Vol. 60 • No. 8

August 2017

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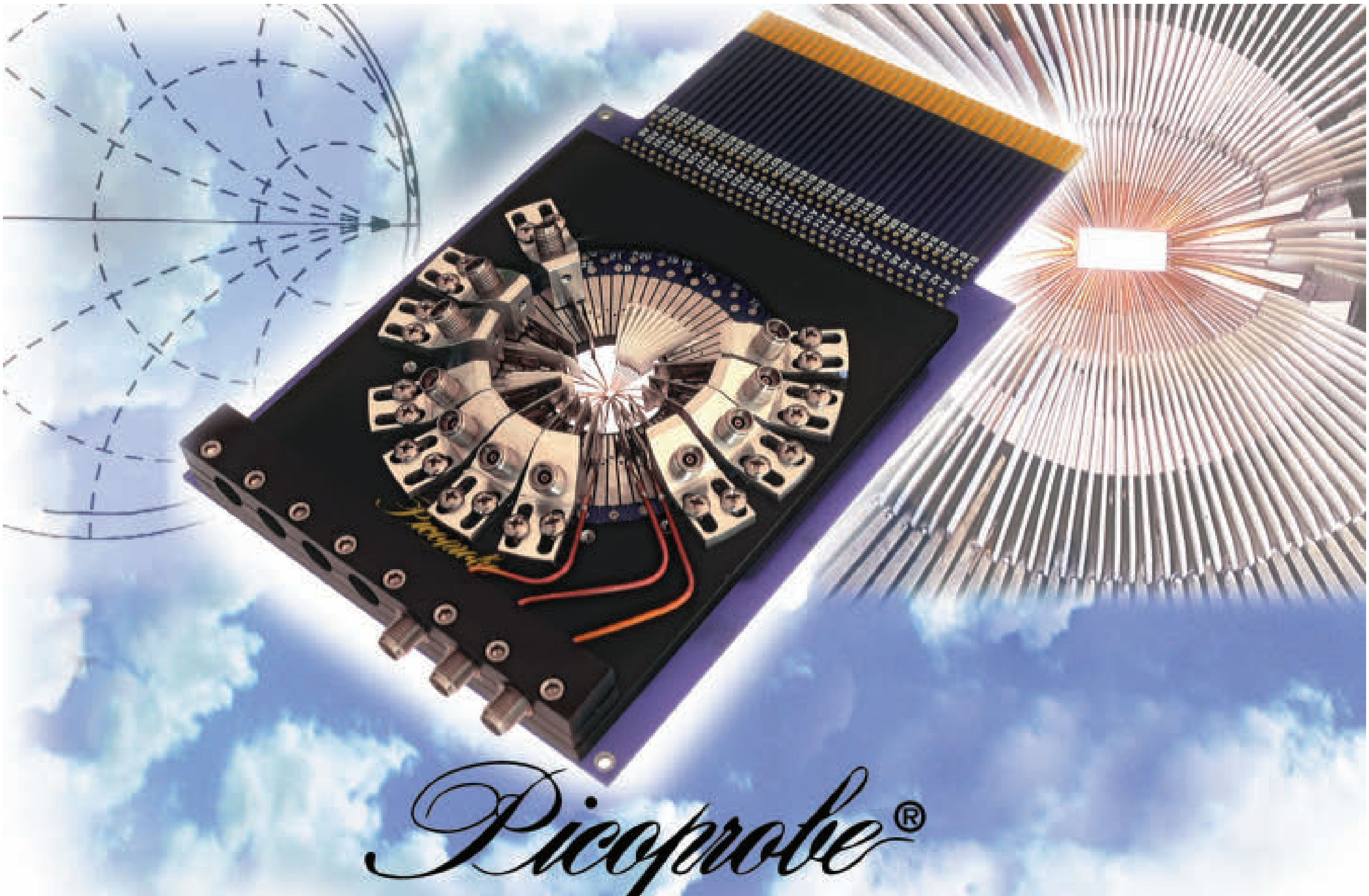

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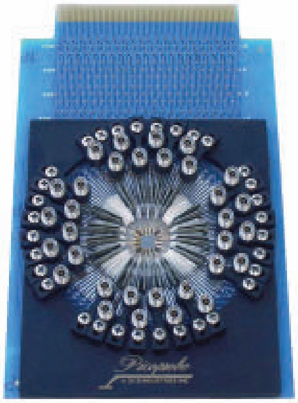

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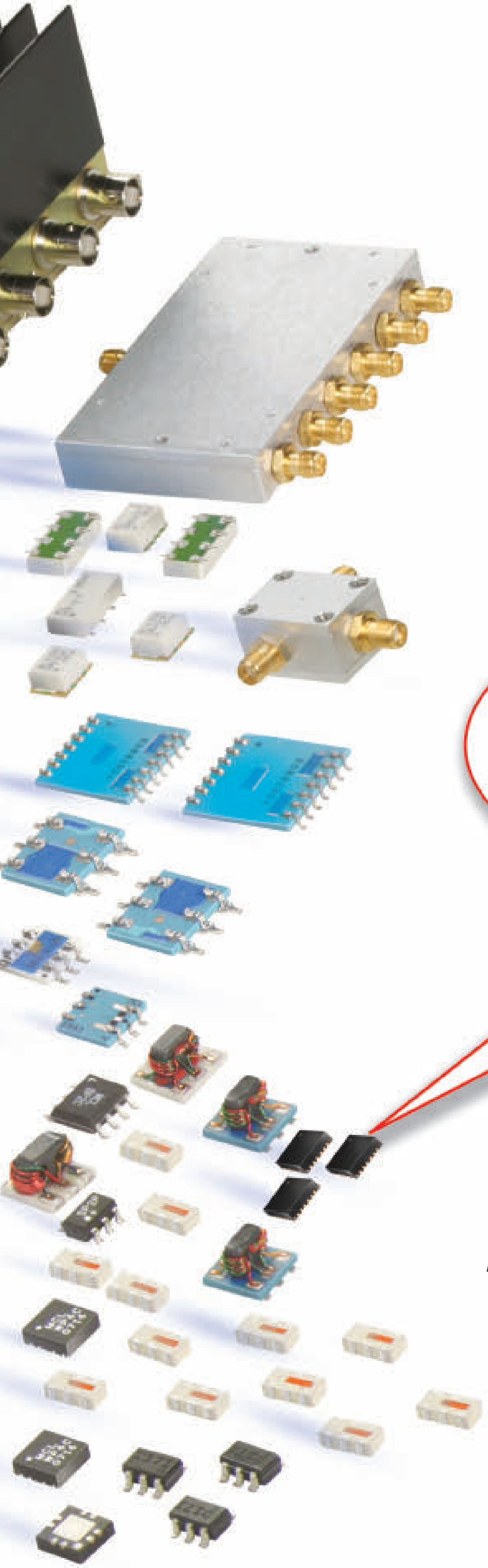

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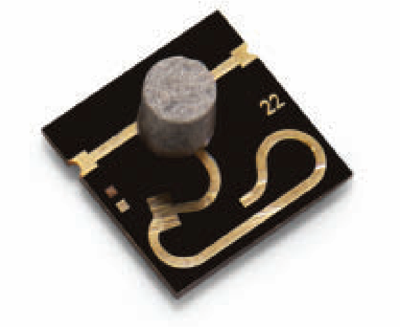

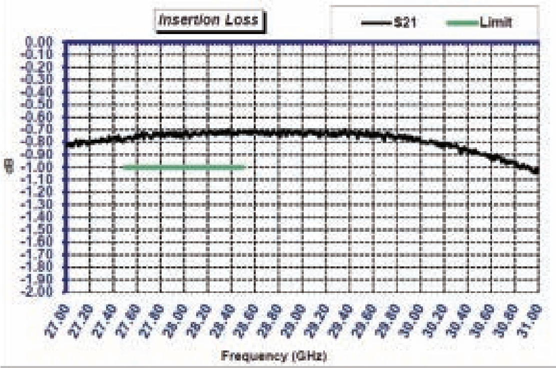

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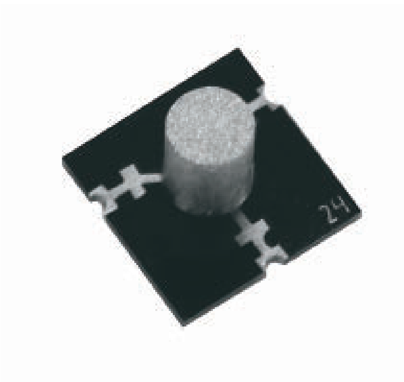

- 200kpcs Sold For Similar Array Application
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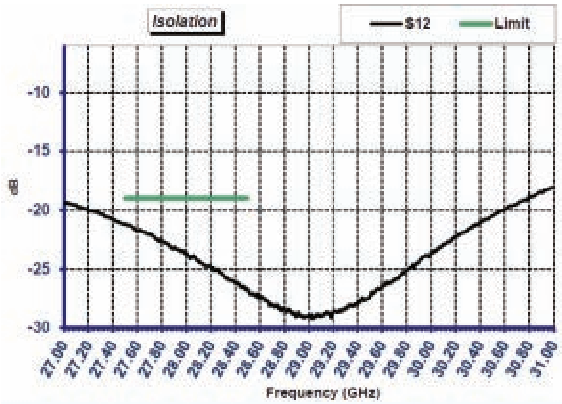
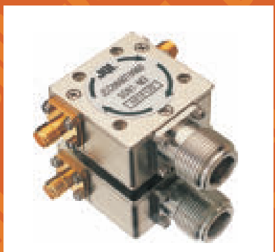


Waveguide Isolators

Surface Mount Circulators



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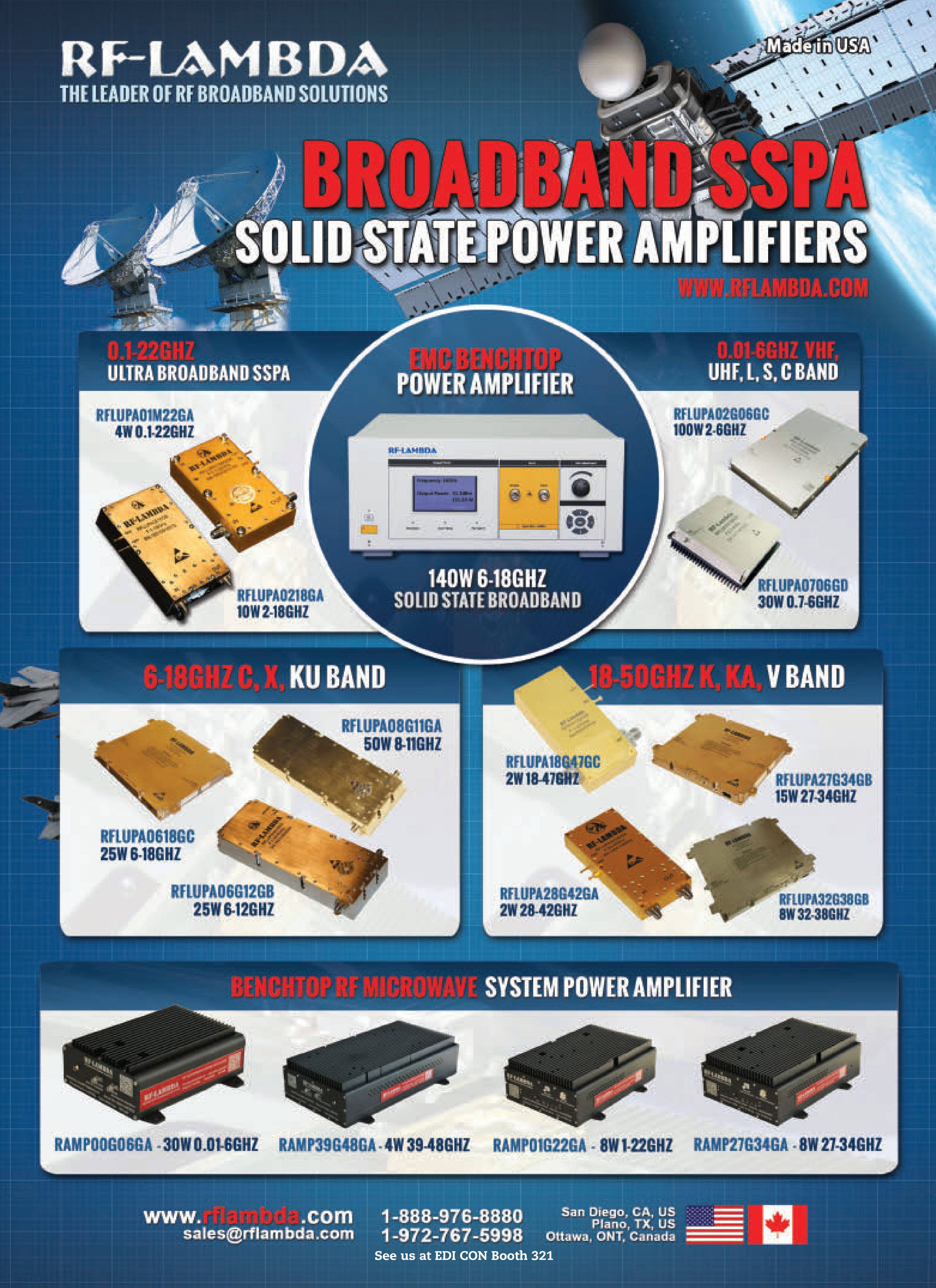
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High Frequency Components and PCBs
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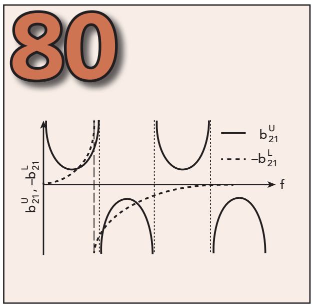

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Application Notes

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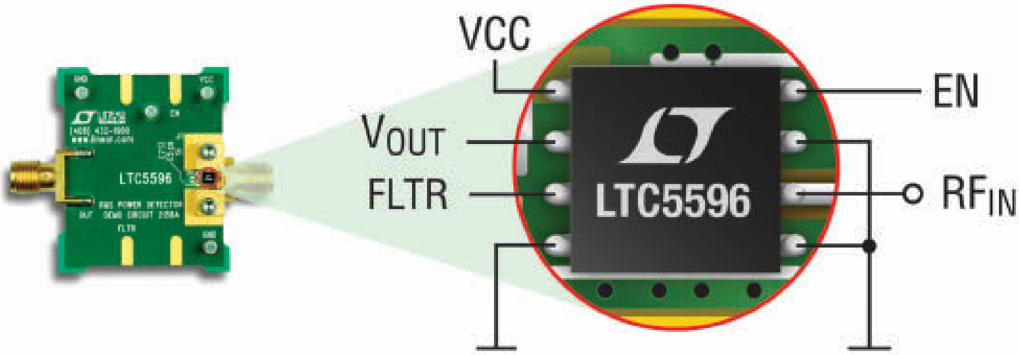

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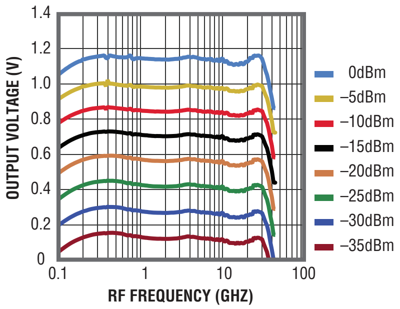

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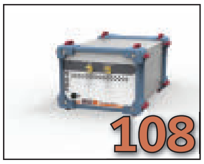

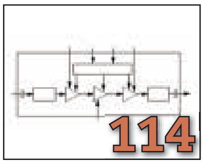

Product Features

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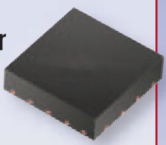

RF AMPLIFIERS
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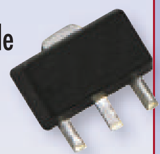

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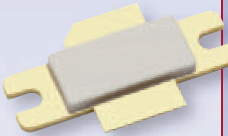

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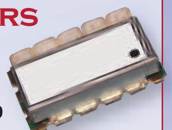
- Cavity



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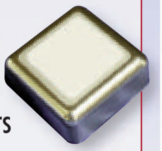
- VCXO
- TCXO
- PLL Synthesizers
- RF Generators



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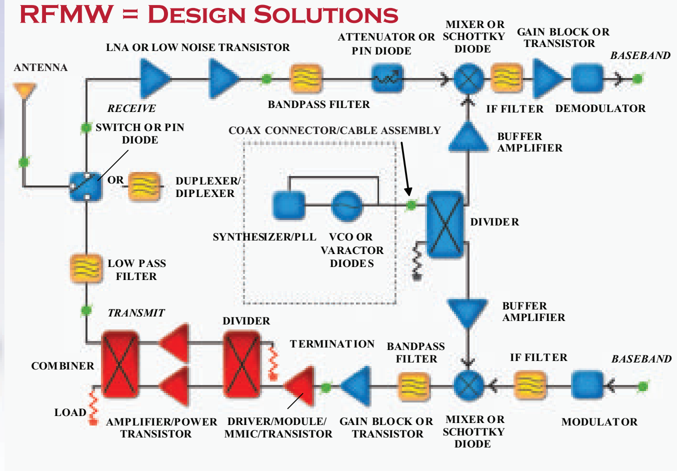
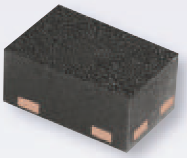


RF DIODES
- PIN
- Schottky
- Varactor
- Limiter
- Gunn



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- Digital
- Coaxial
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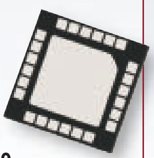
- Temperature Variable



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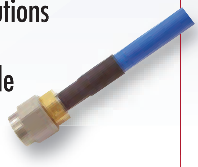

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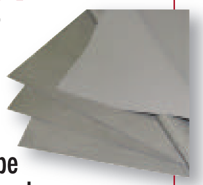

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Design and Simulation of 5G 28 GHz Phased Array Transceiver
Presented by: Keysight Technologies 8/3

Executive Interview

Philippe Garreau, Chairman of **Microwave Vision Group (MVG)**, outlines his early career as an electrical engineer, his history with Satimo, the formation of MVG and the company's advancement of the latest technologies.

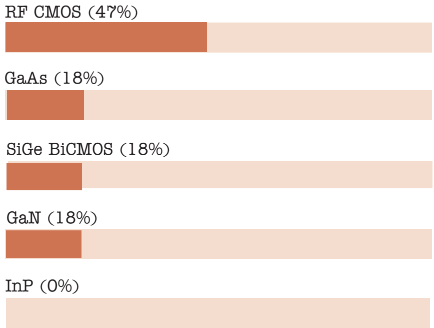
Web Survey

What wireless application above 20 GHz will generate the most component volume over the next five years?

Look for our multiple choice survey online at mwjournal.com

June Survey

What RF IC technology do you mostly design in?



