Vol. 65 • No. 1

January 2022

Microwave Journal

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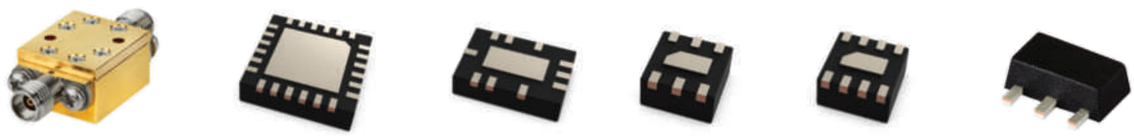

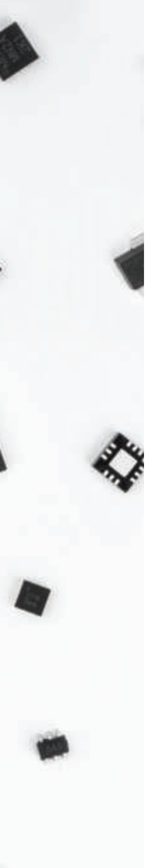

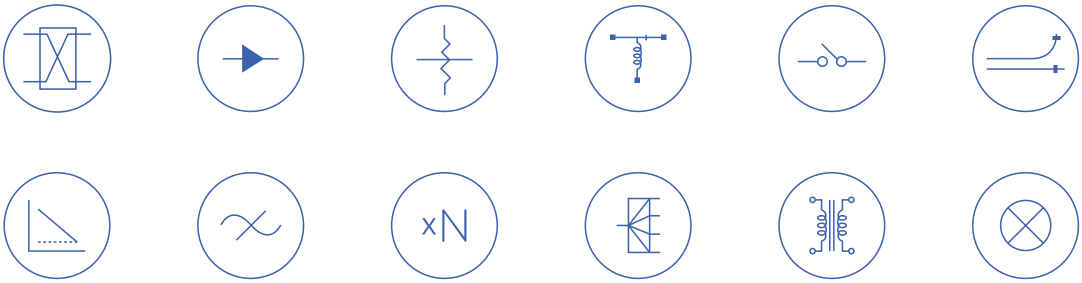

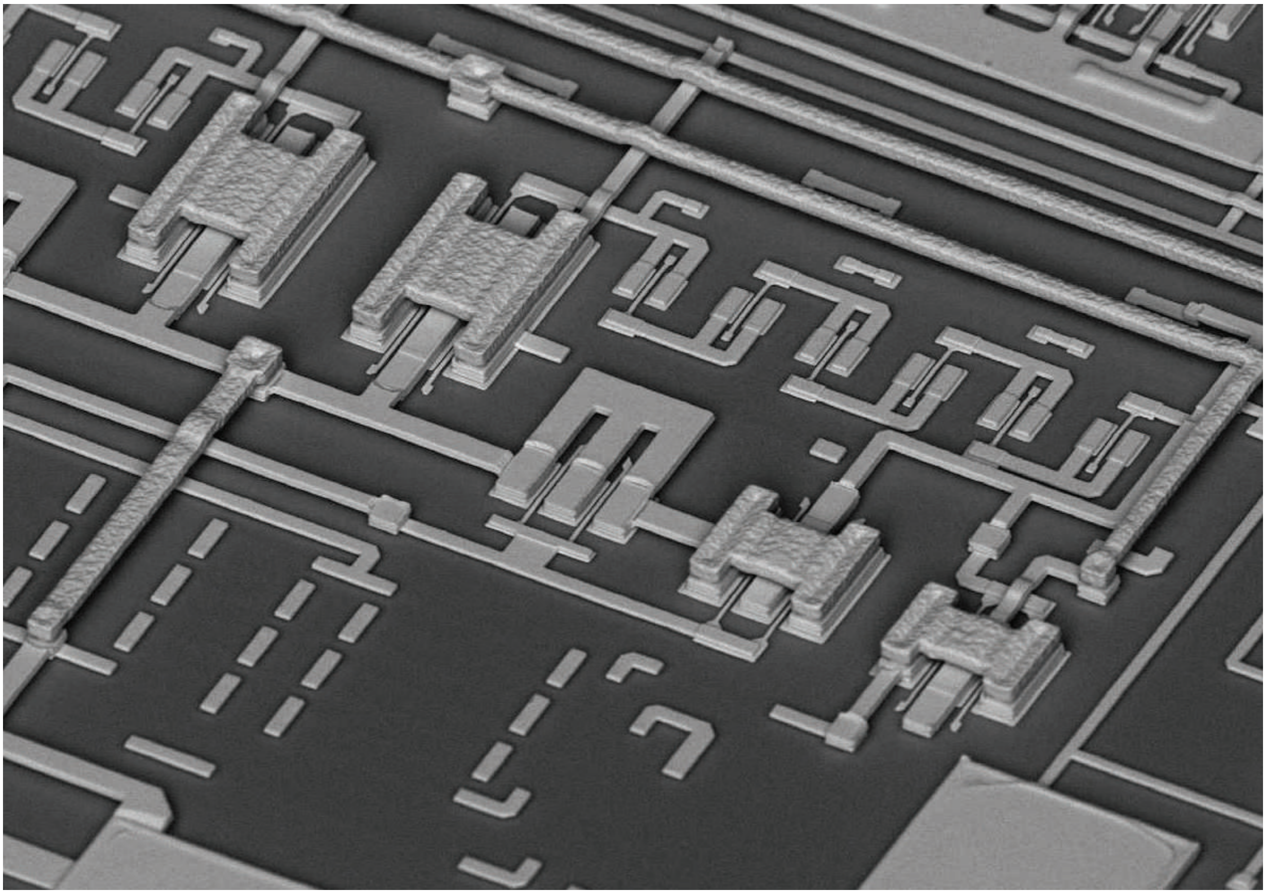

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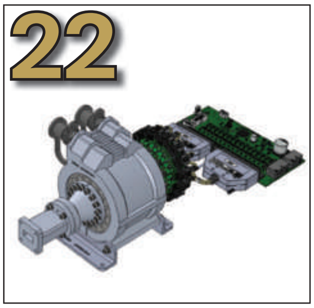

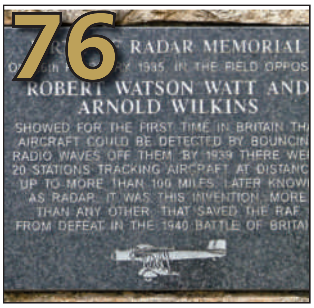

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100 Watt GaN Amplifier	5-6	50	47	22	QPA2309
50 Watt GaN Amplifier	5-6	48	49	23	QPA2310
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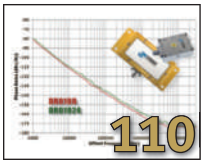

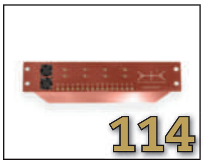

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Maha Achour, founder, CTO and CEO of **Metawave**, discusses the start-up's ambitious goals to supply radar platforms for automotive and aerial imaging, as well as mmWave repeaters and relays for 5G.

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On our Radar

Carl Sheffres
Microwave Journal *Publisher*

With all of the turbulence in the world lately, it is nice to know that some things never change; namely the January issue of *Microwave Journal* theme of "Radar and Antennas." As tradition dictates, we launch the year with this annual reader favorite and technology staple. The cover feature is titled, "A Planetary Radar System for Detection and High-Resolution Imaging of Nearby Celestial Bodies" and is a collaborative effort by experts from Raytheon, NRAO, Green Bank Observatory and Qorvo. You'll find a variety of other technical articles, application notes, product features, news and coming events in these print and digital pages.

Speaking of radar, our industry lost one of its pioneers last month. Eli Brookner, a life member of IEEE and recipient of the Dennis J. Picard Medal, Warren White Award for Excellence in Radar Engineering passed at the age of 90. Dr. Brookner's career spanned more than half a century at Raytheon as a radar engineer where he played a major role in the development of radar and phased array radar systems. He was a renowned international lecturer and published author, educating thousands of radar engineers worldwide. The MWJ team had the honor of working with Dr. Brookner on several of our industry events over the years.

This issue also serves as our show issue for the 2021 European Microwave Week (EuMW) event, now taking place the week of February 13 in London's ExCeL Centre. Helen Duncan provides an article, "The RF/Microwave Industry in the UK and Ireland, Birthplace of Radar and the GaAs MMIC," Editorial Director Pat Hindle gives an overview of EuMW and the Conference Chairs provide their welcome messages. *Microwave Journal* will be well represented, and we hope to see many of you there.

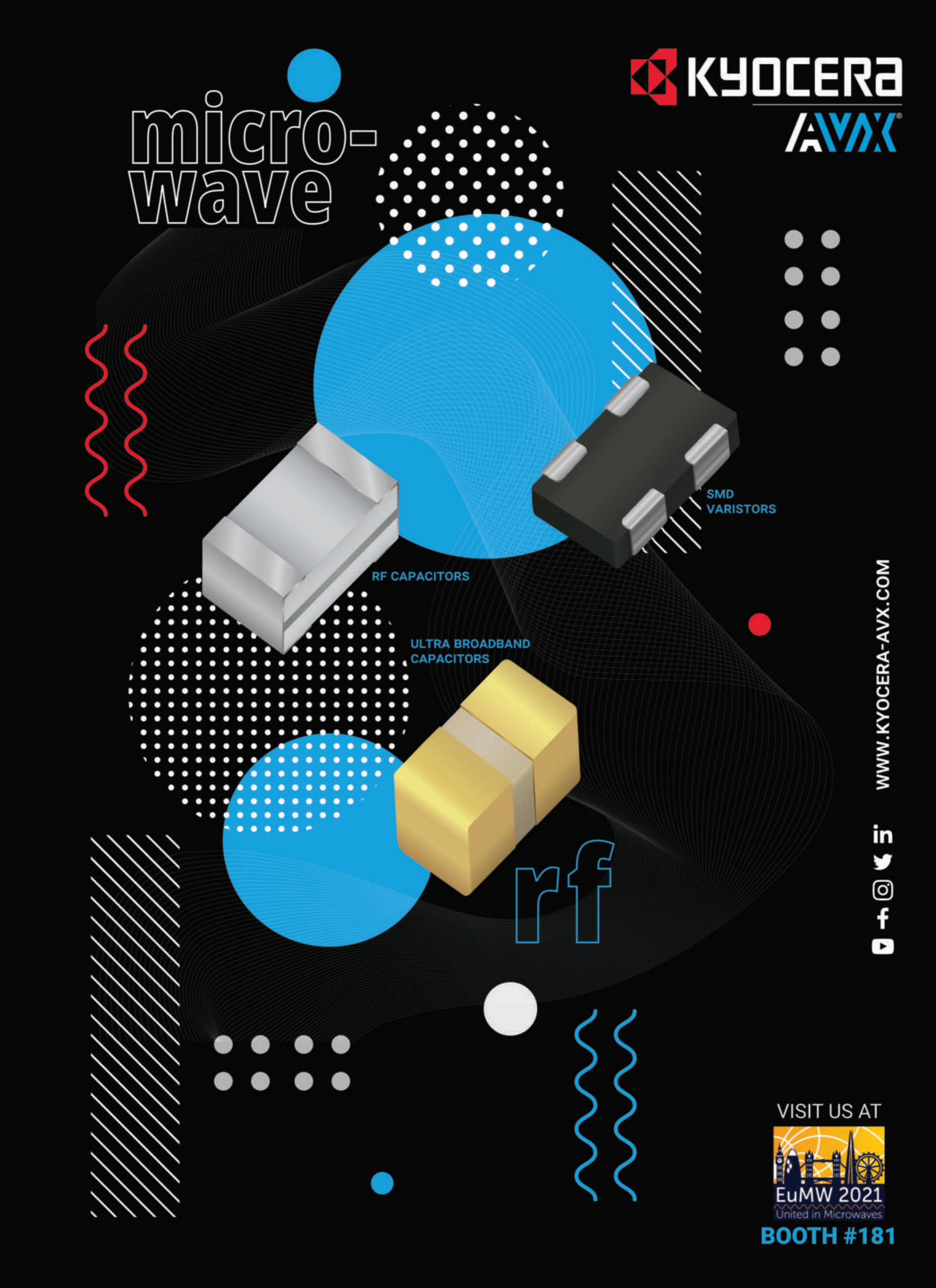
Looking further ahead to events, the IEEE MTT-S International Microwave Symposium (IMS) will be an in-person only event this year. The annual industry gathering will take place on June 19-24 in Denver and will include the RFIC and ARFTG conferences as usual. The IMS conference features some new initiatives, including the "Systems Forum" which will feature Quantum Systems, Radar and Aerospace Systems and Phased-Array and OTA Applications, each on separate days. The Wireless Connected Future Summit will be included in the forum along with panel sessions and a reception. There will be a related Systems Pavilion on the show floor, allowing companies a low-cost, turn-key opportunity to display their products and technology. IMS and RFIC have announced an impressive lineup of keynote speakers, which you can see on the inside back cover of this issue. The exhibition will be equally impressive, featuring more than 300 companies in over 600 booth spaces. Denver is a fantastic city to host the event, with a vibrant downtown featuring the pedestrian-only 16th Street Mall with its many restaurants and bars, the renovated and glorious Union Station, Larimer Square, Coors Field and 300 days of sunshine. I hope to see you there.

EDI CON Across China, an event for analog and digital design engineers, will replicate its successful multiple-venue, hybrid model in 2022. The online forum will take place on April 26-27 with tracks covering 5G, IoT, Satellite, Radar, Automotive and Semiconductor technologies. The in-person events will take place in Beijing (May 26), Shanghai (July 28), Chengdu (October 27) and Shenzhen (December 6).

EuMW will host its second event of the year and celebrate its 25th anniversary in Milan, Italy, on September 25-30. The event has not been in Milan in many years, so it will be nice to visit this fashionable city again.

Mark your calendar for EDI CON Online, which will take place every Wednesday in October. This popular annual conference will feature tracks on Signal Integrity/Power Integrity, 5G/WiFi/IoT, PCB/Interconnect and Radar/Automotive/SATCOM. Last year's edition attracted more than 1,000 live attendees and nearly 6,000 total sessions attended. Registration opens next summer.

It should be an action-packed year ahead. Let's hope it's one that's more stable and reliable, like this "Radar & Antennas" issue of your *Microwave Journal*. Wishing all of our readers a happy and healthy 2022. ■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COVER FEATURE
INVITED PAPER

A Planetary Radar System for Detection and High-Resolution Imaging of Nearby Celestial Bodies

Steven R. Wilkinson, Charlie Hansen, Barry Alexia, Bishara Shamee and Brian Lloyd
Raytheon Intelligence & Space, El Segundo, Calif.

Anthony Beasley and Walter Brisken
National Radio Astronomy Observatory, Charlottesville, Va.

Flora Paganelli, Galen Watts and Karen O'Neil
Green Bank Observatory, W. Va.

Patrick Courtney
Qorvo, Richardson, Texas

In partnership with National Radio Astronomy Observatory (NRAO) and Raytheon Intelligence & Space (RI&S), the Green Bank Observatory (GBO) tested a multi-static radar intended to expand the scientific reach and capability of the Green Bank Telescope (GBT) and the Very Long Baseline Array (VLBA). The experimental effort installed an RI&S Ku-Band transmitter on the GBT and relied on VLBA receiving stations to receive the data transmission. That transmission generated synthetic aperture radar (SAR) images of select locations on the moon and detected asteroid 2001 FO32.

Radio astronomers have long been seeking to expand the capabilities of radar in their observations of the Solar System. In early 2019, efforts were initiated at the GBO GBT and the NRAO's VLBA to accomplish this expansion. Following the collapse of the 300 m Arecibo Telescope in December 2020, the astronomy community raised questions about the future of some types of work conducted there, including the use of planetary radar systems for the observation of asteroids, inner- and outer-Solar System bodies and moons. The GBT and VLBA can expand on this work using an active radar system for planetary radar applications. Tests of this capability resulted in successful experimental efforts toward ground-based high-resolution imaging of nearby celestial bodies.

SYSTEM DESIGN

Selection of the GBT transmission frequency was interesting since NRAO discussions centered on Ka-Band. The experiment planned to use the VLBA as a receiver, but the array did not have a Ka-Band receiver like NRAO's Very Large Array. Review of the VLBA receiving bands focused on the highest frequencies below Ka-Band possible. Analysis determined the best frequencies were from 13.75 to 14.0 GHz. The final license covered a 200 MHz bandwidth from 13.8 to 14.0 GHz.

The transmitter was installed on the GBT at the prime focus (PF) position. It was developed to be compatible with existing GBT interfaces, and to be controlled and monitored remotely via a secure internet link. A duplexer allowed

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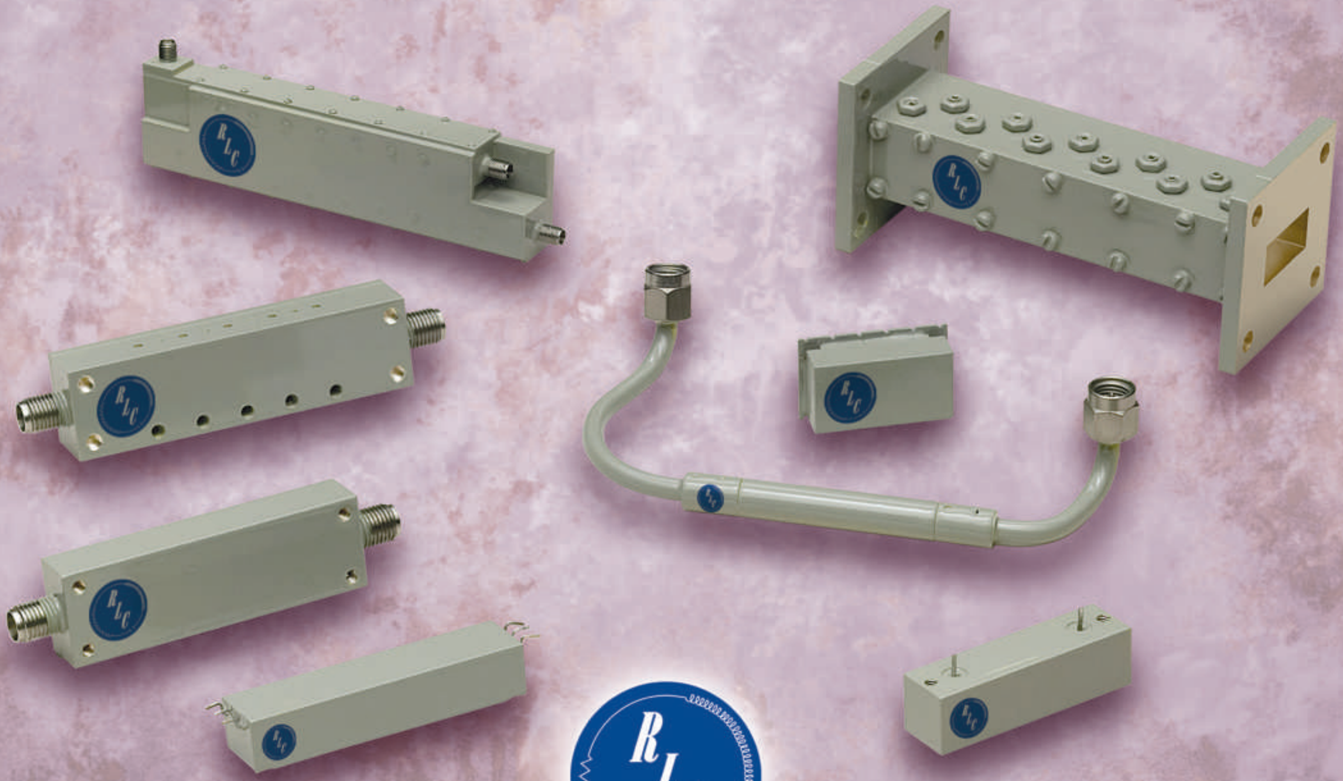

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TABLE 1 GBT TRANSMITTER SPECIFICATIONS	
Parameter	**Value**
Transmitter Output Power	650 W
Transmitter Frequency	13.9 GHz
Maximum Transmit Bandwidth	200 MHz
Receiver Bandwidth	11.0–12.8 GHz
Transmitter-Receiver Isolation	> 85 dB

the transmitter and a pointing receiver to be connected to the same feed horn. The system was either in transmit or receive mode. Specifications for the transmitter and pointing receiver are listed in ***Table 1***.

The GBO uses standard receiver housings for installation at the PF of all large antennas on site. For ease of installation and removal, the RI&S Ku-Band transmitter was built inside one of these PF housings (PFH). The housing consists of a rectangular box approximately 28 × 28 × 60 in.[3] with brackets for hoisting and attaching to the mounting cage at the antenna focus. One 28 × 28 in. panel of the box carries the feed horn, while the opposite 28 × 28 in. panel carries connectors and fittings for the RF, electrical and cooling connections. The receiver mounting cage can be moved small distances in the X- and Y-directions parallel to the primary reflector, moved toward or away from the primary reflector to change receiver focus and rotated in both directions around the receiver axis.

In November 2019, GBO shipped the PFH to RI&S for transmitter installation. The Peltier coolers were removed and replaced with a simple ethylene/glycol heat exchanger. The system block diagram is shown in ***Figure 1***. The blocks in the light gray background were integrated into the PFH. Testing included verification of the gate biasing, power sequencing and pulse testing of the power supply into 5000 W loads. Mechanical members were water-jet-cut from aluminum slabs to ensure structural integrity, weight and balance. The payload needed to remain stable while being lifted and stowed into position atop the 500-ft. telescope. Pre-installation transmission tests occurred in GBO laboratories. The RI&S transmitter (see ***Figure 2***) operated at full power into an RF load, which verified both the transmitter status and remote operations.

TRANSMITTER DEVELOPMENT

The aggressive schedule and budget constraints mandated the use of commercial off-the-shelf hardware. RI&S conducted a detailed survey of high-power microwave amplifiers that included solid-state, TWTs, magnetrons, klystrons and cross field amplifiers. Size, weight, power and cost requirements and the need for continuous wave (CW) operation quickly narrowed the field. The Qorvo Spatium power amplifier was the only option that met these requirements. Graceful degradation, an integrated bias and sequencing, connectorized cooling jacket and simple 28 VDC power requirement in a compact volume made the Spatium the only choice (see ***Figure 3***). The Spatium output power and VLBA sensitivity enabled the capability to generate spectacular lunar SAR images.

The Spatium amplifier is composed of an antipodal finline antenna array that is loaded into a coaxial waveguide to create a broadband multi-element combiner structure. The Spatium structure has demonstrated performance from 2 to 40 GHz and up to a decade of bandwidth in an individual amplifier. Qorvo has released a line of standard products based on the Spatium technology that is broken into three platforms covering typical radar, jammer and communications transmitter bands: 2 to 20 GHz, 8 to 16 GHz and 18 to 40

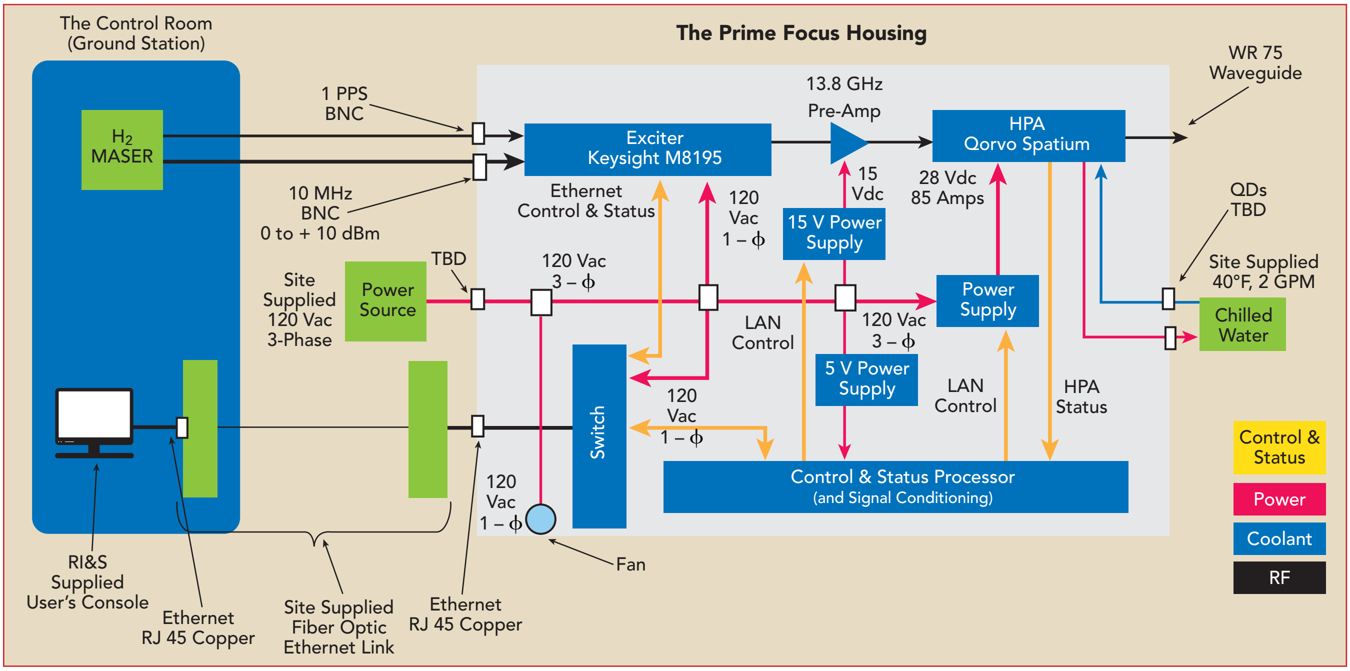

Fig. 1 **System block diagram.**

Fig. 2 **RI&S transmitter.**

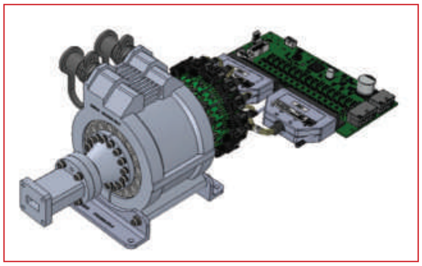

Fig. 3 **Spatium power amplifier.**

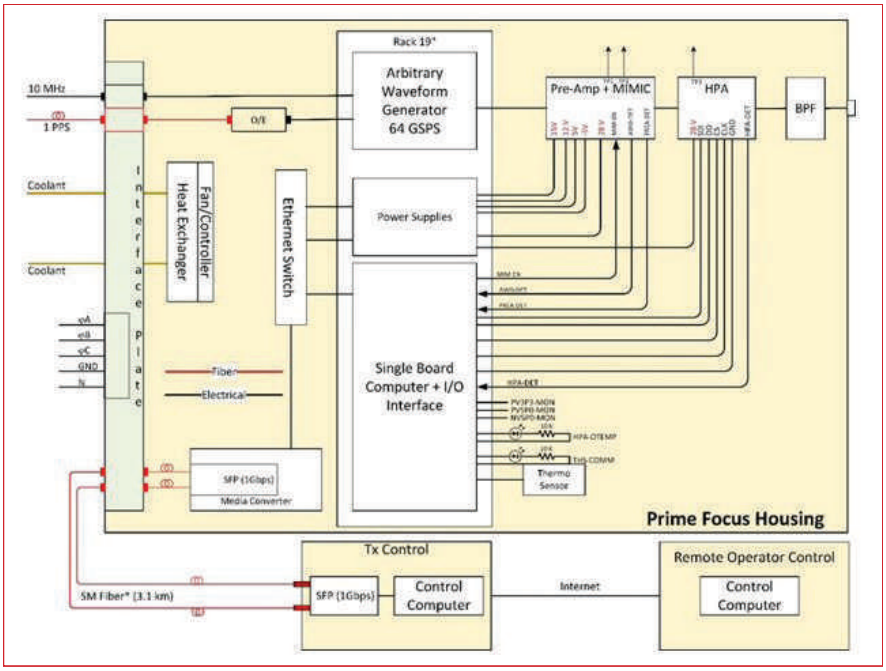

Fig. 4 **Transmitter block diagram.**

GHz. Each of the standard Spatium platforms allows for the combining of 16 solid-state amplifiers.

The Qorvo QPB1316 power amplifier uses the 8 to 16 GHz standard Spatium platform, combining 16 solid-state GaN MMIC amplifiers to achieve greater than 500 W of CW output power with a typical power-added efficiency of 27 percent. This high power amplifier (HPA) is compact with outline dimensions of 4.15 × 5.28 × 9.4 in., and with 3.35 × 6.89 in. for the associated bias control printed circuit board assembly (PCBA). Included in the dimensions is an integrated liquid-cooled clamp that allows the HPA to operate in both pulsed and CW modes while minimizing thermal resistance from the system cooling fluid to the GaN MMIC devices. The bias control PCBA requires a +28 VDC input and contains all required gate voltage and sequencing circuitry required for the GaN MMIC devices along with current monitoring for each of the 16 devices within the Spatium amplifier. The bias control PCBA is standard with Spatium products to ease integration at the next highest assembly transmitter.

TRANSMITTER INTEGRATION AND TEST

Figure 4 is an overall block diagram of the transmitter identifying the GBT interfaces to include power, coolant, references, control communications and RF transmission. The control communications channel is a fiber channel to support a remote distance of 3.1 km between the local control node and the GBT. The operator control node is a remote internet node that was not originally planned but designed into the system to mitigate COVID-19 travel constraints.

Ultimately, the internet became

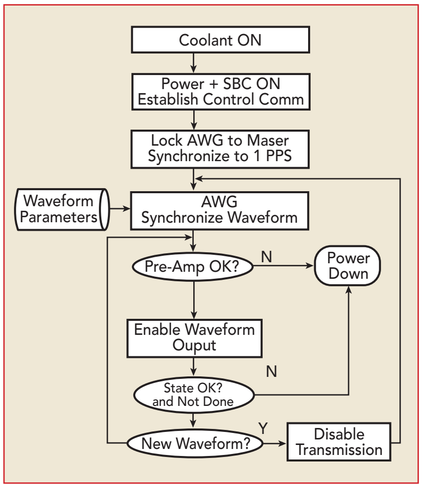

Fig. 5 **Transmitter operation.**

the only way to operate the transmitter. The transmitters critical elements are the HPA driven by an arbitrary waveform generator (AWG) running at 64 giga samples per second with eight bits of precision. The AWG synthesizes the tones and the linear frequency modulated (LFM) waveforms at the center frequency of 13.9 GHz without upconversion to reduce hardware and

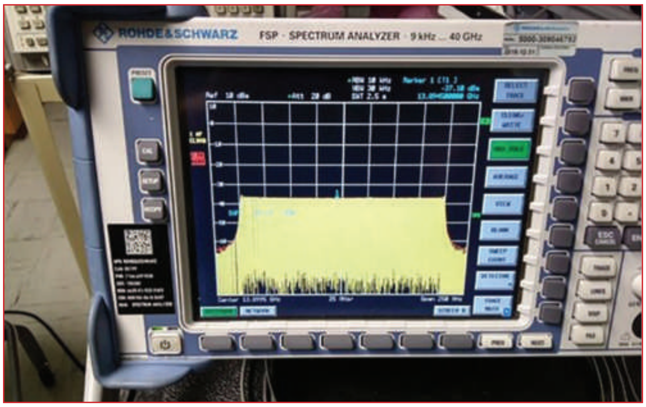

Fig. 6 **200 MHz waveform.**

additional impairments. The preamplifier is enabled to drive the HPA with the synthesized waveform and the state vector is constantly monitored until a new waveform is required, or the test is terminated, by disabling transmission and shutting down gracefully. The flow diagram is depicted in ***Figure 5***.

During pre-installation GBO testing, all potential waveforms and transmission periods were tested at full power with a termination and monitoring coupler in place of the feed to verify system robustness under typical use. Measurement of the 200 MHz waveform is shown in ***Figure 6***.

