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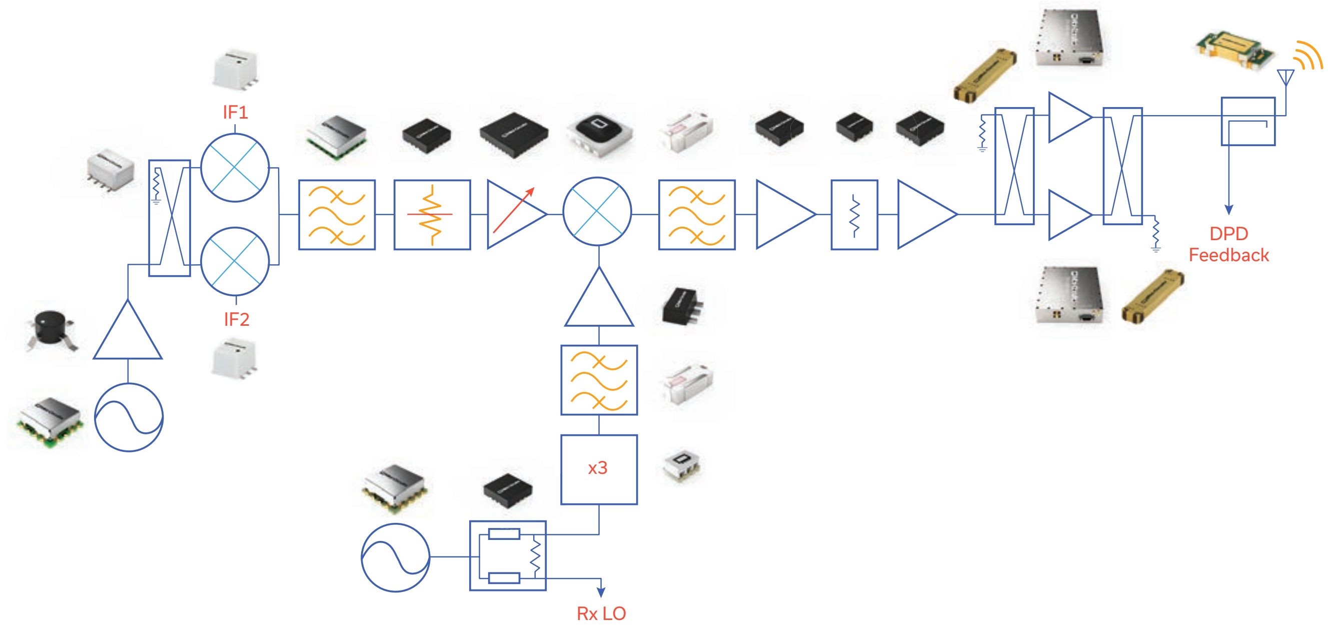

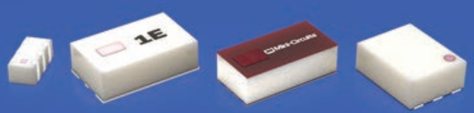

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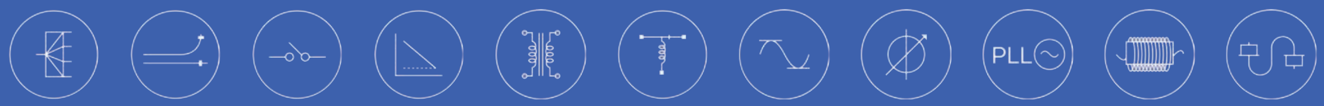


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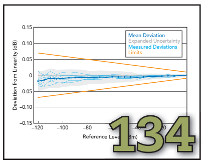

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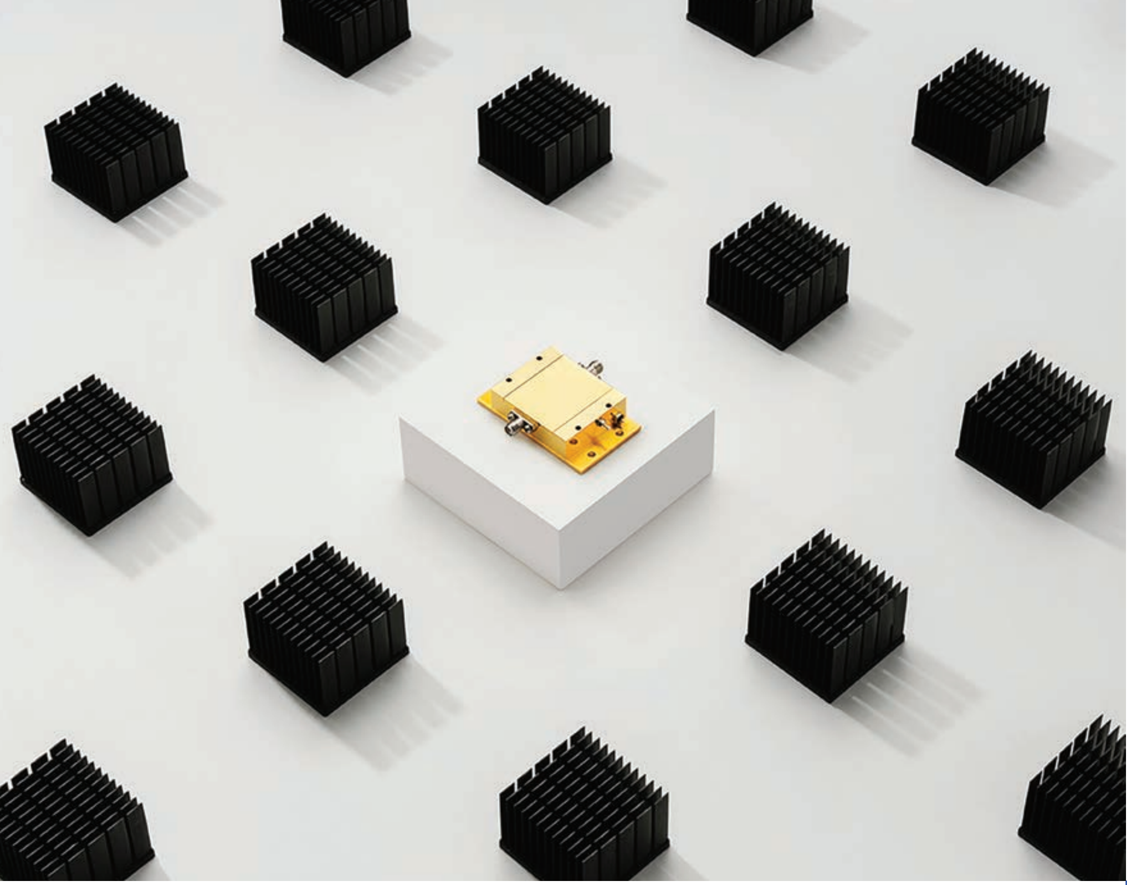

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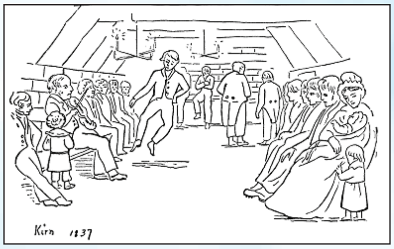
TIME TRAVEL

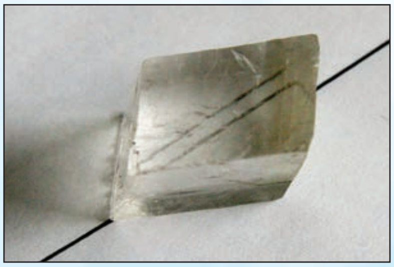
James C. Rautio, IEEE Fellow, FRSE

How Did Maxwell Know That Light Vibrates Transversely?

Seriously folks, we can't look at light and see that it is vibrating, much less vibrating side-to-side. How did Maxwell know?

We have a sketch of six-year-old Maxwell at a dance. Instead of watching the dancer, he is intensely trying to figure out how the violin works. This is foreshadowing. A violin string vibrates transversely. It can do this because the violin string has shear strength. The music from the violin vibrates the air longitudinally. Air has no shear strength. It cannot vibrate transversely.





In April 1847, Prof. Nicol (a friend of Sir David Brewster) gave 15-year-old Maxwell a piece of Iceland Spar. A crystalline form of calcite, it exhibits birefringence, a kind of anisotropy. Everything appears doubled through it. That means there must be two different kinds of light wave. Today we call it, for example, vertical and horizontal, or right-hand and left-hand polarization. The only way we can have two kinds of waves is if it is transversely polarized. A sound wave in air cannot be polarized.

Maxwell decided to ignore several problems, for example, is light even a wave? Newton had insisted it was particles. And then if it is a wave, it must vibrate in some sort of medium, let's call it the 'Luminiferous Aether.' But the Earth plows through this supposed medium and does not spiral down into the sun. So…this 'medium' must have no shear strength. So…light cannot possibly be a wave! These problems were not solved in Maxwell's lifetime.

To make great discoveries, a true genius must choose which information to use. Those who make the wrong choice are guilty of 'Confirmation Bias' and fail. Those who make the right choice, well, that is what Maxwell did.

Of course, today, we view light as having both wave- and particle-like properties. And as for the Luminiferous Aether, it is simply unneeded.

A rich source of information on Maxwell's youth is a reprint of the definitive 1882 biography, "The Life of James Clerk Maxwell (Illustrated)" available on Amazon. An amazing museum of Maxwell is housed in his birth home in Edinburgh, Scotland, Welcome to the James Clerk Maxwell Foundation. Finally, put a visit to Glenlair, Maxwell's country estate, on your bucket list. Recently restored and preserved, about two hours by car from Edinburgh, Glenlair, The Maxwell at Glenlair Trust, it is a richly rewarding journey.

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Anatomy of the 5G Small Cell

Patrick Hindle
Microwave Journal

The industry has been talking about the small cell market for many years as being on the verge of huge growth, but while it is a sizable market and there has been some growth, it has not taken off as quickly as many expected. Though with the emergence of 5G, it is poised to do so; meeting the goals of increased capacity in dense areas and the large number of connections needed for IoT applications. In 2020, the 5G small cell market was $741 million and is expected to grow to about $18 billion by 2028, according to Forbes Business Insights, exhibiting a compound average growth rate of 54 percent.

The Small Cell Forum recently published "5G NR FR1 Reference Design, the case for a common, modular architecture" that outlines the design of small cells in detail (Document 251.10.01). This article is based on sections 3.2-3.4, outlining the architectures for the RF section of small cells.

The market for small cells is diversifying for use in many cases, deployment models and form factors. According to the report, with each scenario having its own connectivity requirements, there is a significant risk of fragmentation, which would make many networks uneconomic. This risk can be eliminated by creating common platforms based on standard interfaces, which enable a wide range of components to interoperate to support diverse small cell designs while retaining economies of scale. This approach is like the Open RAN effort that is being developed at the network level and the Open RF effort to standardize the RF front-end (RFFE).

The interfaces between different vendors' small cells, or between different functional splits, are not uniform. This can increase cost, complexity, integration time and reduce scale. Common interfaces address the challenge that not every component can be uniform. The biggest issue addressed in the report is that the RFFE will be different, depending on spectrum frequency, output power and other factors. Neutral host and enterprise deployments need to support as many frequencies as possible to accommodate many users, which increases the bandwidth requirement.

According to the Small Cell Forum, the solution to the RFFE issue is a modular approach to small cell network design, in which a variety of RFFE designs can be interfaced in a standardized way, like the baseband and transceiver units. The RFFE can be swapped in and out to support different markets without changing the rest of the platform.

While the report provides the framework for the components and interfaces that make up a 5G NR FR1 small cell distributed radio unit, this article will concentrate on the RFFE FR1 architectures outlined by the Small Cell Forum, since those are the ones of interest to RF designers.

RF TRANSCEIVERS

The RF transceivers contain independently controlled transmitters, dedicated observation receiver inputs—for monitoring transmitter channel outputs—independently controlled receivers, integrated synthesizers and digital signal processing to provide a complete transceiver solution as shown in ***Figure 1***. The transceivers support both time-division duplexing (TDD) and frequency-division duplexing (FDD) applications.

To meet the 5G FR1 specifications, the transceiver can operate in a wide frequency band covering a range from 650 MHz to 6 GHz (or higher). Depending on the number of controlled transmitters and receivers in the single-chip transceiver device (2T2R, 4T4R, etc.), the transceiver bandwidth performance can be specified. One or two observation receiver channels can monitor feedback from the transmitter outputs. The feedback loop can be used to implement error correction, calibration and signal enhancing algorithms, such as crest factor reduction and digital predistortion (DPD). The observation receivers operate in the same frequency range as the transmitter channels and can support a channel bandwidth up to more than 2x the transmitter bandwidth.

To improve transmitter dynamic range, the transceiver can provide a power control range using variable attenuator(s). To achieve a high level of RF performance, the transceiver includes integrated phase-locked loops (PLLs). The PLLs provide low noise RF synthesis for the transmitter and receiver signal paths, support an independent frequency for the observation receiver and generate clocks for the converter and the digital circuits for signal processing and communication interfaces.

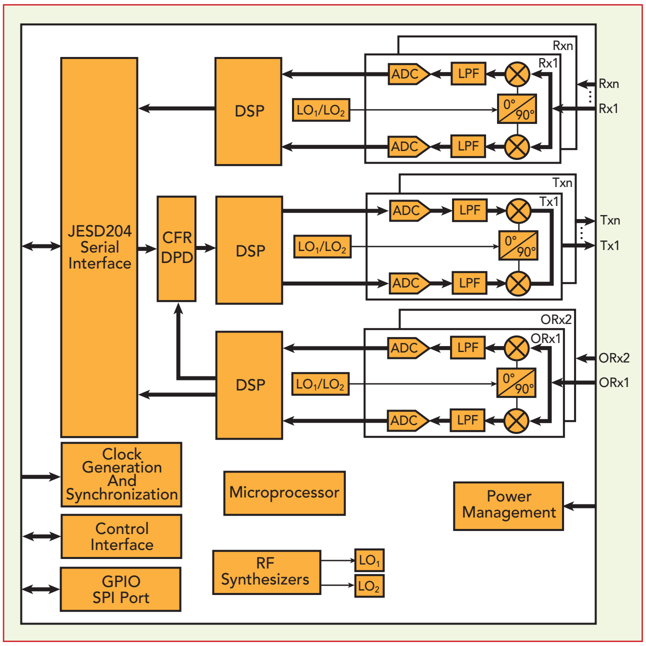


Fig. 1 Example of an RF transceiver architecture.

RFFE

The RFFE in a small cell radio provides the following functionality:

- It sequentially or simultaneously boosts up the power of the transceiver output signal and amplifies the received signal from the user equipment (UE) based on the control from the baseband or the RF transceiver.
- It provides the transmitter observation path to the RF transceiver to further improve the linearity of the entire transmitting path, based on the digital algorithm/calibration, i.e., DPD.
- It filters out the harmonic or intermodulation signals on the transmit path and the jamming or interfering signals on the receive path.

To accomplish this functionality and to optimally balance cost and performance, current RFFE implementations typically fall into heterogeneous integration, which involves multiple discrete active and passive components fabricated by different technologies. For example, the power amplifier (PA) is usually implemented in GaAs, GaN or LDMOS processes because the transistor breakdown voltage is multiple times higher than the CMOS process for generating the desired output power efficiently.

The low noise amplifier (LNA), the first amplifier on the receive path, should ideally have a noise figure (NF) lower than 1 dB and an input third-order intercept point to meet the sensitivity and blocking requirements in the small cell. The PHEMT-based LNA is a common choice due to its low NF and sufficiently high operating voltage.

In the filters, the passband loss, the rejection outside the passband and power handling are the three

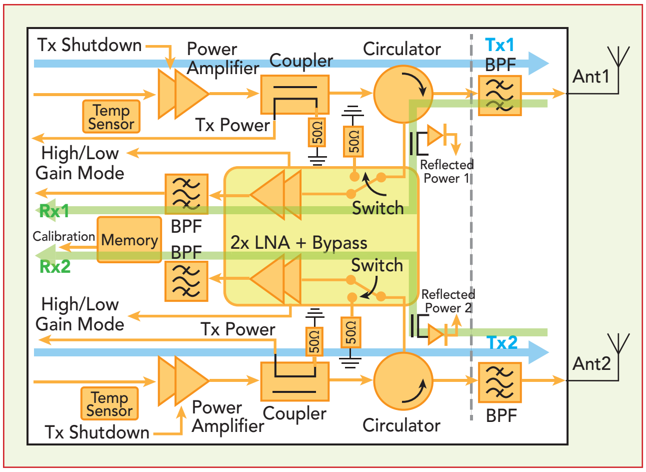


Fig. 2 Small cell RFFE components in TDD mode.

key parameters in the component selection. The acoustic wave filters, including surface acoustic wave and bulk acoustic wave, are currently the popular choice for the receive path due to their high rejection with a small footprint. The ceramic-type filter is typically chosen to connect the RFFE to the antenna, as its power handling is greater than that of acoustic filters.

Based on the current 3GPP definition, there are more than 20 frequency bands for sub-6 GHz 5G. This implies that RFFE hardware will be band selective. The component suppliers will typically try to develop multiple products in a pin-to-pin-compatible family to cover the entire sub-6 GHz bands to minimize RFFE hardware changes when changing frequency bands. In addition, the number of transmitting and receiving paths in the RFFE needs to be scalable by two to meet the desired MIMO configuration, i.e., 2T2R, 4T4R and 8T8R.

The RF transceiver is responsible for converting the digital baseband signals to analog signals at the desired frequency. Most available 5G NR FR1 transceiver ICs are based on a CMOS process, can operate up to 6 GHz to cover the entire FR1 spectrum and support at least 4T4R in a signal IC. (FR1 was changed to 7 GHz but most still refer to it as up to 6 GHz). Some transceivers further integrate digital functions to implement algorithms to calibrate or improve the entire signal chain, e.g., linearity, image rejection, leakage reduction and spurious filtering.

The baseband function is almost entirely digital, configured by software and independent of RF frequency. Baseband components include digital processors, memory and interface components. Small cell radio units designed for high volume markets may integrate all functions onto a single printed circuit board (PCB) for lowest cost. Alternatively, some lower volume markets may be addressed more economically using a modular solution; for example, integrating the interfaces, power, baseband and RF transceiver functions onto one PCB serving multiple markets; while band-specific components are grouped into a separate market-specific RFFE module (FEM).

FUNCTIONAL BLOCK TDD

Figure 2 shows a transmitter/receiver with two observation path RFFEs in TDD for sub-6 GHz 5G. TDD means both transmitter and receiver operate alternately in the same frequency band. Ideally, in a 2T2R configuration, the two transmitting paths are identical; the same holds for the receiving and observing paths. All the RF components in the RFFE interface to each other in a 50 Ω system. The observing path, implemented by the directional coupler, couples a small amount of output power from the PA and feeds it into the transceiver for signal analysis and processing. This enables the transceiver to accurately monitor and control the output power, as well as applying DPD to improve the linearity of the transmit signal. The operating frequency of the observing path is typically identical to that of the transmit path.

TABLE 1

TWO COMMON SMALL CELL USE CASE CONFIGURATIONS

Specification	Indoor Small Cell	Outdoor Small Cell
Pmax/Port (dBm)	24.0	34.0
Pmax/Port (W)	0.25	2.5
Number of TX Antenna Chains/Ports (TX RU)	2	4
Total Pmax (W) - Max rms Rated Power	0.5	10.0
Total Pmax (dBm)	27.0	40.0

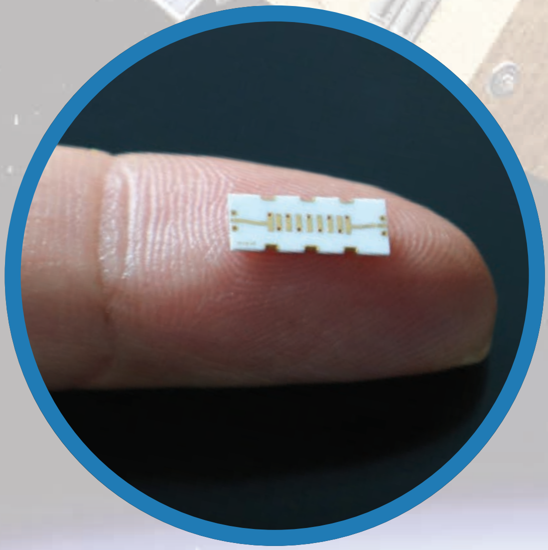
The PA is typically a GaAs-based, high efficiency amplifier that uses the DPD algorithm from the transceiver or baseband to deliver adequate output power with high efficiency and linearity, while reducing the power consumption and heat generation compared to a linear amplifier. The receiver FEM integrates an LNA and a single pole double throw (SPDT) switch into a single component. A single component is favored over a discreet solution, because of improved performance, lower cost and smaller PCB footprint.

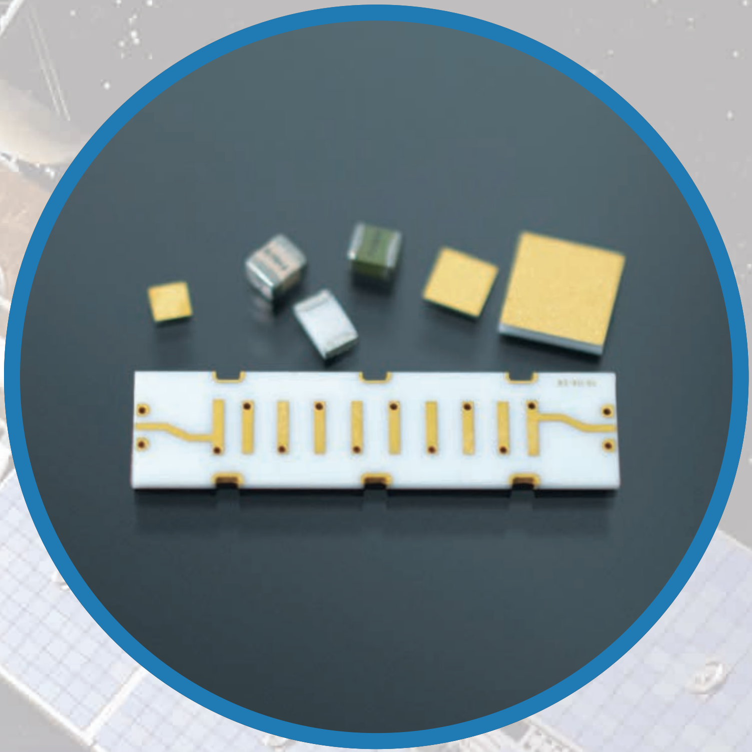
The bandpass filter (BPF) between the circulator and antenna port (i.e., the antenna filter) typically helps eliminate harmonic signals generated by the PA and protect the receiving path from interference and jamming. The filter after the LNA, the second filter in the receive path, further suppresses interfering signals from the antenna (ANT) port. The circulator, which is a non-reciprocal component, transmits the PA signal to the antenna while shielding the PA and switch from the reflecting signal from the antenna port, caused by impedance mismatches.

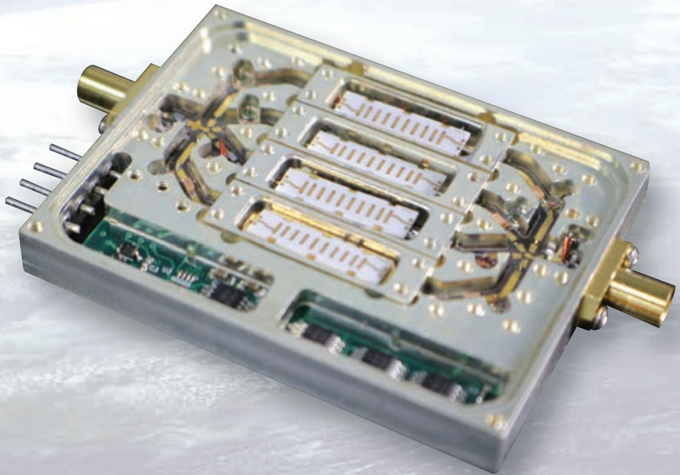
Some systems insert a power sensor between the switch and circulator to monitor the input power coming from the ANT port. When the sensor indicates the input power is higher than the expected value, the receiver components can be shut down or bypassed to avoid damage. Both the antenna filter and circulator must handle the output power of the PA without damage.

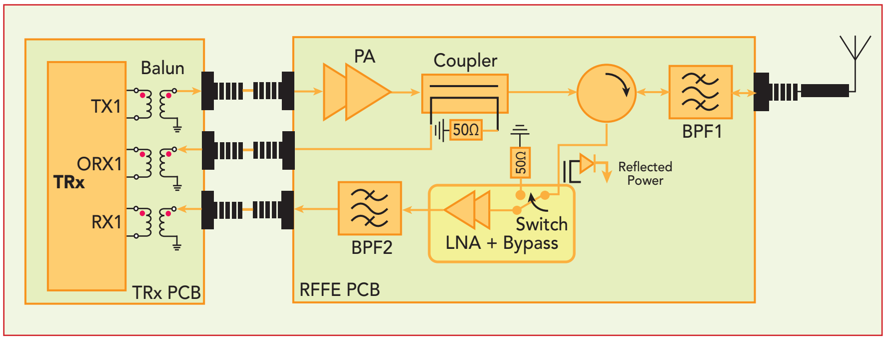
Table 1 shows two of the most typical small cell configurations: one for indoor and one for outdoor. 24 dBm is the required conducted power for the indoor small cell, and the table shows typical line up calculations to illustrate how the RFFE achieves the targeted output power. The analysis is based on typical performance specifications of products generally available in the market, with a few choices made to ensure signal integrity, cost competitiveness and multiple vendors.

For simplicity, the block diagram in ***Figure 3*** only shows a single transceiver RFFE and its interfaces to the transceiver board and external antenna. The passive components and interconnections con-









▲ Fig. 3 Simplified small cell RF line-up in TDD mode.

tribute to loss in the system, as well as path losses. The RF ports of the transceiver are all differential and require passive baluns to connect to the RFFE board. The passive components on the RFFE board include the coupler, circulator and BPFs.

Figure 4 shows the PA output power must be +28 dBm to compensate for filter and antenna losses, ensuring +24 dBm is delivered to the antenna port. Typically, the transceiver can deliver around 4 to 6 dBm power CW. With the peak to average power ratio of the NR signal, targeted DPD expansion and the balun's loss, the average output power from the transceiver board is about -7 dBm. To deliver 24 dBm to the antenna, the power gain of the PA needs to be at least 35 dB to compensate for the loss of the transmitting path. With DPD, the PA's saturated output power should be at least 36.25 dBm, with its 1 dB compression point at least 32.25 dBm. More detail about the RFFE transmit and receive line ups are in ***Table 2***.

In the receive path, the FEM, which integrates an LNA and SPDT switch into a single component, is the only active component. The typical gain and loss of the extra components, including BPF2, with the FEM and transceiver gain and NFs, are summarized in the table.

Using the equation for NF in a cascaded system, the NF of the entire receive path is about 5.47 dB. The effective receive gain, which is the sum of all gains and losses on the receive path, is 35.9 dB. The total NF can be improved by either using passive components with less loss or increasing the LNA gain.

The temperature sensors in the RFFE help the system monitor the operating temperature of the RFFE in operation. Multiple temperature sensors individually measure the temperatures in different locations, outline the temperature profile of the RFFE and assist with making electrical adjustments to minimize RFFE temperature variants, or shutting down the hardware if the RFFE is overheating.

The memory inside the RFFE stores the following information to help the small cell in system initialization, online or offline calibrations.

- Hardware manufacturing information

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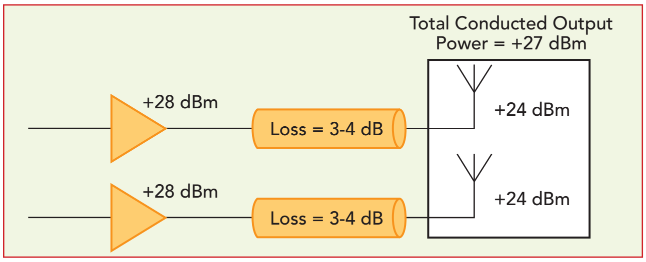

Fig. 4 2T2R Indoor Small Cell TX power budget.

FUNCTIONAL BLOCK FDD

Figure 5 shows the FDD RFFE block diagram. The dashed line in the figure indicates the boundary between the RFFE and two duplexers in a 2T2R configuration. The diagram on the left side of the line is identical to the same portion of the TDD RFFE, except for the connections of the circulators and switch. This design approach consequently unifies the RFFE interface with antennas in the two systems. This methodology can reduce the extra effort when changing the design or implementing a multi-mode small cell to provide TDD and FDD operation in the same hardware.

TABLE 2

RFFE TRANSMIT AND RECEIVE LINE-UP REQUIREMENTS FOR INDOOR SMALL CELL CASE

RFFE Transmit Line-Up	
Parameter	***Value***
CW Power of Transceiver	5.15 dBm
PAPR of NR Signal	8.5 dB
DPD Expansion	3 dB
Balun Loss	0.8 dB
Average Power of Transceiver PCB	-7.15 dBm
Interconnection Loss	0.1 dB
PA Gain	35 dB
Average Power of PA	27.7 dBm
Coupler Loss	0.25 dB
Circulator Loss	0.5 dB
BPF1 Loss	2.5 dB
ANT Interconnection Loss	0.2 dB
Average Power at RFFE ANT Port	24.3 dBm
RFFE Receive Line-Up	
Parameter	***Value (dB)***
ANT Interconnection Loss	0.2
BPF1 Loss	2.5
Circulator Loss	0.5
FEM Gain	28
FEM NF	1.4
BPF2 Loss	3
Interconnection Loss	0.1
Balun Loss	0.8
TRx NF	15
TRx Receiving Gain	15
Total NF of Receive Path	5.47

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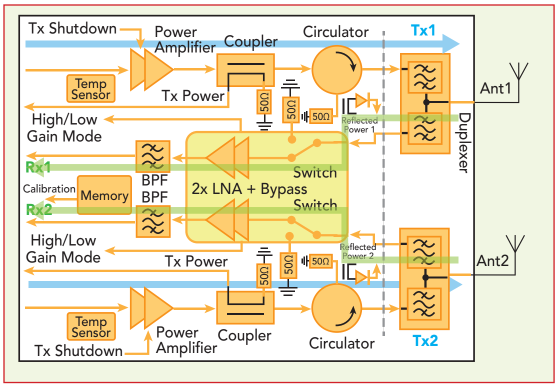

Fig. 5 Small cell RFFE components in FDD mode.

The operating frequencies of the transmitting and receiving paths in the FDD small cell are different. The observation path needs to be designed at the same frequency as the transmitter, and the frequency of the filter after the LNA needs to match the receive frequency. The data formats for the content inside the memory of the FDD block diagram, compared with the TDD diagram, use different frequency points to record the transmitter's and receiver's electrical performances.

Antennas

The antenna radiates the RF power and receives the signal from the UE. In both TDD and FDD small cells, the transmitting and receiving paths from the same RF transceiver share the same antenna. The number of RF transceiver ports and the polarization diversity of the small cell define the total number of antenna elements connecting to the cell. Based on the system requirements, the antenna can be either omnidirectional, for full 360-degree coverage, or directive, to focus the radiation on narrower angles. The antenna can be planar, realized by a multilayer PCB, and integrated into the RFFE board.

A planar antenna (like a patch, slot and planar inverted-F) typically has a gain of 3 to 7 dBi. 3D antennas are also popular in small cells such as dipole, monopole and helical. These typically use cables or connectors to interface to the RFFE and may be integrated within the small cell radio. If integrated, they may be incorporated onto the PCB without connectors or mounted off-board, in which case flying leads may be soldered or connected using, for example, UFL-style connectors. When the antennas are not integrated, as with higher power outdoor small cells, waterproof RF connectors such as N-type or 4.3-10 may be employed.

CONCLUSION

While the small cell architecture is a little different for FDD versus TDD, many common signal chains can be shared. Standardization of architectures can reduce cost, speed time to market and minimize complexity while diversifying the supply chain. It remains to be seen if standard architectures will be widely adopted, but they are gathering momentum; in either case, the architectures covered here will closely represent the design of small cells for the 5G market. ■

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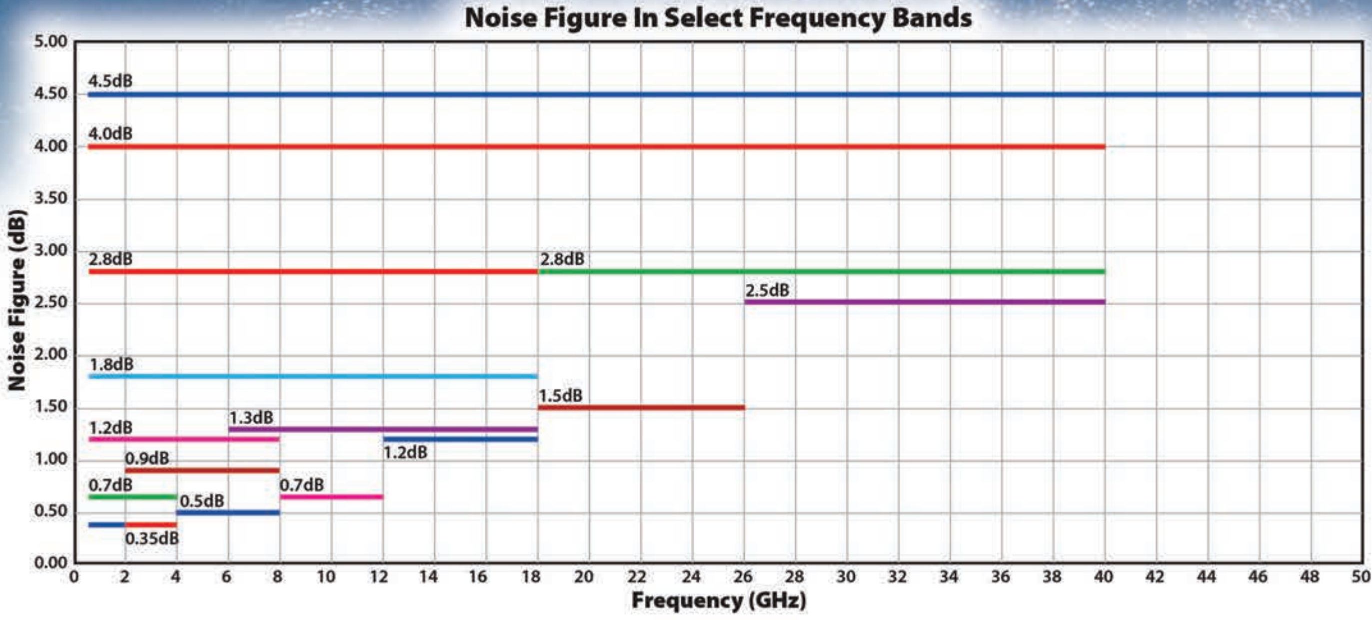
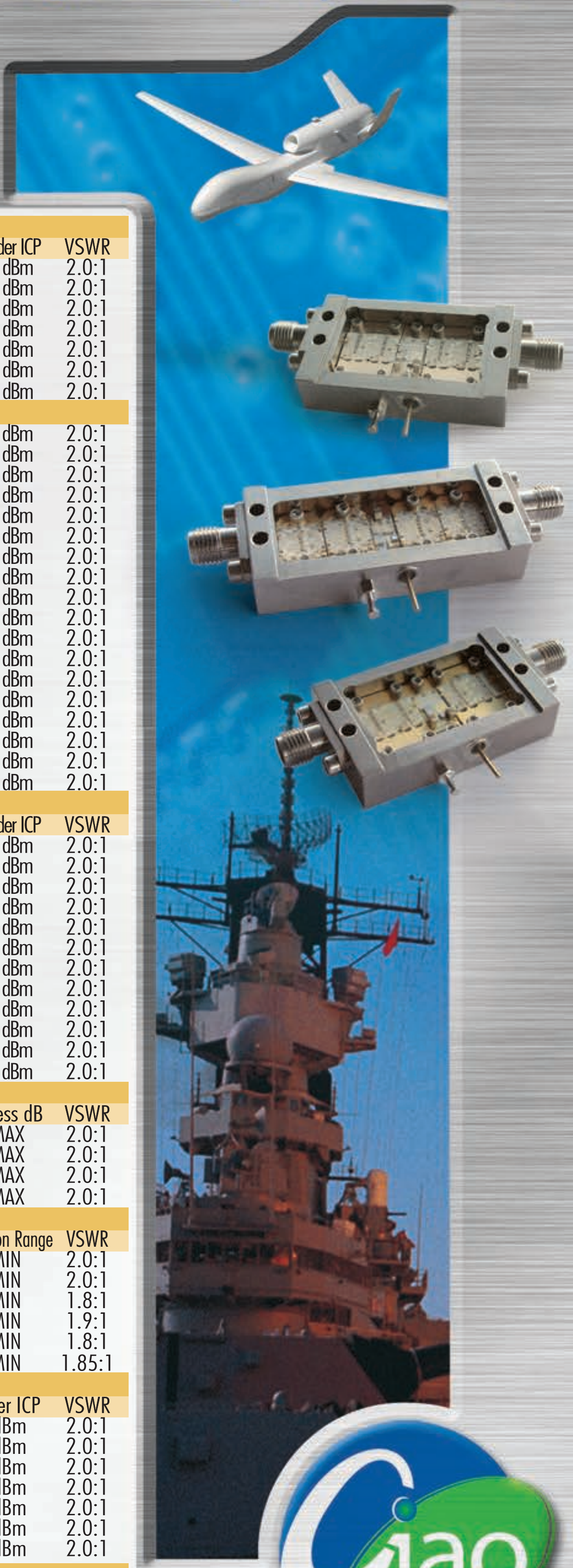


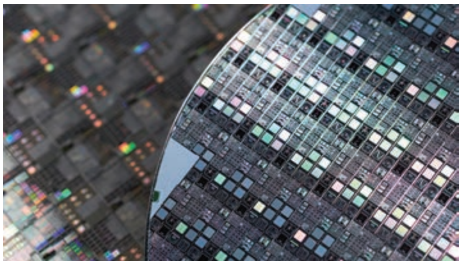


DARPA Awards Phase 2 of Next-Gen Advanced Electronics Program

After the successful completion of Phase 1 of the next-generation electronics program, the Defense Advanced Research Projects Agency (DARPA) has provided BAE Systems' FAST Labs research and development organization a $5 million contract for Phase 2 of the Technologies for Mixed-mode Ultra Scaled Integrated Circuits (T-MUSIC) program.

T-MUSIC is designed to enable disruptive RF mixed-mode technologies by developing high performance RF analog electronics integrated with advanced digital electronics on the same wafer. This technology supports critical communications, radar and electronic warfare capabilities, and is widely used to support commercial telecommunications.

"Building on the success of Phase 1, in Phase 2 we'll continue to develop the advanced electronics capabilities that could serve as the foundation for greatly enhanced Department of Defense (DOD) capabilities in advanced RF sensors and high-capacity communications," said Chris Rappa, product line director for RF, EW and Advanced Electronics at BAE Systems' FAST Labs. "Phase 2 of the program will move the industry closer to the eventual fielding of this disruptive technology to protect our warfighters."



T-MUSIC (Source: BAE Systems)

The next-generation capabilities that could be made possible with this program include a combination of wide spectral coverage, high-resolution, large dynamic range and high information processing bandwidth. As services rely on electronic sensors in highly congested environments, these capabilities can cut through electronic signal clutter to provide mission critical leap-forward performance.

IBCS Expands Capabilities

Northrop Grumman Corporation's Integrated Battle Command System (IBCS) successfully completed two recent U.S. Army flight tests, further demonstrating the system's scalability and resiliency to enable all-domain command and control capabilities.

In the first flight test, the U.S. Army intercepted a high performance, high speed tactical ballistic missile (TBM) target using IBCS, aided by Northrop Grumman's Joint Tactical Ground Station (JTAGS) which delivered space-based sensor data to the system for early warning of an inbound TBM launch. IBCS established a track from the JTAGS data before ground-based sensors were able to detect the target, thus providing increased situational awareness for the operators.

During the second flight test, IBCS demonstrated the resilience of the system to defeat two cruise missile targets in a stressing electronic attack environment. IBCS was able to maintain continuous track custody of the targets by fusing data from multiple sensors degraded by electronic attack.

IBCS (Source: Northrop Grumman)

The testing took place at White Sands Missile Range, New Mexico, utilizing operationally realistic scenarios with soldiers of the U.S. Army 3rd Battalion, 43rd Air Defense Artillery Regiment at the controls of the system. These tests are part of the Initial Operational Test and Evaluation of IBCS, in which the system is evaluated on its operational performance prior to deployment and full-rate production.

Spy-6 Radars for Next-Gen U.S. Navy Ships

Raytheon Missiles & Defense, a Raytheon Technologies business, was awarded a $651 million, with options totaling $2.5 billion, hardware, production and sustainment contract for full-rate production of the AN/SPY-6(V) family of radars. The contract, with options, totals $3.2 billion and five years of radar production to equip up to 31 U.S. Navy ships with SPY-6 radars.

Under the contract, RMD will produce solid-state, fixed-face and rotating SPY-6 variants that will deliver unprecedented integrated air and missile defense capabilities for seven types of U.S. Navy ships over the next 40 years. Those vessels include the Navy's new

SPY-6 (Source: Raytheon Technologies)

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Arleigh Burke class Flight III destroyers, aircraft carriers and amphibious ships. Today's Flight IIA destroyers will be backfit with an upgraded radar.

"There is no other radar with the surface maritime capabilities of SPY-6," said Wes Kremer, president of Raytheon Missiles & Defense. "SPY-6 is the most advanced naval radar in existence, and it will provide our military a giant leap forward in capability for decades to come."

Since its inception, more than $600 million has been invested in the development and manufacturing of the SPY-6 family of radars. When compared to legacy radars, SPY-6 will bring new capabilities to the surface fleet, such as advanced EW protection and enhanced detection abilities.

SPY-6 radar installation is complete on the Navy's first Flight III destroyer, the U.S.S. Jack H. Lucas (DDG 125), which is scheduled to be operational in 2024. Radar array deliveries are complete for the next ship in the class, the future U.S.S. Ted Stevens (DDG 128).

Successful Test of Multiple Object Tracking Radar

BAE Systems successfully completed prototype tests of its Multiple Object Tracking Radar (iMOTR), a mobile instrumentation radar that provides precise radar data on multiple objects.

The company demonstrated iMOTR's ability to meet critical key performance parameters–range, transportability, accuracy and beacon tracking that other radars, with comparable cost, size, weight and power, cannot.

iMOTR is a new approach to radar, as it uses low-cost phased array technology developed by DARPA to provide an affordable high performance radar. The phased arrays are operated with an interferometry design that makes iMOTR more accurate than conventional tactical phased array radars. iMOTR is positioned to be the lowest cost choice for DOD test instrumentation to measure performance at test ranges within and outside of the U.S.

iMOTR (Source: BAE Systems)


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Cliff Drubin, Associate Technical Editor

5G Forecast

After three full years of growth, global wireless 5G adoption has reached the rapid acceleration phase, having exceeded a half-billion connections by the end of 2021 and forecast to reach 1.3 billion by the end of this year, according to data from Omdia and 5G Americas, the wireless industry trade association and voice of 5G and LTE for the Americas.

Chris Pearson, president of 5G Americas said, "We are now out of the opening stages of this generation of wireless cellular technology, as 5G is rapidly getting into the hands of consumers and businesses, who are finding innovative new ways to use mobile connectivity."

According to the most recent data from Omdia, the world added 303 million 5G connections year over year, representing a 139 percent increase from 218 million to 521 million, and sequentially 19 percent growth quarter over quarter from 437 million in Q3 2021 to 521 million in Q4 2021. According to Omdia's forecast, 5G is expected to double to 1.3 billion connections in 2022, nearly double again in 2023 to 2 billion connections and reach 4.8 billion by the end of 2026. Of that, 516 million is expected to come from North America and 301 million from Latin America and the Caribbean.

By region, North America had a total of 72 million 5G connections by the end of 2021, which is an addition of 54 million 5G connections for the year, a gain of 292 percent year over year. Additionally, the region had 514 million LTE connections by the end 2021, which represents near full market maturity.

Although 301 million 5G connections are expected for Latin America in the Caribbean by 2026, 4G LTE remains the dominant wireless cellular technology in the region today with 495 million connections. That represents 17 percent annual growth with the addition of 72.6 million new LTE subscriptions year over year. Omdia expects 4G LTE growth will remain strong in Latin America and the Caribbean through 2022 with the addition of 43.2 million new 4G LTE connections, as 5G adoption begins to overtake 4G LTE.

Overall, the number of 5G commercial networks has reached 216, according to data from TeleGeography and 5G Americas. That number is expected to reach 330 by the end of 2022 and 352 by the end of 2024, representing strong 5G network investment growth in many regions throughout the world.

5G: The Market GaN Needs

The current state of 5G has seen less technological innovation than might have initially been expected with the promise of high frequency, Gigabit download speeds and millisecond latency are yet to be realized in a major way. There is certainly more scope for technical development and hence opportunities for several technologies and materials, a critical one of which is the semiconductor technology with wide bandgap semiconductors. IDTechEx's latest research report on "Thermal Management for 5G 2022-2032" finds that GaN has a significant opportunity within the 5G market and this creates a downstream effect on other components such as die attach materials.

Laterally-diffused metal-oxide semiconductor (LDMOS) devices have been the technology of choice for power amplifiers through the 4G era. These power amplifiers provide the crucial role of boosting the signal for transmission. The trouble is once we move above approximately 4 GHz, LDMOS starts to become inefficient. Efficiency is a critical factor for telecoms infrastructure as it directly impacts the energy consumption of the antenna. With much of 5G infrastructure being deployed alongside existing equipment, the energy consumption of telecoms towers is set to increase dramatically, adoption of wide bandgap semiconductors like GaN is one method to reduce this future impact. GaN provides greatly improved efficiencies at higher frequencies, depending on the specific use case, this can be in the region of 10 percent or more improvements for efficiency.

With the growth of 5G continuing, especially for higher frequencies, we're expecting a significant uptake in GaN over the next decade, especially for the higher end of the sub-6 GHz infrastructure where higher powers are being used and component integration is not quite as challenging as it is in the mmWave region. For this application, IDTechEx predicts a four-fold increase in GaN demand per year by the end of the decade.

The adoption of wide bandgap semiconductors typically raises the junction temperature of devices and starts to bring more thermal management considerations. One critical failure point with thermal cycling is how the semiconductor device is connected, or the die attach material. Junction temperatures for GaN devices are often above 175°C, at this point we start to limit the options for typical solder materials, especially when lead-free is a requirement in most markets. This is leading many players to consider sintering materials. Sintering involves the application of a (typically silver) paste that is heated causing densification. The upshot is a more reliable connection with improved thermal conductivity. This has already started to be adopted in a big way in the electric vehicle market thanks to the transition to SiC and 800 V platforms.

The key limitation historically has been the lack of commercial experience, long curing times and the need for an inert atmosphere or higher pressures, but developments of these materials, greater market adoption and the trend toward GaN could see sintering start to make a big impact in the 5G market too. IDTechEx is expecting a 10-fold increase in demand for sintering materials in 5G infrastructure by 2030. There is also a great

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interest in the development of copper sintering materials over silver due to the potentially reduced costs and improved performance but falls into the same issues as silver sintering had originally compared to solder.