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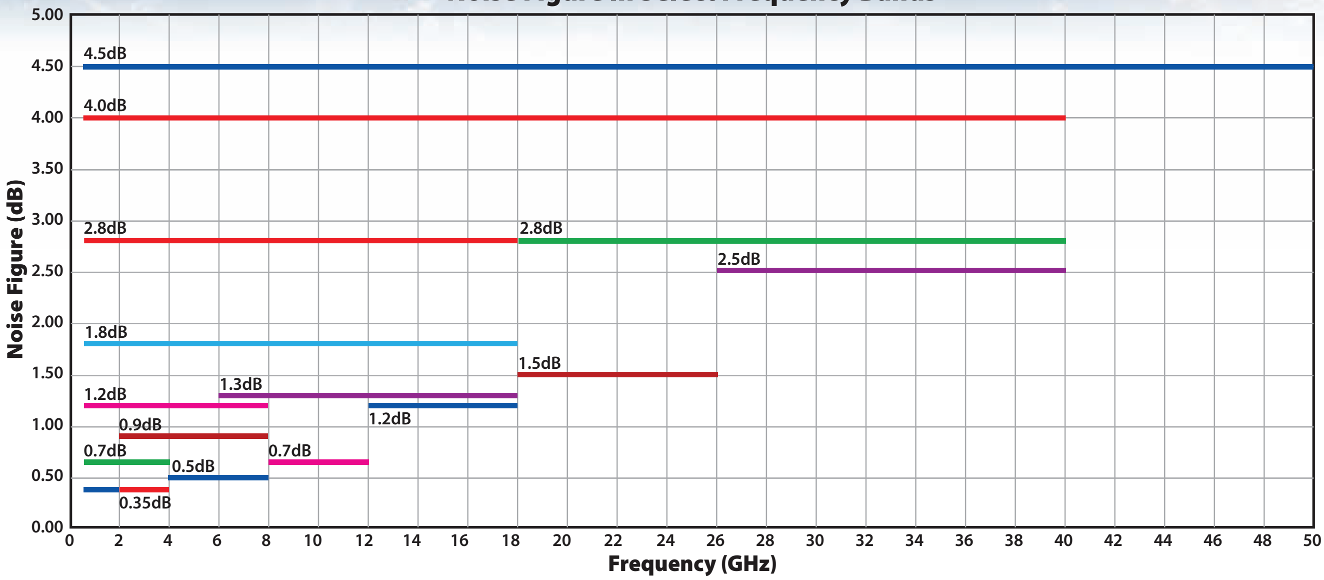

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EuMW 2017
October 8-13, 2017 • Nuremberg, Germany
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AMTA 2017
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www.amta2017.org

IEEE CSICS 2017
October 22-25, 2017 • Miami, Fla.
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ITC/USA Conference
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IEEE APMC 2017
November 13-16, 2017 • Kuala Lumpur, Malaysia
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December 4-6, 2017 • San Francisco, Calif.
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DesignCon
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MARCH 2018

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COVER FEATURE
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mmWaves Hit the Highway

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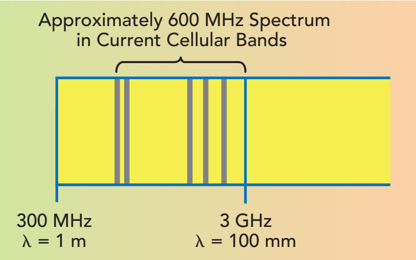
The need for speed and ubiquitous connectivity is a major driver behind today's revolution in MHz to THz technologies. Barely a decade ago, who would have guessed that the world would be trying to connect billions of devices on the Internet and preparing to download a movie in a few seconds to a smartphone? Wireless applications have evolved from point-to-point to broadcast systems to mesh and cellular networks, and now systems with directive networks combining point-to-point and cellular systems are being explored.

mmWave frequencies refer to the electromagnetic spectrum with wavelengths between 1 to 10 mm representing the frequency range between 30 and 300 GHz. There are many innovative applications of mmWave technology being implemented today including telecommunications, wireless communications, automotive, aerospace and defense, imaging, security, medical and other industrial applications. However, in the context of wireless communication and automotive radar sensors, the two fastest growing applications, mmWaves are generally referred to as multiple bands of spectrum in the frequency range of 24 to 86 GHz. This article is focused on the technology and major applications in this frequency range.

The mmWave spectrum has many advantages when compared with lower frequencies, as it is congestion free and has the capacity to move data at speeds of up to 10 Gbps and beyond. Due to its short range, frequency re-use is a big advantage in many use cases. Smaller size components, and particularly antennas, are also an advantage. On the negative side, the transmission distance is typically less than lower frequencies due to higher propagation loss and, presently, is higher in cost.

GROWTH EXPECTATIONS

The mmWave technology market is expected to grow 10x in the next five years to more than $4 billion.[1] The growth of this market is being propelled by the growth in mobile data traffic and higher usage in small cell backhaul networks. Telecommunications are one of the largest markets for mmWave technology because they have been widely used in small cell backhaul networks. The mmWave backhaul equipment is used as an integral part of the LTE/4G deployments. For 5G, the aggregate data rates are expected to be 1000x more than that of the existing 4G data rates; thus, there will be an even greater need

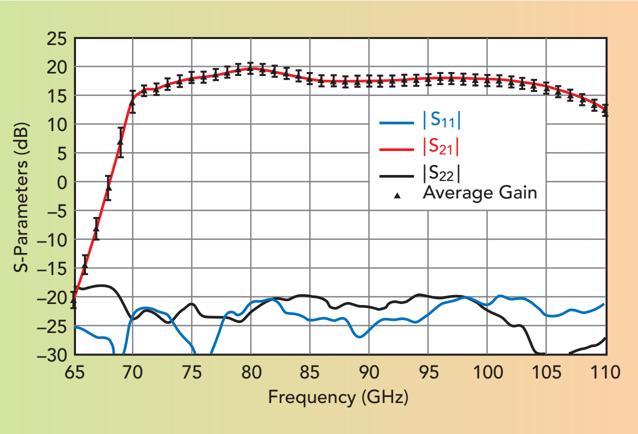


▲ Fig. 1 Frequency bands available for wireless communications in the U.S.

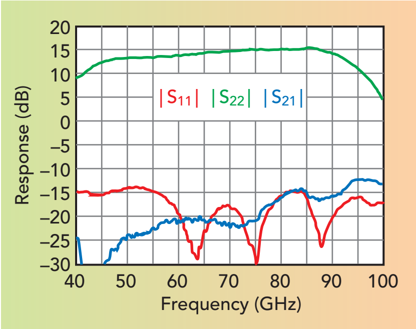
▲ Fig. 2 Microwave Tower, Hamburg, Germany. Photo Credit: Kristof Hamann

for the mmWave spectrum to provide desired data rates. Over the frequency range from 24 to 86 GHz, the potential bandwidth available is about 20 GHz compared to less than 1 GHz bandwidth available in frequency spectrum below 6 GHz. This opens the door to a huge data carrying opportunity (see ***Figure 1***).

mmWave growth in commercial markets started with the need for cellular backhaul in the early 1990s. Long range radio relay links at lower frequencies (1 to 18 GHz) were in use for quite some time, but the need for higher frequency, shorter distance links were necessary with the fast-developing cellular infrastructure. These point-to-point radios used licensed bands of 23, 26 and 38 GHz (see ***Figure 2***). The range for these radios is less than 10 km and enabled the building of worldwide cell phone infrastructure during rapid deployment phases. These developments happened when RF technology developments were going through an evolution to increased use of MMICs. Higher frequencies were added more recently including unlicensed 57 to 64 GHz band and lightly licensed bands of 71 to 76 and 81 to 86 GHz offering higher bandwidths, increased capacities, smaller size but shorter range. All these bands are presently being used for digital radio links for point-to-point links within and outside the cell phone infrastructure providing multiple Gbps capacities. Fiber optical links are a big player in this application, but mmWave links provide faster implementation and lower cost. Additionally, in many locations fiber is not even an option due to challenging terrain or other issues.



▲ Fig. 3 HRL GaN power amplifier MMIC 70 to 105 GHz BAL-WPA.



▲ Fig. 4 Analog Devices LNA MMIC GaAs PHEMT 50 to 95 GHz.

SEMICONDUCTOR TECHNOLOGY

Semiconductor technology development over the last two decades is largely responsible for enabling the mmWaves to meet the growing demand for speed, bandwidth and connectivity. The III-V semiconductors have been carrying the load, with GaAs being the first to support mmWave MMIC functions. It continues to be important for providing individual circuit functions but GaN has become a significant player for broadband power applications. InP HEMT/mHEMT are commonly used for low noise niche applications at ultra-high frequencies. InP HBTs also perform well at high frequencies with sufficient breakdown voltages and moderate integration capability. ***Figures 3*** and ***4*** show examples of a high performance mmWave power amplifier and low noise amplifier MMICs operating in the 50 to 100 GHz band. Recent developments of integrated mmWave transmitters and receivers and new phased array and beamforming techniques are paving the way for the mmWave communications like they did in the military for radar systems.

Operation at mmWave frequencies at reasonable costs is largely the result of the advancements in CMOS and SiGe technologies. Packaging the analog components needed to generate mmWave RF signals, along with the digital hardware necessary to process massive bandwidths, has only been possible in the last decade. Today, transistors made with CMOS and SiGe are fast enough to operate into the range of hundreds of GHz, as shown in ***Table 1***. The SiGe HBT is presently being used in many applications as it is fast and provides high integration, but has low breakdown voltages, which can be overcome by stacking in many cases.

Inexpensive circuit production processes are making system-on-chip (SoC) mmWave radios possible—a complete integration of

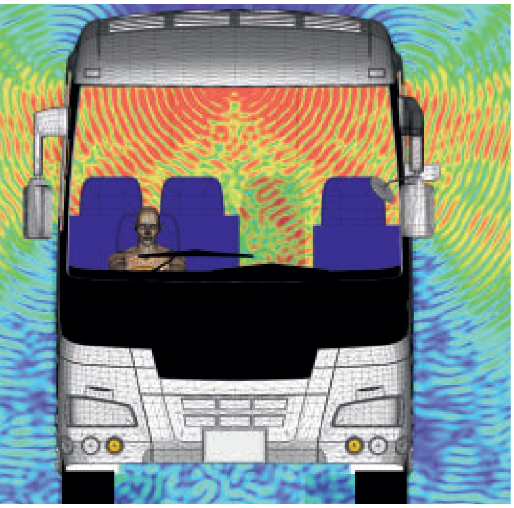
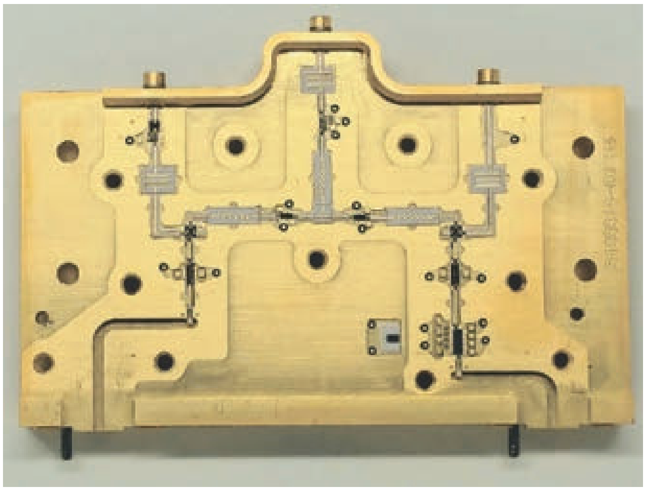


TABLE 1 CUTOFF FREQUENCIES FOR VARIOUS SEMICONDUCTOR TECHNOLOGIES	
Technology	f_T
GaAs mHEMT	1000 GHz
GaN HEMT	300 GHz
InP HBT	500 GHz
SiGe HBT	250 GHz
RF CMOS 45 nm	400 GHz

all analog and digital radio components onto a single chip. For mmWave communication, the semiconductor industry is ready to produce cost-effective, mass-market products. For demanding applications requiring highly customized performance and low volumes, thin film hybrid technology using ceramic/quartz substrates for filters/power distribution circuits and mmWave MMICs are used in shielded metal housings. These applications include test equipment, satellite communications, back-haul radios and mil-aero applications. ***Figure 5*** shows an E-Band transceiver (without lid) using ceramic substrates and mmWave MMICs.

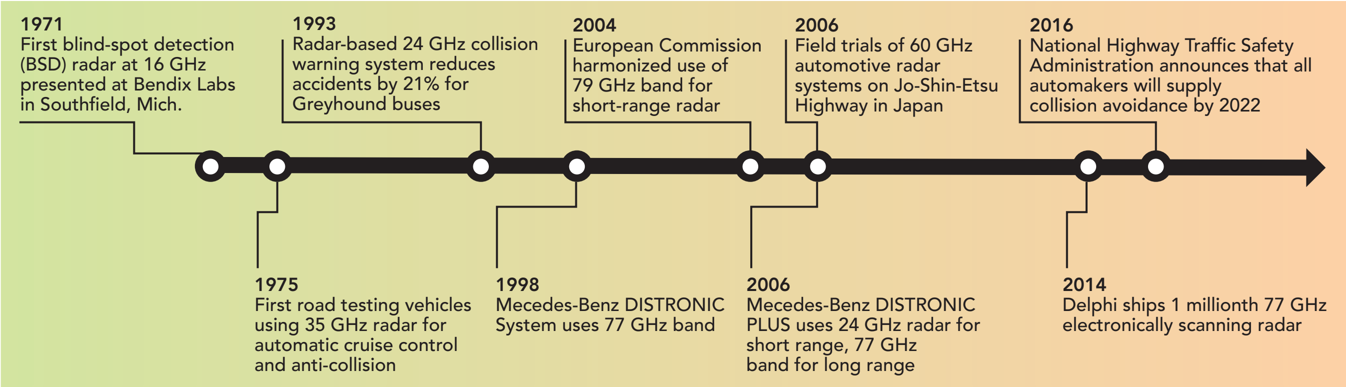


▲ Fig. 5 E-Band transceiver (courtesy National Instruments).

AUTOMOTIVE RADARS

History

Research and development of automotive radars started in the 1970s. Different frequency radars were tested, and in 1989, the World Administrative Radio Conference (WARC) settled on 77 GHz band for this application. It was not until 1998 that a commercial product at 77 GHz was implemented by Mercedes.[2] In 2006, 24 GHz radars were introduced for shorter range applications. While 77 GHz radar was used for obstacle detection and automatic cruise control (ACC), 24 GHz was used for blind spot detection and lane departure warning. A timeline showing the evolution of the automotive radar is shown in ***Figure 6***. As per the National Highway Traffic Safety Administration, 20 U.S. automakers made an agreement last year that all new cars produced starting in September 1, 2022 will be outfitted

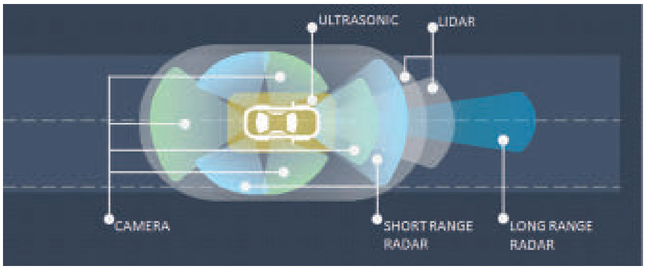


▲ **Fig. 6** Timeline of automotive radar history.

with automatic emergency braking (AEB) systems.[3] Millions of cars on the road today are already outfitted with radar sensors, as the cost has dropped over the years.

Automotive radar is a key sensor of advanced driver assistance systems (ADAS). Other sensors include light detection and ranging (LiDAR), ultrasonic sensors and camera vision systems. Compared to radar, a LiDAR today offers higher resolution and can build a 3D image of the target. However, it is very expensive and offers limited use in bad weather and at night, plus it covers a shorter range. ***Figure 7*** shows a typical ADAS system consisting of various types of sensors.

The rapid evolution of ADAS is paving the path to fully autonomous vehicles. At one time, ADAS systems, or parts thereof, were the domain of high-end luxury



▲ **Fig. 7** Advanced Driver Assistance System sensors.

cars. But now, thanks to technology evolution and reduced costs, they are finding their way into mid-range and economy vehicles. Consumer demand for ADAS is high, and governments worldwide are considering ben-

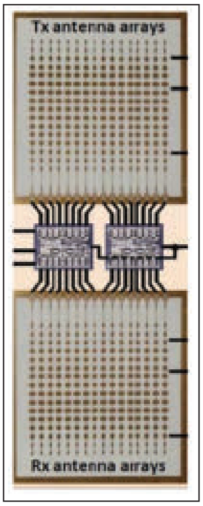
efits of passing laws to make such systems standard equipment in all vehicles. The need for radar sensors is supported by studies that have shown a significant reduction in fatal accidents by using ADAS systems. According to the World Health Organization, more than one million people die every year in traffic accidents. Once ADAS systems are implemented, this number is expected to decline more than 50 percent.

In order to reduce costs and size, automakers would like to integrate multiple ADAS functions onto a single platform that handles data from multiple sensor types. This "sensor fusion," representing the combination of data derived from different sensors, results in a higher level of accuracy and is more comprehensive than would be possible if the sensors were used individually. Fusion sensors, particularly ones combining radar chips and image sensors (cameras), are now becoming available.

Radar Technology

Automotive radars for ACC and collision avoidance operate over 76 to 77 GHz and are used for Long Range Radar (LRR) up to 300 m, with typical bandwidths between 400 MHz and 1 GHz. Using a linear FMCW modulation, these sensors provide resolution of about 0.5 m. Until 2010, GaAs PHEMT was the technology typically used for these frequencies. As the technology matured and volumes increased, SiGe MMICs took over as the technology of choice. Presently, RF CMOS using 45 nm or FD SOI 22 nm has advanced to cover this frequency range and is expected to take the lead because of cost advantages and the potential for higher levels of integration.

A new frequency band 76 to 81 GHz has been approved in many countries and is expected to become the long-term solution for automotive radar sensors globally. Using 4 GHz of bandwidth, it has the potential to achieve resolution better than 10 cm. As an example, ***Figure 8*** shows a 75 to 85 GHz, 8Tx/8Rx chip with up/down-converter and built-in self-test (BIST) for automotive radar applications. It was made with the GF8HP 0.12 µm SiGe BiCMOS process (200 GHz f_T) and has an area of 26 mm.[2] Receiver gain



▲ Fig. 8 SiGe BiCMOS 8Tx/8Rx chip. (Courtesy Gabriel Rebeiz, UCSD)

is 24 dB at 77 GHz and Tx to Rx coupling is an impressive 52 dBc.[4] Over the last few years, several semiconductor companies have released high performance and small size 77 GHz ICs that enable potential use of multiple radar sensors in a car to provide high resolution 360 degrees coverage. Multi-channel ICs providing electronic scanning are also available.

The 24 GHz radar sensor covers 24 to 24.25 GHz and is used as Short Range Radar (SRR) for distances to 50 m. It is commonly used for parking aid, blind spot detection and lane change assist. Using linear FMCW modulation, range resolution of 1.5 m can be achieved. Highly integrated transceiver MMICs based on 0.18 µm SiGe technology are commercially available. Millions of 24 GHz sensors are in operation presently and are also used in industrial sensing. It is important to note that in Europe, there is a sunset date in 2018, meaning no new cars will be fitted with these sensors there. This assumes that 76 to 81 GHz sensors will be fully deployed by that time and will cover both SRR and LRR applications.

Test Challenges

Testing vehicular radar sensors involves target simulation as well as measurement of key RF parameters. Until recently, testing for target distance, speed, angle and size was accomplished in a field using physical obstacles and moving vehicles. With the increasing volumes and technology advancements, it has become possible to simulate the targets and take measurements of EIRP, spectral occupancy, phase noise, antenna beamwidth and chirp analysis. An example is shown in ***Figure 9*** of the National Instruments' Vehicular Radar Test System. A 76 to 77 GHz signal from the radar sensor

▲ **Fig. 9** 77 GHz Auto Radar test front-end (courtesy National Instruments).

is received and down-converted to C-Band before feeding a vector signal transceiver (VST) that measures desired parameters. Beamwidth is measured by placing the radar on a calibrated rotor, and signal strength is measured as a function of angle. This will become even more important for autonomous driving as it is difficult to test all the physical scenarios in the field.

