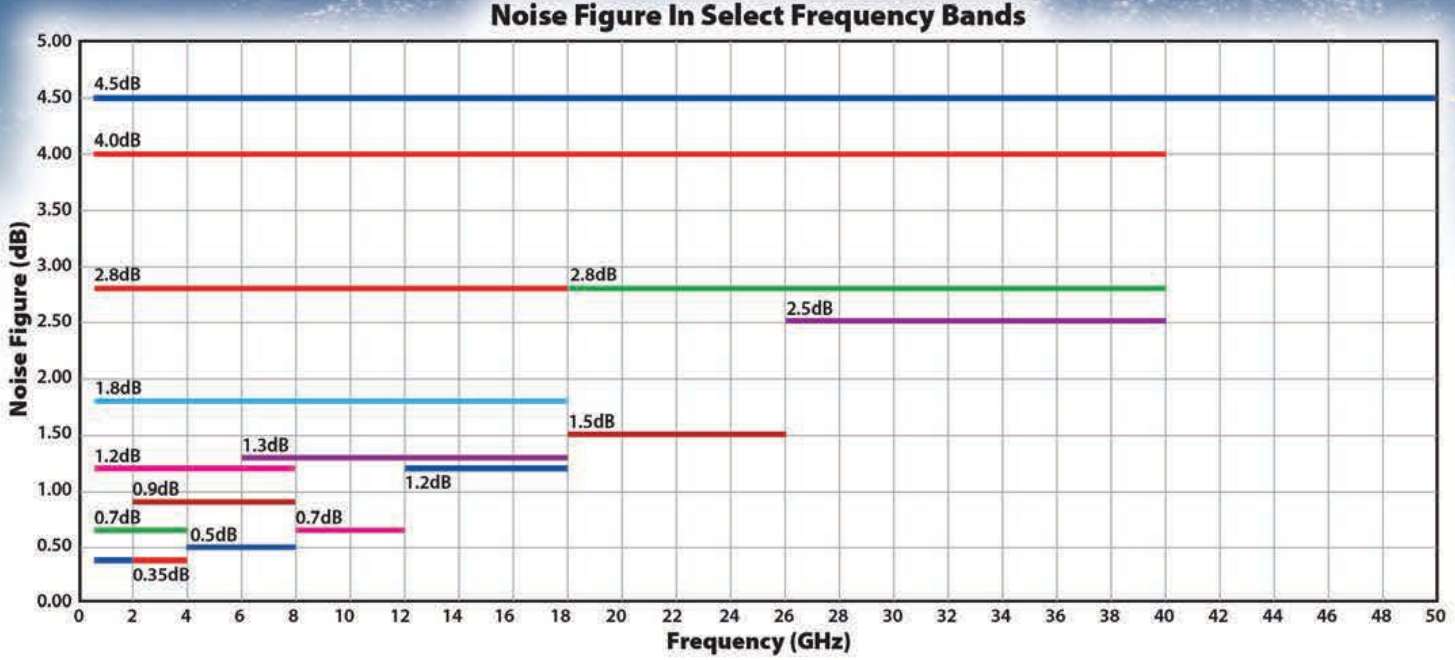

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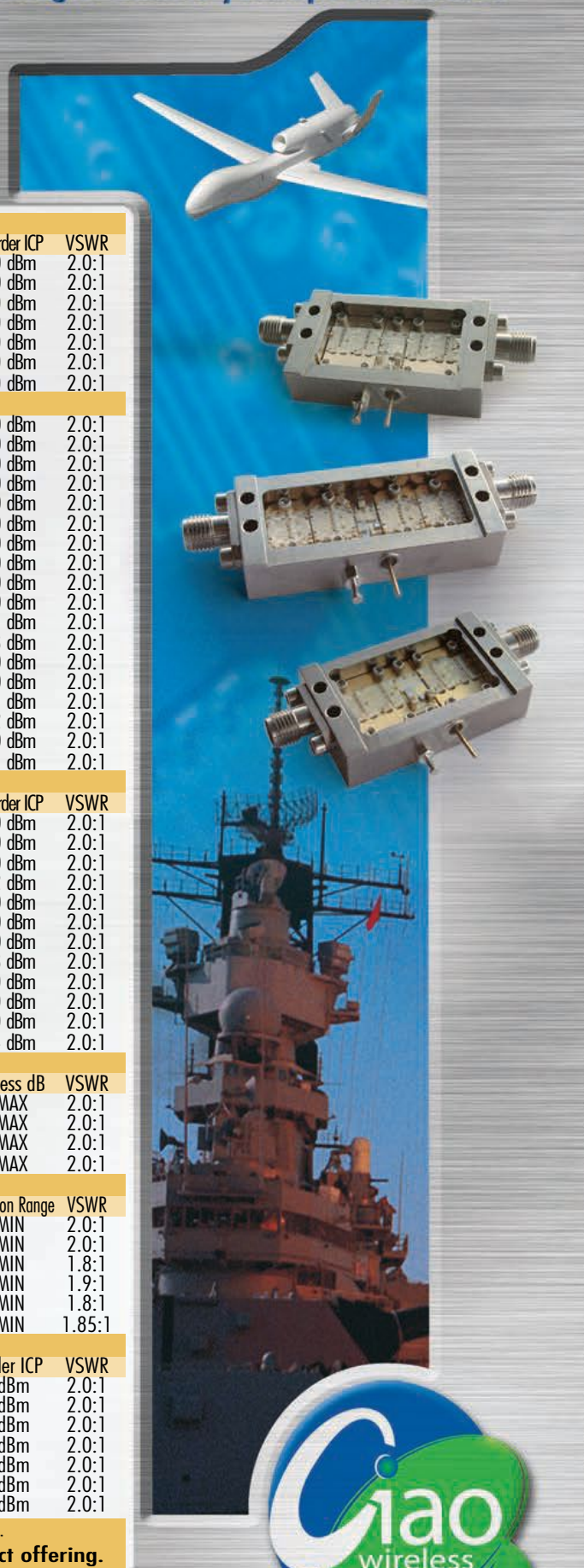

OCTAVE BAND LOW NOISE AMPLIFIERS

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

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

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

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

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

LIMITING AMPLIFIERS

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

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

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

LOW FREQUENCY AMPLIFIERS

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

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Leonardo's Growing Role in the Multinational Eurodrone Program

Leonardo will be developing the mission system for Eurodrone, the medium altitude long endurance class remotely piloted aircraft set to strengthen Europe's strategic defense autonomy with high performance independent operational systems. The aircraft's airborne mission system (AMS) incorporates a suite of advanced sensors, including radar and the multi-purpose mission computer. Within the program, worth a total of €7 billion, Leonardo is playing a key role through an industrial workshare regarding the on-board electronics and aerostructures component, which in addition to the AMS also includes the airborne electrical and environmental control system, the airborne armament system and the design and production of the aircraft's entire wing structure.

Thanks to the AMS's advanced suite of sensors, the Eurodrone will be able to perform intelligence, surveillance and reconnaissance missions at sea and on land, collecting and integrating data from the various on-board sensors, even in critical operational conditions, while also recording and sending it to the ground station and cooperating units to provide a complete tactical picture. The fusion of data in real time has the advantage of minimizing the time and effort needed by operators to analyze and understand events that are happening in the area of interest, thus accelerating response times throughout the entire chain of command.

Eurodrone (Source: Airbus)

The design, development, integration and production phases for the AMS system will all take place at Leonardo's Caselle Torinese location. The company will also be engaged in supporting the integration of prototypes at the Manching base and flight testing activities in relevant locations. Through its joint venture MBDA, Leonardo will integrate the air to surface Brimstone missile. The weapon system will enable the platform to engage and neutralize a wide range of static and moving threats day or night in all-weather conditions.

The multinational program, managed by the Organisation Conjointe de Coopération en Matière d'Armement (OCCAR), at present has the participation of Germany, Spain, France and Italy and has orders for 20 systems, each made up of two ground stations and three aircraft plus ground support equipment, spare parts, training and five years' support in the initial phases of the service.

The innovative technologies that the platform will have available, designed for dual-use purposes, will enable it to become one of the pillars of all next-generation aircraft systems for the benefit of national governments and armed forces. The twin-engine drone is the first unmanned aircraft system conceived for flying in non-segregated airspace. Its modular design will provide advanced operational capabilities for intelligence, surveillance, target acquisition and reconnaissance missions, helping to expand the independent technology base in the uncrewed sector. Finally, taking the digital approach in drone design, production and services will create significant improvements in development times, quality and cost reduction, generating 7,000 highly qualified jobs in Europe.

IAI Announces New Generation Reconnaissance System

Israel Aerospace Industries (IAI) recently announced the release of the ELM-2060PES, a new generation active electronically scanned array (AESA) synthetic aperture radar (SAR)/ground moving target indication (GMTI) Pod for fighter aircraft, recently developed by its defense systems subsidiary, ELTA Systems Ltd. The ELM-2060PES builds on the legacy of the combat proven ELM-2060P system, in service for decades with air forces worldwide.

The ELM-2060PES Pod is a self-contained AESA airborne radar system, providing state-of-the-art SAR and GMTI capabilities; a bi-directional line-of-sight wideband datalink, interconnected with a ground datalink and exploitation station. The airborne system is housed within a fully autonomous detachable centerline pod that mirrors the aerodynamic envelope of a certified fighter aircraft fuel tank and is operated by aircraft avionics or via the datalink from the ground station.

The ELM-2060PES produces radar images that approach photographic quality, for operative reconnaissance and surveillance of time critical targets, precision strike support and battle damage assessment and operates as a true day and night sensor capable of penetrating clouds, rain, smoke, fog and smog. The ELM-2060PES has advanced radar modes for high-resolution target classification

AESA SAR/GMTI (Source: Israel Aerospace Industries)

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and precision geolocation against both fixed and moving ground targets, providing operational users with quality actionable intelligence. The ELM-2060PES extended-range and ultra-wide swath capabilities provide real-time, all weather and visibility stand-off reconnaissance and surveillance mission capabilities while operating in the most challenging scenarios.

Ensuring Reliable Communications Between U.S. and Allied Partners at the Tactical Edge

DARPA's Secure Handhelds on Assured Resilient networks at the tactical Edge (SHARE) program successfully developed and integrated software and networking technologies to enable secure and resilient information sharing between U.S. forces and international allies in tactical operations. The program also adapted rapid commercial development, security and operations models for Defense Department research and development, pioneering novel ways to get new technology to operational warfighters faster.

SHARE software runs on military end-user mobile devices allowing real-time data sharing with allied forces, at the appropriate classification levels, over available military or commercial networks. The software is now integrated with the U.S. military's Tactical Assault Kit (TAK), an operational map-based situational awareness application used by warfighters.

SHARE (Source: U.S. Marine Corps)

DARPA collaborated with military end-users throughout the effort including delivery of prototype software for independent experimentation, which informed program development and reduced transition risk.

"SHARE brings next-generation networking technology to the TAK ecosystem," said Ryan McLean, director of the TAK Product Center. "The SHARE team chose to transform how tactical edge networks are deployed through innovative research using named data networking and digital rights management on the widely adopted Android TAK software platform. Because of this, SHARE is now primed for rapid technology transition to the TAK user community. This transition is already underway and, with the release of TAK 5.0 in November 2023, U.S. soldiers, marines, sailors and airmen, as well as our allied mission partners, will experience the immediate benefits that SHARE provides for resilient tactical networking in contested environments."

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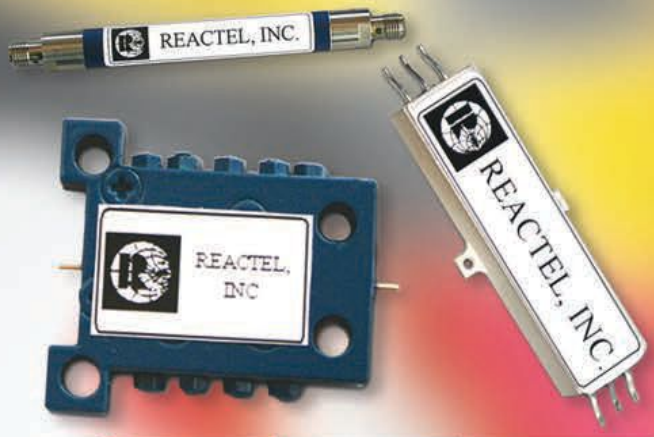

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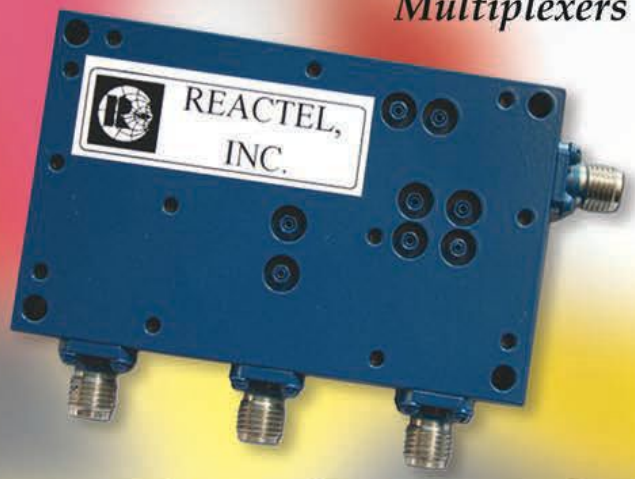

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5G Growth Progresses as New Services are Developed

In the first quarter of 2023, 5G adoption continued to set a torrid pace, putting the fifth generation of wireless cellular technology on track to add nearly a billion new connections each year. Data from Omdia and 5G Americas indicates strong penetration in the North American market, even as new 5G network buildouts are accelerating around the world.

The latest data from Omdia reveals a significant progress on 5G as 157 million new global 5G connections were added between Q4 2022 and Q1 2023. This surge in adoption sets the stage for even more accelerated growth throughout 2023, with the number of global 5G connections projected to approach the 2 billion mark. The forecast indicates an extraordinary trajectory, as the global 5G connections are predicted to reach a staggering 6.8 billion by the end of 2027. This translates to an average annual growth of nearly one billion new connections, highlighting the unprecedented scale and impact of 5G technology.

North America continues to assert leadership in 5G wireless connectivity, as continued adoption fuels additional demand for improved 5G network services. By the end of Q1 2023, the region boasted an impressive tally of 133 million 5G connections and a staggering 503 million LTE connections. The 5G penetration rate in the North American market is steadily climbing and currently stands at nearly 36 percent, as 14 million new 5G connections came online in the first quarter of 2023.

In Latin America and the Caribbean, 4G LTE networks continue to demonstrate resilience and robust growth in Q1 2023. The region recorded a formidable 553 million 4G LTE connections, reflecting a quarterly growth of 2.1 percent, and the equivalent of 11 million new LTE subscriptions. Additionally, by the end of 2023, the region is projected to quadruple its number of 5G connections to reach 62 million. The region is estimated to reach 407 million 5G connections by 2027.

Overall, the number of 5G commercial networks globally has reached 267, according to data from TeleGeography and 5G Americas. That number is expected to reach 386 by the end of 2023 and 413 by the end of 2025, representing strong 5G network investment growth in many regions throughout the world.

RF GaN: Telecom Infrastructure Takes the Lead

In telecom infrastructure, GaN has penetrated various base stations with its high power and high frequency performance benefits. With the transition from remote radio heads to advanced antenna systems in macro/microcells, massive MIMO (mMIMO) requires more power amplifier units per base station. The higher PAE and broadband capability at frequencies above 3 GHz compared to LDMOS is an opportunity for GaN to grow. The GaN-based telecom infrastructure device market will represent almost 45 percent of the total market by 2028.

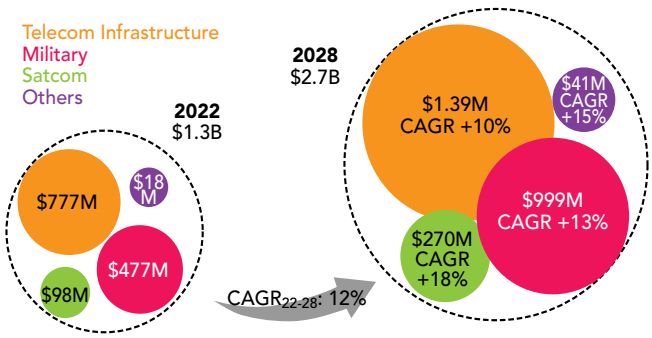
As a traditional GaN market, the defense segment is one of the main drivers for GaN RF. GaN-on-SiC is still the primary platform supplying demanding applications in defense radar, electronic warfare and defense communication applications.

In this dynamic context, Yole Intelligence releases its annual RF GaN report. This study provides an overview of the market and the players in the various segments, along with their product ranges and technologies. The company, part of Yole Group, outlines each segment's market dynamics and main technologies. Analysts also explain the requirements of the various RF markets and their corresponding impact on the need for different technologies, along with geographical specificities.

In 2022, SEDI, Qorvo and Wolfspeed were the leading players in the RF GaN device business, while NXP has gained significant growth by entering the telecom market's supply chain. The semi-insulating SiC wafer market remains shared by the three major suppliers, Wolfspeed, Coherent and SICC. In the defense segment, Raytheon, Northrop Grumman and Chinese CETC are leading GaN adoption. Department of Defense-trusted Wolfspeed and Qorvo are also GaN foundries. Focusing on the suppliers to the telecom market, Ericsson and Nokia continue developing the supply of RF GaN devices to source from multiple suppliers while Samsung cooperates closely with Korean device players. Since the U.S. sanction, Huawei and ZTE have turned to the Chinese supply chain to develop domestic capability.

With technology node evolution, device players developing platforms for the Ku/K/Ka-Bands are even targeting nodes under 0.1 µm for sub-THz frequencies and a potential 6G market in the future. The target of the emerging GaN-on-Si platform for RF applications is a sub-6 GHz small cell by leveraging the efficiency

2022-2028 RF GAN Device Market Forecast



GaN Device Market Forecast (Source: Yole Intelligence)

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and wide bandwidth at a lower power level. However, considering the complexity of changing the design of handset systems, it is a longer-term target market for GaN-on-Si.

Strong Growth in the Satellite IoT Industry Expected

Decreasing costs of satellite launches and lower capital outlays have enabled several new small satellite (SmallSat) operators (such as Swarm Technologies, Kepler, FOSSA Systems, Sateliot, Lacuna Space, HEAD Aerospace Group and Totum Labs) to enter the satellite IoT market with low-cost and low-power satellite connectivity offerings.

These new entities seek to challenge traditional satellite IoT incumbents, including Inmarsat, Iridium, ORBCOMM and Globalstar to provide a more cost-effective solution for end customers. According to ABI Research, total satellite IoT connections will increase from 10.4 million in 2022 to 27.0 million in 2030 (at a CAGR of 12.7 percent), with satellite IoT connection revenue growing from U.S. $2.2 billion to U. S. $7.8 billion in the same period (at a CAGR of 16.6 percent).

"Reusable rocket technology has driven down the cost of launching satellites into orbit, with prominent players such as SpaceX and its Falcon rockets. Increased competition in the space launch services industry from China, for example, is expected to further drive down launch costs," explained Matthias Foo, industry analyst at ABI Research. "Beyond that, CubeSat technology has also enabled quick and low-cost deployment of new LEO satellites as they can be built rapidly with standard off-the-shelf components."

Fleet management and condition-based monitoring applications, such as for agriculture, utilities and environmental monitoring use cases, are expected to see high growth rates. Maritime vessels and aircraft frequently move out of the reach of terrestrial cellular networks, while farmlands, utility network pipelines/infrastructure and environmental monitoring devices are often located in remote areas without reliable terrestrial cellular connectivity. Some notable partnerships include the agreement between Shell and Hiber for a satellite-based oil well monitoring solution and Wyld Networks' infrastructure monitoring solution provided for a Middle Eastern water utility provider.

Additionally, it can also be observed that traditional terrestrial network players are increasingly looking to satellites to complement their terrestrial IoT service offerings. Deutsche Telekom announced a partnership with Intelsat and Skylo to provide global connectivity for IoT devices. At the same time, Telefónica has also teamed up with Sateliot to trial seamless connectivity for IoT devices.

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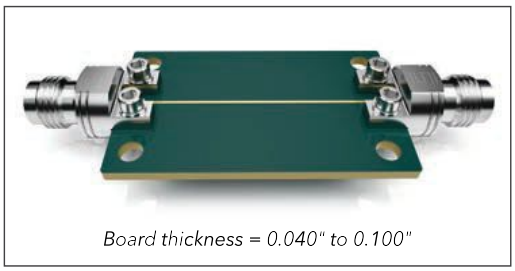
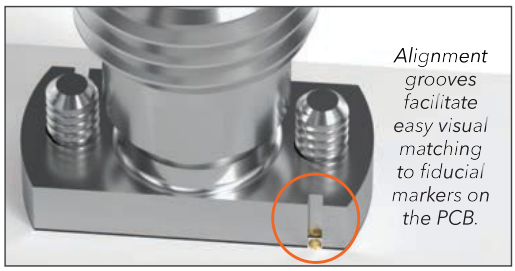


Edge Launch: Small Form Factor Improves Density



Vertical: Alignment Features Ensure Repeatable Peak Connector Performance

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Microwave Techniques LLC (MT) of Gorham, Maine, U.S., a provider of high-power microwave solutions, announced it has acquired **Valvo Bauelemente GmbH (Valvo)**, of Hamburg, Germany, a company specializing in the manufacture of passive RF and microwave components for high-power applications. Valvo Bauelemente GmbH products are deployed in a wide range of global markets, serving customers in several growing high-power microwave and RF applications, including scientific research, medical research and plasma-based science.

COLLABORATIONS

Anokiwave Inc. and **Starry Group Holdings, Inc.**, a licensed fixed wireless technology developer and internet service provider, have collaborated to develop Starry's next-generation customer premises receivers (CPE) to deliver affordable, high capacity home broadband access across the 24 GHz and 37 GHz spectrum bands. As part of this collaboration, Anokiwave designed a complete phased array antenna module using its industry-leading Gen-4 silicon ICs, to accelerate Starry's time-to-market for outdoor CPE units, that met or exceeded all cost and technical specifications and is now ready for production.

Sierra Wireless, a subsidiary of **Semtech Corporation**, has announced it has partnered with leading software and services provider **Amdocs**, to provide customers with a complete solution that reduces the complexity of designing, deploying, managing and servicing a private cellular network. Customers are increasingly looking to private networks to provide high-reliability coverage, increased security and better flexibility for their applications. According to a recent report by analyst firm Counterpoint Research, the global LTE/5G private networks infrastructure market will increase from approximately $2.5 billion in revenue at the end of 2022 to reach $21.8 billion at the end of 2030, representing a CAGR of 30.7 percent over the forecast period.

NEW STARTS

Orolia Defense & Security, a **Safran Electronics & Defense** company, has announced at the Institute of Navigation's 2023 Joint Navigation Conference that it will re-brand under a new name, **Safran Federal Systems**, following its acquisition by Safran in 2022, a global aerospace and defense company. In addition to its Resilient PNT solutions, M-Code/GNSS testing and simulation tools, precision time synchronization systems and navigation warfare equipment, Safran Federal Systems is now one of the only companies with a full complement of PNT technologies with proven inertial navigation solutions. Safran Federal Systems continues to be the trusted Resilient PNT solution provider for military end users and industry partners, from the lab to the field.

ACHIEVEMENTS

Qorvo announced that **Raytheon Technologies** has recognized Qorvo with its 2022 Premier Award for performance and overall excellence. This is the second consecutive year Qorvo has been honored with the Premier Award. The Premier Award is an annual recognition platform under the Raytheon Technologies Performance+ Program to honor suppliers with superior performance who have provided exceptional value to Raytheon Technologies in one of the four key categories: cost competitiveness, technology and innovation, business management and collaboration and customer service. For 2022, Qorvo was selected for two categories: technology and innovation and collaboration and customer service.

CONTRACTS

BAE Systems has successfully secured a significant £270 million 10-year contract from the **British Ministry of Defence**. Every major Royal Navy ship from the Queen Elizabeth Class aircraft carriers to the Type 45 destroyers features at least one of these systems, which are designed and built by BAE Systems. The £270 million support contract replaces a number of existing contracts, delivering increased value for money and allowing greater investment in future technology development. Under the contract, BAE Systems engineers will provide maintenance support and upgrade existing radars, including a rollout of technology upgrades to systems already in use as well as those being installed on the Royal Navy's new Type 26 frigates, which the company is currently building in Glasgow.

The Commonwealth's Capability Acquisition and Elbit Systems announced that it was awarded an additional contract by **Airbus Helicopters** to support the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support. The contract includes provision of airborne electronic warfare (EW) self-protection systems for the CH-53 GS/GE transport helicopters, as part of the platform upgrade program led by Airbus Helicopters. Under the contract, Elbit Systems, supported by Elbit Systems Deutschland, will provide digital radar warning receivers (RWRs), EW controllers (EWCs) and counter measure dispensing systems. The digital RWR and EWC rapidly detect and accurately locate a wide range of threats, even in a dense EW environment, enabling reliable and timely warning and effective protection.