Industry Collaboration to Develop 5G Device Power Profile Study

The Open RF Association announced it completed the initial phase, in collaboration with Signals Research Group, of a study determining RF power levels used in 5G handsets to help the industry better optimize data throughput performance and ultimately improve battery life.

"This project is an important step toward optimizing battery life of 5G devices," said Open RF Association President Kevin Schoenrock. "Comprehensive data around the power levels in 5G handsets will be critical for our members, and the industry in order to develop leading-edge technologies to set the performance standard for next-generation wireless devices."

Open RF Association members and affiliates have contributed data and analysis to the study, which the consortium will use to create a histogram showing RF power levels used in 5G handsets under real-world network conditions. Understanding network use cases will enable OpenRF members to develop best-in-class, optimized solutions.

"With the field data collected from a commercial 5G SA network and the detailed analytical work that Signals Research Group performed on behalf of OpenRF, there are now 5G PA characterization profiles in place," said Michael Thelander, president of Signals Research Group.

> Will enable optimized power solutions for handsets and IoT devices.

The study is the first of a series commissioned by the Open RF Association to help update and improve power profile data as handsets and IoT wireless devices evolve with the buildout of 5G networks over time. The newly established usage curves will provide the industry with a key data set enabling interoperable system optimization among OpenRF members to improve system performance over time. OpenRF will continue working with Signals Research Group on the continued development of the study. Mobile Experts, Inc. will also support the collection and integration of additional data as the study evolves to impact all 5G devices.

The initial study is expected to be released to members in June 2022.


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Around the Circuit

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Kratos Defense & Security Solutions, Inc. has acquired **CTT Inc.** Based in San Jose, Calif., CTT is a leading supplier of RF/microwave power amplifiers, low noise amplifiers, frequency converters and frequency multipliers. CTT delivers products from 10 MHz to 50 GHz, with applications including EW, ECM, ESM, radar, missiles, jammers, UAVs, test and measurement, telecom and more.

Leonardo DRS Inc. announced it has signed a definitive agreement to sell its Global Enterprise Solutions business to **SES** for $450 million. The transaction has been approved by the boards of directors of Leonardo and of SES. Finalization of the deal is targeted for the second half of 2022 subject to regulatory approvals.

Qualcomm Incorporated announced it has completed its acquisition of Arriver™ from **SSW Partners**, enhancing Qualcomm Technologies' ability to deliver open, fully integrated and competitive advanced driver assistance system solutions to automakers and Tier-1 suppliers at scale. As a result of the acquisition, Qualcomm Technologies will incorporate Arriver's Computer Vision, Drive Policy and Driver Assistance assets into its leading Snapdragon Ride™ Platform portfolio.

COLLABORATIONS

Aitech Systems, a leading provider of rugged boards and system level solutions for military, aerospace and space applications, announced its strategic partnership with **Sidus Space, Inc.** to develop and deliver custom command and data handling flight computers and peripherals for LizzieSat™ microsatellites. Its flagship multi-mission microsatellite, LizzieSat, seamlessly links with the Sidus constellation, leveraging the full in-space services of the Sidus fleet. This dramatically enhances the collection and intelligent analysis of space-born data returning richer, more precise data down-to-Earth in less time.

Anokiwave, Inc. and Swedish antenna manufacturer **Requtech** have announced a collaboration to enable satcom-on-the-move applications over LEO/MEO/GEO communication satellites. As part of this collaboration, Anokiwave provides advanced, low-cost Si second generation satcom Ku- and K/Ka-Band ICs to power Requtech's RESA-S family of fully integrated phased array flat panel antenna terminals.

Ball Aerospace, in collaboration with diversified manufacturer **Flex**, started production on its Ku-Band and Ka-Band modular electronically steered antenna subarrays at the Flex site in Austin, Texas. By leveraging Flex's global supply-chain organization and experience manufacturing complex communications products, Ball will be able to provide these advanced satellite-based mobile communications solutions at an affordable price.

ACHIEVEMENTS

Mission Microwave Technologies, LLC, announced that it has reached a milestone in the manufacturing of more than 10,000 solid-state block up-converters for their customers. The company was founded in 2014 to bring advances in GaN semiconductors to the satellite terminal business. The majority of the 10,000 units manufactured since inception were built and shipped over the past two years and have supported the rapidly growing satcom mobility market in X-, Ku- and Ka-Band at power levels up to 400 W.

Powercast Corporation, a leader in RF-based over-the-air wireless power-over-distance technology, announced that it has shipped 10 million wireless RF Powerharvester® PCC110 chips in the last two years alone. The company attributes this milestone to increased demand for wireless power-over-distance solutions which free devices from wires, batteries and placement restrictions such as the direct contact with a charging surface that the Qi wireless charging standard requires.

CONTRACTS

Echodyne, the radar platform company, announced that **Advanced Technology Systems Company**, the prime contractor for the $191 million indefinite delivery, indefinite quantity (IDIQ) contract for the **U.S. Army**'s Security Surveillance System (SSS) program of record and a leader in force protection systems and border/maritime surveillance systems, has received its first order for Echodyne radars to be used under the SSS program. The IDIQ contract has a five-year base period, with a three-year option to extend the period of performance.

Mercury Systems, Inc. announced it received a $4 million order from a leading commercial technology company for advanced Si packaging to be used in electronic warfare, active electronically scanned array beamforming and command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) systems. The order was received in Mercury's fiscal 2022 third quarter and is expected to be delivered over the next several quarters.

PEOPLE

▲ *Gregory Bryant*

Analog Devices Inc. (ADI) announced that **Gregory Bryant** will be appointed to the newly created position of executive vice president and president of business units. In this role, Bryant will have oversight of the company's business units—Industrial, Automotive, Communications, Digital Healthcare and Consumer—and will be responsible for continuing to scale ADI's rapidly growing businesses.

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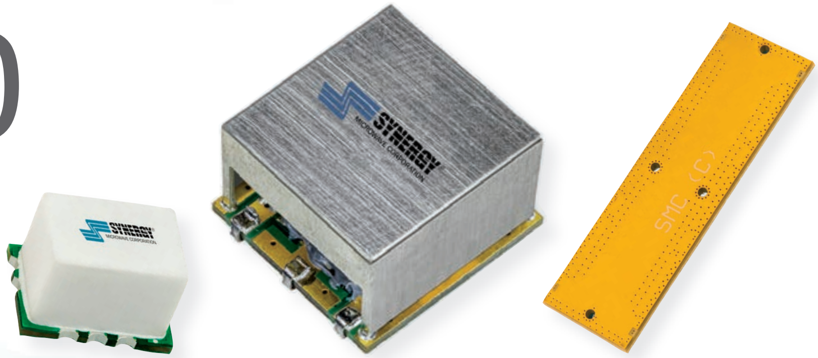

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SDCHP-255	20 - 550	20 - 0.6	0.4	0.25 - 0.35	23 - 20	27.5
SDCHP-335	30 - 350	20.1 - 0.7	0.85	0.24 - 0.32	24 - 20	75
SDCHP-484	40 - 840	19.2 - 0.8	0.9	0.3 - 0.4	24 - 20	30
SCCHP-560	50 - 560	14.6 - 0.7	0.7	0.48 - 0.65	23 - 20	75
SBCHP-2082	200 - 820	11 - 0.46	0.5	0.74 - 0.9	22 - 19	22.5
KDS-30-30-3	27 - 512	27.5 - 0.8	0.75	--	23 - 15	50
KDS-30-30	30 - 512	27.5 - 0.8	0.75	--	23 - 15	50
KBK-10-225	225 - 400	11 - 1	0.5	0.6 - 0.7	25 - 18	50
KBS-10-225	225 - 400	10.5 - 1	0.5	0.6 - 0.7	25 - 18	50
KDK-20-225	225 - 400	20 - 1	0.5	0.2 - 0.4	25 - 18	50
KDS-20-225	225 - 400	20 - 1.0	0.5	0.2 - 0.4	25 - 18	50
KEK-706H	500 - 2500	31.5 - 2	2.5	--	--	100
SCS-8012D	800 - 1200	20 - 1	0.6	--	22 - 18	100
KEK-704DH-2	850 - 1250	30 - 1.5	0.25	--	--	500
KEK-704H	850 - 960	30 - 0.75	0.25	--	--	500
SCS100800-10	1000 - 8000	10.5 - 1.5	2	1.2 - 1.8	8 - 5	25
SCS100800-16	1000 - 7800	16.8 - 1.5	2.8	0.7 - 1	14 - 5	25
SCS100800-20	1000 - 7800	20.5 - 2.0	2	0.4 - 0.75	12 - 5	25
SCS-1522B	1500 - 2200	10 - 1.0	--	--	23 - 18	100
SCS-1522D	1500 - 2200	20 - 1	--	--	23 - 20	100
SCS1701650-16	1500 - 15500	17 - 1.5	2.5	1 - 1.4	16 - 5	25
SCS1701650-20	1700 - 15000	21 - 1.5	2.5	--	10 - 7	25
SDC360440-10	3600 - 4400	8.6 - 0.5	0.25	--	18 - 10	10
SDC360440-20	3600 - 4400	19 - 0.5	0.25	--	16 - 10	10

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Around the Circuit


▲ *Jim Francey*

Isola Group, a leader in circuit materials and materials technologies, announced the hiring of **Jim Francey** as RF Business Development director, Europe. Francey will report directly to David Humby, vice president of Sales and OEM Marketing Europe, in the new role and will apply his industry background and considerable experience in the RF/microwave electronics industry to help Isola explore and expand new opportunities for high frequency circuit materials within printed-circuit boards.


▲ *Mark Schreiner*

The **MegaPhase** team welcomes **Mark Schreiner** as chief engineer. In his new role, Schreiner will oversee all aspects of R&D, product improvement and sustainment efforts. Schreiner joins MegaPhase with over 30 years of experience in RF and microwave technology.


▲ *Tatsuo Bizen*

pSemi® Corporation announced the appointment of **Tatsuo Bizen** as CEO. Succeeding interim CEO Takaki Murata, Bizen joins pSemi from parent company Murata, where for more than 30 years he has served in a variety of global leadership roles in the U.S., Japan and Europe. He brings an extensive background in RF and power management, and a passion for driving innovation.

REP APPOINTMENTS

Kymeta and **OneWeb** announced a distribution partner agreement to offer broadband connectivity services across the globe. The OneWeb LEO satellite network will give Kymeta customers access to high speed, low latency broadband connectivity while on the move or while stationary, anywhere in the world. Kymeta's distribution agreement with OneWeb will enable the company to resell OneWeb services in conjunction with fixed and mobility hardware solutions to government and commercial customers globally.

RFMW announced a global distribution agreement with **ED2 Corporation** of Tucson, Ariz. Under the agreement, RFMW becomes a franchised distributor for worldwide marketing and sales of ED2 Corporation products including RF antennas, filters and new glass-based components and modules.

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THz – To Be or Not To Be in 6G?

Tomasz Waliwander
Farran, Cork, Ireland

While the story is still being written for 5G as the networks are being deployed in many parts of the world, this fifth-generation communication technology is already conditioning the path for what follows: 6G. With 5G still to deliver on its promises, and mmWave bands largely underutilized in comparison with the sub-7 GHz range, the research community is already investigating the next generation of communication technology. The 6G specifications are expected to be developed and released around 2026 to 2027; at the moment, it is challenging to provide a clear and concise vision for 6G. However, three things about 6G appear to be certain:

- 6G is expected to be more capable, intelligent, reliable, scalable and power efficient, satisfying all the requirements that cannot be realized at present with 5G.[1]
- 6G will employ a combination of technologies already used in 5G and other previous generation wireless networks, as well as new technologies that were either deemed too immature for 5G or will be adopted or developed specifically for 6G.[2]
- 6G will most likely continue the trend of using higher and higher carrier frequencies beyond the mmWaves through THz bands and up to visible light, to provide high capacity point-to-point communication with an aim to achieve spectral efficiency 5x greater than 5G.[3]

6G will inevitably continue the expansion into higher frequencies, with a 100 to 300 GHz range being considered as the first opportunity window, where a number of services for radio astronomy, satellite Earth exploration, mobile satellite and inter-satellite are already allocated in the 141.8 to 275 GHz band.[3] The Federal Communication Commission (FCC) has designated 21.2 GHz of spectrum for unlicensed use in the 116 to 123, 174.8 to 182, 185 to 190 and the 244 to 246 GHz bands.[4]

The basic 6G requirements for peak data rates are expected to be 50x those of 5G, with the user data speed experience at least 10× better than with 5G networks (see ***Figure 1***). Additionally, 6G is to offer much higher area traffic capacity and connect an even greater number of devices than 5G. With even lower latency and much improved reliability, 6G will truly address the needs of autonomous mobility, industrial automation and robotics. A detailed comparison of current 5G and expected 6G key performance indicators (KPIs) is summarized in ***Table 1***.

THZ KEY ENABLERS

Achieving this next step in wireless communications evolution will require a much better understanding of technology limitations compared to the previous generations, i.e., 3G, 4G and 5G. The technology readiness levels will have a significant influence and impact on the timeline of 6G adoption, with its rollout expected to start between 2028 and 2030.

The success of 6G will rely on several enablers, described in the following paragraphs. We will concentrate only on those that expand and unlock additional spectrum for the purpose of wireless communications. While there are already plans to extend the upper limit of 5G to 71 GHz, the studies of 6G focus on upper mmWave bands, also known as sub-THz, with frequencies ranging from 100 to 300 GHz. This will most likely be the most interesting band for research on new wireless communication systems.[6] One thing to note, however, is that 6G will not go about providing enhancements over 5G

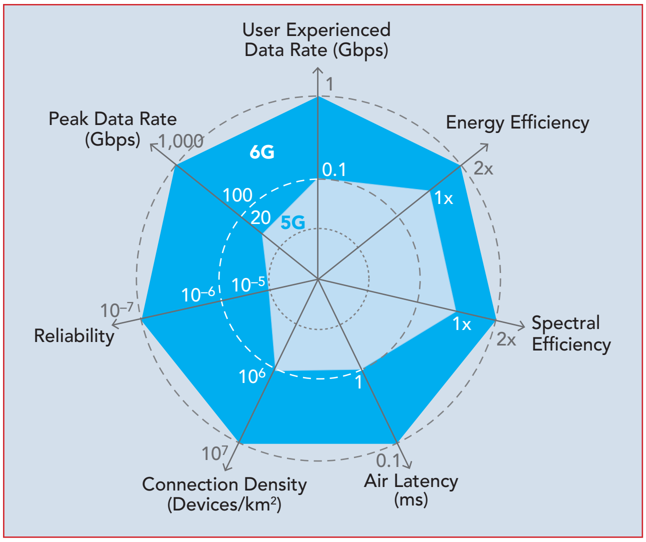

Fig. 1 Notional 6G performance improvements compared to 5G.[5]

by just employing new spectrum; it will do so by using legacy and new bands in a seamless and dynamic way to provide the required quality of service for the given use cases.

RF Engineering and Device Physics

The development of 6G and use of sub-THz bands will pose even greater challenges than has been the case for 5G, for RF engineering and device physics.[2] Generation, modulation, detection and demodulation of THz signals in an energy efficient manner has always been very difficult, and progress in this field over the last few decades has been relatively slow. In the last decade, however, we have seen several new technologies: in particular, III-V InP devices and Schottky diodes reaching the 1 THz mark.

6G devices will require very high levels of integration and ultra-low energy consumption, and extensive capability for energy conservation and harvesting to maintain long periods of standby activity, especially in case of IoT devices.[1] 6G in the sub-THz range will face challenges due to available transistor speeds in CMOS, SiGe and HBT, to ensure the available gain, output power and noise figure required to overcome the higher path loss.[6,7] Integrated circuit technologies currently available are not yet sufficiently mature or economical for Tbps data transfers to 1 km distance (see ***Figure 2***). Data transfer speeds of a few tens of Gbps have been reported below 120 GHz and within 10 m range using CMOS, while using InP and high directivity antennas enables comparable speeds to 1 km.[8]

Therefore, a stringent requirement is to develop semiconductor technology and devices that can supply enough RF power that will enable large array antenna systems to overcome path loss. The larger the antenna array, the more output power is required. For example, a 45 dBm EIRP from a handset equipped

TABLE 1

NOTIONAL 6G VS. 5G PERFORMANCE[2]

KPI	5G	6G
Peak Data Rate	20 Gbps	1 Tbps
Experience Data Rate	100 Mbps	1 Gbps
Peak Spectral Efficiency	30 b/s/Hz	60 b/s/Hz
Experience Spectral Efficiency	0.3 b/s/Hz	3 b/s/Hz
Maximum Bandwidth	1 GHz	100 GHz
Area Traffic Capacity	10 Mb/s/m²	1 Gb/s/m²
Connection Density	1 Million Devices/km²	10 Million Devices/km²
Energy Efficiency	-	1 Tb/J
Latency	1 ms	100 μs
Reliability	10^{-5}	10^{-9}
Jitter	-	1 μs
Mobility	500 km/h	1000 km/h

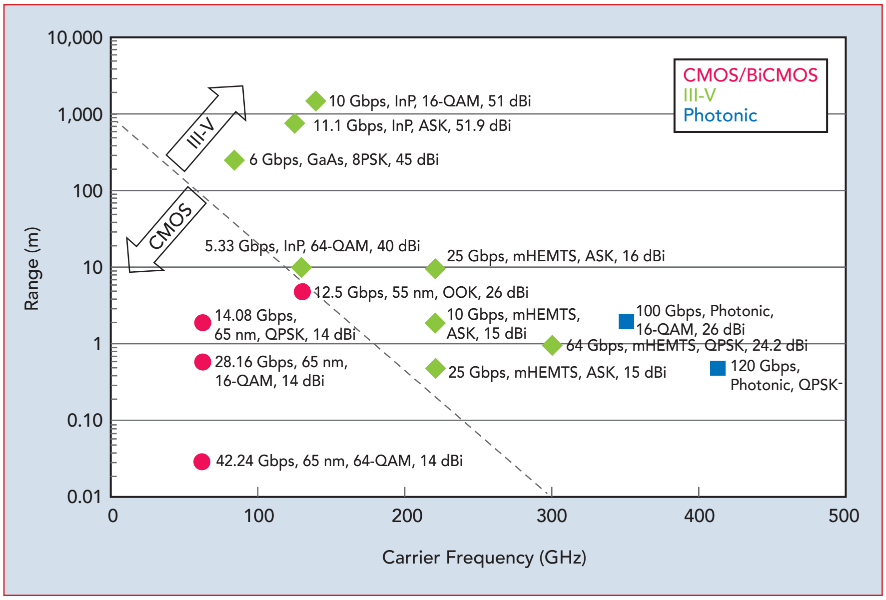

Fig. 2 IC technology demonstrations: range vs. operating frequency. Labels show the data rate, technology, modulation and antenna gain.[8]

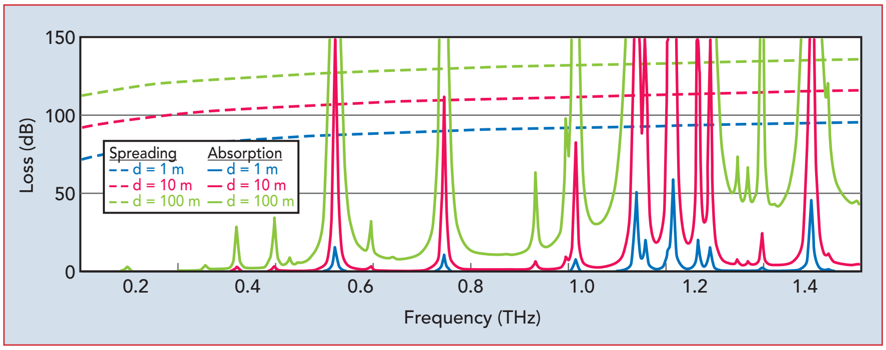

Fig. 3 Spreading (dashed lines) and molecular absorption (solid lines) losses for frequencies from 0.1 to 1.4 THz and distances of 1, 10 and 100 m.[2]

with a 16-element array requires a power amplifier (PA) delivering 16 to 20 dBm, while 75 dBm EIRP from a 256-element array at the base station requires a PA output power of 25 to 27 dBm.[6] The best amplifier devices available are based on InP HBT technology, which is superior to CMOS in generating power above 100 GHz. InP PAs can deliver 23 and 18 dBm at 170 GHz and 220 GHz, respectively. Research to reduce the size of GaN transistors may enable this technology to be used in the range from 100 to 300 GHz.[6] Such devices and systems should come on the market within the next few years.

At the receiver, sensitivity is mainly determined by the noise figure (NF) of the first element of the down-converter, i.e., the low noise amplifier. We can expect a receiver operating at 280 GHz will have a NF of at least 5 dB higher than that of its counterpart in a 28 GHz communications link.[6] Additionally, integrated transceivers are currently limited to 10 to 12 percent of the fractional bandwidth; in practical terms, this means the RF front-end will have only 20 to 30 GHz of effective bandwidth when operating in the upper range of the sub-THz band.[6] This bandwidth will still require adequate analog-to-digital and digital-to-analog converters with at least 6-bit resolution.[7] Such requirements also pose a significant challenge to minimizing the power consumption.

In summary, due to the relatively low-cost and high level of integration, CMOS and SiGe technologies will perform well in applications up to 150 GHz. GaN and InP technologies will dominate applications where higher frequencies and higher output power are required, such as extreme capacity backhaul

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networks.[2,6] Although at a very early stage of development, graphene-based electronics is a very promising technology for THz RF systems.[1]

Communication Channel Properties

While the communications channels in the sub-7 GHz and mmWave bands have been relatively well investigated and modeled, thanks to 5G development, the same is not true of the sub-THz range, where characterization activities have been scarce.[6] Accurate understanding of the properties of THz channels, especially signal spreading loss and molecular absorption, is fundamental to implementing 6G technology. Signal spreading loss is a phenomenon associated with wave spreading that occurs when an electromagnetic wave passes through the medium, while molecular absorption is associated with the loss that occurs when a portion of the energy of the electromagnetic wave is converted into kinetic energy that vibrates the molecules of various atmospheric gases (see ***Figure 3***).

Several transmission windows occur on the molecular absorption characteristic of the THz band, in which the effective susceptibility of molecular gases to vibration is limited and much lower than the spreading loss. For the lower range, these windows are between 120 to 140 GHz and at 240 and 300 GHz.[2] Additionally, outdoor THz wireless communication can differ significantly under various meteorological conditions, with snow and rain introducing additional losses in the signal propagation. With indoor communication, the walls, plants, animals and humans affect the propagation properties, causing the signals to be absorbed, reflected, transmitted and diffracted, making long distance communication challenging. High gain antennas can compensate for the high propagation losses, and ultra-massive MIMO (UM-MIMO) antenna systems are emerging as practical means of solving the range issues.[9]

For all these reasons, the THz channels must be empirically characterized using channel sounding techniques, which are far more challenging than at cellular bands. This is due to the high attenuation of THz signals in both indoor and outdoor environments and the high directionality of THz waves. These factors impose limitations on the channel sounder system architecture and, consequently, on the availability of measurement equipment. While at sub-7 GHz, complex wideband channel sounders with more than 50 dual-polarized antenna element arrays can be used, the channel sounders for THz tend to rely on traditional high directivity horn antennas and single receiver architectures to preserve high dynamic range and measurement fidelity. Achieving high directional resolution, large bandwidth and high phase stability comes at the expense of system complexity and its associated cost.[3] The need for mechanical positioners slows down the measurement and currently makes channel sounding impractical and unfeasible. For these reasons, few radio channel models are available for the upper mmWave bands; the available models often rely heavily on simulations and are valid for very specific indoor scenarios. More work


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is required to model industrial settings, accounting for construction materials, mechanical and electrical noise and the presence of robots and heavy machinery.[3]

Energy Consumption and Sustainability

The required leap into the sub-THz frequencies with its abundant bandwidth cannot be achieved by merely increasing the carrier frequency.[6] Analog RF electronics operating at these high frequencies with large bandwidth has limited power-added efficiency (PAE). Currently, high frequency PAs can only deliver PAEs of 7 and 4 percent at 170 and 220 GHz, respectively. The PAE of a transceiver would be expected to fall well under 10 percent.

The digitalization of large bandwidths and the speed of digital signal processing become major issues. Sampling frequencies of A/D converters and their associated power consumption remain inadequate for efficient signal processing and the energy consumption demands that will be imposed on 6G networks. Energy efficiency is increasingly important as the world shifts toward sustainability.[5] 6G infrastructure energy consumption is expected to be at the level of 4G networks irrespective of the number of terminals, so the expected growth in data traffic volume does not result in a comparable growth in energy consumption.[10]

Packaging the Front-End and Antennas

Component and system level packaging and antenna array integration pose significant challenges at 5G. With additional transmission line losses from sub-THz propagation, higher integration will be required. Resolving these issues may require novel 3D packaging and structures with the chips and antennas stacked on each other to reduce interconnect lengths, footprint and tight antenna array (UM-MIMO) integration.[6] The combination of tight integration and low efficiency of the RF circuitry poses yet another major challenge: thermal management.

TECHNOLOGY CHALLENGES

A new generation of communications technology occurs when two driving forces align: one that stems from societal needs, the other when technologies are mature enough to address the need. Wireless communication that operates in the sub-THz and THz bands will only make sense for those use cases that are not focused on cost and energy efficiency. These likely include indoor communications in data centers, where massive amounts of data could be transported without a complex and costly cable infrastructure. With outdoor communications, backhaul will emerge as an application where fiber-like data transfers will be achievable over 0.1 to 1 km links. The lower sub-THz band, with frequencies in the 100 to 200 GHz range, seems like a good candidate for such applications. Researchers and engineers are already conducting studies and developing devices and systems in

D- (110 to 170 GHz) and G-Band (140 to 220 GHz).

There is still significant progress to be achieved in developing more efficient modulation. Supported by artificial intelligence and machine learning, new modulation schemes will emerge, tailored for specific use cases, throughput and latency.

Realistically, it is difficult to imagine 6G communication networks using the bands beyond 300 GHz. Not only is the free space loss often greater than 100 dB—reducing the range of a wireless link to a few tens of meters, at best—but semiconductor devices, materials and integration technologies are not developed to support Tbps connectivity above 300 GHz. While RF electronics will improve with time and, when combined with advanced antenna beamforming techniques, will mitigate the higher signal losses and limited link distances, it is unreasonable to assume the required maturity of RF technology is simply a matter of time. It is uncertain if CMOS and SiGe BiCMOS will provide adequate performance at THz frequencies by the time 6G is implemented. Additionally, nano- and meta-materials, as well as graphene-based electronics, need time to mature and prove viability. Will the trend of ever-increasing speed of analog and digital CMOS and BiCMOS based electronics, so fundamental to large scale communications, continue? Or is it a time for other semiconductor technologies such as InP HBT to form the foundation for 6G?

Also uncertain: will the complexities of RF circuit parallelization, antenna design and fabrication, high speed and power components, efficiency, power consumption and heat dissipation and system integration challenges can be resolved in time for the 6G rollout. Even assuming that all the RF electronics and technology issues can be resolved, with stringent requirements on power consumption and energy efficiency for 6G devices and networks, data processing may become the bottleneck. Allowing for the most optimistic assumptions about RF circuit performance at sub-THz, the applicability of such systems will be very limited for any battery-powered devices.

True THz communication beyond 300 GHz may come, but it may only be in time for 7G. The biggest challenge is the achievable link distance, as transceiver available output power and sensitivity are and will remain low for the foreseeable future. There is a strong possibility, however, that the sub-THz bands will be employed in 6G for all those applications and use cases where the sheer amount of data transfer capacity will be the main KPI and can be justified by the business case.

As people have moved to meeting and collaborating virtually, communications have become as vital as water and electricity. We are constantly bombarded with a vision of the future in which billions of humans, things and connected vehicles, robots and drones will share zettabytes of data in the all-connected world.[10] The vision for

6G is to provide an affordable and scalable network with great coverage everywhere, so it ends the digital divide and truly provides an all-connected world.

TO BE OR NOT?

Sub-THz 6G faces significant unresolved challenges. For the RF circuits, higher output power and efficiency, lower NF and phase noise must be achieved, with even more advanced antenna beamforming solutions used to combat signal losses and limited link distance. Propagation channels at THz frequencies for both indoor and outdoor communications remain uncharacterized and largely depend on simulation rather than measurements, as channel sounding techniques and measurement equipment are primitive. The energy consumption and sustainability requirements expected for 6G networks are daunting, which reveals the need for novel energy harvesting and energy transfer for devices and networks to meet stringent bit-per-joule requirements. Packaging and integration techniques that largely rely on rectangular waveguide and milling technique must be simplified to support volume manufacturing and reduce cost.

The immaturity of the technologies and fabrication techniques make the challenge of developing 6G even greater than it was for 5G, which piggy-backed on a more mature foundation. For 6G to deliver THz communication and enable many new use cases in the typical decade timeframe is more difficult. Considering the current maturity of the enabling technologies and the required development, THz communication in 6G seems an unlikely scenario. A more realistic bet is for THz communication to arrive in time for 7G. ■

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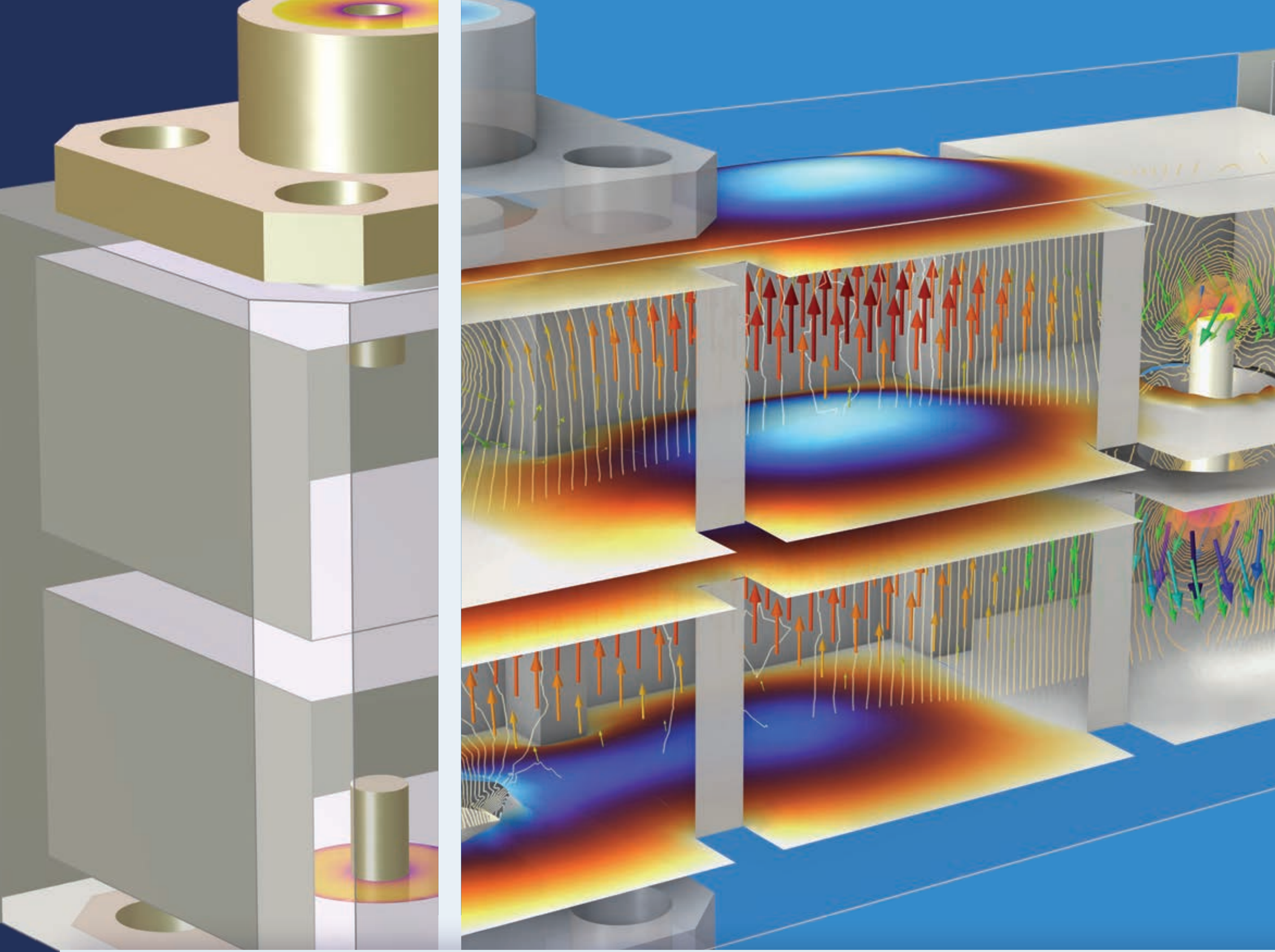

INVITED PAPER

The Perfect HF Receiver. What Would it Look Like Today?

Ulrich L. Rohde
Universität der Bunderwehr, Munich, Germany

Thomas Boegl
Rohde & Schwarz, Munich, Germany

Modern HF receivers must fulfill requirements such as sensitivity, robustness and many others. Key requirements often lead directly to RF concepts and architectures with their specific advantages and disadvantages. What would the perfect HF receiver look like today, one that combines all available technologies into the most modern concept of a software-defined receiver? Would it employ "IF sampling," "direct sampling" or something else?

The architecture of a receiver is directly driven by some key requirements which must be fulfilled. The number of these requirements can be quite high but for an HF receiver design there are only three major ones: 1) pick up weak and wanted signals, 2) in the presence of strong interferers within a given frequency offset, 3) at the same time.

Within these requirements are hidden values that must be known in detail, for example, the required sensitivity, the maximum level for interferers and the frequency offsets between wanted signals and interferers. These three "golden parameters" can and must be extracted from the operational scenario in which the receiver is used. In combination with the capabilities of typical building blocks, such as analog-to-digital converters (ADCs), these three parameters determine the most suitable receiver architecture.

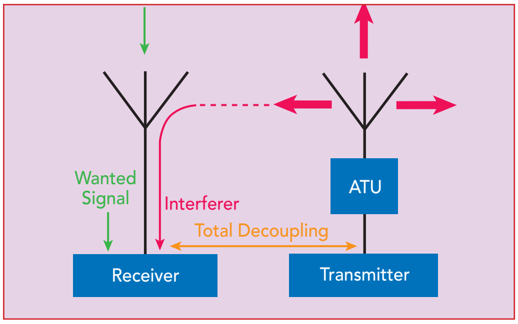

Fig. 1 Receiver co-location scenario.

OPERATIONAL SCENARIOS FOR SOFTWARE-DEFINED RADIO (SDR) HF RECEIVERS

High-end HF receivers must be able to provide high sensitivity (if required) while strong interferers are simultaneously present (see ***Figure 1***). Very strong interferers can come quite close to the tuned center frequency of the receiver, which is the case

within some co-located installations, for example, navy ships or coastal stations, but also at field days with many amateur radio stations operated within short distances. Interferers at small frequency offsets not only provide strong signals at the receiver front-end, but also introduce external interference caused by transmitter sideband noise. This falls into the receiver's passband and masks weak signals at the receive antenna.

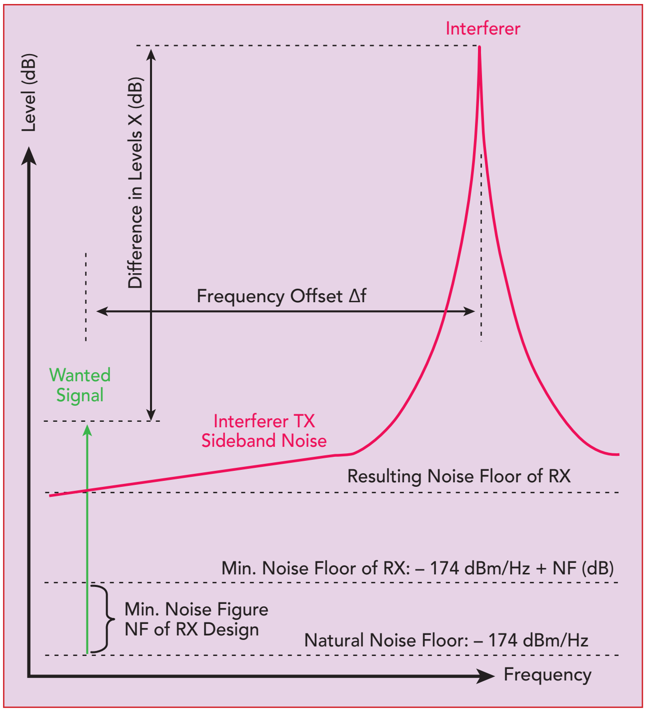

Fig. 2 Key parameters for co-located installations.

The transmitter in Figure 1 radiates a high-power signal shown as red arrows while the receiver tries to pick up the weak signals shown as green arrows. The total decoupling between the transmitter output and the receiver input determines how strong specific parts of the transmitter spectrum appear at the receiver front-end. The receiver specifications must be determined based on the characteristics of the interfering signals and the transmitter installation close to the receiver.

Figure 2 illustrates this situation. The red interferer transmits a strong signal at an offset of Δf and the sideband noise of the transmit signal falls into the receiver passband. This external noise is added to the noise floor of the receiver given by the receiver noise factor which leads to a resulting noise figure that limits its sensitivity.

In Figure 2, it is assumed that the receiver has a noise figure of 10 dB. Other key parameters are strongly dependent upon the installation. The following values are assumed for two different operational scenarios.

For military installations: frequency offset Δf = 10 percent, total decoupling = 15 dB and interferer transmit power = 1000 W.

For amateur radio installations: (e.g., field days), frequency offset Δf1 within same amateur band =100 kHz, frequency offset Δf2 to the next amateur band is greater than 10 percent, total decoupling = 25 dB and interferer transmit power = 150 W.

Note that a high-end receiver will not be able to demonstrate its full performance in the presence of low-end transmitters. This requires feasible values for transmitter sideband noise available in both scenarios. The transmitter parameters stated here are beyond those of currently fielded transmitters because it is assumed there will be improved transmitter capabilities in the near future.

Excellent interferer TX sideband noise: -150 dBc/Hz at 100 kHz for Δf1

Excellent interferer TX sideband noise: -180 dBc/Hz at 10 percent for Δf2

The sideband noise at an offset of 100 kHz is determined by the synthesizer concept within the transmitter while the value at 10 percent can be achieved by using additional so-called cosite filters in the right position within the block diagram. These cosite filters can be switched into the receive chain and then re-

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used as preselector filters in the receive mode.

WHAT IS THE PERFECT SDR HF RECEIVER CONCEPT?

This is determined by combining the best available technology for each of the required building blocks within a block diagram and evaluating its performance with respect to the influence of external interferers. This approach is based on the concept of designing a receiver that may not be as good as technically possible but is as good as operationally usable, which is a significant difference.

The quality of a receiver is defined by the maximum usable sensitivity in the presence of strong interferers. How much stronger can these interferers be compared to the weakest signals which can still be heard while the interferers are present? Clearly, noise plays a significant role in the design of the receiver, therefore the design starts with an analysis of noise.

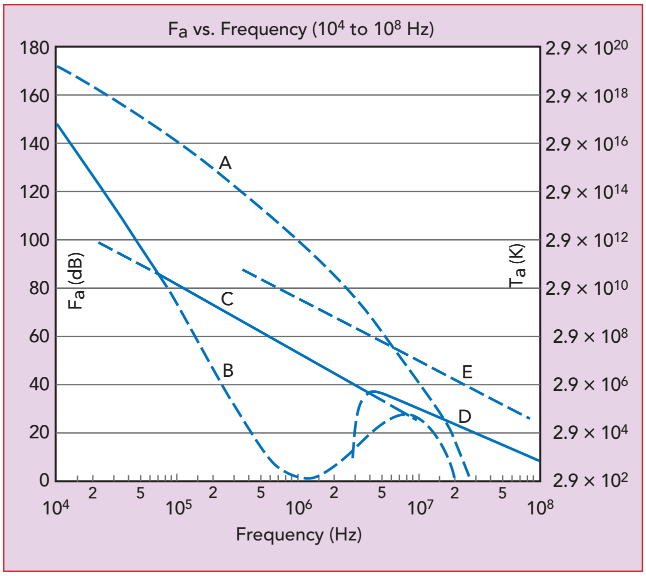

Fig. 3 Noise external to an HF receiver.

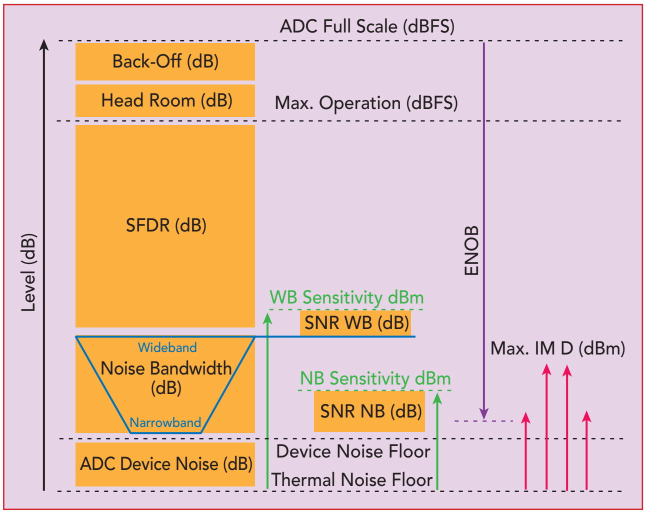

Fig. 4 ADC parameters.

Limits to Sensitivity – External Noise

The sensitivity of a receiver based on its design can be very high. In many operational situations a receiver's noise floor may be obscured by a noise floor picked up by the antenna and applied to the receiver front-end. This noise floor is variable over time, frequency, location and antenna configuration. ITU has provided information within ITU-R P.272 to determine the level of external noise (see ***Figure 3***).

Figure 3 gives guidance on the external noise picked up by an omnidirectional antenna and then fed to the receiver front-end. The curves (A to E) within graph represent the noise level expected for:

A. Atmospheric noise, value exceeded 0.5 percent of the time
B. Atmospheric noise, value exceeded 99.5 percent of the time
C. Man-made noise, quiet receiving site
D. Galactic noise
E. Median city area man-made noise
F. Minimum noise level expected.

The intensity of the external noise within the graph is shown as equivalent noise figure of a receiver, which allows an easy comparison with the noise figure of any given


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receiver design. In addition to the noise contributions shown in Figure 3, sideband noise of interfering transmitters may also be received. Both noise contributions may mask the native sensitivity of the receiver design.

The most challenging environment for a receiver is therefore when the receiver is installed in a very quiet geographical area and all interferers are of high quality. This allows interferers to come very close and with high levels to the receiver's passband channel before their sideband noise masks either the receiver's own noise floor or the low atmospheric noise.

The receiver design provides some gain to adjust its sensitivity and some selectivity to suppress strong interferers. The quality of the receiver design is simply defined, therefore, by the quality of the balance between these parameters to bring the spectrum at the antenna into the operational window of the ADC.

The ADC and its Essential Parameters

An ADC datasheet is filled with specifications, but which ones should be looked at first when selecting a particular ADC type? It is important to know the difference in magnitude between weak wanted signals and strong unwanted signals at the input of the ADC. This determines the operating window of the ADC and is an important characteristic in the receiver design.

The analysis of an ADC data sheet normally starts with resolution, noise factor and other parameters that are fundamentally linked to achievable sensitivity. This is done here in the opposite direction because it is easier to understand the behavior of an ADC within the complete architecture of a receiver. ***Figure 4*** shows the relevant parameters of an ADC that should be analyzed first before any design decisions are made.

We start with the maximum level allowed at the input of an ADC, which is the ADC Full-Scale-Level. Any signal present at the antenna of the receiver must safely remain below this threshold, otherwise further processing steps are strongly affected and will deliver unusable results. If strong signals at the antenna are very close to the wanted frequency, an automatic gain control circuit must set the right maximum gain to avoid ADC overload.

The next important parameter is the effective number of bits (ENOB). It indicates how far below the ADC Full-Scale-Level a weak signal can be found and identified by the ADC. It is important to know that a perfect low-resolution ADC may have a significantly higher ENOB than an imperfect high-resolution ADC.

After sampling the input signals, any ADC will show some jitter within the digitized data. Inside this jitter the information of weak signals is hidden and can be extracted, for example, by decimation mechanisms. These decimation algorithms can be seen as a kind of averaging. Averaging across ten samples, for ex-

ample, may increase the resolution by a factor of ten while reducing the sample rate by the same factor of ten as well. Decimation algorithms basically enhance the effective resolution of the signal processing chain by diving into the noise and jitter at the output of the ADC.

The possible depth of this dive is limited to a point where the jitter of the ADC itself cannot be separated any further from the jitter related to the input spectrum. The jitter from the ADC may also contain jitter from the clock signal, therefore it is important that the applied sampling clock signal is generated with the highest possible quality with respect to phase noise and spurious content.

The value for ENOB does not yet provide any information about the quality of the signal processing chain with respect to intermodulation or any other unwanted signal which is not present at the input of the ADC but appears at its output.

Unwanted signals at the output of an ADC may be caused by a variety of effects, such as nonlinearity of input stages or others. These discrete output signals often show a correlation between the sample rates used and the spectral components of the input signals but are normally not reliably predictable, either in their frequency or in their levels. Within a data sheet of an ADC, its quality with respect to unwanted signals is given as spurious free dynamic range (SFDR). Values for SFDR depend on the settings, especially with sample rates, input spectrum and chosen levels at the ADC input.

Receiver Design

The ADC is the key component within the concept of a software-defined receiver. Dynamic range is one of the most important parameters required for the selection of the ADC itself and the right receiver concept as well. For very high RF frequencies (far higher than 30 MHz) the possible operating frequencies might be the only available criteria for the selection of an ADC. An HF receiver requires either a direct sampling capability of any frequency up to 30 MHz or the capability to process a fixed frequency typically below 100 MHz for an IF sampling concept.

Several companies offer ADCs with up to 18-bit resolution with sample rates of up to 100 MHz or more. The input stages can be operated with a bandwidth of some hundred MHz. This would allow the use of the same devices with subsampling as part of an IF sampling receiver. Subsampling concepts require a clear knowledge of the input spectrum to be sampled, therefore, sufficient band limitation, for example with a bandpass filter, is required. The combination of a bandpass filter with a subsampling ADC would be a valuable back-end part of an IF sampling receiver concept.

With modern ADC devices, an SFDR of 90 to 100 dB can be expected. This means that the maximum allowed difference in level between a weak wanted signal and a strong interferer can be in the order

of 90 dB when both signals are applied simultaneously to the input of the ADC.

Gain and Selectivity Between the Antenna and ADC

The stages between the antenna and the ADC are responsible for bringing the spectrum at the antenna into the operating window of the ADC. If the difference in levels appearing at the antenna are higher than allowed at the ADC input, a preselector filter must suppress the strongest signals. If this suppression is not sufficient, the gain must be set to ensure that the ADC is not overdriven. In total, the receiver may lose some sensitivity compared to a use case with no interferers present. If the interferer's phase noise masks the receiver's own noise floor (see Figure 2) or the natural noise floor from the environment (see Figure 3) even perfect selectivity within the receiver would not help to improve this situation. Reduced gain, in this case, will improve the receivers robustness by reducing nonlinear effects such as cross modulation and/or intermodulation; but, the maximum possible sensitivity will be limited by the external noise.