Simulation of a target includes simulating distance, speed, angle and size of the target. A down-converted signal uses a hybrid method of passive and active approaches to simulate targets covering the full distance range of 3 to 300 m. Active simulation uses the VST to simulate targets with the help of LabVIEW FPGA-based signal processing. Target distance is simulated by delay, speed (Doppler) by Tx-Rx frequency offset and target size (RCS) by controlling power level. The VST also has capability of adding multiple targets. This system was demonstrated by Konrad at NIWeek 2017.[5]

Future Directions

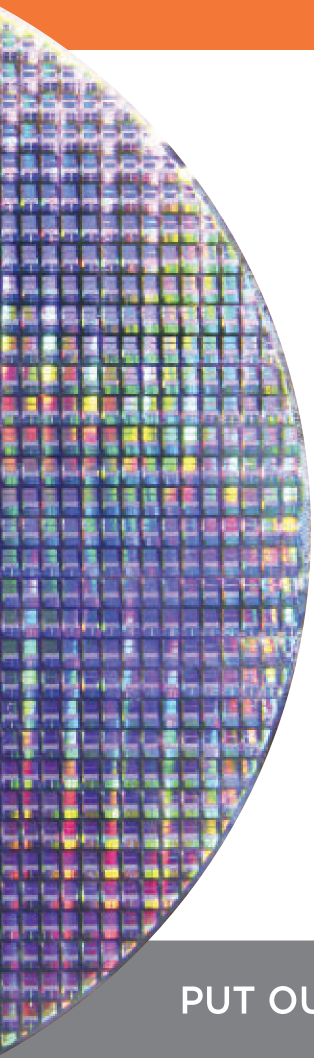
There is a high level of activity to develop radar sensor ICs which can provide 4 GHz bandwidth (77 to 81 GHz) to achieve finer resolution. A combination of high resolution based on wide bandwidth and micro-Doppler techniques will provide enhanced performance. 3D imaging radars are gaining interest in the framework of ADAS, and synthetic aperture radar techniques are being investigated for use in automotive radar applications. In terms of modulation schemes, linear FMCW slow single carrier is being replaced by fast chirp single carrier. Advanced modulations like fast chirp FDM and OFDM PCM will be implemented in a phased manner. Frequencies higher than 77 GHz are also being explored for future use.

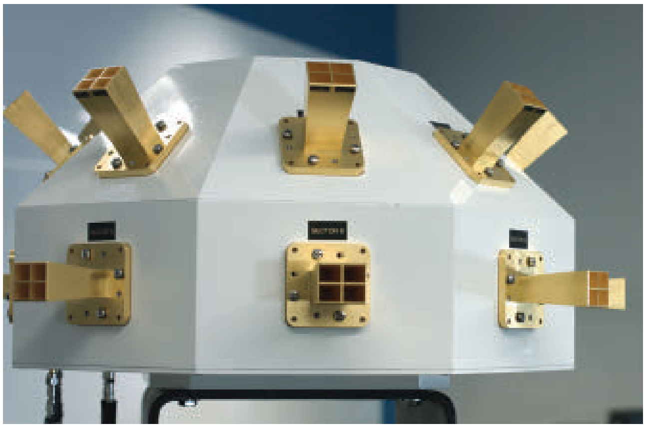
While ADAS is the enabler for autonomous vehicles, there are other technologies which will need to be integrated to arrive at autonomous vehicles, including vehicle to vehicle (V2V) networking, in-car networking, vehicle to everything (V2X) and satellite navigation. The autonomous vehicle technology has the potential of not only dramatically reducing road fatalities, but also providing a new transportation for the disabled and those who are too old or too young to drive. Governments all over the world are interested in enabling necessary regulations, but there are certainly challenges to overcome. In the U.S., 18 states have passed regulations to allow autonomous vehicles on the roads under certain conditions.

5G

The exponential growth of connected "things" and the capacity necessary for intercommunication are fueling the need for speed in wireless communications. From just a few billion "things" connected five years ago, we have already crossed 10 billion devices including handheld smart devices.[6] This number is expected to double in three years and is expected to continue increasing rapidly due to explosion of the Internet of Things (IoT). Everything from smart homes, cities, cars, pets, sensors, etc. are being connected. Industries including health, energy and transportation are expected to go through an unforeseen revolution due to intercommunication of people and things. The combination of need for high bandwidth data capacity, low latency and an exponential number of connected devices has researchers investigating access networks operating above 6 GHz. Frequencies below 6 GHz have wide area coverage when compared with higher frequencies, and while innovative techniques will be put into action to make more efficient use of this already allocated spectrum, there is a growing need to look for new spectrum bands for 5G that are above 6 GHz.

There are several deployment scenarios for mmWaves as part of 5G access network. These include high capacity backhaul point-to-point radio links, point-to-multipoint Fixed Wireless Access (FWA) and cellular access. Backhaul mmWave applications have provided a com-





▲ **Fig. 10** **28 GHz Channel sounder by AT&T and National Instruments (courtesy National Instruments).**

mendable service for the 2G, 3G and 4G infrastructure. Commonly used licensed frequency bands include 23, 26, 38 and 60 GHz. 5G deployments are expected to use upgraded links to handle increased data capacities.

While the use of mmWave frequencies is assured in backhaul and FWA, efforts are still on the way to enable its use in cellular access. In order to evaluate the radio environment for mmWaves communication, especially the systems with multiple antennae, channel sounding efforts were started in the last decade. Many research organizations have been studying and experimenting at different frequency bands all over the world. At NIWeek 2015, Nokia and National Instruments demonstrated a 2 x 2 MIMO system at 73 GHz using 2 GHz bandwidth, which provided a 10 Gb/s link over 200 m with better than 1 msec latency.[7] National Instruments also partnered with AT&T to develop a 5G mmWave channel measurement tool. The channel sounder provides real-time channel parameter measurement and monitoring capability. The channel sounder was designed by AT&T and uses an architecture based on National Instruments' 28 GHz Transceiver System shown in ***Figure 10***. This channel sounder captures channel measurements where all the data is acquired and processed in real-time with the capability to take about 6000 measurements in 15 minutes.[8]

The small size of antennas at mmWave frequencies enables the use of multiple antennas in phased arrays and MIMO systems more effectively. MIMO allows a communications system to use spectrum more efficiently by employing spatial multiplexing and beamforming. With spatial multiplexing, a base station uses multiple transmit antennas to beam distinct streams of information to multiple users at the same time using the same spectrum. Now 5G researchers are looking to massively increase the number of spatial streams used in a mobile communications system. Eventually, the 5Ms (**mm**Wave **m**assive **mim**o) are expected to enable the peak performance of these 5G systems. Hybrid beamforming and MIMO systems will provide significantly increased speeds using directive beam configurations compared

to previous omni-directional radiations.

Several different frequency bands between 24 and 86 GHz are being considered for this application, with 28 and 39 GHz currently being developed for FWA. The final decision for approved frequency bands for mobility will be taken at the WRC19 meeting of ITU in November 2019. ***Figure 11*** shows various bands available for 5G in different parts of the world.

FAST Wi-Fi

Wireless Internet implementation started about 20 years ago using the 2.4 GHz frequency band. Wi-Fi standards have so far been limited to 2.4 and 5.8 GHz; however, the performance over time has slowly evolved through 802.11 a/b/g/n/ and more recently, 802.11ac. These standards can effectively cover a large home or estate, using recently released systems with multiple routers as mesh networks. These links have capability to provide data rates of several hundreds of Mbps. The next standard in the series, 802.11ax, is based on multi-user MIMO and is expected to provide more than a Gbps data rates soon.

On the other hand, 802.11ad is a fast lane Wi-Fi system, operating on an unlicensed 57 to 64 GHz band, that is separate from present Wi-Fi standards in use. Using a maximum of 2.16 GHz of bandwidth, it is designed to support data rates up to 7 Gbps. Using a new mmWave frequency band that has limited range reduces interference. 802.11ad covers about 10 m, effectively making it best suited for in-room activities such as: wireless docking station, streaming from a smart device to a smart TV or Chromecast, transferring heavy media files such as 4K footage or raw images and certain gaming applications. This capability is showing up in laptops but has not yet entered the smartphone market.

802.11ay, an extension of the 802.11ad based on channel bonding and MU-MIMO, is in development and is expected to be ready by the end of the year. This standard is expected to ramp up transmission rates from the current 7 Gbps to about 30 to 40 Gbps, and to extend transmission distance from the current 10 m to as far as 300 m. 802.11ay will use 57 to 70 GHz and bond four of 802.11ad channels together for a maximum bandwidth of 8.64 GHz. 802.11ay applications potentially include replacements for Ethernet and other cables within offices or homes, as well as provide backhaul connectivity outside for service providers. The limitation of practical speeds achieved will shift to the infrastructure and ISPs, which will have a harder time keeping up with the new Wi-Fi standards. It is obvious that mmWaves are bound to play a significant role in future Wi-Fi systems requiring moving large amounts of data. ***Figure 12*** shows frequency bands for the three key mmWave applications discussed.

SECURITY APPLICATIONS

mmWaves are used in various security functions, from wireless

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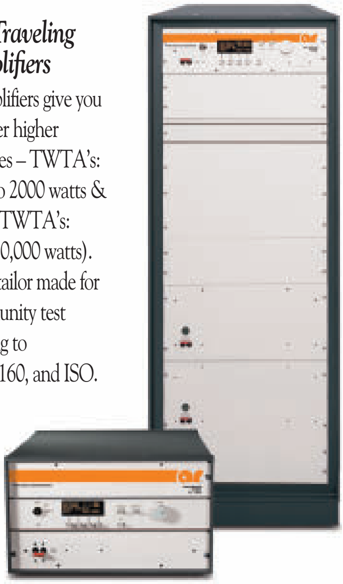

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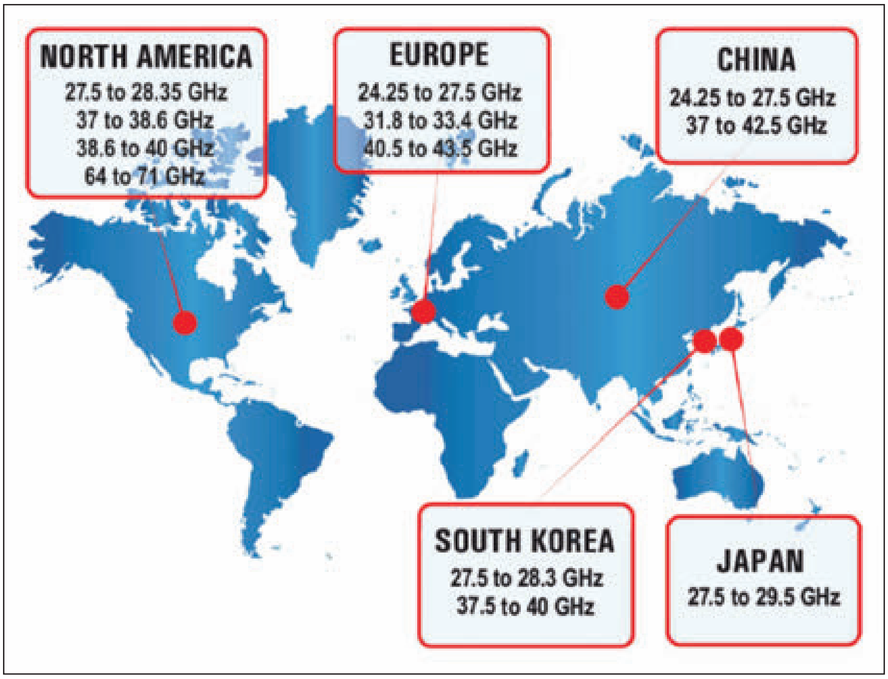
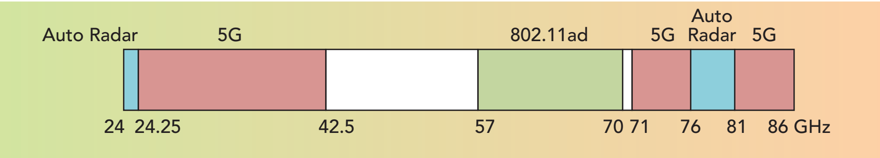


▲ **Fig. 11** Frequency bands available for 5G.



▲ **Fig. 12** Frequency bands available in the U.S. for the three major mmWave applications.

fences to intruder sensors to safe full body scanners. Over the last 10 years, mmWave scanners have gradually replaced metal detectors at U.S. airports. These scanners have the capability of detecting metal and non-metal objects on the body, and due to their low power operation, represent a safe scanning method. The mmWave safety standards are power density based and expressed in mW/m^2. The power density for a mmWave scan is between 0.00001 and 0.0006 mW/cm^2.[9] This type of scanning is thousands of times less than what is permitted for a cell phone. Unlike X-ray scanners, they emit non-ionizing radiation that does not cause cell damage that could result in cancer. Operating between 24 and 30 GHz, mmWave scanners use multiple antenna arrays to transmit and receive high frequency radio waves as they scan the person. The raw data is turned into a hologram that is examined for suspicious objects by algorithms. The holograms are then rendered into 3D figures for inspection. The entire process takes six to eight seconds. For privacy reasons, the algorithms used convert the 3D image to a generic outline of the human body on the computer screen. Presently, mmWave scanners are being used in hundreds of locations in the U.S. and Europe. ***Figure 13*** shows a commonly used mmWave scanner by L-3.

Last year, Rohde & Schwarz introduced a mmWave security scanner operating in the 70 to 80 GHz frequency range that automatically detects potentially dangerous items carried on the body or in clothing. This scanner is being deployed at many airports across Europe for airport security checks. This scanner transmits about 0 dBm power, has an impressive data acquisition time of 32 msec and uses fully electronic scanning.

MEDICAL APPLICATIONS

mmWaves have shown a great promise for medical applications—continuous wireless monitoring of breathing and heart rate is one of them. Using coherent radar systems,

▲ **Fig. 13** Millimeter Wave full body scanner by L-3.

phase shifts associated with small displacements in a human body can be accurately measured. These micro-Doppler features can be used to determine biometric information related to respiration, heartbeats and other subtle motions of the body. This non-contact, remote technique can provide information related to a person's physiological and medical condition. This is useful in maintaining health and timely detection of many health issues. This can enable hospitals to unwire patients who need continuous monitoring.

Many frequencies have been used, including 60, 94 and 228 GHz. In one system by UC Davis using 60 GHz, the mmWave signals were directed to the body and the reflected signal was analyzed for an accurate estimation of breathing and heart rates. Directional beams of mmWave are also used to monitor multiple humans in an indoor space, and can be used to locate individual humans in the room as well. Researchers can measure breathing rates with a mean estimation error of 0.43 bpm and 2 bpm in heart rates. Therefore, the system can locate the human subjects with 98 percent accuracy and is effective in monitoring multiple people in parallel, even behind walls. In another application,

a 228 GHz heterodyne radar system has been used to measure respiration and heart rates simultaneously, at distances of up to 10 m. A key advantage to higher frequency systems is the ability to focus the beam and illuminate one subject at these distances, thus reducing clutter and the complexity of the signal.[10]

mmWave imaging can also be used for noninvasive diagnosis, with one of the applications being skin burn injuries. Using 26.5 to 40 GHz, it has been shown that the degree of skin burns can be diagnosed and the healing process monitored without opening the wound. This technique takes advantage of the fact that reflection properties of the healthy tissue are very different from the drier, burned tissue. Similar approaches have been used for diagnosing skin cancer and breast cancer. The dielectric constant of the tumor tissue is approximately 5x greater than that of fat. In one case, a 30 GHz signal with a bandwidth of 20 GHz was used and the reflected signal was analyzed using stepped frequency continuous wave modulation.[11] Wide bandwidth enables high resolution, while the choice of frequency provides adequate penetration in the human tissues for breast imaging applications. The experimental results obtained by employing the prototype in a real scenario show a cross resolution down to 3 mm, with a range resolution of 8 mm and a high dynamic range of about 60 dB by using 35 antennas. The results to date are promising, and they will serve as the baseline for the development of a full breast imaging system.

CONCLUSION

mmWaves have hit the road—the investments in developing the technology and products are finally paying off, and commercial applications are being released. Once an exotic technology, mmWaves are already used in several applications including short distance links, chip-to-chip connections on board, HDMI video from laptop to screen, fast Wi-Fi, wireless docking stations and automotive radars. Significant efforts are on the way in developing mmWave technology and bringing the cost down to enable continued growth of applications in the mil-aerospace, telecommunications, imaging, security, satellite communications and medical fields. The next decade is expected to see more applications and innovative products in the mmWave frequency ranges to 300 GHz.

Studies and experiments are in place to prove utility of this technology in the cell phone access field. Many propagation studies at 28, 38, 60 and 73 GHz have been carried out with encouraging results. Several challenges remain, and global harmonization of frequency bands needs to be achieved. Acceptance of mmWave bands for cell phone access will potentially provide the final push to get these tiny waves in the hands of billions of people in 5 to 10 years.■

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GRAPHIC INFO The Road to Integration

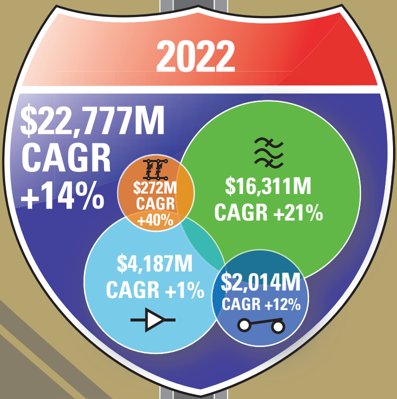
BUSINESS

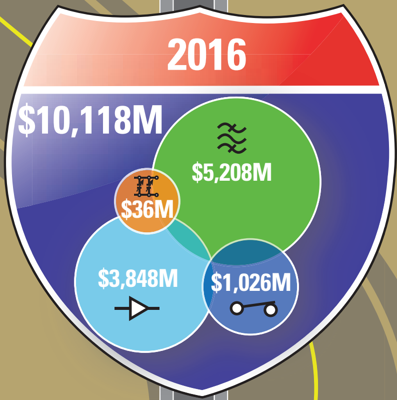
THE BIG MERGE

MARKET OUTLOOK

RF Components & Front-End Modules

Filters | Antenna Tuners | Switches | PAs & LNAs





2010s

April 2017
ADI Acquires OneTree Microdevices
Keysight Acquires Ixia

October 2016
Qualcomm Acquires NXP

April 2016
II-VI Acquires ANADIGICS

December 2015
NXP Acquires Freescale
MACOM Acquires Aeroflex/Metelics
JAC Capital Acquires Ampleon (from NXP)

January 2015
Qorvo Born
RFMD and TriQuint Merge

July 2014
ADI Acquires Hittite

March 2017
ADI Acquires Linear Tech

June 2016
Qorvo Acquires GreenPeak Technologies

February 2016
Avago Acquires Broadcom

October 2015
NI Acquires Micropross

August 2015
Keysight Acquires Anite

June 2015
API Acquires Aeroflex Inmet and Weinschel

2000s

2007
iPhone Launched

1990s

1991
RFMD Formed

1980s

1985
Hittite and TriQuint Formed

1960s

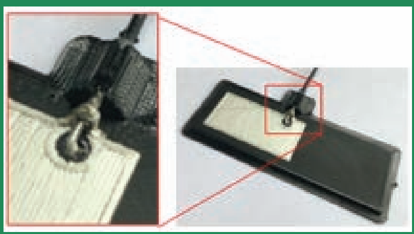
1965
ADI Formed

1950s

1958
Microwave Journal Begins Publication

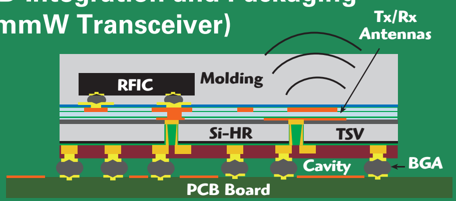
1950
Microwave Associates (MACOM) Formed

EMERGING TECHNOLOGIES



3D Printed Antennas

3D Integration and Packaging (mmW Transceiver)



Metamaterials (Resonators Fabricated on Glass & Quartz)

Global Demand Sparks Standard Missile-2 Production Restart

Due to global demand, Raytheon Company has restarted its Standard Missile-2 (SM-2) production line to meet the needs of four international customers who aligned requirements and pooled resources to make a "bundle" purchase through foreign military sales. SM-2 is primarily used by U.S. and allied navies for fleet air defense and ship self-defense.

SM-2 Launch (U.S. Navy Photo)

The Netherlands, Japan, Australia and South Korea are purchasing SM-2 under this new contact. The missile defends navies against anti-ship missiles and aircraft out to 90 nmi and an altitude of 65,000 ft. SM-2 has an extensive flight test history with more than 2700 successful live firings.