GBT TRANSMISSION TESTING AND CALIBRATION

Prior to the use of the GBT for transmitting, the GBT software pointing model for the PF was only accurate below 2 GHz. Without updating the software pointing model, the errors when used at 11 to 14 GHz at the PF could have been large enough for the transmitter beam to miss the target. By duplexing a pointing receiver with the transmitter using the same feed horn, on-the-fly updates of the GBT software pointing model were possible without the laborious, time-

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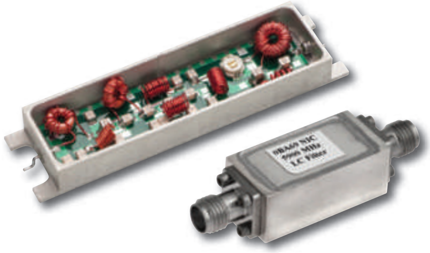

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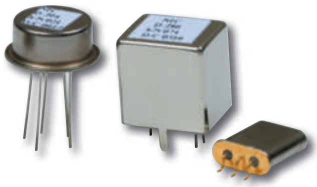

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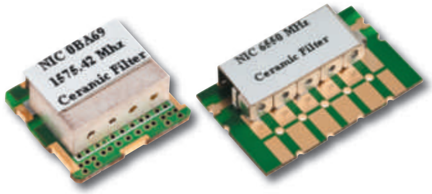
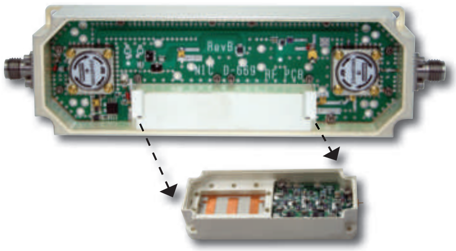
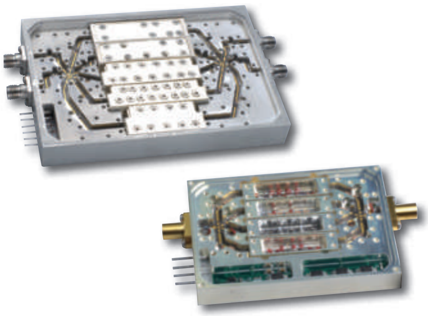


Integrated Assemblies



Switch Filter Banks



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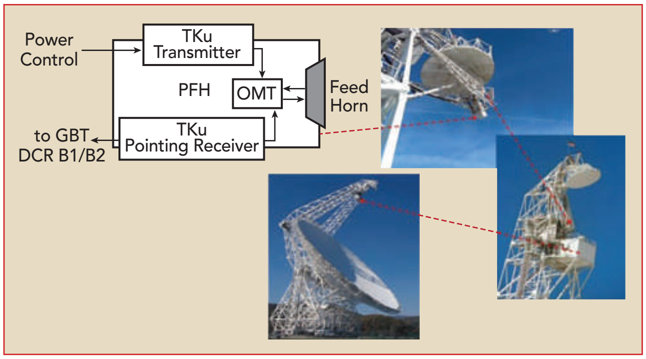

Fig. 7 **PFH block diagram and location on the GBT.**

consuming and potential error-inducing exchanges of the transmitter with a receiver. A general diagram of the PFH and its location on the GBT is shown in ***Figure 7***.

To enable observations with the transmitter, dedicated software changes of the GBT's Manager and Control System were needed. These changes were two-fold: 1) to enable pointing and focusing of the PF receiver; and 2) to enable the 12 GHz during the observations. Implementation of software routines allowed, within ASTRID scripts (GBT Observing Guide, 2017), pointing the transmitter using the PF at 12 GHz (rest frequency center at 11.95 GHz) to peak and focus using the GBT FITS Monitor (GFM) software.

The GFM software fits a beam pattern to a cross-scan on a calibrator and calculates the pointing offset and correction for the observations. The routines were: 1) a new configuration of the transmitter pointing receiver at the PF, rest frequency at 11.95 GHz, connected to the Digital Continuum Receiver (DCR) back-end; 2) running the pointing model at the PF; 3) GFM peak and focus interactive correction using the transmitter pointing receiver at the PF. Prior to transmissions a "pointing run" was executed, where the GBT was pointed at a Ku-Band quasar of well-known location and intensity (ranging 1 to 20 Jansky), and the antenna was moved in azimuth, then elevation. The total power detected in the pointing receiver versus azimuth and elevation directions was measured at a fine scale and from these measurements the pointing model was updated. A focus scan was then executed on the source to calibrate the focus prior to tracking using the ephemeris of the selected target and begin transmission of observations.

Transmission testing consisted of a commissioning phase in which the transmitter went through a series of warm-up cycles through transmission of specific modes of operation including CW and LFM waveforms. The VLBA receiving stations were not involved during the commissioning phase. After the transmit session, tests were dedicated to checking the receiver for pointing and focus corrections/calibration repeatability using geo-stationary (GEO) satellite Ku-Band beacons, i.e. GALAXY18 (GEO Slot#123.0; NORAD#32951, Az 236.5, El 27.1), and radio-astronomical calibrators (Ku-Band quasar). The transmitter was not operating during the calibration session.

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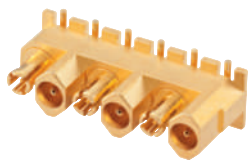

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TABLE 2

VLBA RECEIVER SPECIFICATIONS

Parameter	Value	Notes
Receive Antennas	10	All VLBA Antennas, Subject to Elevation Limits
Antenna Aperture Diameter	25 m	
System Temperature	60 K	Typical Zenith Value
Center Frequency	13.932 GHz	
Receive Bandwidth	128 MHz	

Pointing checks were run through a series of peak scans to test the receiver's sensitivity. The artificial Ku-Band sources saturated the receiver's high-sensitivity channel but were observable switching to the low sensitivity DCR channel B1, X polarization. The radio-astronomical calibrators were observable with the receiver's high-sensitivity DCR channel B2, Y polarization. This configuration was used as default configuration for pointing, focus scans and tracking on targets for observations during transmission and data collection.

DATA COLLECTION

The observations and data collection were coordinated between the GBT and VLBA through planned observations blocks with detailed time sequence, transmit and receive parameters. Target range and elevation above the horizon with respect to transmit and receive sites was based on ephemerides derived from JPL's Horizons system.[3] The GBT operated the transmitter from an elevation between 10 and 80 degrees. The VLBA participated as a set of 10 single-dish receiving stations (see ***Table 2***).

The VLBA's back-end system and recorder were used to acquire the data. Baseband signals were recorded at a Nyquist rate for 16, 32, 128 and 256 MHz bandwidths in both circular polarizations. Data were stored in the VLBI Data Interchange Format with two bits per sample quantization. A portion of the data acquired at 16 and 32 MHz bandwidths was transferred in real time to computers at the VLBA operations center for rapid diagnostic evaluation. The complete set of recordings was later shipped on hard disk from each site. The wide geographic distribution of VLBA antennas meant that, at times, not all antennas were able to participate in the full duration of the observations.

The repeatability of performing blind pointing on preferred targets was satisfactory within a fraction of a beamwidth in azimuth and elevation depending on the sources (20 to 30 arcseconds). Focus offset was established at approximately 1050 mm (900 mm fix correction as per MRQ1R2 +150 mm adjust-

ment), which was added as the default starting correction for the observations. These values were established during the radar run in November 2020 and confirmed in the second radar observation run in March 2021. For the Apollo 15 observation (March 13, 2021) peak and focus scans of the Ku-Band quasar calibrator 0116-1136 (1.151 Jy) are shown in ***Figure 8***, nearby the moon, before tracking on the targeted moon location. Peak scans 38 through 41 on source 0116-1136 are shown in Figure 8a. Focus scan 43 on source 0116-1136 is shown in Figure 8b. During observations, the transmission waveforms and VLBA receive modes would vary depending on observation goals. A summary of used parameters is shown in ***Table 3***.

The opportunity to observe asteroid 2001 FO32 (231937) at a close approach range of 0.01348 AU on March 21, 2021 was planned. The predicted angular difference between transmit and receive ephemeris using JPL's Horizons was 52 arcsec. Therefore, given our 54 arcsec. beamwidth, this ephemeris error required leading the target (courtesy of John Giorgini, JPL) to maximize return SNR. A control panel snapshot during tracking of FO32 and waveform transition detected at the DCR (total power counts) is shown in ***Figure 9***.

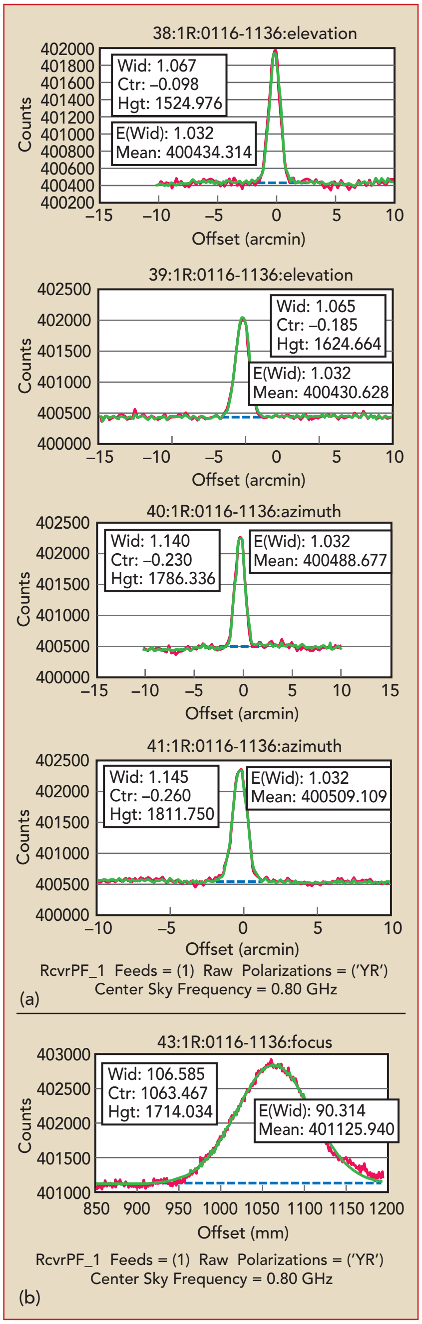

Fig. 8 Peak (a) and focus (b) scans of the Ku-Band quasar calibrator 0116-1136 (1.151 Jy). GFM fits: baseline = dashed blue line; observation data = red; Gaussian fit = green.

TABLE 3 Ku-BAND TRANSMISSION WAVEFORMS AND VLBA RECEIVE MODES

Transmission Waveform Parameters (AWG)								Receive Mode
Code	Description	WF Name	PRI (µs)	BW (MHz)	Frequency (GHz)	Unambiguous Range (km)	Range Resolution (km)	VLBA Baseband (MHz)
W00	Single Tone	LFM00	CW	0	13.9	Infinite	None	U16
W01	Asteroid Detection	LFM01	800	0.05	13.9	120	3.00	U16
W02	Asteroid Detection	LFM02	800	0.085	13.9	120	1.76	U16
W03	Asteroid Detection	LFM03	800	0.1	13.9	120	1.50	U16
W06	Asteroid Detection	LFM06	400	0.14	13.9	60	1.07	U16
W08	Asteroid Detection	LFM08	400	0.4	13.9	60	0.375	U16
W13	Asteroid Imaging	LFM13	200	1.5	13.9	30	0.100	U16
W15	Asteroid Imaging	LFM15	200	3	13.9	30	0.050	U16
W16	Ambiguity Resolution for Lunar Imaging	LFM16	2000	3	13.9	300	0.050	U16
W17	Lunar Course Imaging	LFM17	800	3	13.9	120	0.050	U16
W19	Asteroid Hi-Res Imaging	LFM19	200	6	13.9	30	0.025	U16
W20	Asteroid Hi-Res Imaging	LFM20	100	10	13.9	150	0.015	U16
W21	Asteroid Hi-Res Imaging	LFM21	100	15	13.9	15	0.010	U16
W22	Ambiguity Resolution, Lunar Medium-Res	LFM22	2000	30	13.9	300	0.005	U32
W24	Near Earth Object Imaging	LFM24	30	30	13.9	450	0.005	U32
W26	Hi-Res Lunar Imaging	LFM25	2000	120	13.932	300	0.00125	U128

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Fig. 9 Control panel while tracking FO32.

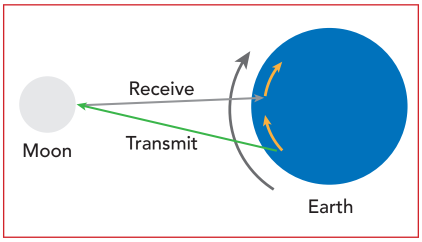


Fig. 10 Earth-moon geometry.

The GBT transmission experiments gave the NRAO and RI&S an opportunity to investigate ways to process long-range radar data collected that included lunar SAR imaging and detection of 2001 FO32. The moon is a perfect candidate for such tests as it is an extremely useful radar calibration target. During the March 2021 testing period, we had an opportunity to observe asteroid 2001 FO32 as well, since it approached within 5.25 lunar distances.

Moon Observations

Consider the geometry in ***Figure 10***. Because the Earth is rotating and the moon is moving in its orbit, the Doppler shifts vary as a function of position that scatter radar energy on the moon. In addition, since the linear frequency modulation on the radar signal has a defined, single-peaked autocorrelation function, processing can separate the radar return in range and range rate. Range corresponds to distance from Earth and range rate corresponds to the east-west position on the moon.

In ***Figure 11***, the vertical extent corresponds to about 25 km, while the horizontal extent corresponds to over 100 km, meaning the curvature is highly exaggerated. A closer view is shown in ***Figure 12***. Note that the inside of the crater in the foreground is visible. This is due to the mismatch between the radar geometry and the observer perspective. From the perspective of the image, the radar energy comes from the top, and illuminates everything in its direct line-of-sight, including the inside of the cra-

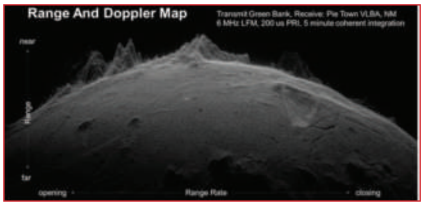


Fig. 11 Image of the moon's surface.

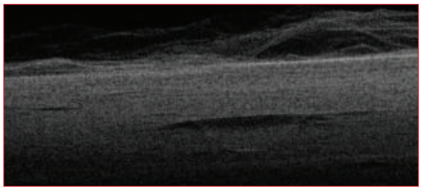
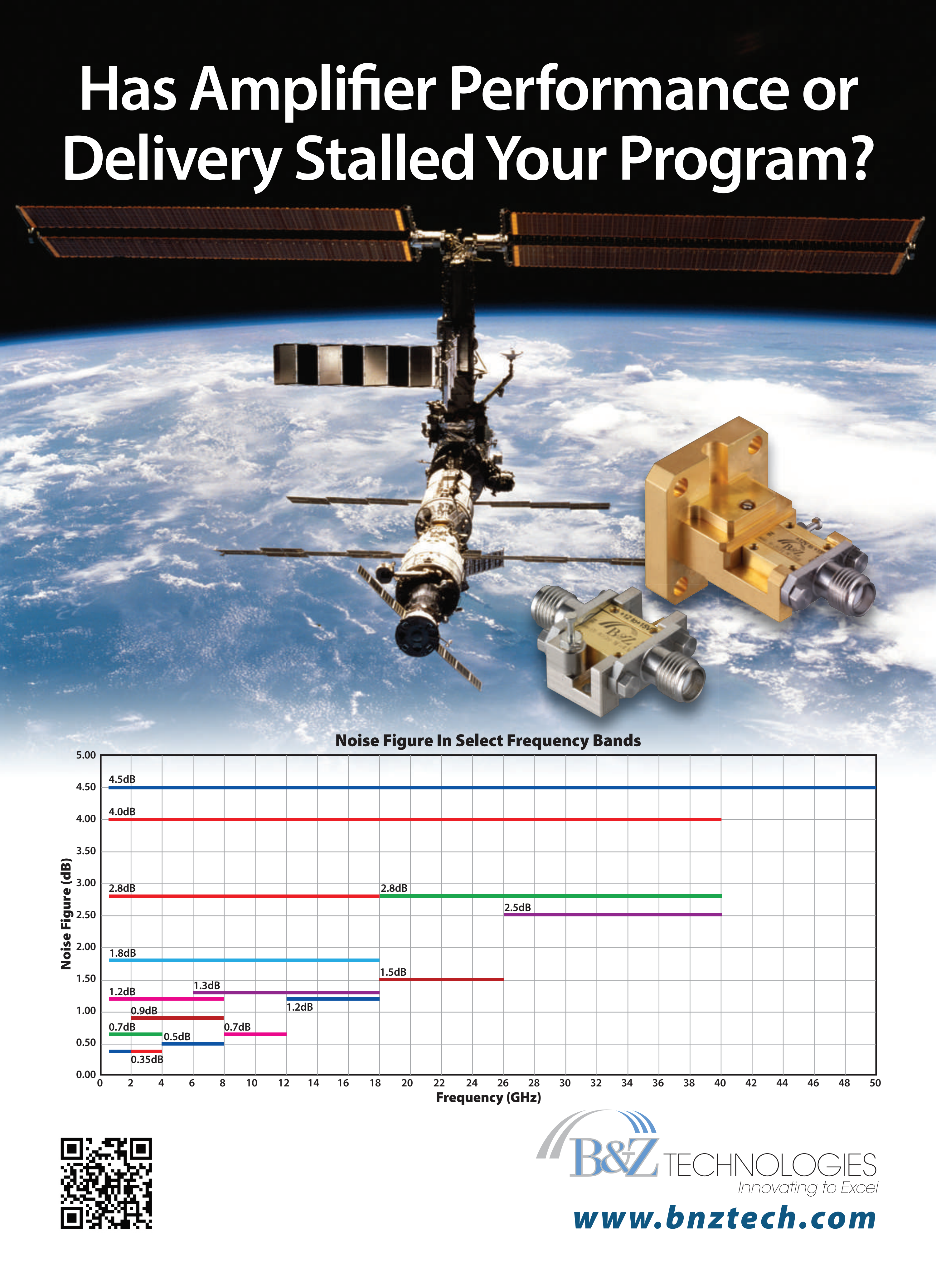


Fig. 12 Closer view of the moon showing the inside of a crater in the foreground.



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ter. This is a common phenomenon in radar images since every point in the radar's line-of-sight appears at a location in the image depending only on that point's range and range rate. Because of this, the horizontal axis in the image corresponds to east and west on the moon, and the vertical axis corresponds to distance toward Earth; it is impossible to know if the image shows the north or south face of the mountains in the background. It may be showing both simultaneously.

When imaging regions of the moon away from the equator, the synthetic aperture created by the rotation of Earth can be exploited to form images. During a five-minute SAR collection, the GBT moves approximately 109 km. Using digital processing, an image can be formed equivalent to a real aperture of that size. The Apollo 15 landing site, shown in ***Figure 13***, has a resolution of 50 x 50 m. With a longer dwell (40 minutes) and higher-bandwidth waveforms, higher resolution images can be formed, as shown in ***Figure 14*** (Apollo 15 with a 5 × 5 m resolution). These images were processed using the Polar Format Algorithm (PFA).[1] The PFA extends the available image size over Doppler-Delay processing, but itself has limitations on image size. Fortunately, correction algorithms are now available that enable larger and higher resolution images.

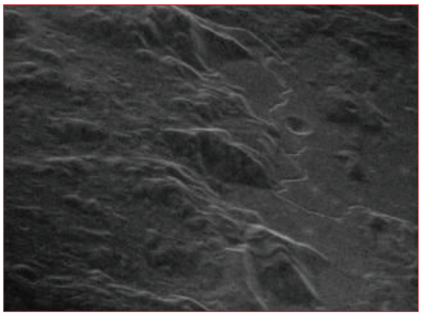

Fig. 13 **Apollo 15 landing site at 50 x 50 m resolution.**

Asteroid 2001 FO32 Observations

During the asteroid close approach, the NRAO/RI&S team tested the Ku-Band transmitter with a variety of waveforms. ***Figure 15*** shows the Doppler spectrum of the return from FO32 during one portion of this test. Because the asteroid has a large line-of-sight acceleration as it crosses Earth's orbit, its Doppler shift is changing too rapidly for coherent integration based on an uncompensated Doppler spectrum. ***Figure 16*** shows the geometry of the closest approach.[2]

At the closest approach, the relative range closure is zero. At five hours before the closest approach, the range rate was—10.3 km/sec (the total magnitude of velocity was 34 km/s.) Therefore at five hours before closest approach, the Doppler at a carrier frequency of 13.9 GHz was approximately 1 MHz and the rate of change of Doppler was roughly 50 Hz/sec.

Using the JPL Horizons tool,[3] a fine-grained prediction of range rate was obtained and applied as a phase to the radar return before coherent integration. The result shows a peak within 100 Hz of the expected location. In a future planetary radar system, this extremely precise measurement could be used to update the orbital ephemeris of the object in real time.

CONCLUSION

The NRAO/RI&S/Qorvo experiments demonstrated the feasibility of GBT as a transmitter to enable radar observations while testing the potential of solid-state microwave technology. The data collected during these experiments using basic radar signal processing algorithms validates the feasibility of an NRAO radar using the GBT as a transmitter and the VLBA antennas as receivers. This points the way to a future, more capable planetary radar system that can provide precision orbit determination and high-resolution images of solar system objects. It has opened the path to a new development for planetary radar capabilities at the GBT that could lead to an effective radar instrument being planned and deployed in the coming years. Microwave technical capabilities are evolving where consideration of future high-power, multiple-frequency phased array systems could provide opportunities to bridge the gap of current radar systems for solar system exploration and more. ■

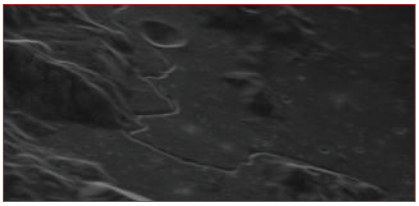

Fig. 14 Apollo 15 landing site at 5 x 5 m resolution.

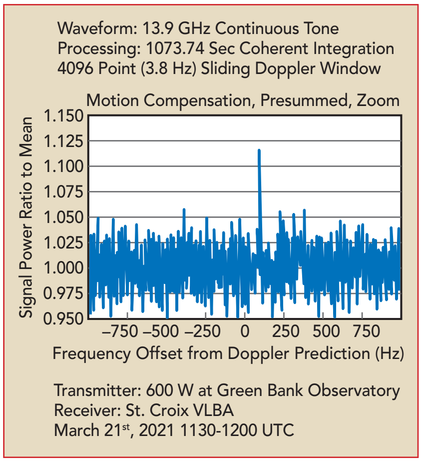

Fig. 15 Doppler spectrum of the return from FO32 during the asteroid's close approach.

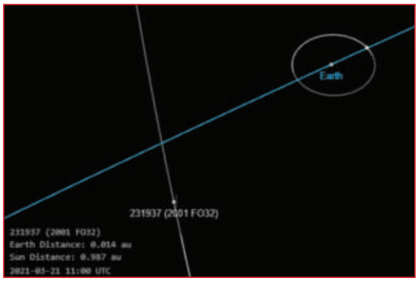

Fig. 16 Geometry of FO32's closest approach to Earth.

ACKNOWLEDGMENTS

The authors acknowledge Frank Ghigo (GBO retiree) for his dedication and guidance through the development, testing and observations phases conducted with the GBT Ku-Band transmission experiments. Associated Universities, Inc. operates both GBO and NRAO under a cooperative agreement with NSF.

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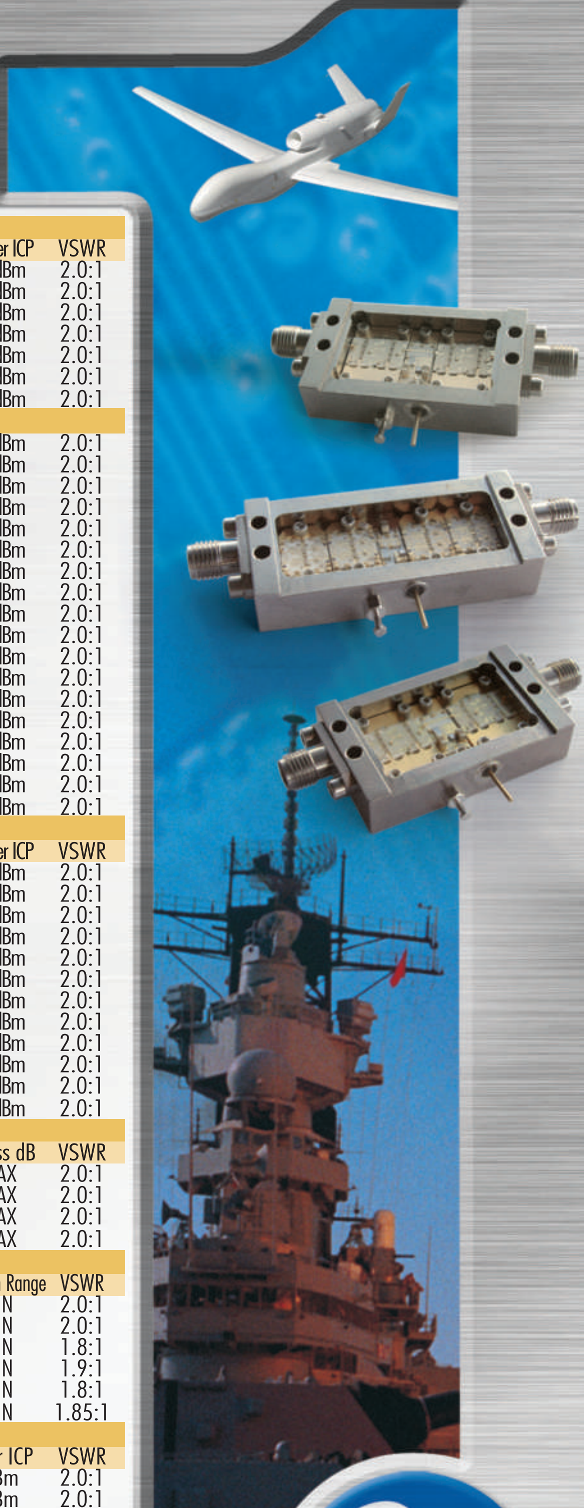

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CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	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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NASA, SpaceX Launch DART: First Test Mission to Defend Planet Earth

NASA's Double Asteroid Redirection Test (DART), the industry's first full-scale mission to test technology for defending Earth against potential asteroid or comet hazards, launched November 24 at 1:21 a.m. EST on a SpaceX Falcon 9 rocket from Space Launch Complex 4 East at Vandenberg Space Force Base in California.

Just one part of NASA's larger planetary defense strategy, DART—built and managed by the Johns Hopkins Applied Physics Laboratory in Laurel, Md.—will impact a known asteroid that is not a threat to Earth. Its goal is to slightly change the asteroid's motion in a way that can be accurately measured using ground-based telescopes.

DART will show that a spacecraft can autonomously navigate to a target asteroid and intentionally collide with it—a method of deflection called kinetic impact. The test will provide important data to help better prepare for an asteroid that might pose an impact hazard to Earth, should one ever be discovered. LICIACube, a CubeSat riding with DART and provided by the Italian Space Agency, will be released prior to DART's impact to capture images of the impact and the resulting cloud of ejected matter. Roughly four years after DART's impact, European Space Agency's Hera project will conduct detailed surveys of both asteroids, with particular focus on the crater left by DART's collision and a precise determination of Dimorphos' mass.

At 2:17 a.m., DART separated from the second stage of the rocket. Minutes later, mission operators received the first spacecraft telemetry data and started the process of orienting the spacecraft to a safe position for deploying its solar arrays. About two hours later, the spacecraft completed the successful unfurling of its two, 28-ft.-long, roll-out solar arrays. They will power both the spacecraft and NASA's Evolutionary Xenon Thruster—commercial ion engine, one of several technologies being tested on DART for future application on space missions.

DART Launch (Source: NASA)

DART's one-way trip is to the Didymos asteroid system, which comprises a pair of asteroids. DART's target is the moonlet, Dimorphos, which is approximately 530 ft. in diameter. The moonlet orbits Didymos, which is approximately 2,560 ft. in diameter.

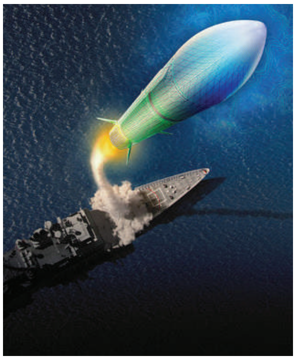
Since Dimorphos orbits Didymos at a much slower relative speed than the pair orbits the sun, the result of DART's kinetic impact within the binary system can be measured much more easily than a change in the orbit of a single asteroid around the sun.

The spacecraft will intercept the Didymos system between Sept. 26 and Oct. 1, 2022, intentionally slamming into Dimorphos at roughly 4 miles per second. Scientists estimate the kinetic impact will shorten Dimorphos' orbit around Didymos by several minutes. Researchers will precisely measure that change using telescopes on Earth. Their results will validate and improve scientific computer models critical to predicting the effectiveness of the kinetic impact as a reliable method for asteroid deflection.

A sophisticated guidance, navigation and control system, working together with algorithms, called Small-body Maneuvering Autonomous Real Time Navigation (SMART Nav), will enable the DART spacecraft to identify and distinguish between the two asteroids. The system will then direct the spacecraft toward Dimorphos. This process will all occur within roughly an hour of impact.

MDA Selects Raytheon Missiles & Defense to Develop First-ever Counter-hypersonic Interceptor

Raytheon Missiles & Defense, a Raytheon Technologies business, has been selected by the Missile Defense Agency (MDA) as one of the companies to develop and test the first interceptor specifically designed to defeat hypersonic threats. The weapon, called Glide Phase Interceptor (GPI), will defeat a new generation of hypersonic missiles—weapons that travel more than 5x the speed of sound and maneuver rapidly in flight.



GPI (Source: Raytheon Missiles & Defense)

"Raytheon Technologies systems are the cornerstone of today's ballistic missile defenses. We're building on that knowledge to advance the missile defense system for future threats," said Tay Fitzgerald, vice president of Strategic Missile Defense. "GPI's speed, ability to withstand extreme heat and ma-

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neuverability will make it the first missile designed to engage this advanced threat."

GPI will intercept hypersonic weapons in the glide phase of flight, which occurs once a missile has re-entered Earth's atmosphere and is maneuvering toward its target. The initial development phase will focus on reducing technical risk, rapidly developing technology and demonstrating the ability to intercept a hypersonic threat.

Developed on behalf of the MDA, GPI will be integrated into the U.S. Navy's Aegis Weapon System, a ship- and shore-based defense system.

DARPA Selects BAE to Advance Quantum Technology for Military Antennas

BAE Systems' FAST Labs will advance quantum technology and revolutionize RF sensing by breaking constraints to antenna designs that have persisted for more than a century.

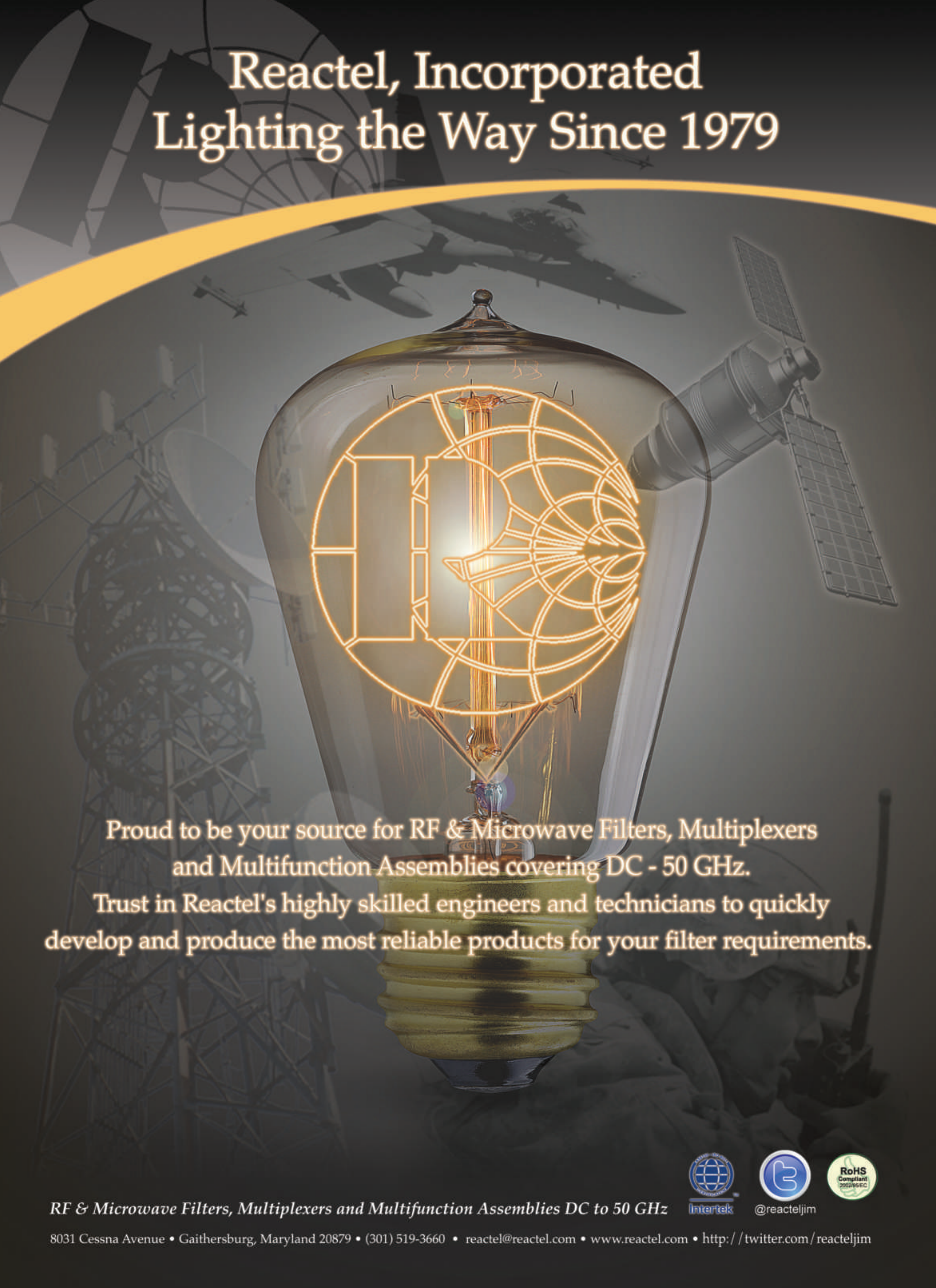
BAE Systems has been awarded multiple development contracts from the Defense Advanced Research Projects Agency (DARPA) to advance quantum technology and revolutionize RF sensing by breaking constraints to antenna designs that have persisted for more than a century. Leveraging quantum sensing can reduce size while increasing sensitivity and accessible bandwidth by several orders of magnitude.