These fundamental facts provide clear advice for choosing the best concept for an SDR HF receiver:

1) If the selectivity of the preselector filters is good enough to bring any spectrum situation into a setting where the ADC is not overdriven and the wanted sensitivity is still available, then a direct sampling concept is usable and is recommended.

2) If the selectivity of the preselector filters is not sufficient, then an IF sampling concept is necessary because the missing selectivity can only be added within the IF domain.

The flexibility of a direct sampling concept is greater than for an IF sampling concept because the digital signal processing has a wider access to the spectrum. Therefore, it is recommended to start first with a direct sampling approach and then try to extend its performance to the technological maximum or to the technological need based on the use cases by selecting a suitable high-end ADC and high performance preselector filters.

Wideband SDR HF Receiver

The main purpose of a wideband receiver is to monitor a wide instantaneous bandwidth up to the complete HF band. The frequency range may start at 10 kHz or even lower and will go up to 30 MHz. It is possible to use a direct sampling SDR concept or transfer the complete HF band to a different frequency for further processing by using a frequency converter, as it is done, for example, within a spectrum analyzer. The frequency conversion will always lead to an IF frequency well above 30 MHz, typically 70 MHz or even higher. In fact, it will then require an ADC with higher performance than one for direct sampling, because the ADC will operate at higher frequencies while the expectation for a high dynamic

range within a 30 MHz bandwidth will not change.

The phase noise and jitter quality of either the local oscillator or the sampling clock determines the achievable quality for desensitization and selectivity of the total receiver. The requirements with respect to the spectral purity of the local oscillator used for mixing will be higher than those for the sampling clock of a direct sampling concept just based on the different frequencies. Additionally, the wideband mixing concept will struggle to achieve good spurious suppression because there are a variety of effects linked to a wideband mixing concept which may lead to unwanted spurious signals in front of the ADC.

These basic facts and their dependencies already lead to a direct sampling receiver concept as the best basis for a wideband HF receiver with the capability to monitor up to 30 MHz of instantaneous bandwidth.

Narrowband SDR HF Receiver

It is assumed that interferers can come as close as 100 kHz to the wanted signal in use cases where CW is received at the lower end of an amateur radio band while SSB is received at the upper end of the same band. If interferers are in the next adjacent amateur radio band, then frequency offsets of 10 percent or more apply.

A sufficiently high selectivity at an offset of 100 kHz cannot be achieved directly with a preselector filter, therefore the spectrum is transferred into an IF domain where additional narrowband filters can provide much higher selectivity than any preselector. If, because of this, an IF sampling concept applies, then an optimization process can be employed.

The choice of the right IF frequency is essential and the best results are achieved at around 70 MHz to keep away from any potential intermodulation products. It is also recommended to use IF filters with different bandwidths, for example, 500 Hz for CW up to 250 kHz for the new upcoming wideband HF data modes according to the latest versions of MIL-STD 188-110. Narrower bandwidths within the bandwidth of the IF filters are realized by digital signal processing mechanisms.

After optimizing the IF filter, a final selection of the ADC can be done because within an IF sampling concept even a low-end ADC may be sufficient to achieve overall excellent performance for the entire receiver.

CONCLUSION

Both direct sampling and IF sampling are state-of-the-art concepts for SDR HF receivers. For wideband receivers direct sampling is the clear choice, while for narrowband receivers an IF sampling concept is recommended. For a high-end receiver providing, for example, a panoramic view of the entire HF band while narrowband signals are operated in parallel, it is recommended to use

two separate and independent receiver paths representing the two SDR receiver concepts.

Table 1 shows what is possible today. The two different paths are Path 1 for direct sampling of wideband signals and Path 2 for IF sampling of narrowband signals.

A full, more detailed, version of this article will be posted on the *Microwave Journal* website.

ACKNOWLEDGMENT

We want to thank Hans Zahnd (HB9CBU), Robert Traeger (Rohde & Schwarz) and Harald Wickenhäuser (DK1OP, Rohde & Schwarz) for their support during the creation of this article. ■

TABLE 1

DATA SHEET FOR A HIGH-END SDR HF RECEIVER

Tuning range:	10 kHz up to 30 MHz
Max. Noise figure of RX without Interferer with Pre – Amp on:	**Path 1 Wideband:** 10 dB
	Path 2 Narrowband: 15 dB
Max. allowed Difference between Interferer and wanted Signal:	**Path 1 Wideband:** A1A (200 Hz): 95 dB J3E (3000 Hz): 95 dB
	Path 2 Narrowband: A1A (200 Hz): 150 dB J3E (3000 Hz): 140 dB
Sensitivity of RX without Interferer (pre Amp on)	**Path 1 Wideband:** A1A (200 Hz): -135 dBm or 0,04 μV J3E (3000 Hz): -123 dBm or 0,16 μV
	Path 2 Narrowband: A1A (200 Hz): -130 dBm or 0,07 μV J3E (3000 Hz): -118 dBm or 0,28 μV
Sensitivity of RX with Interferer present:	**Use case 1 military:** 1000 W with -180 dBc/Hz at 10% and an antenna decoupling of 15 dB **Use case 2 amateur:** 150 W with -180 dBc/Hz at 10% and an antenna decoupling of 25 dB **Use case 3 amateur** 150 W with -150 dBc/Hz at 100 kHz and an antenna decoupling of 25 dB
Path 1 Wideband:	**Use case 1 (with preselector > 55 dB at 10%):** A1A (200 Hz): -106 dBm or 1,12 μV J3E (3000 Hz): -94 dBm or 4,46 μV **Use case 1 (without preselector):** Any mode: - 50 dBm or 710 μV **Use case 2 (with preselector > 55 dB at 10%):** A1A (200 Hz): -124 dBm or 0,14 μV J3E (3000 Hz): -112 dBm or 0,56 μV **Use case 2 and 3 (without preselector):** Any mode: - 68 dBm or 89 μV
Path 2 Narrowband:	**Use case 1:** A1A (200 Hz): -106 dBm or 1,12 μV J3E (3000 Hz): -94 dBm or 4,46 μV **Use case 2:** A1A (200 Hz): -123 dBm or 0,16 μV J3E (3000 Hz): -111 dBm or 0,63 μV **Use case 3:** A1A (200 Hz): -94 dBm or 4,46 μV J3E (3000 Hz): -82 dBm or 18 μV

A1A - Signaling by keying the carrier directly, i.e., continuous wave (CW) or on-off keying (OOK).

J3E - SSB speech communication.

INVITED PAPER

Design of High Performance Microwave and mmWave MMICs for Aerospace & Defense

Bill Pribble and Yueying Liu
Wolfspeed, Durham, N.C.

This article describes how trends in the aerospace and defense (A&D) industry drive power amplifier (PA) design and how device models can accurately predict the performance of GaN PAs to keep pace with increasing demands. These models are consistently verified and validated through stringent practices as RF device process technology evolves.

GaN-based power transistors have been rapidly adopted in an array of commercial, industrial and military applications for their superior performance in PAs. These devices can reduce solution size with increased power density at comparable or even lower system costs than traditional solutions. GaN solid-state PAs have been replacing other technologies such as traveling wave tubes, GaAs MMICs and laterally-diffused metal-oxide semiconductor (LDMOS) transistors in military radar applications with their ability to provide higher peak powers with wider pulse widths and broader bandwidths. This trend is seen across a multitude of applications, from satcom systems to active electronically scanned array (AESA) radars and electronic warfare systems. To fully exploit the intrinsically beneficial characteristics of these devices, RF/microwave design engineers rely heavily on their respective nonlinear models.

TRENDS IN A&D

In military radar systems, AESA phased array antennas are rapidly replacing traditional mechanically steered arrays (MSAs) and passive electronically scanned arrays (PESAs) in air traffic control, marine radar, weather radar and missile seekers. Older MSA radar systems typically use aperture antennas that sit on a gimbal to manually pivot and point the radiated beam in a desired direction for maximum transmission/reception. These systems, however, incur substantial maintenance costs due to moving parts and rotating joints that require frequent repair.

PESAs are electronically "steered" by adjusting the beam of many radiating elements, using passive attenuators and phase shifters, all of which are connected to a single transmit or receive path. A high power pulse from a central transmitter is routed through a single path and emitted from the antenna array and is then rapidly switched to a single receive path to amplify echoes from the desired target.

Unlike MSAs and PESAs, AESAs enable graceful degradation due to a diversity of transmit/receive paths, making them less susceptible to catastrophic common-mode failures. Like PESAs, AESAs are composed of multiple radiating antenna elements, enabling electronic beam steering by controlling the phase and amplitude of each element;

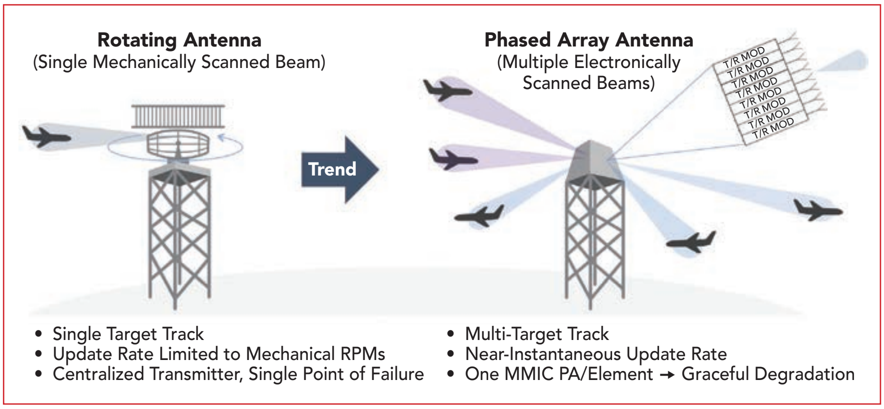

Fig. 1 MSAs with rotating antennas and single beams are being replaced with multi-beam AESAs.


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however, each element in an AESA is an active transmit/receive T/R module with a PA for transmit and a low noise amplifier for receive. This system design not only customizes the strength and radiation pattern of the beam (e.g., sharper beam with a narrow beamwidth) but can also simultaneously search, detect and track multiple objects from different directions and at different heights.

AESAs rely on strict amplitude and phase consistency due to the complex beamforming techniques employed, often using FPGAs for memory, processing and control. Efficiency and linearity are typically dictated by the type of modulation used in the signal to be amplified. These techniques enable real-time, simultaneous multi-object search, tracking, acquisition, identification, guidance and control with a near-instantaneous update rate (see ***Figure 1***). This requires highly linear amplifiers with excellent amplitude and phase consistency.

These systems also have an inherent resistance to jamming, where improved beam shaping control enables considerable sidelobe suppression and a wide operating bandwidth allows the radar to hop along a wider range of frequencies. The wide bandwidth also enables a higher range resolution, a capability of increasing importance to distinguish between two or more targets on the same bearing.

Evolving A&D Market Trends on PA Design

Demonstrations of the intrinsic merits of AESAs over MSAs and PESAs in military radar are plentiful. The evolving requirements of advanced AESA radar systems, however, put strains on both the transmit and receive chains. Wide bandwidths enable high range resolution and wide pulse widths enable the radar to capture more information; GaN HEMTs and MMIC solutions have been adopted by the military over the past decade in L-, S-, C-, X-, Ku- and Ka-Band radar to achieve wider bandwidths and more power.

The design of ultra-broadband PAs often uses multiple transistors in a multi-octave PA design. This involves complex design considerations around realizing a proper matching network, as the optimum impedance varies with frequency. The impedance selected in each octave is critical for maintaining high gain and PAE. MMIC solutions typically involve the use of on-chip passive components that increase the chip area.

GaN on SiC technologies provide several intrinsic benefits, including high breakdown voltages (> 200 V), high saturated electron velocity, high power density (up to 9 W/mm), good thermal conductivity, low parasitic capacitances, a low turn-on resistance ($R_{DS(on)}$) and thus higher power and bandwidth. Wolfspeed has developed several GaN on SiC process technologies to exploit these benefits and improve A&D system performance in areas such as phased array radars (see ***Table 1***).

GaN on SiC offers an optimum balance of power density, cutoff frequency, maximum oscillation frequency and noise figure, allowing for smaller die sizes and simpler input/output matching networks. The typical multi-transistor, multi-octave design for GaAs and Si-LDMOS solutions can now be replaced with a single GaN solution. The simplified matching network allows higher PAEs, which, in turn, reduces electrical power consumption, PA size and cost.

Device Efficiency and Linearity

There are A&D applications such as satellite communications (satcom) that require the use of modulated signals (BSK/QPSK/OQPSK). These systems demand very linear PAs that often operate in the class (ABCF) or back-off class (ABCF) modes. GaN on SiC devices can be combined with sophisticated circuit architectures to achieve the necessary efficiency and linearity. These design methods include Doherty, envelope tracking and outphasing coupled with digital predistortion. To reduce a system's size and resource consumption, the efficiency of the amplifier must be optimized while maintaining all other desired performance objectives. This is a

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TABLE 1

WOLFSPEED RF GAN TECHNOLOGIES

G50V3	G28V4	G40V4	G50V4	G28V5
Features: • 0.4 µm Gate Length • 50 V bias • 150 V Breakdown • 9 W/mm • DC to 6 GHz	**Features:** • 0.25 µm Gate Length • 28 V bias • 120 V Breakdown • 4 W/mm • DC to 18 GHz	**Features:** • 0.25 µm Gate Length • 40 V bias • 120 V Breakdown • 6 W/mm • DC to 18 GHz	**Features:** • 0.25 µm Gate Length • 50 V bias • 150 V Breakdown • 9 W/mm @ 10 GHz	**Features:** • 0.15 µm Gate Length • 28 V bias • 84 V Breakdown • 3 W/mm @ 35 GHz • DC to 40 GHz
Performance: • Broad Band • High Power	**Performance:** • Wide Band • Moderate Power	**Performance:** • High Frequency • High Power	**Performance:** • Mid Frequency • High Power	**Performance:** • High Frequency • Moderate Power
Applications: • Telecom Power Amplifiers • Radar • Backhaul	**Applications:** • General Purpose Amplifiers • Wideband EP Power Amplifiers • Backhaul	**Applications:** • Satcom • Radar	**Applications:** • Radar • Satcom	**Applications:** • Satcom • Wideband Power Amplifiers

challenge when having to back off an amplifier from saturation by several dB. These technical needs are ubiquitous across the frequency spectrum.

DEVICE MODELS

The design of high frequency, high efficiency amplifiers relies heavily on the nonlinear device model used in the foundry's process design kit (PDK). It is critical that the simulated results of the design closely match the measured results well into mmWave frequencies to effectively optimize device performance, minimize design cycles and increase device reliability.

Optimizing GaN HEMT performance with a good nonlinear device PA design and optimization requires accurate and complete simulation tools, including sophisticated models of power device behavior. This is especially true to take advantage of the high efficiency, high gain and relatively straightforward matching methods associated with GaN HEMTs.

There are several factors that contribute to what might be considered a "good" nonlinear device model for the purposes of MMIC design, including:

- Fast simulation with no major convergence issues
- Accuracy over a wide variety of sizes, geometries and bias conditions
- The ability for designers to exploit the device potential by extrapolating beyond the regions of characterization with good accuracy
- A straightforward implementation that supports various simulation platforms
- The ability to be extracted with a finite amount of data
- Simple enough for regular updates with a reasonable dataset.

Device models can vary in form, feature, simulation engine, delivery format and design interface (see ***Figure 2***). With each model, there is a tradeoff between accuracy and computational speed. The physics-based model, for example, predicts device operation under various conditions (e.g., applied bias, temperature, geometries and doping levels). This can quickly become a computationally expensive

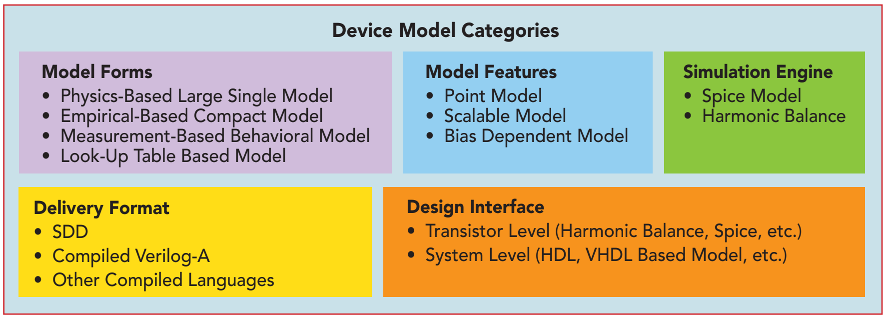

Fig. 2 Device models vary in form, features, simulation engines, delivery formats and design interfaces.

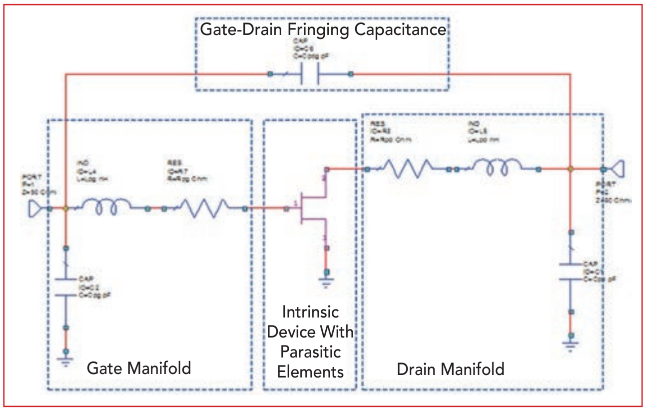

Fig. 3 Wolfspeed's empirically-based model.

process, however, with less than straightforward parameter extraction.

For this reason, a compact model is preferred, in which nonlinear ordinary differential equations are used to represent the semiconductor device behavior. Still, this is a challenge; rational approximations must be made that execute quickly with no convergence problems. It is particularly difficult to achieve convergence for devices with dynamic physical phenomena such as self-heating and trapping. Trapping occurs at a high drain voltage where electrons are injected somewhere in the GaN HEMT heterostructure, resulting in a reduction in drain current.

Empirical models simulate device behavior by using mathematically fitted equations to observed device performance characteristics (i.e., I-V, charge/capacitance). They provide a middle ground between processing time and accuracy. These models can be used universally over a variety of platforms, from higher-level analysis tools such as SPICE-based circuit simulators to more complex CAD tools.

EMPIRICAL-BASED COMPACT MODEL DESCRIPTION

Wolfspeed employs an empirical-based compact model that considers the trapping behavior of GaN devices and is accurate over several bias conditions, sizes and geometries. Models are continuously validated with evolving GaN process technologies. Because the nonlinear model is not derived from device behavior, the accuracy of the fitting procedure is key. To better represent GaN trapping behavior, the model tracks the I-V behavior of the device with different drain biases. It accurately models the optimum power/PAE load lines with drain bias changes. This is critical to provide a reliable size scaling and bias dependency. The model has two main layers, intrinsic and extrinsic (see ***Figure 3***).

Intrinsic Layer

The intrinsic layer contains mainly nonlinear capacitances that can be implemented based in either the two-terminal capacitance form or three-terminal charge form. The three-terminal charge form is preferred, as it accounts for trans-capacitance and ensures charge continuity of the model, a necessary step to ensure the model closely

matches the device's behavior and model convergence.

The intrinsic model can be seen as virtual ports that act as voltage and current probes right at the die, while the extrinsic portion of the model includes packaging effects. The intrinsic model grants the ability to observe the voltage and current waveforms to verify the PA's class of operation and to optimize device matching at the fundamental and harmonic frequencies.[1]

Extrinsic Layer

This layer incorporates parasitics from the gate and drain manifold, as well as the gate-drain fringing capacitances from the coupling of the gate and drain fingers. This includes the access resistances as well as the inductance and capacitance of the metal lines contacting the gate and drain that act as a transmission line at RF frequencies and beyond. The manifolds for the gate and drain introduce an additional inductive and capacitive effect that is considered.

GAN MODELING PERFORMANCE

Small-Signal Model Accuracy

An accurate small-signal model is important to

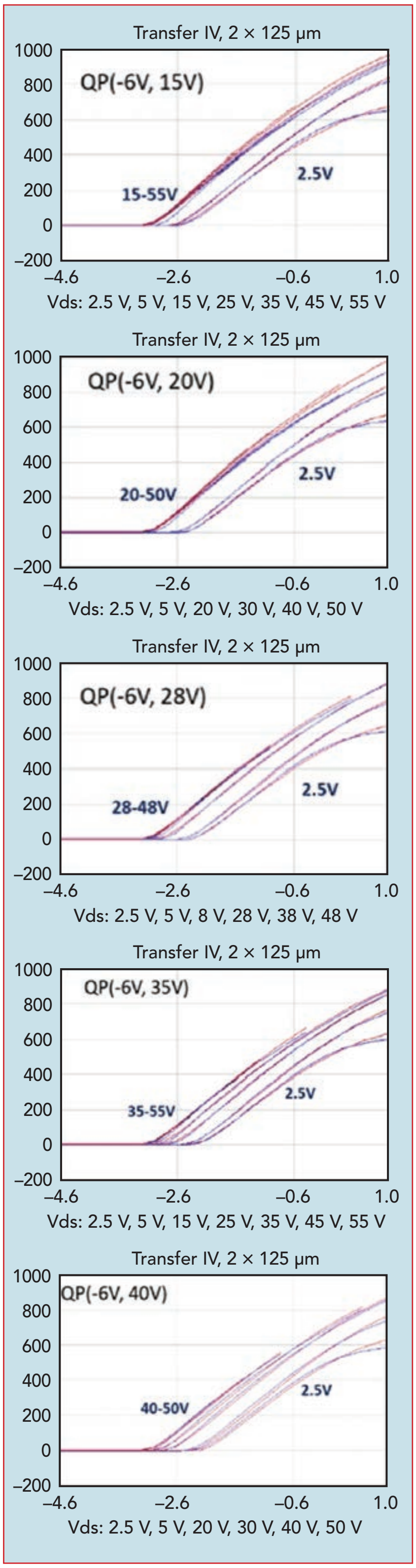

Fig. 4 I-V curves showing a reduction in saturation current and a consistent shift in threshold voltage at and beyond the quiescent point.

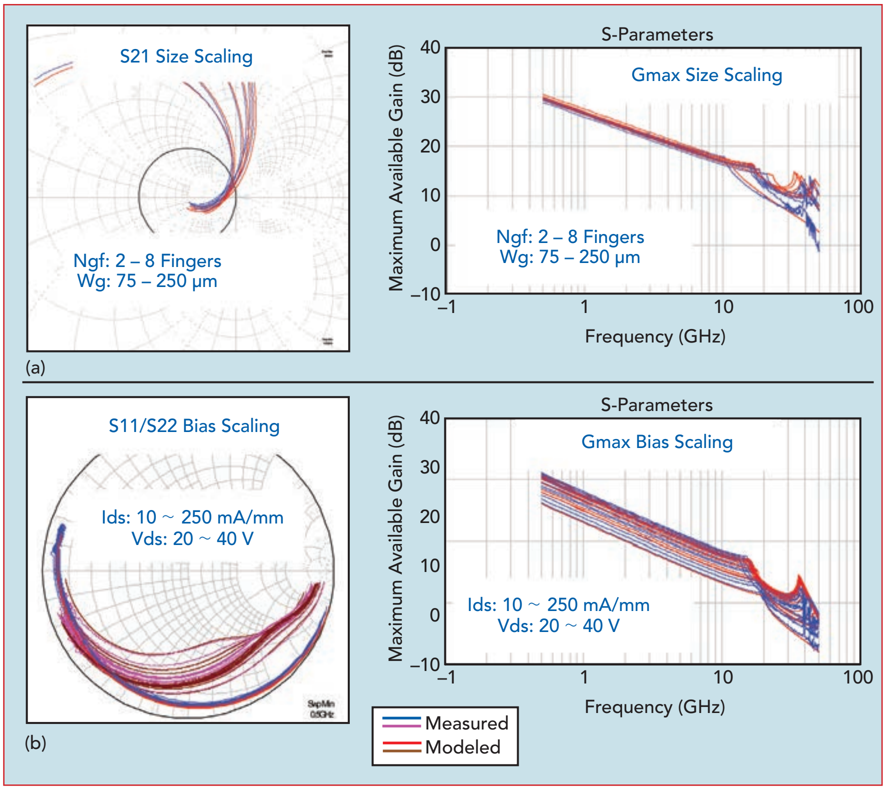

Fig. 5 Small-signal model evaluation for the G40v4 node, checking for S-parameter and gain scaling vs. bias and size.

properly design the matching networks and perform stability analysis. The dynamic nature of GaN devices with trapping and self-heating causes unique changes to the small-signal parameters. The slope of the I-V curve is greatly affected with a changing drain-source voltage (V_{ds}). This can be seen in ***Figure 4***, where the I-V curve is shown at different biases (V_{ds}). This highlights the saturation current (vertical axis) and threshold voltage (horizontal axis).

As shown in every graph, there is an apparent change in the threshold voltage (V_{th}) when the quiescent bias is increased. V_{th} becomes positive until the quiescent bias point; however, this does not go on indefinitely (see Figure 5a). V_{th} becomes positive at 15 V and stays constant beyond 15 V. This apparent shift in the V_{th} must be incorporated in the small-signal model. Wolfspeed models take care of the additional adjustments in the formulation.[2]

The Wolfspeed model is evaluated for its scaling robustness across a wide range of biases and sizes to ensure model accuracy. This can be seen in ***Figure 5***, where the model is validated with various gate fingers, gate widths and bias conditions to provide usage guidelines. Every quarter, six to 12 wafers are submitted for each GaN process technology node to ensure that the nonlinear model continues to accurately reflect the devices. The measured results very closely match the model simulations, ensuring an accurate small-signal model for designers over a wide range of gate widths, above the knee voltage and below the knee frequency.

Large-Signal Model Accuracy

Large-signal load-pull, source pull and power drive-up are also verified for various frequencies, bias conditions and device sizes to ensure accurate large-signal scaling and drive-up predictions (see ***Figure 6***). The power contours in the load-pull analysis are critical not only to observe the impedance but also to readily observe the shape to ensure that the device's large-signal output capacitance or output current and output voltage


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characteristics are within specifications.

This is especially important near the impedance region in which a designer will work to create a wideband PA. The power drive-up curves are useful for overall model validation in the back-off and compression regions. With an accurate and scalable large-signal model in place, it is possible to design much larger power transistors. When working with large-signal models, designers must ensure that they do not drive the model deeply into compression where voltage and current clipping, or breakdown, occurs as the model will not predict this accurately. These parameters are difficult to control, even for measured results.

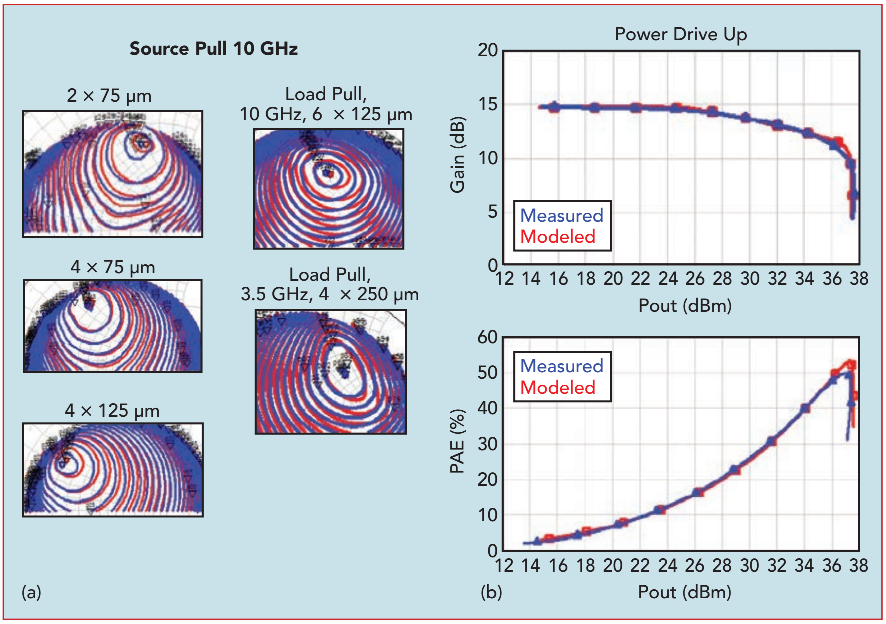

Fig. 6 Large-signal simulation vs. model for the V3-V4 nodes: load and source-pull (a) and gain and efficiency vs. power (b).

Model Verification: MMIC and PCB Levels

Validating the model at the transistor level may not show the bigger picture. Major issues can crop up at the circuit level, where the extrinsic portion of the nonlinear model doesn't necessarily correspond with reality. Wolfspeed

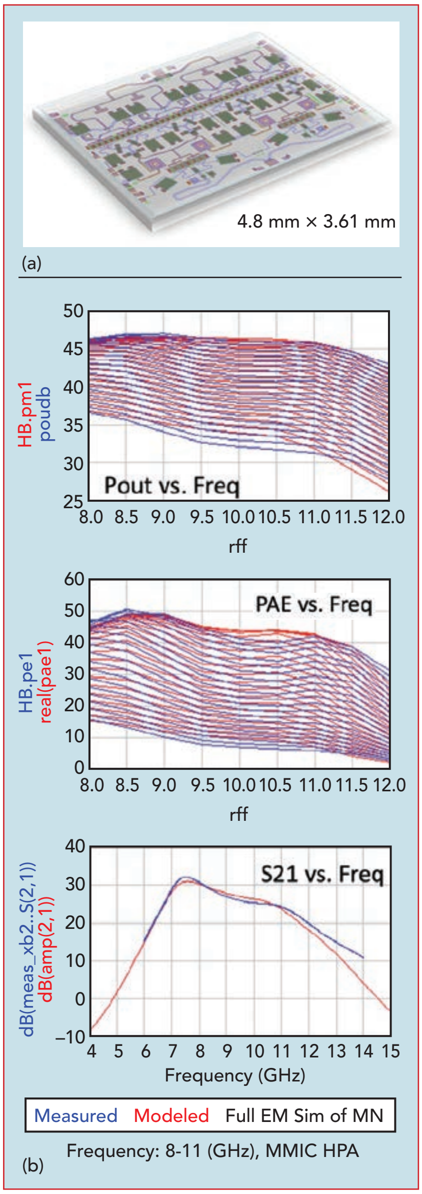

Fig. 7 MMIC PA design (a) with simulated vs. measured performance (b).

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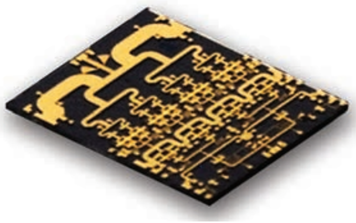

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validates models at the circuit level by dropping the nonlinear model into larger MMIC and printed circuit board (PCB) circuit designs. Model realism is further validated by comparing model results with measured results. The process involves observing the magnitude of key parameters such as output power (P_{out}), PAE and gain ($|S_{21}|$) for wideband circuits and discerning whether the model results track with the measured results (see ***Figure 7***).

Wolfspeed leverages discrete products to visualize modeled and measured S-parameter results at the PCB and package level. ***Figure 8*** shows small-signal S-parameters ($|S_{11}|$, $|S_{22}|$ and $|S_{21}|$) as well as large-signal P_{out}, PAE and gain parameters for old models, updated newer models and measured results. The old models are included to readily note any discrepancies that would make apparent any issues with an updated nonlinear model.

NONLINEAR DEVICE MODEL WITH THE WOLFSPEED GAN PDK

Working with the nonlinear device model using the Wolfspeed GaN PDK involves 13 model parameters that depend upon device geometry, thermal characteristics, yield-analysis parameters, model-related parameters, manifold characteristics and via configuration (see ***Figure 9***).

Geometrical parameters include the scaling size, number of parallel FETs, gate fingers, gate-source

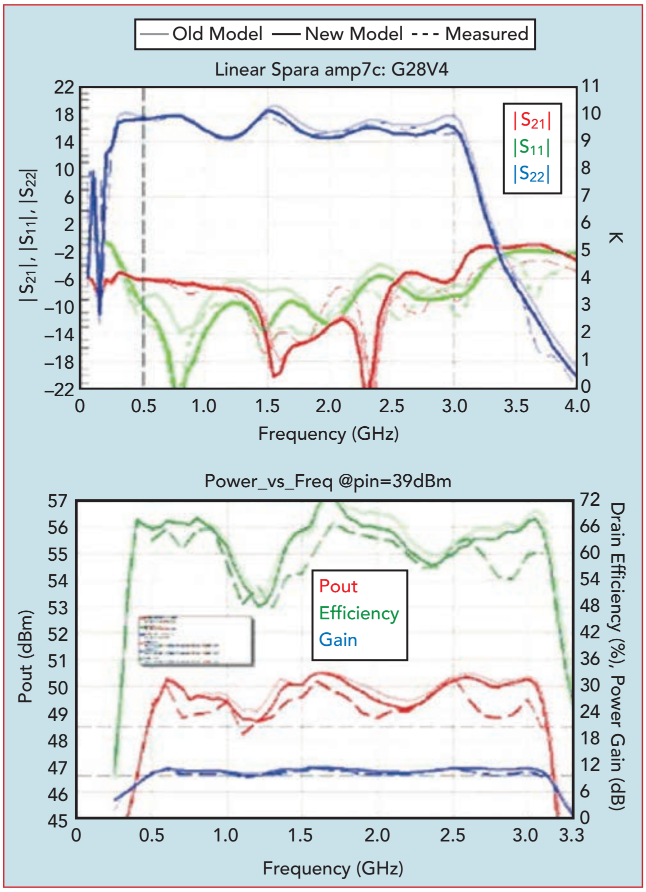

Fig. 8 Discrete product measured vs. simulated performance with updated nonlinear model.

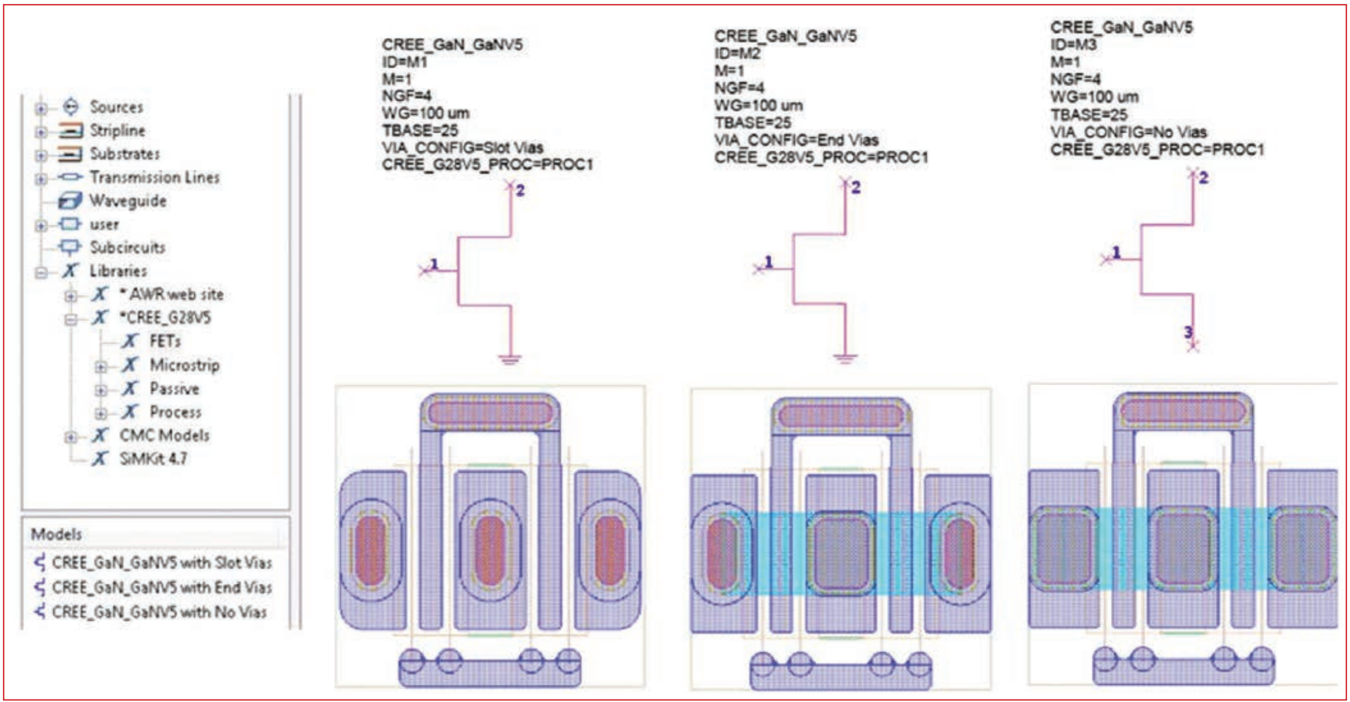

Fig. 9 Nonlinear device model in Wolfspeed's GaN PDK.

pitch and gate-drain pitch, while thermal parameters include base temperature and thermal resistance. Yield-analysis parameters consider process variations that might change intrinsic model parameters such as C_{gs} and transconductance. Designers can either use the manifold parameters set by the model or design their own manifold metallization structure and simulate it using an electromagnetic simulator to obtain an S-parameter model to use in a large-signal model after de-embedding.

Typical Design Process

The general amplifier design process is to first load-pull the transistor model within a harmonic balance simulator in which the designer must ensure that the transistor does not become unstable in the unmatched environment. If this happens, the source and load-pull will give inaccurate results or simply not converge. These source and load impedances are the foundation for the initial circuit design.

After this, the completed amplifier can be simulated and optimized. Finally, amplifier layout can occur with all required electromagnetic blocks. These designs rest heavily on the accuracy and scalability of their small-signal and large-signal models wherein the measured results should be well-correlated with the model results.

GaN Design Considerations

The following is especially true for GaN HEMTs. The dynamic trapping behaviors impact the accuracy of both small-signal and large-signal models. GaN also has a relatively soft compression characteristic under class (ABCF)B to class (ABCF) operation. This shifts the traditional design methodology in which the typical specifications for compression and linearity (i.e., P_{1dB}, P_{3dB}) are not actually relevant for GaN devices. Instead, GaN HEMTs show better efficiency and linearity to higher compression levels than other semiconductor technologies.

Early compression in driver stages of multi-stage amplifiers needs to be considered and accounted for in sizing of drive ratios, as gain may be reduced earlier in the power drive-up curve. GaN HEMTs also tend to have gain expansion near the pinch-off bias condition. To improve linearity, it may be preferable bias the amplifier near class (ABCF)B, where a sweet spot can be found between expansion and soft compression.

CONCLUSION

GaN HEMT devices are highly sought-after devices in the A&D industry due to their high efficiency, high gain and straightforward matching characteristics. To take full advantage of these devices, however, designers must rely heavily on the accuracy of their device models. With good device models, designers can exploit the full device potential and perform more in-depth, what-if analyses for faster design cycles and greater first-pass design success.

This extends to multi-amplifier design architectures where repeatable performance is relied upon for an accurate statistical analysis with real-world component variations and fabrication tolerances. The merit of these nonlinear models for a GaN design as well as the ones provided with Wolfspeed's packaged designs offer massive gains in modeling flow efficiency. ■

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Monolithic Dual-Band Multi-Mode Phase Shifters Based on All-Pass Networks

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Chongqing University, Chongqing, China

Dual-band multi-mode phase shifter MMICs are based on all-pass networks. The 90- and 180-degree phase shifters operate in low-band, high-band and concurrent dual-band modes. The low and high bands are 4.7 to 5.5 and 24 to 27 GHz, respectively, for 5G applications. A phase compensation scheme eliminates phase errors in multi-mode operation. The 90- and 180-degree dual-band phase shifters are fabricated with a 0.15 μm GaAs PHEMT process and have chip areas of 2.7 and 2.9 mm², respectively, including bond pads. Measurements exhibit very low amplitude imbalance and phase error.

Phased array technology plays an important role in rapidly developing smart wireless systems,[1-3] and phase shifters are key building blocks. Multi-functional wireless facilities also need phased arrays that operate over multiple frequency bands.[4-6] So, it is cost effective to develop phase shifters that operate over multiple frequency bands, instead of using multiple single-band phase shifters.

This article describes the design, optimization, control and measured performance of 90- and 180-degree multi-mode dual-band phase shifters. The proposed designs provide independently controlled phase states in the 4.7 to 5.5 and 24 to 27 GHz bands, which supports the sub-6 GHz and 24.25 to 27.5 GHz (n258) 5G bands.

MULTI-MODE DUAL-BAND DESIGN

Figure 1a shows a two-port, four-element all-pass network.[7] When L/C = Z02, |S21| = 1 and |S11| = |S22| = 0. Both ports are matched at all frequencies. The all-pass network has a transition frequency $\omega_t = 1/\sqrt{LC}$. The component parameters in the network are determined using the equation

$$L = Z_0/\omega_t \qquad (1)$$

$$C = 1/Z_0\omega_t \qquad (2)$$

A switched 1-bit, single-band phase shifter cell can be realized by combining two all-pass networks with two single pole double throw switches, as shown in ***Figure 1b***. The center frequency, and ω_C, and ratio factor, k, are given by

$$\omega_C = \sqrt{\omega_{t1}\omega_{t2}} \qquad (3)$$

$$k = \sqrt{\frac{\omega_{t1}}{\omega_{t2}}} \qquad (4)$$

where ω_{t1} and ω_{t2} are the transition frequencies of the reference and phase shifting paths, respectively. The phase shift of the single-band phase shifter is given by

$$\Delta\varphi(\omega) = 2\left[\arctan\left(\frac{k\omega}{\omega_C} - \frac{\omega_C}{k\omega}\right) - \arctan\left(\frac{\omega}{k\omega_C} - \frac{k\omega_C}{\omega}\right)\right] \qquad (5)$$

$d\Delta\varphi(\omega)/d\omega = 0$ when $\omega = \omega_C$. Therefore, $|\Delta\varphi|$ attains a maximum value at $\omega=\omega_C$, and

$$\Delta\varphi(\omega_C) = 2\left[\arctan\left(k - \frac{1}{k}\right) - \arctan\left(\frac{1}{k} - k\right)\right] \qquad (6)$$

$\Delta\varphi(\omega_C)$ is related only to k according to equation (6). ***Figure 2*** illustrates the phase shift of a switched, 1-bit, single-band phase shifter cell versus normalized frequency and values of k.

A simple multi-mode dual-band phase shifter can be realized by connecting two single-band phase

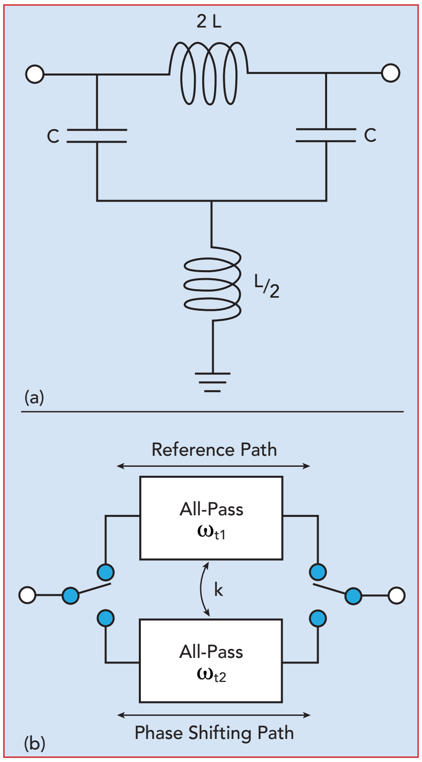

Fig. 1 Four-element all-pass network (a) and switched 1-bit single-band phase shifter cell (b).

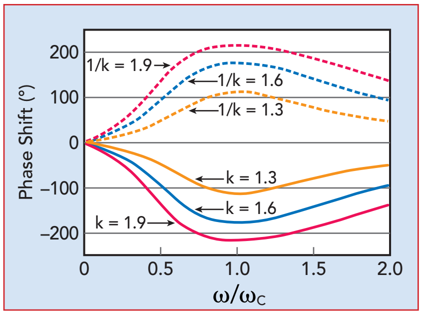

Fig. 2 Phase shift of the switched 1-bit single-band phase shifter cell.

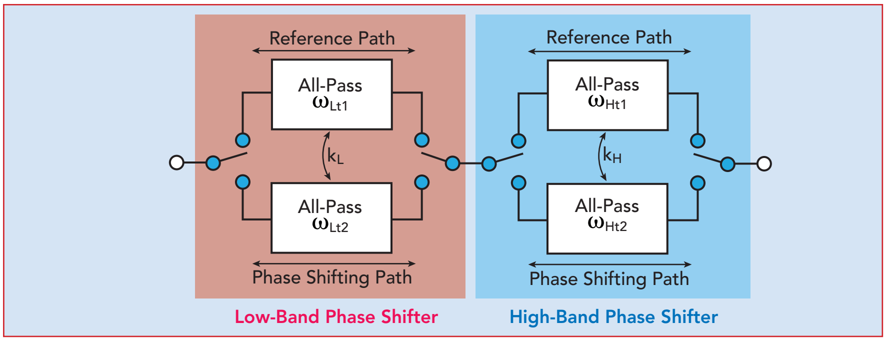

Fig. 3 Multi-mode dual-band phase shifter circuit.

TABLE 1

OPERATING MODES

Low-Band Phase Shifter	Reference Path	Phase Shifting Path	Reference Path	Phase Shifting Path
High-Band Phase Shifter	Reference Path	Reference Path	Phase Shifting Path	Phase Shifting Path
Operating Modes	Reference Mode	Low-Band Mode	High-Band Mode	Dual-Band Mode
Diagram	—	Figure 4a	Figure 4b	Figure 4c

shifter cells in series (see ***Figure 3***). The low-band and high-band center frequencies are given by

$$\omega_L = \sqrt{\omega_{Lt1}\omega_{Lt2}}, \omega_H = \sqrt{\omega_{Ht1}\omega_{Ht2}} \quad (7)$$

respectively ($\omega_H > \omega_L$), where [ω_{Lt1}, ω_{Lt2}] and [ω_{Ht1}, ω_{Ht2}] are transition frequencies of the low-band and high-band phase shifters, respectively. The ratio factors of the low-band and high-band are given by

$$k_L = \sqrt{\frac{\omega_{Lt1}}{\omega_{Lt2}}}, k_H = \sqrt{\frac{\omega_{Ht1}}{\omega_{Ht2}}}, \quad (8)$$

respectively. The relationships between operating modes and selected paths are listed in ***Table 1***.