"For many of our allies, SM-2 is the backbone of their fleet defense, but in 2013, we simply didn't have the international orders necessary to keep the production line going," said Dr. Taylor W. Lawrence, president of Raytheon Missile Systems. "That's changed now, and we'll continue producing SM-2s well beyond 2035."

New deliveries are scheduled to begin in 2020 and will include more than 280 SM-2 Block IIIA and IIIB missiles. Raytheon and the U.S. Navy are using the restart as an opportunity to modernize production and testing processes inside the SM-2 factory.

SM-2 international customers include: Australia, Canada, Germany, Japan, Korea, the Netherlands, Spain and Taiwan.

Leonardo Unveils its Lightest-Ever Multi-Mode Radar, the Gabbiano TS Ultra Light

At this year's Paris Air Show, Leonardo unveiled its new Gabbiano TS Ultra-Light (UL) surveillance radar, the result of the company's efforts to package all the technology and modes of its successful range of Gabbiano radars into a highly affordable product weighing less than 24 kg. The new multi-mode, multi-mission, mechanically scanning product, which is Leonardo's lightest-ever surveillance radar, is available for immediate orders.

The Gabbiano UL is being integrated onto the company's "Hero" mini unmanned rotorcraft, as its reduced weight and compact size—comprising of just two units, a 12-inch nose antenna and separate Receiver Transmitter Processor (RTP)—make it ideally suited.

The new UL model radar has access to the same extensive suite of modes that Leonardo has developed year-on-year for the Gabbiano family since it was launched in 2008, making it an effective option for over-sea, over-ground and air-to-air surveillance. Modes include optimized maritime patrol and search & rescue capabilities—small target, high sea state detection and automatic, long-range non-cooperative sea target recognition—as well as high resolution ground mapping, with both strip and spot synthetic aperture radar (SAR) modes, ground moving target indication (GMTI), weather avoidance and air-to-air search and track capabilities. The Gabbiano TS UL can also work with an Automated Identification System (AIS) and can cue electro-optic sensors, making it an effective and competitive solution for maritime patrol missions, even from small or mid-size vessels.

The Gabbiano family has already been selected by 12 international customers and equips aircraft ranging from unmanned vehicles such as the Hermes 450™, Hermes 900™ and Leonardo Falco EVO, to helicopters including the AW139 and AW101 and fixed-wing vehicles such as the KC-390, Beechcraft B350 and ATR42MP.

ViaSat Tripling MIDS JTRS Production Capabilities for U.S. Airborne Forces

ViaSat Inc., a global broadband services and technology company, has been awarded Lot 5 and Lot 5a contracts totaling $88.3 million from the U.S. Navy Space and Naval Warfare Systems Command (SPAWAR) to provide Multifunctional Information Distribution System (MIDS) Joint Tactical Radio System (JTRS) terminals to the U.S. Navy and Air Force. MIDS JTRS enhances battlefield communications for joint and coalition warfighters by providing the ability to communicate by voice, video and data with a line-of-sight, jam-resistant capability across ground, air and naval assets.

With the Lot 5 and Lot 5a awards, ViaSat will develop, field and support interoperable, affordable and secure MIDS tactical data link and programmable networking technologies and capabilities for the joint, coalition and international warfighter. With these awards, ViaSat remains the largest provider of MIDS JTRS terminals to the U.S. military. The Lot 5 and Lot 5a awards mark a substantial increase in terminal orders and deliveries supporting both the U.S. Navy and Air Force fourth generation fighters as they begin a full transition to MIDS JTRS.

For More Information
Visit mwjournal.com for more defense news.

The MIDS JTRS terminal is a four-channel, software defined radio that delivers Link 16 communications with concurrent multi-netting-4 and tactical air navigation, as well as three channels for future growth.

Work will be performed in Carlsbad, Calif. and Tempe, Ariz., and is expected to be completed by June 2019.

Successful Launch of Iridium NEXT Satellites

The second batch of 10 Iridium® NEXT satellites built by Thales Alenia Space has been successfully launched by SpaceX from the Vandenberg Air Force Base in California. After the perfect commissioning of the first 10 satellites launched in January, eight of which are now interconnected and operating in full compatibility with the initial Block One Constellation, with two being maneuvered to an adjacent plane, this milestone marks a new step for the Iridium® NEXT adventure.

Thales Alenia Space is prime contractor for the Iridium® NEXT program, in charge of engineering, integration, operations and in-orbit validation of the 81 satellites and the overall system. The satellites are integrated in series by Thales Alenia Space's subcontractor Orbital ATK, at its satellite manufacturing facility in Arizona, while Thales Alenia Space teams are both supervising the global integration process and supporting its customer Iridium for the Launch and Early Operations (LEOP) and In Orbit Tests at the Leesburg control center.

"In addition to being a real feat of technological prowess, Iridium® NEXT also provides global coverage and doesn't require local ground infrastructure due to how the satellites can communicate with one another, so it can provide vital assistance under certain circumstances—people lost in isolated areas, natural disasters, conflicts, etc. And that's why all of us feel so proud to have contributed to this program!" declared Denis Allard, Iridium® NEXT program director for Thales Alenia Space. He added, "In addition to this second launch, the production of 26 other satellites has now been completed. We have also started integration of the 57th satellite. Everything is on track to meet our objective, namely to launch all 75 Iridium® NEXT orbital satellites by mid-2018."

The Iridium NEXT® constellation will offer global connectivity thanks to 66 interconnected satellites at an altitude of 780 km, along with nine spares in parking orbits and six more spare satellites on the ground. This international system provides unrivaled capability for communications on the move—individuals, land vehicles, aircraft, ships—and ensures full global coverage, including the oceans.

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The 2017 Defence, Security and Space Forum

At European Microwave Week

EuMA · Microwave Journal

Wednesday, 11 October – Nürnberg Convention Center – Room St. Petersburg

A focused Forum addressing the application of RF and microwave technology to The Internet of Space.

Vast areas of the globe are without sufficient Internet connectivity. Commercial and societal progress as well as safety and security are linked to access to the information superhighway, while military missions require reliable and secure data communication pathways. This one-day Forum highlights **The Internet of Space – Technologies and Applications**, a new class of satellite communication services being developed to address these needs.

Programme:

08:30 – 10:10 EuRAD Opening Session

10:50 – 12:30 The Internet of Space – Technologies and Applications

Two keynote speakers from the industry will present their view on key applications and the related technologies needed for the realisation of the **Internet of Space**. The presentations will cover commercial as well as military applications.

- The World's Largest Satellite Constellation 'OneWeb' – Redefining Satellite Communications *Wolfgang Duerr, Airbus DS Inc.*
- The Connections are Key: The Implications of the Internet of Things on Military Technology – *Joe Mariani, Deloitte*

12:40 - 13:40 Strategy Analytics Lunch & Learn Session

This session adds a further dimension to the topics by offering a market analytics perspective, illustrating the status, development and potential of the market for the **Internet of Space**.

14:20 – 16:00 *Microwave Journal* Industry Panel Session

This session offers an industrial perspective on the key issues to be addressed in the defence, security and space sector. In accordance with this year's Defence, Security and Space theme the panel will investigate the opportunities for applications of the **Internet of Space** as well as address the technological challenges. The presentations are:

- *The Internet of Space – Technologies and Applications – Mark Lombardi, Keysight Technologies*
- *Internet of Space, Past, Present, & Future – Timothy Boles, MACOM*
- *Leveraging Technology to Develop Solutions for IoT to the IoS – Roger Hall, Qorvo*
- *New Approaches in End-To-End Payload Testing – Yassen Mikhailov, Rohde & Schwarz*

16:10 - 17:50 Defence, Security & Space Executive Forum

High level speakers from leading Defence and Space companies present their views and experiences on the upcoming technologies and applications in the civil and military domains. They will be complemented by speakers from a government agency, consulting company and a start-up, who will offer their views on research needs, trends and New Space opportunities and challenges. Speakers at the Forum will include:

- *Erich Auer, TeSat SpaceCom*
- *Wolfgang Duerr, Airbus DS Inc.*
- *Matthias Spott, eightyLEO*
- *Joe Mariani, Deloitte*
- *Siegfried Voigt, DLR*

Register online at www.eumweek.com

A PRIME YEAR FOR A PRIME EVENT

17:50 - 18:30 Cocktail Reception

The opportunity to network and discuss the issues raised throughout the Forum in an informal setting.

Registration and Programme Updates

Registration fees are €20 for those who registered for a conference and €60 for those not registered for a conference

As information is formalized, the Conference Special Events section of the EuMW website will be updated on a regular basis.

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Broadband Forum Attracts Start-ups and Telecoms Giants

The Broadband Forum recently welcomed 15 new members—including three start-ups—as it continues to address the fast-changing broadband landscape. The broad range of industry expertise displayed by the new member companies highlights the continuously expanding breadth of the Broadband Forum's work, which has grown to include a strong focus on next-generation broadband technologies such as virtualization, software-defined networks (SDN), IoT, next-generation optical networks, 5G and Gfast.

The latest additions are CableLabs, EANTC, Fujitsu Ltd., Genesis Technical Systems, Go!Foton, Jabil Circuit (Shanghai) Company, MaxLinear, Radisys, Shenzhen Gongjin Electronics, SK Telecom, Telekom Slovenia, Tellabs, TiBit Communications, VoltServer and Works Systems (Tianjin) Co. Ltd.

Robin Mersh, CEO of the Broadband Forum, said: "We're delighted to be able to welcome so many new members, including—for the first time—start-up companies, as this is where so much innovation is happening. The work the Forum is carrying out to deliver on our Broadband 20/20 vision is attracting a lot of interest from companies across the industry and the Forum is the perfect platform for them, as every member has an equal voice, whether they are a start-up or a long-established operator. The broadband industry is changing and evolving at a rapid pace and the addition of these new members demonstrates the Forum remains a clear voice amid the changes."

Broadband 20/20 focuses on leveraging emerging technologies and approaches to enable new services and business opportunities across the entire network-enabled broadband ecosystem from user devices to cloud data centres.

LTE Unlicensed and Shared Spectrum Technologies Spark Network Evolution

In the *Network Evolution in Unlicensed and Shared Spectrum* report, ABI Research found that technologies taking advantage of this spectrum type are not only attracting mobile network operators' (MNO) interest for low cost network densification, but also brand-new entrants. This is due to the opportunities that the network technologies promote for densification, neutral hosts, as well as enterprise and private network operators. The firm further predicts that new LTE unlicensed and shared spectrum technologies will launch a $1.7 billion hardware market over the next five years, including LTE Unlicensed, CBRS and MulteFire.

"LTE-U/LAA will appeal to MNOs planning to densify but with insufficient spectrum or CAPEX to acquire it," said Nick Marshall, research director at ABI Research. "Meanwhile, MulteFire and CBRS technologies promise very low network buildout costs with economics that threaten to disrupt the DAS market. The technologies appeal to many communications service providers (CSP), especially as CBRS pioneers a significant change in spectrum management for the industry. Also, traditional spectrum refarming cannot match the increasing mobile broadband throughput demands in the migration to 5G."

> "...a $1.7 billion hardware market..."

Given power restrictions in unlicensed and shared spectrum, these technologies are most suitable for small cell indoor or venue deployments. With low to no spectrum acquisition costs and deployment economics comparable to Wi-Fi, in-building wireless penetration in the vast middle-sized and enterprise verticals will increase dramatically and account for more than half of in-building small cell shipments in 2021.

There are many companies innovating in this ecosystem ranging from the Spectrum Access System (SAS) providers and Environmental Sensing Capability (ESC) operators for CBRS, including Alphabet, CommScope, Federated Wireless and small cell and infrastructure vendors like BaiCells, Casa Systems, Ericsson, Huawei, ip.access, Nokia, Ruckus and SpiderCloud.

"We stand at the verge of significant disruption with in-building wireless and spectrum management technologies," concluded Marshall.

Wireless X Labs Advisory Committee Established

The Mobile World Congress Shanghai 2017 saw the establishment of the Wireless X Labs' Advisory Committee, which gathered together leaders from smart manufacturing, automobile manufacturing, drone technology, data intelligence and artificial intelligence. Wireless X Labs is Huawei's mobile application scenarios lab for wireless networks.

At the start of the year, Wireless X Labs targeted connected drones, cloud VR/AR, wireless robotics and connected vehicles as four research priorities. In Shanghai, the committee reviewed the research into these areas during the first committee round-table, examined the topics for 2018 and evaluated the technical and cooperative feasibility for potential projects.

"Wireless X Labs is an open platform that will bring together operators, technology providers and vertical industry partners to jointly explore future use cases for

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mobile applications, drive innovation in business and technology and promote an open industry ecosystem," said William Xu, executive director of the Board and chief strategy marketing officer, Huawei.

Wireless X Labs has looked into various potential 5G applications during the first half of 2017. For example, it worked with automakers in testing Tele-Operated Driving and platooning. With the help of partners, it released a cloud-based virtual reality prototype, conducted cellular network-based drone remote control flying and image transmission tests and analyzed low-altitude coverage for drones. It also set up a smart manufacturing interest group with world-leading robotic manufacturers.

Thales Alenia Space to Construct GX Satellite for Inmarsat

Thales Alenia Space has signed a contract with Inmarsat for the construction of its new communication Global Xpress (GX) satellite. The value of the contract will be approximately $130 million over the three years from 2017 to 2019. The satellite, which is targeted for launch in 2019, will be a very high throughput satellite (VHTS), providing capacity across the Middle East, Europe and the Indian subcontinent.

The combination of latest satellite technology and a focus on areas of high demand, which will drive high capacity utilisation, will result in a very low cost per bit delivered. This new satellite will be based on the flight proven Spacebus B2 enhanced platform and will be fitted with 72 Ka-Band beams. With a specified design life of 16 years, it will weigh less than four metric tons at launch and will offer payload power of about 6.8 kW.

Inmarsat's decision to construct this GX satellite was made following the recent announcement by Qatar Airways to adopt GX Aviation for its In Flight Connectivity (IFC) requirements, as well as other recent important airline IFC wins in the EMEA region, such as the Deutsche Lufthansa Group and Norwegian Air Shuttle.

"Thales Alenia Space is proud to partner with Inmarsat to create an advanced satellite, which will provide additional capacity to support the growing demand for aviation passenger Wi-Fi services across the EMEA and Indian subcontinent. With this new satellite, Inmarsat will broaden its footprint, deliver significant resources for broadband services and set a new benchmark for flexibility in high throughput satellites," said Bertrand Maureau, vice president, Telecommunication Business Line.

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Pulsed RF Power Semiconductor Device Markets Will Exceed US$200M by 2022

ABI Research forecasts markets for pulsed RF power devices up to 4 GHz will show continued moderate growth over the next five years and exceed $200 million by 2022. While their association with consumer spending fuels the volatility of many global electronics markets, pulsed RF power device markets are supported by quite different priorities. Pulsed RF power transmitters generate tremendous amounts of power in small bursts that are useful for radar, airborne collision avoidance systems and military IFF equipment.

"Many RF power semiconductor manufacturers are on a quest to find markets unrelated to mobile wireless infrastructure," says Lance Wilson, research director at ABI Research. "Device prices in wireless infrastructure are falling, and the total available market is flattening out."

The airborne transportation safety market and military market are both experiencing solid growth in pulsed RF power device shipments. The markets use the devices for military radar, weather and marine applications, and in the current worldwide upgrade of the air traffic control system. The avionics transponder and air navigation market segment is also seeing growth, which is further lifted by the overall worldwide air traffic control upgrade. Intrinsically less "optional" than many consumer markets, these segments are therefore less sensitive to economic upheavals than consumer-driven markets, although they are not totally immune to the macro economy.

> GaN continues to drive market growth...

Understanding this, many semiconductor manufacturers are attempting to enter this market space; however, some factors may complicate their efforts. Pulsed RF power device markets are becoming very competitive technologically: GaN devices are vying for market share along with the more established Si- and GaAs-based technologies. With many companies rushing into these markets, ABI Research speculates that there may not be the market size to support them all.

"Undoubtedly, some consolidation will continue to occur beyond what already happened," concludes Wilson. "While not guaranteed success, those companies that have track records working with government agencies and defense contractors will have an advantage over those that are new entrants."

Leaders for high-power RF pulsed semiconductor devices include Ampleon, Integra Technologies, MACOM, Microsemi, Qorvo, Sumitomo Electric Device Innovations and Wolfspeed.

Survey Finds 62% of Technology Implementers Not Ready to Deploy 5G

A recent B2B technology survey by ABI Research that studied 455 U.S.-based companies across nine verticals found that 62 percent of respondents do not plan to deploy 5G technology in the coming years. The report uncovers a severe discord between 5G market hype and the commercial industry's readiness to deploy the technology, with nearly all respondents who plan to one day incorporate 5G technology into their business models citing that they are in the early investigation phase.

"The hype of 5G is currently driven by the technology supply chain rather than by demand from the end-markets," says Malik Saadi, managing director and vice president at ABI Research. "All indicators lead us to believe that 5G will take hold in the consumer market before it claims its stake in the enterprise and industrial sectors. As the 5G roadmap develops, it is now more imminent than ever for technology suppliers to engage with implementers—understand their requirements, educate them on the value of 5G and help bring their specific use case needs to life."

> Disconnect between market hype and industry readiness...

Survey findings indicate that the retail vertical shows the most aggressive outlook in its willingness to adopt 5G technology. With 51 percent of retail respondents assessing or planning to deploy 5G in the coming years, this vertical has a specific need for 5G to support bandwidth-hungry and low latency use cases, including AR, VR and robotic applications. At the other end of the spectrum, autonomous driving ranks as the least popular 5G use case across all verticals.

"Conversely, autonomous driving is the most hyped use case in the 5G technology supply chain," continues Saadi. "The misalignment between demand and supply planning clearly indicates that 5G technology vendors need to better communicate with implementers to ensure that well-informed decisions are being made to ultimately fulfill long-term customer requirements."

Virtual reality (VR) ranks as the most popular use case for 5G across all market segments, with 89 percent of respondents who plan to deploy 5G in the coming years also planning to deploy VR. Robotics also ranks high in use case popularity but remains largely ignored by 5G vendors due to technology complexities and several regulatory and socioeconomic challenges facing this industry.

"5G technology suppliers are currently working in a vacuum, often denigrating the rights of technology

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implementers to influence the 5G development roadmap," concludes Saadi. "The retail, healthcare and federal government verticals show the highest willingness to deploy 5G technology in the coming years and, as such, need careful attention paid by 5G technology suppliers to ensure that their individual, varied use case needs will be properly addressed."

NGC's MMICs Meet FCC's 5G System Requirements

Northrop Grumman Corporation business, Microelectronics Products and Services' (MPS) monolithic microwave integrated circuit (MMIC) products are aligned with the Federal Communications Commission's (FCC) 5G frequency allocations. MPS made the announcement at the recent International Microwave Symposium (IMS) 2017.

Northrop Grumman is leveraging more than 20 years of advanced microelectronics development to offer a suite of MMICs that are applicable for 5G applications. With the expanded 5G network frequencies, Northrop Grumman's MPS technologies and products can be used to provide low noise, high linearity/high output power and/or frequency conversion across all of the 5G frequency bands. The products meet user demands for multi-media access, high QoS and anytime access.

"MPS's low noise and high-power technologies and products provide a differentiating advantage that allows operators the ability to maximize the number of users and revenue generation. The Northrop Grumman power amplifiers provide the high linearity performance near peak output power levels required for complex modulations, which optimizes the data throughput within the FCC allocated bandwidth," said Chris Brown, general manager, Northrop Grumman MPS. "This same performance advantage is realized in the 5G receivers through the use of the Northrop Grumman low noise amplifiers utilizing our GaAs and InP technologies. Between the power amplifiers, the low noise amplifiers and the mixers, we can address all of the 5G frequency bands."

Northrop Grumman engineers presented on high-power and high efficiency chipsets for Ku-, Ka-, V-, Q-, E- and W-Band communications, and on optimizing ground, airborne and space-based communication links using Northrop Grumman's advanced semiconductor products and technologies. The MPS team also presented enhanced GaN manufacturing options showing the transition of communications products in everyday use.