> Quantum sensing decouples antenna size from signal wavelength.

"While still in the early development phase, quantum sensing relies on fundamentally different physics than conventional antennas. This may allow us to circumvent traditional aperture design limits for sensitivity and size," said Julia MacDonough, product line director at BAE Systems. "As a result of these programs, BAE Systems' FAST Labs will be at the forefront of quantum sensing to support the warfighter."

A quantum approach to aperture development decouples the size of the antenna from the wavelength of the incoming signal. This can reduce the size and number of antennas on Department of Defense platforms.

Awarded earlier this year, the three quantum aperture-related contracts, which total $6.5 million, include work as a prime contractor on Quantum Apertures Technical Area 2 and teaming with ColdQuanta in both Technical Area 1 of Quantum Apertures and the Science of Atomic Vapors for New Technologies (SAVaNT) program.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Next-Generation Efforts in Wireless Communications Move Forward

While there is still a lot of innovation ahead for 5G, many projects identified as "Next G" and "6G" are already underway globally with significant leadership from the Americas. 5G Americas announced the publication of a new white paper entitled *Mobile Communications Towards 2030*, which details how the industry will continue to build and evolve wireless communications networks for consumers and enterprises beyond what we know as 5G today.

Chris Pearson, president of 5G Americas, said, "While 5G is at the beginning of a long era of innovation with a full road map of exciting enhancements, the work to research and study the next generation of possibilities is already underway. It is imperative that the Americas region build and maintain leadership, gathering input from wireless operators and vendors, as well as academia, other vertical industries and the government."

Emerging next-generation wireless communications use cases are still several years away from being formulated but include some thrilling opportunities. Early use cases may include multi-sensory telepresence and immersion via extended reality, as well as use of digital twins in Industry 4.0's cyber-physical systems. Additional use cases may include holographic teleportation, tactile and haptic communications and many more.

Wireless impacts on vertical industries may include opportunities in precision crops and livestock, biosensor monitoring in health care, advanced driver assist and autonomous driving for transportation systems, first responder systems that allow rapid data collection from sensors and real-time situational awareness and government and defense systems utilizing ubiquitous connectivity.

Additionally, the white paper provides insight into the vision and requirements necessary for next-generation wireless networks to come to life. Emerging applications may require very high data rates into the Tbps range for digital twins and tactile feedback, extremely wide coverage for rural or defense needs and reliability up to "seven nines" (99.99999 percent uptime) for intense remote control and digital twin requirements.

2022 Will Mark a New Era for Wireless Innovation

As Wi-Fi 6, 6E and ultra-wideband (UWB) adoption accelerates across a growing number of end markets, 2022 will represent a key year for wireless connectivity innovation. ABI Research forecasts that this year Wi-Fi 6 will reach well over 1.5 billion annual chipset shipments, while 6 GHz enabled Wi-Fi 6E chipsets are forecasted to nearly triple year on year. Alongside this, UWB devices are expected to reach nearly half-a-billion units as adoption increases within smartphones, wearables, speakers, personal trackers and RTLS applications.

"The wireless connectivity landscape continues to evolve thanks to the emergence of new technologies, enhancements to established technologies and continued innovation and competition across the chipset, module and device ecosystems," explained Andrew Zignani, research director at ABI Research.

Wi-Fi 6 adoption grew across the board in 2021. High volume smartphone devices from Apple, Samsung, Xiaomi, Huawei, OPPO and Vivo have all adopted the technology. This is expected to continue into 2022, while the growing availability of mobile Wi-Fi 6E chipsets and platforms from leading chipset vendors such as Qualcomm, Broadcom and MediaTek will accelerate the transition to 6 GHz capable devices. The transition to Wi-Fi 6 in the tablet realm is also expected to be swift thanks to adoption from most of the leading vendors, including Apple, Samsung, Lenovo and Huawei.

The PC market is also rapidly transitioning toward Wi-Fi 6 and 6E technology. Intel launched its Wi-Fi 6 solution as a configuration option in 2019 and has been partly integrated into all its PC platforms since then. Hundreds of laptop models from leading notebook vendors, including Lenovo, HP, Dell, Acer, ASUS and Apple, among others, now support Wi-Fi 6 technology. In addition, other PC connectivity chipset suppliers, such as Broadcom, MediaTek, Realtek and Qualcomm, have all had Wi-Fi 6 design wins within notebooks over the last couple of years. Alongside this, Wi-Fi 6E is projected to see considerable growth within the notebook space throughout 2022 and beyond, following initial traction in 2021 and the development of new chipsets and strategic partnerships.

Apple's decision to deploy UWB technology in its iPhone 11, iPhone 12 and iPhone 13 series has accelerated adoption of the technology, as has the support from Samsung in its Galaxy S21+ and Ultra, Note 20 Ultra, Z Fold 2 5G, Xiaomi in its Mi Mix 4 and Google in its Pixel 6 Pro. ABI Research anticipates UWB to be incorporated in nearly one-quarter of smartphones that will ship in 2022 as more models support the technology.

Zephyr HAPS Achieves Connectivity in Trial Conducted by Airbus and NTT DOCOMO

Airbus and NTT DOCOMO, INC. have demonstrated the ability to use its solar-powered Zephyr High Altitude Platform Station (HAPS) to deliver future wireless broadband connectivity. The trial took place in the U.S. in August, when

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the Zephyr S aircraft undertook approximately 18-day stratospheric flights to test various capabilities.

Carrying an onboard radio transmitter, the Zephyr S provided an agile datalink during a stratospheric flight to simulate future direct-to-device connectivity. Test data was captured at different altitudes and at different times of day and night, focusing on assessing how connectivity is affected in the stratosphere by factors including weather conditions, different elevation angles and aircraft flight patterns.

Tests included various bandwidths to simulate direct-to-device service from the HAPS to end users using low, nominal and high throughput. The demonstration confirmed the viability and versatility of the 2 GHz spectrum for HAPS-based services and the use of a narrow (450 MHz) band to provide connectivity in a range of up to 140 km.

The measurement and analysis of the propagation of radio waves transmitted from Zephyr demonstrated the feasibility of stratospheric communications to devices such as smartphones. Based on the results of this experiment, Airbus and NTT DOCOMO aims to provide communication services to mountainous areas, remote islands and maritime areas where radio waves have difficulty reaching.

As part of efforts to further advance 5G and prepare for 6G, "coverage expansion" to expand communication networks to any location, including air and sea, is being studied worldwide. To achieve this, non-terrestrial network technology is expected to be used. In addition to coverage of the air and sea, stratospheric HAPS networking will be useful for disaster preparedness and many industrial use cases, for example, to increase communication capacity in densely populated areas such as event venues and remotely controlling heavy equipment at construction sites.

The test data will be used to inform future LTE direct-to-device services that are expected to be provided via the Airbus Zephyr HAPS solution.

Zephyr (Source: Airbus Defense and Space)

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

IN MEMORIAM

Eli Brookner, 90, a Lexington, Mass., resident since 1962 and Principal Engineering Fellow for Raytheon, died at Emerson Hospital in Concord on November 29, 2021. He was the husband of the late Ethel (Bobick) Brookner. He was born in Brooklyn, N.Y., on April 2, 1931, as the son of the late Angel and Fanny Brookner. He was a graduate of Stuyvesant High School in New York City, and went on to attend City College where he met his future wife. Later, he earned his Ph.D. from Columbia University. With a career spanning more than half a century at Raytheon as a radar engineer, he played a major role in the development of radar and phased array radar systems. He is recognized as a leader and advisor for over twenty leading radar programs for civil and defense applications. A life member of IEEE, Eli received the Dennis J. Picard Medal, Warren White Award for Excellence in Radar Engineering, as well as IEEE Centennial and Millennium medals. A renowned international lecturer and published author, his teachings have educated thousands of radar engineers worldwide. An extensive traveler, he has lectured in and visited 22 countries in every continent but the Antarctic. He will also be remembered as a passionate ballroom dancer up until his passing. He leaves behind two sons, Lawrence Brookner of Paris, along with his wife Vera, and Richard Brookner of Sunnyvale, Calif., one grandson, Daniel Brookner, a nephew, Jonathan Liebowitz, and a sister-in-law, Anita Raynes.

Robert Thiele, 74 of Gilbert, Ariz., passed away on Sunday, November 14, 2021. He was born August 23, 1947, in Los Angeles, Calif., to the late Robert Thiele Sr. and Grace Overton-Thiele. He married Christine Yvonne Malik on October 29, 1972 and they were married for 49 years. Prior to marriage, Bob served in the U.S. Air Force in Vietnam and was honorably discharged with a Commendation Metal. Bob started his engineering career in the early 1970s as the facilities manager and moved up to operations division manager for the West Coast Division of Americon|Omni Spectra|M/A-Com. From 1978 to 1995, he was the founder and CEO of Semflex, Inc in Mesa, Ariz. After selling the company, he stayed on with Emerson|Sterling Holding. He became VP of Engineering until 2008. In 2009, an opportunity came to start up a new cable and connector company based in Massachusetts. He became the VP|general manager of Dynawave Cable, Inc. and retired back in Arizona in 2018.

MERGERS & ACQUISITIONS

Soitec acquired **NOVASiC**, an advanced technology company specialized in polishing and reclaiming wafers on SiC. The acquisition allows Soitec to drive the development of semiconductors for power supply systems in electromobility and industrial applications. The closing of the transaction is expected before the end of calendar year 2021. In a strategic move to address the need of the automotive and industrial markets for performance and energy efficiency, Soitec is expanding its product portfolio beyond SOI with SiC. This crystal material unlocks greater performance, optimized design and lower environmental impact for power electronics.

Molex announced the acquisition of wireless technology and intellectual property from **Keyssa**, eliminating the need for physical cables or mechanical connectors to handle near-field, device-to-device communications. Ideally suited to support high volume mobile and consumer device development, this unique chip-to-chip wireless technology can handle high data rate transmissions while offering greater design freedom and simplified manufacturing. This move will help Molex commercialize next-generation contactless connector capable of supporting exponentially higher data rates and full-duplex communications. The company will leverage its longstanding signal integrity expertise and mmWave antenna capabilities to reduce connectivity barriers while complementing Molex's existing portfolio of industry-leading connectivity solutions.

Safran recently announced that it has entered into exclusive discussions to acquire **Orolia** from **Eurazeo**. Orolia is a leader in Resilient positioning, navigation and timing (PNT) solutions that improve the reliability, performance and safety of critical civilian, military and space operations, including in harsh or altered GNSS environments. Orolia has a broad portfolio of technologies across the Resilient PNT value-chain with full system capabilities and is a provider of PNT equipment, simulation and test solutions. Orolia is also providing emergency locator beacons for commercial aviation and military applications. The acquisition represents a unique opportunity for Safran and Orolia to extend their Resilient PNT solutions globally.

COLLABORATIONS

Modelithics welcomed **IEH Corp.**, a leader in hyperboloid PCB connector products, into the Modelithics Vendor Partner (MVP) Program at the Sponsoring level. In

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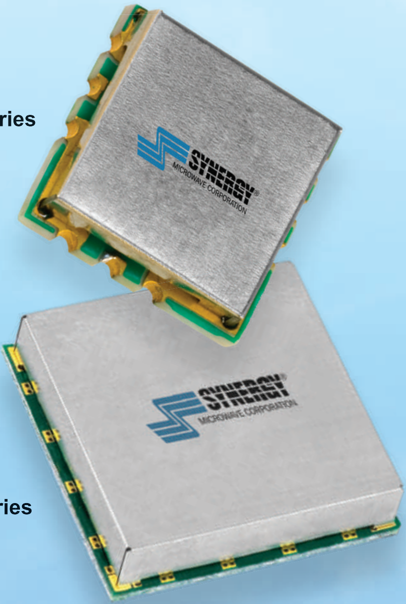
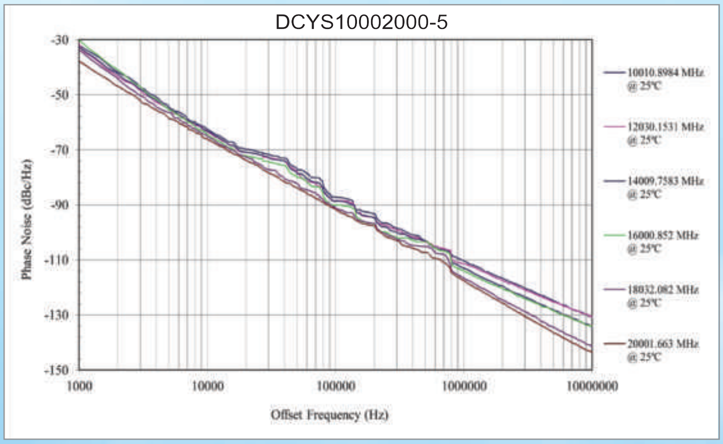
L to K Band Ultra-Wideband
Voltage Controlled Oscillators

Model Number	Frequency	Phase Noise @ 10 kHz offset	Phase Noise @ 100 kHz offset	Tuning Voltage	Output Power
	(GHz)	(dBc/Hz)	(dBc/Hz)	(V)	(dBm Min.)
DCO100200-5	1 - 2	-95	-117	0.5 - 24	+1
DCYS100200-12	1 - 2	-105	-125	0.5 - 28	+4
DCO200400-5	2 - 4	-90	-110	0.5 - 18	-2
DCYS200400P-5	2 - 4	-93	-115	0.5 - 18	0
DCO300600-5	3 - 6	-78	-104	0.3 - 16	-3
DCYS300600P-5	3 - 6	-78	-109	0.1 - 16	+2
DCO400800-5	4 - 8	-75	-98	0.3 - 15	-4
DCO5001000-5	5 - 10	-70	-95	0.3 - 18	-4
DCYS6001200-5	6 -12	-70	-94	0.5 - 15	+2
DCYS8001600-5	8 - 16	-68	-93	0.5 - 15	-1
DCYS10002000-5	10 - 20	-53	-79	0.5 - 15	-4

DCO Series



DCYS Series



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addition to becoming a Sponsoring MVP, IEH and Modelithics are collaborating to develop 3D models for the HGM, HMK, HMM, HRM and HVM hyperboloid PCB connector series. 3D models are also in development for the HKC and HKX Hyperkinetic connectors, which are high speed, high density hyperboloid modular interconnects. Through the MVP Program, these models will be available for free extended 90-day trial use of all Modelithics models available for IEH components to approved customers.

Mini-Circuits and the **National Radio Astronomy Observatory (NRAO)** announced that the National Science Foundation has awarded a Partnerships for Innovation grant to fund the joint proof-of-concept development of low temperature co-fired ceramic (LTCC) reflectionless filters for mmWave applications. The collaboration will combine NRAO's expertise in the design of reflectionless filter circuits with Mini-Circuits' industry-leading design and manufacturing capability for LTCC components.

Ericsson announced a partnership with **Nex-Tech Wireless** to commercially launch Nex-Tech Wireless's 5G capabilities in rural Kansas. Ericsson has been the primary vendor for Nex-Tech Wireless on their 4G deployments and the current 5G technologies utilize Ericsson's 5G Evolved Packet Core, Cloud IMS and RAN products and solutions to support 5G non-standalone in key areas in the carrier's coverage areas. Nex-Tech Wireless is headquartered in Hays, Kan., and has been connecting thousands of people and businesses through a robust wireless network using trusted technology.

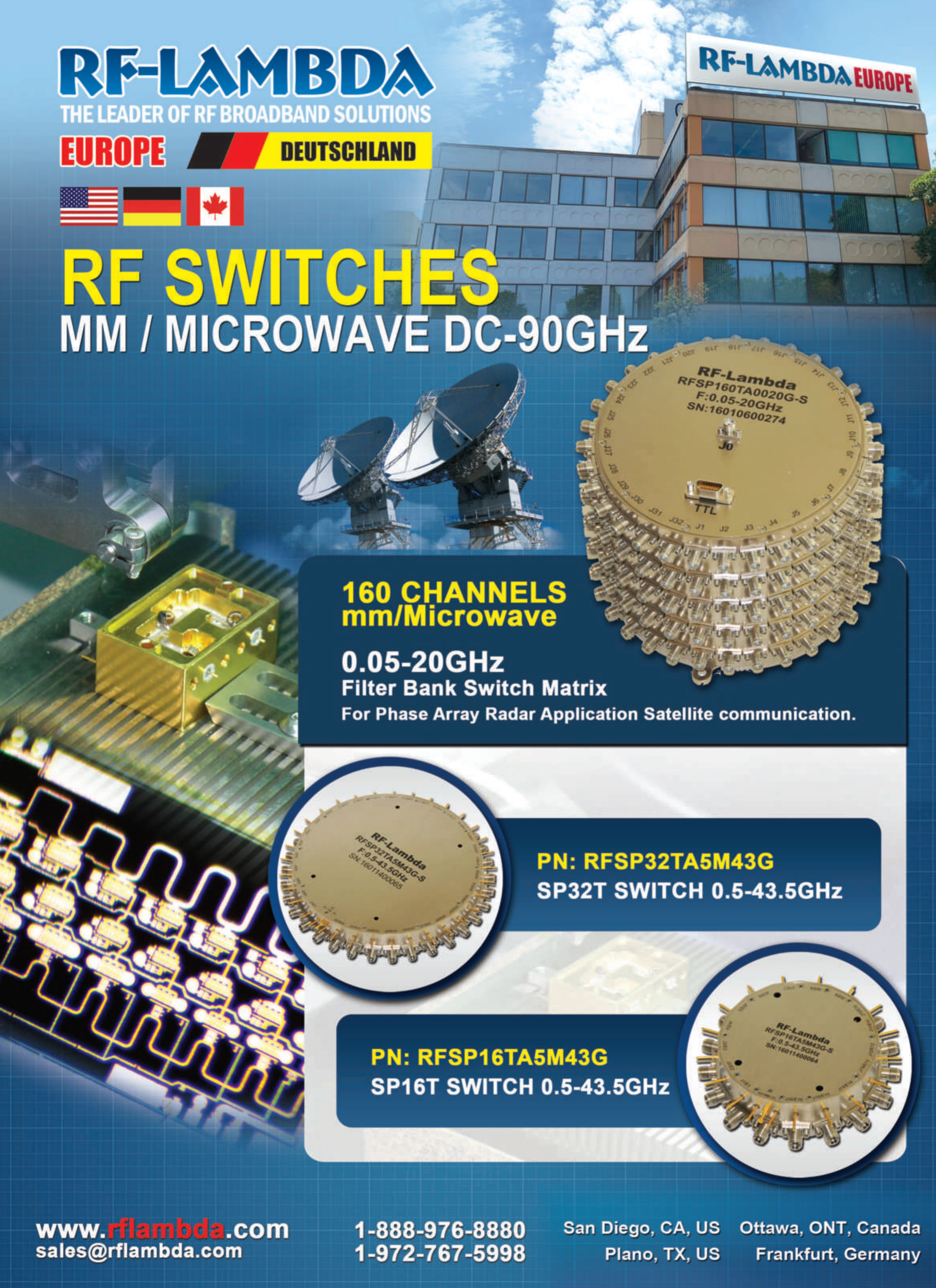
As 5G networks are being rolled out globally, the evolution of the 5G NR standard continues. With Release 17, 3GPP will extend the frequency support of 5G NR mmWave bands into the unlicensed spectrum up to 71 GHz, a frequency band traditionally used by non-cellular standards like IEEE 802.11ad and 11ay. To address new testing challenges related to this bandwidth extension and to evaluate the performance of the latest generation RF transceiver chipsets, **Rohde & Schwarz** and **Sivers Semiconductors** teamed up to test RF transceivers for 5G NR up to 71 GHz.

ACHIEVEMENTS

Analog Devices Inc. (ADI) recently received four Electronics Industry 2021 Awards presented by Datateam Business Media. The Electronics Industry Awards honor the best professionals, products, projects and companies across the electronics sector. Established in 2018, the Electronics Industry Awards annually recognize the best people, products and business practices at the forefront of innovation. The awards winners are determined by a 50/50 weighted decision from an industry vote and a panel of expert judges to ensure the winners are selected for technical expertise and outstanding reputations.

Keysight Technologies Inc. announced that the company is first to deliver a complete CTIA authorized 5G mmWave OTA test system for validating device transceiver performance in a laboratory environment, accelerating the roll-out of wireless connectivity broadband across the U.S. Keysight is the first test and measurement supplier to gain system vendor authorization from CTIA, an organization that represents the U.S. wireless communications industry and companies throughout the mobile ecosystem. Many advanced 5G applications require wide bandwidths, which are only accessible in frequency range 2 spectrum to support ultra-high data rates and ultra-low latencies.

The LoRa Alliance®, the global association of companies backing the open **LoRaWAN®** standard for IoT LPWANs, announced that **LoRaWAN** was officially approved as a standard by the International Telecommunication Union (ITU), the United Nations specialized agency for information and communication technologies. The standard is titled Recommendation ITU-T Y.4480 "Low-power protocol for wide-area wireless networks" and is under the responsibility of Study Group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SP16T SWITCH 0.5-43.5GHz
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20 of the ITU Telecommunication Standardization Sector (ITU-T), ITU's standardization expert group for "IoT and smart cities and communities." The LoRa Alliance has been engaged with ITU throughout much of 2021 to complete its qualification process.

CONTRACTS

The Defense Logistics Agency has executed a $316 million contract option for **BAE Systems**' advanced M-Code GPS modules, raising the contract funding to $641 million. The modules provide dependable PNT for ground troops, vehicles, aircraft and precision munitions. The contract will ensure the availability of Common GPS Modules (CGM) for advanced military GPS receivers with anti-jamming and anti-spoofing capabilities that enable operation in contested environments. Under the contract option executed in November, BAE Systems will manufacture CGMs for future ground, airborne and weapon GPS receivers for the U.S. Department of Defense (DoD) and its allies.

Northrop Grumman Corp. has received a $153 million dollar contract award from the **U.S. Navy** for full rate production of lots 10 and 11 of the AGM-88E2 Advanced Anti-Radiation Guided Missile (AARGM). The contract includes production of missiles for the U.S. Navy and German Air Force. Northrop Grumman has produced more than 1,500 AARGM missiles for the international cooperative acquisition program with the U.S. Navy (serving as the executive agent) and the Italian Air Force. The missile provides a supersonic, air-launched tactical missile system that upgrades legacy AGM-88 HARM systems with advanced capability to perform suppression and destruction of enemy air-defense systems.

Peraso Technologies Inc., a privately held company that has entered into a definitive agreement for a business combination with **MoSys Inc.**, pending certain conditions to be completed, announced that it has received a US$3M purchase order from a tier 1, fixed wireless OEM for its PRM2140X 802.11ad mmWave phased array modules. The introduction of a point-to-multipoint (PtMP) module optimized for long-range outdoor applications into the market is a major milestone for Peraso. A robust PtMP solution allows service providers to leverage multiple customers over a single access point, thereby significantly reducing the total cost of deployment for wireless carriers.

Verus® Research announced it has been awarded a $450,000 one-year task with the **U.S. Army** under its existing Test & Evaluation Non-Kinetic (TEN-K) contract to enhance Directed Energy System Placement Analysis (DESPA) capability for test and evaluation purposes. The ElectroMagnetic Interactive Tool for Test and Evaluation of Radio Frequency Systems (EMITTERS) effort will include tailored capabilities to support the test and evaluation of counter-unmanned aircraft systems and the testing of high-power microwave (HPM) weapons. Verus Research will expand capabilities through EMIT-

TERS to include an interactive, three-dimensional view of outdoor effects testing and pre-defined scenarios for HPM test sites.

PEOPLE

▲ *Philip Chesley*

Qorvo® announced the appointment of **Philip Chesley** as president of Qorvo's Infrastructure & Defense Products segment, effective immediately. Chesley will report to Bob Bruggeworth, president and chief executive officer of Qorvo, and he will succeed James Klein, who previously announced his intention to retire from the company. Chesley most recently served as vice president and general manager of the Industrial and Communications Business Unit at Renesas. He was previously senior VP and general manager of the Automotive, Aerospace and Analog Product Group at Intersil, which was acquired by Renesas in 2017. He joined Intersil in 2004 and served in several executive leadership roles.

▲ *Roger Wells*

Mercury Systems Inc. announced that **Roger Wells** has joined the company as executive vice president and president of Mercury's Microelectronics division, effective immediately. Reporting to Mark Aslett, Mercury's president and chief executive officer, Wells brings more than 25 years' experience across multiple disciplines including engineering, business development, program management and executive management. Previously, Wells served as vice president and general manager for the Unmanned & Integrated Solutions business unit of Teledyne FLIR. Earlier in his career, he worked as a DoD civilian supporting the development and fielding of worldwide C4ISR networks and information systems.

▲ *Tom Casale*

Quantic™ Electronics announced that **Tom Casale** has been appointed general manager of its Corry Micronics and TRM Microwave business units. During his 40-year career, Casale has worked at Cobham Advanced Electronics Systems and L3Harris. Casale earned a B.S. in electrical engineering from Worcester Polytechnic Institute as well as an M.S. in electrical engineering from Tufts University and management from Lesley University. Corry is a supplier of RF and microwave components and subsystems and has been manufacturing EMI/RFI filters for more than 50 years. Specializing in high power and broadband solutions, Corry is a critical supplier and partner to major companies serving the aerospace, defense, medical, communications and specialty test industries.

Anritsu's new Rubidium™ MG362x1A low-noise RF/microwave signal generator redefines signal purity and stability.

Signal purity and frequency stability are essential distinguishing characteristics of a high-frequency microwave signal generator. The Rubidium MG362x1A signal generator product line is built to deliver outstanding signal purity and frequency stability across a broad frequency range from 9 kHz to 43.5 GHz, even at high output power levels.

Along with AM, FM and PM modulation, Rubidium also features comprehensive pulse generation capabilities for radar signal simulation. Coupled with built in, easy to use, on location frequency and power calibration, the Rubidium MG362x1A offers exceptional overall utility and long-term value for a broad range of measurement applications.

Be a Leader – Discover how you can get better measurement confidence with Anritsu. View our complete line of test and measurement solutions at:
www.anritsu.com/test-measurement

KEY FEATURES

- Low phase noise and spurious performance unmatched in today's market
- Atomic clock frequency stability with optional internal Rubidium frequency reference
- High output power with low spurious eliminates need for external power amplification
- Low cost of ownership with on-site frequency and power calibration capabilities

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Around the **Circuit**

▲ *Denis Kohlhagen*

Gowanda Electronics announced that the company's VP of Sales, **Denis Kohlhagen**, will retire on January 31, 2022 after a 23 year career with the company. Kohlhagen joined Gowanda Electronics in early 1999 as a territory manager. After coming on board he nurtured and developed long-term relationships with several major customers who now, two decades later, continue to purchase high performance components from Gowanda. He was also instrumental in expanding into new markets for the company by engaging customers in medical, military, space and high-end commercial sectors. Over the years, Kohlhagen developed strategies to sell new products designed by CEO Don McElheny (now retired) and CTO Jim Cadwallader.

▲ *Zhong Chen*

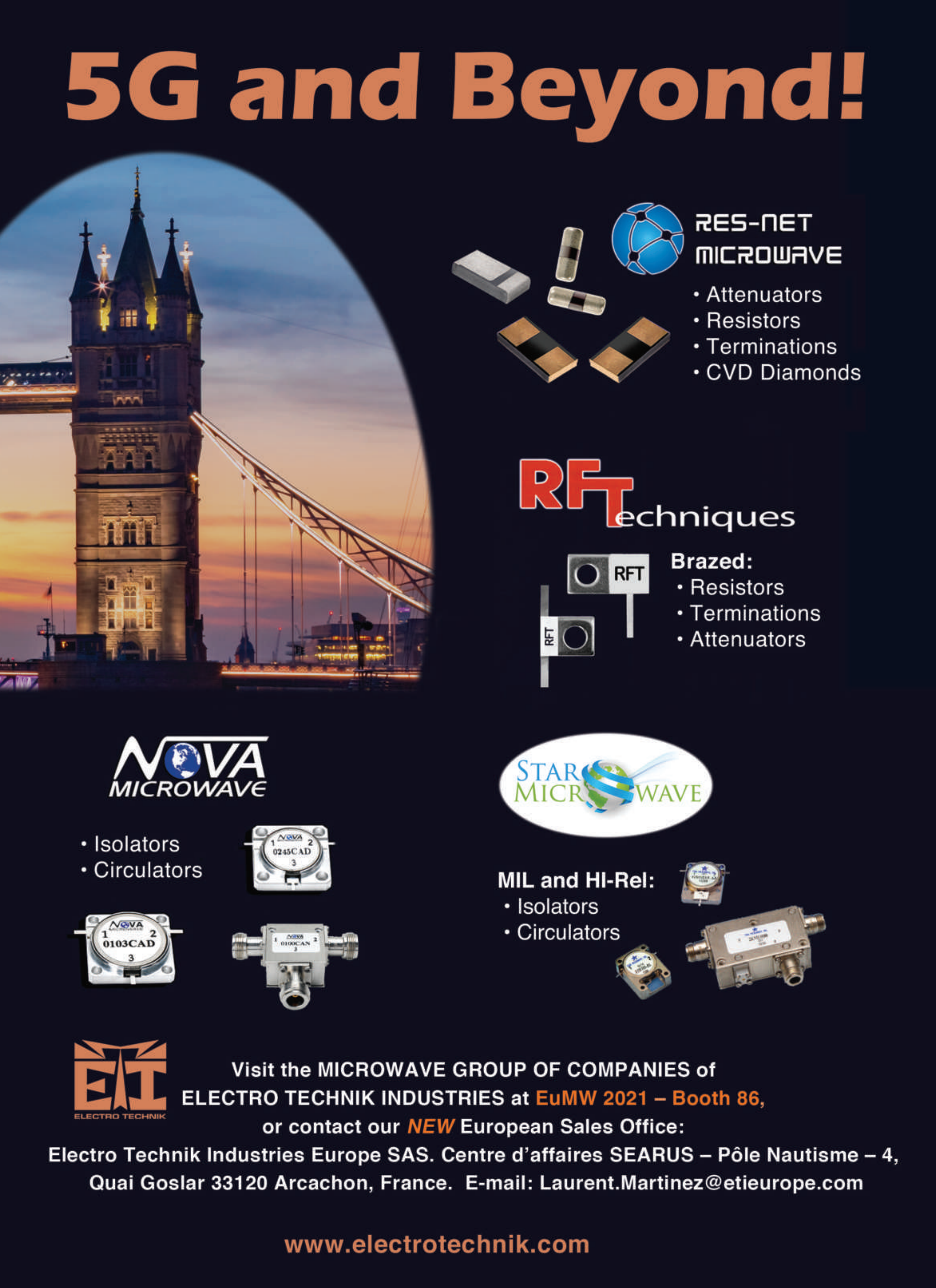
Members of the **Antenna Measurement Techniques Association (AMTA)** elected **Zhong Chen**, ETS-Lindgren's director of RF Engineering, as vice president of its Board of Directors (BoD). Elected during the AMTA 2021 Symposium held from October 24-29 at the Hilton Daytona Beach Oceanfront Resort in Daytona Beach, Fla., Chen assumed his term as vice president on January 1, 2022. The new position follows Chen's two years as secretary of the AMTA BoD in 2020 - 2021. C.J. Reddy with Altair was elected president of AMTA and also assumed his term on January 1, 2022.

▲ *Jonathan Neale*

Filtronic plc announced that further to **Reg Gott**'s retirement at the AGM on October 28, 2021, it has appointed **Jonathan Neale** as non-executive chairman, effective immediately. Jonathan Neale has been chief operating officer of McLaren Group for the past five years, prior to which he held a number of executive roles including chief executive officer of McLaren Racing F1, between 2001 and 2016. He has occupied principal roles, leading strategic operational and infrastructure planning for the business and has been pivotal in the integration of the McLaren Racing, McLaren Applied and McLaren Automotive businesses.

REP APPOINTMENTS

Altum RF announced a new sales representative agreement with **HUTEC Corp.**, covering customers located in South Korea. Founded in 1995, HUTEC has its headquarters office in Seoul, South Korea, and specializes in active and passive components and modules for telecom, military, space and industrial applications. HUTEC focuses not only on superior technical support, but also on providing the right products to meet customers' requirements in a timely manner. Altum RF is an international company, with strategic partnerships and office locations that span the globe to support its growing product portfolio.