The phase shift in the dual-band mode can be written as

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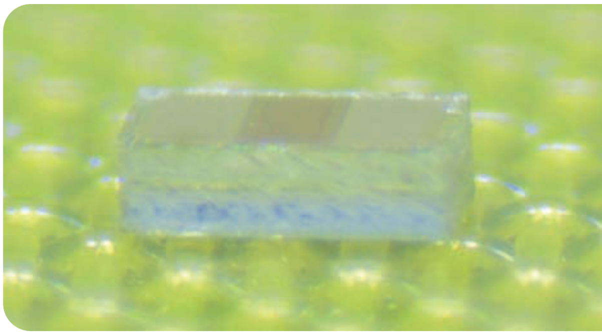

- Low ESR
- High Linearity
- Microsecond Switching Speed
- 0V Capacitance of 0.1pF or more
- 0201 SMT Solderable Form Factor

Applications

- Tunable Phase Shifters
- Tunable Matching Networks
- Tunable Filters
- Beamforming
- Voltage Controlled Oscillators

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$$\Delta\varphi_{DB}(\omega) = 2\left[\arctan\left(\frac{k_L\omega}{\omega_L} - \frac{\omega_L}{k_L\omega}\right) - \arctan\left(\frac{\omega}{k_L\omega_L} - \frac{k_L\omega_L}{\omega}\right) + \arctan\left(\frac{k_H\omega}{\omega_H} - \frac{\omega_H}{k_H\omega}\right) - \arctan\left(\frac{\omega}{k_H\omega_H} - \frac{k_H\omega_H}{\omega}\right)\right] \quad (9)$$

If $\Delta\varphi_{DB}(\omega_L) = \Delta\varphi_{DB}(\omega_H) = \theta_d$, where θ_d denotes the desired phase shift, an accurate phase shift can be obtained in dual-band mode; however, phase errors emerge when the dual-band phase shifter operates in the low-band or high-band modes. Phase errors are caused by the nonzero phase shifts of the low-band phase shifter at $\omega = \omega_H$ and the high-band phase shifter at $\omega = \omega_L$ (see ***Figure 5***). The phase errors of the low-band and high-band modes are given by

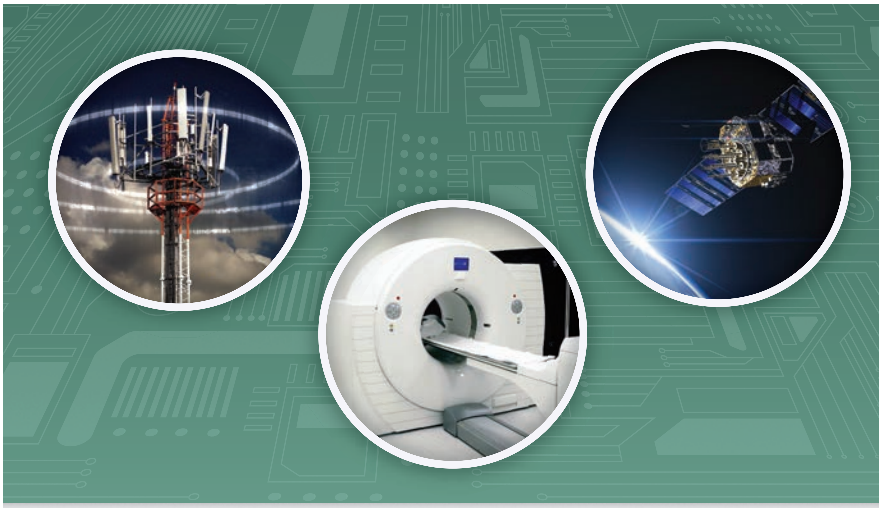
$$\varphi_{err\_L} = 2\left[\arctan\left(\frac{k_H}{p} - \frac{p}{k_H}\right) - \arctan\left(\frac{1}{pk_H} - pk_H\right)\right] \quad (10)$$

$$\varphi_{err\_H} = 2\left[\arctan\left(pk_L - \frac{1}{pk_L}\right) - \arctan\left(\frac{p}{k_L} - \frac{k_L}{p}\right)\right] \quad (11)$$

respectively, where $p = \omega_H/\omega_L$. ***Figure 6*** plots the phase errors versus p and values of k, where $k_L = k_H = k$. As shown, the phase error diminishes with the increasing p or decreasing k.

OPTIMIZATION

A dual-band phase compensation technique eliminates the phase errors. Phase compensation cells are cascaded with the main cells, as shown in ***Figure 7***. To compensate



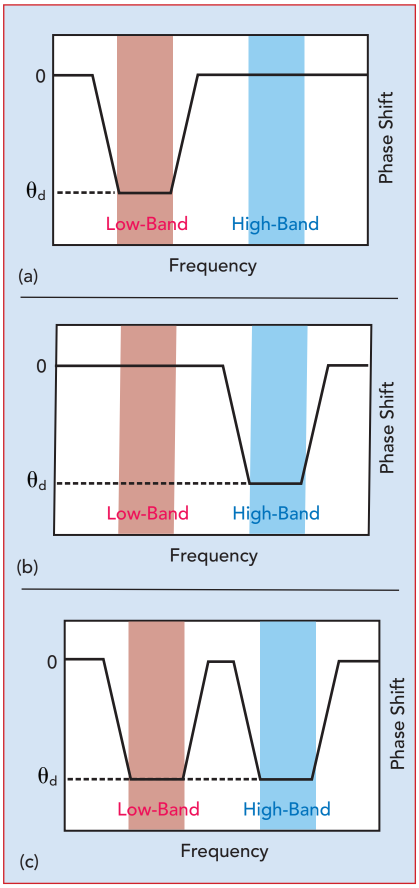


Fig. 4 Dual-band phase shifter operating modes: low-band (a), high-band (b) and dual-band (c).

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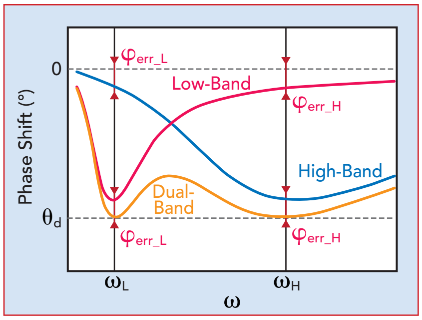

Fig. 5 Phase shift of the simple multi-mode dual-band phase shifter.

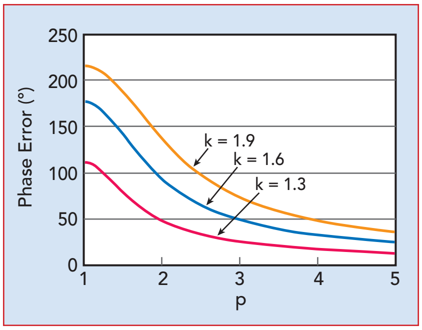

Fig. 6 Multi-mode phase shifter phase error.

for phase errors, the phase compensation cells use the same topology as the main cell but with ratio factors k_{CL} and $k_{CH} < 1$.

Considering the low-band mode, the center frequency of the low-band compensation cell is set as $\omega_{CL} = \omega_H$. The phase shift of the low-band phase shifter is

$$\Delta\varphi_{LB}(\omega) = 2\left[\arctan\left(\frac{k_L\omega}{\omega_L} - \frac{\omega_L}{k_L\omega}\right) - \arctan\left(\frac{\omega}{k_L\omega_L} - \frac{k_L\omega_L}{\omega}\right) + \arctan\left(\frac{k_{CL}\omega}{\omega_H} - \frac{\omega_H}{k_{CL}\omega}\right) - \arctan\left(\frac{\omega}{k_L\omega_H} - \frac{k_{CL}\omega_H}{\omega}\right)\right] \quad (12)$$

To cancel the phase errors at $\omega = \omega_L$ and $\omega = \omega_H$, consider the following equations:

$$\Delta\varphi_{LB}(\omega_L) = \theta_d \quad (13)$$

$$\Delta\varphi_{LB}(\omega_H) = 0 \quad (14)$$

When θ_d, ω_L and ω_H are chosen, the design parameters k_L and k_{CL} can be obtained by solving equations (13) and (14). The design of the high-band phase shifter follows the same process as the low-band phase shifter design. Ideally, $k_H = k_L$ and $k_{CH} = k_{CL}$ if identical phase shifts are desired for low-band and high-band.

Figure 8 plots the simulated phase shifts of the low-band and high-band phase shifters, respectively, with θ_d = 180 degrees, f_L = 5 GHz and f_H = 25 GHz. As shown in Figure 8a, the low-band phase shifter achieves exactly 180 degrees phase shift at f_L = 5 GHz and 0 degree phase shift at f_H = 25 GHz. Similarly, phase errors of the high-band phase shifter are cancelled with the use of the compensation cell, as shown in Figure 8b. Accurate phase shifts are obtained whether the low-band and high-band phase shifters operate individually or concurrently.

CIRCUIT IMPLEMENTATION

Figure 9 shows the multi-mode dual-band phase shifter schematic. For each phase shifter cell, the ref-

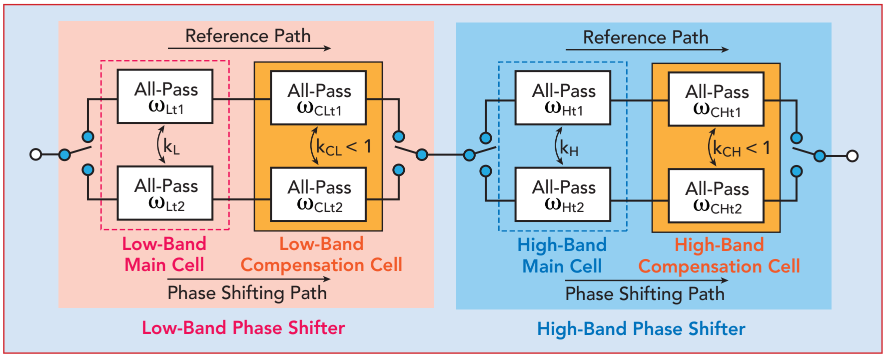

Fig. 7 Prototype multi-mode dual-band phase shifter circuit.

erence path and phase shifting path are combined into one all-pass network with inserted switches. The low-band and high-band phase shifters are controlled with 2-bit logic voltages, V_L and V_H. When V_L = 1, S_{L1}, S_{L4}, S_{CL2}, S_{CL3} are on and S_{L2}, S_{L3}, S_{CL1}, S_{CL4} are off, the low-band phase shifter operates in the reference state. When V_L = 0, S_{L1}, S_{L4}, S_{CL2}, S_{CL3} are off and S_{L2}, S_{L3}, S_{CL1}, S_{CL4} are on, the low-band phase shifter is in the phase shifting state. Similarly, when V_H = 1, the high-band phase shifter operates in the reference state, and when V_H = 0, the high-band phase shifter operates in the phase shifting state.

The values of the components in the dual-band phase shifter are listed in ***Table 2***. Phase shifts at f_L and f_H can be designed to be slightly greater than θ_d to acquire moderate bandwidth. The 90- and 180-degree dual-band phase shifters were designed and fabricated using a commercial 0.15 μm GaAs PHEMT process. As the PHEMT switches have parasitic on resistance and off capacitance, the component values were optimized to compensate for these parasitics. Both phase shifters were designed to provide independently controlled phase shift in the 4.7 to 5.5 and 24 to 27 GHz frequency bands. To verify the phase compensation

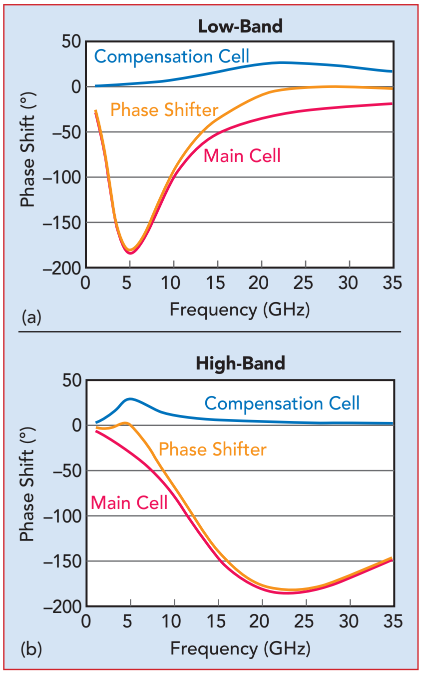

Fig. 8 Simulated phase shift of the low-band (a) and high-band (b) phase shifter with $k_L = k_H = 1.64$ and $k_{CL} = k_{CH} = 0.94$.


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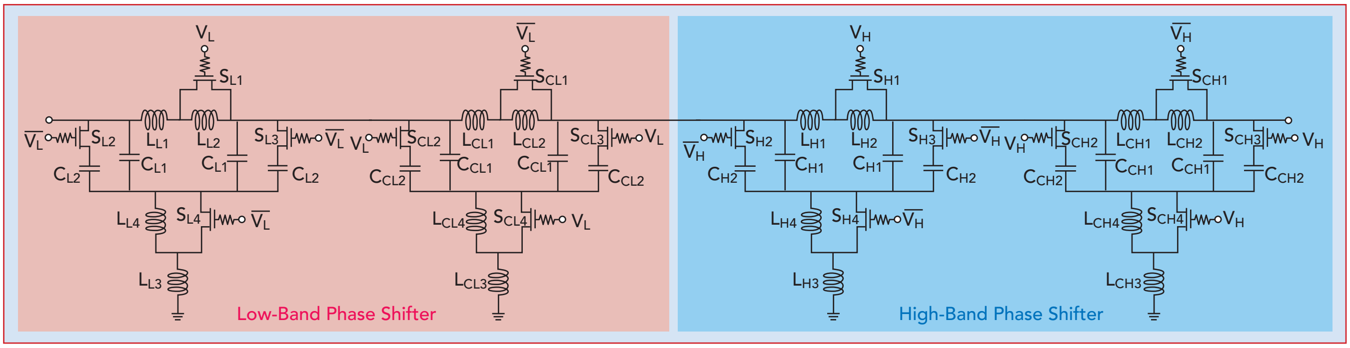


Fig. 9 Multi-mode dual-band phase shifter schematic.

TABLE 2
COMPONENT CALCULATIONS

	Main Cells	Compensation Cells
Low-Band	$L_{L1}=\frac{2Z_0}{\omega_L k_L}, L_{L2}=\frac{2(k_L^2-1)Z_0}{\omega_L k_L}, L_{L3}=L_{L1}/4, L_{L4}=L_{L2}/4$ $C_{L1}=\frac{1}{Z_0\omega_L k_L}, C_{L2}=\frac{k_L^2-1}{Z_0\omega_L k_L}$	$L_{CL1}=\frac{2k_{CL}Z_0}{\omega_H}, L_{CL2}=\frac{2(1-k_{CL}^2)Z_0}{\omega_H k_{CL}}, L_{CL3}=L_{CL1}/4, L_{CL4}=L_{CL2}/4$ $C_{CL1}=\frac{k_{CL}}{Z_0\omega_H}, C_{CL2}=\frac{1-k_{CL}^2}{Z_0\omega_H k_{CL}}$
High-Band	$L_{H1}=\frac{2Z_0}{\omega_H k_H}, L_{H2}=\frac{2(k_H^2-1)Z_0}{\omega_H k_H}, L_{H3}=L_{H1}/4, L_{H4}=L_{H2}/4$ $C_{H1}=\frac{1}{Z_0\omega_H k_H}, C_{H2}=\frac{k_H^2-1}{Z_0\omega_H k_H}$	$L_{CH1}=\frac{2k_{CH}Z_0}{\omega_L}, L_{CH2}=\frac{2(1-k_{CH}^2)Z_0}{\omega_L k_{CH}}, L_{CH3}=L_{CH1}/4, L_{CH4}=L_{CH2}/4$ $C_{CH1}=\frac{k_{CH}}{Z_0\omega_L}, C_{CH2}=\frac{1-k_{CH}^2}{Z_0\omega_L k_{CH}}$

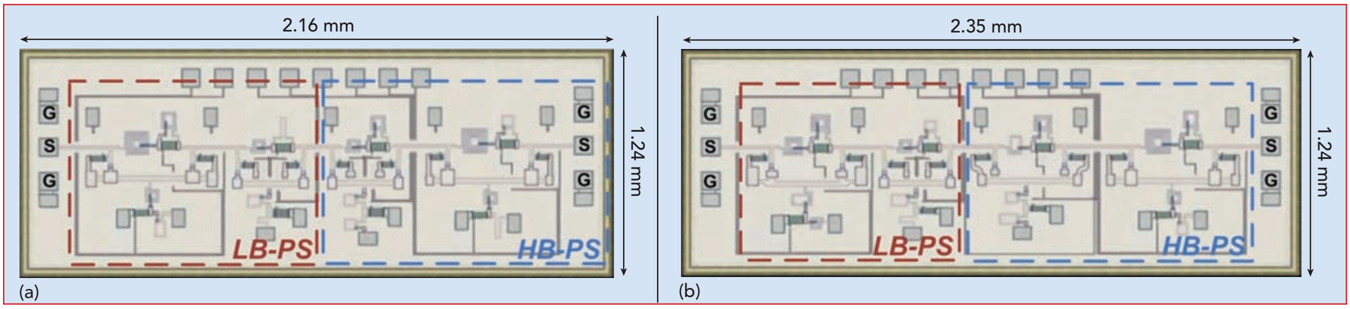


Fig. 10 Chip layouts: 90- (a) and 180- (b) degree dual-band phase shifters.

technique, the compensation cells were designed to be independently controlled. The 90- and 180-degree dual-band phase shifter designs covered MMIC areas of 2.16 × 1.24 mm (2.7 mm^2) and 2.35 × 1.24 mm (2.9 mm^2), respectively, including bond pads (see ***Figure 10***).

MEASURED RESULTS

The MMICs were measured on-chip using a Cascade Summit 12000M microwave probe testing station and a Keysight N5247A PNA-X network analyzer. ***Figure 11*** shows the measured response and amplitude imbalance of the 90-degree dual-band phase shifter in the reference, low-band, high-band and dual-band modes. The insertion loss in the reference mode was less than 1.7 dB and was less than 2.5 dB in the low-band and high-band modes, respectively. $|S_{11}|$ was better than 13 dB in either band. Amplitude imbalances were less than 0.15 and 0.24 dB in the low-band and high-band modes, respectively.

Figure 12 shows the phase shift and phase error of the 90-degree dual-band phase shifter with (solid line) and without (dashed line) the compensation cells. With compensation, the phase errors are less than 2.2 and 2.6 degrees in the low-band and high-band modes, respectively. Without compensation, the phase errors increase to 12.9 and 14.3 degrees in the low-band and high-band modes, respectively.

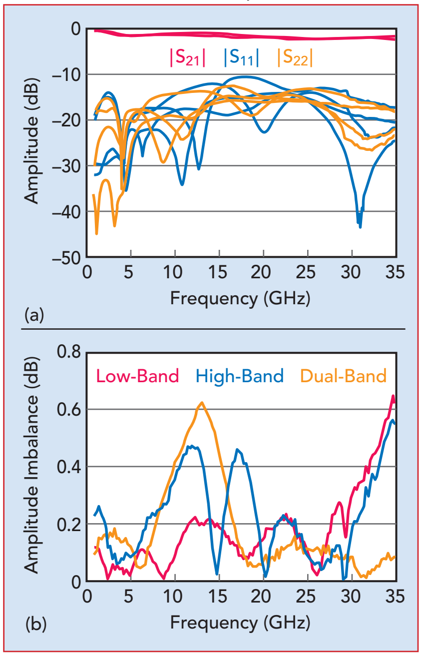
Figure 13 shows the measured response and amplitude imbalance of the 180-degree dual-band phase shifter in the reference, low-band, high-band and dual-band modes. As

shown in Figure 13a, measured insertion losses in the reference mode were less than 2.6 dB and 3.4 dB in low-band and high-band modes, respectively. The return loss was better than 12 dB in either band. Amplitude imbalances were less than 0.36 and 0.25 dB in the low-band and high-band modes, respectively.

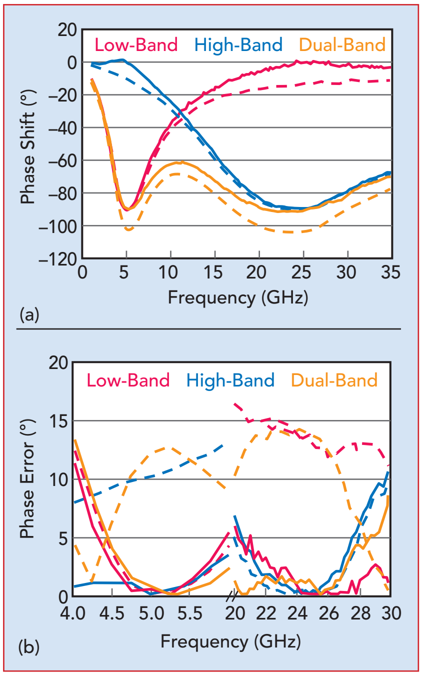
Figure 14 shows the phase shift and phase errors of the 180-degree dual-band phase shifter with (solid line) and without (dashed line) the compensation cells. With compensation, the phase errors were less than 4.1 and 4.5 degrees in the low-band and high-band modes, respectively. Without the compensation cells, the phase errors increase to 30.8 and 38.2 degrees in the low-band and high-band modes, respectively.

CONCLUSION

Using a commercial 0.15 µm GaAs PHEMT process, 90- and 180-degree dual-band multi-mode phase shifters were designed and fabricated. The phase shifters operate in the 4.7 to 5.5 GHz (low-band), 24 to 27 GHz (high-band) and both bands concurrently (dual-band). A phase compensation scheme eliminates the phase errors in multi-mode operation. Measurements confirmed low amplitude imbal-



▲ Fig. 11 90-degree dual-band phase shifter measured performance (a) and calculated amplitude imbalance (b).



▲ Fig. 12 Measured phase shift (a) and calculated phase error (b) of the 90-degree dual-band phase shifter with (solid line) and without (dashed line) compensation cells.

ance and phase error. The prototype phase shifters, which support the sub-6 GHz and n258 bands, are good candidates for 5G systems. ■

ACKNOWLEDGMENTS

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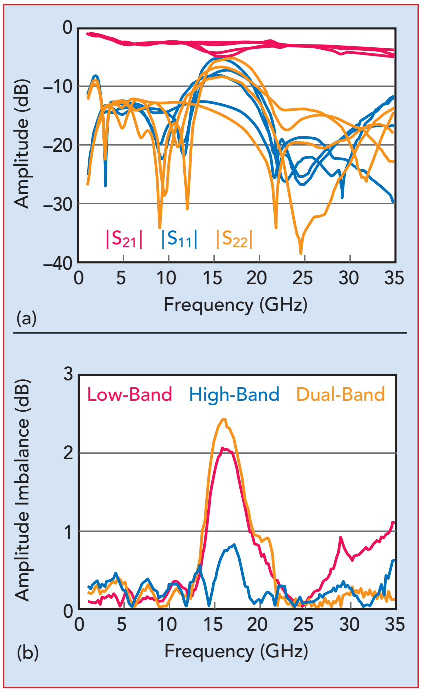

Fig. 13 180-degree dual-band phase shifter measured performance (a) and calculated amplitude imbalance (b).

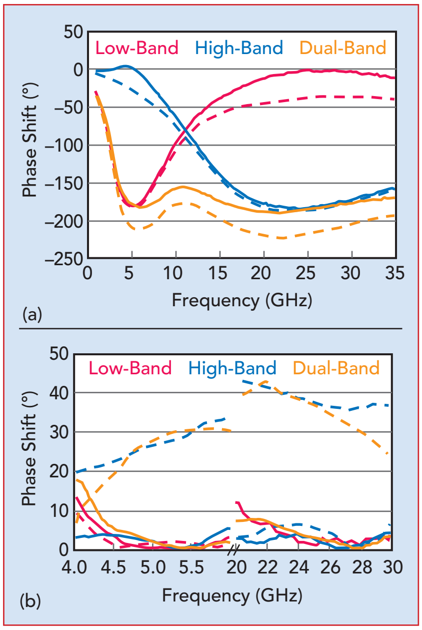

Fig. 14 Measured phase shift (a) and calculated phase error (b) of the 180-degree dual-band phase shifter with (solid line) and without (dashed line) compensation cells.

INVITED PAPER

Measuring Immissions of 5G Base Stations with Beamforming

Holger Schwarz
Narda STS, Pfullingen, Germany
Thomas Jungmann
Texterei Jungmann, Wangen, Germany

5G is the wireless communications standard for the next decade. With frequencies to 88 GHz and peak transfer rates of 10 Gbps, 5G has attracted significant investment across the supply chain, from the semiconductor suppliers through the mobile operators to application developers. From the measurement viewpoint, measuring the RF performance of the 5G base station to the 3GPP standards has largely been addressed except for assessing compliance with the electromagnetic field (EMF) immissions standards for base stations using beamforming. This article addresses the challenges posed by beamforming antennas.

To ensure public safety, Germany and most other countries require an EMF immission evaluation of cellular base stations, beginning when new transmitting equipment is submitted to regulatory agencies for approval. The aim is to determine the worst case (i.e., greatest) field strength people can be exposed to. If this is below the health and safety limits, the equipment can be approved and assumed to operate safely in all situations. Theoretically, to assess immissions, the system operator would run the base station and antennas at full power for the duration of the EMF measurement. Practically, this presents a problem outside of a lab or testing environment. The network operator would have to isolate the system from live operation and test it by itself, offline and at full power. This is not something a government authority could demand from an operator and would be contrary to an independent, unannounced external check of the immissions of a system. If the operator is unaware the system is being measured, the values will be trustworthy and no one can reasonably claim the equipment was manipulated to obtain an acceptable result.

MEASURING IMMISSIONS

To assess the immissions of an installation, the regulations (e.g., BImSchV in Germany) stipulate that the electric and magnetic field strength at the maximum operational load (i.e., power) are to be determined. In the event the maximum cannot be set during the measurement, a suitable extrapolation to the maximum is allowed.

The measurement is where "the wheat and the chaff are separated." First, the signaling, which is always transmitted at a constant power level, must be separated from the data traffic (see ***Figure 1***). The signaling signal is used by a cellphone to synchronize to the network, and it provides the measurement with a reference level for extrapolation. However, the maximum possible immission from the base station is radiated by the traffic, not the signaling. So when measuring immissions, the test instrument must be able to separate the signaling from the composite signal.

How this is done has evolved over the generations of cellular technology (see ***Table 1***). With GSM, it was possible to separate the signaling channels by frequency. For the extrapolation, a technician tuned

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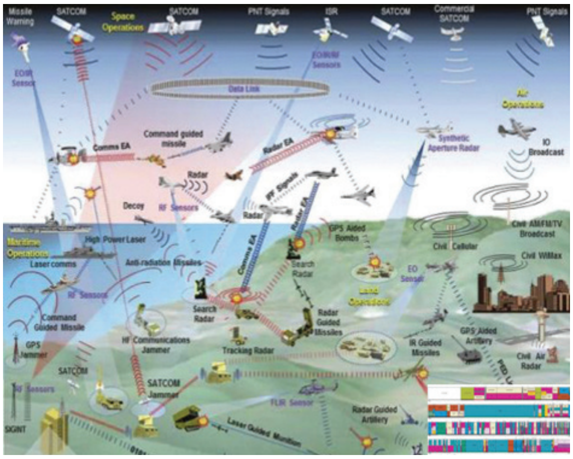

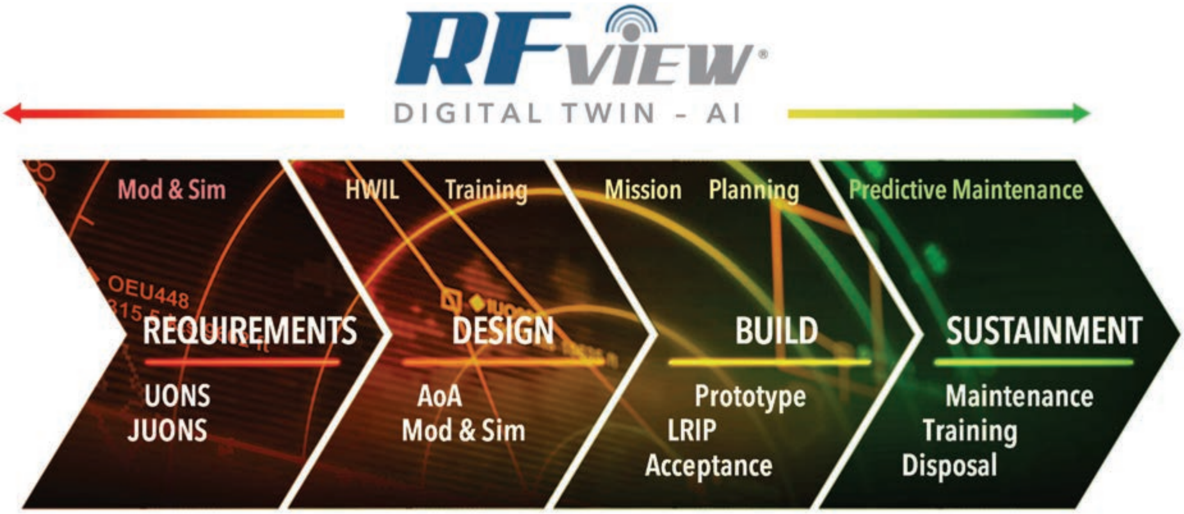

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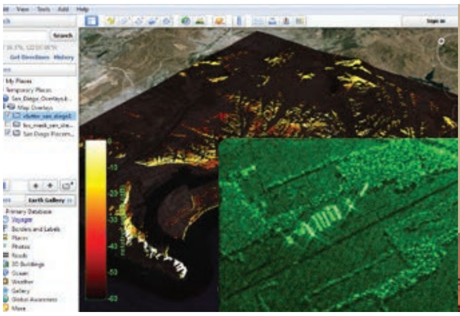

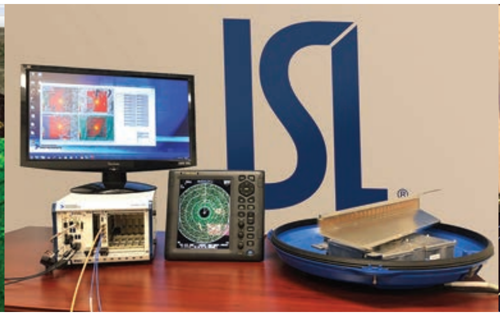

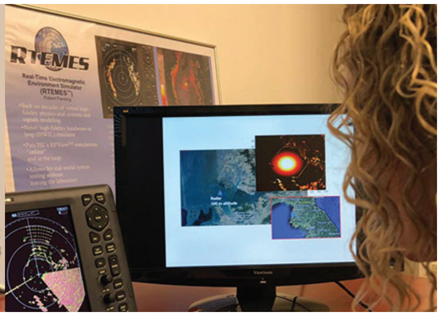

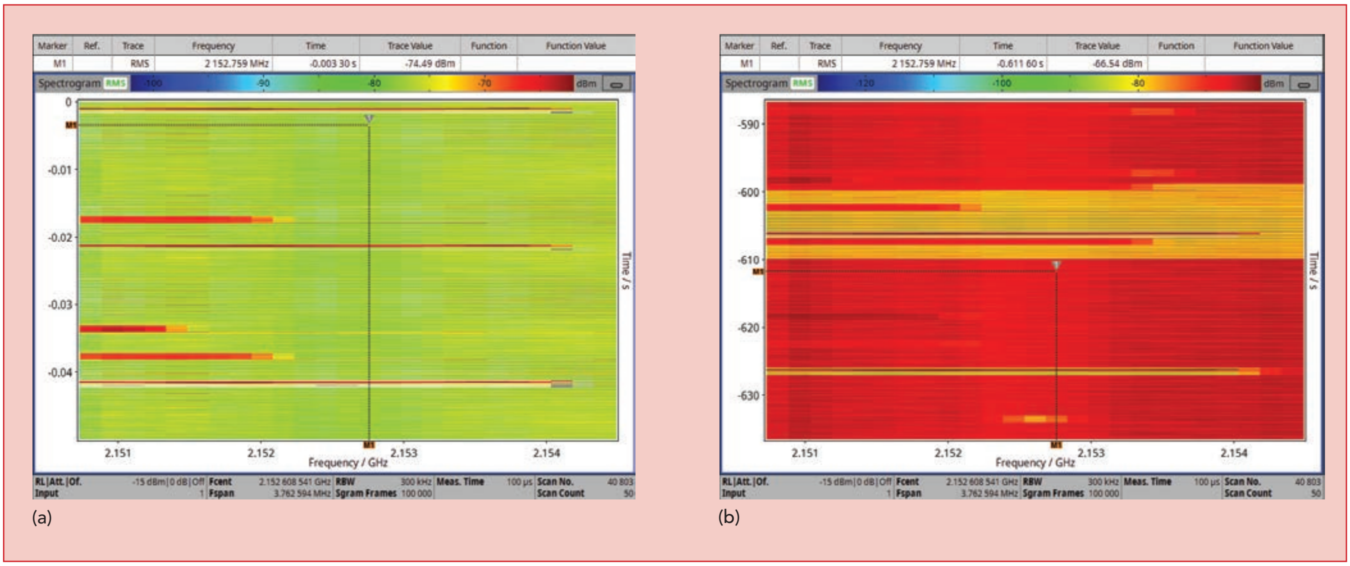

Fig. 1 Spectrograms of 5G transmissions: signaling (a) and signaling with traffic (b).

the measuring instrument to record the frequencies that contained only the signaling signal. With the next generation, UMTS, and the adoption of code division multiple access (CDMA), it was not possible to separate the signaling and traffic by frequency; the old frequency selective test equipment could not distinguish between the signal types. With coding, the signal transports information uniquely assigned to a specific radio cell. Code-selective measurements replaced frequency selective measurements for determining EMF immissions, requiring the testers to decode the coding.

Code-selective measurement methods are now indispensable. Only with this method can testing distinguish between the immissions from two different base stations operated by the same service provider or the individual sectors of a base station, since each sector has a unique code called the physical cell ID.

TABLE 1

EVOLUTION OF WIRELESS NETWORKS

	2G (GSM)	3G (UMTS)	4G (LTE)	5G NR
RF Frequency Range (GHz)	< 3	< 6	< 6	< 6 and > 24
RF Bandwidth Per Carrier	200 kHz	5 MHz	up to 20 MHz	< 6 GHz: up to 100 MHz > 24 GHz: up to 400 MHz
Downlink Data Rate	9.6 kbps	384 kbps	150 Mbps	10 Gbps
Latency (ms)		~100	~30	~1

Narda STS has a heritage developing EMF test and measurement equipment to assess compliance with the standards for safety, environmental and personal protection, and the Narda STS SRM-3006 is one such instrument (see ***Figure 2***). It displays the EMF strength as a percentage of the regulatory limits or standards and covers all the cellular bands, including the new 5G bands in frequency ranges 1 (FR1) and, using two new 5G downconverter antennas, also 2 (FR2).

BEAMFORMING COMPLEXITY

The development and adoption of MIMO and massive MIMO (mMIMO) antenna systems has complicated immissions testing because a beamforming antenna has different antenna patterns and gains for traffic and signaling. mMIMO provides spatial multiplexing and concentrates the transmitter's power into one or more beams that increase the overall data throughput and system efficiency (see ***Figure 3***). Initial 5G deploy-

Fig. 2 The Narda SRM-3006 for frequency and code selective immission measurements of cellular signals.

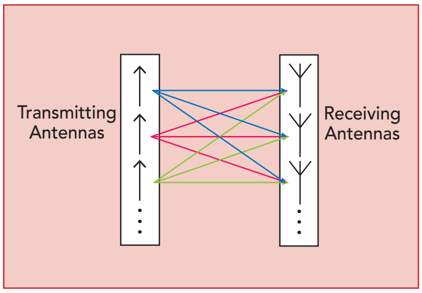

Fig. 3 By increasing the number of transmit and receive antennas, MIMO and mMIMO increase the sector throughput and capacity density of a base station.

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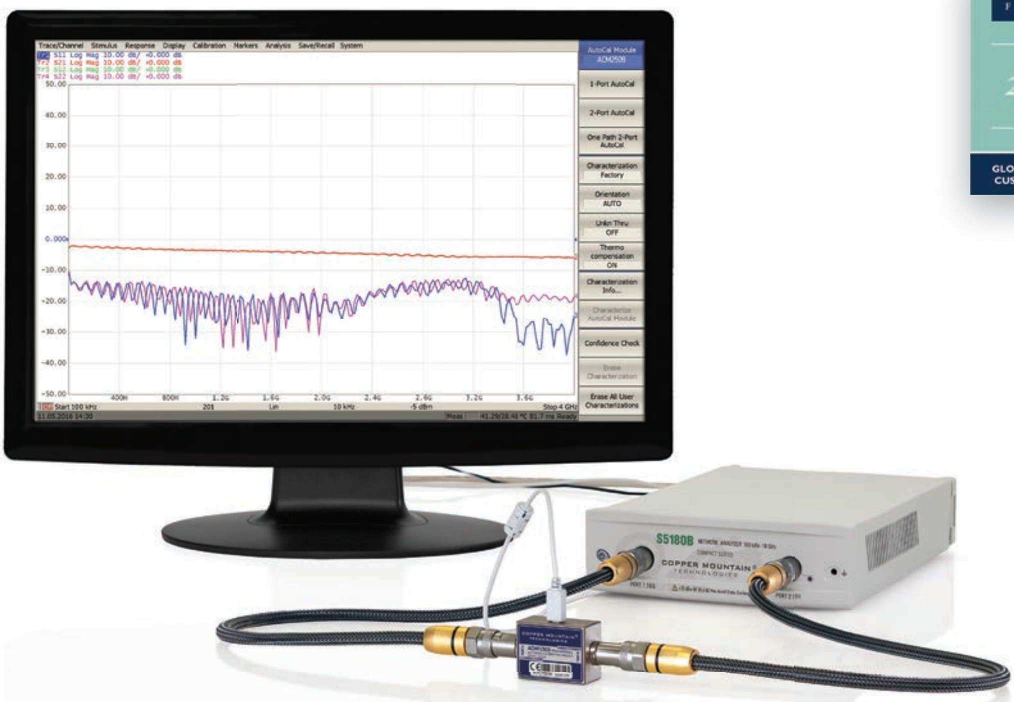

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ments seem to have standardized around 32 or 64 active antenna elements, although that number can potentially grow to between 128 and 1024 antenna elements.

mMIMO directs the output power of the base station to individual cellphones using multi-user beamforming (MUBF), i.e., forming or shaping the antenna pattern by managing the phase differences among the signals applied to the antenna elements. mMIMO uses beam steering to point the antenna beams to focus on a user or group of users. Beamforming and beam steering increase the link range and reduce interference between radio cells, optimizing the radio coverage for smaller areas of a sector. Focusing the transmitted power on the users also increases the efficiency of the base station.

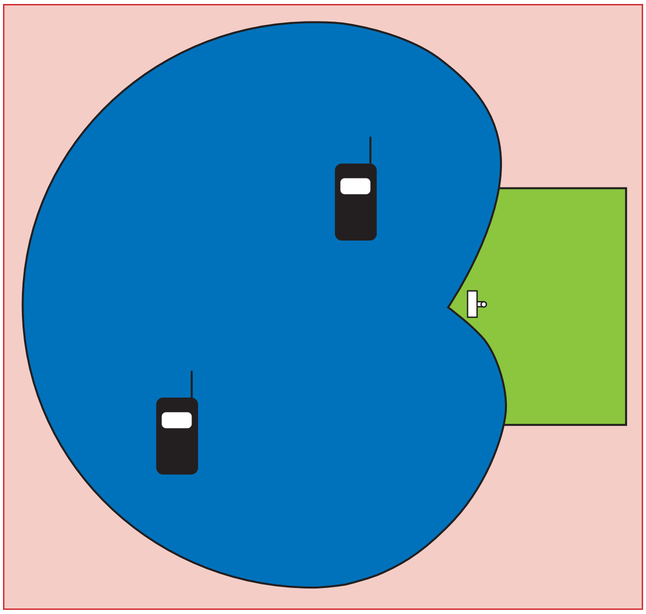

Fig. 4 Typical sector coverage for a base station sector without beamforming.

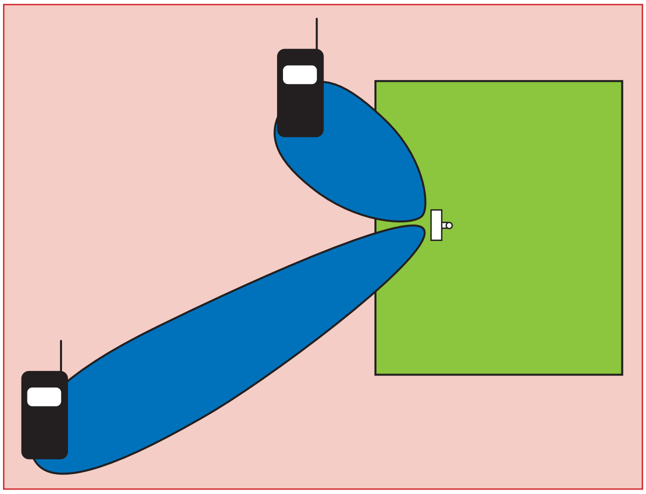

Fig. 5 Notional sector coverage with beamforming.

With beamforming, the antenna no longer covers a 120-degree sector with a single wide beam (see ***Figure 4***). The base station focuses a beam or several beams on the users (see ***Figure 5***). To determine the optimum direction for a user, the base station will transmit the signaling beam in several directions, such as seven horizontal directions 17 degrees apart (i.e., 120/7). As the base station steps through the signaling beams, a receiving cellphone measures the strength of each signal and tells the base station which beam has the best quality. The base station uses this as the best direction for the user until the user moves or the propagation changes.

Beamforming is typically used at the upper frequency cellular bands, i.e., above 2.5 GHz. The lower bands—700, 800 and 900 MHz—are largely used in rural areas because of the lower population density and superior propagation, yielding a longer range between towers. Data throughput is not likely to reach network capacity. Areas with high population density, such as inner cities or exhibition centers, demand higher capacity and data rates. In such cases, base stations tend to use higher frequency bands, where the bandwidth and data capacity are greater. Although the coverage range is less, the cumulative result is more data capacity in the network, which can be further increased with mMIMO.

Implementing beamforming antennas is more practical at the higher bands, where the half-wavelength spacing between the antenna elements results in compact antennas—80 × 80 or 90 × 90 cm—that can be mounted on a rooftop or tower by one or two people. In comparison, a 900 MHz beamforming antenna would be some 3 m^2, too large for most installations.

BEAMFORMING ANTENNA IMMISSIONS

Determining the immissions of a 5G base station without beamforming requires measuring the signaling signal and extrapolating the result to the entire bandwidth. With beamforming, the method requires an additional beamforming factor, derived from the difference between the antenna patterns for the signaling and traffic signals at the measurement location. The two antenna patterns are provided by the operator, and the difference at the measurement location is used with the signaling measurement to determine the maximum traffic immission value, i.e., the maximum possible immission of the base station.

Even with beamforming, the signaling from the base station is radiated using a broadcast beam, which has a wider beamwidth than the traffic signals responsible for the immission. The broadcast beam is measured, and the result is extrapolated using the beamforming factor to give the field strength if the traffic were solely directed to the measurement point. For time-division duplexing networks, the uplink/downlink configuration is another factor that must be included in the extrapolation.

One of the measurement challenges is knowing the location of the measurement point with respect to the direction of the base station being measured. This is often determined the “old-fashioned way,” using a map with a compass, rangefinder and protractor to determine the distance, direction, azimuth and elevation of the measurement point relative to the antenna. The test technician uses this location to determine the antenna gains for the broadcast and traffic beams, which is provided by the operator. The gain difference is part of the immission calculation.

Another challenge unique to beamforming antennas is knowing whether the beam is focusing on the measurement point when the measurement is made, as reliable information about beam pointing is unavailable. Techniques are needed that can extrapolate to the maximum system state from the signaling and address the uncertainty of a moving, narrow lobe. A simple solution would be forcing the beam to point at the measurement location. This could be done using a special handset that requests a massive data download, triggering the transmitter to direct a full power beam toward the handset. The maximum field strength could then be measured. However, this method only works if the measuring device is the only receiver in the cell. With another active user geographically separated, as shown in Figure 5, a second beam will be formed that will reduce the power from the measurement point and lead to an incorrect immission measurement. This simple method is not suitable for a cell operating normally and is not appropriate if the measurement is to be independent and unannounced, which is usually the intention.

SUMMARY

Measuring immissions for 5G NR is not very different from the approach used with earlier cellular generations, i.e., GSM, UMTS and LTE. Measuring instantaneous EMF immissions of a base station is comparatively simple. It becomes challenging when the immission evaluation is to be based on the maximum system state, as required in Germany, for example. Then it is necessary to extrapolate the actual measured field strengths to the maximum possible value, which can only be accomplished by using code-selective measurements. These were developed with the transition from GSM to UMTS and apply directly to 5G NR base stations that do not use beamforming. For 5G systems that use MIMO or mMIMO, typically in the bands above 2.5 GHz, the measurement must account for the added gain of the steered beams. The test approaches and standards for such beamforming immissions measurements are being finalized by the regulatory bodies in several countries. ■

Signal Source Frequency Extender Provides 220 to 330 GHz Coverage

Eravant
Torrance, Calif.

Accurate and reliable signal sources are essential for research and development work at mmWave frequencies. Approaching THz frequencies, the available options for signal generation are limited but, thankfully, growing. The newest offering from Eravant is the model STE-KF1803 frequency extender, which combines Eravant's high power amplifier expertise with multiplier diode technology from ACST GmbH. This ×18 multiplying source extender accepts input signals from 12.2 to 18.3 GHz and delivers full-band frequency coverage from 220 to 330 GHz with a nominal output power of +5 dBm (see ***Figure 1***).

In many applications, power levels greater than 0 dBm are required to provide adequate signal amplitude for driving the mixers and modulators used in radar, communication, instrumentation and remote sensing systems. When testing passive components such as filters, couplers and isolators, higher signal levels provide greater measurement dynamic range.

Used with a low frequency programmable signal generator or sweeper, Eravant's frequency extender preserves the inherent switching speed, frequency accuracy and amplitude stability of the frequency source. With its combination of full-band frequency coverage and ample output power, the STE-KF1803 is a versatile addition to the lab for research and development at sub-THz frequencies. Designed for benchtop use, the unit measures 4.9 × 5.0 × 1.9 in.

The nominal input power level is +3 dBm, provided through a 2.92 mm female coaxial connector. The output uses a WR03 anticocking waveguide flange, with the output level adjustable over a 25 dB range using an integrated manual attenuator. Harmonic content in the output is -15 dBc or lower, and typical spurious signals are -60 dBc or below. The input return loss is 10 dB or better.

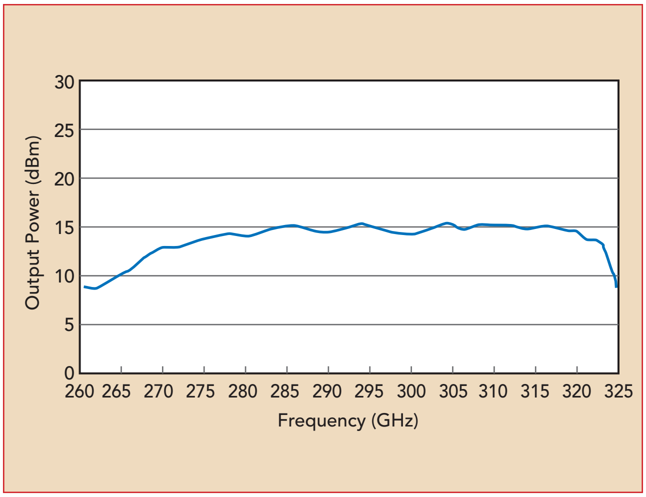

Fig. 1 STE-KF1603-14-S1 typical output power.