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Microsemi has completed the acquisition of **Phonon Corp.**, a global leader in designing and manufacturing custom surface acoustic wave (SAW) components and modules for defense and space. As a result of this transaction, Microsemi now offers one of the most comprehensive portfolios of high performance, high-reliability integrated components and systems solutions for the aerospace, defense and space markets. This acquisition strengthens its product offerings by adding leading SAW components and modules to its current portfolio of FPGAs, timing solutions, mixed-signal/RF devices and high-reliability discrete products.

Honeywell announced that it has signed a definitive agreement to purchase **Nextnine**, a privately held provider of security management solutions and technologies for industrial cybersecurity. The addition of Nextnine's industry-leading security solutions and secure remote service capabilities will enhance the company's existing range of innovative cybersecurity technologies and significantly increase Honeywell's Connected Plant cybersecurity customer base. Nextnine's flagship technology, ICS Shield, protects industrial sites from cybersecurity attacks and enables remote monitoring of assets. It complements Honeywell's extensive cybersecurity portfolio with a solution that is used at more than 6,200 sites globally across the oil and gas, utility, chemical, mining and manufacturing sectors.

Epec Engineered Technologies, a leading build-to print-electronics manufacturer located outside of Boston, announced the acquisition of high-reliability custom RF product manufacturer—**Putnam RF Filters Inc.** Putnam was founded in 2008 in Manchester, N.H. and was designed to serve the military and aerospace industries, with a focus on manufacturing printed circuits board (PCB)-based RF filters, diplexers and other custom products. Epec now offers full design and manufacturing of RF filters, which are passive multiport device(s) that allows signals to pass through at discreet frequencies but rejects any frequency outside of a specified range.

COLLABORATIONS

Keysight Technologies Inc. announced a collaboration with **Qualcomm Technologies Inc.**, a subsidiary of Qualcomm Inc., to enable the realization of 5G technologies. Keysight has a comprehensive suite of design and test tools to support chipset development for next-generation cellular devices. Keysight's new 5G network emulation solutions portfolio, supported by Keysight's new UXM 5G wireless test platform, enables Qualcomm Technologies to validate the chipset technology and the higher-layer protocols needed for 5G. Keysight's scalable solutions support sub-6 GHz and mmWave, which will provide Qualcomm Technologies insights into the performance of their ICs and overcome potential challenges that may surface in 5G trials.

Rohde & Schwarz and **Analog Devices Inc. (ADI)** have been strategic partners for over 30 years. ADI has been involved in R&S product development processes and is regularly provided with information in the form of roadmaps, for which in return, it provides R&S with insights into up-and-coming component generations. To maintain this mutually beneficial and productive collaboration over the long term, the two companies have signed a new contract. The agreement is based on the new R&S supplier management program that uses a more transparent process for evaluating suppliers, and which aims to systematically leverage the synergy potential resulting from close collaboration.

Anritsu Co. and **ETS-Lindgren** announced groundbreaking support of IEEE 802.11 ac/n/a/g/b Over-the-Air (OTA) testing, with an enhanced solution that integrates the Anritsu Wireless Connectivity Test Set MT8862A with the CTIA-compliant ETS-Lindgren EMQuest™ EMQ-100 Antenna Measurement Software. The accurate and flexible turnkey solution now supports 802.11 ac/n/a/g/b WLAN standards, providing device developers and manufacturers with a single solution to characterize and validate designs in accordance with current and emerging versions of the 802.11 standards. The MT8862A is the first solution for testing 802.11 in ac/n/a/g/b devices in full signaling mode with built-in communications protocols.

Anokiwave Inc. and **Ball Aerospace** announced a collaboration that will enable the 5G wireless revolution. The collaboration accelerates mmWave 5G phased array developments with the introduction of a family of commercial, active phased array Innovator Kits. Included are kit offerings like the AWMF-0129 (named *Microwave Journal*'s April MVP), which enables improved mmWave 5G network efficiency and ease of developing commercial phased array antennas. The AWMF-0129 is a 64–element, single polarization 5G phased array antenna designed to cover the 27.5 to 30 GHz frequency band.

Nano Dimension Ltd. announced that its wholly owned subsidiary, **Nano Dimension Technologies Ltd.**, has received a grant approval from the **Israel Innovation Authority**, which will be used to finance a project to develop 3D printing of electronic modules for space applications. The total approved budget for this project is approximately $87,000 (NIS 309,000), of which the Israel Innovation Authority will finance 50 percent. According to the terms of the grant, Nano Dimension will pay royalties on future sales up to the full grant amount. This unique project is done in collaboration with **Harris Corp.**, a leading technology innovator that provides solutions that connect, inform and protect its clients.

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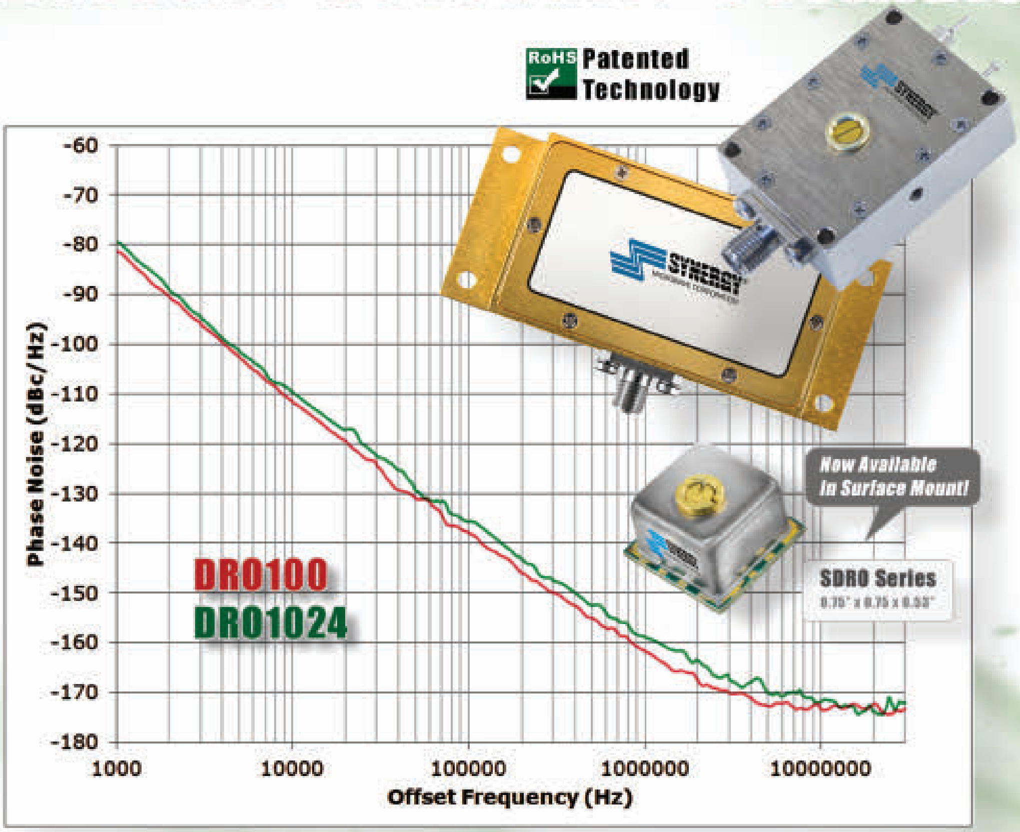

Model	Frequency (GHz)	Tuning Voltage (VDC)	DC Bias (VDC)	Typical Phase Noise @ 10 kHz (dBc/Hz)
Surface Mount Models				
SDRO1000-8	10	1 - 15	+8 @ 25 mA	-107
SDRO1024-8	10.24	1 - 15	+8 @ 25 mA	-111
SDRO1250-8	12.50	1 - 15	+8 @ 25 mA	-105
Connectorized Models				
DRO100	10	1 - 15	+7 - 10 @ 70 mA	-111
DRO1024	10.24	1 - 15	+7 - 10 @ 70 mA	-109

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Around the **Circuit**

ACHIEVEMENTS

Cobham Wireless has announced the delivery of a public safety communications system for the Eurasia Tunnel, the first undersea road tunnel to connect two continents. Its multi-band, multi-technology coverage solution provides the emergency services communication within the 5.4 km tunnel, which links two areas of Istanbul and spans both Europe and Asia. The customized solution incorporates Cobham Wireless' Digital Channel Selective Repeaters (D-CSR) and Band Selective Repeaters (BSR) and supports UHF, VHF, digital mobile radio (DMR) and FM technologies. This ensures that emergency services and operational teams can communicate at all times, throughout the tunnel.

Raytheon's Integrated Defense Systems business instituted the annual Supplier Excellence Awards program to recognize suppliers who have provided outstanding service and partnership in exceeding customer requirements. Award candidates are judged on certain criteria, including overall quality and on-time delivery. **Synergy Microwave Corp.** was one of 84 companies recognized by Raytheon's Integrated Defense Systems business for 4-Star Honors.

RFMW Ltd. is now a distributor member in the **Electronic Components Industry Association (ECIA)**. ECIA serves as the platform to influence policies that directly impact the efficiency of the supply chain and the future of electronics. As such, one of the criteria for distributor membership is that 100 percent of the applicant's published line card(s) must list lines for which the distributor is contractually authorized. This ensures that customers receive authentic, OEM components from suppliers. RFMW is ISO 9001:2008 certified and, as part of their due diligence with their supplier base, each supplier is investigated for counterfeit property policies and procedures.

ATEK Access Technologies announced that its AssetScan® solution is certified Class 1 Division 2 (C1D2), a certification issued to a specific product that allows it to be used in potentially hazardous environments. AssetScan is a complete solution of monitors, hardware, software and data analytics that connects virtually any industrial product or device to the Industrial Internet of Things (IIoT). AssetScan has a portfolio of condition monitoring solutions that include filtration and early bearing fault detection that provide insights on differential pressure, bearing faults, lubrication, cavitation, looseness, misalignment, to name a few.

Qorvo® announced that its Beijing manufacturing facility has earned ISO/TS 16949 qualification for testing and production of automotive RF components, becoming the fifth Qorvo certified facility. The qualification is essential to meet the Automotive Electronics Council (AEC) Q100 qualification for producing reliable, robust integrated circuits for cars. Consumer demand for in-car infotainment, mobile communications and Wi-Fi hotspot accessibility is driving rapid growth in the global connected car market. Technavio expects a compound annual growth rate (CAGR) of more than 32 percent in this market from 2016 to 2020.

CONTRACTS

DynCorp International (DI) was awarded by the **U.S. Army** a firm-fixed-price contract for logistics support services for government-owned fixed-wing fleets performing transport aircraft missions (C-12, C-26 and UC-35 fleets, with limited services for T-6 fleets). The award is for a one year base period that includes a three-month transition, followed immediately with nine months of production and five single year option periods. If all options are exercised, the total program is valued at $795.3 million. DI will provide worldwide program management, CLS, engineering, component repairs, maintenance, paint, modifications, service bulletin kits and support, field team support and other non-routine over-and-above tasks and materials.

Arralis announced a contract with the **European Space Agency (ESA)** for the company's new Leonis Ka-Band chipset, which will enable massive data rate communications speeds for commercial and science missions. This first phase Ka-Band transceiver chipset contract is worth €650,000, which is awarded under ESA's ARTES Competitiveness & Growth programme. Claimed to be the first of its kind the Ka-Band chipset comprises all of the circuits required to build a Ka-Band satellite and ground front-end that will connect easily with high-power amplifiers and antennas.

The National Aeronautics and Space Administration (NASA) awarded **Science Applications International Corp. (SAIC)** an indefinite-delivery, indefinite-quantity contract to provide multidiscipline engineering support services to the Goddard Space Flight Center in Greenbelt, Md. The single-award contract has a five-year base period of performance and an award ceiling of $620 million. Work will be performed at Goddard. The NASA Omnibus Multidiscipline Engineering Services (OMES) II contract covers engineering support to Goddard's Applied Engineering and Technology Directorate (AETD). SAIC will provide engineering services for the study, design, systems engineering, development, fabrication, integration, testing, verification and operation of spaceflight, airborne and ground system hardware and software, including development and validation of new technologies to enable future space and science missions.

Harris Corp. has been awarded a five-year, $500 million ceiling, single-award IDIQ contract from the **National Geospatial-Intelligence Agency (NGA)** to develop software that will enable NGA analysts and customers to search and retrieve data from intelligence systems faster and more efficiently than ever before. The contract was received during the third quarter of Harris' fiscal 2017. The software will process content held within the NGA, the National System for Geospatial-Intelligence and other intelligence-community agencies. It will allow intelligence officials to provide more timely and accurate support to warfighters and the national security community.

Around the **Circuit**

CACI International Inc. announced that it has been awarded an indefinite-delivery, indefinite-quantity contract, with a ceiling value of $94 million, to provide full service automated testing system support services to the **U.S. Air Force 309th Electronics Maintenance Group** under the Automated Test System Sustainment Initiative (ATSSI). The five-year award represents both new and continuing work in the company's logistics and material readiness market area. The Air Force 309th Electronics Maintenance Group repairs, overhauls and modifies various aircraft systems and components, and supports programmed depot maintenance and modification of aircraft weapon systems.

PEOPLE

ITT Inc. announced that it has appointed **David J. Malinas** as president of its Industrial Process business, reporting to Luca Savi, ITT's chief operating officer. In this role, Malinas will be responsible for delivering the strategic and operating plans of ITT's Industrial Process business, which employs about 2,500 people globally and had 2016 revenues of approximately $830 million. The business designs and manufactures an extensive array of highly engineered pumps and valves for the oil and gas, chemical, mining and industrial markets. Its long-standing brands include Goulds Pumps, Bornemann, Engineered Valves, PRO Services and C'treat.

After completing the acquisition of **Linear Technology** on March 10, **Analog Devices Inc. (ADI)** announced the leadership team for the combined company on June 15. These organizational changes were effective immediately. **Vincent Roche**, ADI's president and CEO, remains in his role. **Rick Hess**, the executive VP who was responsible for ADI's automotive, communications and industrial businesses, moves to the role of strategic advisor, reporting to Vincent Roche. **Greg Henderson**, VP of ADI's RF and microwave business, was promoted to senior VP responsible for the automotive, communications and aerospace and defense businesses of the combined company.

▲ *Greg Henderson*

RF Industries Ltd., a designer and manufacturer of interconnect products, has appointed **Gerald T. Garland** to its Board of Directors. Over his 18 years in the wireless telecommunications industry, Garland has been an accomplished senior executive with extensive experience in product management, sales management, solutions development and finance. RF Industries now intends to leverage his skills and financial expertise to improve sales and profitability, as well as expand product offerings in distributed antenna systems, wireless and data center markets.

▲ *Gerald T. Garland*

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SKY66113-11 SKY66114-11	Front-end Module for Bluetooth® Low Energy / 802.15.4 / ZigBee® Applications	2.400 to 2.483
SKY66115-11	Front-end Module for Range Extension Applications	0.400 to 0.510
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Around the **Circuit**

REP APPOINTMENTS

Atlantic Microwave Ltd. is to be the exclusive U.K. sales representative for **Precise Time and Frequency LLC**'s range of high performance time and frequency instrumentation. Atlantic Microwave will sell Precise Time and Frequency Instruments through its AMRF division. Under its AMRF brand, the company acts as a U.K. sales representative for a number of select technology partners in the RF and microwave industry.

Richardson RFPD Inc. announced that it is authorized to market and sell **Sierra Wireless** connectivity and cloud services as part of its global franchise agreement. Richardson RFPD now provides its worldwide customers with a comprehensive, fully-integrated solution from Sierra Wireless, including hardware, the AirVantage® IoT cloud platform and managed connectivity.

W. L. Gore & Associates Inc. announced that **COTSWORKS®** has been recently named an authorized distributor and value-added reseller of GORE®Aerospace Fiber Optic Cables for civil and military aircraft applications in Europe and North America.

PLACES

Rusada Inc., a technology provider for aircraft maintenance, repair and overhaul (MRO) and airline engineering departments, has opened their first office in the U.S., specifically to service the needs of their American customer base and prospects. Based in Boulder, Colo., Rusada is staffed by a team of aviation specialists focused on developing new relationships for the company's leading "Envision nGen" product, while working with existing customers to ensure that the development roadmap is aligned with the requirements of the Americas' client and prospect base. The U.S. office adds to Rusada's global footprint which includes facilities in the U.K., Switzerland, UAE, Singapore, India and Australia.

EDI CON USA 2017 ANNOUNCES SHORT COURSES

EDI CON USA announced the addition of a full day of training to its conference program at the Hynes Convention Center, September 11-13 in Boston, MA. Organizers of EDI CON have invited industry experts to teach 3-hour short courses on relevant topics necessary for success in today's high-speed and high-frequency designs. The day also includes sponsored 3-hour training sessions from industry-leading companies. In addition to access to instructors who are preeminent in their respective fields, attendees will be treated to a lunch, networking breaks, and an afternoon reception courtesy of the day's sponsors: Mentor Graphics Corporation, a Siemens business; Teledyne LeCroy; Rohde & Schwarz; and Analog Devices.

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INVITED PAPER

Microwave Material Measurements Without Cables

John W. Schultz
Compass Technology Group, Roswell, Ga.

Traditionally, RF material measurements have been dominated by the paradigm of taking samples into the laboratory. This is because of the historically large size of both the microwave analyzer equipment and the fixturing. Recent technology developments in both compact spot probes and compact microwave analyzers are enabling a reversal of this paradigm. This article discusses the concept of handheld or robot mounted reflectometers for in situ measurement of microwave relevant materials. The technology described integrates the microwave analyzer and sensor, eliminating the need for RF cables.

Measuring the performance of microwave materials requires a test apparatus that includes a measurement fixture and a microwave analyzer, which are usually connected with microwave or RF cables. These cables are the bane of many measurement scenarios and can be significant sources of measurement error. A lesson learned early in material measurement laboratories is to avoid bumping the RF cables because of the phase and amplitude errors that result. To address this, some RF cable manufacturers include polymer outer jackets with increased surface stickiness to minimize movement when the cable is inadvertently bumped.

Even if cable flex errors are carefully controlled, environmental temperature drift can cause substantial errors. RF cables are generally a coaxial design, with solid or stranded inner and outer conductors made from metal and separated by a dielectric spacer. Teflon is commonly used for the spacer and is subject to thermal expansion or contraction as the temperature changes. With Teflon, a material phase transition occurs near room temperature that significantly increases its thermal expansion coefficient. In the RF measurements industry, this is known as the "Teflon knee."[1] Because of this, RF cables experience sufficient thermal expansion to cause undesired phase drift with just a couple degrees of ambient temperature change. Surprisingly, temperature variation due to normal air-conditioning cycles can cause significant measurement errors as well.

These problems are exacerbated when material measurements are required in a factory or production environment. The usual paradigm in a materials measurements laboratory is to insert a material coupon into a measurement apparatus. Conversely, in a factory, the need is to measure materials in situ, requiring that the measurement apparatus be located at the production line where the part is being manufactured. For example, measurement of materials that are incorporated in a large component such as a microwave radome may require robotic actuation of a sensor over the surface of the structure. Traditionally, this requires that the RF cable connecting the sensor to the analyzer be routed along the robot arm. As the sensor is moved over the part being tested, the cable flexes and creates phase and amplitude errors that are not necessarily repeatable. The RF cable is also subject to wear and must be replaced, as continuous motion eventually results in cable failure. Depending on the production environment, ambient temperatures may vary more than in an air-conditioned laboratory, further increasing measurement errors.

SOFTWARE SOLUTION

One potential solution for reducing cable-induced errors is through software analysis of the measured data. This requires quantifying the phase and amplitude errors induced by the cable, then applying a correction to the measured signal to cancel the cable error. In a recent provisional patent, Compass Technology Group described such a method.[2] It uses the extra reflections that exist within a measurement apparatus that are usually ignored or subtracted.