PEOPLE

Averatek announced **Scott Meikle**, Ph.D., as CEO. Dr. Meikle has more than 30 years of experience in the semi-

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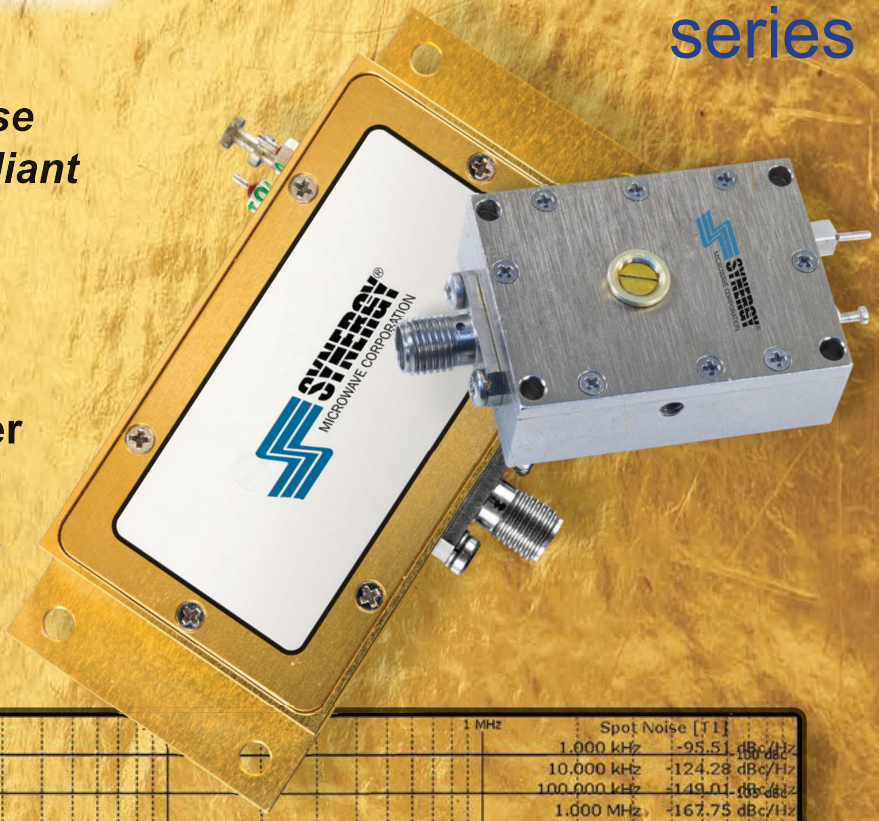

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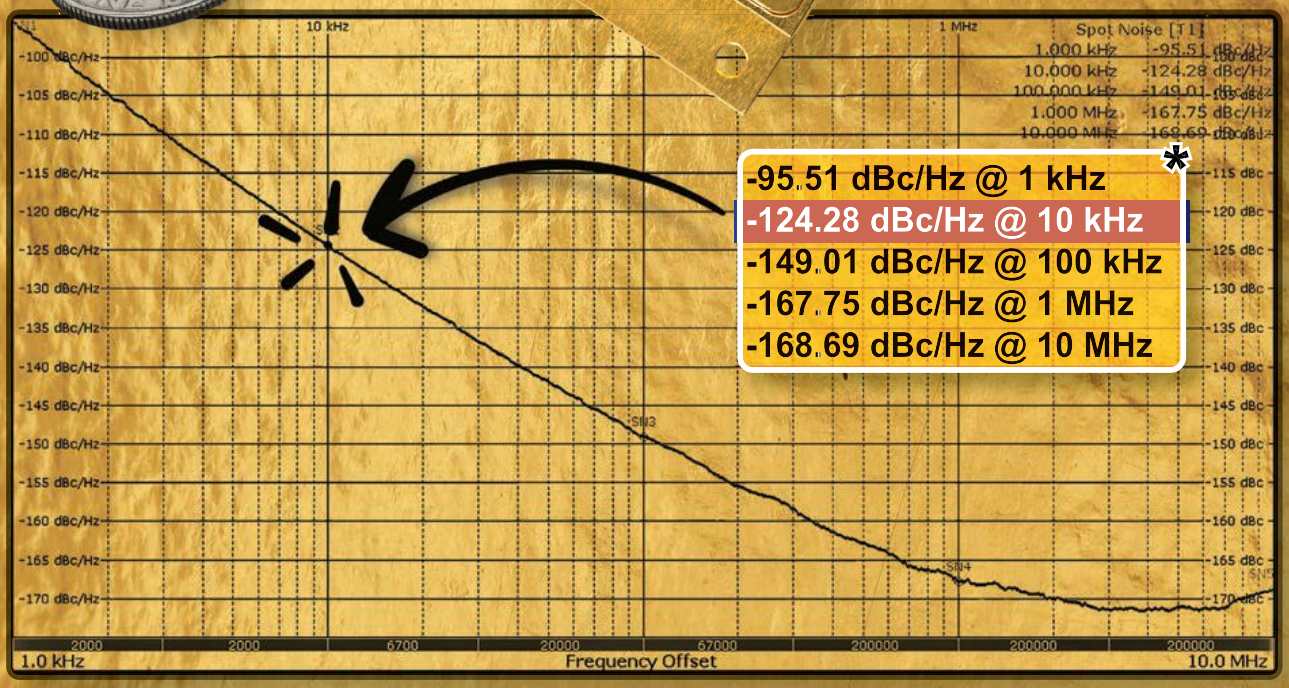

* -95.51 dBc/Hz @ 1 kHz
-124.28 dBc/Hz @ 10 kHz
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Around the **Circuit**

conductor industry. For the past six years he served as senior vice president of global customer operations at Lam Research. Prior to Lam, Dr. Meikle was resident in Taiwan for five years serving as the president of Inotera Memories, a publicly listed company. Dr. Meikle also worked for Micron, another semiconductor giant, for over 20 years in research and development, manufacturing and executive positions.

▲ *Mark Kojak*

Hirose Electric Americas has named **Mark Kojak** as president and COO of Hirose Americas, effective June 1, 2023. Kojak has been with Hirose Electric for five years, most recently as chief marketing officer and senior vice president of sales and operations. Kojak replaces Shinya (Sid) Tono, who will be returning to Hirose Electric Co., Ltd. Japan and will assume a new leadership role in the organization. Hirose Electric Americas was established in 1980 to better serve the Americas. Hirose Electric offers more than 50,000 products, with new products accounting for more than 30 percent of sales.

▲ *Peter Rabbeni*

IQE plc, a supplier of compound semiconductor wafer products and advanced material solutions to the global semiconductor industry, has appointed **Peter Rabbeni** as senior vice president, communications infrastructure and security business unit. In this role, Rabbeni will lead IQE's expansion within the communications infrastructure, data center and aerospace and security markets. Rabbeni brings decades of experience in the semiconductor industry to IQE. He has significant executive experience in business development and sales across the wireless industry, underpinned by a background in product design and engineering. These qualities make him the ideal candidate to grow IQE's presence across its key growth markets.

▲ *David Scott*

Stellant Systems Inc., a manufacturer of critical spectrum and RF amplification solutions, continues to strengthen its executive leadership team with the selection of **David Scott** as general manager of the Williamsport, Pa., facility. Scott is responsible for driving operational performance and process improvements at the Williamsport, Pa., site and reports to Stellant's COO, Steve Shpock. Scott brings 30 years of operational leadership experience which has included roles as vice president of operations and chief operating officer for a variety of companies which serve aerospace, defense, commercial and industrial markets.

Triad RF Systems, a provider of high performance RF and microwave amplifiers, integrated radio systems and advanced RF product solutions, announced the

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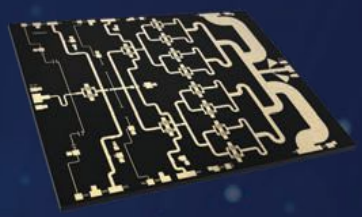
Ka / V / E - Band GaN MMIC Power

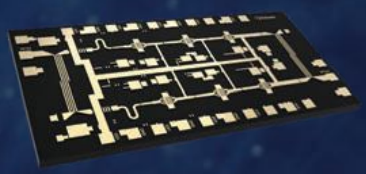
Ka

- NPA2001-DE | 26.5-29.5 GHz | 35 W
- NPA2002-DE | 27.0-30.0 GHz | 35 W
- NPA2003-DE | 27.5-31.0 GHz | 35 W
- NPA2004-DE | 25.0-28.5 GHz | 35 W
- NPA2020-DE | 24.0-25.0 GHz | 8 W
- NPA2030-DE | 27.5-31.0 GHz | 20 W
- NPA2040-DE | 27.5-31.0 GHz | 10 W



V

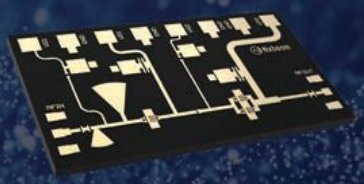
- NPA4000-DE | 47.0-52.0 GHz | 1.5 W
- NPA4010-DE | 47.0-52.0 GHz | 3.5 W



E

- NPA7000-DE | 65.0-76.0 GHz | 1 W
- NPA7010-DE | 71.0-76.0 GHz | 4 W*

* In Fabrication



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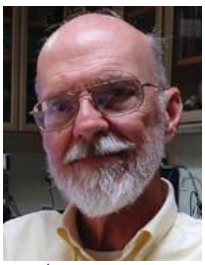
Around the **Circuit**

▲ *Adam Krumbein*

appointment of **Adam Krumbein** as their new vice president of marketing. In this position, Krumbein will lead the company's global marketing efforts, which includes brand development, strategic communications and demand generation. With over 15 years of experience in marketing, Krumbein brings a wealth of knowledge and expertise to Triad. Prior to joining the company, he served as the vice president of marketing for Southwest Antennas, where he successfully implemented strategic marketing programs that transformed the company into a recognized leader in antenna and wireless technology solutions.

▲ *William "Mac" Thornberry*

CesiumAstro, an industry leader in active phased array communications technology for space and airborne systems, announced that the **Honorable William "Mac" Thornberry**, former U.S. Representative to the 13th Congressional District of Texas, joined the company as a strategic advisor and will provide counsel on issues related to U.S. national security. A former chairman and member of the House Armed Services Committee for 26 years, Congressman Thornberry also served as a member of the House Intelligence Committee for 14 years. Widely respected across the political spectrum as an innovator and a strategic thinker, Congressman Thornberry led on critical issues across nuclear posture, homeland security, cyber and space.



▲ *Stephen Maas*

Fabless semiconductor startup **mmTron Inc.** announced that **Stephen Maas** has joined mmTron as a mmWave MMIC mixer design scientist. He will focus on extending the performance of mmWave mixers, particularly to improve linearity to complement mmTron's catalog of high linearity mmWave power amplifiers, very low noise amplifiers and front-end modules. A Life Fellow of the IEEE, Maas is widely known for his expertise in RF, microwave and mmWave mixer technology.

REP APPOINTMENTS

TestEquity, a distributor of electronic test and measurement solutions and production supplies, has announced that it will now offer **Tekbox** test equipment and accessories for customers who need to ensure the quality, compliance and reliability of their products. Tekbox offers a range of EMC pre-compliance test equipment and accessories. These products are designed to help customers meet their testing needs in a variety of industries, including electronics, telecommunications and aerospace. With this new partnership, TestEquity customers can choose from an even wider range of high-quality test equipment, such as LISN devices.

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- Small Signal Gain: 15 dB
- 1 dB Compression: 16 dBm

HL5877 Limiting Amplifier

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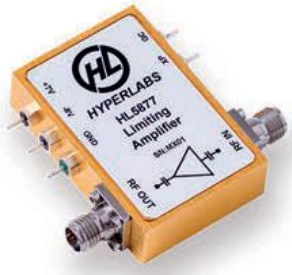
- Amplitude Deviation: ± 3%



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75-110 GHz, 30 dB, 28 dBm
88-115 GHz, 25 dB, 24 dBm
100-170 GHz, 25 dB, 24 dBm
110-145 GHz, 20 dB, 15 dBm
195-220 GHz , 20 dB, 12 dBm
210-230 GHz , 20 dB, 16 dBm

MIXERS

RF Frequency - IF - LO Power - Conversion Loss

120-160 GHz, DC-12 GHz, 13 dBm, 13 dB
170-210 GHz, DC-12 GHz, 12 dBm, 9 dB
210-230 GHz, DC-5 GHz, 13 dBm, 13 dB
200-220 GHz, DC-15 GHz, 0 dBm, 12dB

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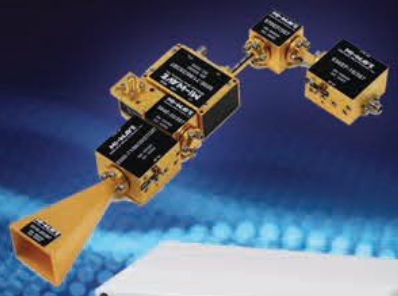

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Welcome to the 26th European Microwave Week

Thomas Zwick
EuMW General Chair
Karlsruhe Institute of Technology

Vadim Issakov
EuMW General Co-Chair
Technical University Braunschweig

Dear friends of the microwave community! It is our great pleasure to welcome you to the European Microwave Week (EuMW) 2023 in Berlin. After 25 very successful EuMWs in different cities in Europe, it's time for us to go to Berlin!

Berlin, the capital and the largest city of Germany, is a fascinating European city that is renowned not only for its landmarks and museums, but also a rich cultural life, vibrant party scene and urban art. Evolving and progressing from a past of division into east and west, it has a distinctive charm of multi-layered uniqueness and a multi-cultural atmosphere. This is the reason we chose the Brandenburg Gate and the torn-down wall as our logo to celebrate the unification. Our slogan "Waves Beyond Walls" for EuMW 2023 shall emphasize that microwaves can unite and bring people closer. We are convinced that science can help tear down "walls."

European Microwave Week 2023 is held in hub27, which is part of the Berlin ExpoCenter City (Messe Berlin). Hub27 is a recently opened, modern conference centre with a large exhibition hall, which can be conveniently reached by public transportation (S-Bahn stop "Messe Süd"). Berlin can be easily reached by train and plane. The Berlin Brandenburg Airport Willy Brandt (BER) opened for international flights in 2020 and has excellent train connections to downtown Berlin. The city of Berlin has exceptionally good public transportation, which allows one to get to any point of the city very efficiently and much more conveniently than by car. We want to make your visit to Berlin as convenient as possible. Therefore, we will include full usage of Berlin's public transportation in your conference badge, including the trip to and from the airport. For more details, please see the registration information.

EuMW 2023 includes the European Microwave Conference (EuMC), the European Microwave Integrated Circuits Conference (EuMIC), the European Radar Conference (EuRAD), the Defence, Security and Space Forum, the Automotive Forum, the 5G to 6G Forum, a large number of workshops covering a wide range of topics, Focused and Special Sessions and special events, such as Women in Microwave Engineering and two Inter-Society Technology Panels by IEEE MTT-S. The opening and closing plenary sessions of each of the three conferences feature keynote lectures by internationally renowned leaders in their fields. In addition to the conferences, the annual European Microwave Exhibition, which is by far the largest RF and microwave trade show in Europe, will offer attendees the chance to explore the latest technological advances in the industry. Since meeting and networking are vital for our community to exchange ideas, make connections, mentor younger colleagues, meet old friends and make new ones, we organized many social activities, such as the EuMIC Dinner, Automotive Forum Dinner, Welcome Reception, Gala Dinner, TPC Lunch and EuRAD Lunch.

Participation of students and young professionals is strongly encouraged. We organized many activities specifically for students, namely the Student and Doctoral Schools, with a get-together for students and young professionals, prizes and grants, an extended student volunteers program and, most importantly, the Student Career Event, which is going to be a great opportunity for students to meet and network with potential employers and have a great party in a club in Berlin.

We extend our sincere gratitude to the EuMW 2023 organization team for their tireless effort in putting together an excellent technical and social program. We also thank EuMA and Horizon House for their continued support and help.

Come and join us in Berlin and enjoy both the European Microwave Week — Europe's premier microwave, RF, wireless and radar event — and the city of Berlin! In Berlin, you will experience the exciting history of divided and reunified Germany and realize how important international exchange is for peace and prosperity. We look forward to welcoming all of you to our capital! ■

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Attending EuMW 2023 in Berlin

Pat Hindle, *Microwave Journal*

The 26th edition of the European Microwave Week (EuMW 2023) will come to Berlin 17-22 September to continue the annual series of highly successful microwave events that started back in 1998. EuMW 2023 comprises three co-located conferences: European Microwave Conference (EuMC), European Microwave Integrated Circuits Conference (EuMIC) and European Radar Conference (EuRAD). In addition, EuMW 2023 includes the Defence, Security and Space Forum; Automotive Forum; 5G to 6G Forum; and an exhibition with about 300 companies. EuMW 2023 provides the opportunity to participate in conferences, workshops, short courses and special events, see pages 62-63.

The theme for EuMW 2023 is "Waves Beyond Walls" as we conceive that science can help tear down walls. In the capital city of Berlin, we can see the history of divided and reunified Germany to realize how important international exchange is for peace and prosperity. The venue for EuMW 2023 will be hub27 at Messe Berlin. The S-Bahn station directly connects it to the city center, the main train station and the new Berlin airport.

All registered delegates and exhibition visitors will have full access to the exhibition area and activities. The exhibition takes place Tuesday through Thursday and offers visitors the chance to see the new products being offered by semiconductor, test and measurement, software and other types of companies in the industry.

There is a Joint Women in Microwaves (WiM) and Young Professionals (YP) Event Tuesday 19 September from 13:00 to 19:00 in Room Beta 6. The main event is a 90-minute moderated panel session with female industry representatives. They will share insights into their careers, companies and industries and provide tips for YP pursuing a career in the industry.

The Automotive Forum will cover Innova-

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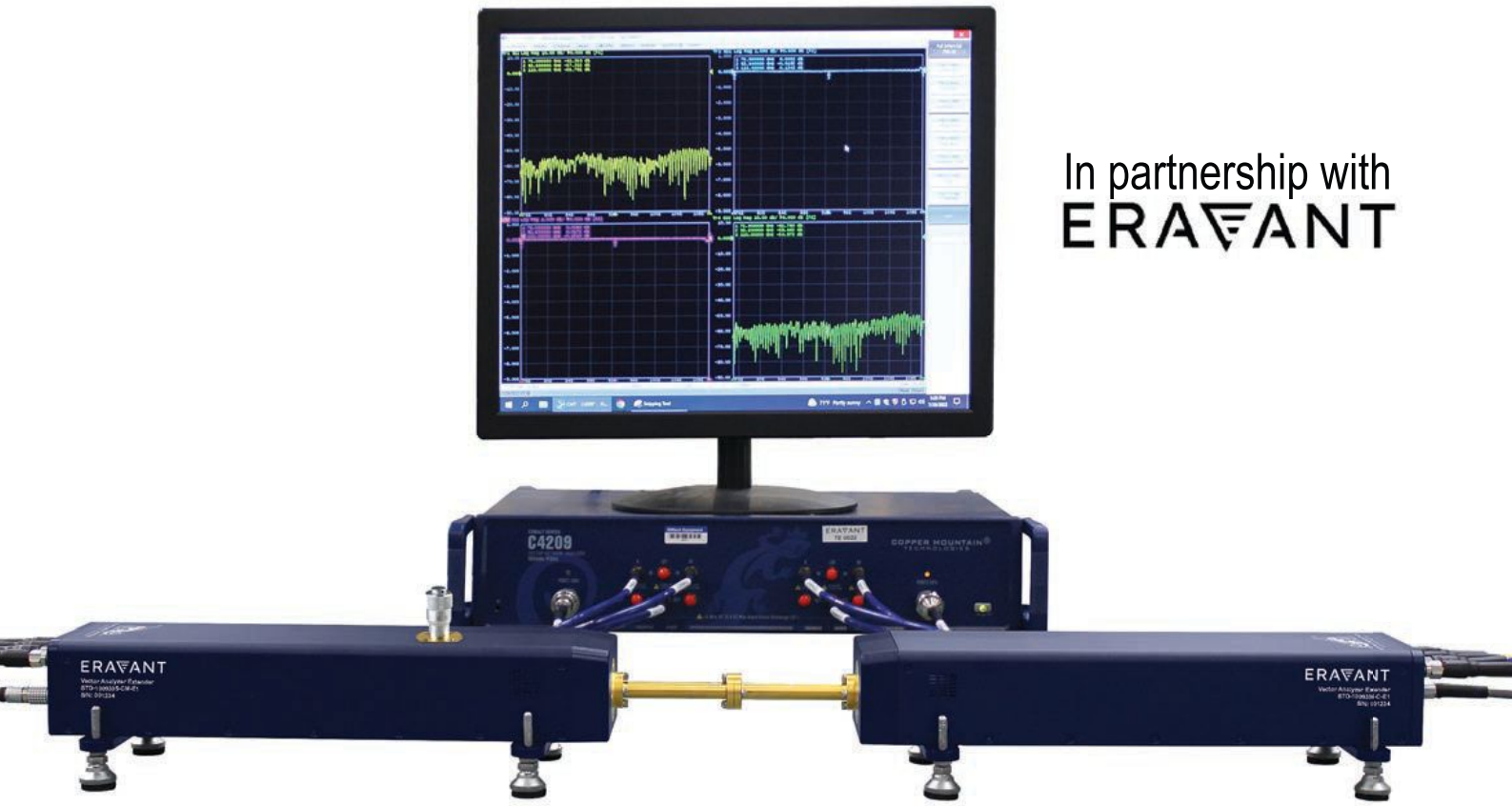

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tions and Trends for Automotive Radar Frontends and Imaging Radars, taking place Monday from 09:00 to 18:20 in Room Alpha 5. The forum consists of a good mix of technical presentations and discussions as well as networking time. The content is mainly devoted to technical experts from the automotive industry throughout the whole supply chain. Keynote speakers will present their views on special technical solutions as well as regulatory or strategic issues.

The Defence, Security and Space Forum theme is Boosting Connectivity for Moving Platforms and takes place Wednesday from 11:20 to 17:40 in Room Alpha 6. This year's forum brings together leading industry, institutional and academic experts to showcase and discuss the latest trends to provide pervasive and persistent connectivity to moving platforms even under congested and contested spectrum access. It will encompass network operator requirements as well as leading edge technologies for spaceborne, airborne and ground vehicles. These topics will be addressed from the commercial point of view of satellite network operators and antenna technology providers for mobile platforms in addition to the perspective of defense-related airborne networks.

The 5G to 6G Forum takes place Thursday from 08:45 to 18:20 in Room Alpha 5. This Forum is a one-day international industry event that looks into the important research and development trends that will permit the evolution of services from 5G to 6G with a clear focus on the RF technologies that will enable the use of the FR3, mmWave and sub-THz bands. The forum consists of invited speakers from industry, operators, vendors, academia and the 6G Platform Germany. It will specifically focus on electronics-relevant technologies and address the question "What do 5G/6G and the transition from 5G to 6G mean at the hardware/electronics level?" The focus covers technologies related to the integration of communications and sensing as well as aspects to improve coverage and performance of mmWave and sub-THz networks.

For students, there is the 13th Tom Brazil Doctoral School of Microwaves – From Microwaves to Machine Learning: Building and Training Artificial Neural Networks for Radar-Based Gesture Recognition and 7th European Microwave Student School Microwave Measurement Techniques on Sunday. On Wednesday, there is the Student Career Event and party and on Thursday and Friday, there is a tour at the Free University of Berlin to visit the Ferdinand-Braun-Institut, Adlershof.

We hope to see everyone in Berlin at EuMW 2023. Please drop by the *Microwave Journal* booth (529B) to say "Hi" and subscribe/renew. ■

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Social Events

EuMW Welcome Reception

Tuesday 19th September 2023
18:45 – 21:45

Cost: Free to conference delegates & invited exhibitors

Location: Palais, Messe Berlin
Sponsors: Keysight, Horizon House, EuMA
(Please bring your badge to gain admission.)
All registered conference delegates, as well as invited representatives from companies participating in the exhibition are invited to the Welcome Reception, sponsored by Keysight Technologies, Horizon House Publications and EuMA. Delegates will need to bring their badge, while exhibitors will need to bring their invitation, in order to gain entrance. The evening will commence with drinks at 18:45, followed by the General Chairs' handover from EuMW 2023 in Berlin to EuMW 2024 in Paris along with an address from the Platinum Sponsor, Keysight Technologies.

The open-buffet dinner will be served from 19:15.

Automotive Forum Networking Dinner

Monday 18th September 2023
19:30 – 23:30

Cost: Free to registered Automotive Forum delegates
(Please bring your badge to gain admission.)

Location off-site: SAGE Restaurant
(Shuttle service from hub27 will be provided including a guided city tour of Berlin. Meeting point at 18:30. The buses will depart no later than 18:45.)
Join us for this unique event, which includes a 3-course dinner. This will provide you with the opportunity to network and discuss the issues raised throughout the Forum in an informal setting.

EuRAD Lunch & Closing Session

Friday 22nd September 2023
13:00 – 15:40

Cost: Free to registered EuRAD delegates
Sponsor: Hensoldt
(Please bring your badge to gain admission.)

Location: Alpha 5/6
An open-buffet lunch for EuRAD delegates to catch up and round off a busy week, followed by the EuRAD Closing Session.

Young Professionals Get-Together

Sunday 17th September 2023
20:00 – 24:00

Cost: Free for young professionals and school participants
Sponsors: Bosch, Fraunhofer IAF, Hensoldt, IEEE MTT-S, Keysight, Nokia, Rohde & Schwarz, Rosenberger, Saab, Siemens, Vega
*(**Tickets required.** These will be distributed in schools and Sunday lunch break in registration area. Only a limited number of tickets are available.)*

Location off-site: Hofbräu Wirtshaus Berlin
Come and enjoy networking in a very informal venue!