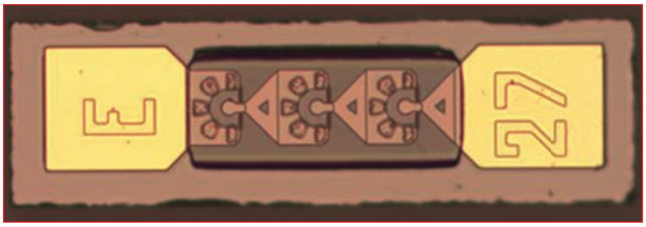

Fig. 2 Three element varactor multiplier diode from ACST GmbH.

WHY FREQUENCY MULTIPLICATION

Several approaches can be used to extend the frequency range of a tunable RF signal source. Up-conversion using a mixer and fixed frequency or tunable local oscillator (LO) may seem like a reasonable approach for covering a narrow range of frequencies; however, this technique has disadvantages. To preserve the frequency accuracy and phase noise characteristics of the low frequency source, the frequency and phase noise of the LO must be low, which typically requires a phase-locked or synthesized LO. Up-conversion may require an LO frequency relatively close to the desired RF output. A sub-harmonically pumped up-converter can be used, although it may not yield sufficient RF output power. Another challenge for up-converting to sub-THz frequencies is suppressing unwanted LO, sideband and spurious signals.

Compared with up-conversion, frequency multiplication with amplification is the preferred approach for generating tunable test signals at mmWave and THz frequencies. However, the frequency of the phase noise sidebands of the low frequency source will be expanded in proportion to the extender's multiplication factor. For an ideal noiseless multiplier, the phase noise power density at a given offset from the carrier, relative to the carrier amplitude, is increased by 20log(N), where N is the multiplication factor. The STE-KF1803 frequency extender employs a cascade of multiplier stages and matching circuits, filters and amplifiers to achieve a net multiplication factor of 18.

ACST DIODE MULTIPLIER

At mmWave frequencies, varactor diodes are often

TABLE 1

STE SERIES FREQUENCY EXTENDERS (PARTIAL LIST)

Model Number	Output Frequency (GHz)	Output Power (dBm)	Multi-plication Factor	Input Frequency (GHz)
STE-SF419-04-S1	40 to 60	+4	4	10 to 15
STE-SF415-15-S1	50 to 75	+15	4	12.5 to 18.8
STE-KF412-15-S1	60 to 90	+15	4	15 to 22.5
STE-SF610-15-S1	75 to 110	+15	6	12.5 to 18.3
STE-KF808-00-S1	90 to 140	0	8	11.25 to 17.5
STE-KF1206-00-S1	110 to 170	0	12	9.2 to 14.2
STE-SF1205-00-S1	170 to 220	-3	12	14.2 to 18.3
STE-KF1603-14-S1	260 to 320	+14	16	16.25 to 20

used for frequency doublers and triplers as they provide nonlinear impedance characteristics that yield good multiplication efficiency and low RF loss. The final multiplication stage in the STE-KF1803 extender uses a pair of Schottky varactor multiplier diodes fabricated using a film diode process developed by ACST GmbH (see ***Figure 2***). ACST GmbH's device capabilities include square-law detectors up to 2.5 THz, resonant tunneling diode oscillators up to 1.1 THz and frequency multipliers up to 600 GHz.

The diodes are fabricated with a planar process on thinned, semi-insulating GaAs substrates, with metal-insulator-metal capacitors and conductors monolithically integrated with the diodes to form an efficient multiplier circuit. The diode terminals and conductor traces are formed on both sides of a 5 µm membrane substrate, resulting in low parasitics and RF loss, with air bridge interconnected mesas reducing the parasitic capacitance. A diamond substrate transfers heat so the diodes can operate at higher power levels with greater conversion efficiency. The size of a typical three-element varactor multiplier diode is 60 × 240 µm.

FREQUENCY EXTENDER FAMILY

The STE-KF1803 frequency extender from Eravant complements the other members of the STE series (see ***Table 1***). The extender family provides frequency coverage from 40 to 330 GHz with output power to +20 dBm, using multiplication factors from 2 to 18. Over 30 standard models are available, and custom configurations are possible.

VENDORVIEW

Eravant
Torrance, Calif.
www.eravant.com

Measurement Receiver Simplifies Signal Generator and Attenuator Calibration

Rohde & Schwarz
Munich, Germany

The R&S FSMR3000 microwave measurement receiver calibrates signal generators and attenuators with a single instrument designed to reduce calibration complexity. It provides features including level and tuned RF level (TRFL) measurements, analog modulation and spectrum analysis. Hardware can be added for high performance phase noise testing, meaning better than the standard phase noise measurements achieved using a spectrum analyzer. With 80 MHz analysis bandwidth, the R&S FSMR3000 handles both digital and analog modulation analysis, as well as pulsed and VOR/ILS signals.

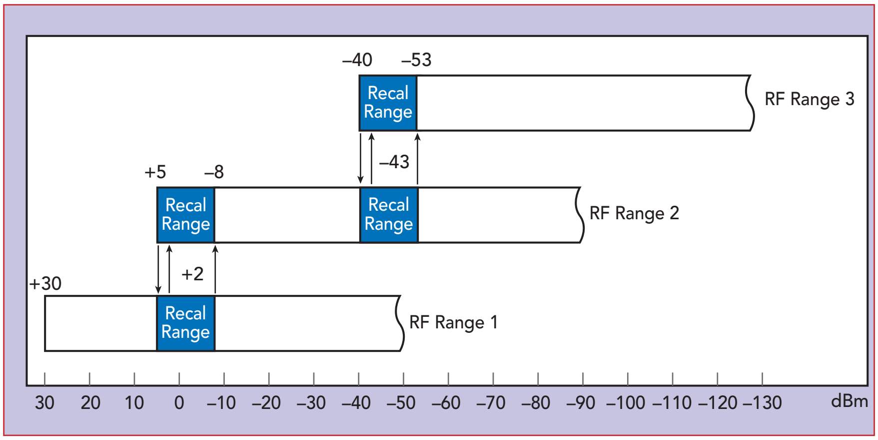

Fig. 1 **Adjacent range calibration for a TRFL measurement.**

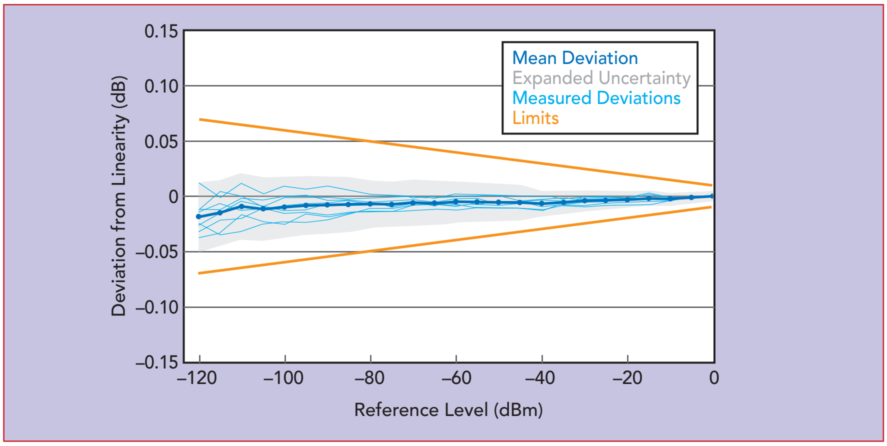

Fig. 2 **Deviation from linearity performance of the R&S FSMR3000.**

TRFL CALIBRATION AND POWER MEASUREMENT

The main application for the FSMR3000 receiver is measuring the power of a signal generator precisely and simply. The absolute power and reference power are measured with high accuracy using a power sensor connected to the R&S FSMR3000. The sensor's input is either connected directly to the output of the generator being tested or by placing a power splitter in parallel with the input of the


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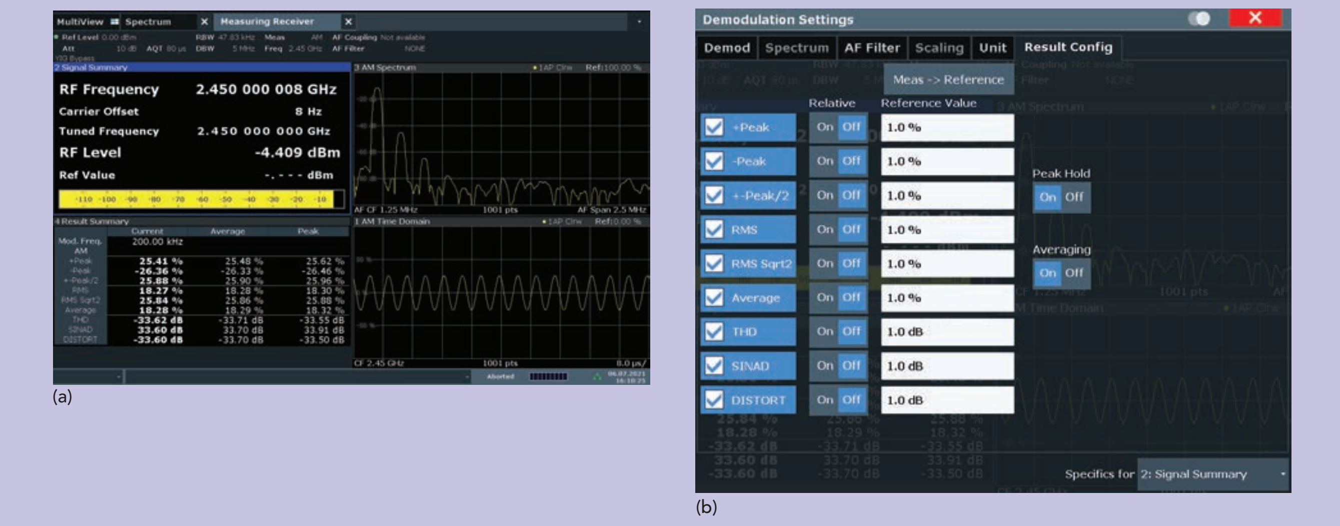

▲ **Fig. 3** **Analysis of an AM signal (a). The user can select which parameters to show in the results (b).**

R&S FSMR3000. The measuring receiver corrects the power splitter's frequency response and insertion loss. Power sensors are available with an integrated power splitter, like the R&S NRP-Z27/-Z37 power sensor modules, which also have automatic VSWR correction, increasing calibration accuracy.

The power sensor cannot measure conventional RF generators over their full range, e.g., from -150 to +20 dBm; this requires a TRFL measurement. To optimize the signal-to-noise ratio for the power level measurement, the input attenuation, preamplifier and IF gain of the R&S FSMR3000 must be switched between ranges, using adjacent range calibration to eliminate potential level errors from parameter changes (see ***Figure 1***). With this approach, the FSMR3000 achieves a high linearity of ±(0.009 dB + 0.005 per 10 dB range) across the entire power range.

Calibrating for this wide dynamic range requires only a few steps, beginning with a reference measurement with the power meter. The level of the device to be calibrated is then reduced by the desired steps and verified. If the test signal is outside the usable measurement range, the input attenuation, IF gain or preamplifier setting of the R&S FSMR3000 are adjusted. The RECAL key initiates the adjacent range calibration, automatically switching the R&S FSMR3000 measurement range. ***Figure 2*** shows the linearity that can be achieved when measuring devices, including the uncertainty and overall limits.

AM/FM/PM ANALYSIS

The R&S FSMR3000 features a complete, integrated modulation analyzer for AM, FM and PM analog modulation. It measures the audio parameters on the demodulated signal or directly on the audio signal, meaning no extra instrument is required for calibrating the modulation settings and modulation generator.

Various audio filters, deemphasis functions and detectors are available for audio analysis. Total harmonic distortion (THD) and signal-

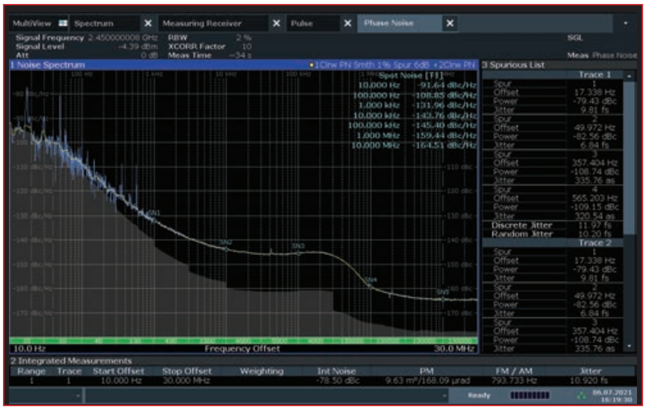

Fig. 4 An option enables measurement of the amplitude and phase noise of a signal.

to-noise and distortion (SINAD) are automatically calculated and displayed, and all key results are displayed simultaneously. Users can also choose only certain parameters to display and arrange the windows (see ***Figure 3***).

SIGNAL AND SPECTRUM ANALYSIS

For calibrating signal generators, a spectrum analyzer is often needed, such as for measuring harmonics. The R&S FSMR3-B1 option makes the measuring receiver a full-featured signal and spectrum analyzer, with functionality and performance equivalent to the R&S FSW signal and spectrum analyzer. Offering excellent performance—phase noise, wide dynamic range because of low intrinsic noise (DANL) and input third-order intercept (TOI) to +30 dBm—the instrument also has several standard functions required for calibration and performance verification of signal generators. For example, the R&S FSMR3-B1 can measure a generator's higher-order harmonics at the press of a key. It also has a routine for measuring TOI or adjacent channel power and an array of marker functions.

In addition to spectral measurements, the R&S FSMR3000 serves as a signal analyzer with an analysis bandwidth up to 80 MHz. It can analyze pulses, digital modulated signals and VOR/ILS signals.

HIGH PERFORMANCE PHASE NOISE ANALYZER

Phase noise is a key parameter for signal generators: the lower the phase noise, the better the signal and modulation quality. While phase noise can be measured with a spectrum analyzer, accurately measuring this parameter requires an analyzer with even lower intrinsic phase noise. The wide dynamic range of the R&S FSMR3000 makes it well-suited for phase noise measurements. At 10 kHz offset from the carrier, the analyzer's phase noise is -133 dBc/Hz with a 10 GHz carrier.

However, if the phase noise performance of the built-in spectrum analyzer is not sensitive enough to calibrate some high-end signal sources, the R&S FSMR3-B60 option turns the R&S FSMR3000 into a phase noise analyzer that demodulates the signal in real time, measuring phase noise and amplitude noise in parallel. A second receive path enables cross-correlation, which increases the sensitivity by up to 30 dB depending on the number of correlations. The cross-correlation gain appears as a gray area below the phase noise trace, showing the expected sensitivity due to cross-correlation (see ***Figure 4***), enabling users to accurately assess the measurement. If the gray area is well below the trace, the device being tested can be accurately analyzed, with errors due to insufficient sensitivity excluded.

The new R&S FSMR3000 is a full-featured tool for calibrating signal generators and characterizing their modulation quality. In addition to this functionality, it has options to incorporate a high performance signal and spectrum analyzer and high performance phase noise tester, becoming the only one-box solution that will cover all the functions needed in a modern high-end calibration lab.

VENDORVIEW

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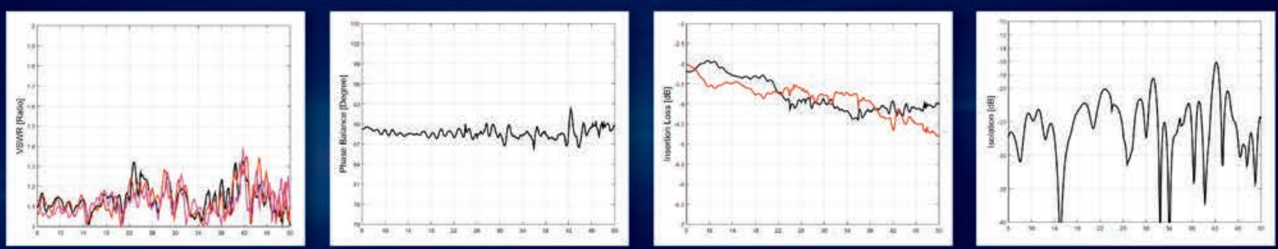
6-50	QN060500	90	1.9	2.7	±1.2	±12	12

*Above Theoretical 3dB

Test Curve（QN060500）



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Measuring Phase Noise To 1 THz Using Cross-Correlated Down-Conversion

AnaPico AG
Zurich, Switzerland
Virginia Diodes, Inc.
Charlottesville, Va.

Increasing operating frequencies for radar and communications are pushing the test and measurement industry to provide solutions for characterizing phase noise in these upper bands. The development of test systems at mmWave and higher frequencies is important for research and will become essential for production testing. This article shows a cost-effective and highly flexible solution for measuring phase noise, demonstrating a practical approach that can be used into the sub-THz range.

MEASUREMENT PRINCIPLE

Current phase noise measurement systems work from the low MHz to GHz frequencies. Using frequency translation, the range can be extended. This can be done in several ways, yet the approach must preserve the noise characteristics of the original signal. Frequency dividers suffer from a higher noise floor and do not preserve the noise characteristics. They are typically not available for higher frequencies. Frequency converters require a low noise local oscillator (LO) signal; however, the noise of the LO will limit the phase noise sensitivity of the system.

A better approach is to split the signal from the device under test and down-convert it in two separate channels using independent LOs (see ***Figure 1***). Even though both LOs are at the same nominal frequency, the two down-converted signals can be measured individually and cross-correlated to suppress the uncorrelated noise, i.e., the contributions from the down-converters and LOs. The uncorrelated noise is suppressed by a factor of $5 \cdot \log_{10}(n)$ in dB, where n is the number of cross-correlations. This approach enables the phase noise to be measured with the better noise floor of a lower signal frequency and without unwanted additive phase noise from the down-conversion process.

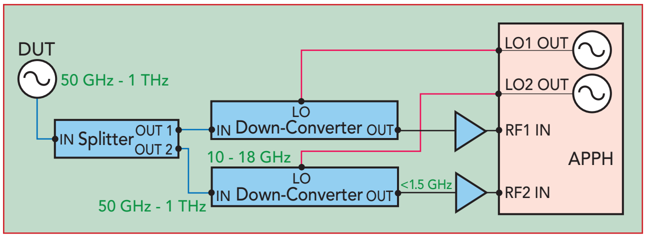

Fig. 1 Phase noise measurement based on cross-correlated down-conversion.

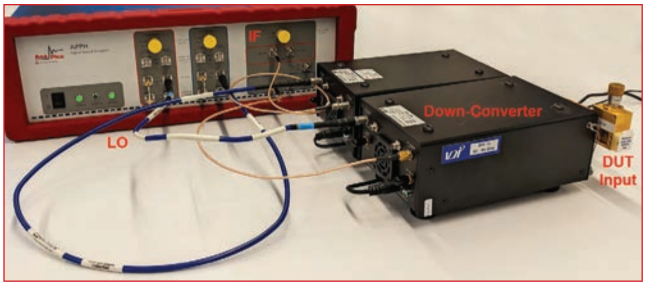

Fig. 2 Phase noise measurement setup using the AnaPico APPH with VDI down-converters.

IMPLEMENTATION

Using this approach, a test setup for phase noise measurements in W-Band (75 to 110 GHz) is shown in ***Figure 2***. It uses AnaPico's APPH40G signal source analyzer with option LO and down-converters from Virginia Diodes (VDI). Using the AnaPico signal source analyzer, the low phase noise LOs can be supplied by the measurement instrument, which supports feeding two separate versions of the same signal into the two internal measurement channels. Range-selectable VDI harmonic mixers are used for the down-converters. They match the LO and IF measurement ranges of the APPH40G and can be used across their full W-Band input range.

Combining AnaPico's APPH phase noise analyzer with the family of down-converters from VDI supports configurations that enable phase noise testing to above 1 THz. Frequency coverage depends on the connection interface and spans waveguide from WR15 (50 to 75 GHz) to WR1.0 (750 GHz to 1.1 THz).

This mmWave test mode has been fully integrated into AnaPico's analyzer and graphical interface. By maximizing the APPH-internal phase detector frequencies used for signal generation, the instrument optimizes the LO and IF frequencies to minimize the noise floor. The user only needs to enter the approximate input frequency; everything else is configured automatically. The system is versatile, able to handle input power down to -15 dBm.

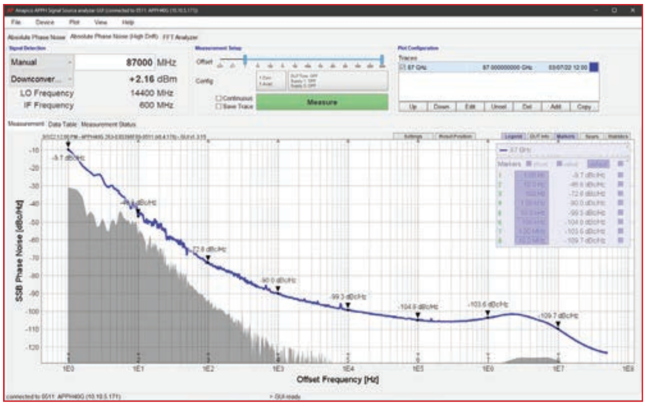

Fig. 3 Phase noise measurement at 87 GHz, showing the APPH graphical view.

Figure 3 shows a measurement at 87 GHz. The noise floor and phase noise contributions from the LO are more than 10 dB below the measurement curve and don't distort the results.

SUMMARY

This article has outlined a method to measure the phase noise of sub-THz signals using two separate down-converters and cross-correlating the results to suppress the noise contributions of the LOs and down-converters. This approach results in a low noise floor with very low noise contribution from the measurement setup. To demonstrate the principle, an 87 GHz measurement using AnaPico APPH phase noise analyzer and VDI down-converters at 87 GHz is shown. By selecting the appropriate VDI down-converters, the measurement frequency range can be extended to 1.1 THz. This setup offers a low-cost and versatile solution that can be configured from mmWave to sub-THz frequencies.

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126–182 GHz UWB Radar Enables Spectral Characterization for Scientific and Industrial Applications

2π-LABS GmbH
Bochum, Germany

The upper mmWave frequencies bands above approximately 100 GHz are the focus of regulatory bodies like the FCC in the U.S. and CEPT in Europe, which are laying the regulatory foundation to enable new innovative applications like 6G communications and industrial radio determination. To address these new applications, 2π-LABS has developed 2πSENSE, a 126 to 182 GHz ultra-wideband (UWB) frequency-modulated continuous wave (FMCW) radar platform.

Fig. 1 The 2πSENSE radar is available with a dielectric lens antenna (left) or WR6.5 waveguide flange (right).

2πSENSE was designed to be a versatile tool to support the complete product life cycle, beginning with scientific research to industrial applications, from material characterization and non-destructive testing to radar imaging. The sensor is available in two versions—one for lab use, with an easy to set up USB interface and a robust, waterproof sensor for industrial use, with an Ethernet interface. The industrial version is well-suited for fielding applications where short time-to-market is important.

The 2πSENSE radar sensors bridge the gap between lab-grade vector network analyzers (VNAs) and industrial distance measurement devices based on radar. For the first time, a sensor enables using measurement grade mmWave spectral characterization in rugged industrial environments. The sensor can be configured with either a

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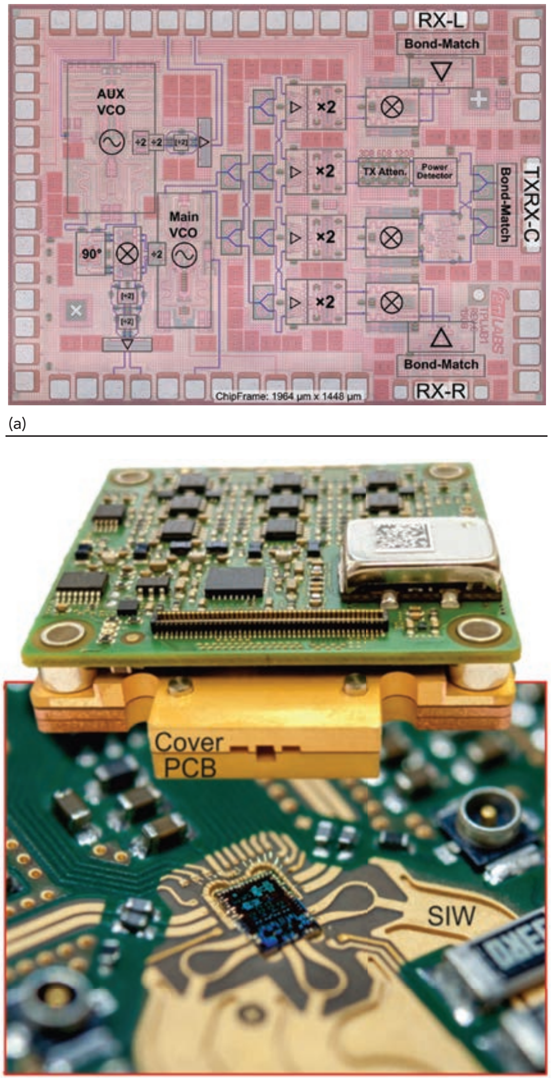
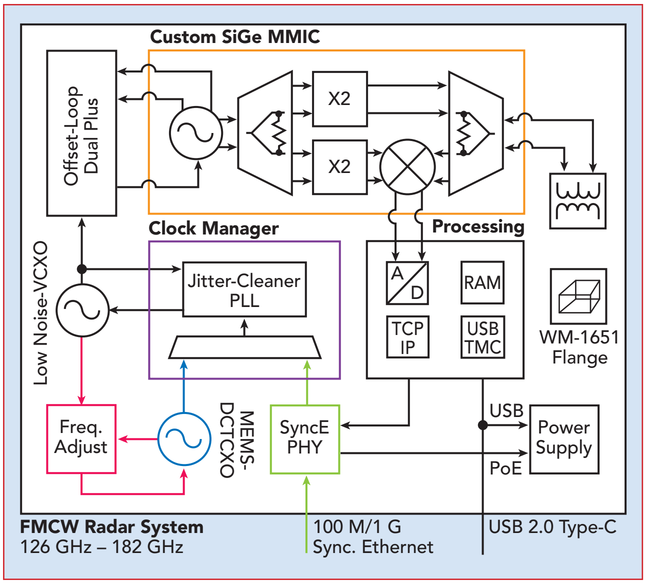


▲ Fig. 2 Three channel SiGe MMIC (a) and integrated front-end using an SIW PCB split-block construction (b).

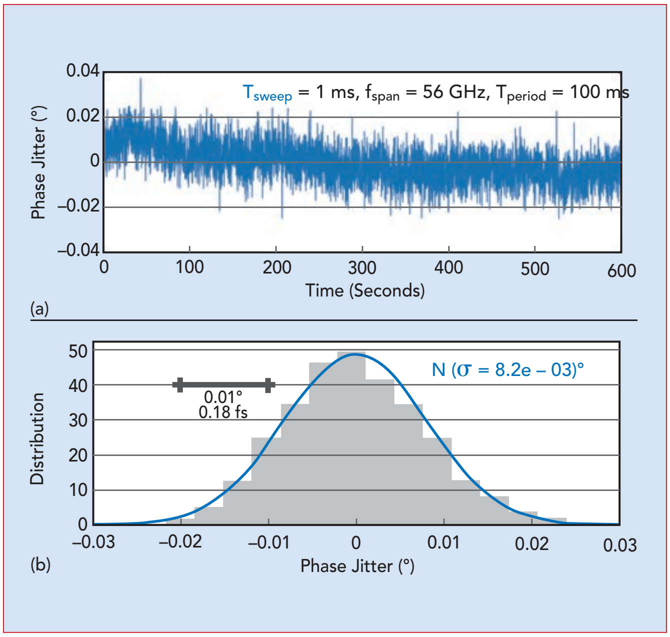


▲ Fig. 3 Block diagram of the radar sensor configured with a single Tx and Rx.

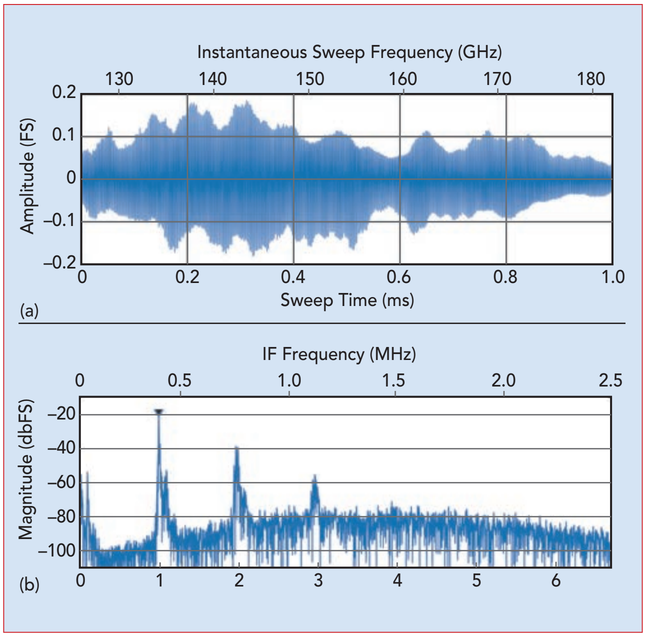
WR6.5 flange or a dielectric lens antenna (see ***Figure 1***). With a versatile application programming interface (API) and raw data access enable extracting the wideband frequency response of targets, achieving VNA-like S-parameter measurements from a small, portable and ruggedized sensor.

2πSENSE TECHNOLOGY

2π-LABS has developed a custom D-Band radar MMIC, which serves as the foundation for its innovative radar products. Designed on Infineon's B11HFC SiGe process (see ***Figure 2a***), the MMIC covers 126 to 182 GHz—56 GHz bandwidth—and has three channels: one transmit (Tx) and two receive (Rx). The MMIC is then embedded in a mmWave sensor module using a substrate integrated waveguide (SIW) PCB split-block technology (see ***Figure 2b***). The sensor can be configured with an



▲ Fig. 4 **Measured jitter over 10 minutes (a) and associated histogram (b) with a waveguide short connected to the sensor.**



▲ Fig. 5 **Measured IF of a 1 m distant target showing the sensor's bandwidth and 80 dB dynamic range**

embedded ortho-mode transducer for dual-polarization receive or, alternatively, a single center transceiver and two additional receive channels for angle estimation applications. A functional block diagram of the sensor in a single Tx/Rx configuration is shown in ***Figure 3***.

The sensor's clock network achieves exceptional frequency stability for very low jitter measurements (see ***Figure 4***) and fast FMCW operation, sweeping the 56 GHz bandwidth in 1 ms. It uses a stable ±100 ppb long-term stability frequency reference and can be locked to Sync-E frequency sources (e.g., global navigation satellite clock sources) for calibration. The sensors include a versatile external trigger with a programmable trigger subsystem, designed to meet the needs of complex applications. The 56 GHz spectral modulation bandwidth makes it possible to measure the transmission and reflection or absorption behavior of a significantly larger portion of the spectrum compared to currently available industrial radar sensors (see ***Figure 5***).

2π-LABS provides an API in Python, which provides access to all the important radar parameters via an SCPI command set, the same protocol used by many VNAs. The documentation includes example scripts for the most common tasks, which are expanding from a growing community of users.

APPLICATIONS

For distance measurements, 2πSENSE radars achieve a target range resolution of just a few millimeters and range accuracies in the single-digit micron range, with short-term jitter an order-of-magnitude lower. The power of these capabilities becomes evident in wideband "radarlytic" applications like spectral mmWave characterization. Many innovative and sophisticated applications become possible because of the bandwidth, stability and VNA-like frequency response characterization packaged in a small form factor.

The first applications demonstrated have been contactless thickness measurements of dielectric materials for plastic extrusion and multi-layer composites with built-in material characterization features. Other interesting applications are monitoring dielectric material parameters: contactless detection of material type, permittivity, thickness, moisture content and coating in glass, polymer—even food production. With the capability to precisely measure complex permittivity, dielectric liquids, foams or polymers can be monitored in line for effective permittivity and losses. Using the data with production optimization algorithms can enhance production quality assurance in many complex applications.

2πSENSE devices cover the complete product development cycle, from early-stage lab experiments for proof-of-concept verification using the USB-powered scientific version to industrial deployment using the configuration with OPC-UA interfaces and power-over-Ethernet capability. As the regulatory bodies lay the foundation to enable new innovative applications, 2π-LABS is advocating regulations that allow harmonized and compliant use of the sensors.

2π-LABS GmbH
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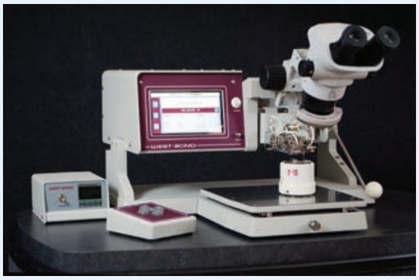
Programmable Ball and Wedge Bonder Designed for Versatility



WEST•BOND's 7KF Bonder is a versatile tool for the challenging bonding needs of RF/microwave, semiconductor, hybrid assembly and medical devices. The bonders in the series are convertible between ball and wedge bonding, presenting the bond wire at 45 degrees for optimal loop and tail control or 90 degrees for deep access and ribbon bonding. Conversion between the two setups take minutes using a single tool head.

The 7KF was designed with a gantry style chassis for virtually unlimited part size capacity. The unique 8:1 ratio, purely orthogonal x-y-z micromanipulator enables the bonds to be placed precisely and easily. The machine will store up to 30 device configuration profiles, or buffers, per mode of operation. Each buffer can store up to 21 bonds with individual ultrasonic power, time, force and loop elevation settings per bond. The 7KF machines have programmable force from 15 to 135 g, primary and secondary ball sizes, pure vertical Z-motion and programmable radiant tool heat.

A 7-in. capacitive touch sensing LCD interface lets the user input and see the programming of each setting, operation of the machine, action prompts and fault diagnostic information.

High and low frequency versions of the bonder are available: the 7KFH and 7KF, respectively. The 7KF series uses an open frame design, the 7KFX models remove the base and work platform of the machine and enable mounting the machine to a tabletop or conveyor system. Risers are available to support working with tall parts.

With a heritage of more than 55 years of quality and service, WEST•BOND is dedicated to the microelectronics industry, offering a range of assembly and test equipment that provide value across a full spectrum of needs.

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Anaheim, Calif.
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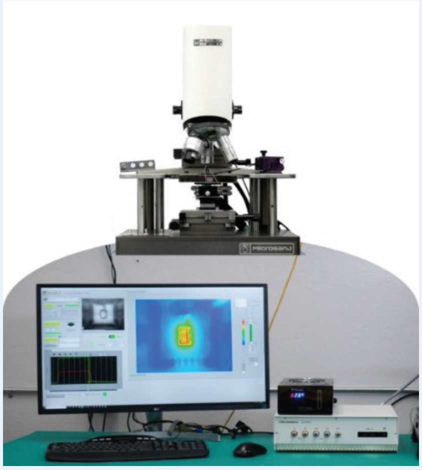
Sub-THz Programmable Tuners Cover WR6, WR5 and WR3 Bands

To support research exploring the frequency options and possible applications for 6G, Focus Microwaves has developed a family of waveguide tuners for the bands spanning 110 to 330 GHz. The sub-THz tuner family comprises three models: W-1701100 (WR6), W-2201700 (WR5) and W-3302200 (WR3).

These tuners were built on the foundation of Focus Microwave's DELTA tuners, which have become an industry standard for on wafer measurements, combined with the micrometric accuracy and repeatability of the small footprint Omega tuners, which have been proven for coaxial applications to 110 GHz. The waveguide sections with round flanges are embedded in the accurate horizontal and vertical control mechanism of the Omega platform, enabling horizontal and vertical probe movement with micrometric accuracy and repeatability. The transmission media are precisely slotted, gold plated waveguide sections with the partly conductive probe moving in, out and along the waveguide slot to generate controllable |Γ| and phase. The waveguide slot and microscopic tuning probe geometry were optimized with HFSS simulation for maximum reflection and minimum signal leakage over the entire band.

Total positioning uncertainty is less than ±1 μm. The maximum tuning resolution of each tuner is 0.19 degree per step at 110 GHz, 0.24 degree per step at 140 GHz and 0.2 degree per step at 220 GHz for the WR6, WR5 and WR3 tuners, respectively. This resolution provides more than 1.5 million tuning points for each tuner. The VSWR ranges for the tuners are from 1.2:1 (minimum) to 20:1 (maximum) for the WR6, 1.3:1 to 10:1 for the WR5 and 2:1 to 10:1 for the WR3. The tuners are compatible with Focus' FDCS software suite for calibration, load-pull and noise measurements.

Focus Microwaves
Saint-Laurent, QC, Canada
www.focus-microwaves.com

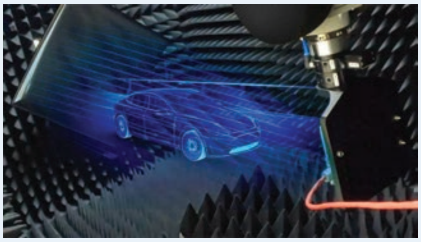


Thermal Imaging System With Macro- to Nano-Scale Resolution

With semiconductor designs pushing submicron features, complex multi-layer structures and new materials, microwave device and circuit designers face growing thermal challenges. Application requirements for increased power, higher frequency and faster switching are leading to higher power densities with rapidly changing thermal events and thermal anomalies that may lead to early failures. Recognizing that traditional techniques cannot fully assess the thermal behavior of these devices, Microsanj has focused on thermal analysis systems that will meet the challenges posed by today's most advanced designs.

The SanjSCOPE™ EZ-THERM series is a compact bench-mountable thermal imaging system that provides the sensitivity, spatial and temporal resolution for designers to fully understand device thermal behavior. With spectral coverage from 365 nm to 1700 nm, GaN HEMTs can be analyzed with a spatial resolution less than 300 nm, and flip-chip mounted microwave devices can be analyzed with thru-the-substrate imaging above 1000 nm. The capability to do infrared macro analysis with better than 10 mK thermal sensitivity and quickly move to nano-scale analysis with thermoreflectance enables designers to capture the smallest hot spots and analyze its characteristics on a nano-scale level.

Microsanj LLC
Santa Clara, Calif.
www.microsanj.com



End-of-Line Test System for Radar Sensors

An end-of-line (EOL) test for automotive radar sensors is required to verify the functionality and automatically calibrate the finished assemblies. This is typically done in a compact, low reflection anechoic chamber using radar target simulation. The sensor's operating parameters and calibration are measured through a defined test sequence, where the radar sensor is rotated around its radiation center in the horizontal and vertical directions using precision drives. An over-the-air approach enables validating the entire radar transmission channel, both antennas and electronics.

dSPACE, working with NOFFZ Technologies, has developed a 3GPP-compliant compact antenna test range (CATR) method for testing automotive radar sensors, and the approach requires only a small footprint. The CATR creates a large far-field distance from a compact range, and the large quiet zone enables interference-free testing. The CATR-based system is precise, accurate and flexible, with high throughput—well suited for automated, EOL testing. A quick-change adapter and parallel mounting hardware support fast set-up times when changing the sensor to be tested. The test system can simulate up to four simultaneous targets from the same direction of arrival, with the distance, speed and size of each target changed individually and continuously. With 5 GHz of instantaneous bandwidth, the system can calibrate the latest 3D and 4D sensors.

The collaboration between dSPACE and NOFFZ Technologies taps NOFFZ's expertise in compact, reliable test systems for radar sensors and anechoic chambers with high reflection suppression. dSPACE provides the assembly of the CATR mirror and the radar target simulators for the 23 to 26 GHz and 75 to 82 GHz radar bands, with a processing bandwidth to 5 GHz.

VENDORVIEW

dSPACE GmbH
Paderborn, Germany
www.dspace.com

Dalicap
DALICAP TECH. CORPORATION

Microwave / RF Ceramic Capacitor

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IMS Booth No. 6104

Hot!

Product Features

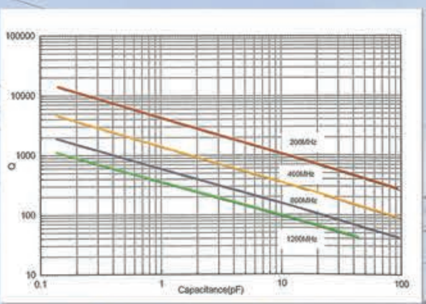
- High Q
- Zero TCC
- Low ESR/ESL
- Low Noise
- Ultra-Stable Performance
- Extended WVDC available

SIZE:0402,0603,0505,0805, 0710,1111,2225,3838 for RF/Microwave; 6040,7575,130130 for High RF Power

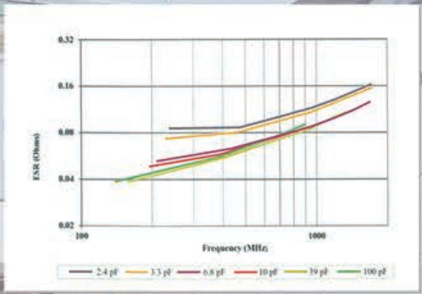
Typical Circuit Application:

UHF/Microwave RF Power Amplifiers, Mixers, Oscillators, Low Noise Amplifiers, Filter Networks, Timing Circuits and Delay Lines.

Stock available



DLC70A(0505) Q Value and Capacitance Curve



DLC70P(0603) Equivalent Series Resistances（ESRs）

Dalicap

Dalicap Tech. is a professional enterprise specializing in R&D, manufacturing and sales of multi-layer ceramic capacitors (MLCC). Dalicap is also a leading supplier of Hi-Q, ultra-low ESR RF/Microwave MLCC, applied especially on the fields of MRI, semiconductor device, industrial laser equipment, testing and analyzing instruments, balise and 4G/5G PA etc.

Dalicap is committed to providing high-performance, high-reliability products to customers. The R&D and engineering teams have extensive experience to quickly support and response to customized request.The company has an unique RF lab, by RF simulation and individual RF testing method to guarantee product realization.

www.dalicap.com dalicap@dalicap.com.cn +86-411-87613673ext.8608

IMS2022 Welcome and Overview

Ron Ginley
IMS2022 General Chair

Welcome to IMS in Denver, Colo., the Mile High City! My Steering Committee and I are very excited about the location and the program that we have put together. I take great pleasure in inviting you to join us in Denver for IMS2022. Colorado might just be one of the most photogenic spots around the world, and Denver is where urban sophistication meets outdoor adventure. The IMS2022 team has put together a great program with many new and exciting elements. There will also be many opportunities to network away from the technical sessions. IMS2022 will be 19-24 June 2022, and will be centered around the Colorado Convention Center in downtown Denver.

COLORFUL COLORADO

The name Colorado is of Spanish origin, meaning "colored red." It came into use because of the red

sandstone soil of the region. Colorado is also called "Colorful Colorado" because of the magnificent scenery of mountains, rivers and plains. There is so much to see and do when visiting Colorado. A short drive takes you from Denver to the Rocky Mountains. There the outdoors awaits, from hiking in Rocky Mountain National Park to riding a narrow-gage railroad train through a canyon inaccessible to cars. Just outside Denver there are miles and miles of hiking and biking trails.

DENVER

Denver is known as the Mile High City, a nickname it was given because a spot on the state capitol steps has been measured to be at an elevation of 5,280 ft. (1,609 m)—exactly one mile above sea level. Denver is Colorado's largest city. It is the commercial, financial and cultural center of the Rocky Mountain region; the city's dry, sunny climate is favored by tourists, the downtown is alive with restaurants, bars, shows, museums and much more. All the hotels are within walking distance of the Colorado Convention Center. Within the downtown Denver area, you can take a walk or ride a bike on the Cherry Creek bike path, visit the Denver Branch of the U.S. Mint, the expansive exhibits in the Denver Art Museum, take a ride at the Elitch Gardens Amusement Park or take in a baseball game at Coors Field, home of the Colorado Rockies. There is so much to do! While you are on your way to an event, stop in at any of the great restaurants that are within walking distance of the hotels and the convention center.

IMS2022 AND WHAT'S NEW

I am really excited to have IMS2022 in Denver. We have taken the established IMS program and added many new elements. The RFIC and IMS workshops start things off on Sunday. The two days of the RFIC technical program start on Monday. ARFTG has joint events with IMS throughout the week and then the ARFTG Symposium on Friday. The technical program for IMS starts on Monday; one of the big events on Monday is the Plenary Session, there will be talks from some well-known companies on microwaves in space and quantum systems for more than just computers. Following the Plenary Session will be the Welcome Reception, which will celebrate all things Denver/Colorado. The Three Minute Thesis program, student, industrial and advanced paper competitions, technical talks, the largest microwave exhibition and lots more will happen throughout the week!

New for IMS2022, we have added the Systems Forum. This Forum combines elements from ARFTG,


Custom RF Testing from JFW...
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• RF Power Distribution Systems
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Indianapolis, Indiana 46237
USA
jfwindustries.com
1 (317) 887-1340
1-877-8874539

RFIC and IMS. The Systems Forum has events on Tuesday, Wednesday and Thursday during week of IMS. Each of those days has a theme that loosely ties together certain material for the day. Tuesday is the Connected Future Summit (think 5G, 6G, etc.) and Quantum Systems Day. Wednesday is Radar and Aerospace Day. Thursday is Phased Arrays and OTA Applications Day. During these days look for additional panel sessions, more focus sessions, technical lectures, socials and more.

We are also working to increase industry participation in IMS. There will be opportunities for industry-based authors to showcase their work. In addition, there will be opportunities for industry-based authors to mention companies supporting their work and show the companies' booth numbers, if they are exhibiting. Speaking of exhibits, at the time of this writing we have over 410 companies exhibiting at IMS2022 and the number keeps growing!

SOCIAL EVENTS

It wouldn't be IMS without social events. Starting with the Welcome Reception on Monday, there is something happening every day and night of IMS. Tuesday, earlier in the day, there will be a Quantum Reception and then a bit later there will be the Young Professional's (YP's) Reception—there will also be other YP events happening throughout the week. On Wednesday, the Women in Microwave events are taking place and the Award Banquet is happening that night. Make sure to save time Thursday to go to the Closing Plenary talk. To see the many more events going on during the week, take a look at the Week-At-A-Glance.

The Technical Program Committee has put together a great program for IMS2022. There are a lot of new elements (see the Technical Program for more information). We have doubled the number of panel sessions and focus sessions and invited many of the top experts to participate. Summer in Denver is wonderful. Come, enjoy and stay a few extra days to experience Colorado. I can't wait to see you all at IMS2022!

IMS

Connecting Minds. Exchanging Ideas.

PROGRAM PREVIEW

Join Us
In-Person

Register Now

19-24 June
Denver, CO

ims-ieee.org

IEEE

MTT-S
IEEE MICROWAVE THEORY & TECHNOLOGY SOCIETY

RFIC

ARFTG

Keynotes & At A Glance

The Future of RFIC is Digital

Dr. Curtis Ling
MaxLinear

RFICs into the Roaring 20's: Hot and Cold

Prof. Sorin Voinigescu
University of Toronto

A Quantum Technology Landscape

Prof. Dana Z. Anderson
University of Colorado and ColdQuanta, Inc.