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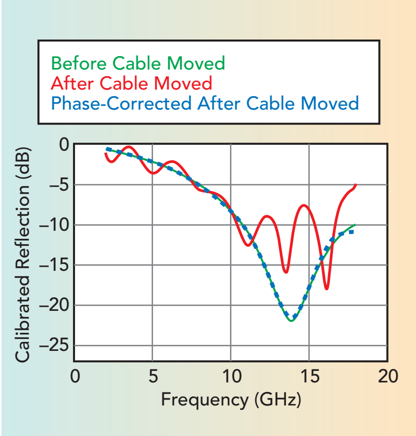
To illustrate this idea, ***Figure 1*** shows a microwave spot probe attached to the end of a robotic arm. A microwave network analyzer (not shown) excites the apparatus from 2 to 20 GHz. A 7.5 m RF cable that connects the network analyzer to the microwave probe is contained within a flexible cable management tube, to protect the cable from excessive wear. During operation, the robot positions the spot sensor just above the surface to be measured. The signal of interest is the energy that is emitted from the probe and reflected by the material beneath it. However, the probe also reflects some of the microwave energy, an otherwise unwanted reflection from the probe that can serve as a phase and amplitude reference signal. Any change in the phase and amplitude of the probe antenna provides a measurement of the phase and amplitude offset due to cable flex.[2] These offsets are applied before the calibration calculation, which minimizes them as error sources.

Measured data from an electromagnetic interference (EMI) absorber (see ***Figure 2***) illustrates the effects of cable flex. This material is designed to maximize absorption near 14 GHz. The data shown in this figure is calibrated using a "response and isolation" methodology.[1] The response measurement is of an ideal microwave reflector, in this case a flat metal plate. The isolation measurement is with no specimen (i.e., free space). The calibration procedure includes a vector subtraction of the isolation measurement from both the response data and the specimen measurement. When the additional cable correction method is used, the phase and amplitude correction is applied before each vector subtraction step: the isolation measurement is subtracted from the corrected specimen-under-test data and from the corrected response data, as appropriate. The final calibrated reflectivity of the specimen is then the ratio of the subtracted specimen data to the subtracted response data.

▲ **Fig. 1 Robotic arm with microwave probe sensor and flexible RF cable along the arm.**



▲ **Fig. 2 Measured reflection from a metal-backed absorber showing software correction of cable movement errors.**

Figure 2 illustrates the care needed to avoid moving the RF cable between calibration and specimen measurements. The green line shows the baseline reflection from a metal-backed absorber before any movement of the connecting cable. The red line shows the same specimen measured after the RF cable is moved and without any phase or amplitude correction. The dashed blue line shows the specimen measurement after the cable is moved and with the phase and amplitude correction using the method described. The corrected data after cable movement overlays the calibrated data for the undisturbed cable. As these results show, cable movement significantly degrades the accuracy of an RF measurement, and this correction method can account for these errors.

CABLE-LESS HARDWARE

While the use of a software algorithm to reduce cable errors is helpful in most situations, it does not eliminate the practical limitations of RF cables. Cables still wear out in measurement systems where motion is necessary, and cables can degrade to the point where no amount of software correction will correct the phase and amplitude errors. The ultimate solution to dealing with RF cables is to eliminate them. A couple decades ago, microwave analyzers were very large and heavy, occupying full-sized racks. Their size has been steadily reducing since then, with network analyzers from several companies now down to a single, rack-mounted component. However, even these are relatively big and heavy, requiring the sensor to be connected with an RF cable. The significant advances in compact microwave circuitry and components—driven by the constant drive for the miniaturization of RF transceivers in consumer electronics—led to the development of ultra-compact lab-grade vector reflectometers that are now commercially available. With a form factor that easily fits in the hand, these analyzers make RF cable-less measurements feasible.[3]

Cable-less RF measurements are especially powerful because they eliminate the errors previously discussed. More importantly, they enable a shift in the paradigm of RF material measurements. With conventional-sized microwave equipment, "witness" coupons must be made and brought to the measurement apparatus for testing. RF analyzers not much bigger than a cell phone provides a new capability to measure materials and components in situ, eliminating the need for witness coupons. This brings accurate and precise material measurements out of the laboratory and into the much more challenging environment of the factory floor. An added benefit is separating the microwave measurement from data processing on a separate PC, which minimizes the amount of work performed on the factory floor and improves productivity.

A key ingredient for handheld measurements is a compact RF sensor or spot probe. The use of spot probes for microwave material measurements goes back to at least the mid-1970s. Musil, Zacek et al. used dielectric antennas to measure transmission through a material specimen and their sensors consisted of dielectric rods inserted into the ends of metal horn antennas.[4] They used their sensors to successfully determine the complex dielectric permittivity of silicon specimens at mmWave frequencies. More recently, Diaz et al. designed "polyrod" antennas using computational simulation tools; their sensor included multiple dielectric layers inserted into a metal horn antenna,[5] and their innovation used computational tools to optimize the inserted polymer material and the impedance match of the probe antenna.

The spot probe described in this article includes both metallic elements and dielectric material. While previous spot probes used dielectric material inserts in conventional horn antennas, this compact probe design optimizes both the dielectric shape and metallic elements within an integrated unit (see ***Figure 3a***). Fed by a single SMA port in the rear, the larger model transmits and receives with linear polarization from 2.5 to 20 GHz; the smaller model covers 4 to 24 GHz. The two probes are 18 cm and 10.2 cm long, respectively. ***Figure 3b*** shows the VSWR for two different large probes; the VSWR is lower than 3:1 for the entire frequency band and lower than 2:1 for most of the band. The smaller probes have similar VSWR characteristics, except they extend to higher frequencies. These probes have measurement accuracies similar to larger laboratory measurement systems when measuring materials at normal incidence.[6] The illumination area is approximately round and has a diameter that depends on both standoff distance and frequency. For the measurement examples discussed in this article, a standoff distance of approximately 7 cm is used, and the illumination area diameter is approximately 5 cm at 10 GHz; the diameter is larger at lower

frequencies and smaller at higher frequencies within the band.

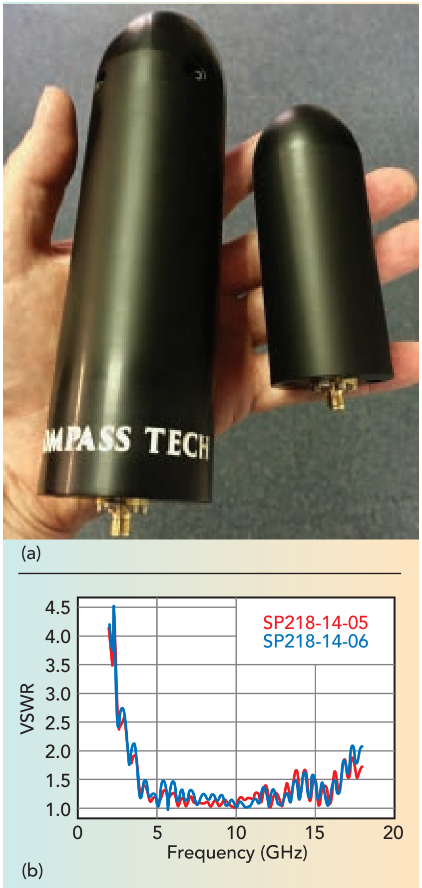
APPLICATION EXAMPLES

This section reviews the use of a miniaturized analyzer that has been integrated with this spot probe sensor. Two examples are presented: 1) monitoring the reflectivity of materials used in EMI mitigation using a handheld device and 2) nondestructive detection of defects in fiberglass composites with robotic scanning.

Material Reflectivity

The proliferation of high speed computing and wireless communications has crowded the electromagnetic environment. Signals generated within a device or between devices can inadvertently interfere with their functionality. One technique for reducing this mutual interference is using materials to block or absorb signals. For example, the housing for a component may be lined with or have embedded materials to absorb RF energy. An active component may have absorbing material directly applied to it to minimize interference. Screens designed to block and absorb energy may be placed between adjacent components.

Figure 4 shows an integrated reflectometer that includes a Copper Mountain Technologies RP180 vector analyzer and a Compass Technology SP218 spot probe. This system is handheld and only requires cables for power and USB communication with a data acquisition computer. Calibration of this device is straightforward and requires only two measurements: a "response" measurement and an "isolation" measurement. The response measurement uses a reference standard such as a flat metal plate. The isolation standard is simply measuring the probe while it is pointed at free space. This isolation measurement allows subtraction of background and foreground signals from the signal of interest, including the probe response. Time domain processing is used to further isolate the signal of interest from other unwanted signals, such as room reflections. Time domain processing transforms the wideband frequency data into the time domain and isolates the reflection of the sample under test from the rest of the detected reflections.



▲ Fig. 3 Large and small spot probes (a) and large probe typical VSWR (b).

▲ Fig. 4 Integrated 2 to 18 GHz reflectometer system including both sensor and vector analyzer.

Figure 5 shows the measured data from two different absorber material samples measured by the reflectometer system shown in Figure 4. These specimens are of a commercial magnetic absorber material that is made by mixing iron particles with an elastomer. The iron loading and thickness of the 70 mil thick absorber enables it to optimally absorb at around 9 GHz, as shown by the data. A second curve shows the measurement of two 70 mil layers of this material, placed on top of each other to double the thickness. As a result, the reflection null occurs at a frequency nearly half that of the original absorber sheet. The compact size of this measurement system makes it conducive for use in factory environments where the materials are being manufactured, which is more convenient than having to bring specimens back to a laboratory for testing. Its portability enables it to be used when and where materials are applied to components or parts. While these measurements are of a magnetic absorber, the reflectometer can also measure the microwave performance of resistive materials, such as EMI shielding, and dielectric materials such as radomes and microwave windows.

Non-Destructive Evaluation of Composites

The modern factory is automated and industrial robots are commonly employed to improve production efficiency and quality. In this setting, direct measurements of manufactured components are desired for quality assurance (QA) and process feedback, so that defects are identified early in the process and manufacturing variation can be managed. Catching problems early saves cost. When manufacturing large or expensive parts, QA requirements may require characterizing every part produced. A compact reflectometer with integrated analyzer and spot probe enables this when integrated into factory automation systems. In this example (see ***Figure 6***), the reflectometer is scanned over the surface of a material to map the positional dependence of microwave properties. Physics-based models can then be used to determine information about the material.

Composites are typically a laminate construction where different layers of fiberglass and resin, for example, are consolidated into a single material. Delamination is one problem that can occur during manufacturing or when using composite parts. For various reasons there may be air gaps or separations between

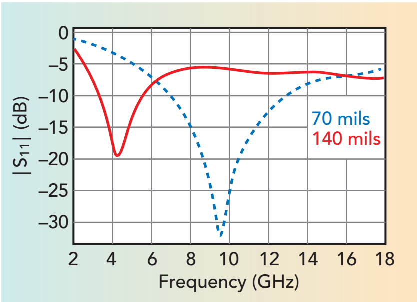
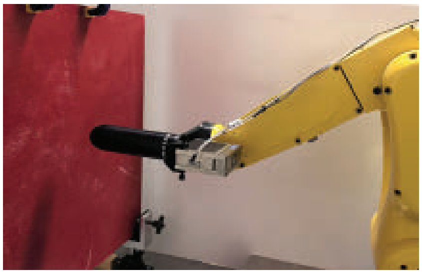


Fig. 5 Reflection data from the hand-held system (spot probe and vector analyzer) showing reflectivity of magnetic absorber material.

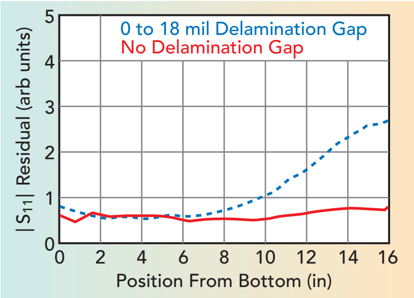


▲ **Fig. 6** **Robot arm with spot probe and vector analyzer scanning a fiberglass panel.**

layers within a part. Since fiberglass is generally opaque, there may be no visual indication of this delamination, and it only shows up when the part fails under mechanical load.

Figure 7 shows a measurement of a 0.5 in thick composite with and without a controlled delamination. The part consists of two 0.25 in thick composite panels sandwiched together. To simulate a delamination, an 18 mil spacer is placed at the top of the part. In both cases, with and without the spacer, the base of the panel is mechanically clamped together to eliminate any delamination gap at the base. The result shown in Figure 7 is calculated by comparing the measured reflectivity in the 2 to 18 GHz band to a single-layer model of a dielectric slab. The amount of deviation from the ideal slab model is plotted as a function of measurement location, while the robot scans from bottom to top. In both cases, there is a low level of residual model-fit error due to the natural inhomogeneity of the fiberglass. When a controlled delamination is induced in the middle of the specimen, the residual fit error shows a clearly increasing trend with the increasing width of the delamination gap.

A second example is shown in ***Figure 8***, with an alternate analysis of reflection data measured from a composite panel. In this case, the measured data is also compared to a simple dielectric slab model. The dielectric composite permittivity is assumed to be known and constant. The model is then used to compute the thickness of the panel being measured based on this model-measurement comparison, with the y-axis the computed thickness. Consistent with physical caliper measurements, the thickness is approximately 0.5 in. Because the composite is not perfectly flat, there is some variability in the thickness as the reflectometer is scanned across the panel. The second curve in Figure 8, shows the measured data when a 6 in wide painter's tape is applied in the rear part of the fiberglass panel, opposite to the side being measured by the reflectometer. As the data shows, the tape extends from about 7 to 14 inches and is clearly evident. The painter's tape is approximately 3 mil thick, which is consistent with the increased thickness determined by the



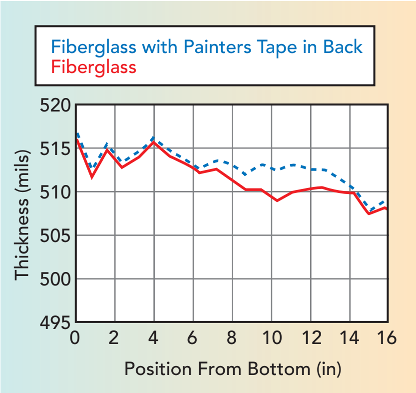
▲ **Fig. 7** **Detecting delamination in a fiberglass panel.**

microwave reflectometer. Detection of this 3 mil thick layer is somewhat remarkable, considering the wavelength of the interrogating microwave energy: from 6 inches at 2 GHz to 0.66 inches at 18 GHz. This method can be used to detect small thickness changes in fiberglass composites and other dielectric materials. Furthermore, since it is easily portable, testing can be done in any environment, such as the factory or in the field.

SUMMARY

RF cables add errors due to thermal drift and flexing. Eliminating the RF cable, measurement reliability and accuracy are significantly improved. As RF cables wear out and must be replaced periodically, especially if they are regularly moved or flexed, eliminating the RF cable can decrease measurement cost and reduce the need for maintenance.

This article discussed two applications using a compact microwave reflectometer: The first used a handheld device to measure the reflection coefficient of absorber materials for EMI mitigation. In the second, an integrated reflectometer system was mounted on an industrial robot to scan fiberglass composites. With appropriate data processing, a microwave reflectometer can detect defects and determine the thickness of non-conductive materials. Both of the examples demonstrate that RF cable-less reflectometer technology is feasible, enabling in situ measurements in field and factory.■



▲ **Fig. 8 Computed thickness of a fiberglass panel, showing detection of painter's tape.**

ACKNOWLEDGMENTS

This work was supported in part by a Cooperative Research and Development Agreement (CRADA) between the Air Force Research Laboratory (AFRL/RX) and Compass Technology Group.

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Compact, Wideband Bandstop Filter with Extended Upper Passband

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A wideband bandstop filter (WBSF) with extended upper passband consists of a modified transmission line ring with one embedded capacitor. Interference between two signal paths produces three adjustable transmission zeros used to create a wide, controllable stopband. Use of the embedded capacitor prevents the stopband from repeating at odd multiples of the fundamental stopband center frequency, resulting in a much wider upper passband. The circuit is simple, very compact and easy to fabricate. A prototype WBSF has a 20 dB rejection bandwidth of 90.7 percent at a center frequency of 1.2 GHz.

Microwave bandstop filters (BSF) are widely used in wireless communication and RF circuits for their effective suppression of spurious while allowing desired signals to pass. Compact WBSFs with high skirt selectivity are in demand for many communication and radar systems. Conventional BSFs using a shunt open circuited stub and coupled-line are generally large and narrowband.[1]

Several BSF configurations in planar technology with rejection and a wide stopband have recently been reported. Li, et al.[2] and Hsieh and Wang[3] describe WBSFs that combine quarter-wavelength lines with coupled-line sections of the same electrical length. WBSFs are also achieved by connecting two quarter-wavelength coupled-line sections, one with a short circuit and the other with an open circuit.[4]

The signal interference technique has been used to design WBSFs with good skirt selectivity.[5-7] The structure is made up of two parallel transmission lines with different electrical lengths and characteristics. By successfully placing the transmission zeros near the stopband edges, signal interference techniques enable sharp rejection with high skirt selectivity. In addition, the performance of these filters can be improved with additional lines. For example, Kanti, et al.[8] use a parallel-coupled transmission line section to improve BSF performance with five transmission zeros in the stopband. Similarly, the use of an open-ended coupled-line significantly enhances the 20 dB rejection bandwidth.[9,10] Furthermore, ultra-wide bandwidth and sharp rejection can be balanced with two-section open stubs.[11] Despite attractive stopband characteristics, the bandwidth of the upper passband in these filters is generally narrow; worse, the bandwidth of the upper passband decreases largely as the bandwidth of the stopband increases.

In this article, we describe a novel WBSF that improves the stopband and broadens

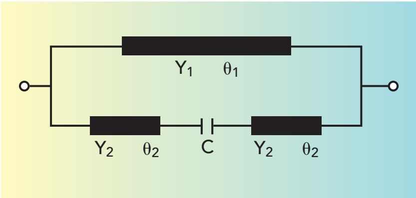


Fig. 1 Bandstop filter structure.

the upper passband. The structure includes two bilateral transmission lines and one embedded capacitor to reduce signal interference. This generates three adjustable transmission zeros in the controllable stopband for sharp rejection and expands the upper passband tremendously compared to the similar structures,[7-11] through the use of the embedded capacitor.

CONFIGURATION

The modified transmission line model (see ***Figure 1***) can be decomposed into two parallel sections. One is the upper transmission line having a characteristic admittance Y_1 and electrical length θ_1; the other is the cascaded structure consisting of two bilateral transmission lines with characteristic admittance Y_2, electrical length θ_2 and one embedded capacitor.

Considering the entire structure to be lossless, the overall Y matrix is

$$Y^U_{21} = jb^U_{21} = jY_1 \csc\theta_1 \quad (1)$$

$$Y^L_{21} = jb^L_{21} = \frac{-j2\pi fC}{\cos^2\theta_2 - 4\pi fC\sin\theta\cos\theta_2/Y_2} \quad (2)$$

If $\theta_1 = \pi$ when $f = f_1$, then $Y^U_{21}=+\infty$ at frequency f_1.

For the lower section, at frequency,

$$f_2 = \frac{Y_2}{4\pi C\tan\theta_2},\ Y^L_{21} = +\infty.$$

Obviously, there is a series resonance for the lower section when $f = f_2$. For this design, f_2 is always set lower than f_1 to generate three transmission zeros. Then the total parallel Y matrix of the structure can be expressed as

$$\left[Y^T_{21}\right] = \left[Y^U_{21}\right] + \left[Y^L_{21}\right] \quad (3)$$

The BSF creates transmission zeros at the frequencies where $|S_{21}| = 0$, and the relationship between the admittance matrices and scattering matrices can be given by

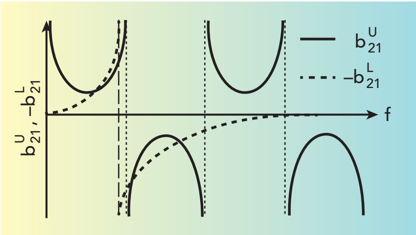


Fig. 2 Graphical view of Equation 5.

$$S^T_{21} = \frac{-2Y^T_{21}Y_0}{\left(Y^T_{11}+Y_0\right)\left(Y^T_{22}+Y_0\right) - Y^T_{12}Y^T_{21}} \quad (4)$$

where Y_0 is the characteristic admittance of the input port and the output port.