5G and Beyond!
RES-NET MICROWAVE
• Attenuators
• Resistors
• Terminations
• CVD Diamonds
RF Techniques
RFT
Brazed:
• Resistors
• Terminations
• Attenuators
NOVA MICROWAVE
• Isolators
• Circulators
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STAR MICROWAVE
MIL and HI-Rel:
• Isolators
• Circulators
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Quai Goslar 33120 Arcachon, France. E-mail: Laurent.Martinez@etieurope.com
www.electrotechnik.com

Around the **Circuit**

Intelliconnect/CryoCoax, leaders in the manufacture of cryogenic cable assemblies, announced it has been appointed as a franchised stocking distributor by **XMA Corporation-Omni Spectra®** focusing on cryogenic connectivity products as well as standard attenuators and high frequency microwave components. This exciting new development for Intelliconnect complements their existing product range of RF, microwave and cryogenic connectivity and increases their ability to offer a one-stop shop to the market. XMA Corporation-Omni Spectra® is considered the market leader of microwave components in the cryogenics and general microwave component spaces and has been a partner with Intelliconnect/CryoCoax for several years.

PLACES

Triad RF Systems announced the opening of a new manufacturing center, conveniently located opposite the company's existing design center in East Brunswick, N.J. This new facility increases Triad's manufacturing capacity sixfold and creates additional space to expand the company's innovative design center. Triad's investment in the new manufacturing center is a direct response to growing global demand for their amplifiers, integrated radio systems and custom RF products for unmanned systems, drones, CubeSat platforms, custom military applications and electronic warfare systems.

Granite River Labs, a leader in engineering services and test solutions for connectivity and charging, announced the opening of its new lab in Karlsruhe, Germany. Located in a major technology hub about one hour from Stuttgart and Frankfurt, GRL's new state-of-the-art lab supports the growing needs of the automotive, medical and industrial automation industries in Europe to validate and troubleshoot high speed connectivity and charging interfaces. These interfaces include automotive Ethernet, HDMI, USB, MIPI and DDR, as well as USB power delivery and Qi wireless charging. Industry-leading test solutions from Rohde & Schwarz will be an integral component of GRL's new compliance test and certification capabilities.

TÜV SÜD is investing £1.65 million in an 1,800 m^2 fully automated EMC and RF testing facility. Based at TÜV SÜD's Hampshire headquarters, the facility's three semi-anechoic EMC chambers will be in addition to five existing ones—significantly increasing test capacity. This will help manufacturers achieve a shorter time to market for products which integrate RF modules, including technologies such as Bluetooth, Wi-Fi and the new 6E frequency bands. As the new chambers will also offer testing to worldwide compliance specifications, this will support growing demand from manufacturers to access multiple global markets simultaneously.

18~40GHz NEW

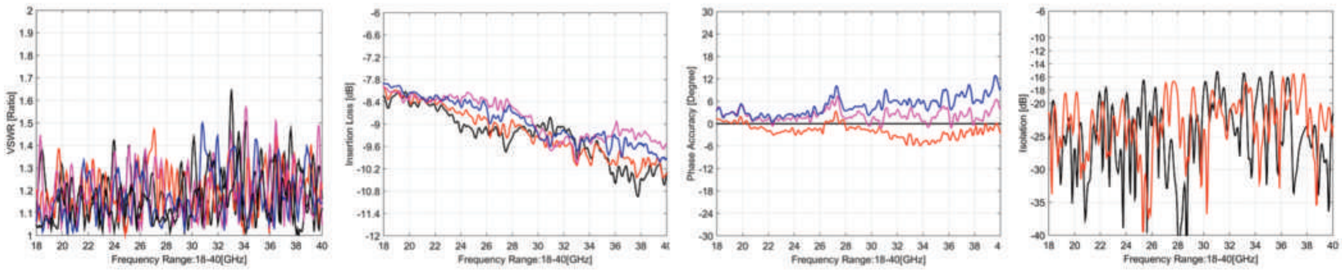
4 × 4 BUTLER MATRIX

- Cover 5g NR FR2 Frequency Bands
- Excellent Phase Accuracy, Amplitude Balance
- Low VSWR / Low Insertion Loss / High Isolation
- Good Stability & Repeatability

P / N	Freq. Range (GHz)	VSWR Max.(:1)	Insertion Loss* Max.(dB)	Amplitude Bal. Max.(dB)	Amplitude Flatness Max.(dB)	Phase Accuracy Max.(Deg.)	Isolation Min.(dB)
SA-07-4B180400	18-40	2	12	±1.2	±2	±15	10

*Theoretical 6dB Included

— Typical Test Curve** —



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

More Information-
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EuMW 2021
United in Microwaves

Welcome to the 24th European Microwave Week

It is with great pleasure that we welcome you to the 24th European Microwave Week (EuMW), which is taking place at ExCeL in London, U.K., 13-18 February 2022. The pandemic has greatly affected the way we live our lives for almost two years now. Many people around the world have lost their lives and many have had their lives changed permanently by the pandemic. One impact has been how we interact with each other. The human instinct is usually to come together to help deal with problems, to form strategies and build partnerships and, to celebrate successes.

EuMW is one such event that is motivated by these instincts. It is for this reason the organizing team for this year's event has worked long and hard to ensure we have an event where we can come together and meet, face to face, as a community to continue to develop and celebrate our area of science, engineering and technology. We feel that it is vital to achieve this goal. This is the reason why EuMW 2021 is taking place during February 2022—we have delayed hosting the event so that it is more feasible to hold a successful in-person event whilst still respecting any national and international restrictions on social interactions and travel.

This is the third time that EuMW has been hosted in London, following on from previous highly successful events in 2001 and 2016. London is a natural venue for prestigious scientific events, being the home of such long-standing scientific institutions as the Royal Society (founded in 1660), the University of London (founded in 1836) and the Institution of Electrical Engineers (founded in 1871), as well as the home to many famous scientists, including James Clerk Maxwell, Lord Rayleigh, Charles Wheatstone, Alan Turing, etc. Our moto for this year's EuMW is 'United in Microwaves.' This reflects the traditional feeling of unity in our community and demonstrates how we can use this conference to re-establish and further develop this feeling of unity within our community of colleagues and fellow professionals, despite the recent problems caused by the pandemic.

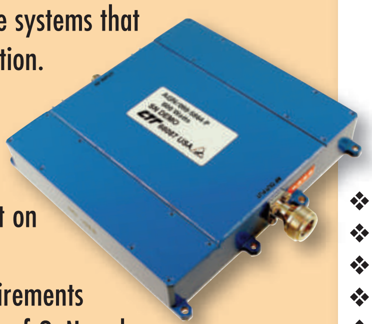
EuMW 2021 continues the annual series of highly successful microwave events that started back in 1998. EuMW 2021 comprises three co-located conferences: European Microwave Conference (EuMC), Eu-

Enabling wideband frequency agility

GaN and GaAs Solid-State Power Amplifiers for Multi-Function, Radar and EW System Design

Whether your application is narrowband, wideband or ultra-wideband, operating in pulsed or CW mode, CTT's power amplifiers are an especially attractive choice for new multi-function frequency-agile systems that effectively conserve weight, space and power consumption.

The characteristics of the portion of the electromagnetic spectrum selected for any of these particular system designs are undoubtably the most important to the end user, as it has the greatest impact on the type of information required and received.



Engineered specifically to meet the stringent requirements imposed by many modern system designs, CTT's family of GaN and GaAs-based solid-state power amplifiers excel in a wide range of applications.

CTT has delivered production quantities of amplifiers with power levels from 10 through 600 Watts – and higher – for a variety of multi-function, radar and EW applications.

• AMDR • Shipboard Radar • SAR • AESA Radar • TCDL
• VLO/FLO Threats • New Land Radar • EW • UAVs

More than 37years ago CTT, Inc. made a strong commitment to serve the defense electronics market with a simple goal: **quality**, **performance**, **reliability**, **service** and **on-time delivery** of our products.

Give us a call to find out how our commitment can support your success.

It's that simple.

Microwave Technology Leadership

- ❖ **Power Amplifiers**
  - **NEW GaN and GaAs Models**
  - Radar Bands up to 1kW
  - EW Bands up to 400W
  - Pulse and CW
  - Solid-State Microwave Power Modules
  - Rack-Mount Configurations
- ❖ **Low-Noise Amplifiers**
- ❖ **Up and Downconverters**
- ❖ **Subsystems**
- ❖ **SWaP Optimization**
- ❖ **Custom Engineered Options**

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ropean Microwave Integrated Circuits Conference (EuMIC) and European Radar Conference (EuRAD). There are also many workshops and short courses associated with each of these conferences, along with several Special and Focused Sessions. Two highlights are Special Sessions on the life and works of two prominent members for our community who sadly passed during 2020: Professor Peter Clarricoats and Professor Roberto Sorrentino. Peter Clarricoats was chair of the first EuMC, held in London in 1969 and chair of the 9th EuMC in the U.K. in 1979; he received a Eu*MA* Distinguished Service award in 2005. Roberto Sorrentino was a founder member of the European Microwave Association and president of Eu*MA* from 1998 to 2009. They will both be sadly missed.

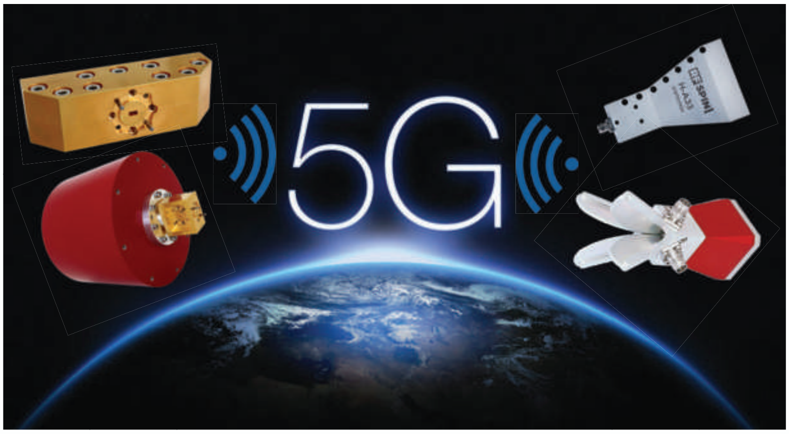
In addition, there are three Forums, covering: Defence, Security and Space; Automotive; and Beyond 5G Technologies. There is also a very large trade show—the largest RF and microwave trade show in Europe—where the leading companies from our industry exhibit their very latest technological developments. EuMW 2021 also has several activities aimed specifically at students. These include: the Tom Brazil Doctoral School of Microwaves, the European Microwave Training School, the Career Platform and IEEE Young Professionals. There is also the Women in Microwaves event, in which both women, and men, are encouraged to participate. We sincerely hope that you will enjoy a memorable experience in London at EuMW 2021.

Nick Ridler
EuMW General Chair
National Physical Laboratory, U.K.

John Cunningham
EuMW General Co-chair
University of Leeds, U.K.

THE FUTURE OF COMMUNICATION

For those who have noticed slow video streaming or download rates for their large digital files on their smartphone or other mobile communications device working on 4G LTE, 5G is the answer. It operates within many of the frequency ranges as 3G and 4G LTE, but it provides much-needed bandwidth for growing numbers of worldwide wireless users and their applications. 5G can be implemented in low-band, mid-band or high-band millimeter-wave 24 GHz up to 54 GHz.



Waveguide transmission lines not only handle more power with much less loss at millimeter-wave frequencies than coaxial cables, but when interconnected to waveguide horn antennas they can combine for the high gain, typically 25 dBi or more at mid-band for even "standard-gain" waveguide horn antennas, and the outstanding directivity needed to maintain line-of-sight (LOS) links at millimeter wave frequencies. Moreover, waveguide horns are also physically small enough to be total unobtrusive within the many indoor 5G infrastructure setups.

When 5G links require even more gain, top component suppliers such as **Impulse Technologies** are ready with high-gain waveguide horn antennas from innovative developers such as Anteral and RF Spin. With waveguide horn antennas, millimeter waves will be the future of 5G.

57%

5G Network technology is projected to cover 57% of the market worldwide by 2025.

3 BILLION

By 2025, there is projected to be 3 billion 5G mobile subscriptions.

Anteral releases a High Performance Diplexer for 5G E-band Backhaul Systems with point-to-point radio links at 71/76 GHz and 81/86 GHz and can deliver up to 10 Gbps in a dense radio environment. The technology used makes it less sensitive to manufacturing tolerances, which is perfect for mass production. Its fabrication robustness makes this diplexer ideal for industrial applications. Anteral also provides a Dual Polarized Lens Horn Antenna for 5G & 6G (E & D-Band) Backhaul Systems ideal for High-Gain Lens Horn Antennas.

RF Spin offers the QRH50E antenna, which is an enhanced version of the broadband bestseller that helps hundreds of the world's leading players develop, test, and deploy 5G networks. This is an advanced antenna with exceptional technical parameters and excellent design in aluminum alloy with a frequency range of 5 GHz to 50 GHz. As part of their ongoing efforts to provide cutting-edge tools for the development, testing and implementation of advanced 5G networks, RF Spin launches a pyramidal horn antenna (H-A33) with a frequency range of 22 GHz to 33 GHz.

Impulse Technologies will provide you with the most innovative components and the latest technology to keep you up to speed. To learn more please contact **mleone@impulse-tech.com.**

ANTERAL

IMPULSE TECHNOLOGIES INC.
AN INTERNATIONAL PROCUREMENT COMPANY

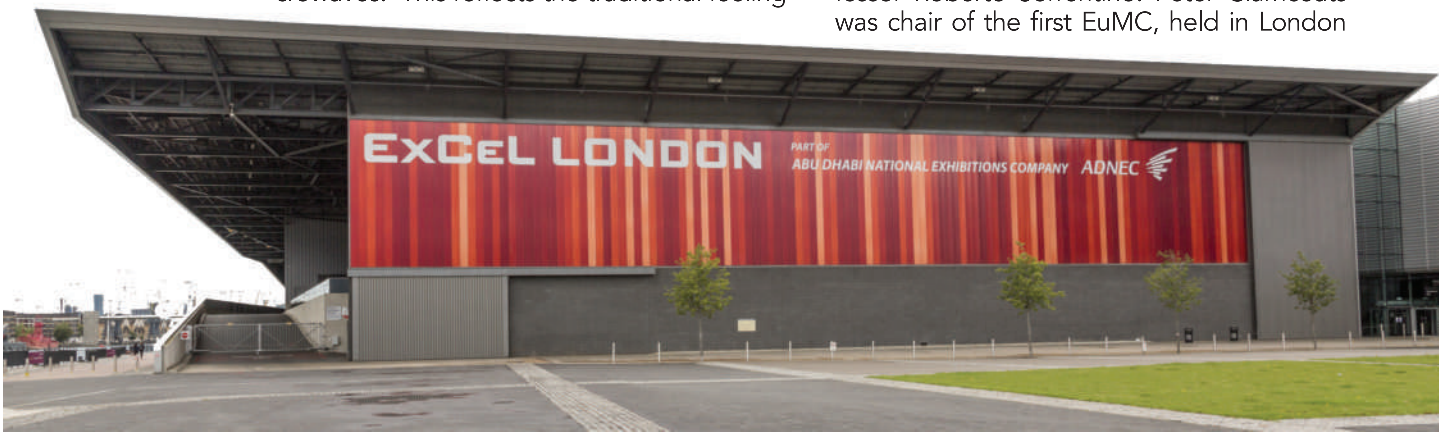
RF SPIN

24th European Microwave Week Overview

Patrick Hindle, Microwave Journal *Editorial Director*

The 24th European Microwave Week (EuMW) is taking place at ExCeL in London, U.K., 13-18 February 2022. EuMW 2021 is taking place during February 2022 as the European Microwave Association (EuMA) delayed hosting the event so that it is more feasible to hold a successful in-person event due to restrictions on social interactions and worldwide travel. We hope that February will be enough time for the COVID restrictions to be relaxed and hope the virus infections are greatly reduced by then so we can gather safely.

As discussed in the welcome message, the moto for this year's EuMW is 'United in Microwaves.' This reflects the traditional feeling of unity in our community and demonstrates how we can use this conference to re-establish and further develop this feeling within our community of colleagues and fellow professionals. EuMW 2021 comprises three co-located conferences: European Microwave Conference (EuMC), European Microwave Integrated Circuits Conference (EuMIC) and European Radar Conference (EuRAD). There are also many workshops and short courses associated with each of these conferences, along with several Special and Focused Sessions. Two highlights are Special Sessions on the life and works of two prominent members for our community who sadly passed during 2020: Professor Peter Clarricoats and Professor Roberto Sorrentino. Peter Clarricoats was chair of the first EuMC, held in London



Social Events

EuMIC Cocktail Reception

Monday 14th February 2022
18:00 – 20:00

***Cost*: Free to all EuMIC delegates (Sponsor: GAAS® Association)**
(Please bring your badge to gain admission)
***Location*: Onsite in the Exhibition Hall N19 – N23**

This event will start at 18:00 to permit attendees to also join the Foundry Session which begins at 18:30. However, there will be plenty of food and drinks for attendees who will join the event after the final EuMIC papers finish at 18:20 - so please join us when you are free!

Automotive Forum Networking Dinner

Monday 14th February 2022
19:00 – 22:00

***Cost*: Free to registered Automotive delegates**
(please bring your badge to gain admission.)
***Location*: Off-site: The Fox Excel**
(Located just outside the West Entrance of Excel.)

Join us for drinks and a 3 course dinner to give you the chance to network and discuss the issues raised throughout the Conference in an informal setting.

EuMW Welcome Reception

Tuesday 15th February 2022
18:30 – 21:30

***Cost*: Free to conference delegates & invited exhibitors**
***Location*: The Platinum Suite (level 1)**

All registered conference delegates, as well as invited representatives from companies participating in the exhibition are invited to the EuMW 2021 Welcome Reception, sponsored by Keysight Technologies, Horizon House Publications and EuMA. Delegates will need to bring their badge and exhibitors their invite along with them to gain entrance. The evening will begin with drinks at 18:30 followed by the General Chairs' handover from EuMW 2021, London to EuMW 2022, Milan as well as an address from the Platinum Sponsor, Keysight Technologies. The open-buffet dinner will be served from 19:00.

The EuMW Cruise on the River Thames

Wednesday 16th February 2022
19:00 – 22:00

***Cost*: £ 39.00 for all guests**
***Location*: North Greenwich Pier (by the O2)**

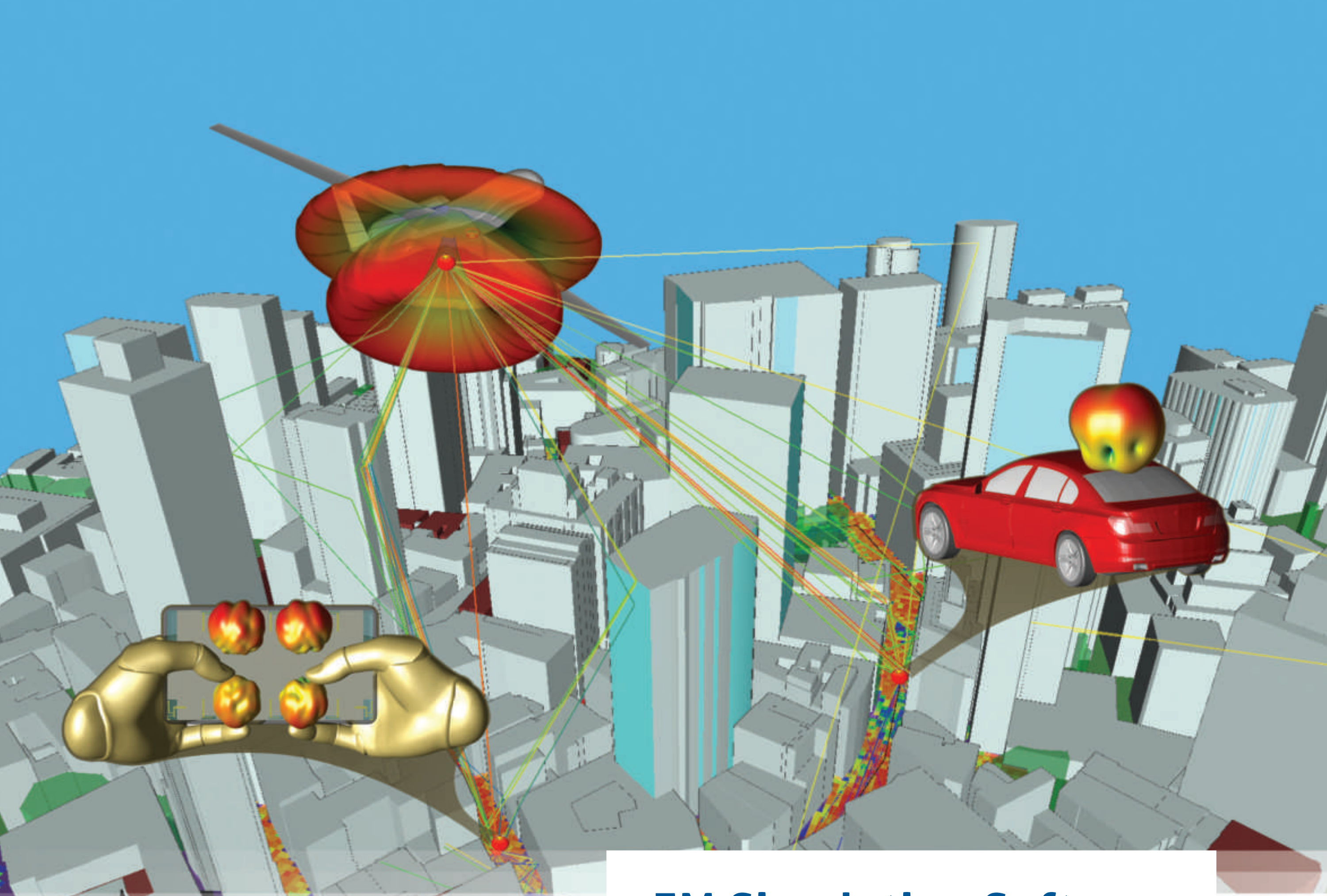
Join us aboard City Alpha and City Gamma boats for a traditional three hour Thames sightseeing cruise leaving at 19:00. The cruise will take you along the Thames into Central London before turning and heading back down river to Greenwich. This unique sightseeing experience will be complimented with drinks and canapes. Tickets are limited, so register today!

EuRAD Lunch

Friday 18th February 2022
13:00 – 14:00

***Cost*: Free to registered EuRAD delegates**
(please bring your badge to gain admission.)
***Location*: ICC Capital Suites 14 – 16**

A seated hot plated lunch for EuRAD delegates to catch up and round off a busy week.



in 1969, and chair of the 9th EuMC in the U.K. in 1979; he received a Eu*MA* Distinguished Service award in 2005. Roberto Sorrentino was a founding member and president of Eu*MA* from 1998 to 2009.

There is also a large exhibition—the largest RF and microwave trade show in Europe—where the leading companies from our industry exhibit their latest technological developments. The exhibition will feature more than 100 companies ranging from devices to components, software to test/measurement, and distribution to services. The MicroApps presentations will also be part of the exhibition featuring product technologies from various companies.

EuMW 2021 also has several activities aimed specifically at students. These include: the Tom Brazil Doctoral School of Microwaves, the European Microwave Training School, the Career Platform and IEEE Young Professionals. There is also the Women in Microwaves event, in which both women, and men, are encouraged to participate. In addition, there are three Forums covering: Automotive; Defence, Security and Space; and Beyond 5G Technologies.

In 2019, Eu*MA* for the first time organized the Automotive Forum to provide an open platform for industrial experts to discuss technical aspects, concepts and radar architectures as well as market issues in the area of microwaves in the automotive industry. The forum takes place on 14 February consisting of a good mix of technical presentations, plenary and panel discussions as well as networking time. This year's event will focus on the following topics: radar testing technologies, virtual radar testing, imaging radar for autonomous driving and radar market, technology and game changers. The forum is mainly devoted to technical experts from 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, Space and Security Forum will kick off with the EuRAD opening and then hold an all-day series of sessions focusing on Space Sensing on 16 February. It will cover the current state-of-the-art in spaceborne RF sensing and discuss its key technical enablers as well as the challenges it faces moving forward. World-renowned experts from aerospace primes, SMEs, space agencies and government across Europe will present their work in this area. Lunch boxes are provided to registrants of the forum for free, compliments of *Microwave Journal*.

The 5G and Beyond Forum focuses on technologies beyond 5G into 6G taking place on 17 February. The forum is for one day with

invited speakers from academia and industry. It covers a wide range of subjects that pertain to next-generation communications including 6G standardization, environment aware networks, advanced sensing and low-power radars. The forum will include a panel session, coffee breaks and packed lunch.

This year is the 16th EuMIC Conference, which has been jointly organized by the GAAS® Association and EuMA since 2006. For the second year, the conference will not happen in autumn but will be held on 14-15 February 2022. EuMIC is the premier European technical conference for RF and microwave microelectronics as part of the EuMW. The aim of the conference is to promote the discussion of recent developments and trends and to encourage the exchange of scientific and technical information covering a broad range of microwave, mmWave, terahertz and related topics, from materials and technologies to ICs and applications that will be addressed in all of their aspects: theory, simulation, design and measurement.

This year is the 51st edition of EuMC, returning to London, the city where EuMC was first hosted back in 1969. EuMC is the largest event in Europe dedicated to a broad range of high frequency topics ranging from novel semiconductor and packaging technologies, photonics, passive and active microwave/mmWave circuits and antenna (arrays), up to system level, with innovative solutions for many applications including for example, biomedical, mobile and IoT.

The 18th EuRAD 2021 will be held from the 16-18 February 2022. This radar conference is the major European event for the present status and the future trends in the field of radar research, technology, system design and applications. The EuRAD conference will bring together a global network of researchers, practitioners and institutes working on topics related to the following four areas of focus: 1) Radar Subsystems and Phenomenology, 2) Radar Signal and Data Processing, 3) Radar Architecture and Systems and finally 4) Radar Applications.

For many delegates, this will be the first face-to-face large-scale event they attend in a long time and hope to have an excellent conference by bringing world-class researchers, industry and academia together. The ability to interact in person at conference is a brilliant opportunity that is difficult to replicate and as the first physical conference for many in two years, let's hope attendees can enjoy this experience and get the most out of it.

The RF/Microwave Industry in the UK and Ireland, Birthplace of Radar and the GaAs MMIC

Helen Duncan
MWE Media Ltd., U.K.

After a year of unprecedented compromises, which nevertheless accelerated the pace of technological progress, European Microwave Week (EuMW) returns to London in February for the first time since 2016. This review of the microwave marketplace in my home country is inevitably a more personal one than those in previous years. In addition to profiling some of the main players in the market in 2021, I will reflect on some of the home-grown heroes of the microwave industry in the U.K. and Ireland who have influenced my own career and whose achievements continue to shape the landscape today.

HISTORICAL LANDMARKS

Within a 20-mile radius of where I live in rural Northamptonshire, in England's East Midlands, are three significant landmarks in the history of RF. Firstly, there is the tiny village of Stowe Nine Churches, where a plaque by the roadside (see ***Figure 1***) commemorates the 1935 experiment when Robert Watson-Watt and Arnold Wilkins used the signals from the nearby BBC radio transmitter at Daventry to demonstrate the feasibility of radar. The local historical connection continues with the world-famous Bletchley Park, where the codebreakers of World War II intercepted German communications and cracked the code of the Enigma machine, giving the U.K. and its allies a critical advantage that helped shorten the war.

Finally—and the reason I originally moved to this part of the country—there is Caswell, the former Plessey research center near Towcester (now owned by photonics manufacturer Lumentum), where the late Jim Turner developed the first commercially-available RF GaAs FET in 1970. In 1976, Turner led the team that included Ray Pengelly, who demonstrated the world's first GaAs MMIC. Caswell was still basking in the glory of these achievements when I started work there as a new graduate, in August 1977, the same week as the late Tom Brazil, who subsequently was a professor at University College Dublin, chaired the 2006 European Microwave Conference and was elected president of the IEEE MTT-S.

The Caswell site's involvement in MMICs continued until the GaAs line was shut down in 2004, by which time it was trading as Bookham Technologies.[1] Several microwave companies trace their roots to the Plessey legacy and remain in the Northamptonshire area: Microwave Technology designs and manufactures GaN power amplifiers (PAs) with output power to 56 dBm at X-Band, as well as offering design consultancy services. Enterprise Control Systems designs and manufactures RF surveillance and countermeasure systems for military and security applications, including bi-directional coded orthogonal frequency-division multiplexing data links and the AUDS C-UAS RF inhibition systems that counter both small consumer and long-range winged drones. SJ Technologie designs passive RF and microwave components and distributes a range of ferrite, garnet, dielectric and load materials.

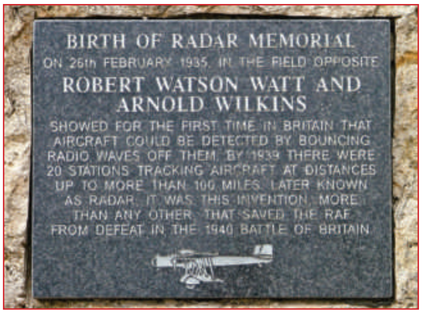


Fig. 1 **Roadside plaque in Stowe Nine Churches, Northamptonshire, commemorating the first demonstration of radar. *Source:* Wikimedia Commons.**

On the former Plessey site in Towcester, the BAE Systems Microwave Materials facility researches low-observable and adaptive stealth technologies and manufactures materials to improve the radar cross section of military platforms, including jet aircraft, UAVs, weapons, ships and submarines. Radomes and test hoods are part of its product portfolio. Intelliconnect has a manufacturing facility in Corby, Northamptonshire, where it produces standard and custom RF connectors and adapters, cable assemblies and specialist cryogenic connectors. Amphenol, a global manufacturer of antennas for base stations and small cells, has its U.K. manufacturing facility in Wellingborough.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LINCOLN

A similar pocket of microwave businesses grew up in the Lincoln area, resulting from the various GEC-Marconi sites formerly there. These include Linwave Technology, which manufactures microwave and mmWave subsystems—including sources, LNAs, SSPAs and control modules to 94 GHz—primarily for satellite communications (satcom), defense and industrial applications. Teledyne e2V has facilities in both Lincoln and Chelmsford, Essex, and manufactures RF power devices from magnetrons to semiconductors. Under development are dual-channel digital-to-analog converters (DACs) capable of operating into Ka-Band, migrating RF hardware into code, supporting beamforming and enabling dynamic RF system reconfiguration on the fly. The DACs have a 25 GHz output bandwidth at 3 dB attenuation, with much wider bandwidth if slightly higher attenuation can be tolerated. Each DAC has built-in signal processing, including a programmable anti-sinc filter, direct digital synthesis, a programmable complex mixer and digital up-converter.

LONDON AREA

Unusual as it may seem, the U.K.'s capital city has relatively little microwave industry within its boundaries. An exception is the National Physical Laboratory (NPL), situated just south of the River Thames in the suburb of Teddington. NPL is the U.K.'s National Measurement Institute and is concerned with scientific measurements in all disciplines. This year's EuMW General Chair Nick Ridler and several of the members of his committee work for NPL. The Electromagnetics group at NPL focuses on providing accurate and repeatable measurements of electromagnetic parameters traceable to the SI system. This work is growing in importance as many 5G use cases rely on accurate and traceable measurements at RF, microwave and mmWave frequencies; NPL's work helps test, validate and bring to market new technology innovations. TMD Technologies also has a London base, where it manufactures microwave power modules, traveling wave tubes, high voltage power supplies and rugged instrumentation amplifiers for radar, EW, communications, electromagnetic compatibility, scientific and medical applications.

The counties immediately surrounding London—the so-called Home Counties—house a number of establishments with microwave expertise. Chelton (formerly Cobham Aerospace Connectivity) has design, manufacturing and test facilities at Marlow in Buckinghamshire and Newmarket in Suffolk, where it produces antennas for air, land and sea platforms, as well as RF components such as diplexers, splitters and couplers. Chelton's anechoic chamber at Marlow is shown in ***Figure 2***. In November 2021, to support its R&D activities, Chelton opened a new research facility at the former Redhill Aerodrome in Surrey. The Redhill site is the design center for Chelton's ground penetrating radar, which is embedded in the company's stand-off mine and IED detection equipment as well as in the latest generation of Minehound and Wirehound detectors manufactured by Vallon. Engineers at Redhill are also developing 5G and 4G LTE technology for use in the U.K.'s airborne public safety program for

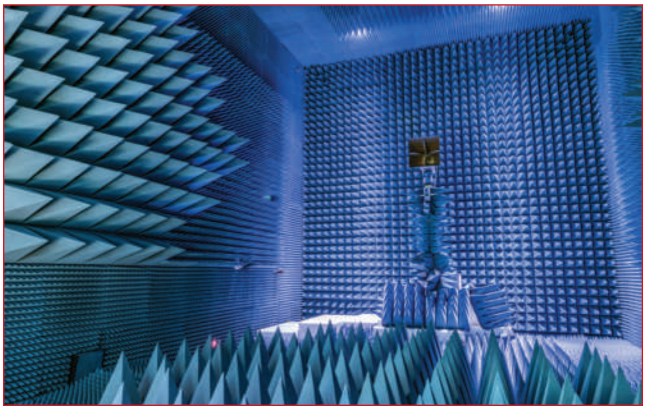

Fig. 2 **Anechoic chamber at Chelton's Marlow antenna facility.**

emergency services.