Space, Changing the Way We Live, Enabled by Microwave Innovations

Gregory E. Edlund
Lockheed Martin Space Systems Company

Learning from the Lightning: How Nikola Tesla Formulated a Scheme for Wireless Power in Colorado Springs

Prof. W. Bernard Carlson
University of Virginia and National University of Ireland Galway

	Sunday 19-Jun-22	Monday 20-Jun-22	Tuesday 21-Jun-22	Wednesday 22-Jun-22	Thursday 23-Jun-22	Friday 24-Jun-22
Workshops	■	■				
Technical Lectures	■	■			■	
RFIC Plenary Session, Reception, Industry Showcase	■					
Quantum Bootcamp	■					
RF Bootcamp		■				
RFIC Technical Sessions and Interactive Forum		■	■			
Three Minute Thesis		■				
IMS Plenary Session and Welcome Reception		■				
IMS Technical Sessions and Interactive Forum			■	■	■	
Panel Sessions		■	■	■	■	
Connected Future Summit			■			
Exhibition			■	■	■	
MicroApps and Industry Workshops			■	■	■	
Amateur Radio Talk and Reception			■			
Young Professionals Talk and Reception			■			
Industry Hosted Reception				■		
Women In Microwaves Talk and Reception				■		
IMS Closing Ceremony and Awards					■	
99th ARFTG						■

- Workshops
- Technical Lectures
- RFIC
- Bootcamp
- Three Minute Thesis
- IMS
- Panel Sessions
- Connected Future Summit
- Exhibitor Activities
- Focus Groups
- ARFTG

Panel Sessions, Technical Lectures & Workshops

PANEL SESSIONS

- Industry vs. Academia: Who is Leading Whom?
- This is the Right Way to Architect the Microwave Control for Quantum Computers!
- Race to the Next G – Ride the mmWave or Wave Goodbye!
- The Trend of Tiny AI: Will Ultra-Low-Power Fully-Integrated Cognitive Radios Become a Reality?
- Small Satellites and Constellations: Who Will Be the Winners of the New Race to Space?
- Wearables – Our Life Depends on Them!
- Modern Phased Arrays and OTA Testing: A Design or a Measurement Challenge?

TECHNICAL LECTURES

- Fundamentals of Noise, and Understanding its Effects on RFICs
- Electromagnetic Fundamentals Underlying Health Impact of Millimeter-Wave Radiations
- Semiconductor Electronics for High Power/High Speed Reconfigurable RF and Microwave Electronics

WORKSHOPS

- Advanced Manufacturing and Design Techniques for Emerging 3D Microwave and mm-Wave RF Filters
- Advances in SATCOM Phased-Arrays and Constellations for LEO, MEO and GEO Systems
- Emerging MIT/PCM Based Reconfigurable Microwave Devices
- Front-End Module Integration and Packaging for 6G and Beyond 100GHz Communication and Radar Systems
- In-Band Full-Duplex Integrated Devices and Systems
- Superposition and Entanglement: When Microwaves meet Quantum
- Supply Modulation Techniques: From Device to System
- RF Large-Signal Transistor Performance Limits Related to Reliability and Ruggedness in Mobile Circuit Applications
- GaN/GaAs Technology Development and Heterogeneous Integration for Emerging mm-Wave Applications
- Microwave Techniques for Coexistence between 5G and Passive Scientific Systems
- On-Wafer mm-Wave Measurements
- Measurement and Modeling of Trapping, Thermal Effects and Reliability of GaN HEMT Microwave PA Technology
- Hands-On Phased Array Beamforming Using Open Source Hardware and Software
- AI/ML-Based Signal Processing for Wireless Channels
- Commercial Applications of Medical RF, Microwave and mm-Wave Technology
- Quantum RF Receivers: Using Rydberg Atoms for Highly Sensitive and Ultra Wideband Electric Field Sensing
- Large-Scale Antenna Arrays: Circuits, Architectures, and Algorithms
- SWIPT — Simultaneous Wireless Information and Power Transmission for Future IoT Solutions
- Health Aspects of mm-Wave Radiation in 5G and Beyond
- Micro and Nano Technology Challenges to Address 6G Key Performance Indicators
- Wideband and High Efficiency mm-Wave CMOS PA Design for 5G and Beyond
- Emerging Low-Temperature/Cryogenic Microwave Techniques and Technologies for Quantum Information Processing
- mm-Wave Design Challenges and Solutions for 6G Wireless Communications
- mm-Wave and THz Systems for Near-Field Imaging, Spectroscopy and Radar Sensing Applications
- Advanced Interference Mitigation in Integrated Wireless Transceivers
- System Design Considerations for Advanced Radios
- Toward Tbps Optical and Wireline Transceivers: a Tutorial for RFIC Designers
- Wireless Proximity Communication
- Recent Developments in Sub-6GHz PAs and Front-End Modules
- Digitally Intensive PAs and Transmitters for RF Communication
- Human Body Communications

For the latest on IMS and Microwave Week visit ims-ieee.org

IMS Technical Sessions

Tuesday, 21 June

- Tu1A: Advances in Synthesis and Design Techniques for Non-Planar Filters
- Tu1B: Advances in Numerical and Computational Techniques for Simulation and Design Optimization
- Tu1C: Advances in RFID Technologies
- Tu1D: Advanced Frequency Synthesis
- Tu1E: Microwave Technologies for Quantum-System Integration
- Tu2A: Advances in Non-Planar Filter Technologies
- Tu2B: A Retrospective and a Vision of Future Trends in RF and Microwave Design Optimization
- Tu2C: Advances in RF Sensors
- Tu2D: Advanced mm-wave-sub-mm-wave Mixers, Switches and Phase Shifters
- Tu2E: Cryogenic Microwave Circuits for Control of Quantum Systems
- Tu3A: Reconfigurable Multi-Mode Resonators and Filters
- Tu3C: Rectenna and Signal Design for RF Power Transmission and Energy Harvesting
- Tu3D: HF-VHF-UHF Power Amplifiers and Systems
- Tu3E: Cryogenic Measurement and Characterization for Quantum Systems
- Tu4A: Integrated Filters in the GHz and sub-THz Range
- Tu4B: Components for Advanced Systems and Applications
- Tu4C: Low-Frequency Wireless Power Transfer and Harvesting Systems
- Tu4D: Advanced High-Speed Mixed-Signal Circuits For Optical and mm-Wave Systems
- Tu4E: Next-Generation mm-wave GaN Technologies and MMICs for 5G-6G and DoD Applications

Wednesday, 22 June

- We1A: High-Density Integration of Transmission Line Structures
- We1B: Advances in High Frequency Device Modeling
- We1C: Advanced 5G Wireless System Architectures and Underlying Over-the-Air Characterization Techniques
- We1D: Nonlinear Analysis and Design of Microwave Signal Generation and Processing Circuits
- We1E: High Power GaN RF and Microwave Power Amplifiers
- We1F: Radar from Space to Ground (and Below) - The Synergy Between Commercial, Government, and Metrology Applications
- We1G: Millimeter-Wave and Terahertz Power Amplifiers and Frontend Modules
- We2A: Advancements in Planar and Substrate Integrated Filters and Multiplexers
- We2B: Advances in the Characterization of Microwave and Millimeter-Wave Materials and Components
- We2C: AI-ML for RF and mmWave Applications
- We2E: Advanced Linearization Techniques for PAs and MIMO Transmitters
- We2F: Advanced Concepts for 77 GHz Radar
- We2G: Millimeter-wave and Terahertz System Demonstrations and Concepts
- We3A: Advances in Passive Devices
- We3B: Advances in Interconnects
- We3C: Towards Physically Secure Communication and Computation
- We3D: LNAs and Receivers at W-band and Beyond
- We3E: New Advances in RF Circuits and Systems
- We3F: Cognitive Radar
- We3G: Millimeter-Wave and Terahertz Signal Generation
- We4A: Advances in mmWave Passive Components & Systems
- We4B: Advanced Manufacturing and Novel Substrates
- We4C: Advanced System Architectures and Concepts
- We4D: Advances in Low Power CMOS Low Noise Amplifiers (LNAs)
- We4E: Special Session in Memory of Professor Tatsuo Itoh
- We4F: Advanced Radar Imaging and Signal Processing
- We4G: Millimeter and Terahertz Integrated Circuits and Components

Thursday, 23 June

- Th1A: Microwave Interaction and Characterization of Biological and Semiconductor Materials
- TH1B: Advances in SAW and Acoustic Components Technology
- Th1C: Microwave and Terahertz Photonics
- Th1E: Compound Semiconductor Power Amplifiers
- Th1F: Efficient Characterization and Test of Phased Array Antenna Systems: Is it Really a Nightmare?
- Th2A: Measurement and Instrumentation Techniques for Evolving Standards in Future Technologies
- Th2B: Recent Advances on Acoustic Resonators and Filters
- Th2C: Nano-Devices and Their High Frequency Applications
- Th2E: Recent Advances in Microwave Semiconductor Technology
- Th2F: Antenna Systems for 5G and SATCOM Applications
- Th3A: MHz-to-THz Instrumentation for Biological Measurements and Healthcare Applications
- Th3B: Emerging Phase-Change and SIW Technologies for mmWave to sub-THz Applications
- Th3C: Silicon Based Digital Power Amplifier Architectures
- Th3E: Reconfigurable RF Systems for 5G mmWave Communications
- Th3F: Advances in Integrated Transceivers for Beamforming and RADAR Applications

Technical Track Key:

Field, Device and Circuit Tech.	Passive Components & Packaging	Active Devices
Emerging Technologies	Focus or Special Sessions	RFIC Sessions
	Systems & Applications	

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RFIC Technical Sessions

Monday, 20 June

- RMo1A: mm-Wave Transmitters & Receivers for Communication & 5G Applications
- RMo1B: Cryogenic and Advanced Front-End Circuits
- RMo1C: RFIC Systems and Applications: Custom RFICs for Emerging Systems
- RMo2A: Multi-Gigabit Transceivers & Modules for Point-to-Point & Emerging Applications
- RMo2B: Power Switches, Amplifiers and Power Dividers for mm-wave and sub-THz Applications
- RMo2C: RF & mm-Wave Transmitters
- RMo3A: Millimeter-Wave & Sub-THz Circuits & Systems for Radar Sensing and Metrology
- RMo3B: Mixed-Signal Building Blocks for Next-Generation Systems
- RMo3C: Frequency Generation Techniques for 5G and IoT
- RMo4A: Power Amplifiers for 100+GHz Applications
- RMo4B: Switch Technology, CMOS Reliability, and ESD
- RMo4C: RF, mmWave and Sub-THz VCOs

Tuesday, 21 June

- RTu1A: mm-wave and Wide Band Low-Noise CMOS Amplifiers
- RTu1B: Efficiency Enhancement Techniques for Power Amplifiers
- RTu3A: Circuits and Techniques for Full Duplex Transceivers
- RTu3B: Millimeter-Wave-THz Devices and BIST-Calibration, and Circuits for Emerging Applications
- RTu4A: Emerging Wireless Communications
- RTu4B: Building Blocks for Next Generation Frequency Synthesis

The Systems Forum, Connected Future Summit, and Boot Camps

With a special focus on systems design across three days, The Systems Forum includes technical topics showcased in the Connected Future Summit, panel sessions, focused sessions, and an interactive Systems Pavilion on the show floor.

TUESDAY: Connected Future Summit and Quantum Systems

WEDNESDAY: Radar and Aerospace

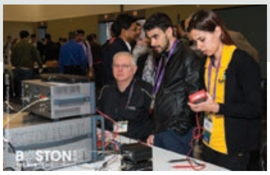
THURSDAY: Phased Arrays and Over-the-Air

Connected Future Summit

The Connected Future Summit will be held on Tuesday, 21 June 2022. The Summit will review core technologies for future wireless networks along with their human and societal impacts. Topics will include future trends of 6G and beyond; standardization of both cellular (3GPP) and Wi-Fi Alliance; broadband wireless with satellite constellations and other high-altitude platform; V2X technology with beyond 5G; semiconductor technologies; reconfigurable front ends and system architectures; and test and measurement challenges impacting next-generation connectivity evolution. Visit **ims-ieee.org/connectedfuturesummit** to view the agenda and speakers.

RF Boot Camp

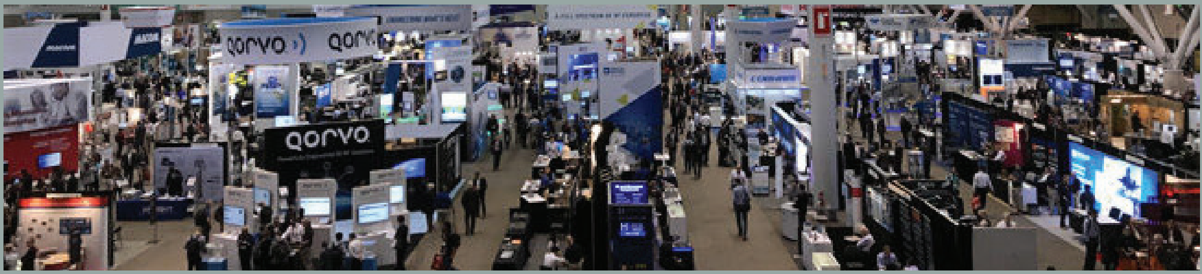
Join us for an introduction to RF basics on Monday, 20 June 2022! This one day course is ideal for newcomers to the microwave world, such as technicians, new engineers, college students, engineers changing their career path, as well as marketing and sales professionals looking to become more comfortable in customer interactions involving RF & Microwave circuit and system concepts and terminology. The format of the RF Boot Camp is similar to that of a workshop or short course, with multiple presenters from industry and academia presenting on a variety of topics. Visit **ims-ieee.org/RFbootcamp** to view the agenda and speakers.



NEW! Quantum Boot Camp

This course will provide an introduction to the basics of quantum engineering, targeting microwave engineers who want to understand how they can make an impact in this emerging field. The intended audience includes new engineers, engineers who may be changing their career path, marketing and sales professionals, as well as current university students. Speakers will cover quantum engineering basics with a focus on the control and measurement of quantum systems and will conclude with a hands-on introduction to the design of superconducting qubits using modern microwave CAD tools. Visit **ims-ieee.org/quantumbootcamp** to view the agenda and speakers.

Exhibition, MicroApps, Industry Workshops and Mobile App



EXHIBITION OVERVIEW

The exhibition at IMS2022 includes 425+ exhibitors from around the world, showcasing their products and services. All conference pass holders gain free access to the exhibition. "EXPO only" passes are also available. You can sign up for a FREE EXPO only pass for the Wednesday exhibition or gain access to three days of exhibition and show-floor presentations in the MicroApps Theater for $30.

SHOW HOURS

Tuesday, 21 June 2022
09:30-17:00

Wednesday, 22 June 2022
09:30-18:00

Thursday, 23 June 2022
09:30-15:00

SHOW FLOOR NETWORKING HIGHLIGHTS

- Continental Breakfast each morning Tuesday-Thursday
- Sweet Treat Tuesday (during afternoon)
- Coffee breaks throughout the day Tuesday, Wednesday, and Thursday
- Industry Hosted Reception, Wednesday, 22 June 2022, 17:00-18:00
- Societies Pavilion
- Systems Pavilion
- Three networking lounges with charging stations

MICROAPPS

The Microwave Application seminars (MicroApps) offered Tuesday, 21 June through Thursday, 23 June 2022, provide a unique forum for the exchange of ideas and practical knowledge related to the design, development, production, and test of products and services. MicroApps seminars are presented by technical experts from IMS2022 exhibitors with a focus on providing practical information, design, and test techniques that practicing engineers and technicians can apply to solve the current issues in their projects and products. View the complete MicroApps schedule at https://ims-ieee.org/exhibition/microapps/microapps-seminars.

INDUSTRY WORKSHOPS

The Industry Workshops are 2-hour industry-led presentations featuring hands-on, practical solutions often including live demonstrations and attendee participation. These Workshops are open to all registered Microwave Week attendees for $25 per Workshop. View the complete Industry Workshop schedule at https://ims-ieee.org/exhibition/microapps/industry-workshops.

IMS MICROWAVE WEEK MOBILE APP

The IMS Microwave Week app is now available in the Apple App store and Google Play store. Install the app on your Android or iOS device to view the full schedule of Workshops, Technical Lectures, IMS and RFIC Technical Sessions, ARFTG, Panel Sessions, Social Events and Exhibition information. On-site during Microwave Week you will be able to download IMS and RFIC papers and presentations, access Workshop materials, locate exhibitors and explore all that Denver, CO, has to offer! Download today!

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Exhibitor List

2pi-Labs GmbH
3D Glass Solutions Inc
3G Shielding Specialties
3RWAVE
A-Alpha Waveguide Inc.
ACE-Accurate Circuit Engineering
ACEWAVETECH
AdTech Ceramics
Advanced Assembly
Advanced Circuitry International
Advanced Test Equipment Corp.
Aerospace & Defense Technology
AFT Microwave Inc.
AGC Multi Material America Inc.
Agile Microwave Technology Inc.
AI Technology Inc.
A-INFO Inc.
AJ Tuck Co.
Akoustis Inc.
ALMT Corp.
Altum RF
AMCAD Engineering
AMD-Xilinx
American Microwave Corp.
American Standard Circuits Inc.
Amotech Co. Ltd.
Ampleon
AmpliTech Inc.
Analog Devices Inc.
AnaPico Inc.
Anoison Electronics LLC
Anokiwave
Anritsu Co.
Ansys
APITech
AR Modular RF
AR RF/Microwave Instrumentation
Artech House
ASI CoaxDepot
Association of Old Crows
Astronics Test Systems
AT Wall Company
Auden Techno
Avalon Test Equipment
B&Z Technologies
Barry Industries Inc.
Benchmark Electronics Inc.
Berkeley Nucleonics Corp.
Boonton
Cadence Design Systems Inc.
Cernex/Cernexwave
Charter Engineering Inc.
ChongQing Ceratronics Technology Ltd.
Ciao Wireless Inc.
Cicor Group
Cinch Connectivity Solutions
CML Microcircuits
Colorado Engineering Inc.
Colorado Microcircuits Inc.
CommAgility
Communications & Power Industries
Component Distributors Inc.
Conduant Corporation
Connectronics Inc.
Copper Mountain Technologies
Corning Inc.
Corry Micronics LLC
Crane Aerospace & Electronics
Criteria Labs Inc
Crystek Corp.
Custom Cable Assemblies Inc.
Custom Microwave Components Inc.
CW Swift & Associates Inc.
CX Thin Films
Dalicap Tech
dB Control
Delta Electronics Mfg. Corp.
Denka Corporation
DeWeyl Tool Company
Diamond Antenna & Microwave Corp.
Diramics
DiTom Microwave Inc.
dSPACE Inc.
Ducommun LaBarge Technologies Inc.
Eclipse MDI
ED2 Corporation
Egide USA
Electro Ceramic Industries
Electro Rent Corp.
Element Six
Elite RF
EM Labs Inc.
EMC Elektronik Ltd.
Empower RF Systems Inc.
EMSS Antennas
ENGIN-IC Inc.
Eravant
ETL Systems Ltd.
ETS-Lindgren
Eureka Aerospace Inc.
European Microwave Week
Evans Capacitor Company
Everything RF/Microwaves 101
evissaP Inc
EZ Form Cable, a Trexon Company
F&K Delvotec Inc.
Filtronetics Inc.
Filtronic Broadband
Fine-Line Circuits Limited
Flann Microwave Ltd.
Flexco Microwave Inc.
Focus Microwaves Inc.
FormFactor Inc.
Fortify
Geib Refining Corp.
Gel-Pak
General Microwave Corporation
GGB Industries Inc.
Glenair Inc.
Global Communication Semiconductors
GLOBALFOUNDRIES
Golden Loch Ind. Co. Ltd.
Guerrilla RF
Harbour Industries LLC
HASCO INC
Hermetic Solutions Group
Herotek Inc.
Hesse Mechatronics
High Frequency Electronics
Hirose Electric USA
Holzworth
HRL Laboratories LLC
Hughes Circuits Inc.
HYPERLABS
IEEE Future Directions: LEO Sats Project
IHP GmbH
IMS Connector Systems
IMST GmbH
InCompliance Magazine
Indium Corp.
Innertron Inc.
Innovative Power Products Inc.
InPack
In-Phase Technologies Inc.
iNRCORE
Inspower Co. Ltd.
Integra Technologies Inc.
Intelliconnect LLC
International Manufacturing Services Inc.
inTEST Thermal Solutions
Ironwood Electronics
Isola/Insulectro
ITF Co. Ltd.
IVWorks Co. Ltd.
IW Microwave Products
JFW Industries Inc.
Johanson Technology Inc.
JQL Technologies Corporation
Junkosha Inc.
Keysight Technologies
Knowles Precision Devices
KOSTECSYS Co. Ltd.
KREEMO Inc.
KRYTAR
KVG Quartz Crystal Technology GmbH
Kyocera AVX
Kyocera International Inc.
LadyBug Technologies LLC
Lake Shore Cryotronics Inc.
Laser Processing Technology Inc.
Leader Tech Inc.
Leonardo
Liberty Test Equipment Inc.
Linear Photonics
Linearizer Technology Inc.
Linwave Technology
Logus Microwave
Low Noise Factory AB
LPKF Laser & Electronics
M2 Global
MACOM
Marki Microwave Inc.
Maury Microwave
MaXentric Technologies LLC
MCV Microwave
Measure Tech Inc.
MECA Electronics Inc.
Mega Circuit Inc.
MegaPhase
Menlo Microsystems Inc.
Mercury Systems
Metamagnetics Inc.
Mician GmbH
Micro Harmonics Corporation
Micro Lambda Wireless Inc.
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First time exhibitors are noted in white.

This information is accurate as of 16 March

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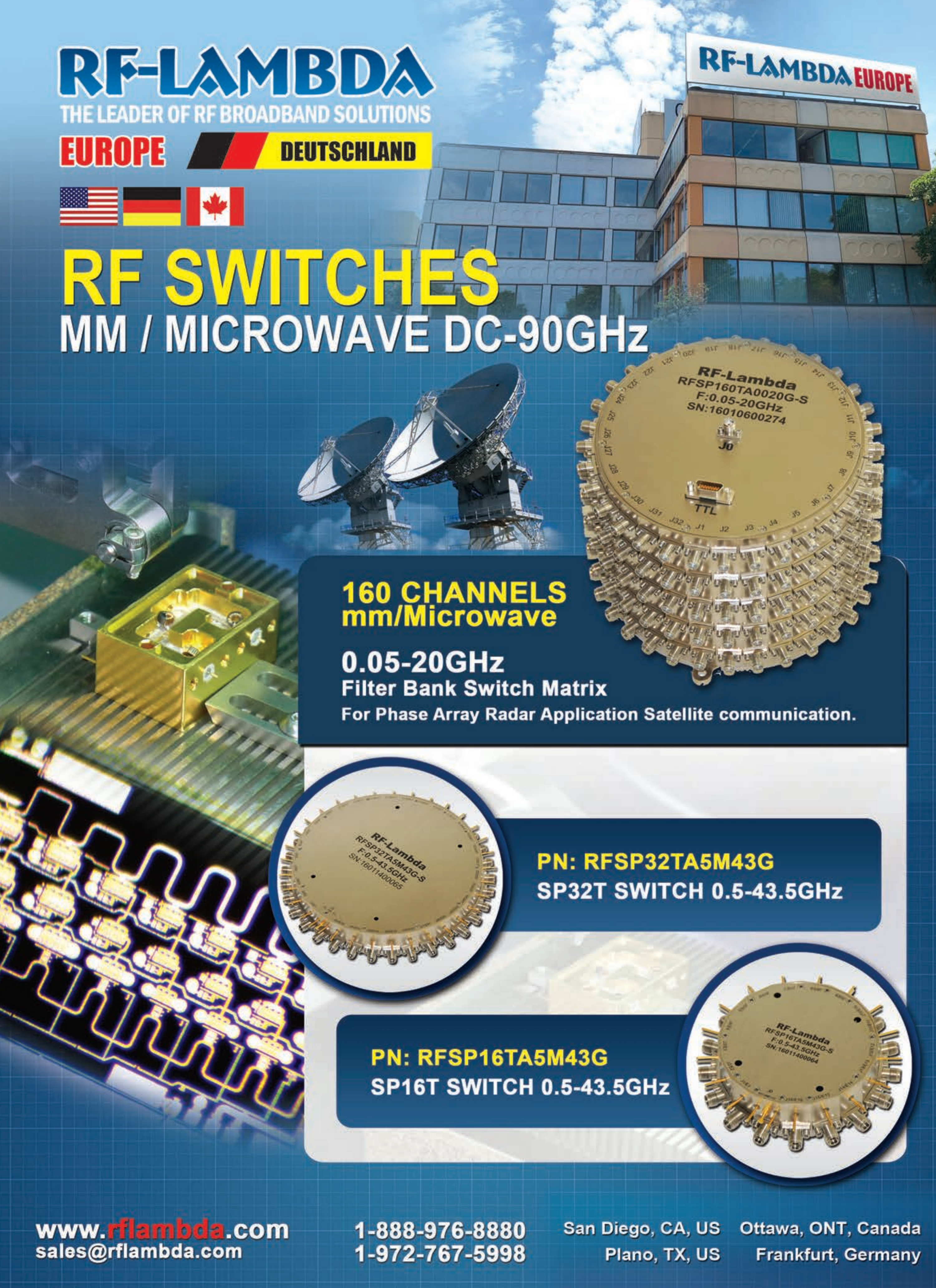
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2022 RFIC Symposium Overview

Osama Shana'a
RFIC 2022 General Chair
MediaTek Inc., USA

Donald Y.C. Lie
RFIC 2022 Technical Program Chair
Texas Tech University, USA

Danilo Manstretta
RFIC 2022 Technical Program Vice-Chair
University of Pavia, Italy



The IEEE RFIC Symposium (RFIC) is the premier annual forum focused exclusively on presenting the latest research results in RF, mmWave and wireless ICs. RFIC is part of the International Microwave Symposium Week (IMS), the world's largest RF & microwave technical convention.

RFIC 2022 will be held at the Colorado Convention Center, in Denver, Colo. starting on Sunday, 19 June 2022 and lasting through Tuesday, 21 June 2022. The RFIC and IMS2022 Organization understands that everyone is concerned with the situation regarding COVID-19. Our primary concern is for the health and welfare of all the attendees, staff and workers involved in IMS2022 week. We will be following the guidelines/mandates set forth by the IEEE and the Denver and Colorado Governments.

We are quite excited to see a very healthy RFIC paper submission this year, which has rebounded back to the pre-pandemic level and with a 47 percent increase from 2021. The technical papers will be presented through parallel sessions on both Monday and Tuesday. Our sessions will include topics spanning from highly integrated wireless systems-on-chip and low-power radios to detailed publications on new power amplifiers (PAs), voltage-controlled oscillators and front-end circuitry. As the 5G market heats up, increasingly more mmWave content is being published at RFIC, as well as sub-THz papers targeting the future 6G.

Continuing in 2022, the RFIC Symposium has an expanded scope that includes RF systems and applications related to novel applications of RFICs at the systems level. This is reflecting the fact that more research challenges are being addressed at higher levels through new architectures, usage models, calibration techniques and integration approaches.

The 2022 RFIC Symposium will feature a rich educational and workshop program on Sunday, 19 June 2022, with 13 RFIC focused workshops and one technical lecture. The RFIC workshops cover a wide range of advanced topics in RFIC technology, which are as follows:

- Digitally Intensive PAs and Transmitters for RF Communications
- mmWave and THz Systems for Near-Field Imaging, Spectroscopy and Radar Sensing Applications
- Wideband and High Efficiency mmWave CMOS PA Design for 5G and Beyond
- Human Body Communications
- Recent Developments in Sub-6 GHz PAs and Front-End Modules
- mmWave Design Challenges and Solutions for 6G Wireless Communications
- Wireless Proximity Communication
- Toward Tbps Optical and Wireline Transceivers: a Tutorial for RFIC Designers
- System Design Considerations for Advanced Radios
- Advanced Interference Mitigation in Integrated Wireless Transceivers
- Large-Scale Antenna Arrays: Circuits, Architectures and Algorithms
- Micro and Nano technologies challenges to address 6G Key Performance Indicators
- Emerging Low-Temperature/Cryogenic Microwave Techniques and Technologies for Quantum Information Processing.

Also, RFIC 2022 will feature an excellent one and a half hour short course, which we call a "Technical Lecture," delivered by a world-renowned educator, during lunchtime on Sunday. For 2022, Prof. Asad Abidi from the University of California, Los Angeles, and a member of the U.S. National Academy of Engineers, will teach "Fundamentals of Noise and Understanding its Effects on RFICs." This lecture should be instructive and beneficial for newcomers and practicing designers alike.

Following the full day of Sunday workshops, the RFIC Plenary Session will be held in the evening beginning with conference highlights and the presentation of the Student/Industry Best Paper Awards. The 2022 RFIC Plenary Session will conclude with two visionary plenary talks:

Dr. Curtis Ling, co-founder and chief technology officer, MaxLinear, will share his vision for the future of RFIC in his talk "The Future of RFIC is Digital." The talk provides a historical perspective and examines the evolution and current state of communication systems-on-chips, highlighting the role of digitally enabled analog. The talk then speculates about where this might take us.

Prof. Sorin Voinigescu, The Stanley Ho Chair of Microelectronics, the director of the VLSI Research Group and a Profes-

sor of Electrical and Computer Engineering at the University of Toronto, will deliver his vision on breaking the speed limits of RFIC in his talk "RFICs into the roaring 20's: Hot and Cold." The talk gives a look ahead to the challenges and research problems RFIC designers will have to address through the end of the decade, a breadth of addressing the power/speed limitations of future circuits and provides possible solutions to the future extremely high-data rate circuits.

Immediately after the plenary session, the RFIC reception and symposium showcase will follow, with highlights from our industry showcase and student paper finalists in an engaging social and technical evening event supported by the RFIC 2022 Symposium corporate sponsors. In addition, some authors, especially system and application papers, will demo their work in a lab-like environment for more close-up discussion and interaction. You will not want to miss the 2022 RFIC reception!

On Monday and Tuesday, RFIC will have multiple tracks of oral technical paper sessions. On Tuesday, there will be a joint panel with IMS on which panelists will discuss the topic of "The race to the next-G: ride the mmWave or wave Goodbye?" This will provide an interesting and provocative debate related to the proper technology for beyond 5G, and on whether mmWave would dominate and perhaps lead to THz, or if the world will continue to largely invest in sub-10 GHz bands.

On Monday, panelists will debate the topic "Industry vs. Academia: who is leading whom?" As we are seeing more professors quitting academia to start companies, while industry leads are becoming adjunct faculty to teach classes in universities. Furthermore, with the lack of university access to very expensive but most advanced process nodes, such as 7 or 5 nm, the state-of-the-art and technical breakthroughs in some areas are starting to come from the industry instead of from academia. We expect an interesting debate on the future of RFIC education, research and support model.

RFIC 2022 and IMS2022 have many educational and professional development opportunities for students. New in 2022, we will have two hand-crafted student events scheduled on Tuesday. The first event is called "Student-Industry CHIPs," in which students can meet industry experts and learn technology trends in the field. The other event is called "Student Entrepreneurship Forum," in which students can learn from successful entrepreneurs the art of founding successful RFIC startups. Additionally, RFIC will once again conduct a contest to select the top student papers from the symposium. These top papers will be featured at our Sunday Symposium Showcase. All RFIC authors will have the opportunity to apply for and participate in the Three-Minute Thesis (3MT®) program.

On behalf of the RFIC Steering and Executive Committees, we welcome you to join us at the 2022 RFIC Symposium in Denver, Colo.

99th ARFTG Microwave Measurement Conference

Jeffrey Jargon,
Jon Martens,
Andrej Rumiantsev
and
Marc Vanden Bossche




Welcome to the 99th ARFTG Microwave Measurement Conference. The Automatic RF Techniques Group (ARFTG) is a technical organization interested in all aspects of RF and microwave test and measurement. Originally created as a users' forum focused on the calibration and automation of early vector network analyzers, ARFTG has grown to encompass all aspects of microwave measurements from RF to Terahertz.

ARFTG's core mission is education. ARFTG achieves this by hosting conferences, workshops and short courses covering a wide range of measurement topics. As well as by awarding fellowships and sponsorships to students. Additionally, ARFTG's close association with the top vendors of measurement instrumentation ensures high-quality exhibits at its conferences. The extended breaks from conference technical sessions enable meaningful interactions to take place among colleagues, students, experts and vendors.

ARFTG sponsors two conferences each year. The fall/winter conference has recently been co-located with Radio & Wireless Week, while the spring/summer conference is co-located with the International Microwave Symposium. The 2022 spring/summer conference will be a single-day event on Friday, June 24. The theme of this 99th ARFTG Microwave Measurement Conference is "From Fundamental to Cutting-Edge Microwave Measurement Techniques to Support 6G and Beyond." Conference topics will cover mmWave over-the-air (OTA) and MIMO characterization, modulated waveform measurements, on-wafer techniques up to terahertz frequencies, techniques for connector-less environments; as well as many other subjects including RF/digital mixed-signal measurement and calibration, nonlinear/large-signal measurement and modeling techniques, traceability in calibrations and measurement uncertainty, material properties characterization and applications and advances in vector network analysis.

Oral technical sessions are presented in a single-track format. Extended breaks combine an exhibition and interactive forum, which provides networking opportunities with vendors and colleagues, whether researcher or practitioner. The conference is preceded by the Nonlinear Network Vector Analyzer Users' Forum and the On-Wafer Users' Forum, both held on Thursday, June 23.

Additionally, ARFTG is co-sponsoring two full-day workshops on Monday, WMK: "On-Wafer mmWave Measurements" and WML: "Measurement and Modeling of Trapping, Thermal Effects and Reliability of GaN HEMT Microwave PA Technology."

On Thursday morning, ARFTG is co-sponsoring panel session PL7: "Modern Phased Arrays and OTA Testing: A Design or a Measurement Challenge?" and focus session Th1F: "Efficient Characterization and Test of Phased Array Antenna Systems: Is It Really a Nightmare?"

Finally, ARFTG is co-sponsoring a technical session that morning, Th2A: "Measurement and Instrumentation Techniques for Evolving Standards in Future Technologies."

ARFTG also offers student sponsorship and fellowship programs. The sponsorship program gives financial aid to students presenting at an ARFTG conference, and the fellowship program provides financial assistance in support of research.

If you have an interest in measurements from 1 kHz to 1 THz and beyond, be sure to add the 99th ARFTG Conference to your plans in Denver this June. You will find our atmosphere to be informal and friendly. For further details regarding the conference as well as the student sponsorship and fellowship programs, visit the ARFTG website.

2π-Labs GmbH
mmWave FMCW VNA Radar System

2πSENSE – Innovative FMCW radar systems operating in the 126 GHz to 182 GHz frequency band are ideally suited for advanced vector network analyzer (VNA)-like use cases such as product inspection, 6G research, material characterization, NDT applications or generic S-Parameter measurements. The 2πSENSE radar technology platform is unrivaled in bandwidth and signal stability performance and offers high flexibility in terms of interfacing (USB or GbE with trigger/synchronization options) as well as RF options (from waveguide to multi-polarization focus lenses) for adapting to your needs.
www.radarlytics.com

Altum RF
MMIC Amplifiers

Altum RF announces new MMIC amplifiers for Q-, V- and E-Band. ARF1208 is a 37 to 57 GHz low noise amplifier (LNA) that has a typical noise figure of 3 dB and 26.5 dB linear gain. ARF1207 is a 57 to 71 GHz linear amplifier that offers 5 dB gain and 22 dBm P1dB output power. ARF1206 is a 71 to 86 GHz LNA that delivers 22 dB gain and 3.5 dB noise figure at 77 GHz. Discover Altum RF for high performance RF to mmWave solutions.
www.altumrf.com

American Microwave Corp.
Power Divider

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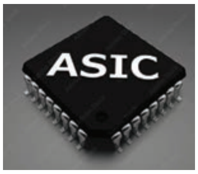
American Microwave Corp. offers model number PDV-6W01, a brand-new power divider (PD6). The power divider has a frequency range of 2.0 to 4.2 GHz with an insertion loss of < 0.74 dB maximum and an isolation of 16 dB minimum. This module has an amplitude balance of 0.7 maximum, a phase balance of 8 degrees maximum on the output ports. These are non-coherent at 1 W at each port. The size is 3.20" × 4.00" × 0.38".
www.americanmic.com

AmpliTech
5G Networks with Anti-Hackable Encryption



AmpliTech Group, Inc. and joint venture partner SN2N LLC have delivered a fully working proof of concept of their field programmable gate array (FPGA) solution, with an intelligence-community-caliber hardware encryption communications channel. The joint venture's solution enables network providers to achieve substantially improved data carriage capacity, speed and security, while significantly reducing related Capex requirements, enabling AmpliTech Group to be the only provider of 5G networks with this anti-hackable encryption security solution.
www.amplitechinc.com

Analog Devices Inc.

VENDORVIEW

X-Band Phased Array Development Platform

Analog Devices, Inc. is developing a X-Band hybrid beamforming phased array radar development platform as a reference design for customers to leverage and accelerate design time. The development platform consists of the ADAR1000EVAL1Z 32-channel beamformer front-end, ADXUD1AEBZ quad channel up-/down-converter, and AD9081-FMCA-EBZ high speed converter. The development platform demonstrates a full hybrid beamforming antenna to bits system capable of being controlled and evaluated with example HDL and software scalable to a customer's end system requirements.

Vector Network Analyzer Front-End

The ADL5960 is a wideband vector network analyzer front-end targeting multi-port VNAs, test equipment and materials analysis to name but a few use cases. The IC consists of a resistive bidirectional bridge, down-conversion mixers, programmable IF amplifiers and filters and a highly flexible local oscillator (LO) interface. The bridge provides > 10 dB of directivity up to 17 GHz and the primary transmission line of the bridge, from RFIN to RFOUT, is wideband impedance matched to 50 Ω.
www.analog.com

Anokiwave Si ICs

Anokiwave has been providing mmWave technology for A&D applications for over 20 years and enables new capabilities in satcom, radar, electronic warfare (EW), communications, NextG and space by leveraging the advances in mmWave Si commercial technologies. Its solutions offer low SWaP-C, flexibility to customize for specific needs and a phased IC development approach to meet budgetary constraints, all with an assured supply chain to support volume demand.
www.anokiwave.com

AR RF/Microwave Instrumentation
RF Test Solutions
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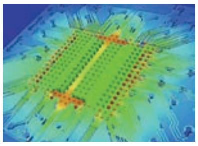
The 75S1G6C, with a signal generator, will provide a minimum of 75 W from 1 to 6 GHz. The low spurious signals and high linearity make it ideal for use as a driver amplifier in testing wireless and communication components and subsystems. It is also suitable for EMC Test applications where class A amplifiers are desired. Visit AR RF/Microwave Instrumentation at IMS to learn more.
www.arworld.us

Boonton
RF Signal Generators

Boonton enters the signal generation market with the new SGX1000 series of RF signal generators delivering a unique combination of high performance and ease-of-use in a compact form factor. The SGX1000 utilizes a proprietary blend of direct digital and direct analog synthesis to provide ultra-fine frequency resolution, lightning-fast frequency switching, ultra-low phase noise and jitter and superior reliability. It brings high performance signal generation at an affordable price for broad use in the semiconductor, military, aerospace, medical and communications industries.
www.boonton.com

Cadence
Wireless Products



Cadence provides engineers developing wireless products for 5G, radar and automotive applications with high-capacity simulation, multiphysics analysis and design interoperability through the Cadence® Virtuoso®, AWR Design Environment® and Allegro® PCB Designer platforms. Cadence will showcase its latest innovations that address IC through system-level design (chip, package and board) including integrated EM and thermal analysis for large-scale systems with the Clarity™ 3D Solver, Celsius® Thermal Solver, and EMX® Planar 3D Solver.
www.cadence.com

CernexWave
Frequency Multipliers
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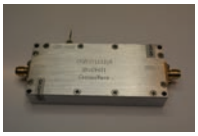
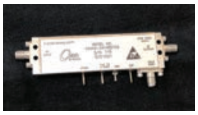


CernexWave's active and passive frequency multipliers cover the frequency range of 10 MHz to over 1000 GHz. They can be designed to multiply an RF signal 2x, 3x, 4x or as many as 64x with our custom multiplier chain assemblies. These multipliers utilize state-of-the-art MIC and MMIC technologies to provide highly stable, reliable and efficient frequency extenders for system applications.
www.cernexwave.com

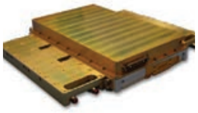
Ciao Wireless Inc.
Amplifiers



Standard models include units with instantaneous bandwidths covering 10 MHz to 6.0 GHz and 24 to 43 GHz (designs for 52 GHz available), to support both the uplink/downlink bands for 5G NR. Designs are available with O/P levels up to +33 dBm P1 dBPT and functions including detectors, switched/RF bypass (TTL), variable gain (digital and VVA), or full rack-mount with ethernet control. Multiple gain levels from 10 dB and up are available, typical noise figures in the 3 to 5 dB range.
www.ciaowireless.com

Communications & Power Industries LLC
VSX3716 X-Band SSPA
VENDORVIEW

CPI's VSX3716 is a conduction cooled, 1.5 kW X-Band solid-state



power amplifier (SSPA) optimized for pulse radars. X-Band SSPA transmitters are efficient, high-power and compact with proven GaN transistor technology. This VSX3716 SSPA is rugged, reliable and easy to maintain. This amplifier utilizes GaN transistors, providing high gain, high efficiency and excellent pulse fidelity. Contact the SSPA experts at ElectronDevices@cpii.com.
www.cpii.com

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Connectronics Inc. has manufactured standard and custom RF connectors and adapters since 1985. Our newest designs address the need to achieve higher frequencies with minimal return loss. Our 1.85, 2.4, 2.92 and 3.5 mm connectors and adapters are manufactured and assembled at our Edinburgh, Ind., facility to meet specific requirements up to 67 GHz and low VSWR. Allow us to design the perfect solution for your project with fast lead times and reasonable minimum order quantities. Visit us at IMS Booth 10082.
www.connectronicsinc.com

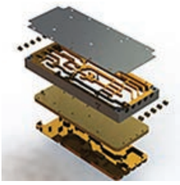
Copper Mountain Technologies
USB VNA
VENDORVIEW

The newest 2-port USB VNA from Copper Mountain Technologies is the first CMT VNA to offer pulse modulation capabilities. The S5180B 18 GHz VNA is perfect for development, manufacturing and testing of high-power amplifiers.
www.coppermountaintech.com

Crane Aerospace & Electronics

RF Converter Miniaturization Using Multi-Mix®

Our multilayer Multi-Mix technology provides a miniature footprint with maximum flexibility and performance. Key benefits include a 5×—10× reduction over traditional converters with packages less than 5" × 2" × 0.5", multilayer Multi-Mix motherboard with double-sided SMT populated in a lightweight housing frame that provides excellent RF channelization and isolation, four integrated coherent wideband synthesizers, embedded pre-select frequency filters and fast tuning and settling times. Let us meet your most complex RF converter needs.



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CMCI1150: 8×8 Non-Blocking Matrix

A 20 to 40 GHz frequency range makes model CMCI1150 switch matrix 5G ready. This solid-state non-blocking 8 × 8 matrix enables the connection of any of eight inputs to any combination of eight outputs. Intuitive browser graphical user interface, integral embedded processing unit server, easy to network, repeatable and reliable performance of solid-state. Applications include Ku-/Ka-Band RF signal routing and 5G system performance testing.

www.customwave.com

Delta Electronics Mfg. Corp.

Customized Gang Mounts

With today's industry trends for higher frequency performance and increased density, Delta's SMP, SMPM and SMP3 gang mount designs are solving engineering packaging and performance challenges. Delta's gang mount designs assure true position for each port, save valuable PCB space and provide reliable connections every single mate. Our hyper-responsive engineering team offers design solutions based on port density requirements, insertion force considerations and return loss performance targets. With SMP3 port counts up to 64, think of the design possibilities.

www.deltarf.com

dSPACE

Radar Sensors

VENDORVIEW

Modern radar sensors are crucial for advanced driver assistance systems and autonomous driving, but validating these sensors is a challenging task. With a dSPACE radar test bench, you can perform easy and reproducible tests using over-the-air (OTA) simulation. Using highly accurate simulation models and a graphical editor, engineers can create maneuvers for realistic traffic scenarios and play them out in real time on the test bench equipped with an anechoic chamber, the DUT, a simulation system, radar target simulators and antennas.

www.dspace.com

Eclipse MDI

Schottky Detector Diode

EZR2018QFN4 zero-bias Schottky detector diode, exhibits broadband flat frequency response, low video capacitance of 20 pF typical, high voltage sensitivity of 1800 mV/mW typical, high sensitivity—without external biasing. These versatile detectors offer a dynamic range of -30 to +20 dBm, are hermetically sealed and operate from -54°C to +100°C. Eclipse MDI ZBD detectors are designed for such applications as power measurements, analyzing radar performance, leveling pulsed signal sources, AM noise measurements, system monitoring and pulsed RF measurements in ultra-broadband and mmWave applications.

www.eclipsemdi.com

Empower RF

Solid-State Tri-Band Amplifier

VENDORVIEW

Empower RF Model 2198 is a solid-state tri-band amplifier in a single 3U chassis and is ideal for general purpose lab and production line test applications. With user selectable modulation and power output modes this amplifier integrates easily into any test system and simplifies test setups with selectable AGC and ALC modes. The amplifier is ready to go out of the box with its built-in browser GUI so there's no software to install for PC or Lan control.

www.EmpowerRF.com

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Solid-state compact scalable modular architecture, tunable in 100 MHz to 1 GHz range, high (10s of GW) peak microwave power, integrated microwave source/radiator, high (> 20) Q waveform implementation of PCSSs triggered by laser diode arrays, low SWAP, no cooling is needed, no external antenna is needed, multiple directed energy weapon applications at large standoffs: Remote neutralization of explosive hazards and IEDs, remote neutralization of UAVs, ground vehicles and boats and nonlethal area denial.

www.EurekaAerospace.com

AMCOM COMMUNICATIONS
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ISO 9001

GaAs FETs pHEMTs

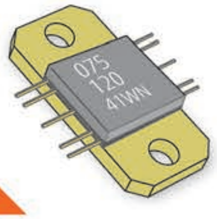
AMCOM's AM030MH4-BI-R is part of the BI series of GaAsHiFETs. The HiFET is a partially matched patented device configuration for high voltage, high power, high linearity, and broadband applications. This part has a total device periphery of 12mm. The AM030MH4-BI-R is designed for high power microwave applications, operating up to 3GHz. The flange at the bottom of the package serves simultaneously as DC ground, RF ground and thermal path. This HiFET is RoHS compliant.

AMCOM's AM005MH2-BI-R is a part of the BI series ofGaAs HiFETs. The HiFET is a partially matched patented device configuration for high voltage, high power and broadband applications. This part has a total device periphery of 1mm. The AM005MH2-BI-R is designed for high power microwave applications, operating up to 6 Ghz. It is also an ideal driver for larger power devices. The flange at the bottom of the package serves simultaneously as DC ground, RF ground, and thermal path. This part is RoHS compliant.