The condition for production of the transmission zeros can be simplified by setting $Y^T_{21}=0$, which yields the relationship

$$Y_1\csc\theta_1 = \frac{2\pi fC}{\cos^2\theta_2 - 4\pi fC\sin\theta_2\cos\theta_2/Y_2} \quad (5)$$

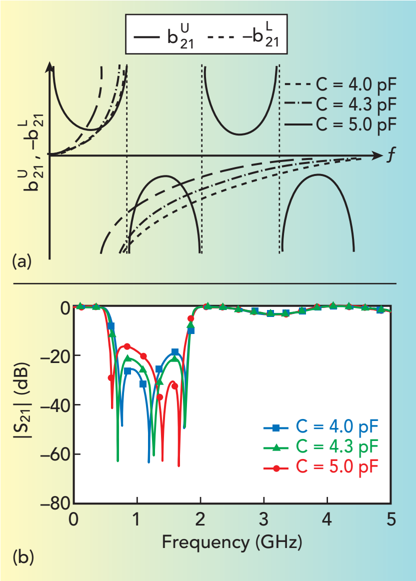
The relevant graph of Equation 5 is shown in ***Figure 2***. The solid line and dashed line represent b^U_{21} and $-b^L_{21}$, respectively, and the intersection points in the curves reveal the approximate locations of the stopband transmission zeros.

As shown in Figure 2, the first transmission zero positioned at f_{z1} is generated at the lower side of f_1 since $f_2 < f_1$ is satisfied in this design. Another two transmission zeros f_{z2} and f_{z3} are provided between f_1 and $2f_1$ when

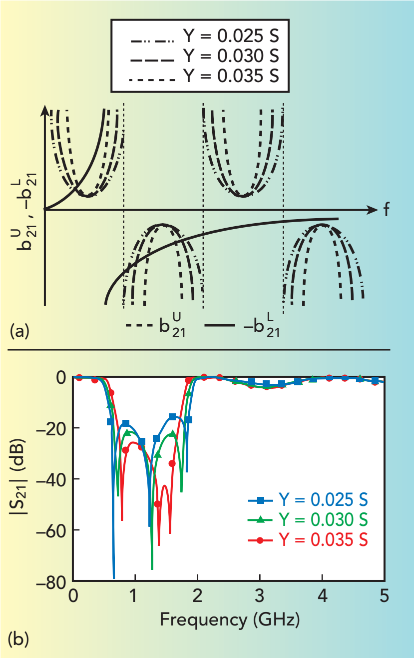
$$b^U_{21}\left(\frac{3f_1}{2}\right) > -b^L_{21}\left(\frac{3f_1}{2}\right).$$

With the choice of appropriate parameters, the structure produces three transmission zeros for a BSF response.

Note that the transmission zero distribution in this design is not inherently symmetrical about the central transmission zero, while the transmission zero distributions of almost all the previous reported WBSFs are symmetrical. In fact, by tuning C or Y_1, different transmission zero distributions can provide either symmetric or asymmetric BSF responses. The asymmetric bandstop filter response can also eliminate the restriction of a fixed central transmission zero, resulting in better adjustability and flexibility compared with the previous reported WBSFs.



▲ **Fig. 3** Susceptance (a) and simulated $|S_{21}|$ of the structure with different capacitances (b).



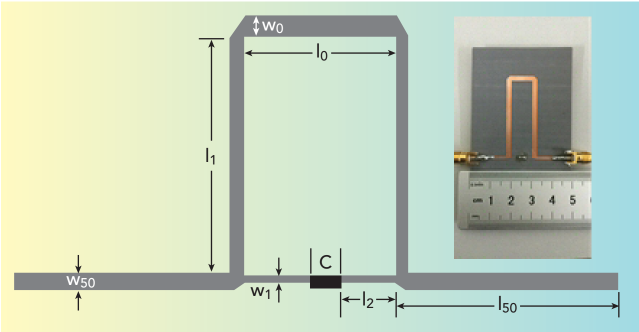
▲ **Fig. 4** Susceptance (a) and simulated $|S_{21}|$ of the structure with different upper line characteristic admittances (b).

As shown in ***Figure 3a*** and the above analysis, for given upper and lower transmission line parameters, the transmission zero distribution can be adjusted effectively by changing C. With increasing C, f_2 decreases, moving the first transmission zero lower. Meanwhile, the dashed line ($-b^L_{21}$) becomes sharper, pushing the second transmission zero higher and drawing the third transmission zero lower. Accordingly, the transmission zero separation between f_{z1} and f_{z2} increases while the transmission zero separation between f_{z2} and f_{z3} decreases with increasing C. As shown in ***Figure 3b***, different BSF responses with different transmission zero distributions can be obtained by changing C.

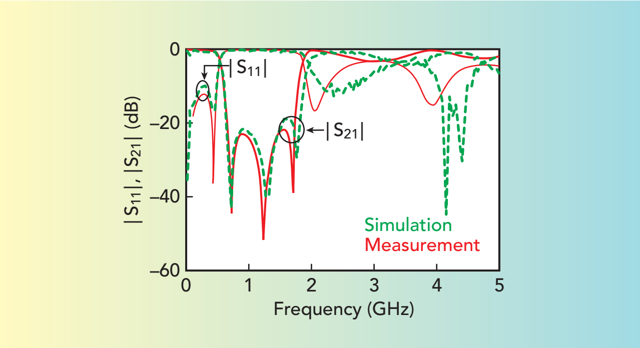
The characteristic admittance of the upper transmission line is also an important factor in adjusting the transmission zero distribution. As indicated in ***Figure 4a***, when increasing the upper transmission line's characteristic admittance Y_1, b^U_{21} becomes sharper, pushing the first and the second transmission zeros higher and drawing the third transmission zero lower. Accordingly, the transmission zero separation between f_{z1} and f_{z2} changes slightly while the transmission zero separation between f_{z2} and f_{z3} becomes smaller with increased Y_1. Therefore, as shown in ***Figure 4b***, different bandstop filtering responses with different transmission zero distributions can be achieved by altering Y_1.

FABRICATION AND MEASUREMENTS

A prototype WBSF having a 20 dB fractional bandwidth (FBW) of 90.7 percent at f_c = 1.2 GHz was fabricated on a 0.5 mm substrate with a relative dielectric constant of 2.65 and loss tangent 0.02. The physical dimensions and photograph are shown in ***Figure 5***. The optimized parameters are w_0 = 2.4 mm, l_0 = 10.4 mm, w_1 = 0.32 mm, l_1 = 38.2 mm, l_2 = 4.7 mm, w_{50} =1.35



▲ **Fig. 5** Microstrip layout and photograph of the wideband bandstop filter.



▲ **Fig. 6** Simulated and measured responses of the fabricated filter.

mm, l_{50} = 19.8 mm and C = 4.3 pF (achieved using MURATA 1.6 mm × 0.8 mm patch capacitors). Ansoft HFSS was used for simulation, and the Keysight 8510C vector network analyzer was used for the corresponding measurements.

Figure 6 shows good agreement between simulation and measurement. Measured transmission zero locations are at 0.71 GHz (with a suppression of 42.9 dB), 1.25 GHz (with a suppression of 40.2 dB) and 1.73 GHz (with a suppression of 29.9 dB), respectively. The measured 20 dB attenuation band is from 0.65 to 1.8 GHz, forming a wide attenuation bandwidth and a high FBW of 95.8 percent. Measured passband insertion loss, including connector loss, is less than 1 dB up to 0.50 GHz, increasing slightly in the upper band. The loss is less than 2 dB from 1.87 to 2.58 GHz and 3.45 to 5 GHz, and it is less than 3 dB for the entire upper passband. Attenuation rates at the passband to stopband transition knees are 171.3 dB/GHz (measured attenuation of 5 and 29.5 dB at 0.55 and 0.69 GHz, respectively) and 163.3 dB/GHz (measured attenuation of 5 and 29.5 dB at 1.90 and 1.75 GHz, respectively) on the lower and upper side of the stopband.

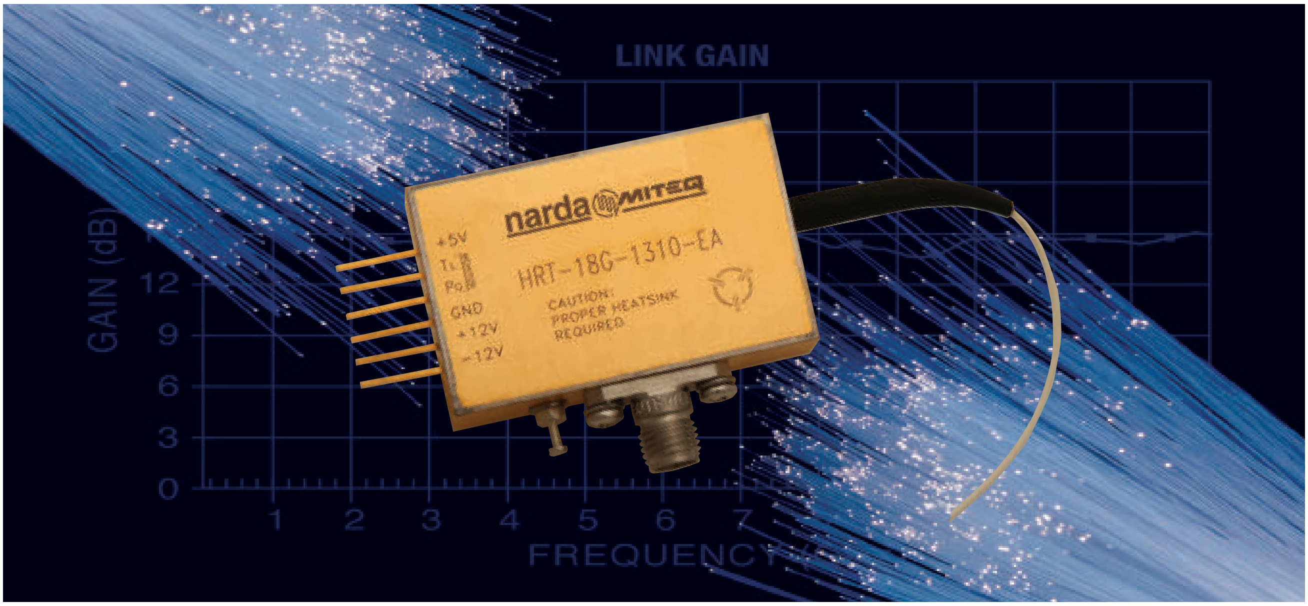
Without the feed line, the WBSF occupies a compact size of 41 mm × 15.2 mm, corresponding to $0.022\lambda_g^2$ ($0.243\lambda_g \times 0.09\lambda_g$), where λ_g is the guide wavelength of a 50 Ω transmission line at the center frequency of 1.2 GHz.

A comparison of this filter with other reported WBSFs is provided in ***Table 1***. It exhibits a wider stopband, sharper rejection level and wider upper passband. Additionally, its size is much smaller.

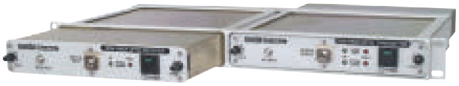
CONCLUSION

A novel compact WBSF with extended upper passband is realized by using the signal interference technique and one embedded capacitor. The distributions of the three transmission zeros can be easily and flexibility adjusted by changing the value of the embedded capacitor and the circuit characteristic admittance to obtain the desired performance. Moreover, the WBSF exhibits sharp rejection in the stopband. The circuit size is only 0.022 λ_g^2 making it suitable for applications where small size is important. Design equations, curves and theoretical analyses are provided. The theoretical predictions are verified through measurement of a prototype WBSF with a 20 dB FBW of 90.7 percent centered at 1.2 GHz.■

18 GHz THAT MOVES AT
THE SPEED OF LIGHT.



narda MITEQ



Enclosures are available for multiple transmitter or receiver combinations.

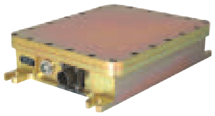


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TABLE 1
COMPARISON WITH OTHER REPORTED WBSFs

Parameters/Ref	7	8	9	10	11	This Work
f_c (GHz)	1.5	1.5	1.5	1.5	2	**1.2**
Stopband 20 dB FBW (%)	98.5	67	100	122.5	100	**95.8**
No. of Zeros	3	5	3	3	4	**3**
Zero Distribution	Symmetrical	Symmetrical	Symmetrical	Symmetrical	Symmetrical	**Both**
Attenuation Slope Lower (dB/GHz) Upper (dB/GHz)	215.1 117.6	92.85 95	56.7 45.3	227.9 123.2	85 135	**171.3 163.3**
Upper Passband IL (dB), FBW (%)	< 2, 31.1	unknown	< 2, 12.8	< 2, 16.5	< 2,31.8	**< 3, > 91.9**
Circuit Size (λg^2)	0.2	0.005	0.021	0.09	0.11	**0.022**

IL = Insertion Loss, FBW = Fractional Bandwidth

ACKNOWLEDGMENT

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INVITED PAPER

Phase-Locked Loops Enable Phase Alignment and Control

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Phase resynchronization and phase adjust features place phase-locked loop synthesizers into known phase states. This enables many applications and greatly simplifies calibration.

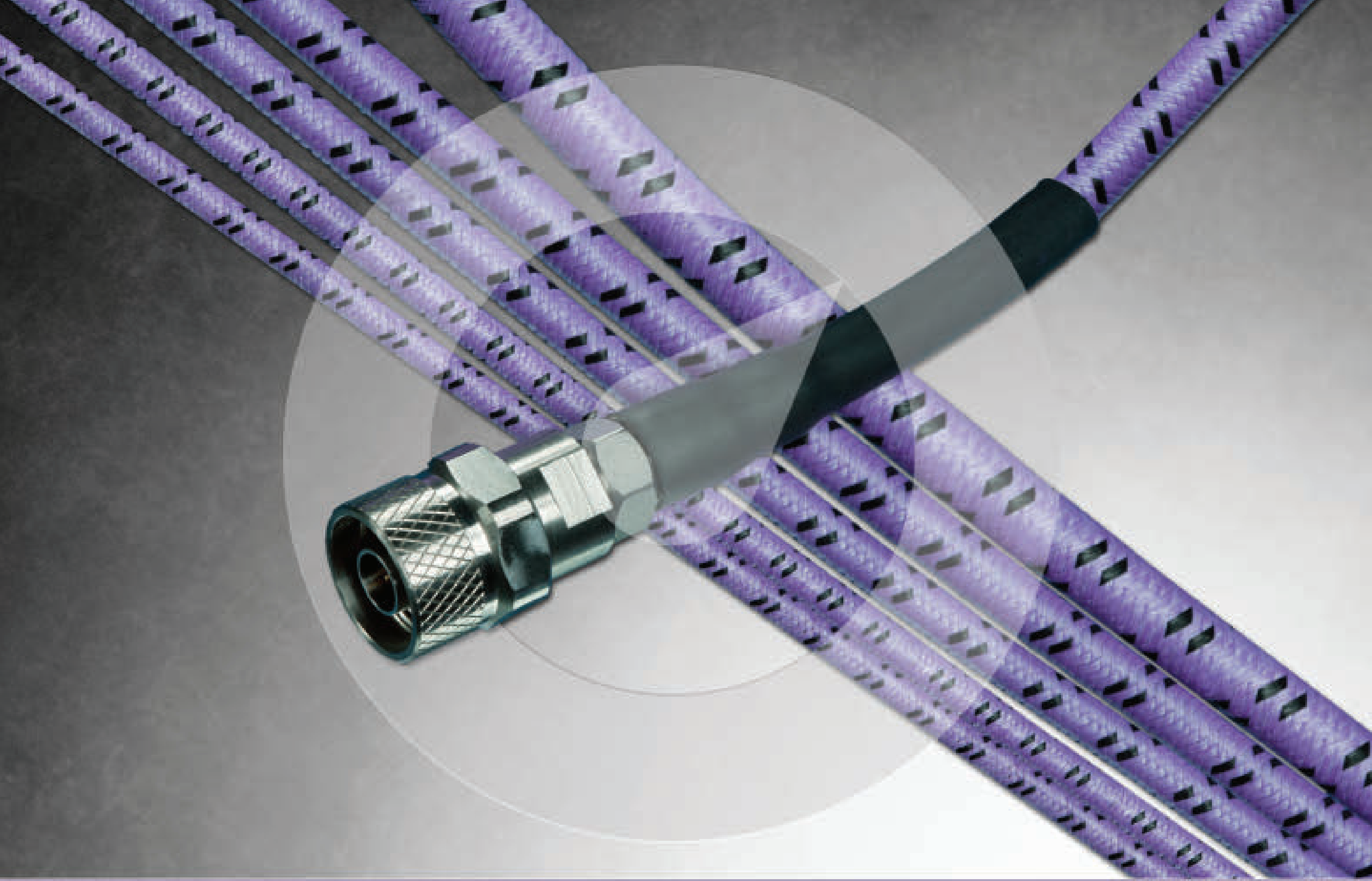
As the name suggests, a phase-locked loop (PLL) uses a phase detector to compare a feedback signal with a reference signal, locking the phases of both signals together. While this property has many applications, PLLs today are most commonly used in frequency synthesis, generally as local oscillators (LO) in frequency up- and down-converters or clocks for high speed analog-to-digital converters (ADC) and digital-to-analog converters (DAC).

Until recently, little attention was paid to the behavior of phase in these circuits, but with a growing demand for efficiency, bandwidth and performance, RF engineers must devise new techniques to improve spectral and power efficiency. Repeatability, predictability and adjustability of the phase of a signal all play an increasingly important role in modern communication and instrumentation applications.

It is meaningless to refer to a phase measurement unless it is relative to another signal or to the original phase. For example, a vector network analyzer (VNA) phase measurement of a two-port network, such as an amplifier, relates the output phase to the input phase ($\angle S_{21}$) or the phase of the reflected signal to the incident signal ($\angle S_{11}$). For a PLL synthesizer, a phase measurement relates to the input reference phase or compares the phase of one signal to another. The "holy grail" or ideal state for any phase measurement is to be at a precisely desired value compared to the original phase. However, non-idealities such as nonlinearities, temperature differences and manufacturing variances mean that phase is among the more variable of properties in signal generation. In this article, the term "in phase" refers to signals that have precisely the same amplitude and timing properties, and "deterministic phase" means that the phase offset between them is known and predictable.

OSCILLOSCOPE PHASE MEASUREMENTS

A high speed oscilloscope is a relatively intuitive way to compare output phase to a reference phase. To be visible, the input and output phases generally must be integer multiples of each other, a relatively common case in many clocking circuits. For integer-N PLLs, the relationship between the input frequency REF_{IN} and the output frequency RF_{OUT} is generally deterministic and repeatable. Scope probes are placed on both the REF_{IN} and RF_{OUT} ports, taking care to only capture the signal when the phase has settled. A sophisticated oscilloscope, such as the Rohde & Schwarz RTO1044, allows the event trigger to activate only when a specific digital pattern has been written to the PLL device and a rising edge from the known signal is present. Since there may be a delay between writing the digital pattern and when the final signal settles, some delay must be inserted between the two events, which is a capability provided in the RTO1044.



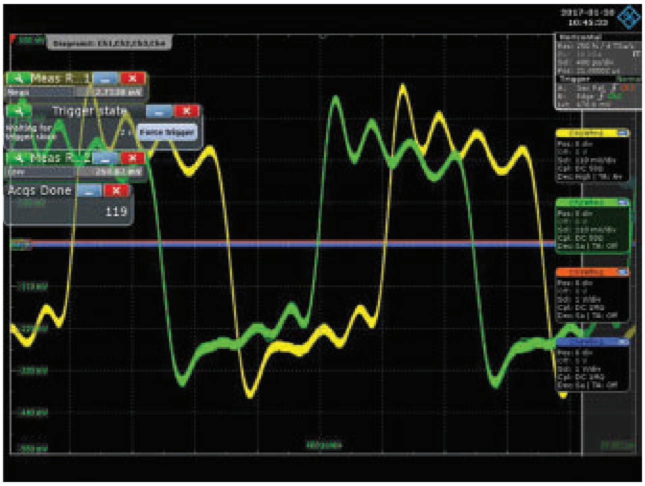


Fig. 1 Phase repeatability measurement.