The U.K. site of API Tech—also formerly part of Cobham—is in Milton Keynes, where it designs and makes active electronically scanned array radar systems, along with high reliability subsystems, modules and components for defense and space. Spacechips in Harpenden is a startup targeting the space industry with products that include L- to Ku-Band ultra-high throughput onboard processors and transponders for satcom, aiming to make payloads smaller, lighter and less power consuming. It also offers design consultancy services for manufacturers of satellites and spacecraft.

In Stevenage, the Wireless Business Unit of Viavi Solutions manufactures the TM500 Network Tester, which is used by virtually every wireless base station manufacturer. Earlier this year it unveiled TMLite, a streamlined version that delivers features, a software environment and user experience consistent with the TM500 but is hosted on a commercial off-the-shelf server. This enables infrastructure vendors to identify software errors by deploying focused functional test tools earlier in the development cycle, in a more compact package than the standard product. Another test manufacturer, Anritsu, has its U.K. base in Luton, comprising software development, sales and support.

CAMBRIDGE CLUSTER

The Cambridge area is a renowned hub of technology innovation, home to both ARM and the Qualcomm site that was formerly Cambridge Silicon Radio. Huawei also has its U.K. R&D center at the Cambridge Science Park. Design consultancies and innovative startups are a specialty, the best known probably Cambridge Consultants, which was founded in 1960 to connect the academic excellence of Cambridge University with business and industry. Covering a wide range of technical disciplines, including RF, it has created more than 20 successful spinout ventures, including Cambridge Silicon Radio.

PRFI, with offices and labs near Cambridge, is a technical design consultancy providing services to design and develop MMICs, RFICs and microwave and mmWave modules. Services include feasibility studies as well as the design and testing of custom ICs, components and subsystems for international clients in communications, defense and aerospace and at frequencies to 100 GHz. Surface-mount packaging design for volume production at mmWave frequencies is also a specialty. Forefront RF, a recent Cambridge startup, has developed a new approach to mobile phone front-ends, replacing SAW and BAW crystal filters with an adaptive passive cancellation (APC) circuit. It cancels receiver self-interference in a way similar to noise-cancelling headphones. Because one APC circuit can cover many frequency bands, it saves space and reduces complexity.

TIGHT COMMUNITY

The U.K. boasts a particularly tight-knit community of RF and microwave engineers, many of whom regularly attend the bi-annual meeting of the ARMMS RF & Microwave Society, which will make a welcome return in April 2022 after a gap due to COVID-19. Another organization that actively brings engineers together is Cambridge Wireless (CW). In addition to running an annual international conference and a number of focused networking events for the wireless community, CW has an active Special Interest Group for Radio Technology. CW also hosts a 5G testbed, where it runs an accelerator program in partnership with Huawei U.K.

The U.K. Government is actively stimulating technology innovation and manufacturing through Innovate UK and its associated Knowledge Transfer Network and network of Catapults—the most relevant to the microwave sector being the Compound Semiconductor Applications (CSA) Catapult, based in Newport, South Wales. The CSA Catapult supports the U.K.'s RF and microwave industry by providing the following facilities to companies:

- Design studio that helps develop accurate models of the electri-

cal, thermal and electromagnetic behavior of a device, package or module

- Test lab for high bandwidth transmitter and receiver characterization of component and subsystems to 67 GHz
- Packaging lab, applying specialist knowledge to optimize high-frequency packaging
- Evaluation lab that helps companies develop RF and microwave system designs for production.

In December 2021 the UK's Department for Digital, Culture, Media and Sport (DCMS) announced the 15 projects that had won funding under its Future RAN competition, including many companies named in this article.[2]

WALES AND WELSH BORDER

The CSA Catapult is part of the Cardiff Compound Semiconductor Cluster, CS Connected,[3] which is centered on Cardiff University and encompasses wafer manufacturer IQE and Newport Wafer Fab. CS Connected was the first semiconductor cluster in the U.K. and the first in Europe devoted to compound semiconductors (CS). The experience with other clusters has shown that similar and complementary activities in proximity can build momentum that stimulates further activity. Investment in the area began in 2014 with the Innovation Campus at Cardiff University, continuing with the Compound Semiconductor Institute and the Compound Semiconductor Centre, a joint spin-off with IQE to seed the commercialization of CS technology. This was followed in 2016 with the CSA Catapult and the EPSRC CS Manufacturing Hub; the latter seeks to strengthen the transfer of designs into manufacturing. Cardiff's Institute of High Frequency and Communication Engineering was initially founded in 1997 and has expertise in nonlinear measurement systems, device characterization and circuit design. A spinout from the Institute, Mesuro, was acquired by Focus Microwaves in 2015, merging their respective load-pull and modeling technologies.

Just across the Welsh border in Herefordshire is ETL Systems, a manufacturer of RF distribution systems and satcom equipment. In November 2021, ETL received orders of more than $830,000 from a major U.S. Government defense contractor in Colorado, which included its new HAV-80 Havoc RF matrix (see ***Figure 3***), which was configured to 96 x 160 inputs/outputs. The orders also encompassed design and engineering to configure three of ETL's established Hurricane HUR-10 matrices to operate alongside its L-Band combiners, part of a custom combining matrix. The three 64 × 64 combining matrix systems and one 256 × 256 distributive matrix will be housed within a single 42U chassis, achieving significant savings of rack space and maximizing efficiency. Another well-established Herefordshire microwave enterprise is Teledyne Labtech, one of several Teledyne companies located around the U.K., which specializes in the design, manufacturing and test of RF and microwave printed circuit boards for applications in defense, telecommunications, space and satcom.

SOUTH AND SOUTHWEST

RF and microwave companies to the south of London include Lime Microsystems in Guildford, which


(a) (b)

Fig. 3 Front (a) and rear (b) of a 256 x 256 single-chassis RF matrix built by ETL Systems.

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specializes in field programmable RF transceivers and software-defined radio (SDR) technology for mobile base stations. Also based in Guildford is Surrey Satellite Technology Ltd. (SSTL)—originally a spinout from the University of Surrey and now a subsidiary of Airbus—which designs and builds small satellites and payloads.

The Isle of Wight is home to broadband amplifier manufacturer Milmega and Vectrawave, which develops MMICs and multi-chip modules for defense, space and communications applications. Further to the west are two waveguide companies: Quasar Microwave Technology in Devon and Flann Microwave in Cornwall. Located in Paignton, Devon, is test manufacturer Spirent Communications. In November 2021, it announced the launch of a simulation test solution for the Galileo High Accuracy Service, a free service providing high accuracy positioning corrections through the Galileo E6-B signal, to an accuracy of less than 20 cm. Bristol is home to a cluster of wireless companies, including Blu Wireless, which uses mmWave frequencies to generate cost-effective carrier-grade wireless networks.

NORTHERN ENGLAND

Another cluster of microwave companies is situated in the north and the northeast of England, in the counties of Yorkshire and Durham. This hub of innovation is largely from the preeminence in microwave research during the late 20th century at the University of Leeds. Leeds professor John David Rhodes established Filtronic in 1977 to develop electronic components for the aviation industry, which he initially made and tested in his home garage and bedroom. The company grew rapidly and, in 2004, was said to be the most successful company ever spun out of a U.K. university.

Today, Filtronic has a manufacturing facility in Sedgefield,[4] where it specializes in E-Band mmWave transceiver modules for high capacity radio links for Xhaul and for high altitude platform systems and LEO satellite links. It also offers a custom hybrid microelectronics manufacturing service. In the past decade, Filtronic has shipped more than 63,000 transceivers, including the most recent Morpheus II (see ***Figure 4***), with 99.9 percent exported outside the U.K. As a result, the company was recently presented with the Queen's Award for Enterprise for International Trade 2021.[5] A paper by Filtronic and co-authored by NPL entitled "Low-Loss 140-175 GHz MMIC-to-Waveguide Transitions and MMIC-to-MMIC Interconnections," will be presented at EuMW during EuMC.

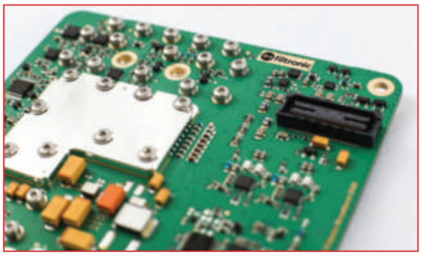

Fig. 4 **Morpheus II E-Band transceiver built by Filtronic.**

Many other companies have grown up in the area, mostly with roots connected to either Leeds University or Filtronic. At least four such companies are located in Shipley, Yorkshire, including Radio Design, which manufactures tower mount amplifiers, combiners and interference mitigation filters for sub-6 GHz wireless communications. A second is Slipstream Design, which specializes in designing PAs, transponders and low noise amplifiers with high speed digital electronics and embedded controller software, progressing projects from concept through volume manufacture. Slipstream's products include radar signal processors for transponder applications. Teledyne Defence & Space, formerly part of Filtronic, specializes in adaptive filters and microwave front-ends for sea, land, air and space. It also manufactures radar warning receiver, radar electronic support measurement and electronic intelligence subsystems, as well as systems capable of handling the dense signal environments found in military operations and highly integrated receiver and broadband jammer subsystems. Finally, Diamond Microwave designs compact, high-power microwave

solid-state power amplifiers (SSPAs) using chip and wire GaN technology for applications such as radar, EW, aerospace and communications. The products are optimized for high power-to-volume ratio. Early last year, TMD Technologies Ltd became a shareholder in Diamond Microwave Ltd.

SARAS Technology, in Leeds, manufactures a range of PAs, filters and subsystems to 40 GHz, mainly for defense, aerospace, security and telecom applications. A short distance away, in York, BSC Filters—part of the Dover Corporation—designs and produces active microwave assemblies and modules for phased array radar, EW and commercial applications. These include front-end preselectors, switched filters for antenna front-ends, IF assemblies, digital RF memory front-ends, adaptive filtering and switched multiplexers and filter assemblies for SDR.

THE NORTHEAST

Viper RF is a MMIC designer and manufacturer based in Newton Aycliffe, County Durham. Both of its co-founders, with others on the team, formerly worked for Filtronic Compound Semiconductors prior to its acquisition by RFMD (now Qorvo). Newcastle in northeast England is home to INEX Microtechnology Ltd., which produces nanotechnology and compound semiconductor products. INEX was established in 2014 as a commercial unit of Newcastle University and has since developed collaborative relationships with partners and customers to deliver devices that include power transistors for SSPAs to X-Band from its 6-in. GaN line. INEX has 400 m^2 of class 1000 cleanroom for front-end processing and 150 m^2 of class 10,000 cleanroom for back-end processing, packaging, test and characterization. It has been promoted as developing a sovereign GaN technology supply chain to mitigate many of the barriers encountered by existing GaN foundries around the world, due to a combination of IP, competition and export issues.

SCOTLAND

Some years ago, Scotland was home to a cluster of telecoms, defense and semiconductor companies, earning the corridor between Edinburgh and Glasgow the nickname "Silicon Glen." In recent years, however, many of these facilities have either closed or scaled down.

Trak Microwave, now a Smiths Interconnect brand based in Dundee, designs and manufactures RF and mmWave passive components and subassemblies, including ferrite isolators, circulators, transitions, terminations, loads and couplers for defense and space applications. NXP still operates at the former Motorola/Freescale site in Glasgow but now focuses on automotive applications such as ADAS.

IRELAND

Both Northern Ireland and the Republic of Ireland have a strong history of microwave and, particularly, mmWave technology. Arralis has sites in Belfast in the north and Limerick in the south, as well as Swindon in England. It specializes in mmWave components and modules for the communications, satellite, aerospace and defense markets, specifically at K/Ka-, E- and W-Band. It recently announced that its LE-KaTR-102 Ka-Band transceiver (27 and 30.5 GHz uplink and 17 to 21.2 GHz downlink) had been deployed in the OHB Cosmos CubeSat launched in January 2021. Ferfics, based in Cork, provides design services for front-end RFICs and mmWave semiconductor devices for wireless connectivity applications, including mobile handsets, Wi-Fi, wireless infrastructure, CATV, radar and satcom.

Farran Technology has been developing mmWave products for more than 40 years. Its standard and custom systems and subsystems find applications in test and measurement, radar and imaging, communications, research and development and aerospace. These include 6G products aimed at enabling next-generation devices and systems, as well as facilitating scientific studies of communication channels and new materials for 6G. Analog semiconductor specialist Skyworks has a design center in Cork, as well as another in Bishops Stortford, England.

A VARIED MICROWAVE LANDSCAPE

The U.K.'s microwave industry is no longer shaped by the huge, vertically-integrated defense and telecoms contractors of the past, but their influence can still be detected. Large vendors like Airbus, Leonardo and MBDA have major operations in the U.K. but tend to purchase both components and design services from the vibrant ecosystem of small and medium-sized companies, rather than making them in-house. Space and satcom are currently growing in importance as a market, complementing rather than displacing the more conventional telecoms market.■

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Be There

Exhibition Dates	Opening Times
Tuesday 15th February 2022	09:30 - 18:00
Wednesday 16th February 2022	09:30 - 17:30
Thursday 17th February 2022	09:30 - 16:30

The Conferences

The EuMW 2021 consists of three conferences, three forums and associated workshops:

- European Microwave Integrated Circuits Conference (EuMIC) 14th - 15th February 2022
- European Microwave Conference (EuMC) 15th - 17th February 2022
- European Radar Conference (EuRAD) 16th - 18th February 2022
- Plus Workshops and Short Courses (From 13th February 2022)
- In addition, EuMW 2021 will include the Defence, Security and Space Forum, the Automotive Forum and the Beyond 5G Forum

The three conferences specifically target ground breaking innovation in microwave research. The presentations cover the latest trends in the field, driven by industry roadmaps. The result is three superb conferences created from the very best papers submitted. For the full and up to date conference programme including a detailed description of the conferences, workshops and short courses, please visit www.eumw2021.com. There you will also find details of our partner programme and other social events during the week.

How to Register

Registering as a Conference Delegate or Exhibition Visitor couldn't be easier. Register online and print out your badge in seconds onsite at the Fast Track Check In Desk. Online registration is open now, up to and during the event until 18th February 2022.

- Register online at **www.eumw2021.com**
- Receive an email receipt with barcode
- Bring your email, barcode and photo ID with you to the event
- Go to the Fast Track Check In Desk and print out your badge
- Alternatively, you can register onsite at the self service terminals during the registration.

Please note: NO badges will be mailed out prior to the event.

Registration opening times:

- Saturday 12th February 2022 (16:00 - 19:00)
- Sunday 13th - Thursday 17th February 2022 (08:00 - 17:00)
- Friday 18th February 2022 (08:00 - 10.00)

Registration Fees

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Registration at one conference does not allow access to the sessions of the other conferences.

Reduced rates are offered if you have society membership to any of the following: EuMA✪, GAAS, IET or IEEE. Reduced rates for the conferences are also offered if you are a Student/Senior (Full-time students 30 years or younger and Seniors 65 or older as of 18th September 2021). The fees shown below are invoiced in the name and on behalf of the European Microwave Association. All payments must be in £ (pound sterling) – cards will be debited in £ (pound sterling).

CONFERENCES REGISTRATION	ADVANCE DISCOUNTED RATE (FROM NOW UP TO & INCLUDING 31st DECEMBER 2021)				STANDARD RATE (FROM 1ST JANUARY 2022 & ONSITE)			
	Society Member ✪		Non-Member		Society Member ✪		Non-Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	£430	£120	£600	£160	£600	£160	£830	£230
EuMIC	£330	£110	£460	£150	£460	£150	£640	£210
EuRAD	£290	£100	£410	£140	£410	£140	£570	£200
2 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC	£600	£230	£840	£320	£840	£320	£1,180	£440
EuMC + EuRAD	£570	£220	£800	£300	£800	£300	£1,120	£430
EuMIC + EuRAD	£490	£210	£690	£290	£690	£290	£970	£410
3 Conferences	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.	Standard	Student/Sr.
EuMC + EuMIC + EuRAD	£730	£330	£1,020	£460	£1,020	£460	£1,430	£640
Full Week Ticket	£1,140	£680	£1,490	£870	£1,490	£870	£1,920	£1,070

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Members have full e-access to the International Journal of Microwave and Wireless Technologies. The printed version of the journal is no longer available.

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The Eu*MA* website has its Knowledge Centre which presently contains over 20,000 papers published under the Eu*MA* umbrella. Full texts are available to Eu*MA* members only, who can make as many copies as they wish, at no extra-cost.

SPECIAL FORUMS AND SESSIONS REGISTRATION		ADVANCE DISCOUNTED RATE (UP TO & INCLUDING 31st DECEMBER 2021)		STANDARD RATE (FROM 1ST JANUARY 2022 & ONSITE)	
	Date	Delegates*	All Others**	Delegates*	All Others**
Automotive Forum	14th February 2022	£240	£290	£330	£390
Beyond 5G Forum	17th February 2022	£60	£70	£80	£90
Defence, Security & Space Forum	16th February 2022	£20	£60	£20	£60
European Microwave Student School	14th February 2022	£40	£40	£80	£80
Tom Brazil Doctoral School of Microwaves	14th February 2022	£40	£40	£80	£80

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

Workshops and Short Courses

Despite the organiser's best efforts to ensure the availability of all listed workshops and short courses, the list below may be subject to change. Also workshop numbering is subject to change. Please refer to www.eumw2021.com at the time of registration for final workshop availability and numbering.

Sunday 13th February 2022

WS01	EuMC	Full Day	Advances of wireless sensing in harsh and severe environments
WS02	EuMC/EuMIC	Full Day	Terahertz device, circuit and system fundamentals and applications
WS03	EuMC	Full Day	mmWave Plastic Waveguide High Data Rate Communication
WS04	EuMC	Full Day	New trends in microwave and mmWave filters
WS05	EuMC	Full Day	On-chip and scalable RF packaging solutions with integrated antennas for 5G mmWave and 6G applications
WS06	EuMC/EuMIC	Full Day	Progress and status of Gallium Nitride monolithically microwave integrated circuits
WS07	EuMC	Half Day AM	RF reliability status and challenges for 5G mmWave and 6G applications
WS08	EuMC	Full Day	Technology for RF 5G and satcom: from material to packaged demonstrators
WS09	EuMC	Full Day	Research in power and S-parameters measurements at mmWave and terahertz frequencies
SS01	EuMC	Half Day PM	Advanced non-linear characterization and design of highly efficient power amplifiers using load pull data for sub 6GHz and mmWave applications
SS02	EuMIC	Full Day	Fundamentals of microwave PA Design
SS03	EuMC	Half Day PM	5G mmWave OTA measurements – best practices for fast and reliable results
SS04	EuMC	Half Day AM	Terahertz technology, instrumentation and applications

Monday 14th February 2022

WM01	EuMC	Half Day PM	Optimizing modulation quality measurements on wide bandwidth signals – from conformance through R&D
WM02	EuMC/EuMIC	Full Day	Advances in circuits and systems for mmWave radar and communication in silicon technologies
WM03	EuMC	Full Day	Sensing, imaging and biological tissues characterization using microwaves and mmWaves
WM04	EuMC	Full Day	RF on-wafer calibration and measurement eco-system workshop
WM05	EuMC	Half Day AM	Novel technologies for emerging on-board microwave equipment based on surface mounted electromechanical relays
WM06	EuMC	Full Day	Recent developments in wireless power transfer and energy harvesting
WM07	EuMC	Half Day AM	Beyond 5G: mmWave and terahertz techniques of 6G research
SM01	EuMC	Half Day AM	R&D trends and challenges in RFPAs for medium/high-volume products
SM02	EuMC	Half Day PM	Intuitive microwave filter design with EM simulation
SM03	EuMC	Half Day PM	Phase-noise in next-generation aerospace/defense and commercial wireless communications
SM04	EuMC	Half Day PM	Solid-state microwaves applications in industrial, scientific and medical fields

Wednesday 16th February 2022

WW01	EuMC/EuMIC	Full Day	Technologies for 6G FEMs
WW02	EuRAD	Full Day	Virtual validation of automotive sensors
SW01	EuRAD	Half Day AM	Joint range-angle superresolution MIMO radar
SW02	EuRAD	Half Day PM	Radar design from the ground up

Thursday 17th February 2022

WTh01	EuRAD/EuMC	Half Day AM	Advances in drone antenna measurement techniques for Satcom and RADAR applications

Friday 18th February 2022

WF01	EuMC	Half Day AM	Advanced manufacturing and packaging
WF02	EuRAD	Half Day PM	Paradigm change in automotive mm-Wave radar applications – from technology push to demand pull
WF03	EuMC	Full Day	Innovative THz technologies for imaging, radar and communication
WF04	EuRAD	Full Day	Advanced processing and deep learning approaches for indoor sensing using short-range radars
SF01	EuMC	Half Day AM	AI techniques for microwave antenna and filter design: from theory to practice
SF02	EuMC	Half Day AM	Microwave superconductivity: applications of SQUID and Josephson junctions in microwave circuits

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Single Antenna Measurement Using Image Reflection

Michael D. Hillbun
Diamond Engineering

A methodology for determining antenna gain and pattern parameters uses the image created by a conductive plane located at a desired reference position relative to the antenna phase center. The measurement consists of two states. The first is bore-sight perpendicular S_{11p} and the second is free space S_{11fs}. The original work was derived by Edward Purcell.[1] Later, Lee and Baddour[2] refined the derivation to include a finite mismatch between the antenna and its feed. The method they used involved taking several measurements over distance and performing a best fit line; reflection phase was not considered. Now that modern vector network analyzers (VNAs) can include phase, accuracy is enhanced and the separation is fixed. In addition to antenna under test (AUT) gain, phase can also be calculated such that a full 2-port [S] matrix can be determined.

It is well established that boundary conditions on metallic surfaces require $E_t = 0$. An incident electric field is made zero on the surface by setting up currents equal in amplitude but with opposite phase (see ***Figure 1***). The induced currents are equivalent to the inverted image on the opposite side of the conductor surface and reflect off the surface with the same pattern as the incident wave.[1] Equivalently, the field incident on a perfect conductor generates a conjugate field at the surface to maintain the tangential boundary condition $E_t = 0$, which generates an image at the same distance on the opposite side.

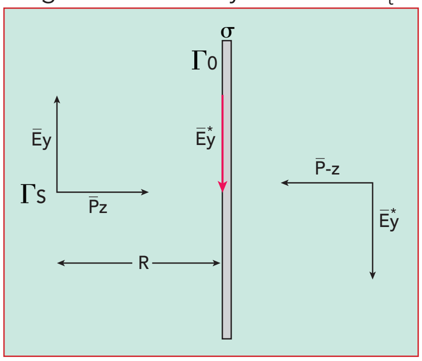

Fig. 1 Field incident on a perfect conductor.

The original work began with the Friis Equation[3]

$$P_r = G_{Tx} G_{Rx} P_{Tx} \qquad (1)$$

The reflected wave undergoes the same path loss so that the reflection coefficient at the source is

$$\Gamma_s = \bar{\Gamma}_0 \left(\frac{\lambda}{4\pi 2R}\right)\bar{G} \qquad (2)$$

where all variables are linear vectors. R is multiplied by 2 to include the round trip and Γ_0 is the reflective surface. If the source reflection is Γ_s, then the transmit field is

$$\bar{E}_{tx} = \bar{E}_y \left(1-|\bar{\Gamma}_s|^2\right)^{\frac{1}{2}} \qquad (3)$$

and the field received at the source is

$$\bar{E}_{Rx} = \bar{E}_{tx}\bar{\Gamma}_0 \left(\frac{\lambda}{8\pi R}\right)^2 \left(1-|\bar{\Gamma}_S|^2\right)|\bar{G}|^2 \qquad (4)$$

It is assumed $\bar{G}$ and path loss are linear vectors. The $\bar{E}_{Rx}$ vector linearly combines with the source mismatch so that

$$\bar{E}_{rx}' = \bar{E}_{Tx}\bar{\Gamma}_S - \bar{E}_{Rx} \qquad (5)$$

$$= \bar{E}_{tx}\bar{\Gamma}_S - \bar{E}_{tx}\left(\frac{\lambda}{8\pi R}\right)^2 \left(1-|\bar{\Gamma}_S|^2\right)\bar{\Gamma}_0|\bar{G}|^2 \qquad (6)$$

The ratio $\frac{\bar{E}_{Rx}}{\bar{E}_{Tx}} = \bar{\Gamma}_S$ forms the match vector due to the received reflection. While Equation (4) is a primary reflection, the higher order reflections are ignored imposing the condition $|GP_L| << 1$.

Solving Equation (6) for gain[2] gives

$$\bar{G} = \frac{1}{\bar{\Gamma}_0}\sqrt{\frac{\bar{\Gamma}_S - \bar{\Gamma}}{\left(1-|\bar{\Gamma}_S|^2\right)}\left(\frac{8\pi R}{\lambda}\right)^2} \qquad (7)$$

It should be mentioned that all reflection quantities are vectors or Equation (7) will not be accurate.[4] The vector difference between the source and measurement reflection yields the AUT gain and phase referenced from the AUT connector and phase center. Equation (7) includes the conductive surface conductivity

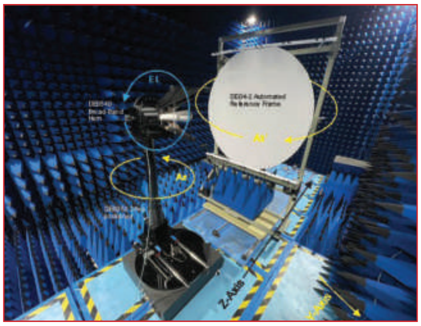

Fig. 2 Image reflection setup.

σ. The surface reflection is given by

$$\bar{\Gamma}_0 = \sqrt{\frac{8\varepsilon_0\omega}{\sigma}} - 1 \quad (8)$$

For high conductivity, $\bar{\Gamma}_0 \rightarrow -1$.

For our measurements the conductive surface is aluminum with σ = 3.5e7 S/M and Equation (8) yields

$$\bar{\Gamma}_0 = \sqrt{\frac{50.265\left(8.854e^{-3}\right)f}{3.5e7}} - 1 =$$

$$\bar{\Gamma}_0 = 1.128e^{-4}\sqrt{f} - 1 \quad (9)$$

Where f is in GHz.

At 10 GHz, $\bar{\Gamma}_0$ = -0.9996 or 0.003 dB.

Equation (7) has a phase component determined by $\frac{1}{\bar{\Gamma}_0}$ and $\sqrt{\bar{\Gamma}_s - \bar{\Gamma}}$.

Equation (8) demonstrates that the sheet reflection loss is negligible as would be the angle deviation from 180 degrees so the AUT phase is entirely determined by the difference between the source reflection and the measured reflection. The resulting gain is

$$\bar{G} = \left|S21\right| e^{j\phi} \quad (10)$$

where

$$\phi = \tan^{-1}\left(\frac{\mathrm{Im}\left(\frac{1}{\bar{\Gamma}_0}\sqrt{\bar{\Gamma}_S - \bar{\Gamma}}\right)}{\mathrm{RE}\left(\frac{1}{\bar{\Gamma}_0}\sqrt{\bar{\Gamma}_S - \bar{\Gamma}}\right)}\right) \quad (11)$$

$$\bar{S} = \begin{bmatrix} \Gamma & \left|S21\right| e^{j\phi} \\ \left|S21\right| e^{j\phi} & \Gamma \end{bmatrix} \quad (12)$$

Equation 10 represents the system magnitude and phase. If it is assumed that the AUT is lossless, then $S_{11} = S_{22}$ where S_{11} is relative to a 50 ohm source and S_{22} relative to a 377 ohm load. To establish an [S] matrix for the AUT, the phase center must be known relative to the connector. The AUT shown in ***Figure 2*** uses a lens that also serves to maintain a somewhat constant phase center location. This is measured using a least squares convergence algorithm for phase center offset (PCO) determination. The AUT measured |S21| data is given phase, based on the PCO value. Equation (7) is replaced with

$$\bar{G} = \left|\frac{1}{\bar{\Gamma}_0}\sqrt{\frac{\bar{\Gamma}_S - \bar{\Gamma}}{\left(1 - \left|\bar{\Gamma}_S\right|^2\right)}}\left(\frac{8\pi R}{\lambda}\right)^2\right| e^{j\frac{2\pi(POC)}{\lambda}} \quad (13)$$

To calculate S_{22} it is necessary to transform S_{11} from 50 ohms to 377 ohms. These types of transformations were originally derived by G. Bodway[5] as

$$S'_{11} = \frac{A_1^*\left(\left[1 - \bar{\Gamma}_L S_{11}\right]\left(S_{11} - \bar{\Gamma}_S^*\right) + \bar{\Gamma}_L S_{11} S_{21}^2\right)}{A_1\left(1 - \bar{\Gamma}_S S_{11}\right)\left(1 - \bar{\Gamma}_L S_{22}\right) - \bar{\Gamma}_L \bar{\Gamma}_L S_{21}^2} \quad (14)$$

where

$$A_1 = \frac{\left(1 - \bar{\Gamma}_S^*\right)}{\left|1 - \bar{\Gamma}_S\right|}\left(1 - \left|\bar{\Gamma}_S\right|^2\right) \quad (15)$$

and

$$\Gamma_s = \frac{Z_L - Z_S}{Z_L + Z_S^*} = \frac{377 - 50}{377 + 50} = .765 \quad (16)$$

and

$$A_1 = \frac{(1 + .765)}{(1 - .765)}\left(1 - .765^2\right) = 3.127 \quad (17)$$

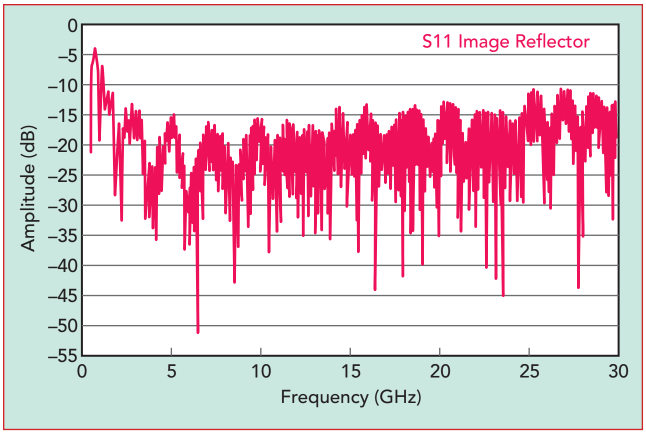

Fig. 3 Measured $|S_{11}|$ of the DE0540 horn at boresight and radiating into a conductive sheet.

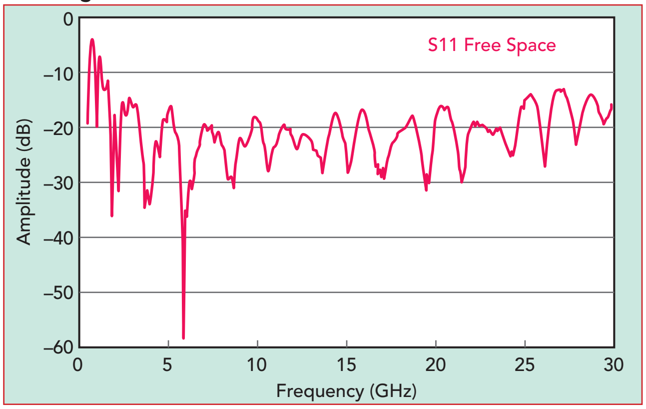

Fig. 4 Measured $|S_{11}|$ of the DE0540 horn with absorber between the horn and conductive sheet.

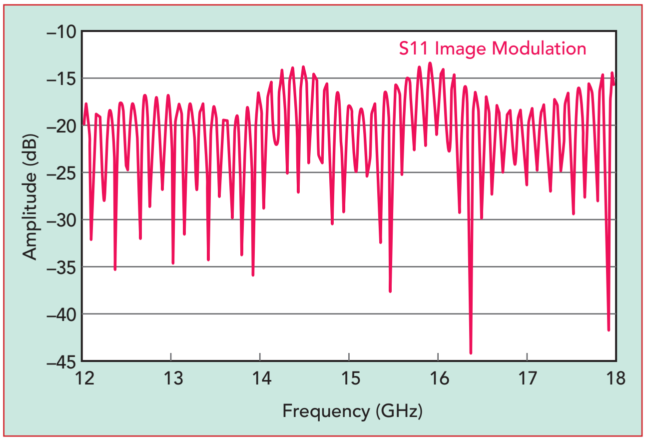

Fig. 5 Modulation of the AUT image reflection.