AMCOM's AM032MH4-BI-R is part of the BI series of GaAs HiFETs. The HiFET is a partially matched patented device configuration for high voltage, high power and broadband applications. This part has a total device periphery of 12.8mm. The AM032MH4-BI-R is designed for high power microwave applications, operating up to 6GHz. The flange at the bottom of the package serves simultaneously as DC ground, RF ground and thermal path. This HiFET is RoHS compliant.

AMCOM's AM030WX-BI-R is a discrete GaAs pHEMT that has a total gate width of 3.0mm. It is in a ceramic BI package for operating up to 10 GHz.The BI package uses a specially designed ceramic package with bent (BI-G) or straight (BI) leads in a drop-in mounting style. The flange at the bottom of the package serves simultaneously as DC ground, RF ground, and thermal path. This part is RoHS compliant. For more information on this product or any other AMCOM product visit our website at www.amcomusa.com.

GaN MMIC Amplifiers



The AM07512041WN-SN-R is in a ceramic package with a flange and straight RF and DC leads for drop-in assembly. It has 27dB gain, and 41dBm output power over the 8.25 to 11.75 GHz band. Because of high DC power dissipation, good heat sinking is required.

Model	Freq(GHz)	Freq(GHz)	Gain(db)	Psat(dBm)	Eff(%)	Vd(V)	ECCN
AM003042WN-XX-R	0.05	3	23	42	33	40 / -2	EAR99
AM003042WN-00-R	0.05	3	24	42	35	40 / -2	EAR99
AM206041WN-SN-R	1.8	6.5	30	41	23	+28 / -1.8	EAR99
AM206041WN-00-R	1.8	6.5	32	42	27	+28 / -1.8	EAR99
AM408041WN-SN-R	3.75	8.25	31	41	23	+28 / -1.8	3A001.b.2.b
AM408041WN-00-R	3.75	8.25	33	42	27	+28 / -1.8	3A001.b.2.b
AM00010037WN-SN-R	DC	10	13	37	23	+28 / -1.8	EAR99
AM00010037WN-00-R	DC	10	13	37	25	+28 / -1.8	EAR99
AM00010037WN-QN6-R NEW	DC	10	13	36	25	+28 / -2.0	EAR99
AM08012041WN-SN-R	7.5	12	21	41	20	+28 / -1.9	3A001.b.2.b
AM08012041WN-00-R	7.5	12	22	42	20	+28 / -1.9	3A001.b.2.b
AM07512041WN-SN-R	7.75	12.25	27	41	22	+28 / -1.8	3A001.b.2.b
AM07512041WN-00-R	7.75	12.25	28	42	27	+28 / -1.8	3A001.b.2.b

MMIC in a Box

www.amcomusa.com

Phone 301.353.8400 - www.amcomusa.com - info@amcomusa.com

Eravant

THz Frequency Extender

VENDORVIEW

Using input signals from 12.2 to 18.3 GHz, model STE-KF1803-S1 is a multiplying source extender that delivers full-band coverage from 220 to 330 GHz. Nominal output power is +5 dBm. The extender combines multiplier technology from ACST GmgH with Eravant's high power amplifier expertise. Input signals are applied through a 2.92 mm female coaxial connector. The required input power is +3 dBm. Output signals are provided through a WR-03 anti-cocking waveguide flange. Harmonic and spurious outputs are -15 dBc and -60 dBc respectively.

VNA Test System

Designed to bring transformative changes to how mmWave components are measured, Eravant's tools for extending VNA test capabilities provide full-band frequency coverage from 50 to 220 GHz. VNA upgrades are realized using the STO series of VNA frequency extenders, the STQ-WG series of Proxi-Flange™ contactless waveguide flanges and the STQ-TL series of Wave-Glide™ alignment fixtures. Test system productivity and durability are greatly enhanced by streamlining calibration and measurement operations while preventing physical damage to waveguide components.

Compact Noise Sources

Delivering calibrated ENRs of 15 to 18 dB in a compact package, the -02 and -0T2 models in Eravant's STZ series of noise sources measure 4.0 × 1.2 × 0.8 in. Typical ENR flatness is ± 2 dB over their full operating bandwidths. Configuration options include a 1.85 mm output connector that yields continuous frequency coverage from 0.5 to 67 GHz. Other options include 2.92 and 2.4 mm coaxial connectors as well as WR-19, WR-22 and WR-28 Uni-Guide™ waveguide connectors.

Gaussian Optics Antenna

Supporting point-to-point data transmission at extremely high bandwidths, model SAG-1442244501-059 Gaussian optics antenna provides a 1-degree half-power beam width and 45 dBi gain from 140 to 220 GHz. The circular waveguide feed is 0.059 in. in diameter and supports vertical, horizontal and circular polarizations with low cross-polarization responses. Side lobe levels are -25 dB or less and return loss is 15 dB or better. With a lens diameter of 6 in. the antenna is packaged in a 7-in. diameter housing.
www.eravant.com

MiCable

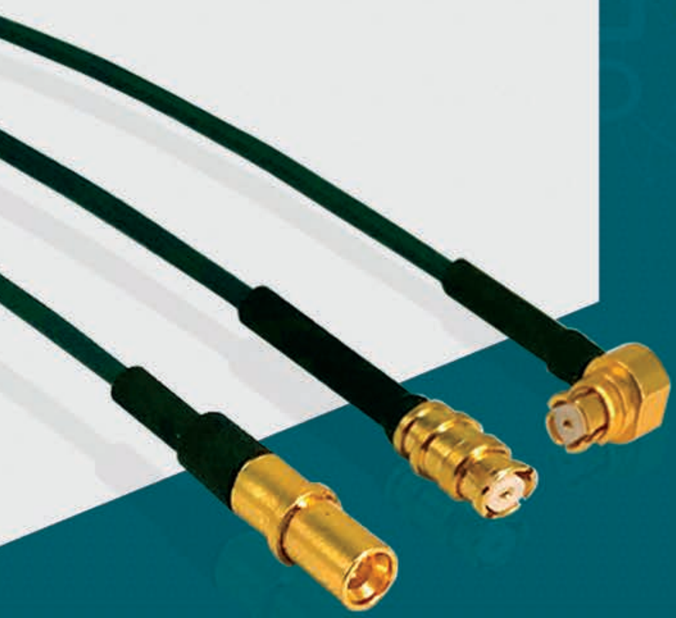
NEW

192 Hours

Salt Spray Test

C25F / High Corrosion-Resistant Microwave Cable Assemblies

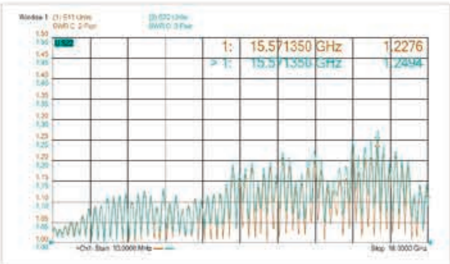
Ideal for the shipborne & internal connection of equipment under various high corrosion environments



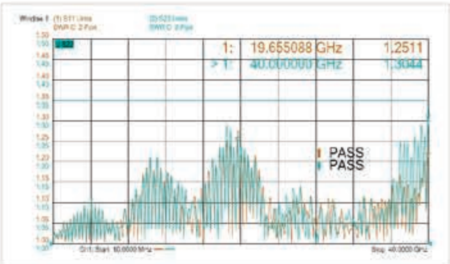
- 192 Hours Salt Spray Test Qualified per MIL-STD-202G
- **Cable Loss:** <4.96dB/m@18GHz
  <7.69dB/m@40GHz
- **Shielding Effectiveness:** <-100dB
- **Phase Stability over Temp.:** 500ppm@-40°C~+70°C
- **Cable Dia.:** 1.42mm

Connectors Available

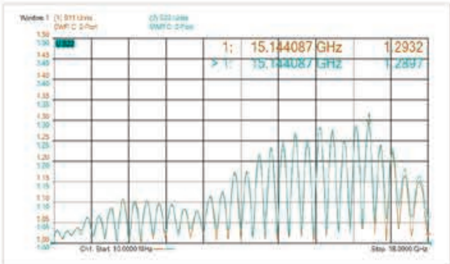
Connector	Gender	Operating Freq. (Max.)	VSWR (Max.)	Remarks
LRM/SSMP-J	Male	18 GHz	1.20:1@6GHz, 1.30:1@18GHz	For LRM Module
SMP-K	Female	40 GHz	1.30:1@18GHz, 1.40:1@40GHz	
SMP-KW	Female RA	18 GHz	1.20:1@6GHz, 1.30:1@18GHz	



LRM/SSMP-J (Dual Port)



SMP-K (Dual Port)



SMP-KW (Dual Port)

More Information-
Scan the QR Code

Fujian MIcable Electronic Technology Group Co.,Ltd
Tel: +86-591-87382856 Email: sales@micable.cn Website: www.micable.cn

Fujian MIcable Electronic Technology Group Co. Ltd.

6-50 GHz Ultra-Wideband 90-Degree Hybrid

VENDORVIEW

MIcable 6 to 50 GHz ultra-wideband (UWB) 4-Port 90-degree hybrid covers multiple microwave frequency bands such as L, S, C, X, Ku, K, Ka and Q by a single unit. Due to extremely wide bandwidth, excellent amplitude and phase unbalance, it can be widely applied in testing, wireless communication and other fields.

4×4 High Accuracy Beamforming Network

MIcable 2 to 8/6 to 18/18 to 40 GHz 4×4 butler matrix can transfer the signal reciprocally from any of four ports to any of other four ports. Because the high performance passive components and cables are used inside, the system has super phase accuracy, amplitude balance, stability and repeatability. They cover multiple microwave bands such as S, C X, Ku, K and Ka, making them an ideal choice for 5G testing, MIMO testing, multipath simulation and performance evaluation, antenna array beamforming and other applications.

www.micable.cn

HASCO Inc.

Littlebend^{TM} Ultra-Flexible RF Cables

VENDORVIEW

HASCO, Inc., a global supplier of just-in-time RF and microwave components, now offers over 100 unique configurations of their new line of Littlebend™ Ultra-Flexible RF Cables, which are designed for demanding microwave interconnect applications and system designs requiring dense packaging. These extremely flexible, triple shielded cables support a minimum bend radius of 0.20" (5 mm), and a high retention force of > 90 N, eliminating the need for right-angle adapters.

www.hasco-inc.com

Herotek

Limiter

Herotek offers a wide range of high-power limiters. Model LS0812PP100A is a 100 W CW limiter operating from 8 to 12 GHz with 1 kW peak, 1 microsecond pulse width limiting protection. It has a low insertion loss of 2 dB and 2:1 VSWR with typical leakage of +13 dBm at 100 W CW input. This limiter comes in a hermetically sealed package with removable connectors for drop in assemble and designed for both military and commercial applications.

www.herotek.com

HYPERLABS INC.

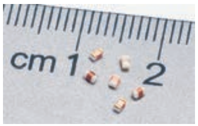
100 GHz Ultra-Broadband Components

HYPERLABS INC. is expanding their industry-leading component line to frequencies up to 100 GHz. To compliment the HL9409 100 GHz Broadband Balun, HYPERLABS is releasing the HL9439 DC Block (2 dB bandwidth from 200 kHz to 100 GHz) and the HL9449 Bias Tee (3 dB bandwidth from 160 kHz to 100 GHz, 175 mA). Both offerings show exceptional return loss out to band edge. The HL9439 and HL9449 are available in 11 or 30 V versions and can be sold individually or in matched pairs. Demos are immediately available.

www.hyperlabs.com

iNRCORE/Gowanda Electronics

Power Chip Inductors



Gowanda's new ceramic core power chip inductor series—SMP0603—is designed for high current handling as needed in DC/DC converters and switching power supplies. The series can also be used in RF applications. Performance range includes: Inductance from 1.8 to 27 nH, DCR ohms from 0.01 to 0.04 and current rating mA DC from 1750 to 3400. Learn more about Gowanda, iNRCORE and the POWERFUL TOGETHER Brand Family at www.inrcore.com/brands or visit IMS Booth 3058.

www.inrcore.com

Insulated Wire Incorporated (IW)

Coaxial Cable Assemblies

Insulated Wire Incorporated (IW) Microwave Products is a manufacturer of low loss phase stable coaxial cable assemblies operating to 70 GHz. Our unique dielectric lamination technique provides exceptional attenuation and phase performance over temperature, and with a range of diameters from 0.034" to 0.750", our cables are suitable for inside enclosure through to system level applications. Various jacketing, armor and interconnect options are available including high power (EIA flanges, 7/16) to mmWave (SMP, SMPM, 2.4 mm, 1.85 mm), making our products suitable for a wide range of military RF/microwave systems.

www.iw-microwave.com

JFW Industries Inc.

Solid-State RF Switches

VENDORVIEW

JFW has added a new line of 50 Ω solid-state RF switches that operate from 20 MHz to 8 GHz. The flagship

model in this line of switches is our 1P8T version, the 50S-2145 SMA (1P2T & 1P4T are also available). All these switches are commercially rated and are ideal for constructing low-cost RF testbeds or automated testing. The switches are controlled with TTL control lines. The switches can hot switch up to +26 dBm and have a typical isolation of 55 dB at 8 GHz.

www.jfwindustries.com

JQL Technologies Corp.

Isolators and Circulators

JQL manufactures surface-mount, microstrip, waveguides, drop in and coaxial isolators and circulators up to 110 GHz. JQL has innovative SMT designs in 5 and 7 mm for high-power applications up to Ka-Band. JQL's filters have found an important spot in 5G applications. JQL manufactures RF filters in various topologies. The Monoblock and Ceramic waveguide filters have become the choice of our customers for 5G systems. When the requirement is high-power and low IMD, JQL has the solution.

www.jqltechnologies.com

Kratos/General Microwave Corp.

mmWave Control Components and Integrated Assemblies

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

www.kratosmed.com

Krytar

Directional Coupler

VENDORVIEW

Model 264030 offers 30 dB of nominal coupling over the frequency range of 26.5 to 40.0 GHz (Ka-Band), in a compact and lightweight package. The coupler lends itself to wireless designs and many test and measurement applications within Ka-Band. Ka-Band is used for commercial and military satcom. Frequency sensitivity of ±0.5 dB, insertion loss of 1.3 dB, directivity greater than 12 dB, maximum VSWR is 1.7. Compact package measures 1.12 (L) × 0.40 (W) × 0.62 in. (H) and weighs 1.0 ounces. Visit us during IMS at booth 1139.

www.krytar.com

Kuhne electronic GmbH

RF Power Meter

The KU PM BB 001800 A is a cost-efficient RF power meter covering frequencies from 10 MHz to 8 GHz. It utilizes two independent channels with a dynamic range of 65 dB. The instrument can be operated stand-alone or as data-logger for monitoring applications. Readings are displayed directly at the device and can be recalled via ethernet. Web interface, CSV-file-export and configuration of the instrument are realized using SNMP or HTTP (JSON). PoE allows usage without additional power-supply.

www.kuhne-electronic.de

KVG

1 GHz OCXO

To meet the increasing demand for high frequency OCXOs with ultra-

low phase noise KVG's engineers have developed a 1 GHz OCXO. Using the advantages of a SC-cut crystal-based oscillator stage in combination with new analogue frequency multiplication, the OXCO provides tight temperature stability and very good long-term stability. The 1 GHz OCXO comes up with excellent phase noise performance near the carrier with better than -112 dBc/Hz at 100 Hz as well as a very low noise floor below -155 dBc/Hz.
www.kvg-gmbh.de

LadyBug Technologies
RF & Microwave Power Sensor

VENDORVIEW

On display for demonstration at IMS2022 booth 2029, is LadyBug's fully self-contained, thermally stable, LB5944A True-RMS power sensor. The sensor offers 44 GHz frequency coverage with an 86 dB dynamic range. Options 50 GHz. Optional autonomous mode has non-volatile storage for over 50 million measurements. Once setup, the sensor only requires power to make and store accurate NIST traceable measurements with no power meter or computer. Ask for a demonstration of our exclusive Unattended Operation at IMS2022.
www.ladybug-tech.com

Logus Microwave
Single and Ganged Waveguide Switches

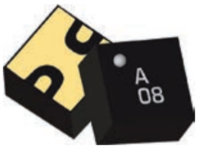
LOGUS WRD180 single and ganged waveguide switches operate across the full band of 18 to 40 GHz and deliver a maximum VSWR of 1.30:1, insertion loss of 0.40 dB maximum (single)/ 0.80 dB maximum (ganged) and a minimum isolation of 50 dB. The switching time is 50 ms typical and are available with Indicators, TTL compatible and your voltage choice. This Logus series can be completely weatherized and also available from WR10 through WR112 and double-ridge WRD180 through WRD750.
www.logus.com

LPKF
Laser-based PCB Development Systems

LPKF's first ever desktop model with the compact tabletop format, the LPKF ProtoLaser ST, can be used in any laboratory for processing materials from FR4 to sensitive RF substrates. The laser system achieves exact geom-

etries on almost any material and is ideal for creating single or double-sided circuit boards, antennas, filters and many applications where precise, steep sidewalls are required.
www.lpkfusa.com

Marki Microwave
Chip-Scale Package (CSP) Attenuator



Part of Marki Microwave's high performance CSP lineup, the ATN-0050CSP1 is a surface-mount GaAs MMIC attenuator featuring 10 dB attenuation from DC to 50 GHz and an excellent 22 dB typical return loss over band. Its 1.5 × 1.5 mm chip-scale packaging allows for extreme miniaturization of the SMT footprint, making it ideal for applications such as airborne, SWaP-C and high channel count systems. Two new MMIC equalizers are also available on the same CSP platform: the MEQ10-45CSP1 and MEQ6-26CSP1.
www.markimicrowave.com

Mercury Systems
Customizable RF SiP

The new RFS1140 system-in-package (SiP) combines 64 GSPS data converters, FPGA processing, memory and power in a single BGA package, lowering system costs and complexity and enabling placement closer to the sensor edge for reduced latency. Manufactured in Mercury's trusted onshore DMEA-accredited facility, the RF SiP directly supports Department of Defense requirements for critical state-of-the-art microelectronics. By delivering the latest commercially developed integrated circuits for use in radar, EW and 5G communications, Mercury's SiP devices revolutionize edge processing by maximizing performance in a trusted, highly customizable architecture.
www.mrcy.com

Mician GmbH
µWave Wizard Software

Mician µWave Wizard software products are geared towards rapid development of passive RF components in aerospace and telecommunications. Typical applications include horn and reflector antennas, feed clusters, OMTs, polarizers, circulators, waveguide and combline filters, multiplexers, couplers and more. Integrated COM/VBA interfaces support external control and third-party add-ons. At IMS Mician will preview µWave Wizard 2022 which is due to be released later in 2022. The new release comes with an all-new user interface, new features and new building block elements.
www.mician.com

Micro Lambda Wireless, Inc.
Programmable Attenuators

Micro Lambda Wireless, Inc. offers the MLAT-Series single channel programmable attenuators, ideal for a wide range of test equipment applications. They provide 0 to 30 dB or 0 to 60 dB attenuation in 0.5 dB steps over the 10 MHz to 21 GHz frequency range. All attenuators are housed in a compact package with SMA female RF connectors. Controlled via USB or SPI, full software support provided and optional temperature ranges available.
www.microlambdawireless.com

Microwave Products Group
Thin Film Filters

Microwave Products Group offers a full range of thin film filters covering a frequency range of 2 to 30 GHz, 2 to 40 percent relative bandwidth and 1.5:1 VSWR. These products feature an extremely small footprint and low profile delivering the best size to performance ratio combination. These filters are available as bandpass, lowpass, highpass, notch (band reject), tunable and multiplexers technologies and are ideally suited for phased array radars, communication links, ESM receiver, UAVs and military communication equipment. Visit us at IMS at booth 6029.
www.klmicrowave.com

Millibox
Three-Axis mmWave/THz Antenna Positioner

Modular in size, GIM05 possesses a resolution down to 0.001-degree and an unprecedented 285-degree field-of-view, where the DUT as big as 15" diagonal (38 cm) is unobstructed by the positioner chassis itself. This allows for very efficient and precise radiation pattern captures and OTA characterization, especially for mmWave radar tests. GIM05 connects to USB with a Python controller delivered in source for painless instrument integration.
www.millibox.org

Morion
Miniature Rubidium Clocks

Morion's RFS-M102 is a 10 MHz rubidium atomic clock having daily aging of ±4E-12 and annual aging of ±5E-10; ADEV is < 5E-11 at 1 sec, < 2E-11 at 10 sec and < 8E-12 at 100 sec. The unit measures 51 × 51 × 25 mm and operates from +12 V. The RFS-M120 has excellent temperature stability of <±1E-10 (-40°C to +80°C) and is available in SIN or LVCMOS output. Retrace (24h ON → 6h OFF → 2h ON) is <±5E-11.
www.morion-us.com

Mini-Circuits

USB-Connected VNA

Mini-Circuits' model eVNA-63+ is a two-port VNA with frequency range of 300 kHz to 6 GHz. With test-port power from -50 to +10 dBm and low trace noise of typically 0.005 dB RMS, the VNA achieves a dynamic range of typically 132 dB. It has Type-N female signal connectors and integrated bias tees for active-device measurements. The VNA operates under USB-connected computer control with included GUI and API software, features electronic calibration and performs time-domain analysis.

Coaxial Amp

Mini-Circuits' model ZHL-2425-250+ SSPA capable of 300 W (+54.8 dBm) typical CW or pulsed output power across the ISM band from 2.4 to 2.5 GHz. It provides 42 dB typical gain with 60 percent typical power-added efficiency (PAE) but measures just 6.750 × 2.20 × 0.80 in. (171.450 × 55.880 × 20.320 mm) with MCX input and N-type output connectors. The rugged 50 Ω amplifier has simple TTL control and draws 16 A at 32 VDC.

Coaxial Amplifier

ZVA-71863HP+ is a high-gain coaxial amplifier with 38 dB typical gain and +24 dBm typical saturated output power from 71 to 86 GHz. It runs on a single supply voltage, from +10 to +15 VDC, drawing 490 mA at +10 VDC. Well suited for 5G networks, automotive radar, satcom and mmWave test systems, the amplifier has internal circuitry to protect against damage from DC over-voltage and reverse voltage. It is equipped with 1.0 mm female coaxial connectors.

Frequency Extender

Mini-Circuits' model FX-30G-RC is a frequency extender with buffer amplifier that provides output signals from 10 MHz to 30 GHz at levels to +20 dBm with ±1 dB output power accuracy. It forms a seamless interface with the 15 GHz model SSG-15G-RC signal generator, boosting its frequency range to 30 GHz while maintaining low harmonics of -40 dBc and spurious content of -70 dBc. It is simply controlled by Ethernet or USB connection to an external computer running FX software.

Smart Sensor Reads

Mini-Circuits' model PWR-40PW-RC is an advanced power sensor that can measure peak and average power from -20 to +20 dBm across frequencies from 500 MHz to 40 GHz. Its 10 MHz modulation bandwidth and 20 million samples/s sampling rate aid power measurements of complex modulation formats while a 30 MHz video bandwidth enables power measurements of automatic level control (ALC) circuits. The power sensor, which includes full software support, connects to an external computer via Ethernet or USB port.

VENDORVIEW

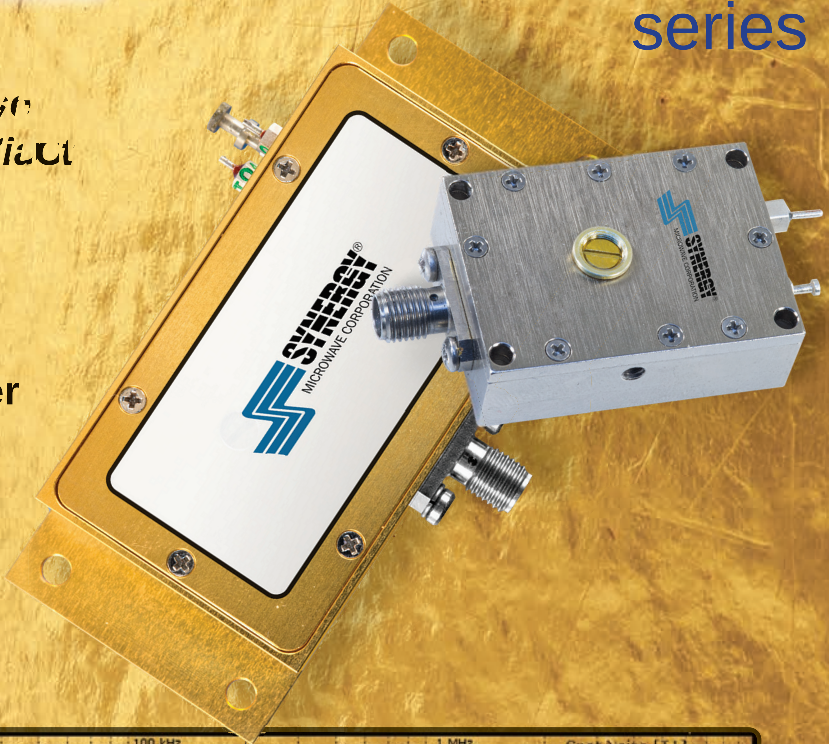
www.minicircuits.com

GOLD STANDARD

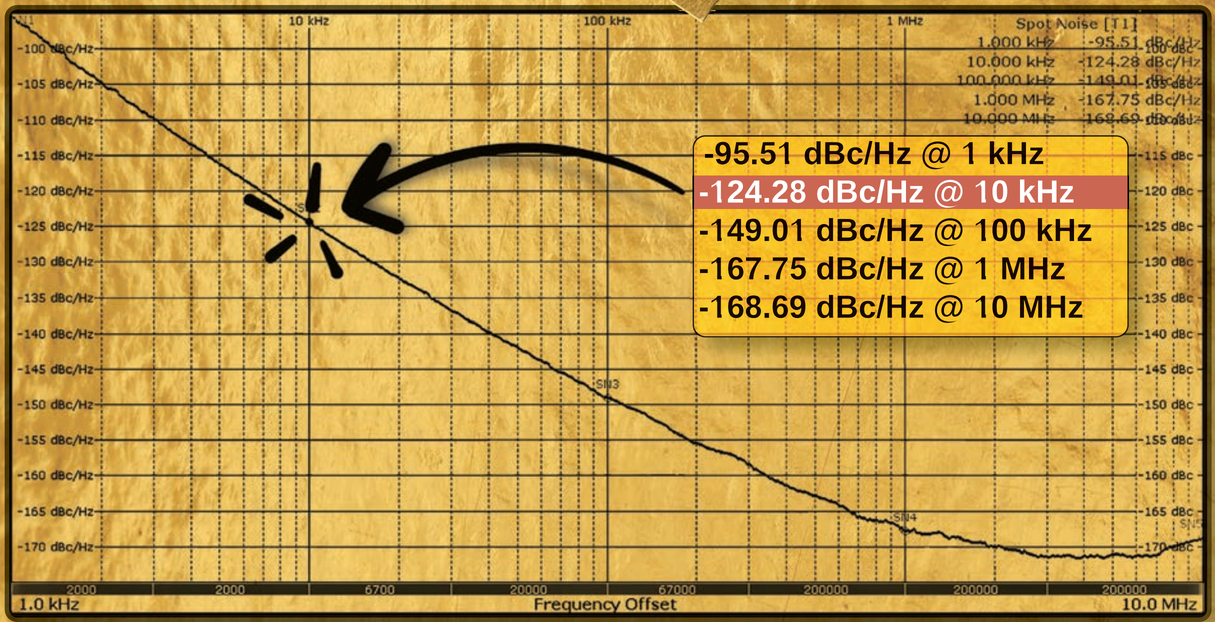
8 to 15 GHZ DRO / SDRO series

FEATURES:
- Exceptional Phase Noise
- Lead Free RoHS Compliant
- Patented Technology

Applications:
Radar, Test Equipment,
5G, Frequency Synthesizer



SDRO Series
0.75" x 0.75 x 0.53"



Talk To Us About Your Custom Requirements.

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E-mail: sales@synergymwave.com | Web: www.synergymwave.com
Mail: 201 McLean Boulevard, Paterson, NJ 07504

Networks International Corp.
Thin Film Filters

NIC's engineering expertise includes a specialty in thin film filters that span from 1 GHz to 26 GHz. They offer a compact package size with low profile of < 0.08 inches. The filters also offer high selectivity and out of band rejection of > 60 dB. Whether your challenge is a small form factor, high-power, tough electrical specifications or cost, NIC's unique products showcase a variety of creative solutions for all of your radar and communications needs. Please stop by booth #7014 for additional information.
www.nickc.com

Norden Millimeter
Custom Transceivers

VENDORVIEW

Norden designs custom transceivers for military and commercial applications including airborne, UAV and EW. They have "catalog" models which provide wideband RF and up to 1.5 GHz IF with low phase noise. Norden can provide custom designs which incorporate temperature compensation, variable gain and meet military environmental requirements. Norden also offers models in a low SWaP 3U VPX module which includes a built-in LO. Norden engineers utilize proven designs to provide low risk, cost-effective solutions.
www.nordengroup.com

Nxbeam Inc.
Ka-Band 25 W Power Amplifier

Nxbeam's NPA2003-FL is a GaN Ka-Band high power amplifier in a high performance leaded flange package. The part operates from 27 to 31 GHz and provides an average of 25 W saturated output power, 15 W of linear power, 25 percent PAE and 23 dB of linear gain. The amplifier consists of three independently biased gain stages provided flexibility to tailor linear power performance to specific application needs.

www.nxbeam.com

Orolia
Miniaturized Rubidium Oscillator

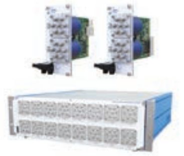
The mRO-50 is the latest breakthrough low SWaP-C Miniaturized Rubidium Oscillator designed by Orolia to meet the latest commercial, military and aerospace requirements where time stability and power consumption are critical. It provides a one-day holdover below 1 μs and a retrace below 1 × 10-10 in a form factor (50.8 × 50.8 × 19.5 mm) that takes up only 51 cc of volume and consumes only 0.45 W of power, or about 10x less than existing solutions with similar capabilities.
www.orolia.com

Pasternack
5G RF Components

VENDORVIEW

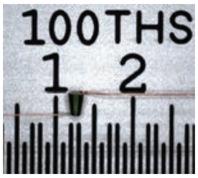
Pasternack offers a large selection of antennas that operate in the sub-6 GHz and mmWave frequency bands for 5G telecom and wireless applications. These 5G cellular waveguide antennas include standard gain horns, conical horns, scalar feed horns, lens horns and omni-directional antennas with waveguide flanges. These high-quality 5G waveguide antennas are in stock and ready to ship today.
www.pasternack.com

Pickering Interfaces
Microwave Multiplexers



Pickering Interfaces, the leading supplier of signal switching and simulation solutions for electronic test and verification, showcases its range of microwave multiplexers with a maximum frequency of 67 GHz in SP4T and SP6T form factors. The higher frequency PXI/PXIe multiplexers (model 4x-785C) and LXI multiplexers (models 60-800 and 60-803) maintain the same physical dimensions as existing lower frequency products, enabling users to upgrade to 67 GHz products while maintaining the same slot count/rack height test systems.
www.pickeringtest.com

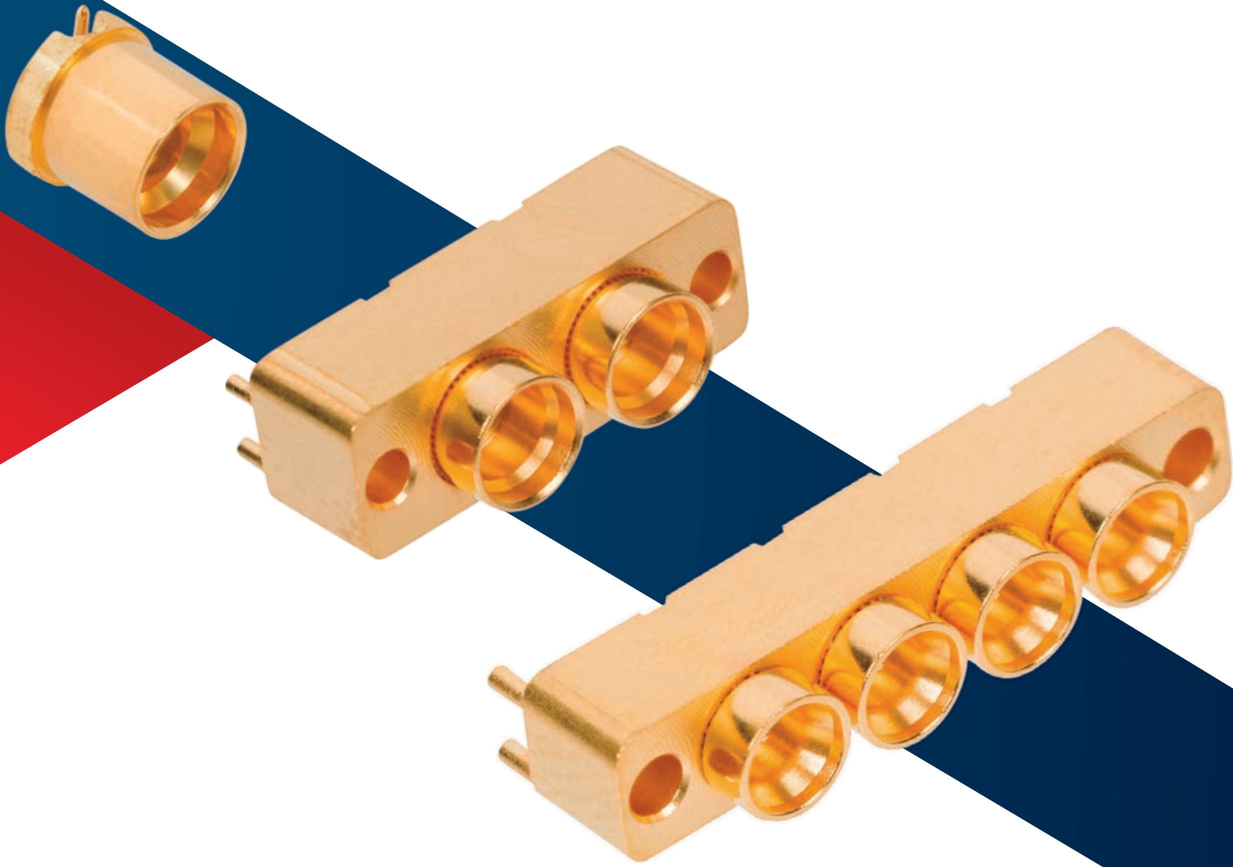
Piconics Inc.
Pure Gold Conical Inductors



Piconics Inc. introduces a new line of broadband conical inductors utilizing 99.9 percent pure gold wire. The Pure Gold Broadband Conical Inductors series offers enhanced reliability when bonding to delicate metallization structures while maintaining the same performance as traditional copper wire conical inductors. By utilizing pure gold wire, designers avoid the oxidation, corrosion and hardness issues commonly associated with copper wire bonds. Typical applications include bias tees, broadband amplifiers, high speed switches. Samples are currently available.
www.piconics.com

Pixus Technologies
OpenVPX & SOSA Aligned Chassis Platforms

With expertise in 100 GbE+ high speed designs, Pixus is the premier solution for VITA 66/67 OpenVPX and SOSA aligned solutions. Our enclosures are renowned for superior cooling and design quality. With a vast array of COTS OpenVPX backplane profiles and MIL rugged enclosures, Pixus can help you get started.
www.pixustechnologies.com



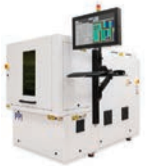
PPG Cuming Microwave Corp.

Engineered Solutions for Telecom and 5G Applications

Engineered solutions for telecom and 5G applications, including noise suppression, resonance elimination, passive intermodulation problems and antenna side lobe suppression; elastomeric, foam and castable microwave absorbers, standard and custom solutions available. Ask about our new C-SHIELD 685, a PIM reduction paint for cell sites, rooftops and indoor systems. Provides shielding from RF test facilities, labs or wherever protection against RF energy is required. Visit us at booth #10044.
www.cumingmicrowave.com

PPI Systems Inc.

RapiTrim™



PPI continues to expand the range of advanced fixturing and probing solutions for its laser resistor trimmers. The RapiTrim™ family of products covers all trimming requirements from thick film to thin film to semiconductor wafers. PPI offers turnkey solutions for all trimming needs, from standard component and circuit trim to complex active-trim scenarios with custom fixturing. Manual loading, internal stack loader, magazine loading or custom automation are all available. RapiTrim products are The Future of Resistor Trimming™.
www.ppisystems.com

Qorvo

2-Stage Power Amplifier Module

VENDORVIEW

The QPA3908 is an integrated 2-stage power amplifier module designed for massive MIMO applications with 8 W RMS at the device output covering frequency range from 3.7 to 3.98 GHz. The module is 50 Ω input and output and requires minimal external components. The module is also compact and offers a much smaller footprint than traditional discrete component solutions. The QPA3908 incorporates a driver and Doherty final stage delivering high power-added efficiency for the entire module at 8 W average power.
www.qorvo.com

Quantic PMI

mmWave Products up to 65 GHz

VENDORVIEW

Quantic PMI has expanded their product offering with a variety of new LNAs, digitally-controlled attenuators, high power limiters, solid-state switches (SPST to SP16T) that operate up to 65 GHz for 5G and mmWave mission-critical applications. Select from standard designs or custom products can be designed to meet your most demanding electrical, mechanical and environmental specifications. Visit us at booth #8080.
www.pmi-rf.com

Quarterwave

3U Rack-Mountable Amplifiers

The new 9103 series is offered as 3U rack-mountable amplifiers, with standard models providing frequency coverage of 2 to 8 GHz and 6.5 to 18 GHz, with output power ratings of 300 W CW or 1.5 to 2 kW pulsed. All of Quarterwave's amplifiers feature low noise, high PRF, optional touch screen interface and are fully customizable. Other models of amplifiers are capable of covering 0.8 to 40 GHz, with an output rating of up to 50 kW.
www.quarterwave.com

Reactel Incorporated
Filters, Multiplexers and Multifunction Assemblies

VENDORVIEW

Celebrating its 43rd Anniversary, Reactel will feature its full line of filters, multiplexers and multifunction assemblies covering up to 67 GHz at IMS2022. From small, lightweight units suitable for flight or portable systems to high-power units capable of handling up to 25 kW, connectorized or surface-mount, large or small quantities—our talented engineers can design a unit specifically for your application and deliver quickly. Visit us in booth 9006 to discuss your requirements and visit with our engineering team.
www.reactel.com

RelComm Technologies Inc.
Coaxial Relays

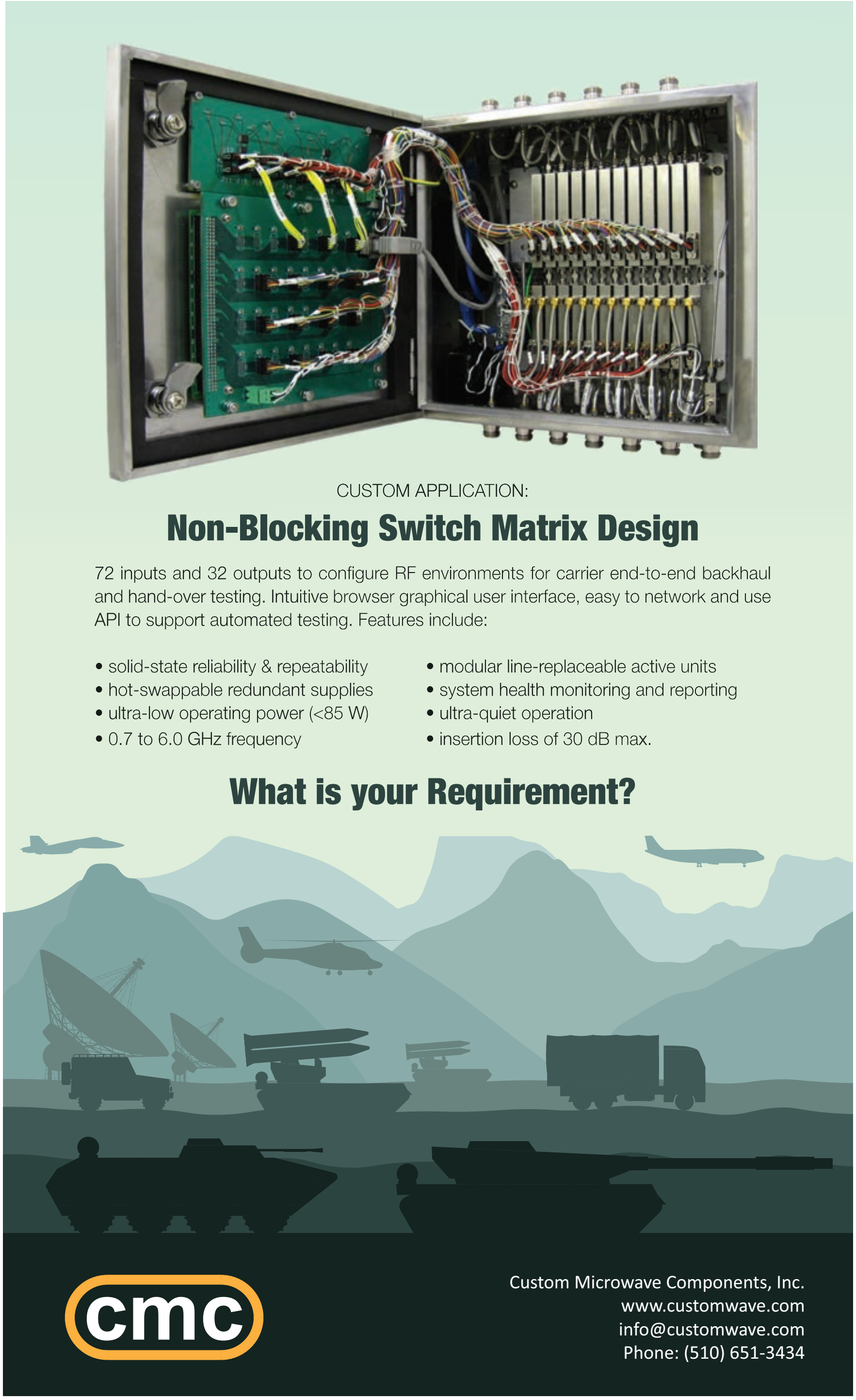
RelComm Technologies, Inc. introduces coaxial relays to 40 GHz configured with 2.9 mm connectors providing excellent RF performance which are well suited for 5G and other high frequency applications. Pictured here is our miniature transfer switch that measures 1-inch wide × 1.5 inches tall. The relay is RoHS compliant. It is available in failsafe or latching configurations with 12 and 24 V DC operation. Options include auxiliary position indicators, splash proof sealed and TTL controlled input.
www.relcommtech.com

Renesas
Phased Array Beamforming ICs

Renesas beamforming ICs enable cost-effective, next-generation system solutions for 5G, satcom and radar applications. Each IC contains multiple independently controlled active channels for element-level beam pattern shaping in ESAs. The compact devices are available in planar BGA or QFN packages to realize very low profile and small form factor phased array antennas with λ/2 element spacing. Tx, Rx or TRx variants are shipping now and cover all of the common 5G and satcom frequency bands.
www.renesas.com

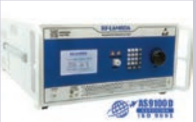
Microwave Journal IMS2022 SHOW COVERAGE

Be sure to check out mwjournal.com/ims2022 for all products featured at this year's IMS2022 in Denver.



RF-Lambda

300 W, 6 to 18 GHz, EMC Power Amplifier



RF-Lambda's EMC/AC powered rack-mount amplifiers offer UWB operation up to 100 GHz and 2 kW of output power. This 300 W, 6 to 18 GHz EMC power amplifier provides 90 dB of gain and a typical Psat of 55 dBm. Features include a large, easy to read LCD screen and a digital control attenuator offering 31.5 dB attenuation range with an 0.5 dB step size. Applications range from military/aerospace, test and measurement and 5G wireless communications.

400 W, 2 to 6 GHz, EMC Power Amplifier

RF-Lambda EMC/AC powered rack-mount amplifiers offer UWB operation up to 100 GHz and 2 kW of output power. This 400 W, 2 to 6 GHz, EMC power amplifier is loaded with features such as temperature compensation, auto calibration, as well as over current, over temperature and input overdrive protection. The unit also supports ethernet control and monitoring. Applications range from military/aerospace, test and measurement and 5G wireless communications.

Q-/V-/W-Band AC RF Amplifier

RF-Lambda EMC/AC powered rack-mount amplifiers offer UWB operation up to 100 GHz and 2 kW of output power. This Q-/V-/W-Band AC RF amplifier is loaded with features such as a wide frequency range from 71 to 76 GHz, gain of 21.5 dB with a flatness of ±1.5 dB. The output power is 20 dBm typical. Applications range from military/aerospace, test and measurement and 5G wireless communications.

AC Low Noise Amplifier

RF-Lambda's EMC/AC powered rack-mount amplifiers offer UWB operation up to 100 GHz and 2 kW of output power. This AC LNA covers 84 to 100 GHz, with gain of 16 dB and an output power of 1 dBm typical. Applications range from military/aerospace, test and measurement and 5G wireless communications. **www.rflambda.com**

Richardson RFPD

RF Front-Ends

Richardson RFPD introduces RadioCarbon, frequency-specific RF front-ends that include full Tx chain with up to 45 dBm output and receiver with as low as a 2.3 dB noise figure. These RadioCarbon RFFEs are combined with the BytePipe, 0.03 to 6 GHz system on module (SoM) that includes a highly integrated transceiver with DPD and FPGA. The SoM can be mounted on the RFFE boards and be used as a reference design, evaluation board, prototyping platform or for demonstration purposes.
www.Richardsonrfpd.com

RLC Electronics

C-Band Cavity Filter

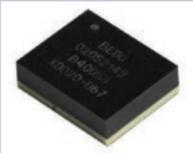
RLC Electronics announced the release of our "Weightless," 6-gram, C-Band cavity filter. Founded on high Q cavities and engineered to provide premium RF performance, these new miniaturized filters boast low insertion loss (typically 0.6 dB maximum over operating temperature) and excellent power handling capabilities, up to 60 W cW. The filter pictured measures 0.8"× 0.46"× 0.46", utilizing GPO connectors to save space and eliminate the need for cables at the system level. Custom options are available to 46 GHz.

www.rlcelectronics.com

RFMW

Revolutionary Ideal Switch™

VENDORVIEW



The MM5120 is a high-power DC to 18 GHz SP4T switch built on Menlo Micro's innovative technology. This ultra-reliable switch, capable of handling greater than 25 W with over 3 billion switching cycles, is perfect for replacing large RF electromechanical relays. In RF/microwave solid-state switching applications, where linearity, insertion loss and high reliability are critical parameters, the MM5120's low insertion loss of 0.4 dB at 6 GHz and superior IIP3 of > 90 dBm makes this switch the ideal solution.

Small Cell Amplifier for DPD Designs

The QPA9909 is a high efficiency, linearizable power amplifier targeting 758 to 798 MHz small cell wireless infrastructure systems. The product delivers high efficiency of 37.7 percent at +29 dBm average output power, while providing excellent DPD linearized ACPR of -52 dBc for signal bandwidths of up to 40 MHz. The QPA9909 is housed in a 5 × 5 mm SMT package. It is pin-to-pin compatible to QPA9901, QPA9903, QPA9907, QPA9908, QAP9940 and QPA9942.