Student Career Party

Wednesday 20th September
20:00 – 01:00

Cost: Free for microwave students
Sponsors: Bosch, Fraunhofer IAF, Hensoldt, Keysight, Nokia, Rohde & Schwarz, Rosenberger, Saab, Siemens, Vega
*(**Tickets required.** These will be distributed during the Student Career Event at the entrance of hub27 on Wednesday, 12:00 – 15:00. Please note that only a limited number of tickets are available.)*

Location off-site: Palais Kulturbrauerei
Students, come party with representatives of leading RF companies. Expect a free buffet, open bar, DJ, and the chance to meet your future employer.

EuMIC Dinner

Monday 18th September 2023
19:30 – 22:30

Cost: Free to all EuMIC delegates
Sponsor: Infineon
*(**EuMIC Dinner admission tickets required.** These will be distributed to EuMIC delegates on site. Please note that only a limited number of tickets are available.)*

Location off-site: Meistersaal am Potsdamer Platz
(Shuttle service will be provided from hub27. Meeting point at 18:30. The buses depart no later than 18:45.) All registered EuMIC delegates are invited to our traditional and convivial "get-together". A good occasion to unwind at the end of the first conference day, and enjoy a dinner with speakers and colleagues.

EuMW 2023 TPC Lunch

Wednesday 20th September 2023
13:00 – 14:20

Special event for the EuMW 2023 Technical Program Committee members (by invitation).

Location: Funkturm Berlin

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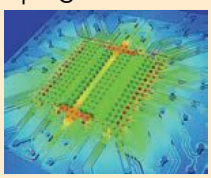

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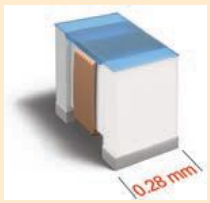

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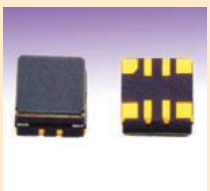
T58 TCXO



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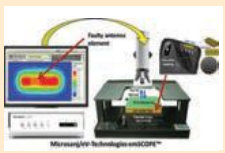

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INVITED PAPER

RF GaN Market Broadens Its Appeal with an Appetite for GaN-on-Silicon

Aymen Ghorbel, Ezgi Dogmus and Poshun Chiu
Yole Intelligence, Lyon, France

GaN technology continues to deliver performance and efficiency in both the defense and the telecom markets. The RF market applications are currently dominated by GaN-on-SiC devices. While GaN-on-silicon (GaN-on-Si) does not threaten the dominance of GaN-on-SiC now, its emergence will impact the supply chain and possibly shape future telecom technologies.

In the 1990s, the U.S. Department of Defense recognized RF GaN-on-SiC's higher output power and efficiency compared to materials such as InP, GaAs HBT, GaAs HEMT and Si LDMOS. RF GaN has a wider bandwidth and offers the ability to reduce system size. Both of these capabilities are in demand as the telecom infrastructure extends its frequencies and base station models. These power and efficiency attributes led to widespread adoption in defense, where RF GaN-on-SiC could meet the challenges of thermal conditioning in higher-power applications, such as airborne radar.

Defense remains one of the largest sectors in the RF GaN market. In parallel, RF GaN has started being adopted by the satellite communications (satcom) market, where its high efficiency, compared to other materials, enables smaller device sizes, freeing up valuable space at the system level. Yole Group's RF GaN 2023 report forecasts that the defense and satellite communication sectors are expected to see a compound annual growth rate (CAGR) of 13 percent and 18 percent, respectively, from 2022 to 2028. This will propel the defense market to an estimated $1 billion in revenue, while the satcom market will grow to reach an estimated $270 million in revenue in 2028. Yole Intelligence's forecast for RF GaN revenue and segmentation is shown in ***Figure 1***.

RF GAN IN TELECOM INFRASTRUCTURE

In 2023, the mainstream GaN technology is on a SiC substrate. This mature technology demonstrates remarkable characteristics such as enhanced power-added efficiency, thermal conductivity and power density in sub-6 GHz frequencies. First introduced by Huawei in 2015, volume production of GaN-on-SiC began in 2020 for 4G base stations. Since then, the GaN RF telecom industry has evolved into a high volume market by driving the need for cost-competitive 6 in. SiC wafers. As of 2023, 6 in. SiC wafers are commercially available and the transition at the facilities of leading players is ongoing. There have also been large investments from companies around the world, such as SEDI, Wolfspeed, NXP and Qorvo, ensuring GaN-on-SiC dominates in its target applications and replaces its counterpart Si LDMOS. ***Figure 2*** shows the anticipated evolution of market share in the telecom infrastructure market for various RF power technologies.

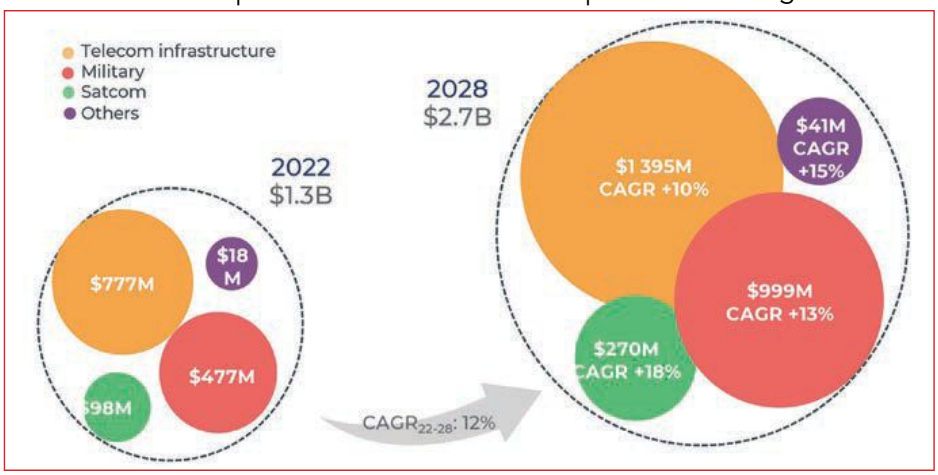

Fig. 1 **Forecast and segmentation of RF GaN device revenue from 2022 to 2028.** ***Source:*** **RF GaN 2023 report, Yole Intelligence, 2023.**

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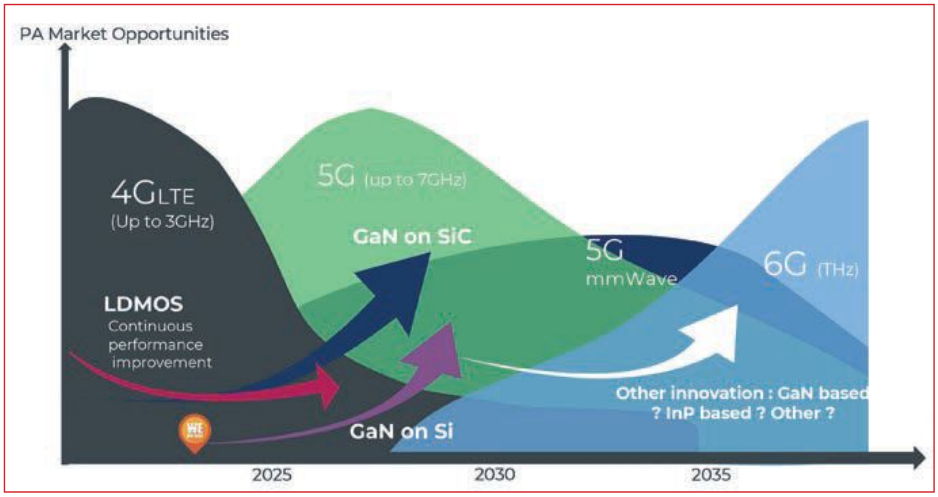

Fig. 2 **RF GaN penetration in the telecom infrastructure market as of 2023.** ***Source:*** **RF GaN 2023 report, Yole Intelligence, 2023.**

4G micro and macro site base stations are predominantly based on remote radio heads (RRH), which integrate the base station's RF chains and analog-to-digital conversion components with up to eight multi-stream power amplifiers (PAs) at up to 100 W of output power. As the 4G era is coming to an end, the reliance on LDMOS-based PAs in 3 GHz base stations is expected to recede. Emerging sub-6 GHz 5G base stations are moving from a 2 × 2 MIMO model to a 64 × 64 massive MIMO (mMIMO) model with active antenna systems (AAS) to replace RRHs. In addition to increasing the number of PAs, this architecture is expected to be at a lower output power for each PA. These output powers will range from 100 to 5 W. There is also the requirement for the PA to reduce power consumption while handling increasing data traffic volumes. ***Figure 3*** shows a vision of the evolution of 5G telecom infrastructure.

GaN can address all these requirements. The LDMOS market share is expected to decline as GaN-on-SiC addresses frequencies up to 7 GHz for 5G. In the short term, RF GaN-on-SiC is also expected to benefit from further penetration as new regional markets, such as India, adopt AAS in building the telecom infrastructure. For 5G mmWave and 6G, as the requirements focus more on high frequencies and lower-power, RF GaN technology is expected to face tougher competition with other materials such as SiGe and InP.

MAKE ROOM FOR GAN-ON-SI

As the sub-6 GHz 5G telecom base station requires PAs with lower power, GaN-on-Si could find a sweet spot in 32T32R and 64T64R mMIMO base stations below 10 W. Over the last two years, the ecosystem has grown. Players such as STMicroelectronics with MACOM, OMMIC (now part of MACOM), GCS, Infineon Technologies and foundries like Global Foundries and UMC have been working on introducing RF GaN-on-Si technology.

The reduction in output power with the adoption of mmWave small cells having two or four streams and operating at 28 to 60 GHz also presents a potential opportunity for GaN-on-Si. As telecom infrastructure continues to move toward lower output power systems, AAS and small cells will drive the adoption of GaN-on-Si to meet multi-stream, small cell and mmWave beamformer performance demands. The next generation, 6G, will have even higher frequencies and GaN-on-Si is likely to play a role here, sharing the space with the incumbent GaN-on-SiC technology.

WHAT ABOUT GAN-ON-SI AVAILABILITY?

GaN-on-Si technology is commercially available today with mainstream 6 in. wafers, while 8 in. GaN-on-Si wafers are becoming available and 12 in. GaN-on-Si is being developed. Starting this year, companies like STMicroelectronics and Infineon Technologies, are introducing GaN-on-Si. It is important to note that these companies do not offer GaN-on-SiC; they are entering the telecom market only with GaN-on-

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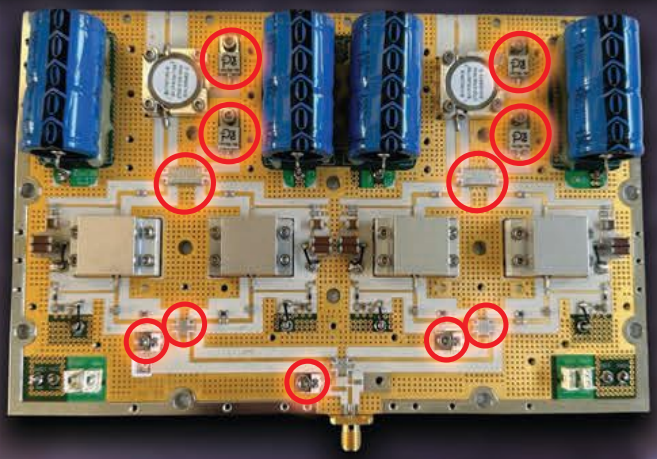

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Si technology. On the other hand, MACOM has expertise in both GaN-on-SiC and GaN-on-Si technologies. They have recently acquired OMMIC to expand their portfolio and cater to mmWave applications, primarily focusing on satcom applications.

In addition to being available at a lower cost than GaN-on-SiC, GaN-on-Si is of interest because it could be compatible with existing silicon manufacturing lines. The possibility to scale up to 12 in. GaN-on-Si could be a game changer if the market pull happens. As of 2023,

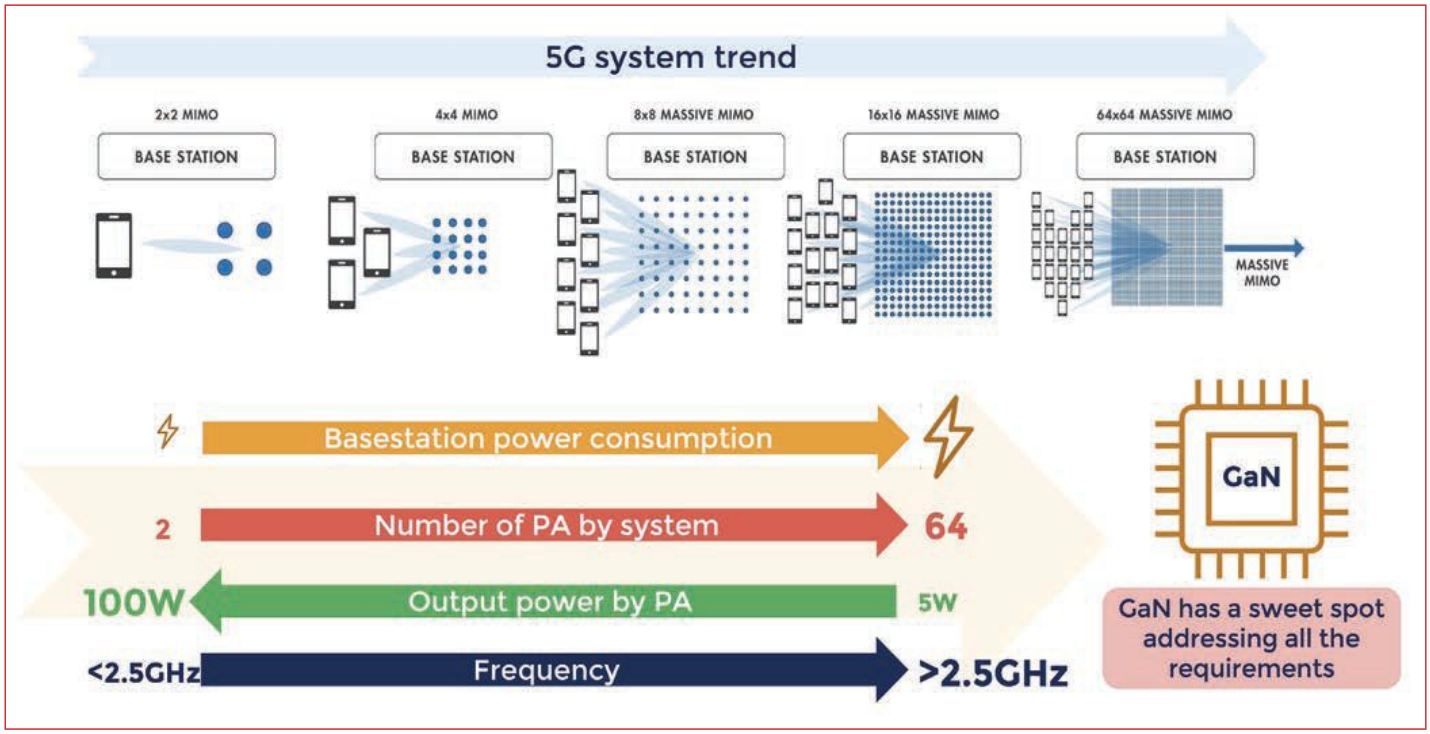

Fig. 3 **Telecom infrastructure system trends.** ***Source:*** **RF GaN 2023 report, Yole Intelligence, 2023.**

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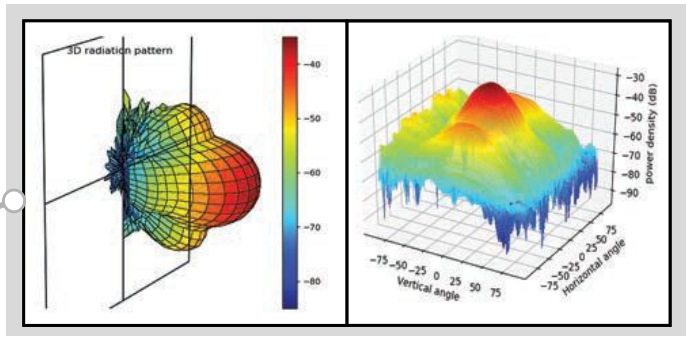

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▲ Fig. 4 **RF power market share forecast for telecom infrastructure.** ***Source:*** **RF GaN Compound Semiconductor Market Monitor Q2 2023, Yole Intelligence, 2023.**

players such as IQE, Global Foundries, UMC, GCS and Soitec are pushing for GaN-on-Si technology.

MAKING ROOM IN AN EXPANDING MARKET

Telecom infrastructure remains the largest single market for RF GaN devices. According to Yole Intelligence's "RF GaN Compound Semiconductor Q2-23" report, revenue in this market segment is expected to increase in value from nearly $777 million in 2022 to around $1.4 billion by 2028, a CAGR of 10 percent. However, an expanding telecom infrastructure market for GaN-on-Si does not mean GaN-on-SiC will be completely eclipsed. Instead, the increased telecom market will allow room for growth in both the GaN-on-SiC and GaN-on-Si sectors. GaN is predicted to make up more than 75 percent of telecom infrastructure device shipments by 2028. Of this, more than 70 percent will be GaN-on-SiC, and 5 percent will be GaN-on-Si, with the rest of the total market attributable to LDMOS, which will continue to lose market share. ***Figure 4*** shows the latest Yole Intelligence forecast for the market share of the various RF power technologies in the telecom infrastructure market.

Today, as the primary platform, GaN-on-SiC has a well-established supply chain. Device suppliers such as SEDI, Qorvo, Wolfspeed and NXP, as well as defense-related companies Raytheon, BAE Systems and Northrop Grumman, offer GaN-on-SiC technology. In 2022, SEDI, Qorvo and Wolfspeed were the leading players in RF GaN. The newcomer in the GaN space, NXP, has experienced significant growth by entering the telecom market supply chain with the opening of its 6 in. GaN-on-SiC fab in the U.S. in 2020. In a short time, the company, which also has an LDMOS offering, has become a leading player in the GaN-based telecom infrastructure sector. Now this expanding industry makes more room for GaN-on-Si technology, where

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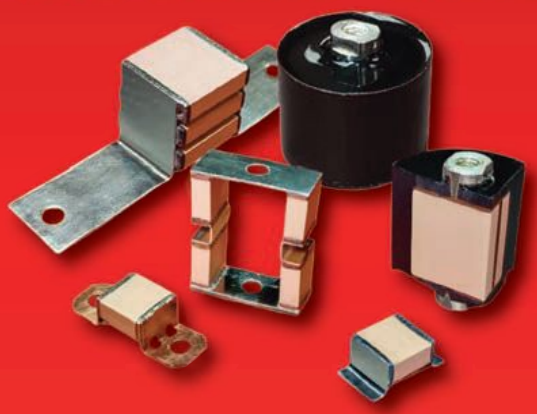

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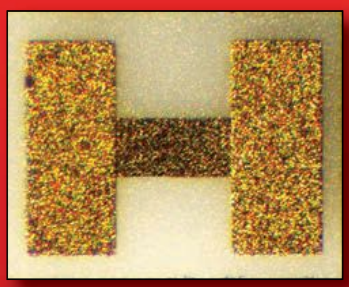

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low-power GaN solutions are promising for 32T32R and 64T64R mMIMO base stations below 10 W with more and more products becoming available this year.

But that is not all for GaN-on-Si technology! There is also a promising opportunity emerging for 5G handset PAs in the new Frequency Range 3 (FR3) band. Although there is potential for GaN-on-Si in sub-7 GHz and 5G mmWave frequencies for handset PAs, it is important to note that well-established GaAs solutions already exist for sub-7 GHz, and silicon-based solutions have gained traction for mmWave applications. These existing technologies have matured in terms of both technology and supply chain, posing as significant competitors. In the case of FR3, where the competition is still open, GaN-on-Si could potentially fulfill the requirements and find an opportunity for implementation. However, it is essential to consider that integrating GaN-on-Si into handset systems requires complex design changes, making the adoption of this technology in the FR3 band a longer-term goal. The final word is always said by the smartphone OEMs like Apple, Samsung and Xiaomi, which could be an inflection point for the GaN-on-Si industry.

Regarding the GaN-on-Si ecosystem over the last few years, companies such as STMicroelectronics, MACOM, Infineon Technologies and foundries like Global Foundries and UMC have been actively involved in the development and introduction of RF GaN-on-Si technology. These players are working towards bringing this technology to the market. Additionally, there are innovative companies like Finwave, which is focused on developing 3D GaN FinFET technology on 8 in. GaN-on-Si wafers. They are utilizing standard silicon foundry tools in their development process. Alongside these innovative companies, established companies like GCS, UMC and Global Foundries have the potential to quickly adapt and enter the market. The players are getting ready for these killer applications to run their technology and open a new era for high volume GaN-on-Si manufacturing in the RF industry. ***Figure 5*** shows some of the major RF GaN device manufacturers, along with a possible scenario for the adoption of GaN-on-Si for handset applications.

CONCLUSION

In 2023, GaN-on-SiC is still the primary platform for RF GaN, benefiting as it does from a well-developed supply chain. Yole Group expects to see GaN-on-Si entering the market starting at the end of 2023 and begin taking some market share in the coming years. This will not be at the expense of GaN-on-SiC, which will continue to grow with the rollout of 5G, 6G, multi-stream small cells and wireless backhaul systems. Instead, the market share for LDMOS is expected to diminish as PA requirements change.

High volume production of GaN-on-Si is not expected for

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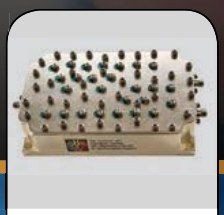

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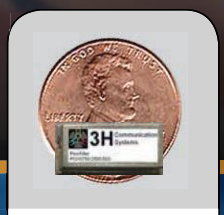

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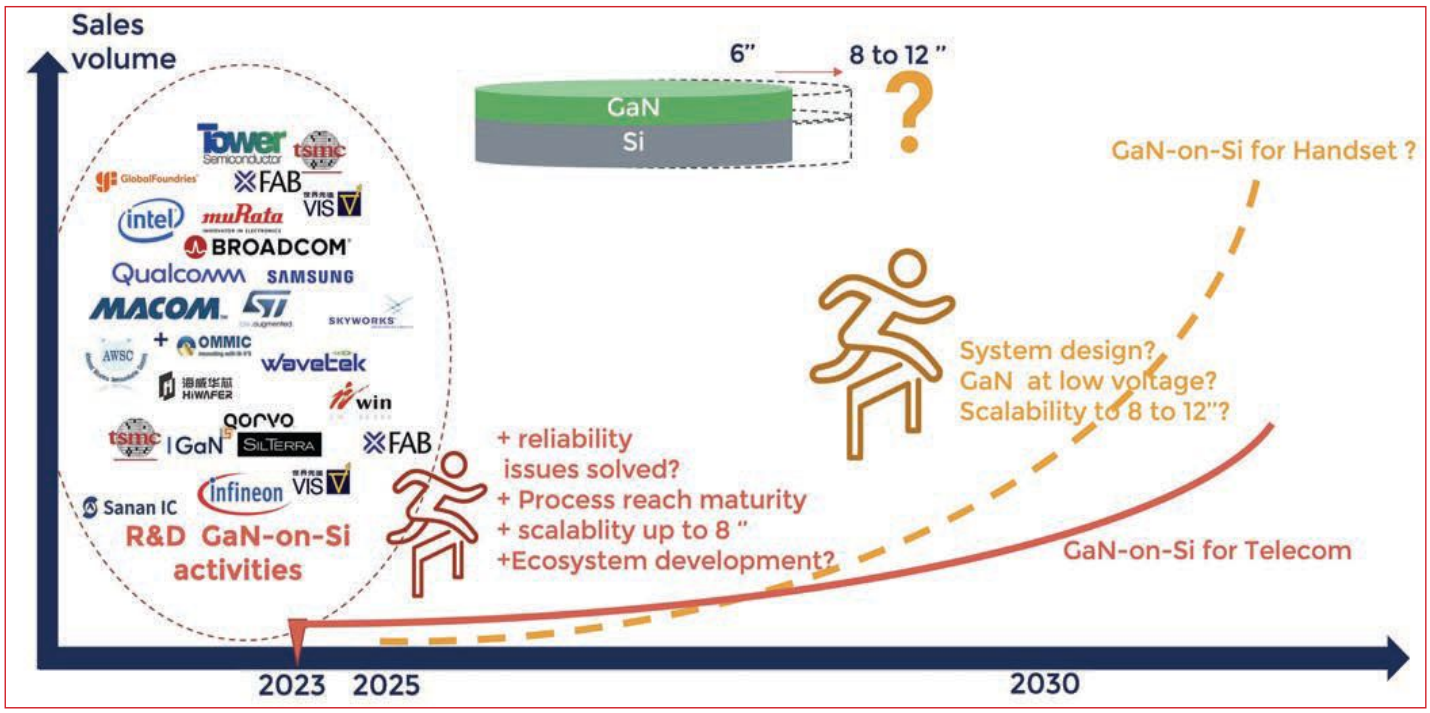
another three to five years, allowing OEMs time to adopt new technology. Today, the industry is working on solving the challenges, including reliability, process maturity and scalability to 8 or 12 in. wafers in a market segment where cost is key. Remarkable tech advances and the involvement of industry giants are more promising than ever. It is evident that in the medium to long term, GaN-on-Si will capture market share, potentially extending to the handset market. ■



▲ Fig. 5 The ecosystem and potential evolution of GaN-on-Si for handset applications. *Source:* RF GaN 2023 report, Yole Intelligence, 2023.