With the previous assumptions the antenna scattering matrix may be written as

$$\left[\bar{S}\right]=\begin{bmatrix} S_{11} & \left|\frac{1}{\bar{\Gamma}_0}\sqrt{\frac{\bar{\Gamma}_S-\bar{\Gamma}}{\left(1-\left|\bar{\Gamma}_S\right|^2\right)}}\left(\frac{8\pi R}{\lambda}\right)^2\right| e^{j\frac{2\pi(POC)}{\lambda}} \\ \left|\frac{1}{\bar{\Gamma}_0}\sqrt{\frac{\bar{\Gamma}_S-\bar{\Gamma}}{\left(1-\left|\bar{\Gamma}_S\right|^2\right)}}\left(\frac{8\pi R}{\lambda}\right)^2\right| e^{j\frac{2\pi(POC)}{\lambda}} & \frac{A_1^*\left[\left(1-\bar{\Gamma}_L S_{11}\right)\left(S_{11}-\Gamma_S^*\right)+\bar{\Gamma}_L S_{11} S_{21}^2\right]}{A_1\left(1-\bar{\Gamma}_S S_{11}\right)\left(1-\bar{\Gamma}_L S_{22}\right)-\bar{\Gamma}_L\bar{\Gamma}_L S_{21}^2} \end{bmatrix} \quad (18)$$

VERIFICATION MEASUREMENTS

Verification is performed on a very broadband (500 MHz to 30 GHz) reference horn. The image reflection setup uses a Diamond Engineering DE0540 horn antenna and an aluminum sheet at distance R (see Figure 2). Antenna gain and phase is determined from S_{11} measurement. The phase center is determined to be 228.6 mm.

The gain of the AUT ranges from 3 to 23 dB. The conductive surface is set perpendicular to the AUT using a laser and an optically flat mirror. The sequence is to first measure the AUT S_{11} magnitude and phase directly pointed into the surface. Then the measurement is repeated after the absorber is placed between the surface and the horn, nearer the horn. ***Figures 3*** and ***4*** show the measurement results.

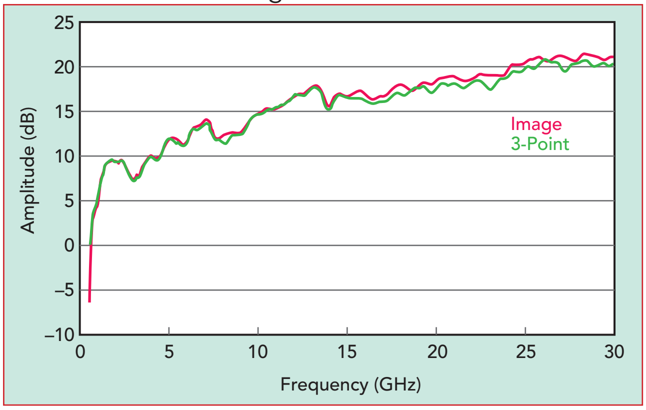

Fig. 6 Measured image (red) and 3-point (green) gain.

A magnified view of Figure 3 (see ***Figure 5***) reveals the modulation of the AUT match profile. Since the reflection repeats every half wavelength, the distance between the source and mirror is:

$$R=\frac{c}{2\Delta f}=1.25M \quad (19)$$

The reflection ripple in Figure 5 is easily filtered using a moving average. The number of points should be large enough to include at least three points in a single reflection cycle. The number of measurement points over the bandwidth generates the following measurement frequency steps:

$$\Delta fs=\frac{BW}{n} \quad (20)$$

where BW is the measurement bandwidth and n is the number of measurement points.

From Figure 5, the path generates a reflection ripple of 133.3 MHz. If the measurement spanned 1 to 30 GHz, then the minimum number of measurement points would be $\frac{29}{.133}\times 3$ or 654. The measurements in this work use 2001 points.

Applying Equation (13) to Figures 3 and 4 and performing the moving average yields ***Figure 6***.

S-Parameter Determination

Measurement data is processed through a schematic construct (see ***Figure 7***) enabling Equation (18) to be calculated. ***Figure 8*** shows the complex S_{21} polar plot. S_{22} (see ***Figure 9***) is calculated from Figure 7 by changing the output impedance from 50 to 377 ohms. Using the calculated results from Figures 8 and 9 and the measured S_{11} completes the [S] matrix for the AUT.

BEAM MEASUREMENTS

The AUT is mounted on a full spherical positioner and laser boresight aligned with the conductive surface (see Figure 2). The movement extents are set to beam scan AZ/EL ± 15 degrees in 0.5 degree steps. The required measurement

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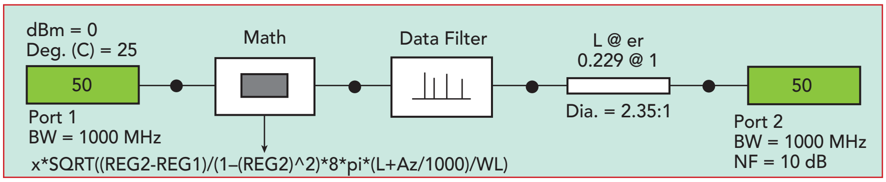

Fig. 7 Schematic construct used to calculate S_{21} and S_{22}.

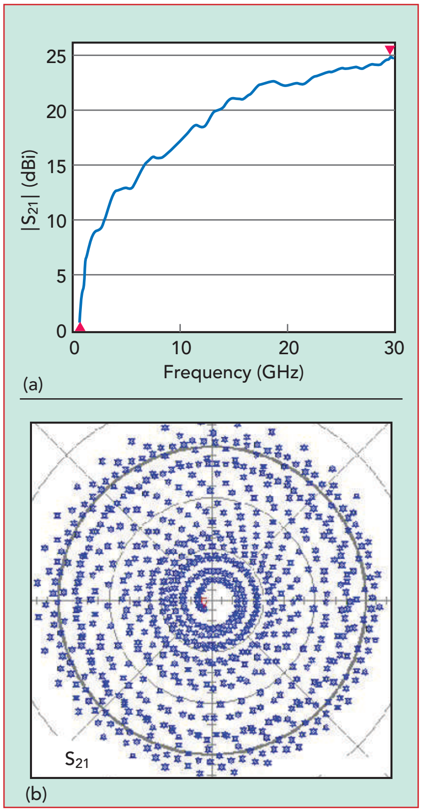

Fig. 8 $|S_{21}|$ (a) and linear polar S_{21} (b) responses.

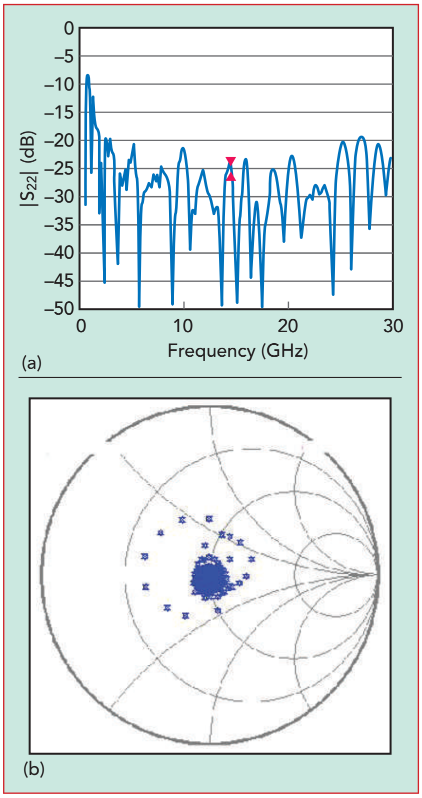

Fig. 9 $|S_{22}|$ (a) and linear polar S_{22} (b) responses looking into free space (377 Ω).

ACCURACY CONSIDERATIONS

The ratio of measurement wavelength to reflector size sets the lowest frequency that can be measured accurately. Careful inspection of Figure 6 shows that for frequencies below 1 GHz, the image gain is much higher than the 3-point gain. At 200 MHz the wavelength (59 in.) is larger than the 48-in. reflector. Inspection of Equation (7) reveals the possibility that as Γ becomes smaller, the source reflection dominates the calculation giving rise to a possible larger gain value depending on phase.

$$\bar{G} \sim \sqrt{\Gamma_S - \Gamma} \quad (21)$$

Figure 12 shows gain measured at 1 and 3 meters. A 5 dB gain error exists at 500 MHz. For a 48-in. square mirror this results in two wavelengths. As the frequency increases the error decreases to be negligible at about 2 GHz, and at 1 GHz the error is –1.2 dB. The vector ratio of the two traces represents the measurement error between 1 meter and 3 meters (see ***Figure 13***). Ignoring edge diffraction, the forward S_{21} vector will add to the reflected S_{21} by a factor proportional to $L\frac{\lambda}{W}$ where W is the width or height of the reflector and L is the path length. The relationship can be expressed as

$$S'_{21} = S_{21} + k * L\frac{\lambda}{W} \quad (22)$$

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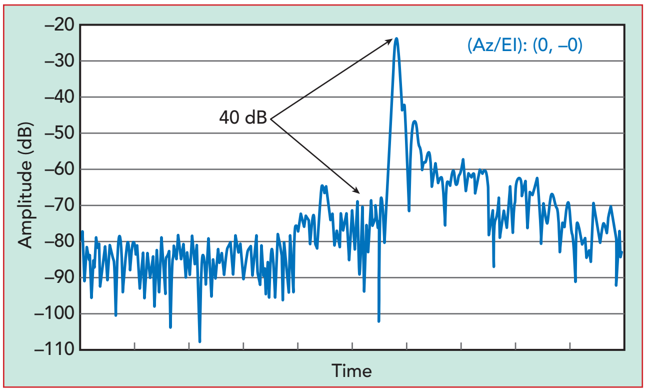

Fig. 10 **AUT time domain response.**

From Equation (22), the smaller $\frac{\lambda}{W}$ the less error is present. The constant, k, may be determined from a data set where it can be assumed L is small enough to ensure accuracy, 1 meter in this example. The corrected data then becomes

$$S_{21} = S'_{21} - kL\frac{\lambda}{W} \quad (23)$$

When Equation (23) is solved for k,

$$k = \left(S'_{21} - S_{21}\right)\frac{W}{\lambda L} \quad (24)$$

While a least squares algorithm would be most useful for the determination of k, a simple value can be determined by adjusting k until the lowest frequency S_{21} at 3 meters matches S_{21} at 1 meter. This is applied to data of Figure 13. ***Figures 14*** and ***15*** plot the results with k = 3.8.

CONCLUSION

The work of Purcell has been re-derived in vector form to take advantage of a modern VNA's vector calibration capabilities. The resulting derivation is in good agreement with the classical 3-point method. The methodology enables antenna phase determination and a resulting S-parameter matrix. The matrix can then be used in system simulators to determine antenna bit rate error versus pointing angle. The reflection method has the advantage that only a single antenna is required; however, limitations determined by the wavelength to reflector ratio are not addressed here. The measurement is real-time, non-invasive and enables rapid antenna calibration with only a single port S_{11} measurement. It is shown that accurate measurements can be made down to two wavelengths (half the reflector width/height). ■

ACKNOWLEDGMENTS

The author wishes to express his thanks and appreciation to Diamond Engineering Inc. CEO James Matthew Martin and design engineer Joshua Taylor for their valuable support and contributions without which this effort would not have been possible.

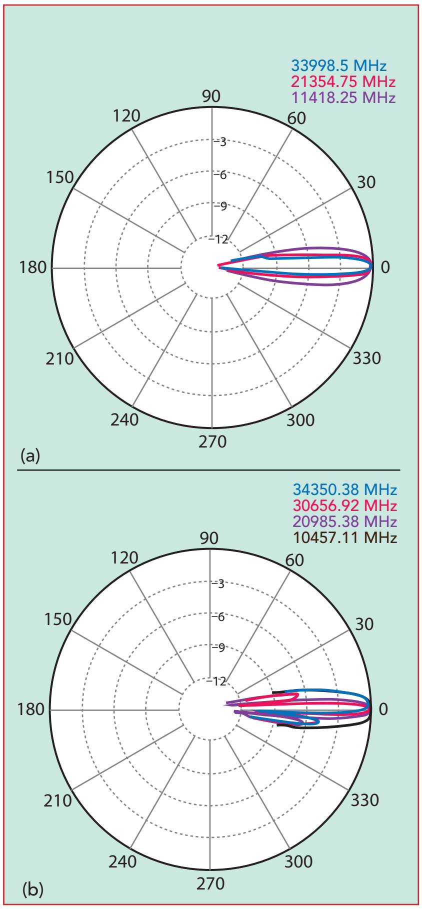

Fig. 11 **Elevation (a) and azimuth (b) beam measurements at several frequencies.**

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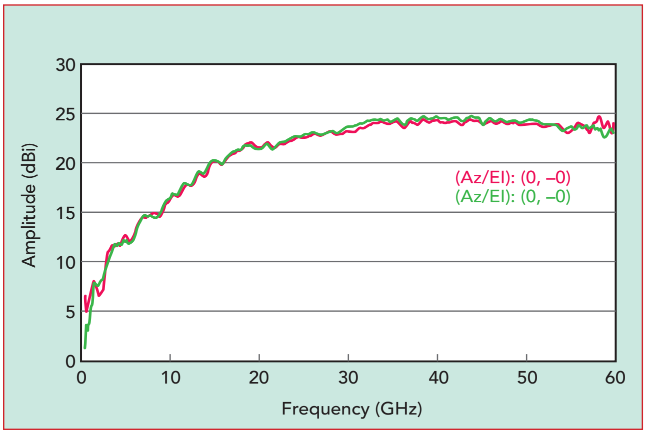

Fig. 12 DE0540 horn antenna gain vs. frequency with a 48-in. reflector at 1 m (red) and 3 m (green).

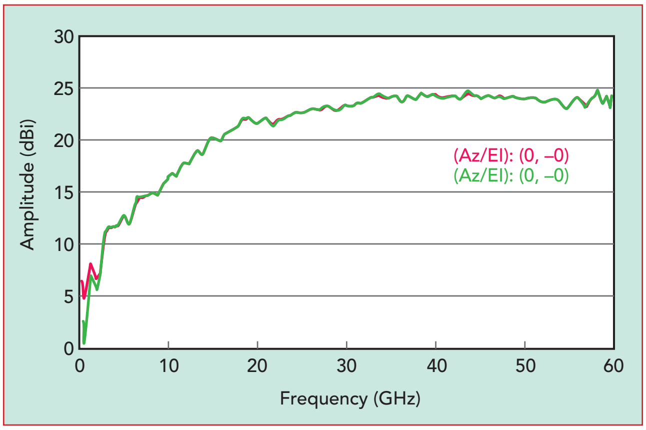

Fig. 14 DE0540 horn antenna gain vs. frequency with a 48-in. reflector at 3 m (red) and with correction (green).

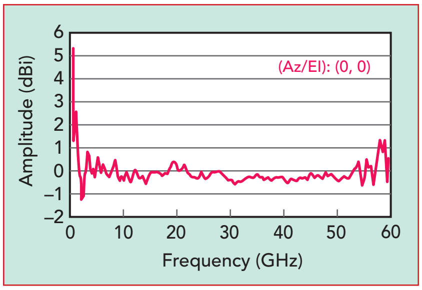

Fig. 13 DE0540 horn antenna 1 and 3 m differential gain with a 48-in. reflector.

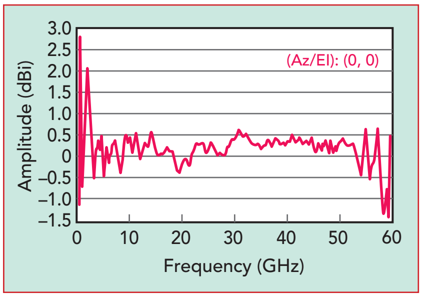

Fig. 15 DE0540 horn antenna 1 and 3 m differential gain with a 48-in. reflector and correction.

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Rohde & Schwarz, Munich, Germany

The primary goal when measuring a device under test (DUT) is that its measured parameters are unaffected by ambient conditions and unwanted influences from the test setup. While environmental influences are easier to compensate or correct, more effort and know-how may be required with the test setup. This effort increases disproportionately with how precisely the DUT performance is to be determined.

In principle, test and measurement (T&M) setups are often similar. A signal source provides the input signal to the DUT, and the output is measured with a spectrum analyzer, network analyzer or power sensor. For a quick test of the DUT performance, it may be sufficient to simply use this setup and record the measurement; however, more precise data requires more effort. Under certain circumstances, for example, losses or full S-parameters from the test fixture must be considered, as well as the performance of the T&M instrument itself (e.g., phase noise, power supply noise).

In this article we examine the role of the signal source, showing that unwanted influences from an "unsuitable" signal source never yield useful results. Using measurement examples, we show the actual performance of the DUT can only be determined with a "suitable" signal source, i.e., with performance that ensures accurate measurement results that are not falsified by the T&M instrument. As examples, we have selected several components and three typical measurements: harmonics, compression and single sideband (SSB) phase noise (PN). In each example, the performance of the signal source is measured alone and its influence on the measurement result discussed. We refer to typical or measured performance to make it easier to understand how the actual performance of the DUT can be hidden by unwanted factors, such as insufficient harmonic suppression of the signal source.

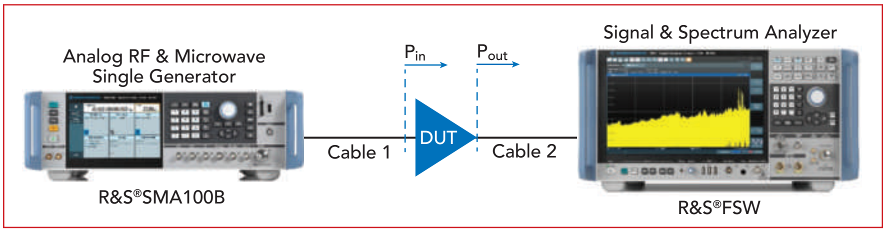
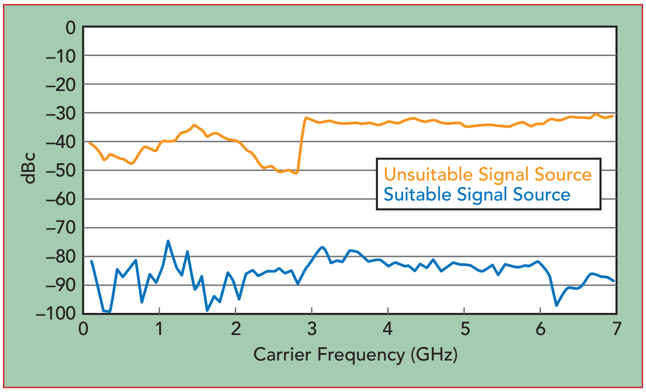


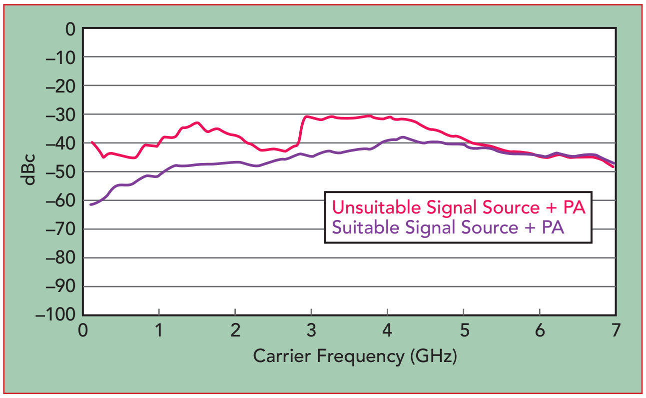
Fig. 1 Test setup for measuring the second harmonic.

HARMONIC MEASUREMENTS

When a single CW tone is applied to a nonlinear component such as a power amplifier (PA), unwanted signals will be generated at n multiples of the original frequency, n being the order of the harmonic. To illustrate how the signal source will affect the harmonic performance of a PA, we used two signal sources: 1) an analog RF and microwave signal generator with high harmonic suppression, the suitable signal source. The R&S SMA100B was used for these measurements. 2) An "unsuitable"



▲ Fig. 2 Second harmonic of the suitable and the unsuitable signal sources.



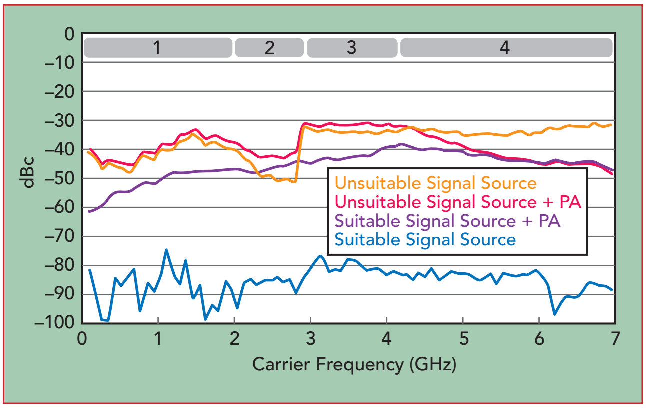
▲ Fig. 3 PA second harmonic measurements with the two signal sources.

source with harmonics greater than -30 dBc. The PA used for the measurements was a GaAs design covering 100 MHz to 7 GHz with 27 dBm saturated output power (Psat) and 7 to 8 dB gain.

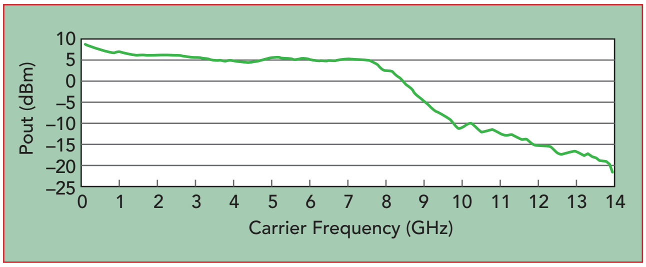
Figure 1 shows the test setup for the harmonic measurements, using an R&S FSW signal and spectrum analyzer to measure the second harmonic. The suitable and unsuitable signal sources were used to drive the PA, sweeping from 100 MHz to 7 GHz while keeping the output power (Pout) of the PA constant at approximately 7 dBm. The input power (Pin) was leveled to compensate for the cables and the frequency response of the PA.

The measured second harmonic performance of the two signal sources is plotted in ***Figure 2***, showing a significant difference in harmonic suppression between the suitable and unsuitable sources. Inserting the PA and measuring the harmonic performance with each reveals how the harmonics from the unsuitable signal source make the apparent performance of the PA worse (see ***Figure 3***). The effects of the harmonic performance of the signal sources is clearer by comparing the measurements of the individual sources with the combination in a single plot (see ***Figure 4***), where the sweep is divided into four frequency ranges. Because the harmonic performance of the combination is the vector sum of the harmonics from the signal source and the PA, depending on the relative phase of the two signals, the combined performance is not simply the addition of the magnitudes of the two.

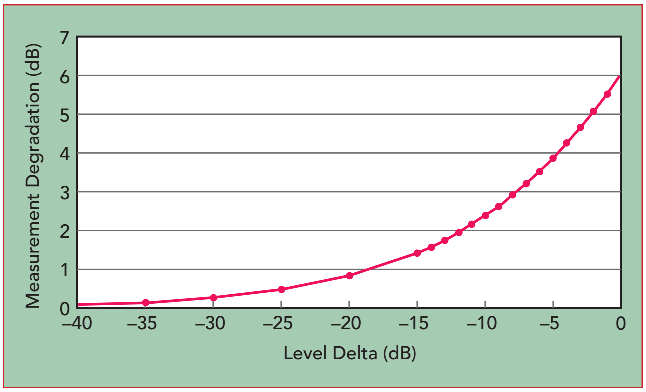
In ranges 1 and 3, the measurement reflects the



▲ Fig. 4 Comparing second harmonic measurements of the two signal sources and PAs driven by the respective sources.



▲ Fig. 5 Measured PA frequency response.



▲ Fig. 6 Measurement degradation caused by the second harmonic of the signal source.

performance of the unsuitable signal source rather than the PA's harmonics. In range 2, the measurement is closer to the PA's actual performance because the performance of the unsuitable signal source is slightly better than the PA's, so the contribution from the source is less. The interpretation of the measurement in range 4 is trickier. Why is the performance of the unsuitable signal source with the PA better than the source's, when the opposite is expected? The PA's frequency response provides the answer (see ***Figure 5***). Above 8 GHz the gain drops; consequently, as the carrier frequency increases above 4 GHz, the second harmonic of the source is increasingly attenuated by the PA, and the measurement of the second harmonic from the combination gets closer to the PA's actual performance.

The conclusion of the test: to avoid harmonic contributions from the signal source, a source with low harmonics should be used to prevent the source from

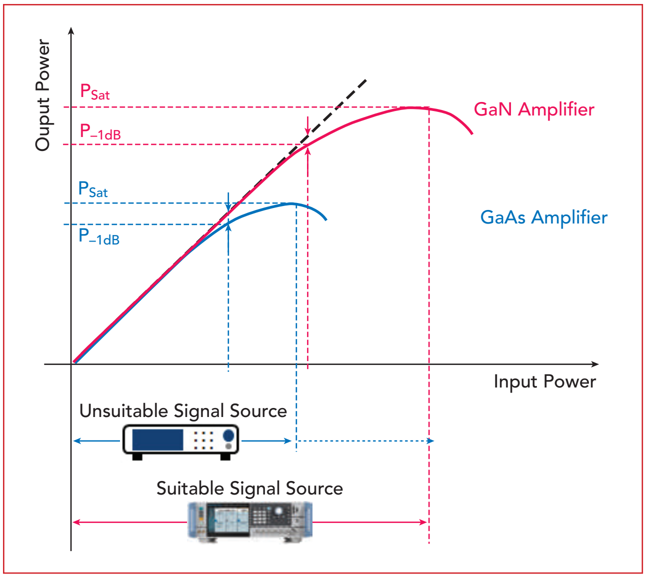


Fig. 7 **Input power range required for GaAs and GaN PAs.**

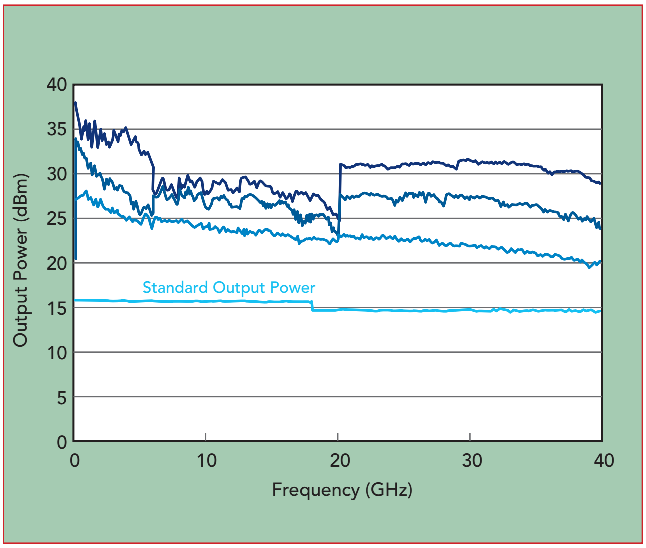


Fig. 8 **Output power options of the R&S SMA100B signal generator.**

"distorting" the PA measurement. ***Figure 6*** quantifies how much better the signal source should be to obtain reliable measurements, assuming the worst case where the second harmonics of the signal source and the PA are in phase. For instance, if the second harmonic from the source is 30 dB below the PA's actual performance, the second harmonic measurement of the PA will be degraded by approximately 0.3 dB, worst case.

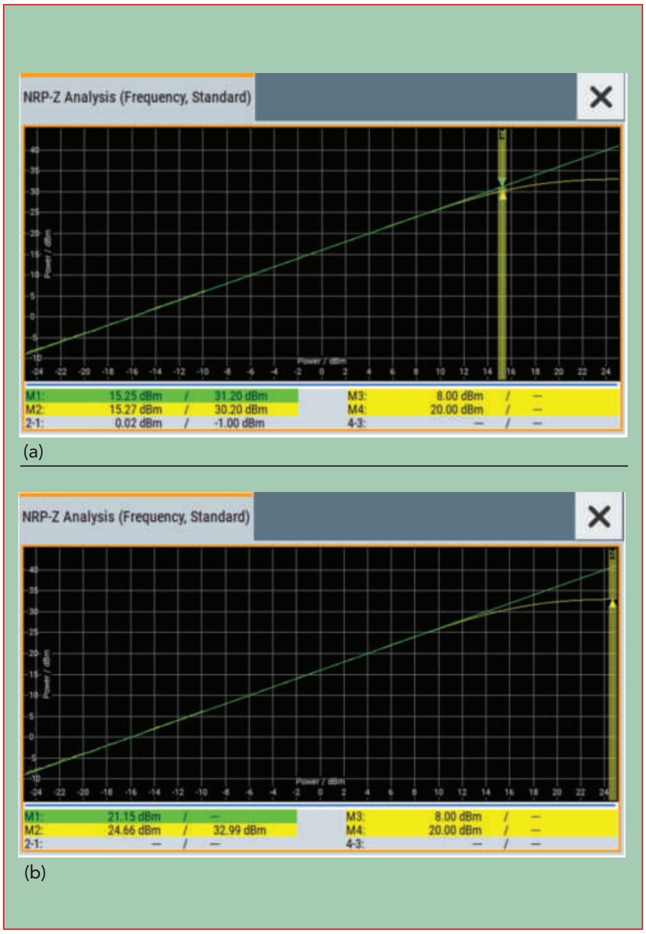


Fig. 10 **P_{1dB} (a) and P_{sat} (b) measurements using the suitable signal source.**

COMPRESSION MEASUREMENTS

The 1 dB compression point (P_{1dB}) at the output of a PA defines the boundary between linear and nonlinear behavior. This is the input power where the small-signal gain of the PA is reduced by 1 dB. As the input power increases, the PA becomes increasingly nonlinear and produces significant harmonic distortion and intermodulation products.

GaN PAs have higher saturated output power capability than GaAs PAs. Assuming the same gain, the GaN PA will require higher input power to reach P_{1dB} and the maximum or saturated output power, designated P_{sat} (see ***Figure 7***). For measuring the P_{1dB} and P_{sat} of a PA, the signal source must have suitable output power. Addressing this need, Rohde & Schwarz designed the R&S SMA100B to have four output power options (see ***Figure 8***). From 20 GHz to approximately 38 GHz, the R&S SMA100B provides more than 30 dBm—compared to the 16 dBm available from traditional signal sources. Higher output power from the signal source may eliminate the need for an external amplifier at the output of the source to drive the PA into compression.

To illustrate this, ***Figure 9*** shows a typical test setup for measuring P_{1dB}

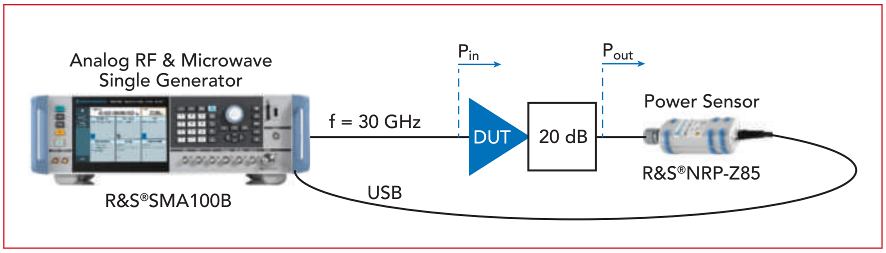


Fig. 9 **Test setup for measuring 1 dB compression (P_{1dB}) and saturated (P_{sat}) power.**

and P_{sat}. The power sensor measures the PA output power and feeds back the measurement result to the signal generator via USB, where it can be graphically displayed on the signal generator's display. The 20 dB attenuator after the PA ensures the power sensor is not overdriven. The DUT is a GaN PA covering 27 to 41 GHz with P_{sat} = 33 dBm and 16 dB gain. The input power (P_{in}) is swept from -25 to +25 dBm at a carrier frequency of 30 GHz. ***Figure 10*** shows the P_{in} versus P_{out} measurements of the PA using a suitable signal source, the yellow trace reflecting the output power and the green trace the linear gain. The y axis accounts for the 20 dB attenuator following the PA. Figure 10a shows a P_{1dB} measurement of 30.2 dBm, and Figure 10b shows a P_{sat} of 33.0 dBm. To measure the P_{sat} of the GaN PA requires P_{in} = ~25 dBm at 30 GHz, which is more power than the capability of many signal sources (see ***Figure 11***). Using a signal source with lower output power, P_{1dB} and P_{sat} cannot be measured directly without an additional amplifier. Figure 11 shows 30.0 dBm maximum output power from the PA, which reflects the shortfall of the signal source rather than the performance of the PA.

These measurements show that using a signal source with sufficient output power simplifies the test setup, enabling higher power P_{1dB} and P_{sat} measurements without requiring an external amplifier that could introduce measurement errors.

SSB PN MEASUREMENTS

Analog and digital circuits rely on pure clock signals. Typical clock signal performance indicators are PN, jitter, wideband noise and spurs. Similarly, a low PN signal source is needed for measuring DUT performance. The residual PN of the DUT determines the PN added by the DUT to the PN of its input signal. Phase-locked loops in high speed digital applications require an input signal with excellent PN performance, i.e., negligible compared to the residual PN of the DUT.