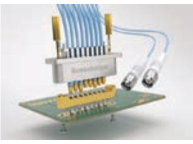
Two-way Splitter/Combiner

MiniRF Inc. has extreme broadband splitters/combiners for all your signal path needs. It covers 2 MHz to 3 GHz with > 25 dB isolation between ports and excellent return loss in a small surface-mount package with a very low profile (0.115 maximum). MiniRF offers both 50 Ω and 75 Ω versions of the MRFSP8525 & MRFSP8725 in a micro 0.150 × 0.150 footprint. Achieve consistency and repeatability in your RF design with MiniRF "Passives with a Passion for Performance."

www.rfmw.com

Rosenberger

Multiport-Mini-SMP



Rosenberger introduces Multiport Mini-SMP cable assemblies and PCB connectors which can be mounted solderless on PCBs. The PCB connectors offer superior signal integrity for all kinds of PCBs and can be connected with Mini-SMP – RPC-2.92 cable assemblies for frequencies DC to 40 GHz or with Mini-SMP – RPC-1.85 cable assemblies for frequencies up to 65 GHz. The system is available with eight or 16 channels. The multiport mini-SMP system is very cost-effective—designed solderless, easy to assemble by using screws.

www.rosenberger.com

Samtec

1.35 mm, 90 GHz Solutions

Samtec has released a new family of mmWave products: 1.35 mm coaxial connectors. 1.35 mm solutions are ideal for precision, high frequency E-Band applications to 90 GHz and offer a robust mechanical design. Samtec's 1.35 mm family of products include compression mount board connectors (135 Series: microstrip or stripline), cable connectors (PRF13 Series) and cable assemblies (RF047-A Series). Samtec also offers board launch optimization and personalized RF and Signal Integrity support for increased system performance.

www.samtec.com

Signal Hound

Spectrum Analyzer and Monitoring Receiver

Signal Hound's SM435B, a high performance spectrum analyzer and monitoring receiver, will expand your reach into mmWave spectrum analysis at an affordable price point. Tuning from 100 kHz to 43.5 GHz, this next-generation SM-series analyzer has 160 MHz of instantaneous bandwidth,110 dB of dynamic range, 1 THz/sec sweep speed at 30 kHz RBW (using Nuttall windowing), ultra-low phase noise and PC connection via USB 3.0. The SM435B continues the Signal Hound tradition of unrivaled value. Available for purchase June 2022.

www.signalhound.com

Signal Microwave

Edge Launch Connector

Signal Microwave's new line of higher performance edge launch connectors is designed for the thinner substrates used today. 1.15:1 maximum connector VSWR through 40 GHz (23 dB return loss). The data shown is for two connectors on a 1 in. 8 mil RO4003 substrate with an FR-4 backer. The new design of the connector is intended for substrate thicknesses between 5 to 10 mils (0.005" - 0.010"), (0.127 to 0.254 mm).

www.signalmicrowave.com

SignalCore Inc.

Signal Synthesizers

The SC801A and SC802A fully integrated broadband CW signal synthesizers are the smallest in their class with the best phase noise on the market. Their miniature surface-mountable package measures only 2.75" × 1.75" × 0.31". The SC801A frequency range is 625 MHz to 10 GHz, while the SC802A range is from 1.25 to 20 GHz, both tuning at 1 mHz resolution with typical phase noise < -115 dBc/Hz at 10 kHz offset of a 10 GHz signal.

www.signalcore.com

Smiths Interconnect
TSX High Frequency Surface Mountable Chip Attenuators

VENDORVIEW

Smiths Interconnect's TSX fixed chip attenuator series is designed to offer excellent broadband performance up to 50 GHz, while delivering increased power handling in a small 0604 surface-mount package. It allows wider coverage than traditional components while providing optimized return loss for multiple frequency ranges. This allows the customer to use a single chip in multiple applications, reducing the bill of material item count and consequently, the cost of ownership.
www.smithsinterconnect.com

Southwest Microwave
SuperMini Board-to-Board Solutions

Southwest Microwave's SuperMini Board-to-Board (SSBB) solutions are ultra-high frequency, miniaturized push-on blind-mate connectors for high density PCB interface. The SSBB product line features advanced bullet and receptacle designs, accommodating misalignment of up to 10 mils axial or ±10 degrees radial with no performance degradation. The unique construction of the bullets extends mating and de-mating cycles and enables board-to-board spacing as close as 3 mm. Configurations include stacking, edge-mount, backplane and front panel applications.
www.southwestmicrowave.com

Stellant Systems
K-Band Quad Space nanoMPM®

Stellant Systems' K-Band Quad Space nanoMPM® is a state-of-the-art RF power amplifier for use in satellite downlink applications, specifically designed to enable the next generation of software-defined satellites utilizing phased array antennas for increased flexibility while on-orbit. This product delivers the ultimate performance by leveraging the best of solid-state and TWT vacuum technology. Utilizing a high-gain pre-distortion solid-state linearizer, wideband high-power mini-TWT and proprietary compact nanoMPM® EPC designs, the B3400H series bridges the gap between solid-state amplifiers and traditional space LCTWTAs.
www.stellantsystems.com

SV Microwave

75 Ω D38999 Circular RF Cable Assemblies

SV Microwave has just released a line of high performance 75 Ω D38999 circular RF cable assemblies. High performance true 75 Ω video connections are critical when high-definition video feeds from camera to receivers are needed. Unlike many video cables which use 75 Ω cables and standard 50 Ω connectors, SV's D38999 contacts have a true 75 Ω impedance construction, which assures a high fidelity signal in 3G SDI, 4K and 8K video feeds. Now in stock through distribution: https://bit.ly/3NxYnXl.

www.svmicrowave.com

Taitien USA

NK-H Type OCXO

The Taitien NK-H type offers big OCXO performance in a small 14 × 9 mm package. Available from 10 MHz to 40 MHz, the 6-pin Hermetic SMT package is ideal for outdoor applications such as small cell and IEEE-1588. With excellent long-term aging the stability is as low as ±10 ppb (-40°C to +85°C). The phase noise is <-145 dBc at 100 Hz and <-160 dBc at the floor.

www.taitien.com

Tecdia Inc.

Dielectric Varactor

Made with a unique tunable dielectric, ideal for phase shifters, VCO's, tunable filters and tunable matching networks with high linearity requirements. The dielectric maintains a low ESR, even up at mmWave frequencies. These varactors maintain microsecond level switching speed and are SMT compatible. Tecdia has a range of capacitance values and form factors that are available for samples upon request.

www.tecdia.com

Transline Technology Inc.

Printed Circuit Boards

Transline Technology Inc. is a manufacturer of RF/microwave, hybrid and standard PCBs, flex and rigid-flex PCB, photo-chemical etching, metal etching and large PCBs. ISO 9001:2015, AS9100D and SDB 8(a) Certified ITAR registered and UL listed.

www.translinetech.com

WavePro®

Low Loss RF Dielectric for Antennas

Materials science and manufacturing innovation can help you design better antennas. Our made-to-order dielectric introduces new possibilities. Reduce antenna size with a high dielectric constant material (Dk = 12+), improve antenna efficiency with a low Dk 2.5, or increase bandwidth with a thicker material. WavePro® is available in flat panels up to 375 mil thick, conformal surfaces and 3D shapes. Take your antenna design to the next level. Get started at Waveproantenna.com.

www.waveproantenna.com

Wenzel Associates Inc.

VPX Card Assembly Frequency Sources

Wenzel Associates' offers card assemblies in VPX SOSA compliant form factors as well as other platforms to provide low phase noise performance at frequencies up to 16 GHz for operation in static and demanding dynamic environments. Each card assembly is comprised of an industry-leading ultra-low noise

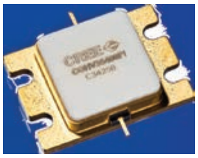
ovenized crystal oscillator (hard mounted or vibration isolated), frequency conversion circuits and other hardware mounted or integrated on a specified card assembly to provide a high performance frequency source with unparalleled phase noise performance.
www.wenzel.com

West•Bond
7KF Bonder

The 7KF bonder with our new 7" capacitive touch sensing LCD displayed is designed with a gantry style chassis enabling unlimited part size capacity. Our exclusive 8:1 ratio, purely orthogonal X-Y-Z Micromanipulator allows the operator to place bonds very precisely, and is convertible between ball bonding and wedge bonding, presenting bond wire at both 45 degrees and 90 degrees for deep access and ribbon bonding capabilities is an excellent tool for RF, microwave, semiconductor, hybrid and medical device fields applications.
www.westbond.com

Wolfspeed
Enabling S-Band Long-Pulse Performance

The Wolfspeed CGHV35400F1 has been upgraded for long-pulse S-Band applications and offers superior drain efficiency. It is a GaN IM FET, matched to 50 Ω, operating from 2.9 to 3.5 GHz. At 50 V, it can



deliver > 500 W output power under long pulse conditions of 2 mS pulse width at 20 percent duty cycle. Wolfspeed continues to address the high performance needs of the aerospace and defense industry with products supporting wider pulse conditions up through CW. Learn more at booth 2060.
www.wolfspeed.com

Z-Communications
Smart PLL Signal Generator

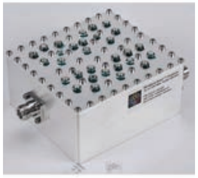
The new Smart PLL series from Z-Communications is a line of programmable signal generators providing both versatility and high performance for equipment operators looking for quick and adaptable solutions. The units are available in several frequency ranges, like the SSG3400, covering the C-Band from 3.3 to 4.2 GHz. Multiple functions like frequency, output power, step size and sweep mode are controlled through a mobile app, or PC via USB connection. An internal 100 MHz reference or external reference connection add to the versatility.
www.zcomm.com

NEW PRODUCTS

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

3H Communication Systems

Microwave and RF Filter Products



Microwave and RF filter products from DC to 50 GHz, Type: BPF, LPF, HPF, BRF, multiplexer and high-power products up to 30 kW. 3H offers low profile packages starting at < 0.065, available with connectors and SMT, Mil-Std-202 conditions. All backed by 3H's five-year warranty.

www.3hcommunicationsystems.com

Accel-RF Instruments

AARTS Platform

Key design features of the industry standard Accel-RF AARTS platform have been redeployed to provide a precise, economical HTRB tester solution. The modular, adaptable configuration allows testing of any semiconductor technology in various package types using world-class fixturing techniques. Precision-controlled heater elements are used rather than an oven-based approach to provide more finite temperature resolution and greater test flexibility. Multi-channel test drawers stack within a rack to provide maximum channel density with minimal lab footprint.

www.accelrf.com

Besser Associates Inc.

RF Technology Certification

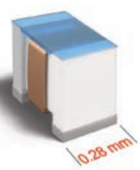
BESSER ASSOCIATES

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

www.besserassociates.com

Coilcraft

Chip Inductors



Measuring just 0.47 × 0.28 × 0.35 mm, Coilcraft 016008C Series chip inductors are the smallest wire-wound chip inductors in the world. They are offered in 36 inductance values from 0.45 to 24 nH and feature up to 40 percent higher Q factors than the best thin-film counterparts. High Q is required to minimize insertion loss in RF antenna impedance matching circuits, making the 016008C Series ideal for high frequency applications such as cell phones, wearable devices and LTE or 5G IoT networks.

www.coilcraft.com

COMSOL Inc.

Multiphysics® Version 6.0

COMSOL Multiphysics® version 6.0 and the add-on RF Module offer new functionality for the design of microwave and mmWave devices. A computationally efficient boundary element method speeds up the simulation of scattering problems such as an antenna placed on a large platform. The RF Adaptive Mesh study step simplifies model setup of antennas and circuits by finding optimal mesh for PCBs. The Model Manager—a new platform feature fully integrated with the Model Builder and Application Builder in COMSOL Multiphysics®—enables data management and collaboration including version control, advanced search and efficient storage of models and apps.

www.comsol.com

COMTECH PST

GaN Amplifier

COMTECH PST introduces a new GaN amplifier for ground or surface X-Band radar applications for 9.2 to 9.7 GHz over an instantaneous bandwidth of 500 MHz. Development of this product is for a TWT Replacement. The amplifier design features self-protection for load VSWR, duty factor, pulse width and temperature. This solid-state power amplifier (SSPA) increases MTBF 10x compared to TWTs, resulting in lower overall costs. Comtech supports custom configurations and features are available as well as specific power levels up to 16 kW.

www.comtechpst.com

Cosmic Microwave Technology, Inc.

SiGe Low Noise Cryogenic Amplifier

The CITLF3 is a Silicon Germanium (SiGe) low noise cryogenic amplifier, intended for radio astronomy and quantum physics applications. The amplifier achieves an average noise temperature of 4 K (0.06 dB)

over a frequency range of 0.01 to 4 GHz when cooled to a physical temperature of 12 K or less. Gain is 33 dB and the input/output return losses are less than -10 dB. Typical supply voltage is 2 V at 13 mA.

www.cosmicmicrowavetechnology.com

CTT Inc.

Solid-State 40 W GaN PA

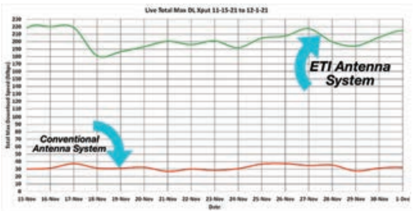
CTT's GaN-based SSPA offers frequency coverage of 3 to 18 GHz with 40 W of CW power output. The compact size of Model AGX/180-4656, 5.16 (L) x 4.9 (W) x 0.28 (H) in. gives RF/microwave designers an excellent choice for multi-band SWaP-C solutions in many applications, including electronic warfare (EW) jammers, radar and for transmit power in military and commercial multi-band satcom terminals. Systems can benefit from improvements in: reduced size and weight, higher efficiency, wider bandwidth, reduced cost and system power efficiency.

www.cttinc.com

Electromagnetic Technologies Industries

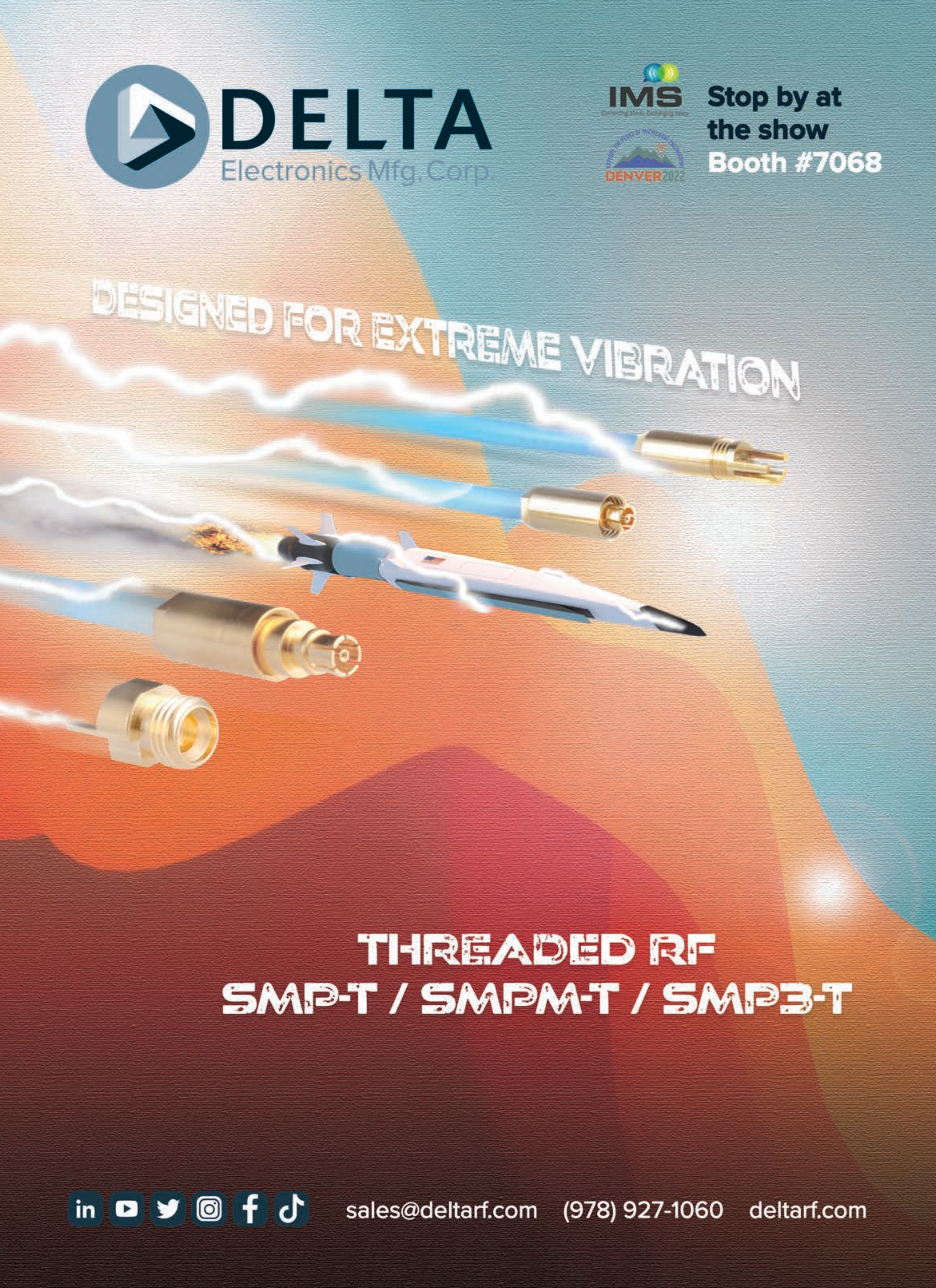
Multibeam Antenna System

VENDORVIEW



A cost-efficient multibeam antenna system that requires no external electricity or software input to operate is provided by ET Industries. Depending on the model, up to 32 beams can be achieved. Each beam multiplies and repeats the total available spectrum, thus, increasing the available data throughput. Live results for a four-beam antenna system are presented in the figure showing quadrupling of data rates for an urban environment with a population of 3 million. Frequency reuse eliminates costly purchases of additional spectrum.

www.etiworld.com


DELTA
Electronics Mfg. Corp.
IMS
DENVER 2022
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Booth #7068
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THREADED RF
SMP-T / SMPM-T / SMP3-T
sales@deltarf.com
(978) 927-1060
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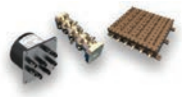
NewProducts

Exceed Microwave

Passive Components

VENDORVIEW



Exceed Microwave provides custom high performance passive microwave component designs up to 110 GHz for defense, space and commercial applications. Exceed Microwave is AS9100 certified and ITAR registered, providing high-quality, high performance passive components. Exceed provides various types of designs, each with its own unique values and are designed and made in U.S. Many of Exceed's designs offer extremely high Q factor, allowing very low insertion loss and high-power handling.

www.exceedmicrowave.com

Exodus Advanced Communications

Solid-State Amplifier

VENDORVIEW

Exodus AMP2085P-LC is a robust 2 to 8 GHz, 500 W pulse/CW amplifier. The perfect replacement for aging TWT amplifiers. Ideal for commercial EMC/EMI lab applications, automotive pulse/radar tests and Mil-Std 461. Up to 100 percent duty cycles, 57 dB minimum gain, outstanding pulse fidelity, monitoring parameters for forward/reflected power in Watts and dBm, VSWR, voltage, current, temperature sensing for unprecedented reliability and ruggedness in a compact 7U chassis of 12.25 (H) × 19 (W) × 29 (D) in. nominally 90 lbs.

www.exoduscomm.com

Fairview Microwave

Fixed Waveguide Attenuators

VENDORVIEW

Fairview Microwave now offers waveguide fixed attenuators that consist of 30 models with operating frequency range up to 110 GHz. These products are available in waveguide sizes from WR-10 to WR-28 with UG style cover flanges. They offer excellent RF performances to meet diverse application requirements. All of Fairview's products are available in-stock and same-day shipping.

www.fairviewmicrowave.com

GeoSync Microwave Inc.

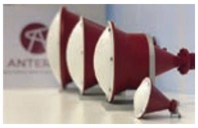
C-Band LNA Series

A C-Band LNA incorporating a high rejection filter blocking 5G signals is now available from GeoSync Microwave. The series of five models offers the flexibility to choose either the full 3.4 to 4.8 GHz range as the passband or four other models with narrower pass-bands, such as 3.7 to 4.2 GHz. Sharp rejection of -65 dB at 100 MHz off the edge of the passband is nominal for all models.

www.geosyncmicrowave.com

Impulse Technologies

Lens Horn Antenna



Anteral's Lens Horn Antennas are conical horn antennas with a plano-convex Teflon (PTFE) lens added in the aperture, in order to apply phase correction and achieve superior performance with minimum size. They are designed to cover the frequency range of 8 to 170 GHz in 11 bands with 30 dB nominal mid-band gain. Anteral optimizes all designs to show not only high gain, but also low VSWR (< 1.3) and low side lobes. Custom bands and gain values can be requested.

www.impulse-tech.com

Information Systems Laboratories

Virtual RF HIL Flight Testing

ISL's real-time hardware-in-the-loop (HIL) RTEMES® system enables for the first time, virtual flight testing of advanced RF systems for radar, ELINT and EW applications. It supports multi-channel RF systems from VHF to Ku-Band and is based on a cost-effective digital COTS transceiver/FPGA architecture. RTEMES® is designed to seamlessly integrate with ISL's RFView® RF digital engineering tools including high-fidelity, physics-based modeling and simulation. As such, far more extensive and stressful testing can be performed on the actual flight hardware than what is possible in traditional range testing.

www.islinc.com

INGUN

Test Probes, Test Fixture Kits and Accessories

INGUN is a worldwide leading manufacturer of test probes, test fixture kits and accessories for the quality assurance of electrical and electronic products.

www.ingun.com/en-GB

Knowles

RF Filtering

The Knowles DLI brand continues to expand its RF Filtering options with newly acquired lumped element and ceramic resonator filters to go alongside its SMD high frequency microstrip filters. The company's filters offer stable performance over a wide temperature

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SAGE Millimeter is now Eravant, a change that renews our commitment to the millimeterwave industry. Since 2011, we have been delivering quality products and energizing the customer experience to meet the needs of RF engineers working on the technology of the future.

The Proxi-Flange™ is constructed with a special waveguide flange populated with an array of small pin-like structures to realize RF choking actions. The Proxi-Flange™ avoids the problem of poor return loss and high insertion loss caused by imperfect contact when two waveguide flanges are mated.

Captive screws in conventional waveguide test sets can cause cocking issues when they are tightened unevenly. Common results include poor measurement consistency and accelerated test port damage. **Proxi-Flange™ eliminates the need for waveguide screws**, improving test set performance and durability while increasing measurement speed.

WHY PROXI-FLANGE™?

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range, -55°C to 125°C, and are rigorously tested to ensure the highest standards. Whether you're changing to higher frequencies or looking to reduce footprint and weight, Knowles has a solution!
www.knowles.com

MCV Microwave
Exact Shape Ceramic Filters

MCV Microwave, a leader in high Q dielectric resonator, substrate and filter, is offering high performance exact shape ceramic filters to space, aerospace, defense and military industries. These bandpass filters maintain exact shape with matched delay over a wide frequency range in the same footprint. A typical filter exhibits low passband insertion loss, exact 6 dBc bandwidth of < 100 MHz and 60 dBc bandwidth of < 250 MHz from 650 MHz to 1250 MHz in a low profile package of 0.55 × 0.4 × 0.118 in. MCV also offers a series of band reject filters from UHF to GPS frequency.
www.mcv-microwave.com

M Wave Design
C-Band Isolator

The 187IR1203 is a C-Band isolator rated at 320 kW peak and a 320 kW average designed to protect high-power tube amplifiers.
www.mwavedesign.com

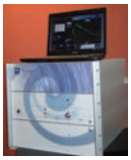
Narda Safety Test Solutions
SignalShark

VENDORVIEW

Narda Safety Test Solutions extends the spectrum of applications for its SignalShark with functions for broadband mobile signal monitoring and real-time analysis. Therefore, Narda collaborates with PROCITEC, the specialist for software-based signal processing. The aim was a perfect measurement system for land, sea and air-based wireless communication systems. The combination of the robust yet highly sensitive real-time receiver, and the go2MONITOR software defines state-of-the-art in mobile automatic radio signal monitoring and evaluation units.
www.narda-sts.com/en

OEwaves
Phase Noise Analyzer

OEwaves OE8000W HI-Q® W-Band phase noise analyzer offers ultra-low phase noise floor < -150 dBc/Hz extending across 40 to 110 GHz frequency range. This homodyne-based system is unique in wide mmWave



band measurement without requiring another low noise reference source or external mixer, as required in conventional approaches. The system operates with ease, speed and precision using a simple graphic user interface via a notebook PC. The OE8000W features cross-correlation, residual phase noise and AM noise measurement among other upgrades and options.
www.oewaves.com

OML
Portable Compact Signal Generator Module

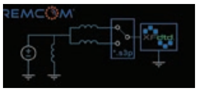
OML introduces the new SxxMPS Series compact version of its mmWave frequency extender for signal generators. The new, compact S12MPS multiplier signal generator covering 60 to 90 GHz is only 2.12 (L) × 1.64 (H) × 3.72 (W) in. and can be powered via USB 2.0 power port. This innovative small compact design module is targeted for portable field applications and is fully compatible with Keysight FieldFox analyzers. Contact OML for more details.
www.omlinc.com

Pulse Genex
Pulse Generator

Pulse Genex announces its new mid-cost range pulse generator. Its engineers were tired of the over-complicated user interfaces on other pulse generators so Pulse Genex came up with the Bulldog. It is designed for ease of use and offers four-channel output, ModBus communication and user-defined fault limits to protect your equipment. It generates pulses with programmable relative timing and is capable of remote operation with a provided graphic user interface. The Bulldog is available in both benchtop and rackmount models.
www.pulsegenex.com

Remcom
XFdtd®3D EM Simulation Software

VENDORVIEW

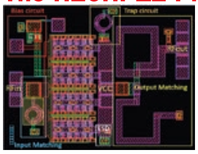


XFdtd®3D EM simulation software features a new schematic editor and frequency-domain circuit solver, enabling advanced antenna matching network and corporate feed network analyses, including multi-state and multi-port devices. Various use cases that the schematic editor supports include simple pi or T matching networks, multi-state and multi-port aperture or impedance tuners and corporate feed networks with digital phase shifters. With the ability to connect to multiple full-wave simulations, XFdtd reveals operating modes for different frequency bands and physical configurations.
www.remcom.com

Rigol
Digital Oscilloscope

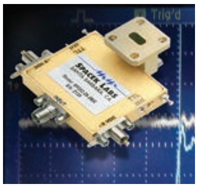
RIGOL's most powerful oscilloscope ever—StationMax DS70000 is available in 3 or 5 GHz bandwidths, four channels, 20 GSa/sec sampling, 1 million wfms/sec, 2 Gpts memory depth and high-resolution measurements to 16 bits. DS70000 provides outstanding performance, speed and analysis with a completely new interface designed for the 15.6" multi-touch display. Powerful analysis capabilities include real-time spectrum analysis, EMI debugging and multi-domain analysis, eye diagram and jitter analysis.
www.rigolna.com

Sanan-IC
The H20HP12 Process



Sanan-IC has released its latest GaAs HBT technology called the H20HP12 process which meets high linearity requirements in wireless communication applications such as 5G NR HPUE. Excellent PA performance can be obtained together with outstanding harmonic suppression and higher delivered linear power. Its epitaxial structure, developed and manufactured in-house, exhibits lower V_{CE} (offset) and lower V_{knee} on its I-V curve.
www.sanan-ic.com

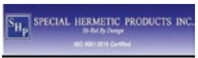
Spacek Labs
Ka-Band Power Amplifier



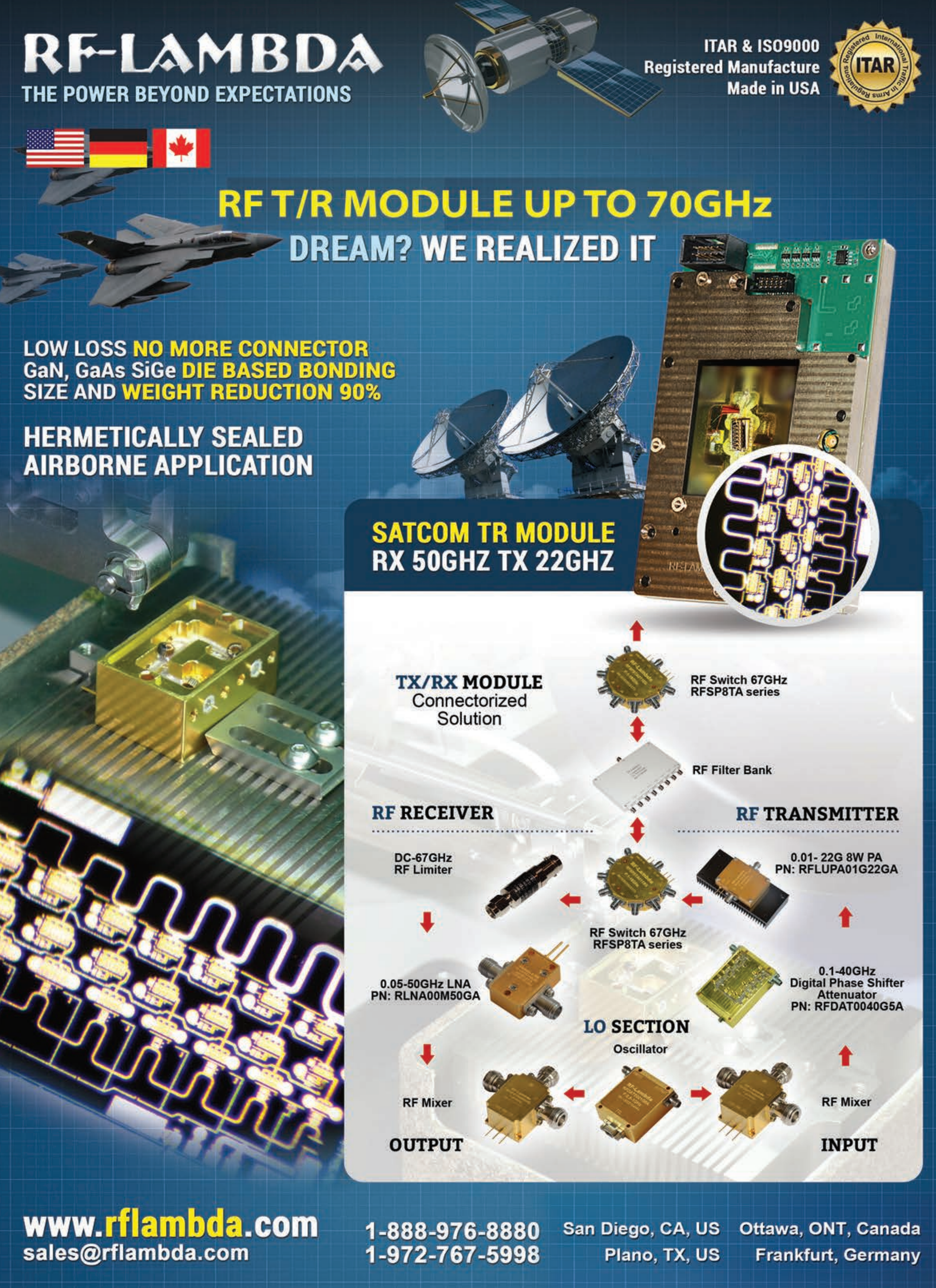
This compact high-power amplifier, SP352-25 to 38 W, is designed for use from 32 to 38 GHz. 100 nSec switching speed is controlled using TTL. Saturated output power is 6 to 7 W typical, ideally suited for communication and radar applications. Nominal gain is 35 dB with VSWR less than 2:1 at both ports.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

Special Hermetic Products Inc.
Hermetic Seals

VENDORVIEW



Special Hermetic Products Inc. (SHP) products set you on the path to ZERO failures. SHP is unmatched in its breadth of standard products and application knowledge in the hermetic packaging area. Since the company designs and manufactures every type of glass sealed product and the packages in which they are used, as well as direct-glassed packages in various materials, SHP is in the unique position of offering essentially all possible solutions.
www.shp-seals.com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New**Products**

Spectrum Instrumentation GmbH

Next-Generation PCIe Digitizers

VENDORVIEW

Two new digitizer cards from Spectrum Instrumentation raise the standard of PC-based instrumentation performance. The cards are capable of streaming acquired data over the PCIe bus at an impressive 12.8 GB/s—nearly 2x as fast as any other PCIe digitizer currently on the market. It means they can continuously run at their maximum sampling rate of 6.4 GS/s, with 12-bit resolution, streaming this massive data to CPUs or CUDA GPUs for real-time processing.
www.spectrum-instrumentation.com

Synergy Microwave Corp.

Bi-Directional Couplers

Explore the specifications of Synergy's SBCHP, SCCHP and SDCHP surface-mount, high directivity, bi-directional couplers. These are an asset for monitoring power on antenna ports or sampling power in feed-forward amplifiers. These cover the combined frequency range between 10 to 820 MHz, with coupling values of 11, 15, 18 and 20 dB and with input power ratings of 25 to 100 W, depending on the model. Available in package sizes of 0.375 × 0.5 × 0.275 in. and 0.94 × 0.94 × 0.4 in.
www.synergymwave.com

Taiyo Yuden USA Inc.

High Q Capacitors

TAIYO YUDEN's High Q capacitors, MSAR and MBAR series, provide an excellent performance of low dielectric loss, low-power dissipation and better efficiency compared with standard MLCCs. They have copper inner electrodes, which realize superior Q factor with low ESR. Remarkably, the company's High Q MLCC lineup is designed for RF module applications: MSAR series is the best suited for mobile communication devices including smartphones and tablets, MBAR series is ideal for high reliability RF market, including base stations, telecommunication networks and more.
www.t-yuden.com

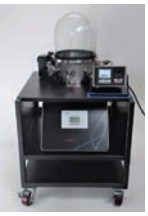
Tamagawa Electronics

Up-/Down-Converter Module

Tamagawa Electronics has developed a multi-channel mmWave up- and down-converter module for prototyping and testing 5G beamforming. The MMCX module covers 27.5 to 28.5 GHz with 1 GHz instantaneous bandwidth and an IF frequency of 3 GHz. It interfaces with up to 32 antennas. Both analog and digital beamforming are used to create the beams, and both can be used simultaneously. The analog beamforming module controls from four to 32 systems, and the digital beamforming module supports up to eight.
www.tmeleus.com

TotalTemp Technologies

Thermal Platforms and Chambers



TotalTemp offers new products and features to elevate your testing. Its thermal platforms and chambers always help you get the job done efficiently. And now: cloud storage technology. Circle-chart recorders and manual plots are history, your test results can be most effectively reported, stored, emailed PDF or sent to network printers or the Synergy Server. Plus, space simulation chambers. The advantages of thermal platforms are a natural fit for conductive heat transfer testing in high vacuum applications. 70°C to +175°C, 1×10^{-6} Torr.
www.TotalTempTech.com

New**Products**

Wenteq Microwave
Low Noise Amplifier

Model ABL1800-01-3330DP is a SMA connectorized low noise amplifier offering 33 dB linear gain and 3 dB typical noise figure over the frequency range from 0.1 to 18 GHz with input over drive protection. The amplifier requires a single DC power supply and can operate from +12 V. The package size of the amplifier is 1.5 × 1.0 × 0.4 in.
www.wenteq.com

Wilson Electronics
Network 257

Extend and strengthen high band 5G coverage outside with WilsonPro's innovative Network 257. Using dielectric waveguide antennas to efficiently optimize mmWave 5G, Network 257 supports donor or service beamwidths, from 8 to 45 degrees. This flexibility allows for the dual-polarized units to maximize non-line-of-sight coverage, eliminate coverage gaps and redirect 5G on the edge of service. The ideal repeater for amplifying mmWave, the Network 257 is cost-effective, efficient and rapid-to-deploy.
www.wilsonelectronics.com

Wright Technologies
1 to 20 GHz Series Amplifiers

The newly released ASL20B series amplifiers feature extended frequency operation. The ASL20B series products consist of gain blocks with +20, +30 and +40 dB. The noise figure levels are +2 dB typical and +2.7 dB maximum out to 20 GHz. The output P-1dB is +21 dBm typical and +18 dBm minimum 1 to 20 GHz. Like all WT products the ASL20B series amplifiers are battle tested and backed with the four-year warranty program. This type of service can give customers the support they need for long term uses reducing costly replacements. All WT products are RoHS compliant and burn-in tested for 48 hours at +50°C.
www.wrighttec.com

Würth Elektronik
Proteus-III-SPI

Würth Elektronik presents the Bluetooth low energy 5.1 module Proteus-III-SPI. The module, measuring only 8 × 12 × 2 mm, with a payload of up to 964 bytes, integrated antenna, encryption technology and six configurable IO pins, is based on the Nordic Semiconductor nRF52840 chipset. It can be used for IoT and M2M applications, for example, to build radio-based maintenance interfaces and sensor networks. The WE-ProWare firmware from Würth Elektronik, which has been industrial proven over many years, makes the module extremely versatile.
www.we-online.com

16Tx/16Rx Direct L-/S-/C-Band Sampled Phased-Array Platform

Targeted to quickly enable customer demonstrators within the A&D market, ADI demos a multi-purpose 16-channel phased-array radar, EW and satcom platform based on four of the newly-released AD9081 MxFE ICs.

Analog Devices

https://bit.ly/37ZPGov

Enabling High Performance, Cost-Effective Satcom Connectivity

Anokiwave enables satcom OEMs to realize their potential with high performance, cost-effective Si IC solutions for active antennas that are available in high volume now.

Anokiwave

https://r99ud.app.goo.gl/GoWC

Telecommunication Testing on Relevant RF Components

This resource reviews how the air interface layer has changed throughout this digital evolution and explains how systems often need to be upgraded to meet the new criteria.

AR RF/Microwave Instrumentation

https://bit.ly/3Ihzlrt

Designed for Extreme Vibration

Delta's threaded SMP-T, SMPM-T and SMP3-T have been added to their website. Designed for hypersonic, airborne and space launch applications, with board-to-cable and cable-to-cable mechanical schemes, designed in Delta's robust, low profile solutions.

Delta RF

www.deltarf.com

Frequency Synthesizers for Quantum Computing & More

GeoSync updated their website to include an array of 1 to 18 GHz synthesizers, 16 total, all in a 1 RU rack. See the GS50 data sheet online.

GeoSync Microwave

www.geosyncmicrowave.com

POWERFUL TOGETHER Brand Family

The POWERFUL TOGETHER brand family now includes iNRCORE, Gowanda Electronics, TTE Filters, DYCO Electronics, RCD Components and Bicron Electronics. Learn more about high performance power and signal components from each brand/company at this new webpage. Visit us at IMS booth 3058.

iNRCORE

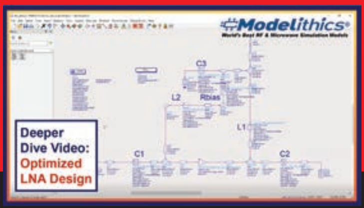
www.inrcore.com/brands

INRCORE

Modelithics Deeper Dive: Optimized LNA Design

This new video demonstrates how designers can optimize the noise figure performance of designs that feature a MMIC low noise amplifier using Modelithics models.

Modelithics
www.youtube.com/watch?v=CtzPU79wHhk



Miniature Rb Atomic Clock Improves Military Communications Performance

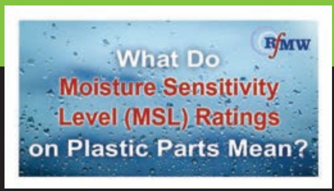
This document describes how the use of the mRO-50 addresses problems that can be seen on ground or mobile platforms using the LTE waveforms as example.

Orolia
https://bit.ly/3KbxQx5

What do MSL Ratings Mean?

A Moisture Sensitivity Level (MSL) indicates the amount of time a moisture-sensitive device can be exposed to ambient conditions prior to reflow. Learn more here.

RFMW
https://rfmwblog.com/2022/02/14/what-do-msl-ratings-mean/



Advanced Automation for Laser Resistor Trimmer Systems

PPI continues to add to the available automation options for the RapiTrim laser resistor trimmer systems. Standard stack loaders and magazine handlers can be customized to suit any requirement.

PPI Systems
www.ppisystems.com/blog

The Lowest Dielectric Loss In the Industry

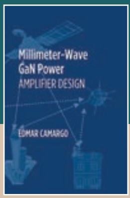
With Df = 0.0006, ceramic-filled PTFE and Dk = 2.5 at 2.4 GHz, WavePro® makes it possible with a made-to-order, high performance dielectric. Visit the all-new website to learn more and request a sample kit for prototyping.

WavePro ®
WaveProAntenna.com

Rethink 5G Testing

Designed to make 5G testing as simple and straightforward as never before, the R&S CMX500 enables even complex test setups for all 5G NR deployments, supporting a large variety of the present and future 3GPP band combinations, all in a single box.

Rohde & Schwarz
rohde-schwarz.com/rethink5Gtesting



Bookend

Millimeter-Wave GaN Power Amplifier Design

Edmar Camargo

This book gives you—in one comprehensive and practical resource—everything you need to successfully design modern and sophisticated power amplifiers at mmWave frequencies. The book provides an in-depth treatment of the design methodology for MMIC power amplifiers. It brings you step by step through the various phases of design, from the selection of technology and preliminary architecture considerations, to the effective design of the matching circuits and conversion of electrical-to-electromagnetic models.

Detailed figures and numerous practical applications are included to help you gain valuable insights into these technologies and learn to identify the best path to a successful design. You will be guided through a range of new mmWave power applications that show particular promise to support new 5G systems, while mastering the use of GaN technology that continues to dominate the power mmWave applications due to its high power, gain and efficiency.

This is a valuable resource for power amplifier design engineers, technicians, industry R&D staff and anyone getting into the area of power MMICs who wants to learn how to design at mmWave frequencies.

Contents

Models for GaN Technology; FET Based Amplifiers; Impedance Matching; High Power Amplifiers; State of The Art Amplifiers.

About the Author:

Edmar Camargo is a MMIC designer consultant. He holds a Ph.D. and a M.S. in Electrical Engineering from the University of São Paulo, Brazil.

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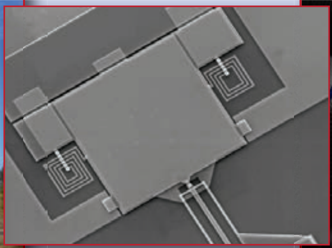
FABS and LABS

NIST's Communications Technology Laboratory: Pushing Metrology to Quantum Scale



The U.S. National Institute of Standards and Technology (NIST) is charged with maintaining traceable standards built on a foundation of measurement science, a mission essential to the country's scientific and economic health. NIST was established by Congress in 1901 to improve U.S. competitiveness by strengthening the country's measurement infrastructure to keep up with countries such as Germany and the U.K. NIST closed the gap and has achieved a preeminent position in metrology. As part of the Department of Commerce, NIST's budget for fiscal year 2022 is approximately $1.1 billion, and the Biden administration's proposed 2023 budget increases the agency's funding some 40 percent, which reflects NIST's important role supporting emerging technologies and advanced manufacturing.

NIST's Communications Technology Laboratory (CTL), based in Boulder, Colo., supports the development of advanced communications technologies and focuses on four areas: 5G and future standards, public safety communications, spectrum testing and communications metrology. The first of these, called "5G & Beyond," encompasses channel measurement, modeling and algorithms for over-the-air testing of massive MIMO. One example of the work in this area: to accurately characterize the propagation of a mmWave or sub-THz channel, NIST has developed an integrated platform named the Quasi-Deterministic (Q-D) framework, an open-source tool that combines the Q-D methodology with ray tracing to simulate the channel between nodes (antenna pairs) in a network.

In the area of 'communications metrology,' the laboratory is developing a hybrid anechoic/reverberation chamber to test mmWave IIoT devices under realistic and repeatable multipath conditions.

Another project at the edge of microwave technology—"Getting from Qubit to Mega-Qubit Quantum Computers with RF Calibrations"—aims to develop the world's most sensitive vector network analyzer (VNA). This collaboration between CTL and NIST's Physical Measurement Laboratory and Materials Measurement Laboratory is designing a way to make ultra-sensitive, calibrated, cryogenic on-chip microwave and modulated-signal measurements to support the development of quantum computing. CTL is extending its expertise with VNA measurements to measure microwave signals with orders-of-magnitude greater sensitivity than currently possible. The roadmap for the five-year program includes developing a broadband, high dynamic range Josephson parametric amplifier for the front-end of the VNA to establish the capability for weak modulated-signal and single photon measurements.

To support these varied endeavors, CTL operates five facilities: 1) The Antenna Communication and Metrology Laboratory uses dual robots and NIST's "Configurable Robotic MilliMeter-wave Antenna" to characterize steered-beam and other antennas from 300 MHz through 500 GHz. 2) The NIST Broadband Interoperability Test Bed combines large anechoic and reverberation chambers to study wireless coexistence, enabling researchers to assess how radar, LTE, Wi-Fi and other systems interact in a real-world environment. 3) The 5G Coexistence Testbed is dedicated to 5G spectrum sharing, coexistence and interference testing, focusing on spectrum sharing among government and commercial organizations. 4) The Public Safety Communication Innovation Laboratory supports first responders to extend their communication capabilities. 5) The NIST "Synthetic Aperture Measurement Uncertainty in Angle of Incidence" (SAMURAI) Over-the-Air Testbed for mmWave beamforming 5G and IIoT products.

In the 121 years since NIST was formed, the world has changed dramatically. Standards for distance, mass and time seem almost antiquated compared to the sub-THz and quantum challenges CTL is embracing today. NIST has kept ahead of these changes in technology, providing the metrology to help create the future.

www.nist.gov/ctl

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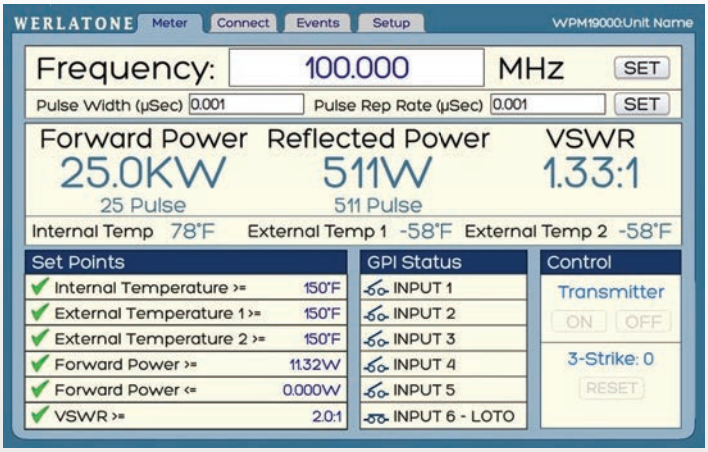
- Multi-Window Display for access to up to five Meters on screen.
- VSWR Indication & Reflected Power on main Power Sensor display.
- MIB File available for use with SNMP software.
- LabVIEW Driver Available.



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