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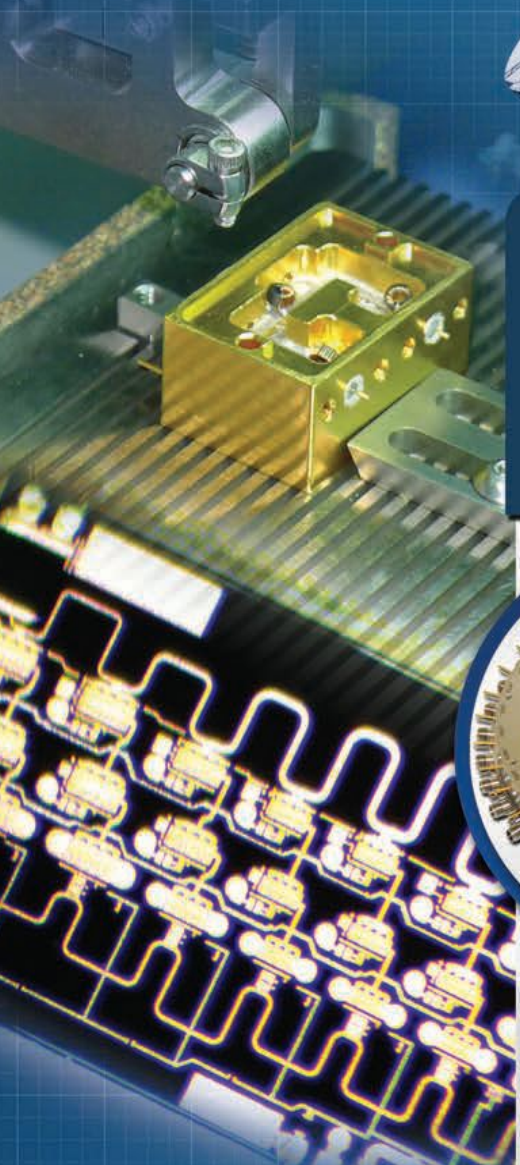

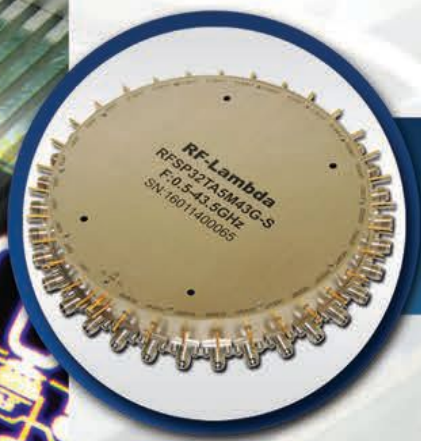

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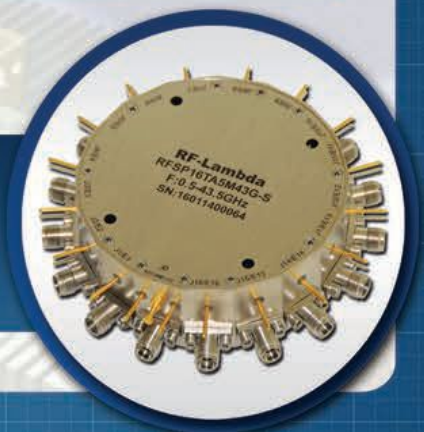

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INVITED PAPER

V-Band and E-Band Radio Links Are Becoming Important for 5G Fixed Wireless Access and xHaul

Terry Edwards
Engalco-Research, Bridlington, England

Until recently, Ka-Band was the dominant choice for fixed wireless access (FWA) connections and frequency bands up through Q-Band (33 to 50 GHz) were commonly used for wireless xHaul opportunities, the umbrella term describing backhaul, fronthaul and midhaul applications in 5G radio access networks. The ever-burgeoning demand for more and more bandwidth is continually placing pressure on band selection and this has led to the choice of V-Band (centered on 60 GHz) for new FWA installations and E-Band, mostly at 71 to 76 GHz, for xHaul.[1] This article provides some background information together with data forecasts addressing the expected progress for these mmWave FWA and xHaul market opportunities out to the year 2030.

INTRODUCTION

When posed with the question regarding the communications links associated with cellular networks, most people would immediately think about fiber-optic cabling. This is because fiber cabling plays an important role in the broadband networks that connect customer premises equipment in homes and businesses. In most situations, fiber is synonymous with broadband. This is hardly surprising considering that fiber cables can have available bandwidth measured in the several terahertz (THz) range.

However, there are notable issues with fiber cables. They typically require permission before physical installation. This often means that the installation requires a considerable planning period. Especially in urban areas, installation often becomes a costly, prolonged effort that involves digging up roads and/or sidewalks as part of the fiber trenching process.

Wireless transmission between radios provides a simpler alternative to the challenges presented by fiber. The bandwidth of this wireless solution is currently measured in GHz, but this is proving to be sufficient for many applications. Despite less signal bandwidth, wireless radios benefit from a faster, less expensive planning and deployment process than fiber networks. Currently, wireless radio networks intended to meet FWA and xHaul requirements operate in mmWave frequency bands to take advantage of the substantial bandwidths and the resulting capacities available in these bands. Within that broad mmWave frequency range, the portion of the unlicensed V-Band centered around 60 GHz has become popular for new FWA installations. The xHaul applications that connect the wireless radio to the core network are using the lightly-licensed E-Band frequency range, mostly in the 71 to 76 GHz portion of the band. The analysis that follows considers only outdoor radio links, as these links have increasingly

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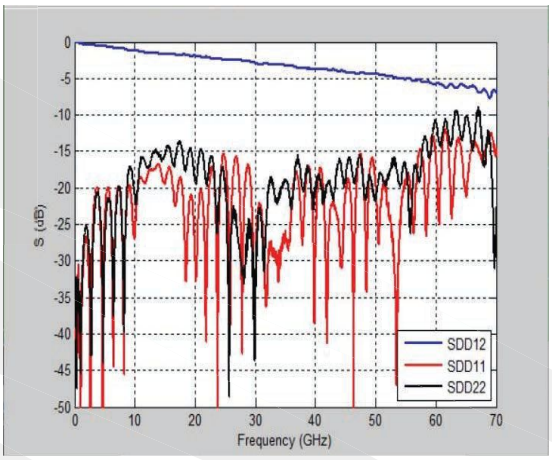

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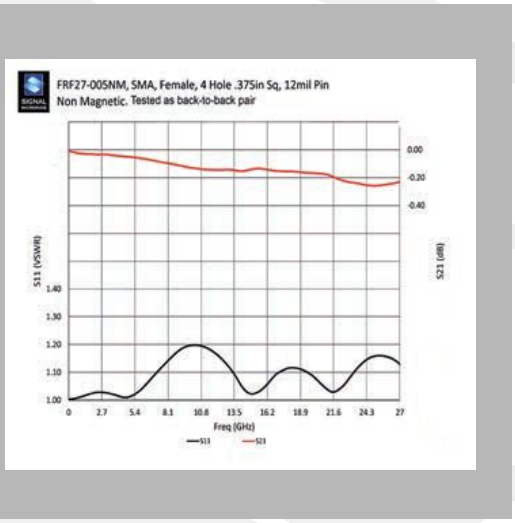

Typical test data through 27 GHz using FRF27-005NM-12 back-to-back connector pair with test pin.

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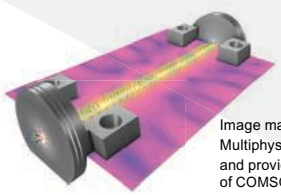

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SUPPLIERS OF MMWAVE RADIOS

A wide range of global companies are supplying mmWave radios.[2] While not exhaustive, a list of these suppliers includes Ceragon, Filtronic, Movandi, Nokia, REMEC and Siklu. The pie chart in ***Figure 1*** shows a segmentation of the number of companies supplying radios covering various frequency bands in 2023.

The trend is clear. We expect that the number of companies supplying V-Band and E-Band radios will continue to increase along with the shipment quantities as we move forward. By 2030, we expect that the quantity of V-Band and E-Band radio shipments will increase at the expense of K-Band and Ka-Band, along with lower frequency radios.

COMMUNICATIONS SERVICE PROVIDERS (CSPS)

Engalco-Research investigated the following 21 CSPs who operate regionally and globally. The companies that were investigated include A1 Telecom Austria, America Movil, Asia Pacific Telecom, AT&T, British Telecom (including a subset for EE), Charter Communications, KDDI Corporation, KT Corporation, LG Uplus, NTT DoCoMo, Ooredoo, Orange, Reliance Jio, SK Telecom, Telefónica, Telstra, Telus, Three UK, T-Mobile US, Verizon and Vodafone.

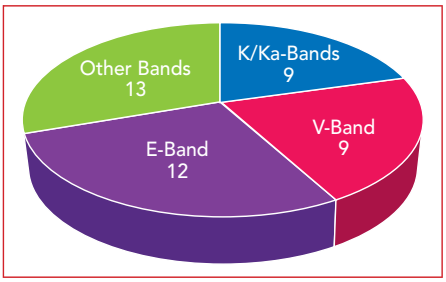

Fig. 1 **Number of companies supplying radios in various bands.**

After primary and secondary research on each radio supplier, Engalco-Research built up a numerically detailed assessment of the total addressable market (TAM). We segmented these results into FWA and xHaul applications for wireless radios. The relative market shares for FWA radios are segmented by frequency range in ***Figure 2***.

Fig. 2 **Ka-Band and V-Band market shares in FWA applications.**

Fig. 3 **Adoption of various bands for xHaul.**

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1.85mm Male - 1.85mm Female Right Angle	
1.85mm Male - 1.85mm Male Right Angle	
1.85mm Female - 1.85mm Female Bulkhead	
1.85mm Male - 1.85mm Female Bulkhead	

Between Series	VSWR (Max.)
1.85mm Female - 2.92mm Female	1.15 : 1@40GHz
1.85mm Female - 2.92mm Male	
1.85mm Male - 2.92mm Female	
1.85mm Male - 2.92mm Male	
1.85mm Female - 2.4mm Female	1.20 : 1@50GHz
1.85mm Female - 2.4mm Male	
1.85mm Male - 2.4mm Female	
1.85mm Male - 2.4mm Male	
1.0mm Female - 1.85mm Female	1.30 : 1@67GHz
1.0mm Female - 1.85mm Male	
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It is clear from Figure 2 that the market share of the V-Band radios in FWA applications will increase, expanding from a 38 percent share in 2022 to reach an estimated market share of 72 percent by 2030. By contrast, Ka-Band radios experienced a market share of 62 percent in 2022 but Engalco-Research estimates that this share will decline to just 28 percent by 2030. Although V-Band has taken off in many regions, K-Band appears set for substantial market values and annual growth in India due to the current success of the Sivers/Intel/WiSig network consortium. Other Asian, as well as some African, markets may follow with residual market opportunities that will be well-suited for Ka-Band radios beyond 2030.[3] In total, we expect that the TAM of these FWA networks will increase to more than $1 billion.

Parsing these data regionally yields the following observations:

- North America (mainly the U.S.) remains the leading regional market over the forecast period. This is driven primarily by AT&T, Verizon and private 5G networks.
- Southeast Asia is consistently the second largest region over the forecast. The biggest regional contributors to this result are Australia, India, Japan and Korea.
- Europe, driven by Western Europe including the U.K., occupies the third position until 2025, when it is passed by the Middle East.
- Markets in the Middle East are relatively small in the earlier years but gather pace throughout the middle and later years.

We also anticipate steady to strong growth rates in these regions:

- For V-Band radios, markets in the Southeast Asia region already exhibit the highest growth rates. We expect these rates to exceed 24 percent over the 2024 to 2027 period.
- Markets in North America continue growing rapidly with a compound annual growth rate (CAGR) averaging more than 20 percent over the full forecast period. We expect that this growth rate will reach 23.5 percent over the 2024 to 2027 period.
- Markets in the Middle East will continue to grow steadily throughout the forecast period and we anticipate this growth rate will accelerate from 2025 onwards.
- In Western Europe (including the U.K.) markets will grow steadily throughout the forecast period.

XHAUL APPLICATIONS

The xHaul network interconnection architectures and opportunities are different from the FWA application. As mentioned, xHaul has become the umbrella term that the industry uses to describe data transport options encompassing backhaul, fronthaul and midhaul, although backhaul remains the most widely known of these applications. Many xHaul networks include fiber-optic cabled systems, but we believe that mmWave wire-

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less is steadily capturing market share in these network applications. This analysis considers K-Band to Q-Band (24 to 43 GHz) and E-Band (mostly 71 to 76 GHz). The market data relating to xHaul is indicated proportionately in ***Figure 3***.[3]

From Figure 3, the trend of increasing market share as E-Band radios increasingly penetrate these xHaul applications is clear. Engalco-Research anticipates that the share of E-Band radios used in xHaul applications will expand from a 29 percent share in 2022 to an estimated 53 percent by 2030. By contrast, Ka-Band radios occupied a market share of 71 percent in 2022 but Engalco-Research anticipates that this will decline to just 47 percent by 2030.

The geographic segmentation for xHaul is similar to FWA with one exception:

- North America is always the largest region and by a substantial margin.
- Southeast Asia, driven by Australia, India, Korea and Japan occupies the second position and this region also grows rapidly. We anticipate a compounded average growth rate of more than 11 percent overall with the mid-years seeing a CAGR of 12.5 percent.
- The Middle East, driven by the Emirates and the UAE, remains in third position over the forecast.
- Europe is always in the last position in this analysis.

The difference in Europe's relative position in the xHaul market versus its FWA market position is the exception. This is at least partly due to the relatively strong fiber-optic activity across Europe. Despite this, the E-Band growth rate in this region is 17 percent overall and 22 percent CAGR over the 2022 to 2026 period.

CONCLUSION

Broader 5G network deployments and new applications will increase data traffic. This will place more demands on the transport networks and wireless mmWave radios will become an increasingly important part of both the FWA and xHaul network architectures. In time, even higher frequency bands, like W-Band (75 to 110 GHz) and D-Band (110 to 170 GHz), are likely to be incorporated into operators' frequency plans to provide the bandwidth to address the ever-increasing demand for data traffic. The shift to higher frequencies from the operators will provide many opportunities for the RF and microwave supply chain and ecosystem.

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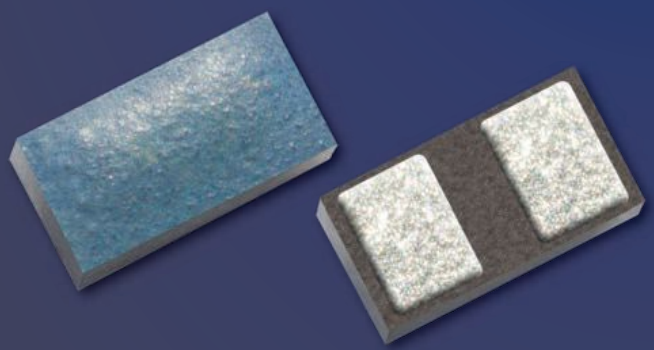

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Inspiring Innovation

INVITED PAPER

Selecting Probe Antennas for Near-Field Antenna Measurements

Andrew Laundrie
Eravant, Torrance, Calif.

With continuous growth in new applications for antennas operating at mmWave and sub-THz frequencies, the need for economical and accurate antenna measurement systems increases. At RF and microwave frequencies, the cost and size of antenna test ranges are often cost-prohibitive or impractical for many system developers. Antenna measurements for design verification and acceptance testing are commonly outsourced, frequently incurring high costs and long delays. At mmWave frequencies, the smaller footprint of antenna test ranges has the potential to make them much more practical for rapid prototype development and production testing.

Small-footprint antenna test chambers include near-field scanning systems as well as indirect far-field chambers. These are also known as compact antenna test ranges. This article briefly explores some of the issues surrounding near-field antenna measurements and how different probe antennas can affect measurement speed and data quality.

As an alternative to large and expensive far-field antenna test facilities, near-field test systems were developed to measure antennas using a much smaller anechoic environment. Near-field scanning systems differ from compact ranges in several respects. A compact antenna range typically employs a large reflector antenna or an antenna array to project a plane wave test signal toward the antenna under test (AUT). The transmitting antenna remains stationary while the AUT is rotated in azimuth and elevation. To the extent that the illuminating antenna projects a true plane wave toward the AUT, the signal source is effectively located in the far-zone of the AUT even though its actual location is well within the near zone.

In compact antenna test ranges, the power transferred over the signal path between the AUT and the measuring antenna is directly proportional to the far-zone gain of the AUT. As a result, compact ranges provide a straightforward measurement approach for obtaining antenna responses within a small anechoic environment. However, compact ranges can be difficult to design and construct and they are often limited in measurement accuracy due to a variety of influences. At higher frequencies, some of these influences become more difficult to control.

Near-field antenna test ranges use a moving probe to measure the transmission response between the probe and the AUT. Measurements are obtained with the probe located at various points within the near-field zone of the AUT. The collection of scan points forms a synthetic antenna aperture that captures the AUT antenna pattern as it exists within the near-field zone.

Many near-field test systems position the probe over a planar scan surface. This is shown in ***Figure 1***. Planar scans are well-suited for measuring directional antennas that do not exhibit significant gain outside of their main beam. The directional antenna pattern of the AUT allows a limited scan area to capture all the significant features in the radiation pattern.

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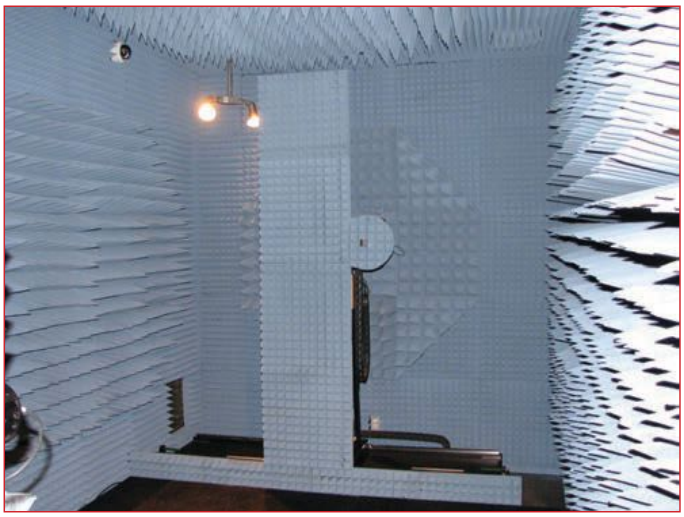
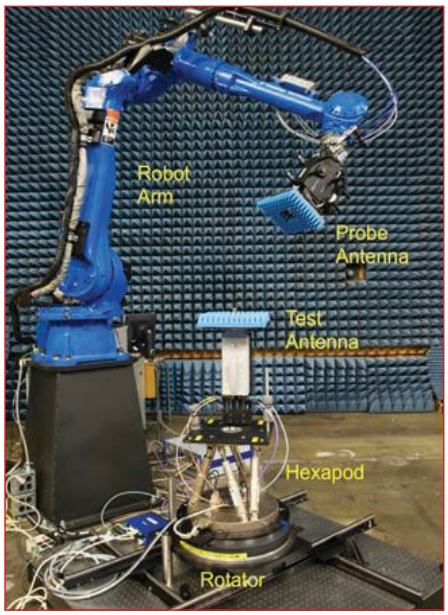
sidelobe levels, spherical or cylindrical scan surfaces may be used. Spherical near-field scanning systems typically use a probe with low gain that approximates an omnidirectional antenna for angles close to boresight. An example of this type of system is shown in ***Figure 2***. The low probe gain allows for greater variation in the probe's angular position or attitude relative to the AUT and it often eliminates the need for probe correction during data processing.



▲ Fig. 1 **A near-field scanner moves an open-ended waveguide probe over a planar surface. *Source:* Concordia University in Montreal.**

The scan surface should be large enough to capture all significant near-field energy generated by the AUT. The required scan area and scan type is typically determined by the locations of the sidelobes that must be measured. As a rule of thumb for planar and cylindrical scans, the scan height should be approximately equal to the AUT height plus the probe height, plus twice the distance between the AUT and the probe multiplied by the tangent of the maximum processing angle from boresight. For example, if the probe and the AUT are both 1 cm high (apertures of 2 × 2 cm), with the distance between them 20 cm and the maximum measurement angle ±15 degrees, the recommended scan height above or below boresight would be ± [2 + 2 + 40 tan (15°)] cm, or ± 15 cm.



▲ Fig. 2 **A near-field scanner performs spherical scans of an antenna under test. *Source:* NIST, Boulder Colo.**

FAR-ZONE TRANSFORMATIONS

Both the amplitude and phase of the measured transmission path between the probe and the AUT are required to mathematically transform the near-field data into a far-zone antenna pattern. In most cases, a dedicated vector network analyzer performs this measurement task. For each measurement, the location of the probe must be known to within a fraction of a wavelength.

For planar near-field scans, the measured data is typically processed using Fourier optics techniques. If a raster scan is taken at regular intervals in the x- and y-dimensions, a two-dimensional Fourier transform of the measured data produces a spatial frequency spectrum on a scale indicating the number of cycles per unit of distance traversed across the scan plane. If probe correction is required, the measured spatial frequency spectrum is divided by the probe's spatial frequency spectrum over the same scan surface. This operation is equivalent to deconvolution in the near-field measurement domain. The resulting spatial frequency spectrum for the AUT is mapped onto an angular far-zone gain plot in either azimuth or elevation by computing the arcsine of the displacement from boresight multiplied by $2\pi/\lambda$. When other

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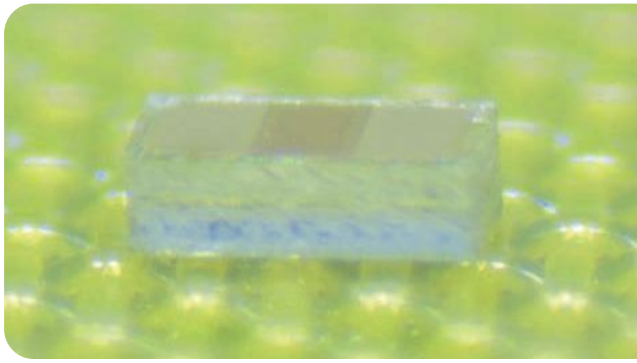

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scanning surfaces or different scan patterns are used, the computations are more complex but the underlying mathematical and physical principles are the same.

NEAR-FIELD PROBE SELECTION

Selecting a probe antenna for near-field measurements requires an understanding of the probe's spatial filtering properties. Spatial filtering refers to the antenna pattern of the probe and its effects on the measurement results. Low gain probes are essentially omnidirectional sensors, with nearly constant gain for all measurement angles encountered between the probe and the AUT. Although low gain probes may eliminate the need for probe correction, they are more likely to pick up unwanted multipath signals.

Higher gain probes provide greater levels of spatial filtering. They function as angular bandpass filters. Data processing must include probe correction unless the probe is pointed directly toward the AUT for all measurements. Monopulse or nulling antennas function as angular band reject filters. They can measure low sidelobe levels in test systems that lack sufficient dynamic range to measure both the main beam and the sidelobes when a more conventional probe is used.

The most effective probe depends on the antenna being tested, the scan type employed, the severity of multipath effects in the test environment and the overall measurement goals. Open-ended waveguide probes are often favored because of their low cost and their ability to sample electric fields with negligible spatial filtering and their minimal disturbance of the electromagnetic fields. ***Figure 3*** shows a D-Band open-ended waveguide probe from Eravant. This probe has 6.5 dBi gain with a 3 dB beamwidth of 60 degrees. With antenna gain on the order of 6 dB, such probes are nearly omnidirectional for a wide range of measurement angles. They are commonly used in spherical scanning systems where the distances between the probe and the AUT may be small because of the higher cost of building a larger scanning system.

Fig. 3 An Eravant D-Band open-ended waveguide probe.

For planar near-field scans, probes with higher gain can provide significant advantages. A common choice is an axially symmetric horn paired with an ortho-mode transducer (OMT). The OMT and horn allow simultaneous measurements of signals that have orthogonal polarizations. One of the most effective probe types for planar scans is the conical scalar horn antenna. An example of an Eravant scalar horn an-

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tenna paired with an OMT is shown in ***Figure 4***. This configuration enables simultaneous measurements of orthogonal polarizations. Scalar horns have highly symmetrical beams and low sidelobe levels, resulting in minimal off-axis responses from multipath effects. The probe's higher gain can also reduce the sampling density required to satisfy Nyquist sampling criteria. Additionally, higher gain improves the overall signal-to-noise ratio (SNR) of the measurements. This allows greater measurement distances, lower signal power or a less sensitive receiver than a lower-gain probe would require.

One complication that arises when using a higher gain probe is the need to compensate for the probe's spatial filtering effects. Probe correction is readily accomplished when processing the near-field data. Probes with higher gain also have larger apertures, which can result in greater mutual coupling between the probe and the AUT. The edges of the probe are often tapered to mitigate probe reflections. Adding isolators to the probe and the AUT can further reduce mutual coupling between the antennas by absorbing any reflections caused by impedance mismatches.

▲ **Fig. 4 An Eravant scalar horn antenna and ortho-mode transducer.**

The cross-polarization response of the probe can also be a significant source of measurement error. For this reason, near-field probe antennas should exhibit low cross-polarization. When a dual-polarized antenna is used with an OMT, high levels of port isolation and good impedance matching are critical for suppressing cross-polarization errors.