How can designers ensure the signal source meets the requirements for SSB PN? First, the requirements for the DUT should be defined. Next, the data sheet of the signal source should be reviewed to determine whether the SSB PN performance meets the requirements with enough margin to minimize the contribution from the signal source. We illustrate this with measurements showing how suitable and unsuitable signal sources affect SSB PN measurements. The R&S SMA100B is used as the suitable source, with the option for a maximum SSB PN of -128 dBc/Hz at 10 kHz offset from a 10 GHz carrier and typically providing -132 dBc/Hz. The unsuitable signal source has a specified SSB PN performance of -115 dBc/Hz at 10 kHz offset from a 10 GHz carrier. Although usable for many applica-

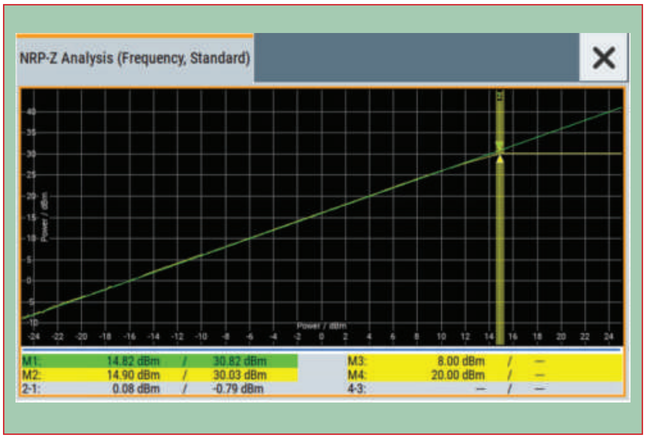


Fig. 11 P_{1dB} **measurement using the unsuitable signal source.**

tions, this signal source may no longer be sufficient to for testing current generation analog-to-digital (ADC) and digital-to-analog (DAC) converters.

In this example, the DUT was a test board with a DAC. The best way to measure the residual SSB PN of the DAC is to generate a sinusoidal signal at its output, where the digital input is I = Q = 1. The DAC used here has a digital signal processing unit with a digital up-converter, enabling the digital input data to be resampled and shifted in frequency. The numerically-controlled oscillator of the DAC was set to $f_{out} = f_{sample}/9$, with f_{sample} = 9 GHz, so the DAC output signal was a 1 GHz sine wave.

As with the previous measurements, the setup comprised the two signal sources and the DUT; an R&S FSWP was used to measure the SSB PN (see ***Figure 12***). The SSB PN was measured with the suitable signal source, with and without the DAC, and the unsuitable signal source, with and without the DAC. ***Figure 13*** shows the SSB PN measurements of both signal sources at 9 GHz with +18 dBm output power and "downscaled" to 1 GHz by subtracting 20log(9 GHz/1 GHz) in dB. Downscaling is necessary to compare the SSB PN performance of the signal sources and the DAC.

Comparing the SSB PN performance of the DAC with the two signal sources, the difference in specific frequency ranges was high (see ***Figure 14***), with the lower curve the SSB PN performance of the DAC measured with the lower PN source. The SSB PN measurement using the unsuitable signal source adds significant contributions to the DAC's residual SSB PN. To show where the poorer signal source influences the SSB PN measurement, the offset frequency range was split into six bands (see ***Figure 15***). In ranges 2, 4 and 6, the measured DAC SSB PN performance was nearly same with both signal sources, as the SSB PN of the unsuitable signal source was better than that of the DAC. In frequency ranges 1, 3 and 5, the SSB PN of the unsuitable signal source was worse than the DAC's

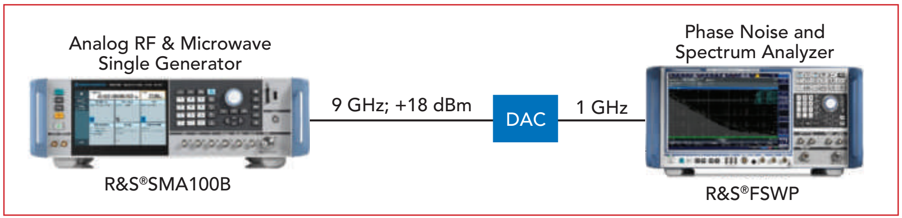


Fig. 12 **Test setup for measuring the SSB PN.**

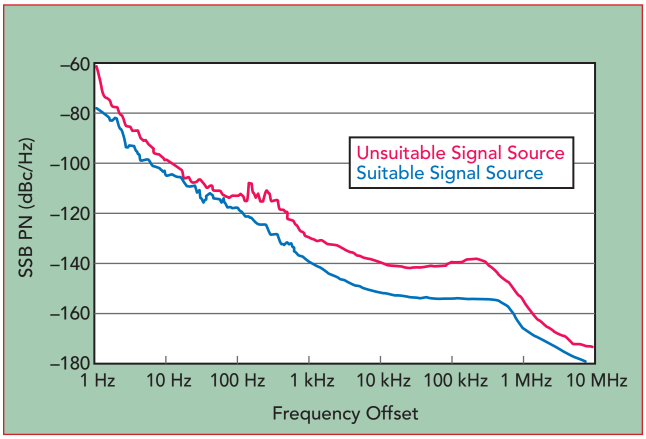


Fig. 13 **Comparing the SSB PN measurements using the two signal sources.**

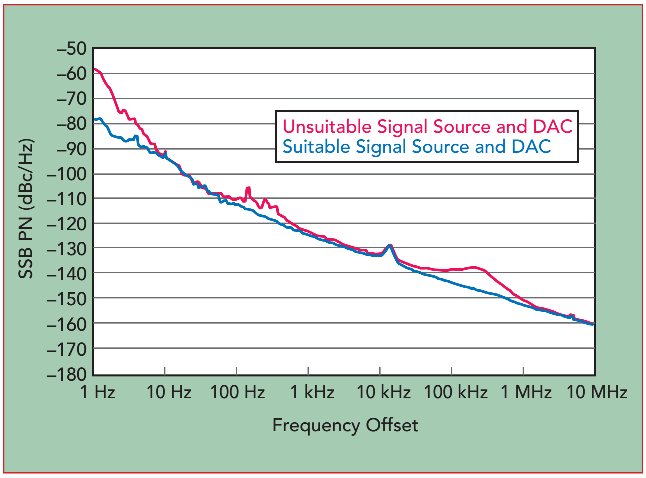


Fig. 14 **Comparing the SSB PN performance of the DAC using the two signal sources.**

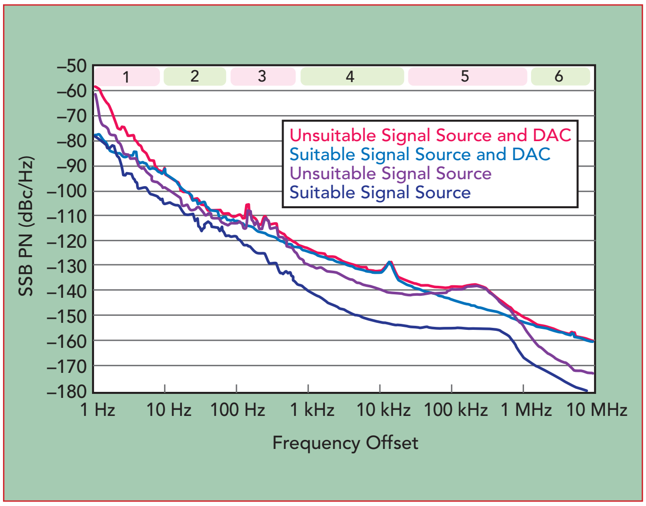


Fig. 15 **1 GHz SSB PN comparisons.**

TABLE 1

SSB PN MEASUREMENT DEGRADATION

Δ SSB PN: Signal Source vs. DAC (dB)	Degradation (dB)
+10	10.4
+6	7.0
+3	4.8
0	3.0
−3	1.8
−6	1.0
−10	0.4

performance, so the SSB PN measurement reflects the performance of the unsuitable signal source, not the DAC.

These measurements show the importance of using a low PN signal source. To ensure accurate measurements, follow this process:

1. Measure the SSB PN performance of the signal source using the same frequency and power level as will be used for the DAC measurement. In this example, the DAC output frequency was 1 GHz, so the DAC clock input signal of 9 GHz was divided by 9 in the DAC.
2. Calculate the SSB PN performance of the signal source at 1 GHz to compare it with the DAC output frequency of 1 GHz: SSB PN (1 GHz) = SSB PN (9 GHz) – 20log (9 GHz/1 GHz) in dB.
3. Ensure sufficient margin between the DAC measurement and the calculated SSB PN of the signal source.

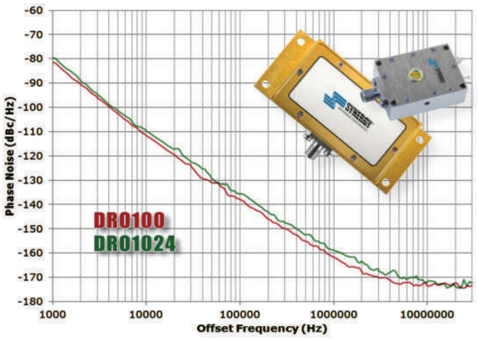
Table 1 shows how the SSB PN of the signal source will degrade the measurement of the DAC's performance. The table shows if the SSB PN of the signal source is 10 dB better at a certain offset frequency than the DAC's performance, the measurement will be degraded by 0.4 dB.

The instrument used to measure the SSB PN is another potential source of measurement error. Although not assessed in this article, a phase noise analyzer with low SSB PN should be used for these measurements to minimize any degradation.

SUMMARY

This article has examined how the harmonics, output power and SSB PN performance of the signal source can degrade measurement accuracy, often without the user realizing the unwanted effects. In each example, the performance of two signal sources was measured, showing the effect on a PA or DAC measurement. Guidelines for harmonics and SSN PN were provided to quantify the impact of the signal source, enabling users to determine the appropriate signal source requirements to achieve the desired accuracy for the application. ■

Metamaterial-Möbius Coupled Dielectric Resonator Oscillators Extend Low Phase Noise Performance into K-Band



Ulrich L. Rohde, Ajay K. Poddar
Synergy Microwave Corp.
Paterson, N.J.

5G communication systems require high speed data transmission, extending the need for high frequency signal sources with low phase noise. Phase noise is an oscillator parameter that has grown in importance with the complexity of modern modulation formats, as phase noise can increase the bit error rate of a telecommunications link, degrade the stability of beams in particle accelerators and degrade the sensitivity of radar systems.

Responding to this need, Synergy Microwave has developed a line of compact, surface-mount, dielectric resonator oscillators (DROs) with extremely low phase noise at fundamental frequencies through 20 GHz.

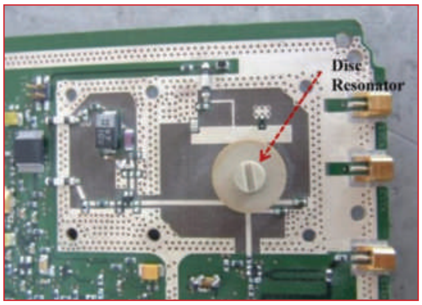


Fig. 1 DRO circuit using a disk DR mounted on a PCB.

ACHIEVING HIGH Q

Electronic oscillators generate low phase noise to a few GHz but the phase noise degrades at higher frequencies, principally due to low Q-factor resonators. Historically, quartz crystals were used as very high Q resonators, but their operating frequencies are limited to less than 200 MHz. The conventional approach to generating higher frequency signals is with a frequency multiplier, but this technique adds phase noise from AM-PM noise conversion and sub-harmonic generation.

Various resonators are used in electronic oscillators: printed coupled transmission lines using surface acoustic wave, dielectric, ceramic coaxial, YIG and sapphire-loaded cavity (SLC) resonators. All have unique characteristics and limitations. They typically operate from 500 MHz to 20 GHz; however, the Q degrades at higher frequencies, at best limited to $f \times Q < 10^{14}$. While SLC-based oscillators provide low phase noise signal generation, they have limited tuning capability and require precise low temperature cooling systems, which make them expensive.

As an alternative, special composite ceramic structures called dielectric resonators (DRs) were developed to achieve a high Q resonator at microwave frequencies, subsequently leading to a family of oscillators

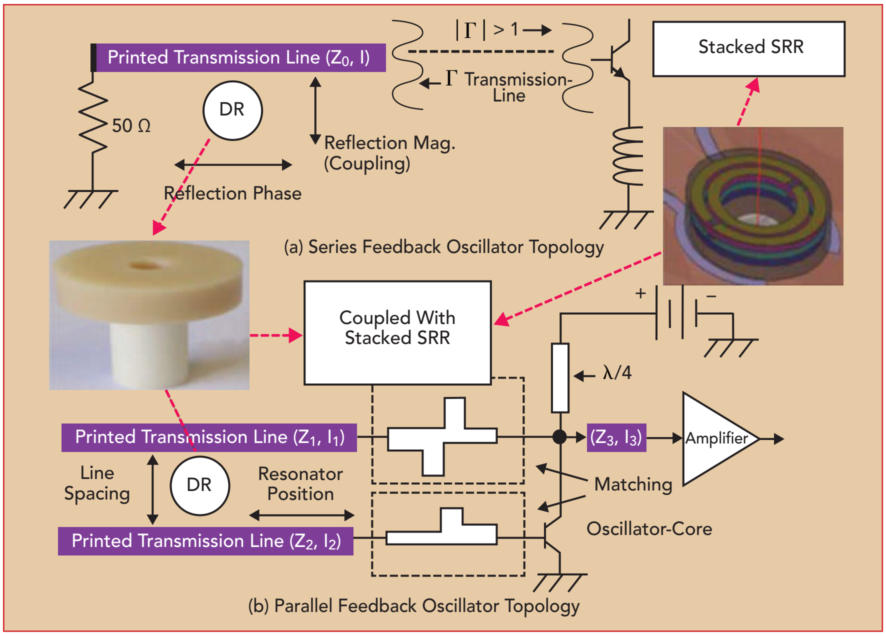


Fig. 2 Typical DRO designs: reflection type with series feedback (a) and transmission type with parallel feedback (b).

called DROs. However, numerous challenges face the design and fabrication of low phase noise DROs at high frequencies, including the proper placement of the DR disk and coupling to the desired mode for stable oscillation. ***Figure 1*** shows a typical DRO for understanding the DR placement on the printed circuit board. Typically, the DR is a disk attached through a spacer made of low dielectric material. Using a screw mounted on the DR, the frequency can be tuned across a narrow band. Unfortunately, DR placement using a spacer and puck for optimum coupling with a mechanical screw for tuning is sensitive to frequency drift under vibration and acceleration. For applications where g-sensitivity is important, this DRO construction has inherently poor phase noise performance.

METAMATERIAL-MÖBIUS STRIPS

With the aid of metamaterial-Möbius coupling, fundamental frequency DROs with low phase noise can operate through X- and K-Band, offering superior figures of merit (FOM).[1] Manipulating and tailoring the electromagnetic wave coupling, several interesting properties of metamaterial-Möbius strips (MMS) can be achieved, such as reducing size for a given operating frequency and suppressing spurious resonance modes to improve the FOM of a tunable oscillator. The FOM can be a limiting factor in modern communications systems, especially those requiring a power efficient, low phase noise signal source. Möbius strips offer unique characteristics, including self-phase-injection properties along the mutually coupled surface of the strips, enhancing the Q for a given sized printed transmission line resonator. The Q is defined by:

$$Q_L = \frac{\omega_0}{2}\left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} = \frac{\omega_0}{2}\tau_d;\ \tau_d = \left|\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} \quad (1)$$

$$\tau_d = \left.\frac{d\varphi(\omega)}{d\omega}\right|_{\omega=\omega_0} = \frac{\varphi(\omega_0+\Delta\omega)-\varphi(\omega_0-\Delta\omega)}{2\Delta\omega} \quad (2)$$

where Q_L is loaded quality factor, $\varphi(\omega)$ is the phase of the oscillator's open loop transfer function at a steady state and τ_d is the group delay of the MMS resonator.[1]

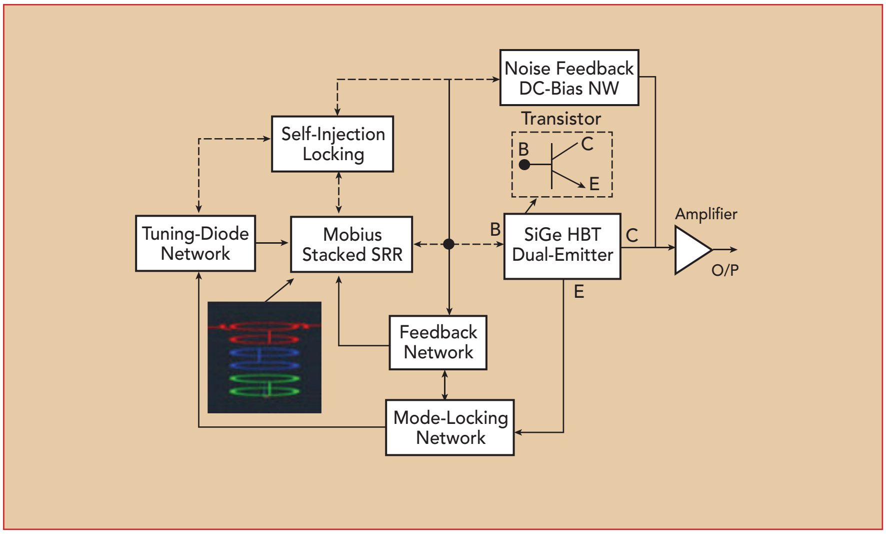


Fig. 3 **Mobius stacked SRR K-Band oscillator.**

MMS DRO PRODUCTS

Work on MMS DROs led Synergy Microwave to develop a line of compact, surface-mount DROs with extremely low phase noise at fundamental frequencies above 8 GHz, making them well suited for commercial, industrial and military applications. ***Figure 2*** shows the typical architecture of a DRO using a disk and stacked split ring resonator (SRR) to realize a metamaterial-Möbius SRR frequency shaping resonant module. This yields an oscillator stable enough to use as a low phase noise local oscillator. ***Figure 3*** shows a block diagram of a K-Band version. An X-Band metamaterial-Möbius DRO achieves a phase noise of -139 dBc/Hz at 10 kHz offset from a 10.24 GHz carrier (see ***Figure 4***), which supports applications such as radar systems requiring high dynamic range and low radar cross section target detection. For systems requiring compact sources, Synergy offers metamaterial-Möbius DROs in both connectorized and surface-mount housings, measuring 0.75 × 0.75 in. The SMD versions can be extended to any number of fixed frequencies, typically from 8 to 20 GHz, without long lead times to produce the sources. These MMS DROs typically draw 30 mA and should be powered by a clean DC bias voltage, using an external regulator if necessary to minimize supply variation.

A standard MMS DRO product set for a 10 GHz output frequency can be mechanically adjusted by about ±50 MHz. To compensate for the frequency drift in phase-locked systems, an electrical tuning port enables ±1 MHz adjustment using a tuning range from +1 to +15 VDC. The operating temperature range is from -25°C to +70°C. By mode-locking, the operating temperature can be extended to -40°C to +85°C, providing excellent output power and phase noise performance over temperature.

Fig. 4 **Phase noise measurement of a 10.24 GHz MMS DRO.**

The MMS DROs developed by Synergy Microwave are used widely in military and commercial applications, including wireless LAN and other communications systems, test and measurement, electronic warfare, missile, radar and medical.[1,2]

Synergy Microwave Corp.
Paterson, N.J.

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Exceptional Phase Noise

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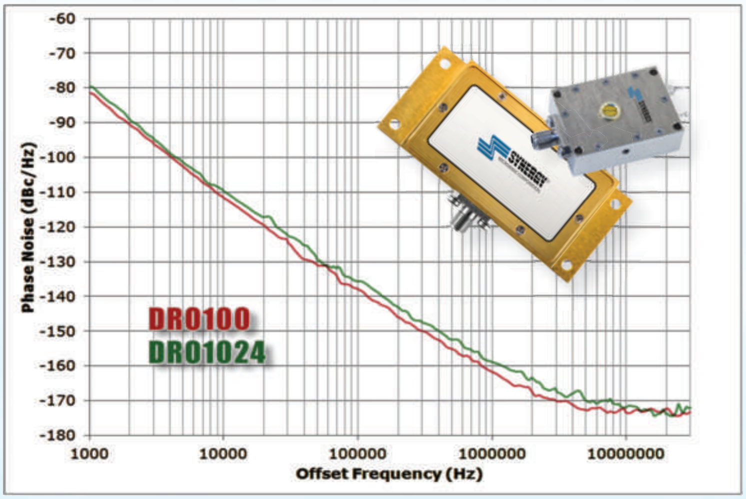

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Surface Mount Models				
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SDRO800-8XT [1]	8	1 - 10	+8 @ 25 mA	-110
SDRO900-8	9	1 - 10	+8 @ 25 mA	-112
SDRO900-8XT [1]	9	1 - 10	+8 @ 25 mA	-112
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-105
SDRO1118-7	11.18	1 - 12	+5.5 - 7.5 @ 25 mA	-104
SDRO1121-7	11.217	1 - 12	+5.5 - 7.5 @ 25 mA	-106
SDRO1130-7	11.303	1 - 12	+5.5 - 7.5 @ 25 mA	-106
SDRO1134-7	11.34	1 - 12	+5.5 - 7.5 @ 25 mA	-107
SDRO1140-8XT [1]	11.4	1 - 10	+8 @ 25 mA	-102
SDRO1250-8	12.5	1 - 15	+8 @ 25 mA	-104
SDRO1300-8	13	1 - 12	+8 @ 25 mA	-104
SDRO1400-8	14	1 - 12	+8 @ 25 mA	-102
SDRO1500-8	15	1 - 12	+8 @ 25 mA	-100
SDRO1800-8	18	1 - 12	+8 @ 25 mA	-100
SDRO2000-8	20	1 - 12	+8 @ 25 mA	-98
Connectorized Models				
DRO80	8	1 - 15	+7 - 10 @ 70 mA	-114
DRO8R95	8.95	1 - 10	+7 - 10 @ 38 mA	-109
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	-109
DRO1024H	10.24	1 - 15	+7 - 10 @ 70 mA	-115
KDRO145-15-411M	14.5	*	+7.5 @ 60 mA	-100

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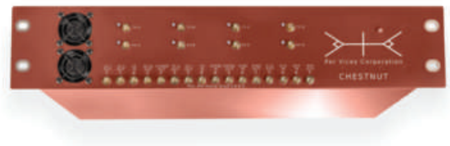


SDR Balances Performance and Cost, Offers Easy Integration into Systems

Per Vices
Toronto, Canada

Per Vices has developed a new software-defined radio (SDR), named Chestnut, to serve mid-range applications seeking a high performance SDR with a smaller form factor, more accessible price range and easy integration in wireless communications and other systems applications. Chestnut is positioned between Per Vices' Crimson TNG and Cyan SDRs.

ARCHITECTURE

With a tuning range from near DC to 9 GHz, this latest SDR is well suited for applications needing wide operating frequencies. The architecture has four receive (Rx) and four transmit (Tx) radio chains, each chain independently controlled yet maintaining phase coherency for applications needing that capability. Each radio has 500 MHz of RF bandwidth, providing 2 GHz total with all chains operating. The architecture supports separately tuned LOs or a common LO for improved coherency and stability, as applications such as radar and beamforming benefit from improved coherency with all channels tuned to the same frequency.

Chestnut is powered by an Intel FPGA SoC, with separate interfaces for management and data. The management interface includes dual 1G ports for full redundancy, with two qSFP+ ports providing 100 Gbps data transfer per port, so the SDR has 200 Gbps total data transfer capacity. The internal oven-controlled crystal oscillator (OCXO) assures highly stable LO and clock performance, and the onboard OCXO can synchronize multiple devices. The SDR also has the flexibility to use an external 10 MHz source, and its flexible features include a compact 19-in. 2U form factor, native web interface and UHD compatibility—out of the box.

Chestnut's modular design comprises of

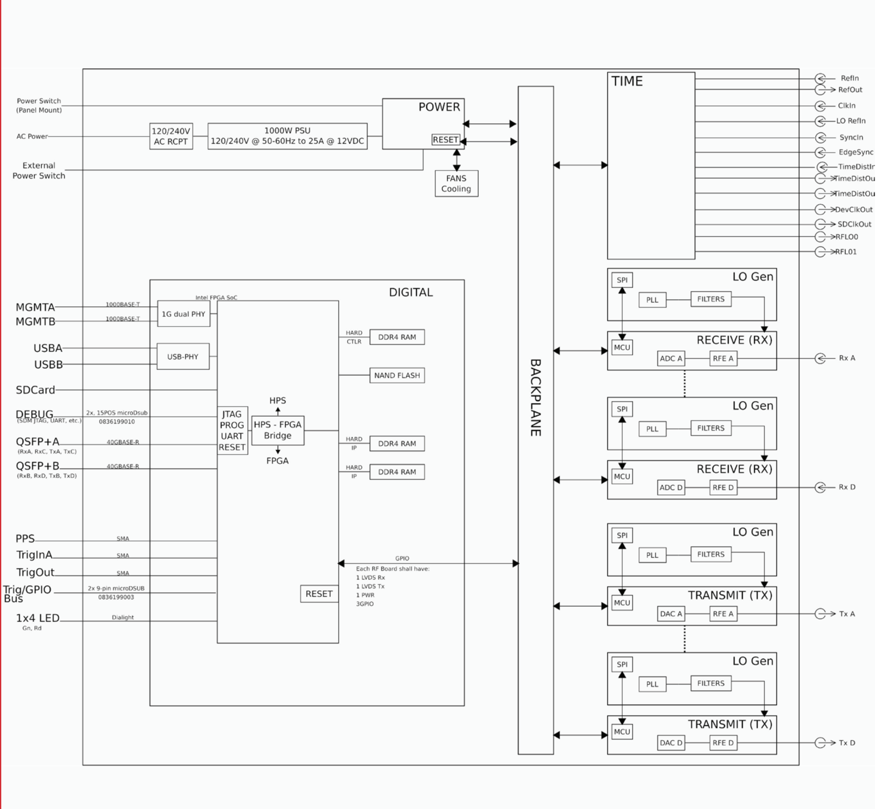
five boards, each connected to a rugged backplane (see ***Figure 1***). The power board provides power to the digital, time, Rx and Tx boards. The digital board has an interface to control, configure, send and receive data between the Rx, Tx and time boards. Clock distribution extends from the time board, providing a clean and stable clock distribution network. The default Rx and Tx boards each have four independent channels. The Rx board consists of a radio front-end terminating with a Texas Instruments (TI) ADS54J69 dual-channel, 16-bit, 500 MSPS analog-to-digital converter on each channel. The Tx board's radio front-end originates with TI's quad channel DAC38J84 digital-to-analog converter. For peripherals, Chestnut offers two USB slots, an SD card slot, two Ethernet ports (MGMT 10/100/1000 Ethernet port), as well as the two qSFP+ ports.

APPLICATIONS

Chestnut addresses a range of applications covering wireless communications, spectrum monitoring, signals intelligence and phased arrays. Its low cost of entry enables users to prototype and test different communications protocols and devices across a wide spectrum or use the SDR for spectrum monitoring, recording and playback or phased array systems. Its unique and modular design enables it to be integrated in enterprise applications, offering interoperability, flexibility and ease of integration into other systems.

For mid-range applications, the market has been seeking a product offering a high performance SDR with a smaller form factor and more accessible price range. After speaking with clients and analyzing the market, Per Vices developed Chestnut to address these specifications and operations at a price of $30,000. This new SDR supports customer needs for easy integration by offering a modular and reconfigurable solution with IP available for many applications.

Per Vices Corporation
Toronto, Canada
www.pervices.com
solutions@pervices.com



▲ **Fig. 1** The Chestnut SDR design is modular: five boards connected to a backplane.

Ultra-Portable Spectrum Analyzer for the 6-20 GHz Point-to-Point Bands

The cost of spectrum analysis for field engineers does not have to break the bank. With this objective, SAF Tehnika added a 6 to 20 GHz model to its series of handheld spectrum analyzers, enabling microwave engineers to efficiently handle line-of-sight verification, installation, site acceptance, maintenance and troubleshooting of point-to-point radio links.

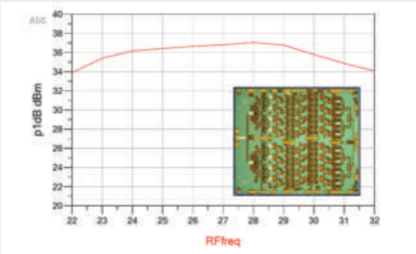
SAF's 6 to 20 GHz Spectrum Compact has -110 dBm sensitivity at a resolution bandwidth of 30 kHz, up to 4 hours battery life, instant-on functionality with a simple and intuitive interface and a small, rugged form factor. The unit will measure in-band power, adjacent channel power, center frequency and signal bandwidth, as well as locate interference. The user sets up the center, start and stop frequencies and the trace mode, such as normal, cumulative and the maximum signal. The Spectrum Compact's 8 GB of memory will save thousands of spectrum traces for offline analysis, investigation and reporting using PC software included with the unit.

Every aspect of SAF's Spectrum Compact has been designed with field use in mind, including the resistive touchscreen that operates with gloves, sturdy thumbscrews for SMA and waveguide connections and the high-contrast and full display modes for easy reading in bright light.

The Spectrum Compact product family covers bands from 300 MHz to 87 GHz, with models to serve wireless ISPs, mobile carriers, tower installation crews deploying 5G networks, utilities, local governments, public safety and other critical network infrastructure.

SAF Tehnika designs and manufactures RF data transmission equipment for global networks. In addition to spectrum analyzers, SAF's products include signal generators, microwave radios and wireless IoT solutions for environmental monitoring.

SAF Tehnika
Riga, Latvia
www.spectrumcompact.com/emulator/



Cost-Effective GaAs MMIC Chipset for 5G mmWave

A radio for the 24 to 29.5 GHz band must achieve both performance and commercial targets. Evaluating antenna options, the system architecture could use a large active array with SiGe RFICs or a passive array driven by a very high power GaN amplifier, though both lack the flexibility to adapt quickly and cost-effectively to the fast-changing telecoms market.

SIAE MICROELETTRONICA chose a third option for its 24 to 29.5 GHz radio system: developing a custom GaAs chipset comprised of up- and down-converters with integrated variable gain and low noise amplifiers (an IF from DC to 7 GHz), with a medium power amplifier for the user terminals and a high power amplifier (HPA) for the network equipment.

The HPA design required major effort to achieve the target specifications using a low-cost 0.25 µm GaAs MMIC process. The 36 dBm output power at 1 dB compression and 44 dBm OIP3 were challenging for a process limited to 6 V maximum operating voltage. At the targeted output power, the DC power consumption is approximately 19 W, meaning the power device draws 3.2 A. Handling such high current would have caused several problems and reduced the efficiency of the system. So a stacked FET topology was chosen, with the stacked FET biased at 12 V and drawing 1.6 A. This approach is typical of Si CMOS PAs, where the process ft is more than 6x the operating frequency; however, it is challenging for a 0.25 µm GaAs process with a ft of 65 GHz, where device parasitics can degrade the theoretical performance.

Nonetheless, the MMIC, packaged in a 6 mm QFN, achieves more than 36 dBm at 1 dB compression and 25 dB small-signal gain from 24 to 29.5 GHz.

SIAE MICROELETTRONICA
Milan, Italy
www.siaemic.com

10 W, K-Band GaN MMIC Power Amplifier Family

Arralis Technologies has introduced a K-Band MMIC power amplifier (PA) with an integrated output power detector, also available in a QFN ceramic package. Its high power makes it well-suited for satellite communications, compatible transceivers for space communications and point-to-point radio links. The surface-mount PA operates from 17 to 20.5 GHz and delivers a minimum of 10 W saturated output power with efficiency greater than 25 percent, associated large-signal gain of 20 dB and small-signal gain of 25 dB.

The three-stage amplifier is fabricated with a space-qualified, 0.25 μm GaN on SiC process and biased at a drain voltage of 25 V. The MMIC is matched to 50 Ω and has integrated DC blocking capacitors on the input and output RF ports.

The surface-mount version is offered in a 7 x 7 mm hermetically sealed ceramic package. Alternatively, the chip is available as bare die or as an integrated PA module with detectors for power and temperature, the latter to detect the output power. The module size is 63 x 60 x 25 mm and has 2.92 mm connectors. Both the bare die and surface-mount versions are available with evaluation boards for system design and test.

These devices are part of the complete Ka-Band satellite family, including GaAs PAs, low noise amplifiers, mixers, phase shifters and core chips. Arralis is a leader in satellite and mmWave technologies that encompass a wide range of transceivers, radars, antennas, subsystems and modules.

Arralis Technologies
Swindon, U.K.
www.arralis.com

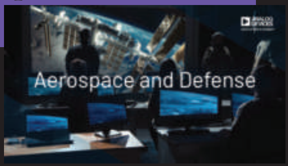
MAKING WAVES

Analog Devices' Signal Processing and System Solutions: A 50-Year Success Story

Analog Devices has a clear mission: to solve today's and tomorrow's aerospace and defense challenges with industry-leading integrated solutions.