SUMMARY

In summary, two of the most common probe types used in near-field antenna ranges include the open-ended waveguide and the conical scalar horn. Open-ended waveguide probes have nearly constant gain over a wide beamwidth, while scalar horns provide higher gain with low sidelobe levels that can reduce multipath effects and improve the SNR of measurements. Probes with higher gain can also reduce the required sampling density, decreasing the measurement time and reducing computational burdens. The angular response of scalar horn probes is uniform and easily modeled for probe correction. The scalar horn may be combined with an OMT to enable simultaneous measurements of orthogonal polarizations. Low cross-polarization responses are desired to minimize measurement errors, and isolators should be used to minimize mutual coupling between the probe and the AUT. ■

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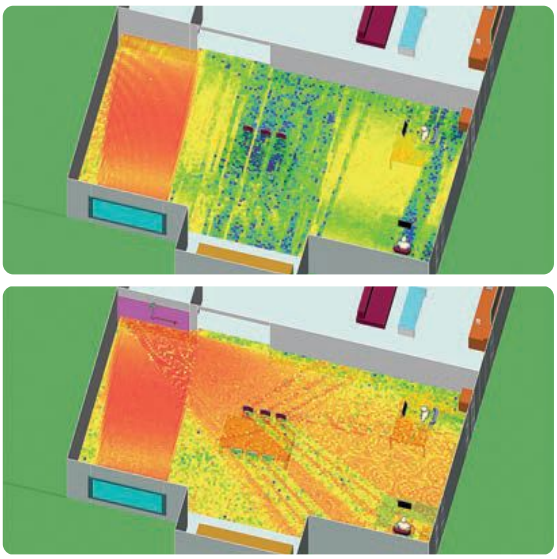

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INVITED PAPER

The 5G CAN: A Scalable Dual-Polarized Omnidirectional Tx/Rx Front-end Module

Winfried Simon, Aline Friedrich, Oliver Litschke, Markus Krengel, Lutz Wunderlich, Michael Wleklinski, Thorsten Liebig and Simona Bruni
IMST GmbH, Kamp-Lintfort, Germany

5G mmWave communication technology is supported in many commercial mobile phones today. Despite broad commercial adoption, the 5G mmWave and 6G frequency bands show a large path loss. In addition, the signal is strongly attenuated when propagating from an outdoor to an indoor environment. To compensate for this and to enable high network capacity requires a small cell size. These cells need to be omnidirectionally covered with sufficient signal strength. All these requirements suggest the use of phased antenna array concepts along with conformal antenna arrays. Based on these indications, IMST has developed a scalable omnidirectional active front-end module called the 5G CAN. The 5G CAN module uses printed circuit board (PCB) technology, includes RF and DC circuitry, incorporates a milled metal block as an antenna aperture and includes a heat sink for the MMICs. The antenna module is intended to be used as an evaluation kit to support the development of 5G/6G communication, along with investigating signal processing and propagation scenarios. As a second use case, the flexible and scalable concept can be used as a basis for customer-specific development. The concept delivers an excellent solution for a small 5G base station unit that might be used in applications like streetlamps or an indoor environment like an exhibition show floor.

THE 5G CAN FRONT-END MODULE CONCEPT

The omnidirectional RF front-end module covers frequencies from 24.25 to 29.5 GHz and it supports horizontally and vertically polarized RF signals. All the antenna beams can be controlled directly via a USB interface and the device operates from a 12 V, 120 W DC source. The antenna module has a cylindrical shape to provide full omnidirectional coverage. The front-end module

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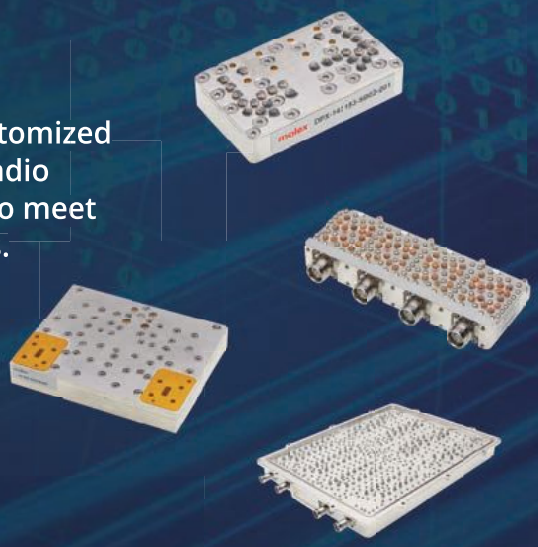

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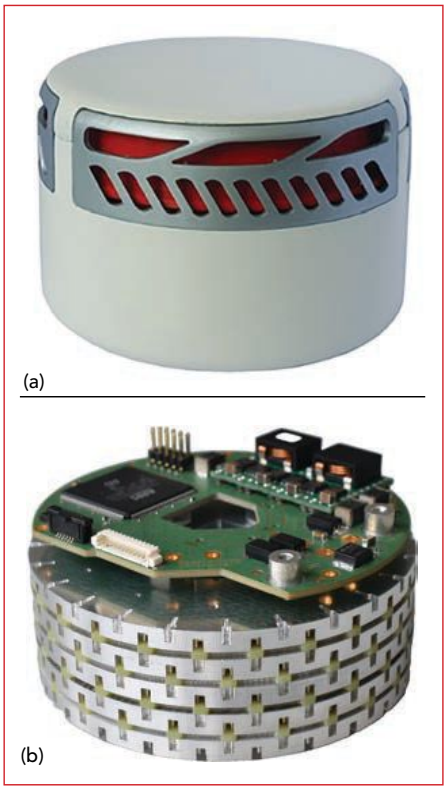

Fig. 1 (a) Omnidirectional mmWave front-end module in plastic housing. (b) Omnidirectional mmWave front-end module hardware.

integrated into a plastic housing is shown in ***Figure 1 (a)*** with the underlying module hardware shown in ***Figure 1 (b)***.

Even though many front-end modules are currently designed in a tile architecture[1] and achieve a scanning capability of up to ± 60 degrees, this module is designed in a brick architecture. This brick design is based on stacking PCBs and milled metal plates as shown in ***Figure 2***. The big advantages of this concept are the scalability and the possibility of integrating a very efficient cooling concept. Thermal management is a major aspect in highly integrated phased antenna arrays and this barrier needs to be considered in the very early stages of the design.

In the proposed antenna module, the brick design is based on four circularly shaped multilayer PCBs that include horizontal and vertical antenna apertures, active circuits and distribution networks. The antenna PCBs, which include beamforming ICs, are combined on an RF backplane PCB that is integrated into the middle of the circularly shaped antenna structure. The DC, control and RF interfaces are integrated at the top of the antenna module. For control and DC circuits, an additional PCB is attached to the top metal plate. DC voltages are converted from 12 V to about 2 V for the internal chip power supply and a microcontroller is used for SPI control. SPI and DC signals are directly connected to the RF PCBs.

The two RF input signals (H- and V-pol) are distributed on each antenna PCB to six Anokiwave beamforming ICs. To improve the isolation between different channels, horizontally and vertically polarized signals are routed on the top and bottom layers, respectively. Each beamforming IC generates four horizontally and four vertically polarized output signals, which can be independently controlled in amplitude and phase. These eight output signals feed the radiators that are realized on the edges of the PCBs.

Five milled metal plates are stacked between the PCBs and these operate as heat spreaders, shielding structures and antenna apertures. To reduce weight, these metal plates are designed with cavities in areas that are not used for heat dissipation. The heat sinking capability of the aluminum parts is enhanced by creating an airflow between the central hole in the metal disc and the outer surface of the

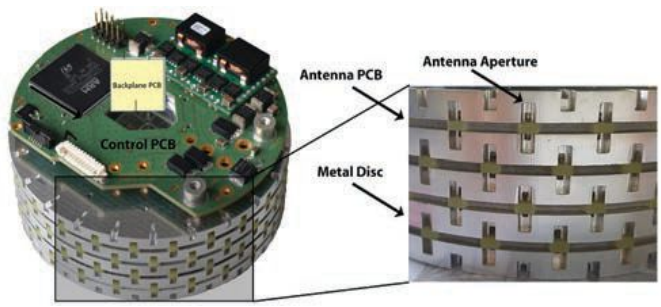

Fig. 2 mmWave 5G/6G front-end module brick architecture showing antenna aperture arrangement.

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disc where the antennas are located. The antenna array is designed in a sparse configuration to allow for a high integration density and excellent RF performance.

This concept scales easily by adding more boards and metal plates to the stack, along with modifying the control and DC boards accordingly. To increase the effective isotropic radiated power (EIRP), the antenna PCB's diameter and the number of elements can be modified. Upscaling the frequency to 39 GHz (5G mmWave band n260) is also supported by this concept.

RF ANTENNA ARRAY CONFIGURATION

The array concept is presented in detail in this section. The single antenna PCB is shown in ***Figure 3 (a)***. It has a diameter of 93 mm and it contains six beamforming chips. Each of these beamforming chips feeds four dual-polarized antenna elements. This results in a total of 24 vertically polarized and 24 horizontally polarized antennas. The radiators are arranged at the edge of the PCB with an angle of 15 degrees. In the 5G CAN module, four PCBs are stacked up with an azimuthal rotation of 7.5 degrees. This creates the sparse array configuration shown in ***Figure 3 (b)***.

The full omnidirectional radiation characteristic is achieved in the horizontal plane, parallel to the stacked PCBs. This is done by switching from one beam to the next. The 3 dB beamwidth of this configuration is 8.5 degrees. Spatially adjacent beams overlap with a maximum signal reduction of about 2 dB between beams, which seems feasible for most applications. Depending on the application, it might also be feasible to increase or decrease the number of radiators used to generate one beam. Users can create flexible configurations in this concept by adapting the control software. A beam scanning in the vertical direction is realized by adapting the feeding phase of the elements with the beamforming ICs, similar to the techniques used in phased arrays. The configuration described here achieves an elevation scan range of ± 30 degrees. Larger scan ranges are possible by reducing the height of the metal plates of the single elements in the vertical direction. The

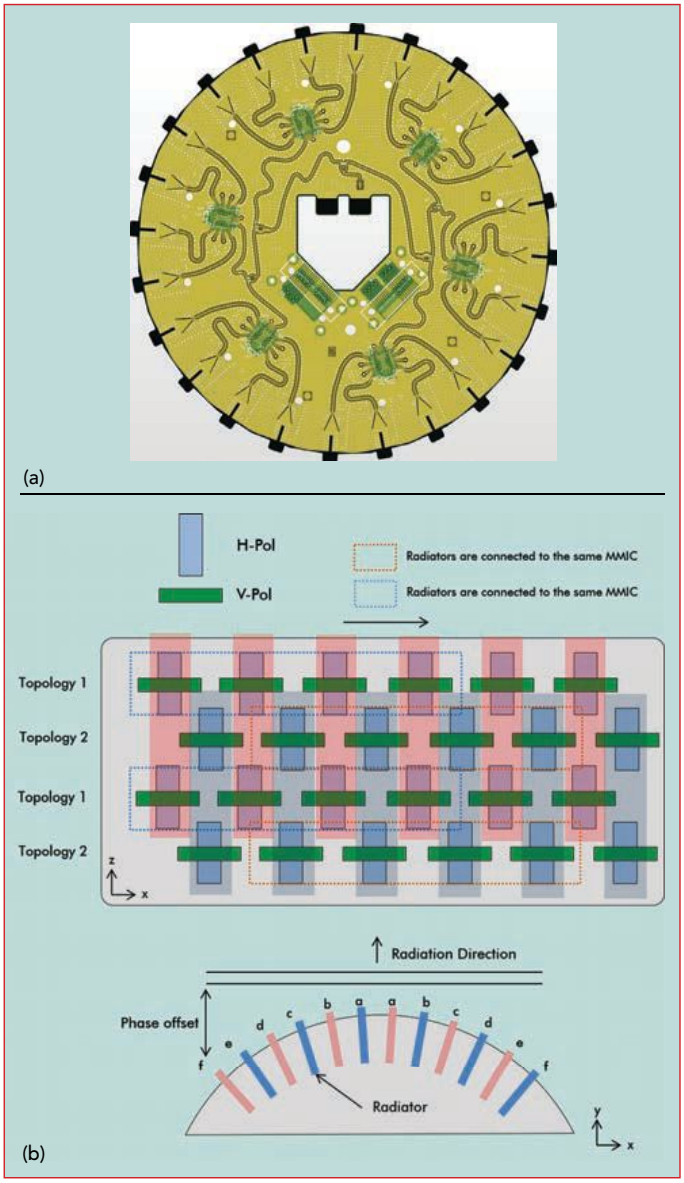

Fig. 3 (a) Antenna array PCB bottom side. (b) Antenna array beam configuration.

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specific configuration of the antenna module allows for four beams to be individually configured and scanned in the vertical plane at the same time. The only limitation is that the beams cannot overlap.

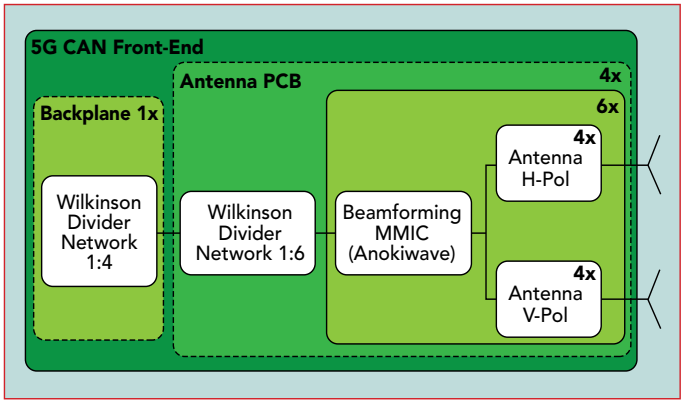

Fig. 4 Building blocks of the 5G CAN front-end.

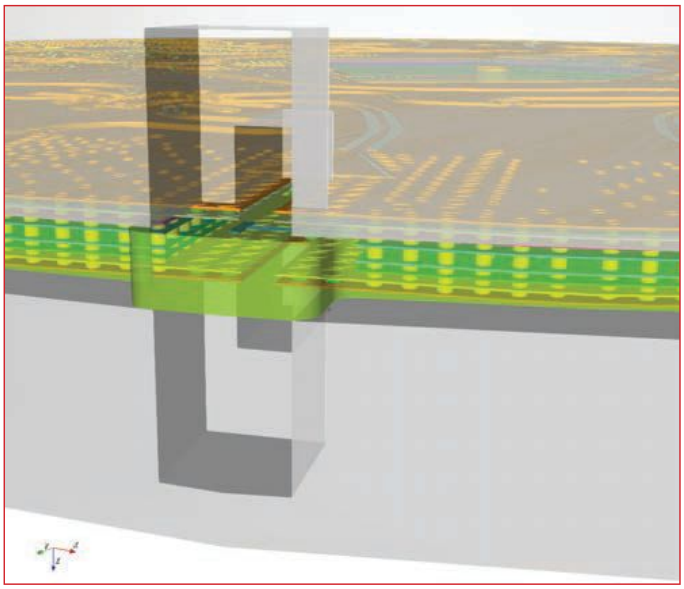

Fig. 5 Single radiator concept.

Single Antenna Radiator Design

This section describes the design of the antenna module in detail. The different building blocks are shown in ***Figure 4***. The vertically polarized antenna is realized as a substrate-integrated waveguide (SIW) antenna. The horizontally polarized antenna is a partially filled waveguide built into the milled metal plates placed on the top and bottom of the PCB. ***Figure 5*** shows a single radiator in detail. Both polarizations are integrated into one aperture. Due to the 90-degree orthogonal arrangement, the coupling between both polarizations can be kept below -28 dB in the operating frequency range.

The vertically polarized antenna and the horizontally polarized antenna are fed with a microstrip line and with a stripline, respectively. To minimize the coupling between the polarizations and in the feeding lines, these two feeding lines are routed in different layers. The antenna matching and decoupling performance, including the feeding network to the chip, are shown in ***Figure 6 (a)*** for the air mode and in ***Figure 6 (b)*** for the SIW mode.

All vertically polarized antenna elements show broadband matching (solid lines) of more than 10 dB for a frequency range from 23 to 29.5 GHz. Isolation to all other IC ports (dashed lines) is greater than 26 dB from 24 to 29.5 GHz. Similarly, all horizontally polarized antenna elements show broadband matching (solid lines) of more than 8 dB for a frequency range from 23 to 29.5 GHz and greater than 13 dB from 24 to 29 GHz. Isolation to all other IC ports (dashed lines) is greater than 23 dB from 23 to 29.5 GHz.

Distribution Network

The beamforming IC allows the phase and amplitude of each radiator to be manipulated with 6-bit resolution. This results in a resolution of 5.625 degrees for the phase value and 32 steps for the amplitude. The signals of all the beamforming ICs on one PCB are summed with a Wilkinson divider network. To keep the coupling low, the signal for the vertical polarization is routed on the top layer, while the signals for the horizontal polarization are routed on the bottom layer of the PCB. Both signals are routed on microstrip lines. Since the six beamforming signals cannot be equally routed in a Wilkinson divider network, an

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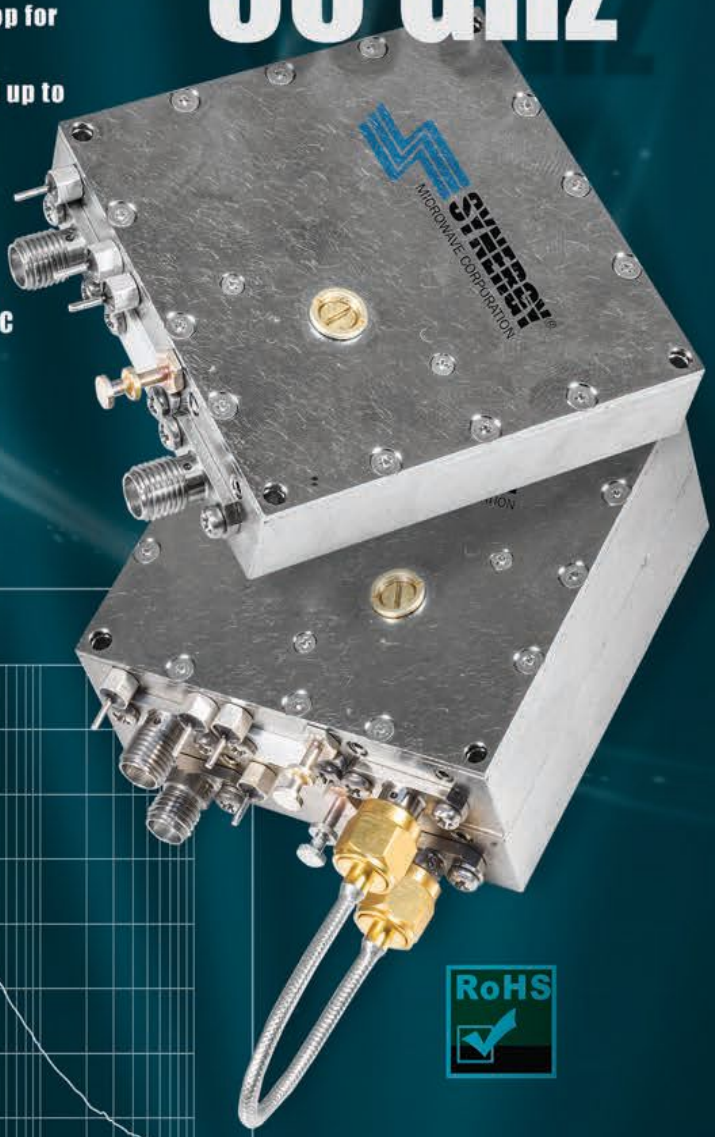

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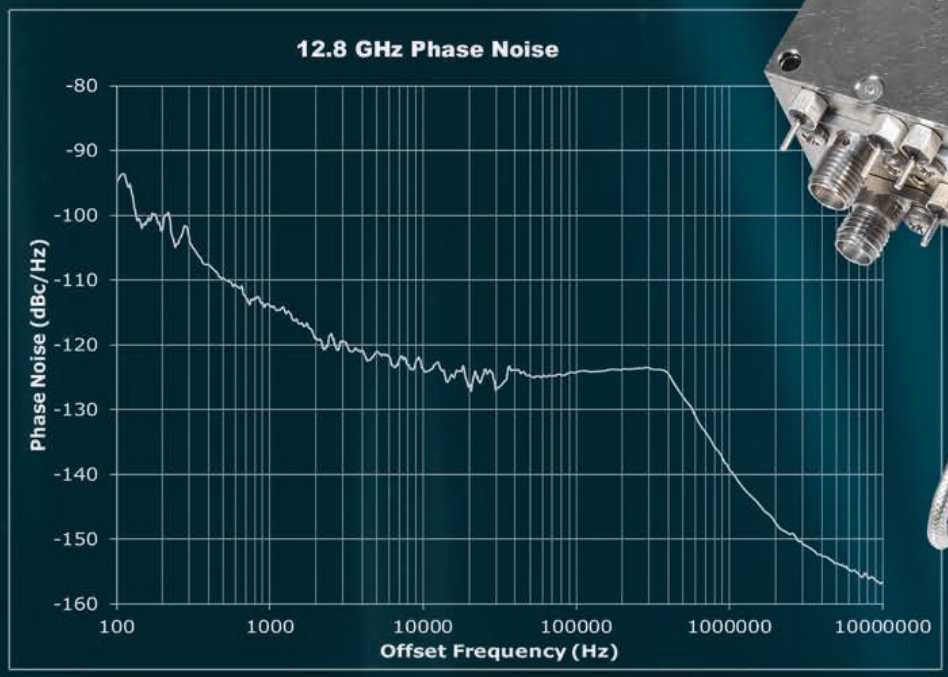

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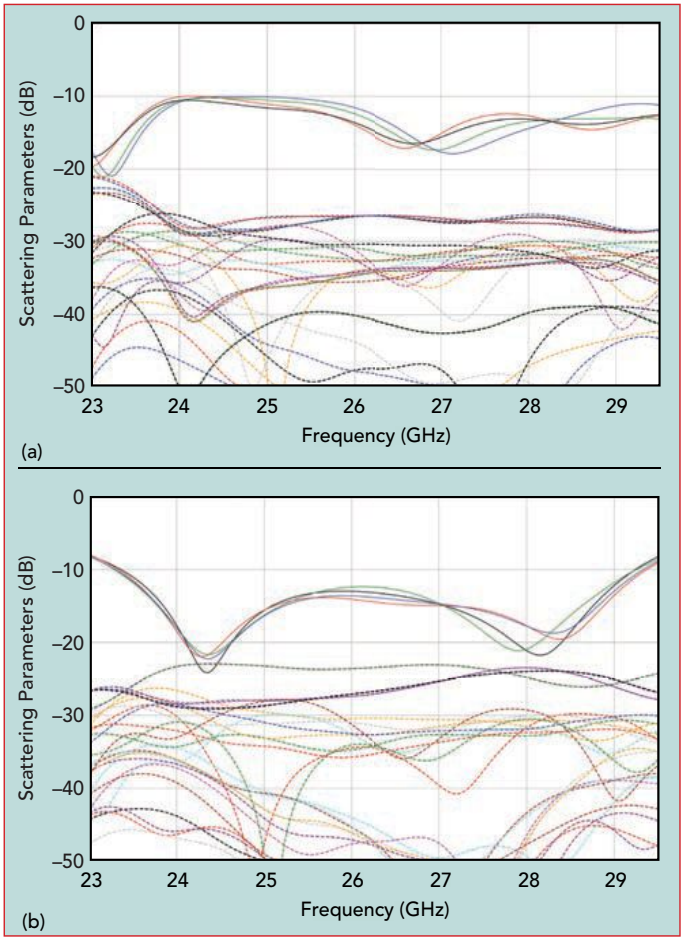
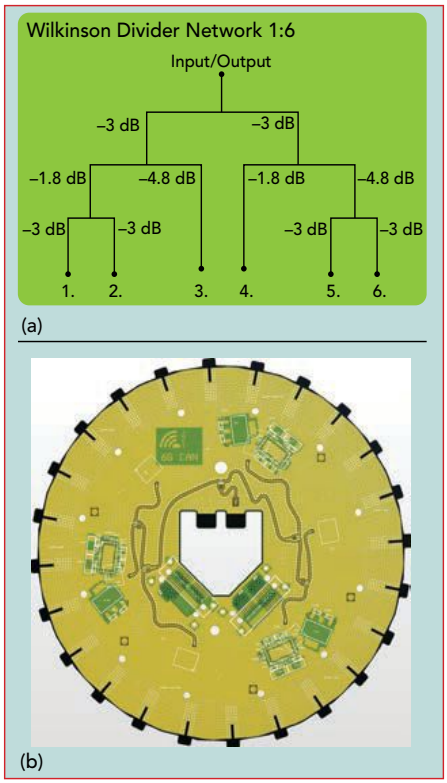
asymmetric Wilkinson divider is used to achieve equal amplitude distribution of all feeding signals. ***Figure 7 (a)*** shows a sketch of the Wilkinson divider network and its distribution function. ***Figure 7 (b)*** shows the network routing of a vertically polarized SIW signal on the PCB. ***Figure 8 (a)*** shows the simulated results for the magnitude of the scattering parameters for the Wilkinson divider. ***Figure 8 (b)*** shows the simulated phase values for the Wilkinson divider. All the sum networks have similar routings, making the line lengths approximately the same to avoid amplitude or phase variation over frequency. The phase values for each path show a maximum deviation of ± 2.5 degrees and the amplitude variation is about ± 0.4 dB. The input reflection coefficient is below -13 dB over the entire operating frequency range.



▲ Fig. 6 **(a) Vertically polarized SIW antenna performance showing matching (solid lines) and isolation (dashed lines) at the IC ports. Horizontally polarized air waveguide antenna showing matching (solid lines) and isolation (dashed lines) at the IC ports (b).**

On the input/output of the combing network, the microstrip signals are routed on a SIW transmission line to a backplane PCB where they are transformed to a stripline mode. The stripline path for each polarization is routed in different layers on the backplane PCB. The backplane PCB uses the same eight-layer stackup as the antenna PCBs. A Wilkinson divider network is used to sum the signals on the backplane PCB. A four-to-one combining network designed for equal distribution can be used in this case. The combined signals are routed to the short edge of the backplane PCB. The stripline transmission lines on the backplane PCB are routed to a 2.92 mm coaxial connector that is used to feed the



▲ Fig. 7 **(a) Wilkinson divider network with distribution function. (b) Top-side antenna PCB including routed SIW network for vertical polarization.**

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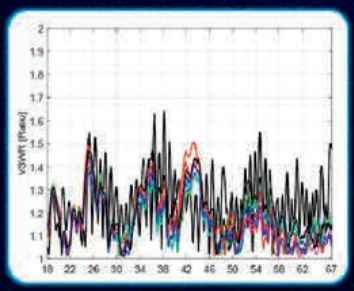

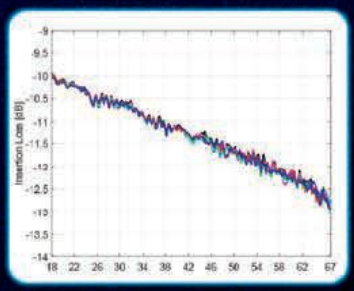

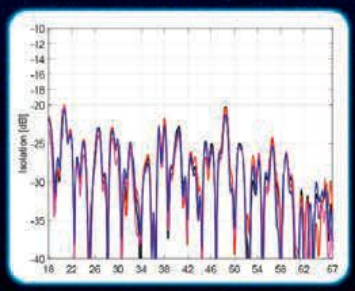

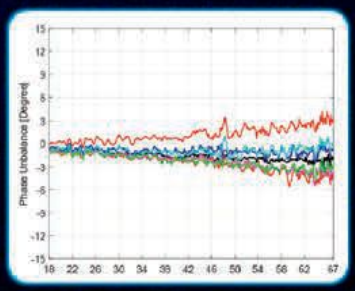

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5G CAN module.

The complete RF design of the module was done with the 3D EM simulation software EMPIRE-XPU.[2] All the individual parts (antenna, PCB divider networks, RF transitions, backplane PCB, etc.) were designed independently as a first step. Next, integrations of these parts were simulated. As an example, the Anokiwave beamforming chip was simulated including eight corresponding antenna elements along with the antenna feed network. Finally, the complete module, including all PCBs with components and antennas was simulated to ensure that the module met the required RF performance. The complete module simulation was completed in a few hours thanks to the efficient simulation technique and simulation software.

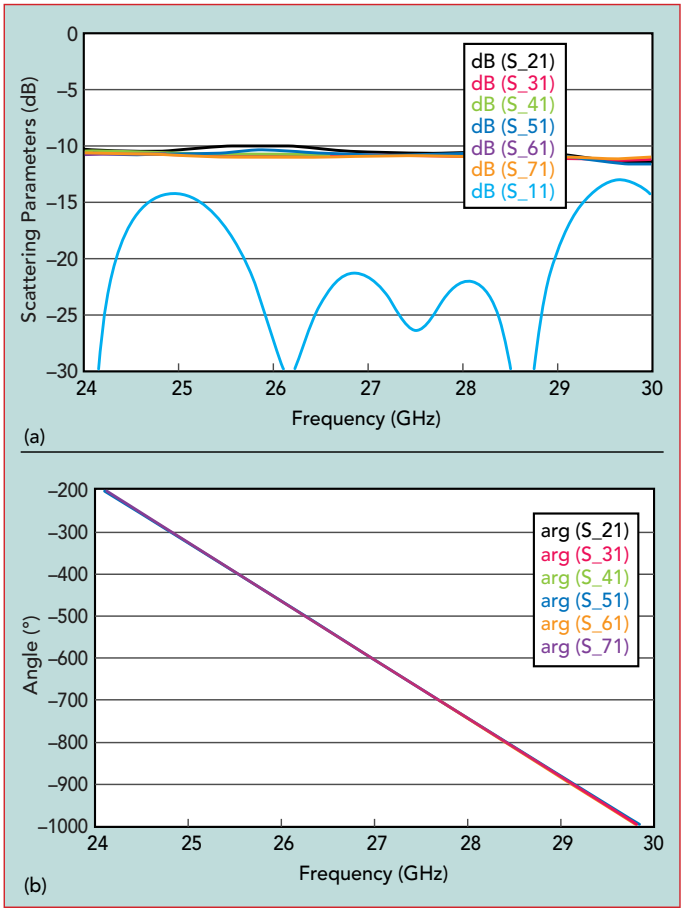

Fig. 8 (a) Simulated Wilkinson divider network scattering parameter magnitude for vertical polarization (SIW). (b) Simulated Wilkinson divider network scattering parameter phase angle for vertical polarization (SIW).

SIMULATION RESULTS

The module achieves excellent performance for the whole frequency range from 24.25 to 29.5 GHz. The omnidirectional coverage in azimuth is achieved with 96 antenna beams, 48 beams for vertical and 48 beams for horizontal polarization. Each beam is created by a 4 × 6 antenna element tile that uses four PCBs and six antenna elements per PCB. The resulting 3 dB beamwidth is about 8.5 degrees in azimuth. ***Figure 9 (a)*** shows the simulated radiation characteristic for the horizontally polarized array (air

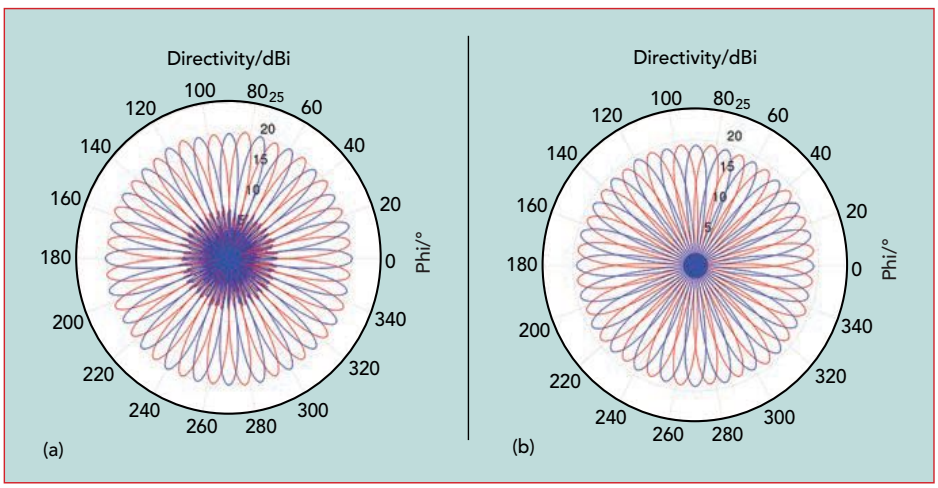

Fig. 9 (a) Azimuth scan performance for horizontal polarization at 27 GHz. (b) Azimuth scan performance for vertical polarization at 27 GHz.

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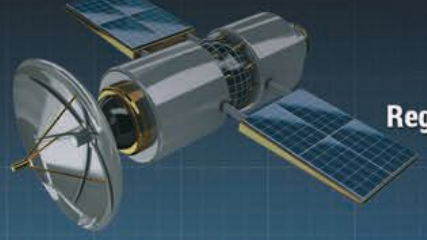

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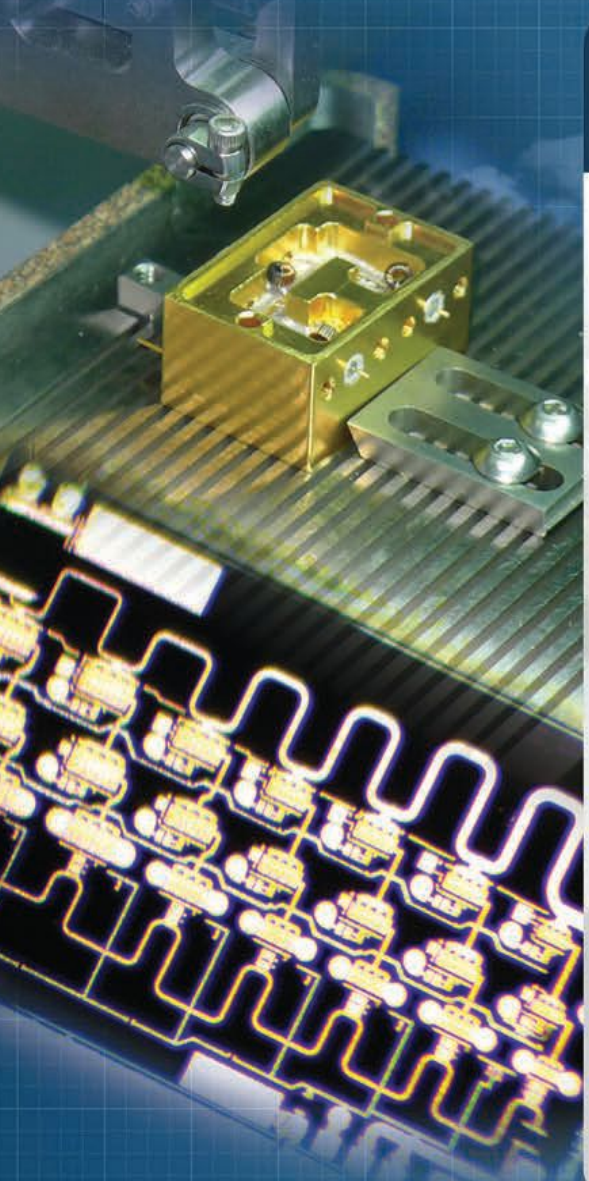

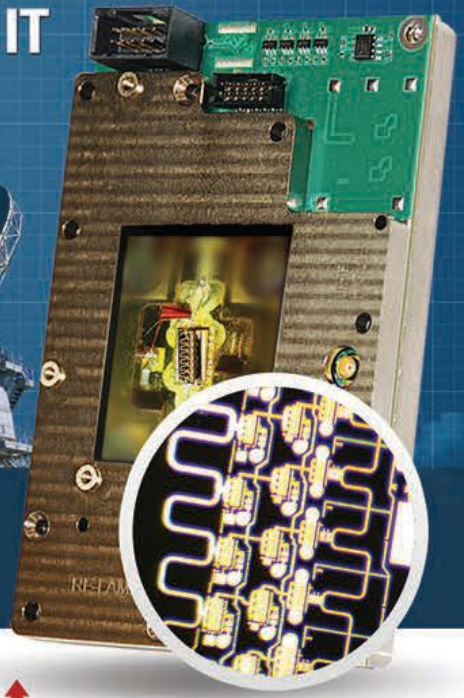

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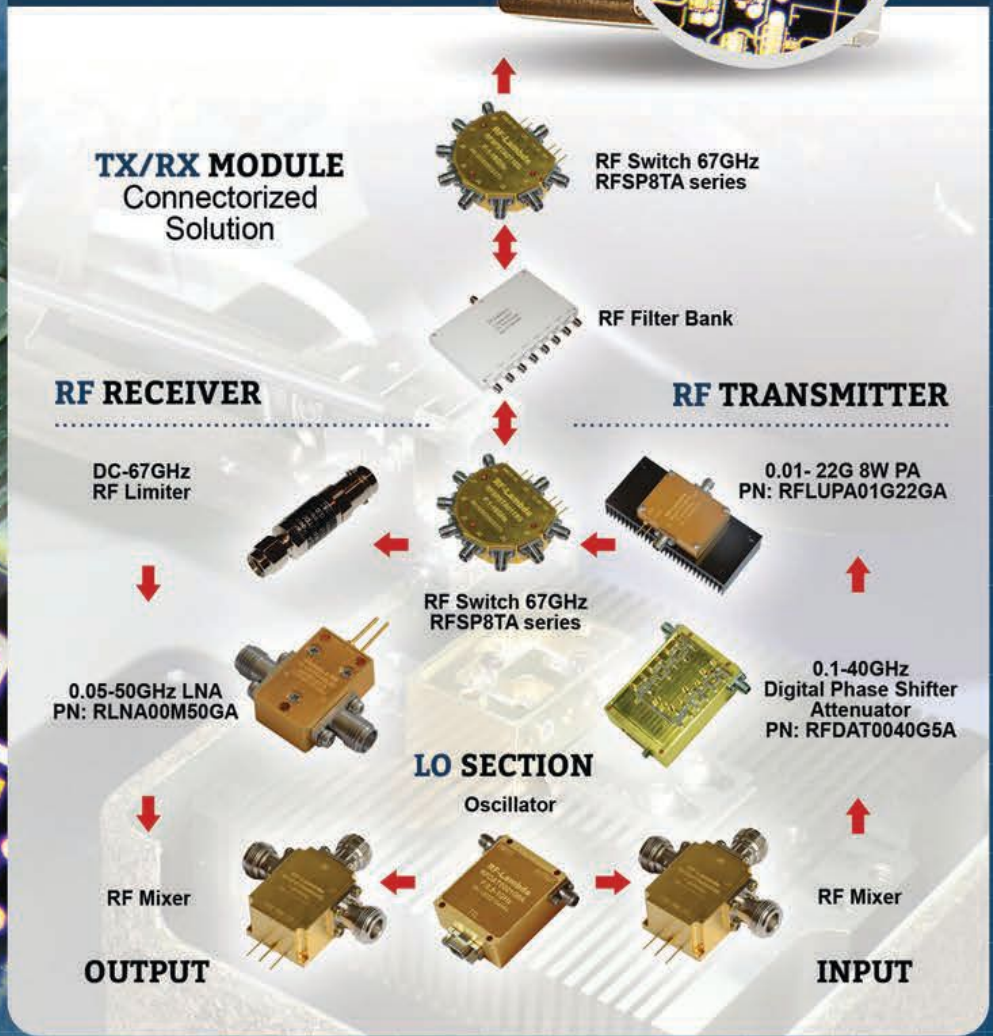

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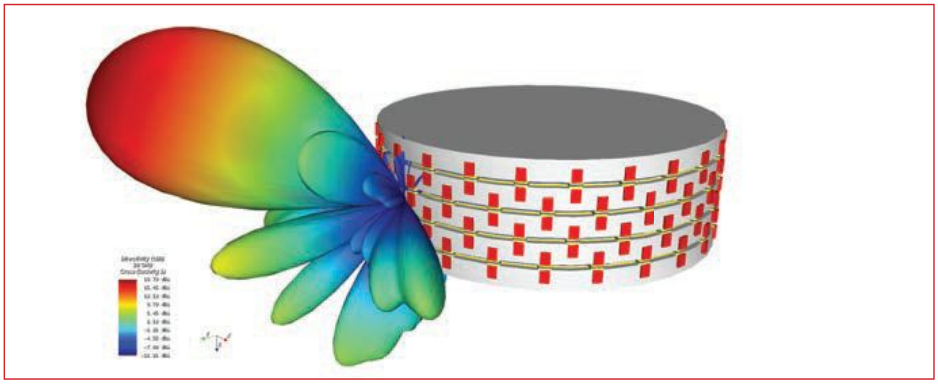

Fig. 10 The 3D radiation pattern for an elevation scan for vertical polarization at 28 GHz.

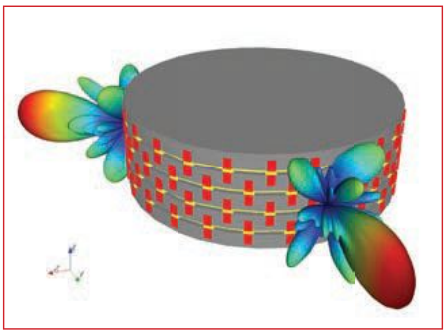

Fig. 11 3D radiation characteristics with two simultaneous antenna beams.

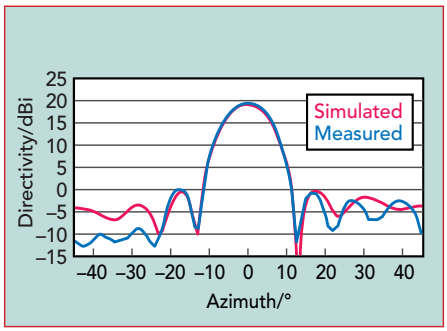

Fig. 12 Simulated versus measured directivity for a vertically polarized beam in the azimuth plane.

waveguide) and ***Figure 9 (b)*** shows the same results for the vertically polarized array (SIW) at 27 GHz. The directivity achieved is about 19 dBi which results in an EIRP of about 50 dBm at P1dB.

The scanning performance in elevation is about ± 30 degrees with less than 3 dB scan loss. ***Figure 10*** shows the simulated 3D radiation characteristic for one beam that is scanned in the vertical direction.

Up to four simultaneous beams are supported, each set up from a quarter of the circular module. ***Figure 11*** shows the simulated 3D radiation characteristic for two simultaneous vertically polarized beams at 26 GHz.

MEASURED RESULTS

The module described in this article is intended for use as a development platform for 5G and 6G systems. It is available as an evaluation kit for 5G and 6G research teams, along with customers who are interested in other applications. ***Figure 12*** shows the simulated versus measured directivity results for a vertically polarized beam in the azimuth plane. The result shows excellent agreement for scan angles less than ± 20 degrees. The deviation at larger scan angles appears to be related to calibration. To minimize this issue, IMST is still working on the best calibration method for the 5G module and the expectation is that the agreement with the simulation will improve as the calibration method is refined. More data will be available as the calibration method evolves.

CONCLUSION

The 5G CAN front-end module is a compact, flexible and scalable phased array front-end that can be used in different 5G and 6G scenarios. The module described operates over a frequency range from 24.25 to 29.5 GHz, covering the n258, n257 and n261 3GPP bands. The module provides omnidirectional coverage in azimuth and ± 30 degrees scanning in elevation. The design can be easily scaled in diameter to increase the EIRP as well as the number of beams. Upscaling the frequency to 39 GHz to cover 5G mmWave band n260 is also possible. ■

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1. W. Simon, D. Schäfer, S. Bruni, M.A. Campo, O. Litschke, "Highly Integrated Ka-Band Front-end Module for SATCOM and 5G," *2019 IEEE APMC*.
2. A. Wien, "EMPIRE XPU Reference Manual," assessed June 2023, Web: https://empire.de/resources/manual/.

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Beamforming ICs Help Close the mmWave 5G Business Case

Anokiwave
San Diego, Calif.

As global wireless data traffic exponentially grows at an annual rate of more than 25 percent, service providers will require mmWave bands to support the emerging "Mobility without Boundaries" trend. While mmWave 5G offers immense potential in terms of bandwidth, user capacity and quality of service, developing a commercially realizable mmWave ecosystem has multiple challenges for cellular service providers. These challenges include CAPEX and OPEX costs, quality of service, along with availability and scalability to surgically address available markets. Using many of the mmWave 5G radio and customer premises equipment (CPE) solutions in the market today, business case does not always close, leading many to believe it is not the right solution to satisfy the immense demand for data. With its Gen 4 IC technology, Anokiwave is changing that perception.

To address the gap in performance at mmWave, Anokiwave recently released its fourth generation of mmWave 5G silicon beamformer ICs (BFICs). The AWMF-0221 and the AWMF-0236 set the benchmark for the industry's highest PAE and linear output power silicon ICs across all 5G bands. As shown in ***Figure 1***, each IC offers a scalable 4 × 2 quad-channel architecture with dual polarization and independent gain and phase control for each channel.

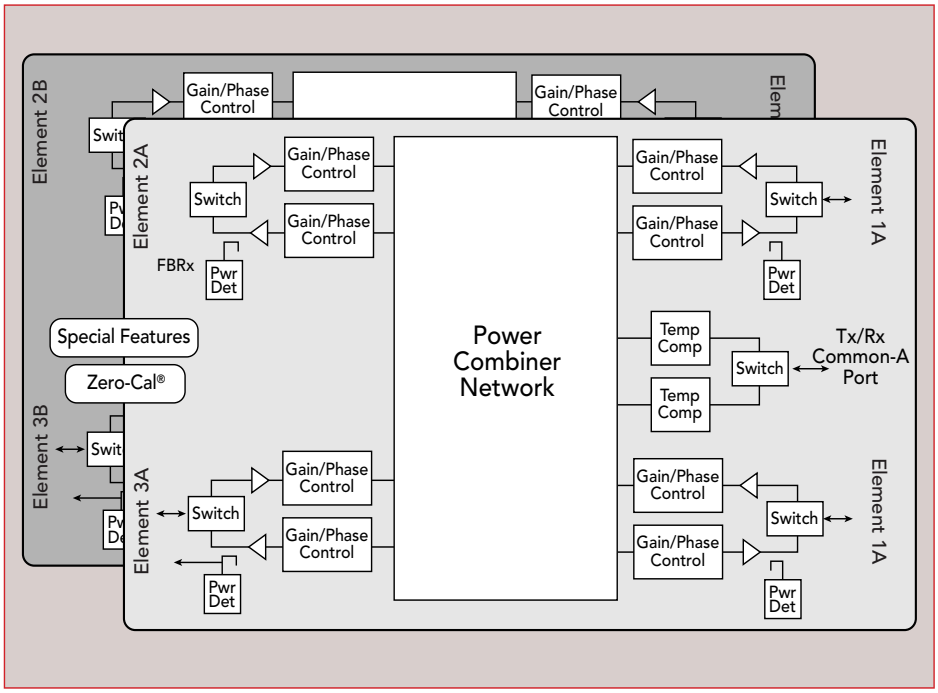


Fig. 1 **BFIC block diagram.**

Building upon multiple generations of released and field-deployed mmWave silicon IC solutions, the new generation of ICs set the groundwork to make mmWave 5G a commercial and technical reality at a mass scale. Anokiwave's AWMF-0221 and AWMF-0236 products redefine innovation and provide an unmatched combination of performance, functions, features and commercial benefits to enable the 5G use case:

Wideband performance: Both ICs provide ±0.5 dB gain flatness across the entire band.

- AWMF-0221: 24.5 to 29.5 GHz covering n258, n261 and n257
- AWMF-0236: 37 to 43.5 GHz covering n260 and n259.

Both ICs work over the entire frequency band without additional tuning or front-end matching. This performance enables OEMs to develop a single radio board to serve multiple operators, minimizing the number of radio SKUs.

Industry's highest PAE percentage and linear output power beamformers: Anokiwave continues to push the limit of output power and PAE in silicon ICs. The combination of linear output power and efficiency reduces the total radio size, the number of silicon ICs needed to achieve the intended performance and the overall DC power consumption of the radio. At a system level and compared to other 5G mmWave solutions, the new ICs enable:

- >4X more area covered per cell site
- >3X additional users for a given data rate
- >70% lower cost by increased radio coverage area

Lowest noise figure: Low noise figure in silicon, especially in mmWave frequencies, is challenging. These BFICs offer the industry's lowest coherent noise figure, providing OEMs with up to 10 dB better EIS in the infrastructure, without increasing antenna size. This allows operators to increase the coverage area and the number of subscribers with the same number of sites.

Automatic temperature compensation: In addition to the RF functionality, AWMF-0221 and

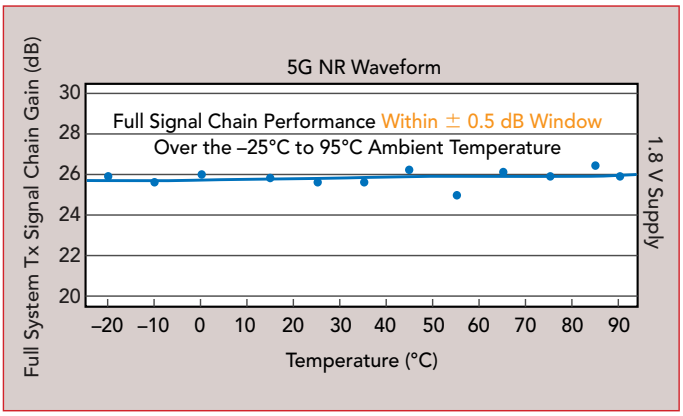


Fig. 2 **Tx signal chain performance.**

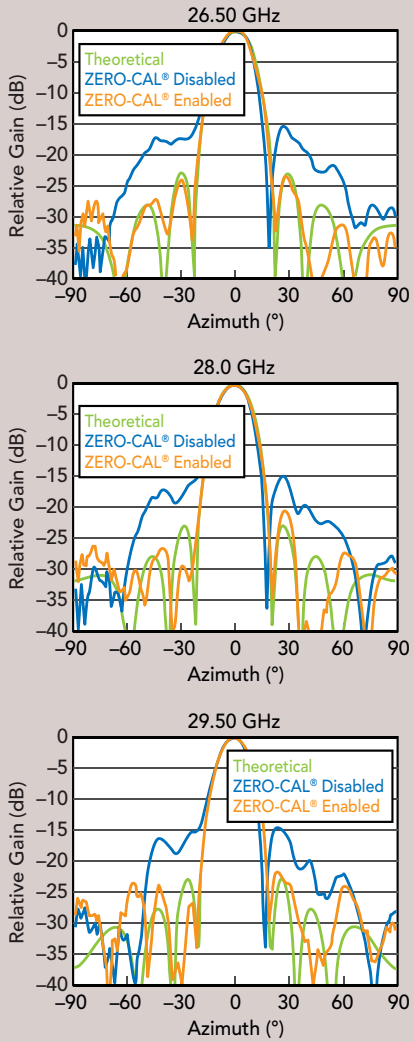
AWMF-0236 feature a uniquely implemented and digitally controlled fully automatic temperature compensation (ATC) function. This built-in ATC ensures stable performance across the entire temperature range with no user input required. The ATC performance has been proven across the entire mmWave signal chain and in radios, providing exceptionally flat gain, error vector magnitude (EVM) and adjacent leakage power ratio performance. ***Figure 2*** shows the overall signal chain performance of the AWMF-0221, IF up-/down-converters and an LO synthesizer maintaining ± 0.5 dB gain flatness across the entire temperature and frequency range, without user feedback.