Analog Devices

www.analog.com/en/applications/markets/aerospace-and-defense-pavilion-home.html

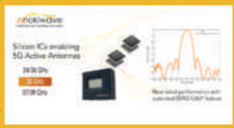


New 5G Enabler: mmWave Phased Array Active Antenna Innovator Kits

The Antenna Innovator Kits are complete antenna front-ends going from mmWave to IF and can be easily used to prototype or to perform a proof of concept for a 5G radio or antenna design.

Anokiwave

www.anokiwave.com/media/blog/articles/anokiwave_innovator.html



Overview of the Latest Applicable EMC Standards

Read the EMC Standards Overview to review some of the more common standards used across the industry.

AR RF/Microwave Instrumentation

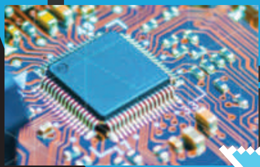
https://bit.ly/3pUqBSP

On Demand: Cadence AWR V16 for RF Design Excellence Webinar Series

Now on demand, the Cadence® AWR® V16 webinar series introduces new EM/multiphysics solvers and cross-platform workflow integration for developing high performance RF to mmWave systems.

Cadence

https://bit.ly/30BTqZq



CAES 3D Printing

CAES' 3D printing capabilities significantly reduce SWaP, eliminate traditional manufacturing limitations and space constraints and enable complex, lightweight RF designs with additional features and performance.

CAES

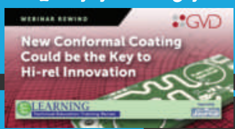
www.caes.com/3dprinting

Ultra-Thin Coating Protects Microwave Circuits & Assemblies

Learn how defense contractors are leveraging SignalSeal, an ultra-thin vapor deposited coating, to cut cost and weight of their assemblies while maintaining signal performance in harsh environments.

GVD Corporation

https://bit.ly/31oBaTU



New JFW 50 Ohm Components Brochure

JFW updated their 50 Ohm Component Brochure to showcase the newest models, this new version includes products specifically designed to meet the needs of the evolving landscapes of 5G, Wi-Fi 6E and mmWave communications.

JFW Industries
www.jfwindustries.com/pdf/JFWCatalog.pdf

Monitor Battery Temperature By Using a DAQ System or Specialized Battery Test System

Testing for lab battery packs and systems occurs during an early product design cycle using several common R&D lab instruments. A DAQ system can be used to monitor temperature at multiple points in a product's battery system, read more in this blog post.

Keysight Technologies
https://bit.ly/3oggK8p

Wideband Connectorized Amplifiers OTA Transmitter & Receiver Testing for 5G FR2 Bands

This blog post briefly describes common test setups for OTA testing of transmit and receive signal chains and illustrate uses for Mini-Circuits' ultra-wideband connectorized amplifiers within these setups.

Mini-Circuits
https://bit.ly/3IcapTv

New High Frequency Catalog from PPI

Passive Plus, Inc. (PPI) has launched a brand-new catalog for its high frequency components: broadband capacitors, broadband resistors, inductors and single layer capacitors.

Passive Plus, Inc. (PPI)
www.passiveplus.com/addldocs_resources.php

Chalk Talk: UWB - Because Location Matters

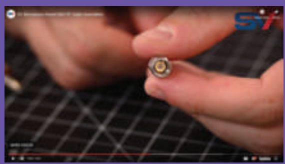
UWB opens up a world of possibilities. Learn all about the exciting technology enabling centimeter accuracy for distance and location measurement in this video.

Qorvo, Inc.
www.youtube.com/watch?v=_1emVaWJC60

New Video: Keyed SMA RF Cable Assemblies

SV Microwave released fixed length Keyed SMA cable assemblies that offer an ideal solution when polarization is required. These new Keyed SMA connectors are available in four keying configurations and are cabled to standard SMAs using Ø.085 cable.

SV Microwave
https://bit.ly/3joJKrU



NEW PRODUCTS

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

COMPONENTS

Fully Integrated Tuner Module

VENDORVIEW

The AM9018 is a fully integrated tuner module that provides high dynamic range coverage from 0.9 to 18 GHz with an instantaneous bandwidth of 1 GHz. The tuner also provides a bypass path from 10 MHz to 6 GHz for direct spectrum capture, and an internal ADC driver amplifier. This miniature heterodyne tuner module is designed for high performance and low size, weight and power and is mechanically mountable to a host circuit board for use in multi-channel receiver applications.

Atlanta Micro Inc.
www.atlantamicro.com

High Frequency RF Loads

VENDORVIEW

Fairview Microwave announces new high frequency RF loads: New RF loads with 1.85 mm, 2.4 mm, 3.5 mm, SMP and SMPM connector. High frequency RF terminations. Operating frequency range up to 67 GHz, coaxial designs with 1.85 mm, 2.4 mm, 3.5 mm, SMP and Mini-SMP connectors, available in both male/female connectorized configurations, flat RF response and performance, excellent VSWR performance as low as 1.15:1.

Fairview Microwave
www.fairviewmicrowave.com

Woven Resistors

After a 15-year hiatus, OhmWeve is back. The high voltage, high-power resistors that pulsed power specialists standardized on is available once again. Ideal for high wattage pulsed power applications, OhmWeve resistors are the lowest weight per Watt resistors on the market. They are available in racks of five, 10 or as individual resistors. Their unique woven design eliminates the need for costly heat sinks or oil tanks.

H6 Systems Inc.
www.h6systems.com

Ultra-Wideband 10 dB Directional Coupler

MIcable 0.2 to 18 GHz ultra-wideband 10 dB directional coupler covers multiple microwave frequency bands such as P, L, S, C, X, Ku, K and Ka by a single unit. It has excellent performance with insertion loss 2.4 dB, VSWR 1.4:1, coupling 10 ± 1 dB, directivity 13 dB and 30 W power handling. It is good for applications like test, instrument and other wideband systems.

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

Directional Coupler

VENDORVIEW

KRYTAR Inc. announced the continued expansion of its line of directional couplers with the addition of a new model offering 13 dB of nominal coupling over the frequency range of 18 to 26.5 GHz (K-Band), in a compact and lightweight package. KRYTAR's new directional coupler, Model 262213, enhances the selection of multi-purpose, stripline designs that exhibit excellent coupling in a single, compact and lightweight package. The directional coupler is uniquely designed for systems applications where external leveling, precise monitoring, signal mixing or swept transmission and reflection measurements are required.

KRYTAR Inc.
www.krytar.com

5 to 300 MHz Transformer

VENDORVIEW

The MXRFXF0014 is 5 to 300 MHz 1:1 high performance, flux coupled SMD transformer with 20 dB minimum input RL minimum across the band and less than ±0.2 dB amplitude balance and excellent ± degree phase balance across both primary and secondary outputs. Add in built-in temperature stability and an active device biasing tap; enabling smaller component count and more board real estate for the best system performance when you need it. Contact the MiniRF local sales office at 408-228-3533 or RFMW Inc. for samples and design with confidence.

MiniRF
www.minirf.com

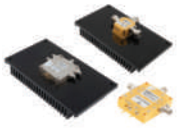
High Frequency Catalog

Passive Plus, Inc. (PPI) has launched a brand-new catalog for its high frequency components: broadband capacitors, broadband resistors, inductors and single layer capacitors. The catalog can be found on PPI's website. The new catalog represents PPI's high frequency products. The full range of broadband capacitors: 01005, 0201, 0402, 0603, 0805; broadband resistors: R35-1209 and R35-2010; spiral inductors; and single layer capacitors: edge to edge, border cap, twin cap and array. Individual component information can also be found on the website.

Passive Plus Inc.
www.passiveplus.com

Coaxial Packaged Switches

VENDORVIEW



Pasternack, an Infinite Electronics brand and a leading provider of RF, microwave and mmWave products, has just launched a new series of high-power RF and microwave PIN diode coaxial packaged switches that are ideal for commercial and military radar, jamming systems, medical imaging, communications and electronic warfare. Pasternack's new high-power RF and microwave PIN diode switches utilize GaN semiconductor technology. GaN and chip and wire technology in the manufacturing process ensures state-of-the-art power performance with excellent power-to-volume ratio that is ideal for broadband high-power applications.

Pasternack
www.pasternack.com

Filters for Citizens Band Radio Service

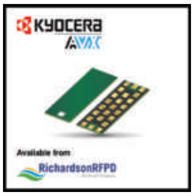
VENDORVIEW

Long-time developer and manufacturer of RF/microwave filters, Reactel Inc., recently announced a series of filters for the Citizens Band Radio Service (CBRS) spectrum. Currently offering both a full band (3550 to 3700 MHz) and narrowband (3550 to 3650 MHz) version, this product line continues to grow to meet the dynamic needs of military, wireless carriers, cable operators and other organizations. Datasheets for these units can be found by visiting the company's website.

Reactel Inc.
www.reactel.com

NewProducts

Multilayer Organic (MLO®) Filters



Richardson RFPD Inc. announced the availability and full design support capabilities for a lineup of multilayer organic filters from KYOCERA AVX. KYOCERA AVX's MLO filters utilize high dielectric constant and low loss materials to realize high Q passive printed elements, such as inductors and capacitors, in a multilayer stack. The filters can support a variety of frequency bands and multiple wireless standards and are less than 1.0 mm in thickness. All filters are expansion-matched to most organic PCB materials, resulting in improved reliability over standard silicon and ceramic devices.

Richardson RFPD Inc.
www.richardsonrfpd.com

SEE US@ EUMW

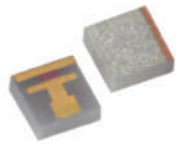
Cellular Band High-Power Directional Couplers

RLC Electronics Inc. manufactures a line of cellular band high-power directional couplers. These devices typically operate below 2500 MHz and can be provided with custom coupling values from 20 to 50 dB. Typical units exhibit low loss (< 0.2 dB), high directivity (> 30 dB), can handle 500 W CW minimum and can be customized to customer specific requirements. RLC can also manufacture form/fit/function replacements for similar obsolete devices from Microlab & Narda.

RLC Electronics Inc.
www.rlcelectronics.com

Wire-Bondable Chip Terminations

VENDORVIEW



Smiths Interconnect extends its offering of high frequency wire-bondable chip terminations with the release of its new HR-CTX Series, a small, easy-to-implement, high reliability product qualified for space applications. The new HR-CTX high frequency termination Series offers excellent broadband performance up to 64 GHz and unrivaled power rating capability up to 5 W in a compact 0404 package. Its 4x smaller footprint allows customers to save space and weight on the board, while the total thin film design optimized on aluminum nitride offers a high power dissipation.

Smiths Interconnect
www.smithsinterconnect.com

SEE US@ EUMW

High Voltage Chip Divider

Vishay Intertechnology Inc. introduced the industry's first high voltage chip divider to be offered in a ribbed molded package with compliant surface-mount leads. Designed to reduce component counts and improve TC tracking performance and ratio stability in automotive and industrial equipment, the Vishay Techno CDMM delivers a maximum working voltage of 1500 V in the 4527 case size. Consisting of two resistors integrated into one molded package, the chip divider provides a single-component replacement for multiple discrete resistors used in voltage divider applications.

Vishay Intertechnology Inc.
www.vishay.com

CABLES & CONNECTORS

1.00 mm RF Cable Connector

VENDORVIEW

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

SPINNER GmbH
www.spinner-group.com

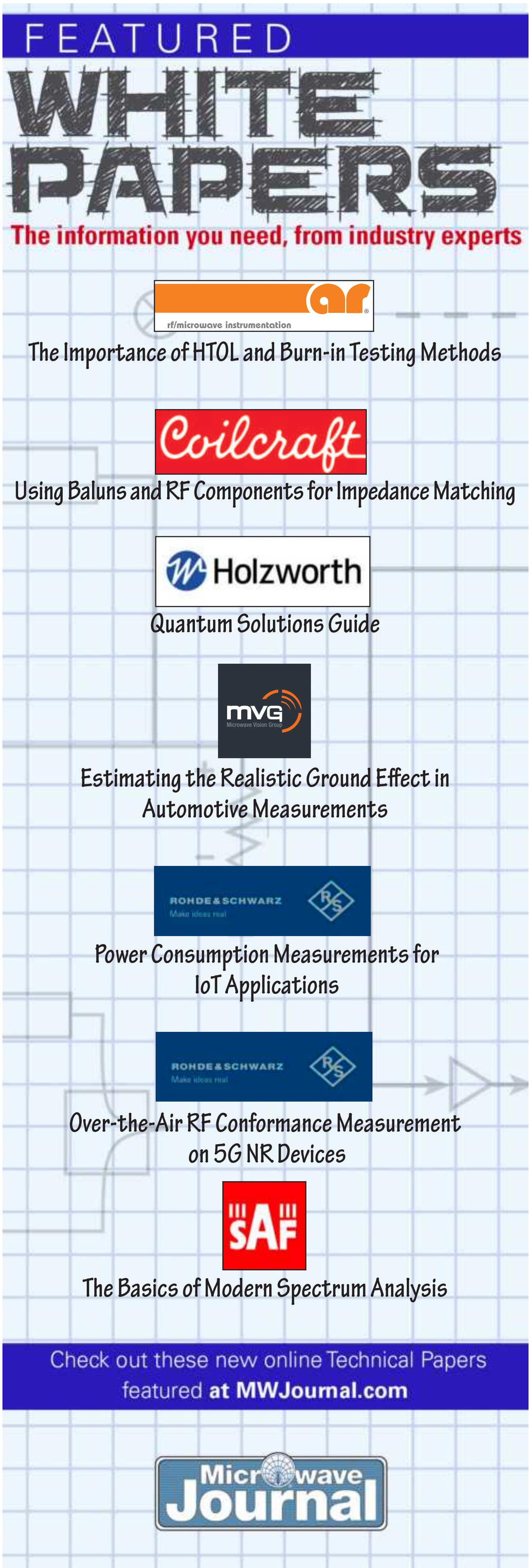
SEE US@ EUMW

AMPLIFIERS

GaN Amplifier

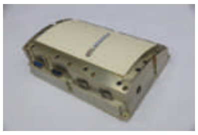
COMTECH PST introduced a new GaN amplifier for applications in the X-Band pulsed radar market. The AB linear design operates from 9.0 to 9.9 GHz frequency range over any instantaneous bandwidth of 500 MHz. Development of this product is intended for use in ruggedized radar applications. The amplifier design features self-protection for load VSWR, duty factor, pulse width, temperature, as well as a graceful degradation in case of a RF power module failure. Custom configurations and features are available as well as specific power levels up to 16 kW.

COMTECH PST
www.comtechpst.com



NewProducts

X- & Ku-Band Solid-State Power Amplifiers



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

Kratos General Microwave
www.kratosmed.com

Miniature Amp

VENDORVIEW

Mini-Circuits' model PMA3-83MP+ is a medium-power, monolithic surface-mount amplifier that is ideal for radar and communications applications from 0.4 to 8.0 GHz. It is capable of +27.8 dBm typical output power at 1 dB compression to 2 GHz and +25.3 dBm to 8.0 GHz. Noise figure is typically 3.5 dB across the full frequency range while full band gain is typically 17.3 dB. The RoHS-compliant amplifier is supplied in a 3 × 3 mm, 12-lead MCLP™ package.

Mini-Circuits
www.minicircuits.com

Successive Detection Log Video Amplifiers

VENDORVIEW

PMI Model No. SDLVA-0R5G18G-50R-30DBM is an SDLVA designed to operate over the 0.5 to 18 GHz frequency range for ultra-high speed applications while maintaining flatness and accuracy. Specifications TSS -71 dBm minimum, dynamic range of -70 to 0 dBm and +30 dBm CW maximum input power. Package size is 3.2" × 1.8" × 0.4" with SMA female connectors.

Planar Monolithics Industries
www.pmi-rf.com

SOURCES

Ultra-Compact Module

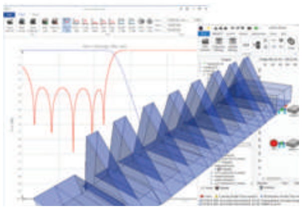
VENDORVIEW

Exodus Advanced Communications introduces their ultra-compact 700 MHz to 6.0 GHz lightweight module. This module produces 25 W minimum, 30 W nominal power. The minimum power gain is 44 dB with < -20 dBc harmonics. Included are current and temperature sensing and built-in protection circuits for optimum reliability and ruggedness for all applications. The nominal weight is 450 grams, and dimensions of 75 W × 105 L × 30 H mm.

Exodus Advanced Communications
www.exoduscomm.com

SOFTWARE

µWave Wizard Version 9.1



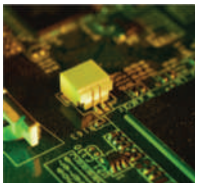
Mician's µWave Wizard software products are powerful tools for synthesis, analysis and optimization of microwave assemblies. The hybrid EM solver guarantees fast and accurate simulation of passive components, feed networks and antennas. The latest release, version 9.1, offers improved CAD export to STEP files of structures containing cylindrical and conical surfaces. The new feature "adaptive frequency sweep on subcircuit level" accelerates the computation for typical cavity filters. It enables a single simulation using individual adaptive frequency loops for each subcircuit. Besides new and modified mode matching based elements the new release also supports second order meshes of all 3D FEM solvers.

Mician
www.mician.com

SEE US@ EUMW

Modelithics MACOM® GaN Library v21.1.5

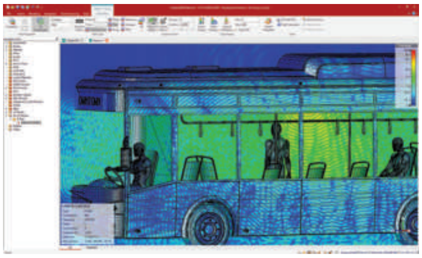
VENDORVIEW



Modelithics Inc. announced version 21.1.5 of the Modelithics MACOM GaN Library. With this latest version, the library now includes a total of six models for MACOM PURE CARBIDE™ GaN devices. Version 21.1.5 of the Modelithics MACOM GaN Library introduces new models for the MACOM MAPC-A1000 and MAPC-A1100 GaN devices. The MAPC-A1000 is suitable for operation from 30 MHz to 3 GHz. This 50 ohm input matched device can deliver 25 W of output power and supports both continuous-wave and pulsed operation at 50 V.

Modelithics Inc.
www.modelithics.com

Software Solutions and Support



Everything we do at SIMUSERV centers around the art of simulation. Digital development based on numeric simulations helps our customers to hold their own amongst their competitors by shortening development times, optimizing products and reducing costs. One of our main competence fields is electromagnetics. As a Dassault Systèmes partner, we offer you software solutions, consulting, training and project support with the CST Studio Suite. At EuMW, we will demonstrate the CST Studio Suite 2022 which introduces a range of new features and improvements to increase the versatility and performance in modeling, meshing and solver technologies.

SIMUSERV GmbH
www.simuserv.de/en

SEE US@ EUMW

ANTENNAS

Waterproof Monopole Whip Antenna

VENDORVIEW

RFMW announces design and sales support for a Southwest Antennas' monopole whip antenna. The 1000-046 omni-directional antenna operates from 330 to 360 MHz with a peak gain of 2.0 dBi. This flexible antenna features a tough, braided aircraft wire element with a sealed heat shrink exterior and fully potted and waterproof base containing the antenna's matching components. The resulting antenna is rugged for use in harsh environments yet is flexible enough to bend if the whip is impacted by another object. The 1000-046 features a BNC male connector for attachment.

RFMW
www.rfmw.com

SEE US@ EUMW

NewProducts

TEST & MEASUREMENT

5 GHz Bandwidth Radar Target Simulator

Ultra-high-resolution imaging radars, often referred to as 4-D radars, provide detailed images of the radar's surroundings with a wide field of view as well as elevation, distance and speed information. Tests of these radar sensors place high demands on the capabilities and bandwidth of the radar target simulator used. The dSPACE Automotive Radar Test System (DARTS) 9040-G is the first RTS to successfully meet these challenges with powerful radio frequency technology.

dSpace GmbH
www.dspace.com

SEE US@ EUMW

Wave-Glide™

VENDORVIEW

STQ-TL-RW-S10-M1 is a patent pending rail system designed to enhance the mmWave VNA testing experience. Trademarked as Wave-Glide™, it is a novel apparatus for accurate, reliable and fast mmWave VNA testing when working with the VNA extenders.

Eravant
www.eravant.com

16-Channel PXI Device Power Supply

Marvin Test Solutions Inc. announced the release of the new GX3116e, 16-channel device power supply/source measure unit (SMU). True four-quadrant operation, isolated outputs, ganging capabilities for higher current and extensive health monitoring and alarms make this the ideal solution for a multitude of semiconductor test applications. Kelvin connection sensing on a per channel basis, ensures that the device under test receives the expected excitation levels, independent of cabling and other interconnects, while over-current sensing and programmable alarms provide protection to the device under test.

Marvin Test Solutions Inc.
www.MarvinTest.com

Phase Noise Analyzer and VCO Tester

VENDORVIEW

Rohde & Schwarz designed the new R&S FSPN phase noise analyzer and VCO tester for production and design engineers who characterize sources such as synthesizers, VCOs, OCXOs and DROs. Providing very high sensitivity and measurement speed, the R&S FSPN is ideal for demanding phase noise and VCO analysis in development and production. The R&S FSPN comes in two models: one covers the frequency range from 1 MHz to 8 GHz and the other from 1 MHz to 26.5 GHz, addressing radar and satellite applications in the C-Band, X-Band, Ku-Band and the complete K-Band.

Rohde & Schwarz
www.rohde-schwarz.com

SEE US@ EUMW

Beamformer Testing up to 50 GHz

Roos Instruments' RI8607 2 GHz to 50 GHz test set, multiport and multi-direction measurements, single insertion S-parameter, IMD, IP3, multi-tone sourcing. Roos Instruments is a leading supplier of fully integrated production test systems for applications from DC to 110 GHz.

Roos Instruments
www.roos.com

Compact Calibration Kits

For calibration of single or two or more port VNAs Rosenberger provides a wide range of compact calibration kits. These compact calibration kits combine all necessary calibration standards in one unit—small, easy to handle and light weight. The 4-in-1 MSOT kits (open, short, load and thru element) and 3-in-1 MSO kits (open, short, load) cover applications in a wide frequency range and are available for a lot of interface standards, e.g. 7-16, 4.3-10, N, RPC-N, RPC-3.50, RPC-2.92 and new RPC-1.35.

Rosenberger Hochfrequenztechnik GmbH & Co. KG
www.rosenberger.com

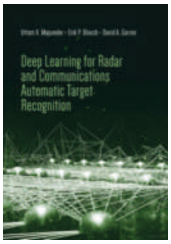
SEE US@ EUMW

Oscilloscope

The SDS6000A is the new flagship oscilloscope from Siglent. The instrument data in a nutshell: 2 GHz bandwidth, 5 GS/s sampling rate at each channel, 500 Mpts acquisition memory, sequence mode capture rate up to 750 kwfm/s, 12.1" touch-screen. The well thought-out and intuitive operating concept together with a lot of functionality increases the efficiency in the laboratory.

SIGLENT Technologies Germany GmbH
www.siglent.com

SEE US@ EUMW



Deep Learning for Radar and Communications Automatic Target Recognition

Uttam K. Majumder, Erik P. Blasch, David A. Garren

This resource discusses how artificial intelligence (AI) and machine learning (ML) can be used to improve radar object detection and target recognition by analyzing the data from synthetic aperture radar (SAR) and high range resolution radar (HRR) systems. The book begins with an overview of the theory, covering the history, development and performance of AI/ML algorithms and unresolved issues. It provides real-world examples of the analysis of SAR/HRR data and communication signals. The book is practical, addressing implementation considerations when deploying AI/ML techniques, including evaluating algorithm performance and computing efficiency.

The authors bring extensive experience to the topic. Erik Blasch is a program officer at the U.S. Air Force Research Laboratory (AFRL), holds a Ph.D. in electrical engineering from Wright State University and is a Fellow of IEEE. Uttam Majumder is a senior electronics engineer at the AFRL. He holds a Ph.D. in electrical engineering from Purdue University and is a senior member of IEEE. David Garren is a professor at the Naval Postgraduate School, holds a Ph.D. from the College of William and Mary and is a senior member of IEEE.

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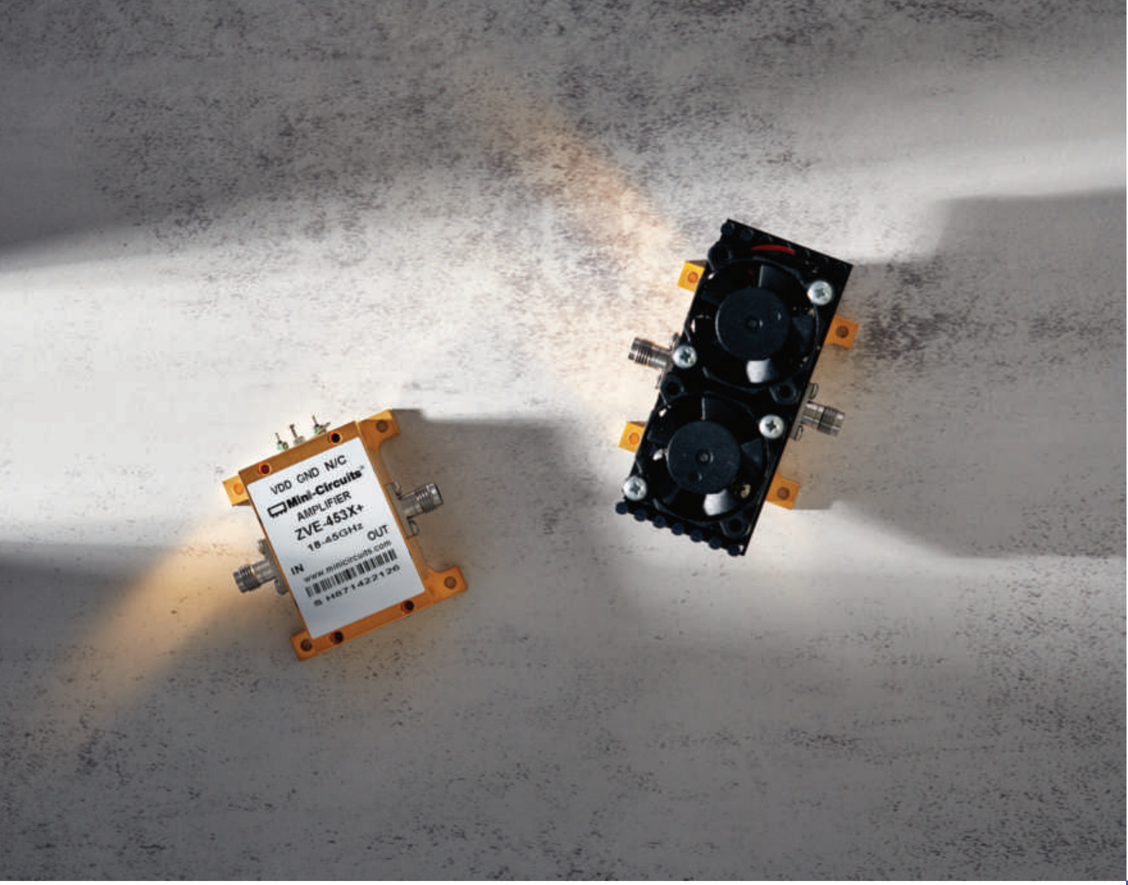


18 TO 45 GHZ

1W Amplifiers

For High-Frequency Test Applications

Easy to use

- Single positive supply voltage design
- Wide supply voltage range, 10V to 15V
- Optional P_{SAT} control pin
- 2.92 or 2.4mm connectors available
- Available with and without heatsink

Robust design

- Built-in over-voltage and reverse voltage protection
- Internal voltage regulation and sequencing

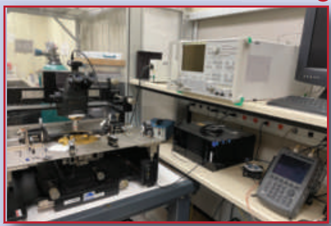
In Stock!

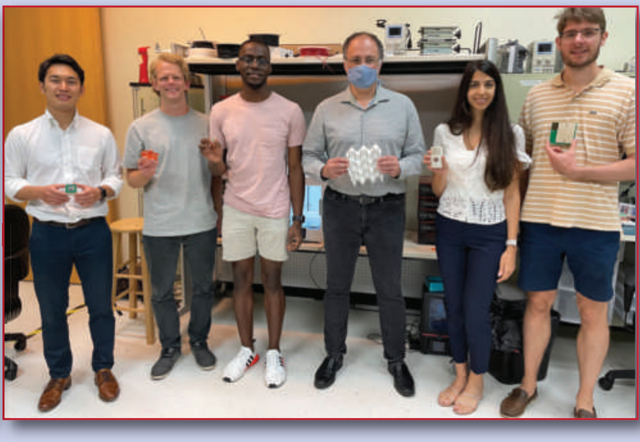
Model Number	Freq. Range (GHz)	Gain (dB)	P_{SAT} (dBm)	OIP3 (dBm)	Price (ea.)
ZVE-453+	18-45	33	+29	+37	$5095
ZVE-453G+	18-45	41	+28	+39	$5095
ZVE-453HP+	18-45	39	+31	+40	$5795

All of the models listed above come with an attached heatsink. To purchase amplifiers without heatsinks, use the following part numbers: ZVE-453X+, ZVE-453GX+, and ZVE-453HPX+.

FABS and LABS

Georgia Tech Sees the Future in RF Printed-Electronics





I have just one word for you, are you listening, "Printed-Electronics" is the future and Georgia Tech is a leader in printed RF electronics among other areas represented in the Agile Technologies for High-performance Electromagnetic Novel Applications (ATHENA) group, led by Dr. Manos Tentzeris. They explore the advancement and development of novel technologies for electromagnetic, wireless, RF, mmWave and sub-THz applications. Their research includes areas such as telecom, defense, space, automotive, health, smart skin, weather/climate and sensing areas and combines inkjet printing, flexible paper/organic substrates, nanotechnology-based structures and green energy scavenging. The activities are typically sponsored by NSF, NASA, DARPA and a variety of U.S. and international corporations.

The group includes the RFID/Sensors subgroup which focuses on the development of paper-based RFIDs and RFID-enabled "rugged" sensors with printed batteries and power-scavenging devices operating in a variety of frequency bands ranging from 13.56 MHz to 60 GHz. In addition, members of the group deal with bio/RF applications (e.g., breast tumor detection), micromachining (e.g., elevated patch antennas) and the development of novel electromagnetic simulator technologies and its applications to the design and optimization of modern RF/microwave systems.

Microwave Journal had a chance to visit their printed-electronics area during IMS in June. The Prototype of Integrated RFID-Enabled Agile Systems (PIREAS) lab is an educational testbed that has been put together at the Georgia Tech Electronic Design Center by a group of graduate and undergraduate students working with Professor Tentzeris in an effort that started in 2006. Currently, the PIREAS lab has expanded beyond UHF RFID applications and introduced microwave and mmWave test and measurement environments. Advanced inkjet printing and other low-cost additive fabrication methods are currently being used within the lab to help advance the state-of-the-art in vertically integrated, flexible electronics. Antennas and RF systems can be measured up to 40 GHz.

The PIREAS lab contains a variety of microwave test equipment. Two Anritsu VNAs provide accurate measurements for antennas and RF systems up to 40 GHz and with a Cascade probe station, small scale signal feeding can be performed. A mmWave far field measurement system provides 360-degree radiation pattern measurements with a high angular resolution. A Keithley Picoamp meter/voltage source provides impedance, voltage and current measurements.

For further dynamic RF characterization, a Tektronix Real-Time Spectrum Analyzer and a Rohde & Schwarz Vector Signal Generator are available up to 8 GHz, as well as oscilloscopes operating up to 3 GHz with passive and active probes for in-circuit measurements. A Keysight FieldFox portable VNA is available for on-field S-parameter measurements up to 4 GHz and a NI PXI system is used for automation of the lab's VNAs, spectrum analyzer, oscilloscopes and data acquisition systems that are used for DUT-excitation signal generation. The lab has custom RFID/sensor wireless interrogating systems/readers built on software-defined radio platforms for frequencies up to 4.5 GHz, and RF-DC rectifier/harvester characterization equipment including a Rohde & Schwarz and Lady Bug power meter to 40 GHz and an Agilent desktop precision digital multi-meter.

For processing, there are two Fujifilm Dimatix Materials Printers, a PixDro industrial inkjet printer, a Formlabs 3D printer and an Ultimaker 3D printer for flexible electronics. The wet lab has a Branson sonicator, Eppendorf Thermomixer and Vacufuge Plus concentrator, used for ink mixing and formulation. A semi-clean room has a Dimatix inkjet printer, UV Crosslinker, Jelight Cleaner, Jeio Tech vacuum oven and KLA Tencor surface profilometer for material curing and characterization.

Georgia Tech is one of the top universities doing research in RF and microwave technologies. They have an active startup community that uses technologies developed in the labs and many students go onto launch companies or continue to research new technologies in our industry, academia or government labs.

https://athena.gatech.edu

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RADIAL COMBINERS

Multi-kW Power Levels ✦ **Low Loss Circuits** ✦ **Custom Designs Available**

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

Specifications subject to change without notice.

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