Ready to support future needs: The new ICs are designed to support mmWave 5G NR and other private wireless network requirements well beyond today's needs. The ICs have been in production arrays meeting or exceeding performance and cost goals supporting 1 percent EVM performance, instantaneous bandwidth up to 1.4 GHz and higher order modulation schemes up to 1024-QAM. These ICs are versatile and scalable enough to address 5G use cases like gNodeB macro base stations, small cells, integrated access and backhaul nodes and CPEs. Complete with future-ready RF performance, these ICs target current and future applications in the 5G ecosystem.

Zero-Cal®: All Anokiwave beamformers feature the patented Zero-Cal® feature that ensures every IC has the same channel-to-channel and IC-to-IC performance. This eliminates the need for array-level calibration to account for IC-level inconsistencies. This feature is commonly used in field-deployed radios and is proven over large production volumes. ***Figure 3*** shows a mmWave 5G antenna array measurement with and without Zero-Cal® enabled. Enabling Zero-Cal® allows the array to achieve near-ideal performance without additional calibrations. Users enabling Zero-Cal® in production see up to 30 percent line yield improvement with this feature.

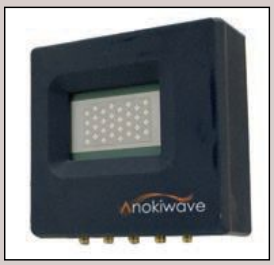
Proven antenna performance: Anokiwave prides itself on providing ICs that successfully work in mmWave active antennas that are used in volume in field-de-

ployed radios. Anokiwave BFICs are designed to perform at an antenna level, as evidenced by multiple antennas in both the 24/26/28 GHz and the 37/39 GHz frequency ranges that Anokiwave and its custom-



Anokiwave Zero-Cal® Technology Ensures:

- Each IC to Self-Align to Prescribed Performance Levels
- High Device-to-Device and Channel-to-Channel



▲ Fig. 3 **Measured results showing sidelobe level improvement with Zero-Cal®.**

ers have successfully developed, FCC certified and deployed into the field. ***Figure 4*** shows antenna patterns at 39 GHz.

These results are revolutionizing the market, making mmWave 5G technically viable as well as commercially viable at scale. The excitement around the mmWave market emergence is something we see infrequently in our careers. Anokiwave saw this change coming years ago and with continued year-over-year innovations, we have enabled each phase of this new technology. Now, with these latest beamformer ICs, they have truly taken the mmWave 5G business case discussion from a typical small-scale deployment to an accessible technology for mass-scale deployment that closes the mmWave 5G business case.

VENDORVIEW

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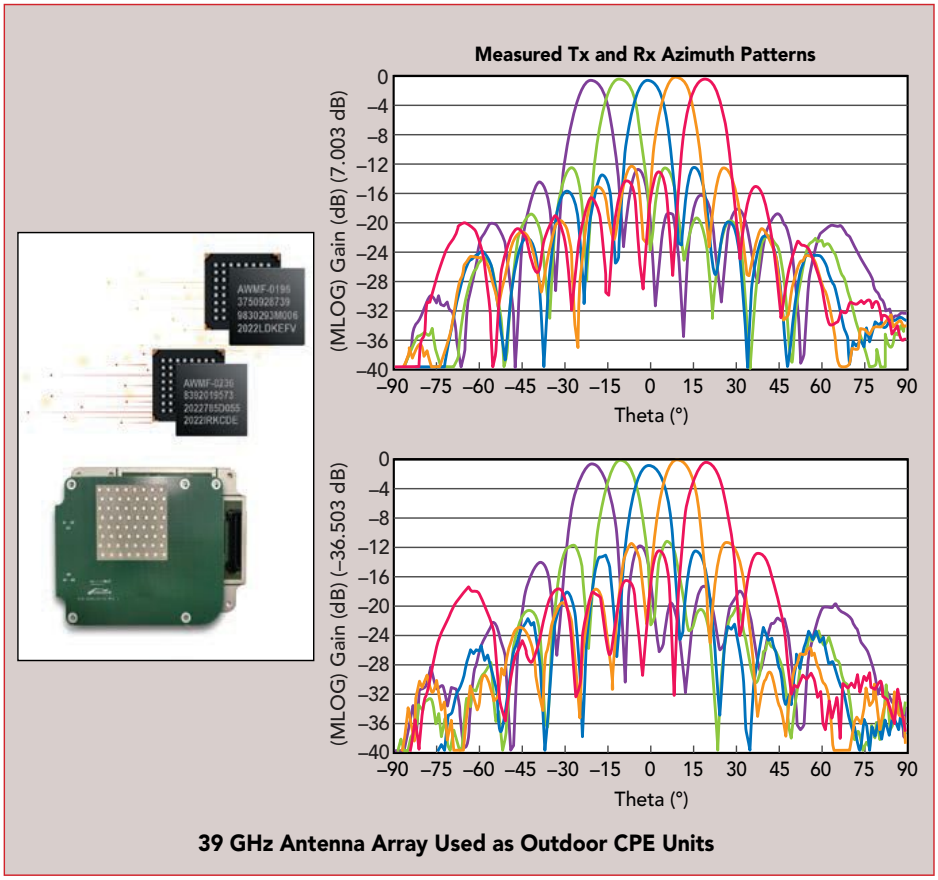

Fig. 4 Measured antenna patterns with Anokiwave BFICs.

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Cassini Is Ready for mmWave Device Production, Are You?

The quest for more safety features, AI content, autonomy and higher data rates will propel next-generation automobiles and communications systems to mmWave frequencies. Manufacturing and production at these frequencies bring new test engineering challenges as device placement, socket design, handler control and package layout can impact yield and performance. This creates a need for higher precision, lab-grade vector measurements to assess performance capabilities on the production floor. Test platforms must be able to measure high speed S-parameters at mmWave frequencies with sufficient precision to ensure conformance to all the system requirements.

A production ATE system capable of making precision measurements at mmWave frequencies is only the first step. A company that can implement production-proven solutions at mmWave frequencies with the depth of knowledge to assist with issues that may arise with cutting-edge technology is also needed. Roos Instruments has a heritage in this area, along with several patents for innovative mmWave testing technology. The patents cover blind mate interfaces, signal switching and routing with dense waveguides used for measuring the performance of mmWave devices.

The Cassini ATE platform gives your team the confidence to produce high-quality, high-yield mmWave devices to cost-effectively provide solutions to system designers. Cassini offers standard mmWave precision measurement test instrument modules up to 110 GHz. The Cassini ATE uses an RF system integration layer in the device interface with 16 universal instrument slots that accommodate interchangeable interface blocks and interconnects. This allows the test system's architecture to be dynamically configured for each device application. Roos Instruments' experienced staff are the partner you need to successfully navigate today's mmWave manufacturing environment.

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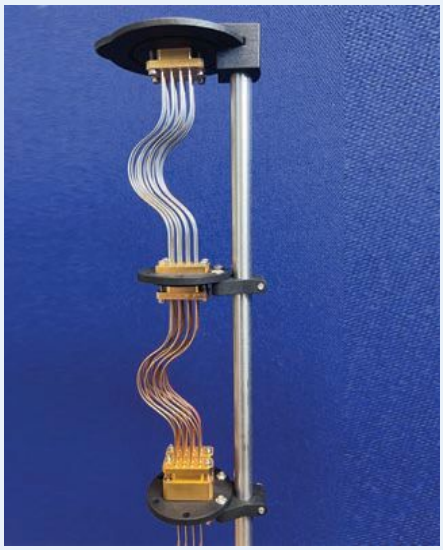

High Density Microwave Interconnects for Quantum Computers

CryoCoax, an Intelliconnect brand, has developed high density multiway connectors based around the SMPM interface. This interface allows many more coaxial lines in a given space along with simplifying the installation and customization within a dilution refrigerator. The typical spacing using SMA connectors is limited to approximately 16 mm, but these high density connectors are designed with a pitch of 4.75 mm. CryoCoax can supply top-to-bottom assemblies, known as "coax sticks," which can be fully customized with attenuator blocks and a full complement of cable types and materials. These assemblies can provide connections from room temperature, through all the cooling stages down to the low temperature level. These interconnects undergo RF testing at room temperature and test data can be provided for DC resistance, return loss and insertion loss up to 40 GHz, even though most applications operate at much lower frequencies. The connector components are machined from high purity copper and beryllium copper and are gold-plated to provide the best thermal conductivity. If required, non-magnetic versions can also be specified. The connectors are compatible with .047 in. (1.19 mm) size coax and they are available in semi-rigid, flexible or conformable versions. Semi-rigid cables are available in niobium-titanium, stainless steel, copper, cupronickel and beryllium copper as well as combinations of these with silver-plated conductors. These options provide the user with a large choice in terms of thermal conductivity and attenuation. CryoCoax also develops solderless connections for high density connectors as well as the traditional SMA, 2.92 and SMP connectors.

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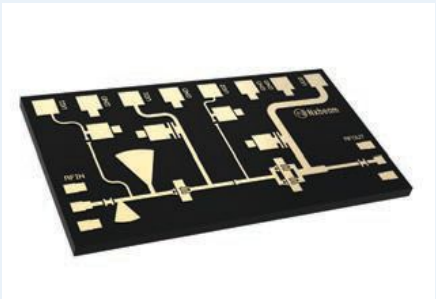

1 Watt GaN Power Amplifier MMIC Operates in E-Band

Nxbeam expands its mmWave MMIC portfolio with the introduction of a GaN E-Band power amplifier MMIC. The NPA7000-DE operates from 65 to 76 GHz and provides an average saturated output power of 1 W, average power-added efficiency of 28 percent and an average linear gain of 13 dB. The chip dimensions are 1.575 x 0.875 x 0.050 mm.

The output power level of this MMIC makes it ideal for point-to-point E-Band communication links. The small size of this MMIC simplifies power combining schemes, which can greatly increase the range of E-Band point-to-point links. The design consists of two amplifier stages that are independently controlled, allowing the bias and performance to be tailored to end-user specifications. The RF input and RF output are matched to 50 Ω with DC-blocking capacitors for easy system integration. Bond pads and backside metallization are Au-based for compatibility with eutectic die attachment methods.

Since 2018, Nxbeam has been developing proprietary mmWave semiconductor MMICs, chipsets and radio products to power the next generation of satellite and terrestrial communication networks.

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IEEE MICROWAVE THEORY & TECHNOLOGY SOCIETY

IMS2024 (www.ims-ieee.org) is the centerpiece of Microwave Week 2024, which includes the RFIC Symposium (www.rfic-ieee.org) and the ARFTG Microwave Measurement Conference (www.arftg.org).

Microwave Week is the world's largest gathering and industry exhibition for MHz through THz professionals. IMS2024 will feature a far-reaching Technical Program focused on **Capitalizing Across the Spectrum** — the electromagnetic spectrum from RF-to-optical, the application spectrum from commercial wireless to scientific sensing, and the human spectrum encompassing diversity, equity, and inclusion. Microwave Week provides a wide variety of technical and social activities for attendees and exhibitors. In addition to the diverse choices in technical sessions, attendees can explore interactive forums, plenary and panel sessions, workshops and technical lectures, application seminars, and also participate in paper contests for Students, Industry, and Young Professionals.

The location of IMS2024 is our nation's capital, Washington D.C. The Walter E. Washington Convention Center is located in downtown Washington D.C., near Chinatown and the city's hip Shaw neighborhood which is known for its lively social and restaurant scene. Washington is home to many famous landmarks and historical sites such as the White House, the National Mall with its famous monuments and memorials, the Smithsonian Institution — the world's largest museum complex, the National Zoo, and the Kennedy Center for the Performing Arts.

Washington D.C. is also home to many agencies and institutions that oversee use of the electromagnetic spectrum. One of our conference themes is to highlight advances in spectrum access and use, including coexistence, sustainability and emerging future-G systems. Other themes will feature the critical role of the RF-to-THz spectrum for aerospace and transportation, national security, and radar. The central role that equity, inclusion and diversity play across the spectrum of our community will be highlighted throughout the week.

WASHINGTON DC 2024
CAPITALIZING ACROSS THE SPECTRUM

Important Dates

15 September 2023 (Friday)
PROPOSAL SUBMISSION DEADLINE
(workshops, technical lectures, focus and special sessions, panel and rump sessions)

5 December 2023 (Tuesday)
PAPER SUBMISSION DEADLINE

1 February 2024 (Thursday)
PAPER DISPOSITION

6 March 2024 (Wednesday)
FINAL MANUSCRIPT SUBMISSION DEADLINE
Manuscript and copyright of accepted papers

16-21 June 2024
MICROWAVE WEEK
IMS2024, RFIC 2024, ARFTG, and Exhibition

IMS2024 Conference Themes

IMS2024 will feature a variety of important thematic areas that highlight the symposium's focus on "capitalizing across the spectrum." In addition to showcasing a broad spectrum of engaging technical topics, IMS2024 will celebrate the diversity of contributions, talents, and accomplishments across our society's "human spectrum" throughout the week. Moreover, the major technical themes of the conference will emphasize the role our host city of Washington D.C. has played in supporting the use and management of the RF-to-THz spectrum, including:

Systems & Applications

The development of RF, microwave, mm-wave and THz systems continues to expand in several areas, with many application examples. This broad theme encompasses design from device and module through to the overall system and applications. Particular areas of focus of IMS2024 will be:

- Radar Systems and Phased Arrays,
- Communications, including 6-and Future-G developments,
- RF and microwave system-on-chip integration,
- Applications of High-Power Microwave Systems

Aerospace and Security

This theme includes use of the electromagnetic spectrum for defense and security as well as air and space-based applications, including secure communications, navigation, remote sensing, design for reliability, radiation hardness, LEO Sat systems, and CubeSats.

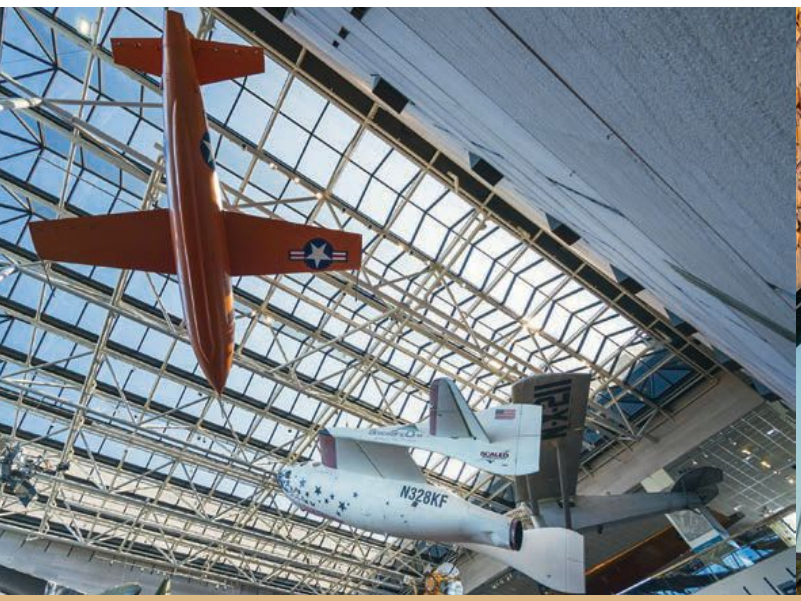
Spectrum CubeSats Coexistence and Sustainability

Access to the RF-to-THz spectrum has become paramount with the rapid advance of wireless technology and applications. Topics in this area include techniques and technologies for spectrum sharing and coexistence between active and passive users, interference mitigation, spectrum monitoring and metrology, energy efficiency and sustainability.

Emerging Technologies and Directions

Innovative and new contributions in AI/ML, quantum technologies, materials, terahertz systems and technologies that enhance security and enable spectrum access across our society.

These technical themes will be aligned with different days of the conference, and will comprise special Focused Technical Paper Sessions, Panel Sessions, Invited Speakers, and Workshops.



IMS2024 ExCom and Technical Program Committee

ExCom (Executive Committee)

Scott Barker, *General Co-Chair*
Sanjay Raman, *General Co-Chair*
Dalma Novak, *TPC Co-Chair*
Bobby Weikle, *TPC Co-Chair*
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Ryan Baker, *MP3 Co-Chair*
Sherry Hess, *MP3 Co-Chair*
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Mark Rosker, *Plenary Session Chair*
Danilo Manstretta, *RFIC Conference General Chair*
Dominique Schreurs, *ARFTG Conference General Co-Chair*
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Ivan Bazzy, *Exhibition Management*
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TPC (Technical Program Committee)

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Mike Hamilton, *Workshops Co-Chair*
Alirio Boaventura, *Workshops Co-Chair*
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Theodore Reck, *Tutorials/Primers/Pre-Conference Chair*
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Thomas Clark, *Focus/Special Sessions Co-Chair*
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Ryan Walsh, *Industry Workshops Co-Chair*
TBD, *TMTT Special Issue Co-Editor*
TBD, *TMTT Special Issue Co-Editor*

To view the full IMS2024 Steering Committee list visit ims-ieee.org.

Technical Paper Submission

Authors are invited to submit technical papers describing original work and/or advanced practices on MHz through THz theory and technology. A double-blind review process will be used ensuring anonymity for both authors and reviewers. The Symposium proceedings will be archived electronically and submitted to IEEE Xplore.

Submission Instructions

- All submissions must be in English.
- Submissions must be a maximum of 3 pages plus one additional page for references, be compliant with the IEEE conference template, which can be downloaded from the IMS2024 website, and be compliant with double-blind requirements.
- The submission must be in PDF format and cannot exceed 4 MB in size.
- Authors must upload their paper submission by midnight Hawaii time on 6 December 2023. Late submissions will not be considered.

Paper Selection Criteria

All papers are reviewed by subject-matter expert sub-committees of the IMS2024 Technical Program Review Committee (TPRC). The selection ciriteria will be:

- **Originality:** Is the contribution unique and significant? Does it advance the state of the art of the technology and / or practices? Are proper references to previous work by the authors and others provided?
- **Quantitative content:** Does the paper give a comprehensive description of the work with adequate independent verification (measurements, if applicable, or otherwise independent simulated data) ?
- **Clarity:** Is the paper contribution and technical content presented clearly and in a logical manner? Are the English writing and accompanying figures clear and understandable?
- **Interest to MTT-S membership:** Will this paper interest the IMS audience and encourage discussion?

Technical areas: During the paper submission process, authors will choose a primary and two alternative technical areas (see the Technical Areas). The paper abstract should contain information that clearly reflects the choice of the area(s). Author-selected technical areas will be used to determine an appropriate committee for reviewing the paper, whereby the TPC co-chairs reserve the right to place papers in the most appropriate technical area. The technical areas are divided into five different categories that are used to organize the paper presentation schedule. It is permissible to choose primary and alternative technical areas that are in different categories.

Presentation Format: IMS offers three types of presentation formats. The authors' preference will be honored where possible, but the final decision on the presentation format is with the IMS2024 TPRC

1. Full-length papers report significant contributions, advancements, or applications in a formal (20 minute) presentation format with questions and answers (Q&A) at the end.
2. Short papers typically report specific refinements or improvements in the state of the art in a formal (10 minute) presentation format with Q&A at the end.
3. Interactive forum papers provide an opportunity for authors to present their theoretical and/or experimental developments and results in greater detail and in a more informal and conversational setting. An IMS2024 template will be provided.

Notification

Authors will be notified of the decision by 1 February 2024. For accepted papers, an electronic version of the final 3-4 page manuscript along with copyright assignment to the IEEE must be submitted by 6 March 2024.

The submission instructions will also be provided through emails and can be accessed through the IMS2024 website.

Clearances

It is the responsibility of the authors to acquire all required company and government clearances, prior to submission of their manuscript

IMS Paper Competitions

Competitions for the best Industry Paper, Advanced Practices Paper, Student Paper, and Early Career Paper will be held at the conference.

Student Paper Competition: Eligible students are encouraged to submit papers for the Student Paper Competition. These papers will be reviewed in the same manner as all other contributed papers. First, second, and third prizes will be awarded based on content and presentation. To be considered for an award, the student must be a full-time student during the time the work was performed and still be a student on the submission deadline, be the lead author, and personally present the paper at IMS. Eligibility details can be found on the IMS2024 webpage.

Industry Paper Competition: Authors from industry are encouraged to submit papers for the Industry Paper Competition. Papers will be evaluated using the same standards as all contributed papers, the work should highlight technical innovation or state-of-the-art performance. The prize will be awarded based on content. and the prize includes a free advertisement in Microwave Journal or IEEE Microwave Magazine, for the author's company.

Advanced Practice Paper: Any author who submits a paper on advanced practices may be entered into the Advanced Practice Paper Competition. A paper on advanced practices describes an innovative RF/microwave design integration technique, process enhancement, and/or combination thereof that results in significant improvements in performance and/or in time to production for RF/microwave components, subsystems, or systems. The prize will be awarded based on content.

Early Career Paper Competition: This novel competition is open to authors from industry, government agencies/laboratories as well post doctoral scholars with less than 10 years of professional experience, and who are not full-time students. These papers will be reviewed in the same manner as all other contributed papers, and the prize will be awarded based on content and presentation.

IEEE Transactions MTT Special Issue

Authors of all papers presented at IMS2024 can submit an expanded version of their paper to a special symposium issue of the *IEEE Transactions on Microwave Theory and Techniques*.

IEEE Microwave and Wireless Technology Letters

Up to 50 of the best papers at the Symposium will be published in a special issue of *IEEE Microwave and Wireless Technology Letters*, at the authors' discretion.

Details at www.ims-ieee.org

Technical Areas

EM Field, Design and Measurement Techniques

1. **Field analysis, guided waves, and computational EM** — Novel guiding, radiating, and electromagnetic structures; new analytical techniques and numerical methods for such structures, and new computational EM methods, incl. EM-coupled multiphysics modeling
2. **Circuit and system CAD** — Linear/nonlinear simulation and design optimization techniques; behavioral modeling; statistical approaches; surrogate modeling; space mapping; model order reduction; uncertainty quantification in simulations; stability analysis; non-EM related multiphysics simulations, design automation
3. **Instrumentation and measurement techniques** — Measurement techniques from microwave to THz for materials, linear and nonlinear devices, circuits, and systems; calibration and de-embedding techniques, measurement uncertainty, and over-the-air measurement methods and novel instrumentation

Passive Components and Packaging

4. **Planar passive components and circuits, excl. filters** — Novel planar transmission-line components; artificial transmission lines, metamaterial structures, and high-impedance surfaces; planar couplers, dividers/combiners, multiplexers, resonators, and lumped-element approaches
5. **Planar passive filters** — Planar passive filters, including lumped elements, theoretical filter and multiplexer synthesis methods
6. **Integrated passive circuits and filters** — Design and characterization of silicon integrated, III-V integrated passive components and filters, including IPDs
7. **Non-planar passive components, filters, and other circuits** — Transmission line components, resonators, filters and multiplexers based on dielectric, waveguide, coaxial, or other non-planar structures
8. **Tunable passive circuits and active filters** — Tunable and active filters, tunable phase shifters and couplers
9. **Microwave acoustic, ferrite, ferroelectric, phase-change, & MEMS components** —Surface and bulk acoustic wave devices including FBAR devices, bulk and thin-film ferrite components, ferroelectric-based devices, and phase change devices and components. RF microelectromechanical and micromachined components and subsystems
10. **Packaging, MCMs, and 3D manufacturing technologies** — Component and subsystem packaging, assembly methods, multi-chip modules, wafer stacking, 3Dcinterconnect, and integrated cooling; package characterization; novel processes related to inkjet printing, 3D printing, or other additive manufacturing techniques

Active Devices and Circuits

11. **Semiconductor device technologies and modeling** — RF to THz devices on III-V, silicon, and other emerging technologies, incl. 2D devices); MMIC and Si RFIC manufacturing, reliability, failure analysis, yield, and cost; linear and nonlinear device modeling (CAD, compact, physics-based, empirical) including characterization, parameter extraction, and validation
12. **HF/VHF/UHF circuits, technologies, and applications** — Advances in passive and active circuits (incl. PAs), components, and systems that operate in the HF, VHF, and UHF frequency ranges ranges (<1 GHz)
13. **Signal generation, modulators, frequency conversion** —CW and pulsed oscillators in silicon and III-V processes including VCOs, DROs, YTOs, PLOs, and frequency synthesizers, frequency conversion ICs in silicon and III-V processes, such as IQ modulators, mixers, frequency multipliers/ dividers
14. **Microwave and millimeter-wave low-noise amplifiers, variable-gain amplifiers, and receivers** — LNAs, VGAs, receivers, detectors, integrated radiometers, and low-noise circuit characterization, including cryogenic circuits
15. **Low-power (<10 W) amplifiers, below 30 GHz** — Advances in discrete and IC power amplifier devices and design techniques based on Si and III-V devices, demonstrating improved power, efficiency, and linearity for the microwave band (1-30 GHz)
16. **High-power (>=10 W) RF and microwave amplifiers, below 30 GHz** —Advances in discrete and IC power amplifier devices and design techniques based on III-V and LD-MOS devices, demonstrating improved power, efficiency, and linearity for the microwave band (1-30 GHz); power-combining techniques for SSPA and vacuum electronics
17. **Millimeter-wave and THz power amplifiers** — Advances in IC power amplifier circuits, design techniques, and power combining based on Si and III-V compound semiconductor devices demonstrating improved power, efficiency, and linearity for millimeter-wave and THz bands; vacuum electronics for millimeter-wave
18. **Linearization and transmitter techniques for power amplifiers** — Power amplifier behavioral modeling; linearization and pre-distortion techniques; envelope-tracking, out phasing, and Doherty transmitters for III-V and silicon technologies

Systems and Applications

19. **Mixed-signal, wireline, and signal shaping circuits** — High-speed mixed-signal components and subsystems, including: PLLs, TDCs, ADCs, DACs, DDSs, and supporting circuits to interface these to the analog world
20. **Integrated transceivers and phased-arrays** — Design and characterization of complex III-V ICs, silicon ICs, heterogenous systems in the RF to mm-wave band including narrowband and wideband designs; innovative circuits and sub-systems for communications, radar, imaging, and sensing applications; Integrated on-chip antennas and on-package antennas
21. **Microwave and Terahertz Photonics** — Photonic techniques for the generation, processing, control, and distribution of microwave, mm-wave, and THz signals, Radio-over-fiber links; Design and characterization of microwave photonic and THz circuits; Interaction between microwaves, THz waves, and optical waves; THz circuits for communications, radar, imaging, and sensing applications; Nanophotonics, nanoplasmonics, and nano-optomechanics.
22. **Wireless power transmission** — Energy harvesting systems and applications, rectifiers, self-biased systems, combined data and power transfer systems
23. **Sensing and RFID systems** — Short range wireless and RFID sensors, gas and fluidic sensors; passive and active tags from HF to millimeter-wave frequencies; RFID systems including wearables and ultra-low-power
24. **Microwave and millimeter-wave wireless subsystems and systems** — Technology advances combining theory and hardware implementation in microwave/millimeter- wave subsystems such as beamformers; microwave and millimeter-wave (<300 GHz) communication systems, incl. 5G – 6G, with hardware implementation for terrestrial, vehicular, and indoor applications, point-to-point links, cognitive and software-defined radios, MIMO, full-duplex technologies, shared and novel spectrum use, novel modulation schemes, and channel modeling
25. **Radar and imaging systems** — RF, millimeter-wave, and sub-THz radar and imaging systems, automotive radars, sensors for intelligent vehicular highway systems, UWB and broadband radar, remote sensing, radiometers, passive and active imaging systems, radar detection techniques, and related signal processing
26. **Airborne and space systems** — Technologies and systems for remote sensing for earth observation; positioning, navigation, and timing; space exploration, human spaceflight and space transportation; satellite communications including 5G, 6G applications involving aerospace platforms; communication and sensor system for UAVs, high altitude platforms, airplanes, and satellites
27. **MHz-to-THz devices, circuits, and systems for biological and healthcare applications** — Electromagnetic field interaction at molecular, cellular, tissue and living systems levels; devices, circuits, and systems for characterizations of biological samples; microwave-enhanced chemistry; instrumentation and systems for biomedical diagnostic and therapeutic applications, incl. MRI and microwave imaging; wireless, wearable, and implantable devices for health monitoring

Emerging Technologies

28. **AI/ML for RF to mmWave** — AI/ML, algorithms implementations, and demonstrations for: spectrum sensing; mobile edge networking; MIMO and array beam operations and management; design and optimization; in-situ sensing, diagnostics, control, reconfiguration of MHz to THz communication and sensing circuits and systems
29. **Quantum devices, circuits, and systems** — Quantum devices and circuits (incl. cryogenic RF circuits); algorithms, interfaces, and systems for quantum computing and quantum sensing applications
30. **SubTHz and THz circuits and systems** — SubTHz and THz systems (300GHz to 1 THz+), incl. sub-THz architectures and implementations for passive and active sensing, 6G and Future-G communication systems.
31. **Microwave field-matter interaction, material sensing and high-power applications** — Industrial and scientific applications of microwave energy (e.g., chemistry, metallurgy, ceramic sintering, plasma generation, waste treatment, “green” materials, energy converters); MHz-to-THz sensing (from microwave microscopy to large surface/volume imaging) of materials for electronics and energy applications; multiphysics modeling of materials processing and characterization.
32. **Other innovative MHz-to-THz systems and applications** — Submissions that describe innovative contributions in new and emerging areas of interest to the MTT community not falling under the above categories are encouraged.

IMS

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IMS2024 will be YOUR Platform to:

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- Educate attendees through various speaking opportunities at MicroApps and Industry Workshops or submit a technical paper!

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IEEE

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MAKING WAVES

SmartStudio Automotive Suite Intro and Demo

Watch this overview of Anritsu's SmartStudio Automotive Suite to learn how it simplifies evaluation of the always-on connection and key high speed communications of #5G telematics services.

Anritsu

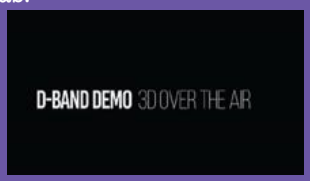
bit.ly/3PBaqXj

MilliBox D-Band OTA Demo

Check out this video demonstration of the MilliBox MBX02 compact mmWave chamber with a GIM04-230 positioner, Copper Mountain C4220 USB VNA, Eravant D-Band frequency extender and Maury Microwave cables to measure the radiation pattern of 20 dBi WR6 waveguide horn antennas.

MilliBox

www.youtube.com/watch?v=BYRoYlQ_Xdcj



COMPLETE Library v23.2 for Sonnet Suites

Modelithics announced the release of version 23.2 of the Modelithics COMPLETE Library for Sonnet Suites. This new release adds 45 new models and is compatible with the latest version of Sonnet (v18.56). With this release, the Modelithics COMPLETE Library for Sonnet Suites now represents highly-accurate models for over 26,000 components.

Modelithics

www.modelithics.com

Keysight Introduces PathWave Design 2024

Keysight Technologies, Inc. introduces PathWave Design 2024, the latest release of its suite of electronic design automation (EDA) software tools, giving design engineers new software automation, design data and intellectual property management, team collaboration and development lifecycle transformation capabilities.

Keysight Technologies, Inc.

www.keysight.com

Radio History: The Evolution of FM Radio

FM radio has evolved with time from its inception to the present day to best serve and adapt to the listener as their needs change through the decades. Read more in this blog post.

Mini-Circuits

https://bit.ly/3PEmTtg

Pasternack Electronics: The Engineers Immediate RF Source

Check out this Pasternack video, featuring their RF and microwave components and growing list of 19 international distributors who service customers in more than 35 countries.

Pasternack

www.youtube.com/watch?v=81x3bH3RGxs

IEEECOMCAS2023

INTERNATIONAL CONFERENCE ON MICROWAVES, COMMUNICATIONS, ANTENNAS, BIOMEDICAL ENGINEERING & ELECTRONIC SYSTEMS

6-8 November 2023
David Intercontinental Hotel
Tel Aviv, Israel

INTERNATIONAL CONFERENCE ON MICROWAVES, COMMUNICATIONS, ANTENNAS, BIOMEDICAL ENGINEERING & ELECTRONIC SYSTEMS

KEYNOTE SPEAKERS

Dr. Michael Peeters
IMEC, Belgium

Prof. Goutam Chattopadhyay
California Institute of Technology, USA

Prof. Stefano Maci
University of Siena, Italy

Dr. Dana Z. Anderson
Infleqtion, USA

IGNITE, ENGAGE, & EMPOWER

Ignite your curiosity, engage, and exchange ideas with leading experts, and empower yourself through captivating workshops and seminars, while gaining valuable insights from the latest breakthroughs in research, advancements in technology, and industry experiences.

IMMERSE IN INNOVATION

Immerse yourself in a world of cutting-edge technology at the exhibition, where you can interact with 100 international exhibitors showcasing the latest advancements. Explore, inquire, and expand your network to connect with top-notch suppliers and potential business partners, discovering new products, components, and materials along the way.

FORGE MEANINGFUL CONNECTIONS

Seize the invaluable opportunity to engage in dynamic discussions, exchange ideas, and collaborate with industry leaders. Elevate your business by not only seeking knowledge but also offering valuable insights and suggestions. Connect with visionary leaders who have the potential to propel your business forward, taking it to new heights of success.

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RF Technology Certification

RF Technology Certification is an online course designed for professionals who need a solid background in RF and wireless technology and products. The four-part program provides the student with a thorough understanding of RF analytical tools, communication signals, RF devices and test instruments. The program was developed by Besser Associates, a worldwide leader in RF and wireless training.
www.besserassociates.com

Cernexwave

Microstrip Circulators

VENDORVIEW

Cernexwave's SMT microstrip circulators and isolators are an ideal solution for broadband or narrowband signal control in a very small package. They are tailored to the exact frequency you need while maintaining low insertion loss and high isolation. The company can also customize the size, shape and port locations to fit perfectly in your system. They can operate from as low as 2 GHz to as high as 30 GHz and handle power levels of 20 W or higher.
www.cernexwave.com

Comtech PST

Solid-State RF Modules

COMTECH PST introduced the highest power solid-state RF modules available in the marketplace today. Comtech's latest development expands on its proven innovative integrated RF GaN power amplifier designs by further increasing the RF power density, while improving overall operating efficiency. Consistent with its planned technology development roadmap, Comtech is leading the field with the latest in GaN-based RF device performance and advanced amplifier development. These highly integrated designs are ideal for use in communication, electronic warfare and radar transmitter systems where space, cooling and power are limited.
www.comtech.com

Empower RF

1 kW GaN Amplifier

VENDORVIEW

Empower's Model 2239 is a long duty cycle pulsed SSPA in a 3U chassis. This rugged air cooled amplifier handles up to 500 µs pulses, producing 1 KW peak power from 2900 to 3500 MHz. GaN on SiC devices are used in a class AB configuration. The unit will self-protect with open/short conditions and is VSWR tolerant up to 3:1 at full power. When operating below half of rated power the unit tolerates any VSWR without shutdown.
www.EmpowerRF.com

Eravant

Noise Source

VENDORVIEW

Model STZ-06-IT2 is a broadband noise source that delivers 15 dB nominal ENR across the frequency range of 110 to 170 GHz. Typical noise flatness is ±3 dB. The WR-06 output port has a UG-387/U-M anti-cocking flange. The included compact isolator provides return loss of 15 dB. The DC bias port accepts +28 VDC and is compatible with standard noise figure analyzers. A TTL control signal input is also provided, as well as a toggle switch for manual control.
www.eravant.com

Fairview Microwave

Horn Antennas

VENDORVIEW

Fairview Microwave components announced the launch of its new mm waveguide horn antennas, designed to deliver superior performance and consistency across a broad frequency range. The new line of antennas is available in a wide array of sizes, from WR-6 to WR-34, and boasts a frequency span from 22 to 170 GHz. They are meticulously engineered with a rectangular waveguide interface and made from high-grade copper, finished with gold plating.
www.fairviewmicrowave.com

HYPERLABS

110 GHz 6 dB Attenuator

VENDORVIEW

HYPERLABS has released the HL9429 110 GHz 6 dB attenuator, which offers industry leading performance and competitive pricing. The HL9429 can be ordered in matched pairs providing optimized phase and amplitude matching for differential signal applications. The HL9429 attenuator housing dimensions are 1.13 × 0.38 × 0.38 in. (28.7 × 9.7 × 9.7 mm) and comes with 1.0 mm connectors. S-parameter data is available upon request. For more information, contact the HYPERLABS factory directly or your local sales representative.
www.hyperlabs.com

MCV Microwave

Waveguide Filters

MCV offers a series of waveguide filters for 5G cellular network operates at 3.3 to 4.2 GHz as well as the MCV BLUE 5G interference mitigation solution for C-Band satellite communication terminals which receive space-to-earth signals in the 3.4 to 4.2 GHz band and transmit signals in the range of 5.85 to 6.425 GHz.
www.mcv-microwave.com

New**Products**

Mini-Circuits

Signal Generator/Controller Programs

VENDORVIEW

Mini-Circuits' model ISC-2425-25+ is a programmable signal generator and system controller for the 2400 to 2500 MHz industrial, scientific and medical band. It tunes in 1 kHz frequency steps and provides output power from -30 to +25 dBm, adjustable with 0.01 dB resolution. Phase can be controlled in 1 degree steps across a 360-degree range. It is supplied in a compact metal enclosure measuring 3.86 × 3.15 × 1.57 in. (98 × 80 × 40 mm) with 50 Ω female SMA output connector and serial USB communications connector.
www.minicircuits.com

Pasternack

Waveguide Power Amplifiers

VENDORVIEW

Pasternack has released a new series of waveguide power amplifiers designed to cover high mmWave frequency bands ranging from 26.5 to 96 GHz. This line of waveguide power amplifiers offers exceptional performance and versatility to meet the demands of industries such as satcom, radar, wireless infrastructure, 5G and more. These new waveguide power amplifiers leverage advanced GaAs and GaN MMIC semiconductor technology, providing high efficiency in a compact package.
www.pasternack.com

RLC Electronics

Directional Couplers

RLC Electronics' high-power, high directivity directional couplers offer accurate coupling (±1.0 dB), low insertion loss (0.1 to 0.35 dB maximum) and > 35 dB directivity in both directions. These high-power couplers are offered with 500 to 1000 W average power handling up to 18 GHz, as well as 100 W versions up to 40 GHz. Couplers are provided in both single and dual directional construction, typically over a two octave bandwidth or less.
www.rlcelectronics.com

Signal Microwave

TDR/VNA Probes

Signal Microwave, in partnership with DVT Solutions, is introducing the DVT-FPPxx series, a 100 Ω true differential probe with bandwidths of 40 GHz, 50 GHz and 70 GHz series to support the industry's demand for higher data rates over differential traces. The new differential probe satisfies the need to probe PCB designs that have wide pitch test pads up to 70 GHz with test pad pitches from 0.6 to 1.0 mm.
www.signalmicrowave.com

Swift Bridge Technologies

ExpressRF™18 LRL

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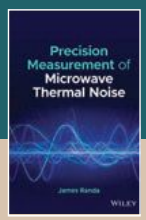

Bookend

Precision Measurement of Microwave Thermal Noise

By James Randa

Precision Measurement of Microwave Thermal Noise by James Randa is, literally and figuratively, a textbook case of complete work. As clear and concise as the title, its 176 pages carry far more content than expected without being so dense the reader need dissect every word. Though every word surely carries purpose, it all comes together in a package that is helpful, frank and pleasantly anodyne.

Speaking of every word having purpose, let's break down the title. Precision Measurement? I subscribe to the concept that "All measurement is wrong; we just need to know how wrong." Plenty of time is dedicated to reference planes, calibration and error analysis, which is fantastic. Dr. Randa (whom I would consider to be a practical physicist) spans that analysis from mechanical issues all the way to quantum mechanics issues. Yes, this is precision measurement.

Next, Microwave. Let me preface by saying this book is ultimately discussing physics. The inclusion of the word "microwave," especially in the context of a review in *Microwave Journal*, isn't to be taken lightly. I'm happy to report that, while weighted heavily toward math and theory as opposed to laboratory experiments or design work, the institutional knowledge conveyed is extremely practical to our industry, especially as it relates to understanding amplifier measurement. Yes, this is microwaves.

Finally, Thermal Noise. This itself is a broad and complicated subject. Dr. Randa starts out with some Nyquist equations and the introduction may concern the reader of a hyper-focused discussion of quantum mechanics. Not that that would have been an issue, exactly, but he quickly establishes those equations as thetical to the mission and that while the literal thermal noise of a resistor is important, it's not necessarily what amplifier designers are concerned with. Awesome, this book is exactly as the title advertises.

Now, let's address why I think this is a complete work. The content is well-referenced from a variety of sources, but curious readers will note citations to many of Dr. Randa's own works. Searching the internet for James Randa will paint the picture of a healthy career in this field at NIST and a recent retirement. There are a lot of esteemed careers in physics, most do not take the time out of retirement to catalog their life's work. So, let's say this clearly — the industry, the current generation of microwave engineers, and future generations of microwave engineers, we thank you.

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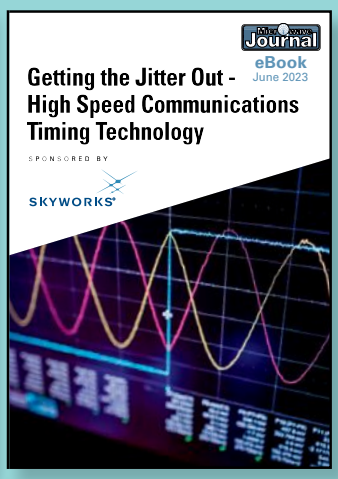

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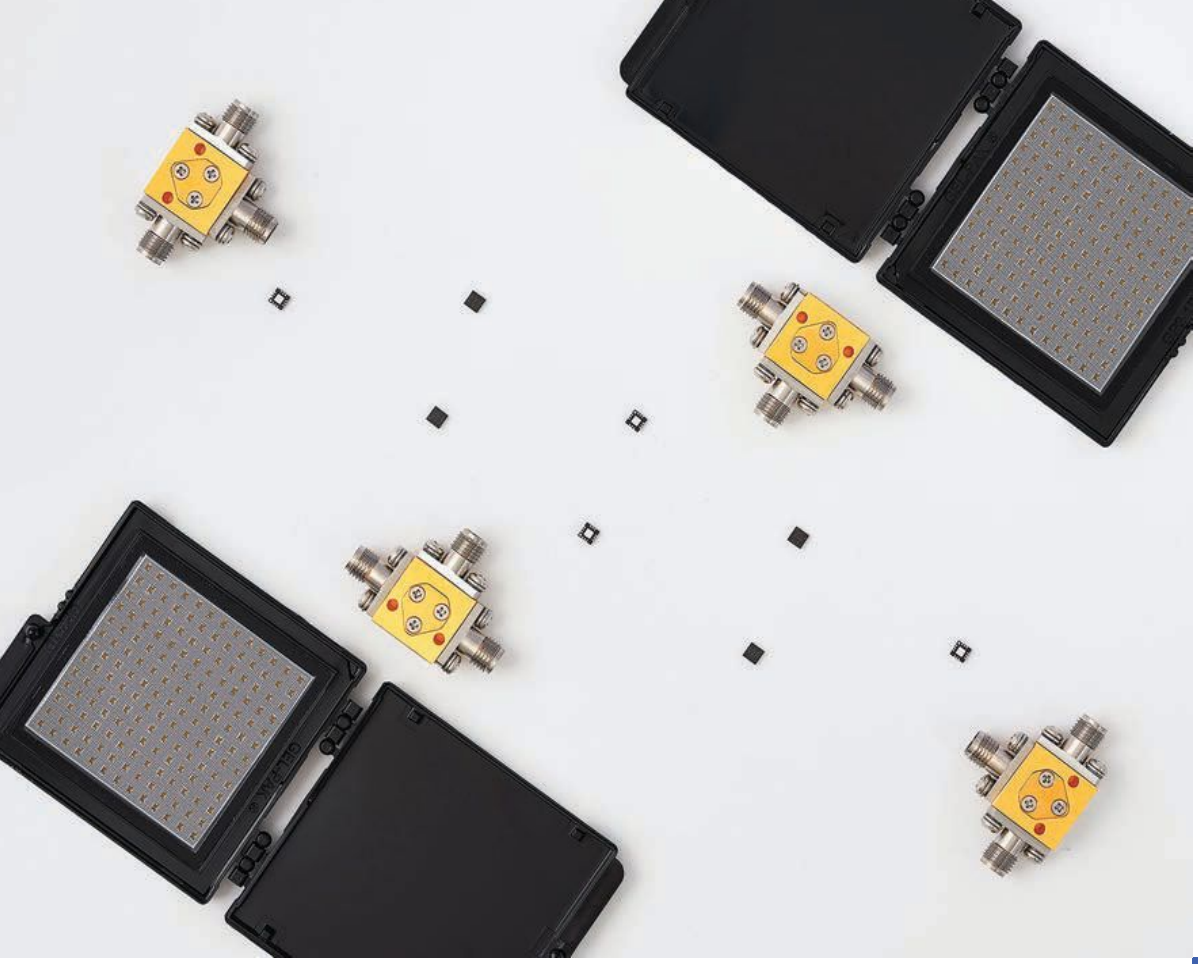

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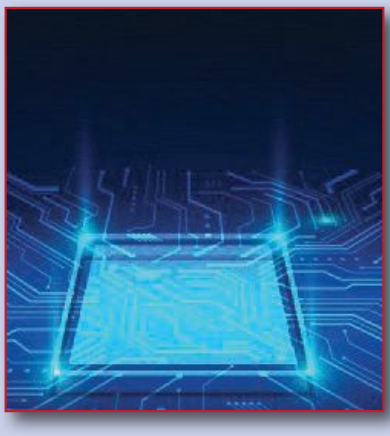

RFMW, founded in 2003, is celebrating its 20th anniversary. Co-founder Joel Levine, RFMW's President or "Chief Execution Officer" and "Director of Advanced Hindsight" has spent more than five decades in the RF component distribution business. Mr. Levine and a savvy senior management team have transformed RFMW into a technical provider of specialized RF and microwave components. The company's mission is to provide customers with products from leading RF and microwave component manufacturers.

RFMW, headquartered in Silicon Valley, has grown into one of the premier technical distributors of RF and microwave semiconductors, connectors, components and most recently, power products. RFMW differentiates itself by providing value-added and design solutions in addition to component sales. To accomplish this, the RFMW approach involves focused technical sales and marketing programs that provide component engineering solutions.

To implement this vision and mission, RFMW adheres to a set of five guiding principles:

- Implement a sales organization that uses its technical aptitude to develop solutions with customers.
- Strive for "best in class" performance with their value-added and design solutions.
- Constantly profile and evaluate inventory to ensure that it is strategically positioned.
- Differentiate with value-added services.
- Maintain a strong focus on the appropriate customer base and market applications.

In 2018, RFMW was acquired by TTI, a Berkshire Hathaway company. When the deal was announced, RFMW became part of the TTI Semiconductor Group (TSG), alongside TTI, Mouser Electronics and Sager Electronics; other prominent component distributors in TTI's family of specialists. The evolution of the specialty strategy, along with more acquisitions and expanded product offerings inspired the organization to become more aligned with Mouser Electronics and create the Exponential Technology Group (XTG). This group, including RFMW and six other distribution entities, specializes in the design-in and supply of component technologies and total solutions that enable electronic systems from automotive and communication applications to the IoT.

At the time of the acquisition, Mr. Levine touted the synergy with TTI's strategy, culture, focus, customer service and technical expertise and noted how these features fit with RFMW. From RFMW's perspective, the acquisition provided additional resources, quality people and investments in inventory to support RFMW's growth trajectory. They embrace the mantra that RF and microwave are in their DNA and they have remained true to their mission. This is the genesis of the tagline; "It's Who We Are, It's What We Do" that they follow to this day.

Along with riding this strategy to expand their core business, the company has sprinkled in some acquisitions and on April 11, 2023, RFMW announced a brand refresh. With this announcement, the company updated its logo, but more importantly, RFMW announced that they were adding power management products to the product portfolio. In their view, this was a natural extension of RFMW's business model. RFMW will implement a similar strategy in power as they have executed in RF and microwave. As some of their core suppliers expand into power electronics applications, the number of opportunities grows and these opportunities are complementary to the existing product base and customers. RFMW will target power electronics in RF and microwave applications first, but they also plan to address broader power management and conversion applications.

With this growth strategy and support from TTI and Mouser, RFMW has grown with more manufacturers and products to support the targeted customer base. There are currently 90 different product categories listed on their website. All these manufacturers and products have propelled RFMW to a global corporate and sales presence. Today's RFMW is RF and microwave and power component distribution focused on technical and supply chain solutions.

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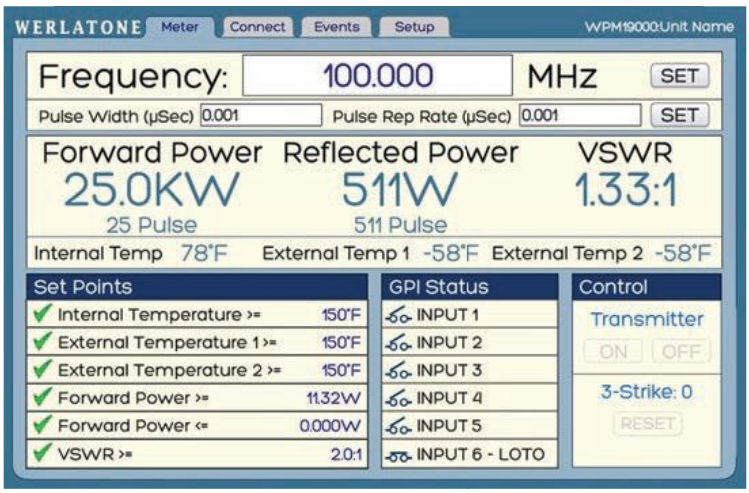

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