Phase Repeatability

The goal of this measurement is to verify that the phase delay of a PLL synthesizer—an Analog Devices ADF4356 for example—relative to a known reference signal—another ADF4356 programmed to the same output frequency—is constant and repeatable when powered on. To measure this, two low speed probes are connected to the CLK and DATA lines of the ADF4356 SPI interface. Once the digital pattern to write the particular frequency is noted, a wait time of 1 s is programmed before the instrument captures the time domain plot showing the output of both PLLs. The two ADF4356 PLLs are locked to a VCO frequency of 4 GHz and divided by eight to generate 500 MHz. One of them is repeatedly powered off and on using the software power-down feature. With the oscilloscope in infinite persistence mode, 119 acquisitions are captured, and the phase difference between the two is shown to be constant and repeatable (see ***Figure 1***).

Several precautions are followed to ensure repeatability. Low R divider values introduce less uncertainty than higher ones, and it is vital that the divided feedback from the VCO output is fed to the N counter input. Given that the ADF4356 PLL and VCO contain 1,024 differing VCO bands, it is important that this uncertainty is eliminated by using the manual calibration override procedure.[1]

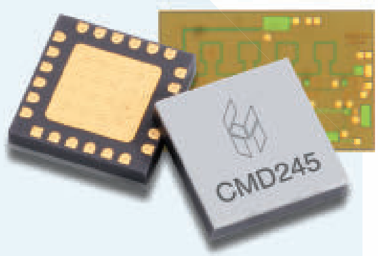
Phase Resync

Phase resync is defined as the ability of a fractional-N PLL to return to the same phase offset at each given frequency: observing frequency F1 with phase P1, when changing channels to frequency F2, the same original phase P1 is observed when the frequency is reprogrammed back to F1. This definition ignores changes due to VCO drift, leakage current and temperature, for example. Resync sends a reset pulse to the fractional-N sigma-delta modulator that places it in a known repeatable state. This pulse must be applied after frequency settling mechanisms are complete, such as VCO band select and loop filter settling time. With the ADF4356 PLL, its value is controlled by a timeout counter in register 12. The ability to adjust the timing of this reset pulse enables a degree of output signal adjustability, with the ability to vary the timing in steps of 360 degrees/2^{25}, which is finer than can easily be measured by most instruments.

To illustrate this measurement, both ADF4356 PLL VCO's are programmed to 4002.5 MHz and divided by eight. One PLL is programmed to a VCO frequency of 4694 MHz and then programmed back to 4002.5 MHz. Using an oscilloscope, as previously described, to examine the behavior of the PLL, with 1,734 frequency changes, the PLL repeatedly settles to the same phase (see ***Figure 2***).

To characterize the variable phase offset feature of the ADF4356, the phase word is programmed to 4,194,304/2^{25}, which equals 90 degrees. Similar values for 90, 180, 270 and 0 degrees are programmed (see ***Figure 3***). Relative to the original signal on channel 1, four equally


Quadrature Axis
In-Phase Axis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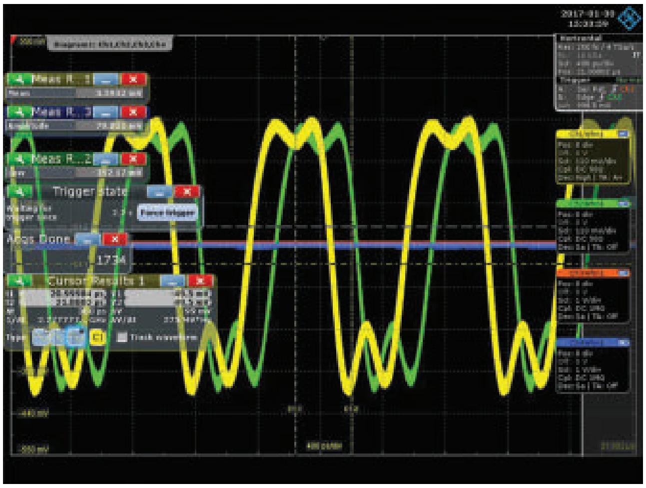
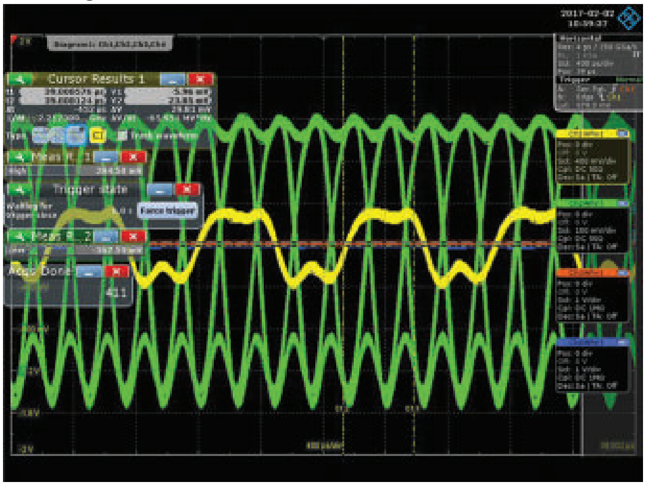
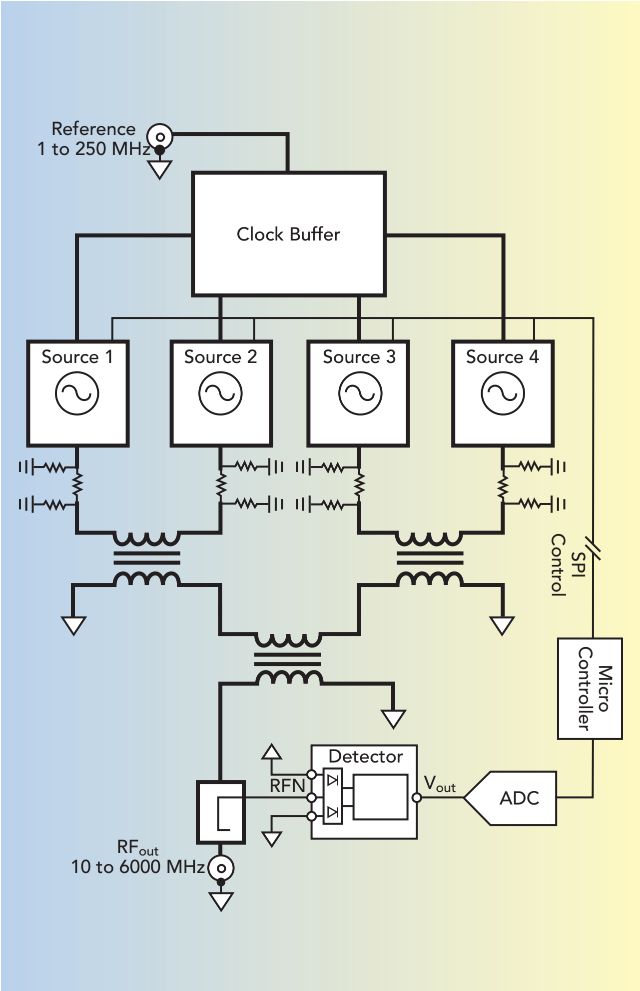
spaced signals are observed, confirming the accuracy of the phase resync with programmable offset. This feature is highly useful. A look-up table of phase values can be created for each user frequency, with the phase value dialed in on each use. In an application which combines four LO frequencies in phase



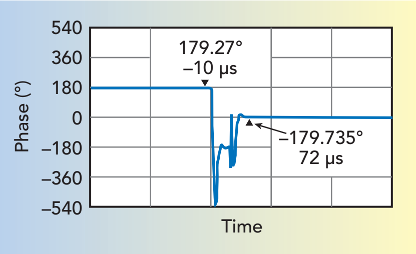
▲ **Fig. 2 Fractional-N PLL resync phase measurement, switching from 4694 to 4002.5 MHz.**



▲ **Fig. 3 Phase resync with variable offsets.**



▲ **Fig. 4 Application requiring precise control of PLL output phase.**

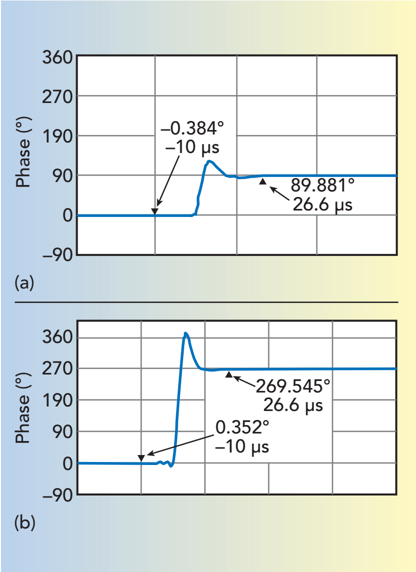


▲ **Fig. 5 Phase output of a 5025 MHz signal switched 180 degrees, measured with a Rohde & Schwarz analyzer.**

(see ***Figure 4***), the phase resync and offset features are used to adjust output phases so that they combine to give 6 dB lower phase noise. If used as a tunable LO (likely on the first stage of a signal analyzer), the resync and phase offset features allow the user to run a one-time calibration when powering up to determine the precise phase value for each LO frequency.

VSA/VNA PHASE MEASUREMENTS

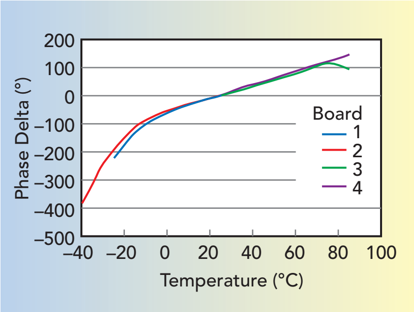
Vector signal and network analyzers are useful for characterizing phase behavior, although their use is limited to comparing the phase of the device to its initial value. Sophisticated analyzers like the Rohde & Schwarz FSWP can be placed in FM demodulation mode, and the phase output selected. This is useful for evaluating PLL phase resynchronization. ***Figure 5*** shows an example of the ADF4356 switching phase by 180 degrees at an output frequency of 5025 MHz.



▲ **Fig. 6 A 90 degree (a) and 270 degree (b) phase adjust, measured with a Rohde & Schwarz analyzer.**

Phase Adjust

The phase adjust feature avoids resetting the sigma-delta modulator and simply adds a phase word between 0 and 360 degrees to the existing phase. This is useful for applications in which a reset of the phase is not desired. It can be used to dynamically adjust the phase word to compensate for known differences in phase due to effects such as temperature. Phase adjust "adds" phase to the existing signal on each update of R0 (with the value programmed to register 3 of the ADF4356). It does not contain a reset pulse like phase resync. Measurements from a Rohde & Schwarz FSWP show the addition of 90 degrees (see ***Figure 6a***) and 270 degrees (see ***Figure 6b***) to the original signal. In both cases, the output frequency of the ADF4356 is set to 5025 MHz before changing the phase.



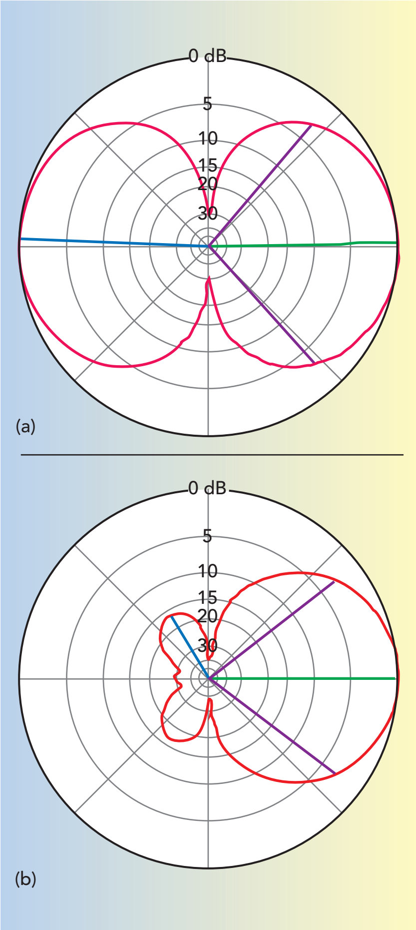
▲ **Fig. 7 Measured phase drift over temperature at a 4 GHz output frequency.**

Behavior Over Temperature

Because the physical parameters of inductors change over temperature, so do the electrical characteristics, which manifests as a change in phase. To mitigate this, a user can program a phase offset. For example, two ADF4356 PLLs programmed to a 4 GHz output frequency and placed in the same oven chamber and at the same initial phase track closely in phase over temperature (see ***Figure 7***). This shows the phase can be adjusted depending on temperature.

ANTENNA SYSTEMS FOR 5G

Beamforming is a technique that will be key to the architecture of 5G networks, i.e., using multiple antenna array elements with varying phase and amplitude at each element to steer the antenna energy to the end user. ***Figure 8a*** shows the E-plane array pattern of two half wavelength elements spaced λ/4 apart and driven in phase. The antenna radiation pattern is omnidirectional in the H-plane. ***Figure 8b*** shows the E-plane pattern of the two elements driven by signals 90 degrees out of phase; the resulting radiation pattern becomes more directional. As the number of elements increases and are properly phased, the beam becomes more focused or directional, enabling more of the transmitted energy to be directed toward a particular user. Beamforming results in greater spectral efficiency. However,



▲ **Fig. 8 E-plane pattern of two, λ/2 dipole antenna elements spaced λ/4 apart and fed in phase (a) and 90 degrees out of phase (b).**

for beamforming to be repeatable, the LO phase must be repeatable, and that repeatability is enabled by the PLL and synthesizer. PLLs with the features described in this article will eliminate the need for additional calibration of the beamforming circuitry.

CONCLUSION

The phase adjust and phase resync features incorporated into modern PLL synthesizers ensure that uncertainties in the phase characteristic of the LO are eliminated. The ability to adjust phase using these features provides the user with additional levers to overcome other phase delays in the circuit that are difficult to adjust by the beamformer or the baseband circuitry.

Reference

1. ADF4356 Data Sheet, www.analog.com/media/en/technical-documentation/data-sheets/ADF4356.pdf

INVITED PAPER

Clocking the RF ADC with Phase Noise Instead of Jitter

Thomas Neu
Texas Instruments, Dallas, Texas

When designing an RF sampling receiver, system designers can use frequency domain analysis to better specify the phase noise requirements of the external sampling clock. Instead of working with the simplified jitter value, frequency domain analysis preserves crucial application-specific frequency offset information and may be better suited for working with modern, high performance RF sampling converters.

Heterodyne receiver designers traditionally specify sampling clock requirements in terms of jitter. Clock jitter is calculated by integrating the clock source phase noise over a certain bandwidth. This process removes all frequency-dependent noise information. The passband of a bandpass filter on the clock input, or the bandwidth of the clock input to the analog-to-digital converter (ADC) itself, often determines the far integration limit. The jitter of clocking devices is often specified over a band from 12 kHz to 20 MHz offset, which originates from an older telecom synchronous optical network (SONET) classification and is reasonably close for most applications (equivalent to using a bandpass filter with a ~40 MHz passband). It also enables system designers to easily compare the jitter performance of different devices. Using this jitter specification in heterodyne receivers is usually acceptable, as most systems use moderate ADC clock rates (< 250 MSPS). External devices can also provide low phase noise clock signals (< 120 fs) to the data converter by internally dividing from a high frequency, low phase noise voltage-controlled oscillator (VCO).

When using time domain jitter, in theory, clock phase noise should be integrated over approximately 2x the clock input bandwidth.[1] However, as designers develop radios using direct RF sampling converter, such as the TI ADC32RF45, a different method may be much more appropriate: focusing on clock phase noise in the frequency domain within the relevant band of interest and ignoring noise beyond that. For example, a system specification for a radar receiver or multicarrier GSM (MC-GSM) base station may state a minimum signal level at the antenna input (see ***Table 1***) to provide accurate detection in the presence of an in-band interferer (a signal located within the passband of the filters in the signal chain). A typical example would be a radar receiver in the presence of a jammer or a cell phone tower trying to communicate with a cell phone at the edge of the coverage zone, while a different cell phone is transmitting at full power close by.

TABLE 1
3GPP MC-GSM SPECIFICATION FOR IN-BAND BLOCKER

	Channel Bandwidth	Blocker Offset	Wanted Signal Level	Blocker Level
In-Band Blocking GSM1800	200 kHz	800 kHz	−101 dBm	−25 dBm

The receiver requirement may focus on only a small frequency spectrum within the 3GPP MC-GSM specification, 800 kHz offset from the blocker with a 200 kHz channel bandwidth, for example. There are several different noise contributors to consider, such as spurs and intermodulation distortion products caused by large interferers, thermal noise and clock noise. For the clock noise (see ***Figure 1***), rather than trying to solve for a 6 GHz integration bandwidth when operating the RF ADC at 3 GSPS, it may be more accurate to simply figure out the clock noise contribution within the 200 kHz channel bandwidth of interest.

CLOCK NOISE FOR DIRECT RF SAMPLING RECEIVERS

When asked about phase noise requirements for RF sampling converters, the an-

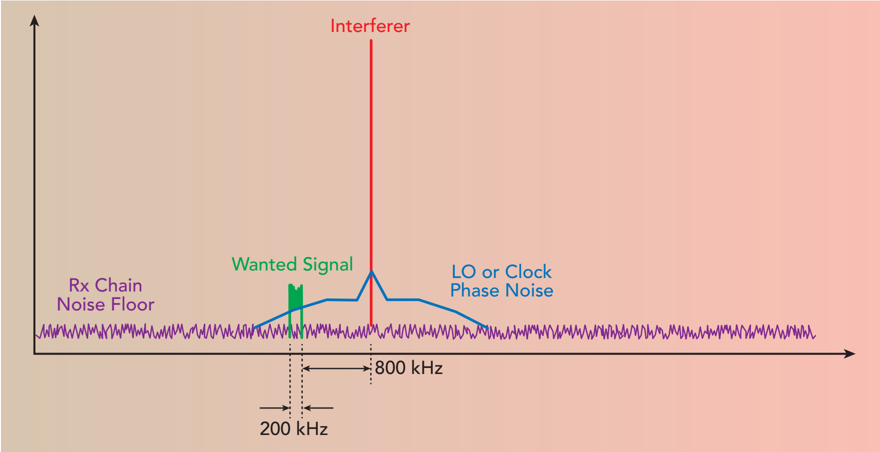


Fig. 1 A low-level desired signal in the presence of clock noise from a large interferer.

swer depends on the product specifications and several factors that impact the clock noise of data converters. These include:

ADC aperture jitter[2]—Aperture jitter is timing uncertainty inside of a data converter. During the sampling process, the external clock signal triggers the capture in the presence of noise. Ideally, this is flat noise in the frequency domain, but with low geometry CMOS converters, a 1/f noise component can be present.

Clock amplitude or slew rate—The ADC aperture jitter is quite sensitive to clock slew rate or amplitude, especially as input frequencies increase (see ***Figure 2***). When using a sine wave clock signal, slew rate and amplitude are directly related to each other. The data converter signal-to-noise ratio (SNR) in the data sheet is typically characterized with a large clock signal (> 1.5 V peak-to-peak) for minimum aperture jitter degradation.

External clock phase noise—During the sampling process, both the external phase noise and ADC aperture jitter are modulated on top of the input signal. Spurs on the external clock are modulated onto the input signal as well.[3] This is illustrated in ***Figure 3***, where a 5 MHz-wide noise pedestal at a 6 MHz offset is added to the sampling clock. A close look at the fast Fourier transform (FFT) spectrum shows the same noise pedestal modulated to the input signal with a 6 MHz offset on either side.

Signal input frequency—ADC SNR degradation due to clock noise is directly affected by the frequency

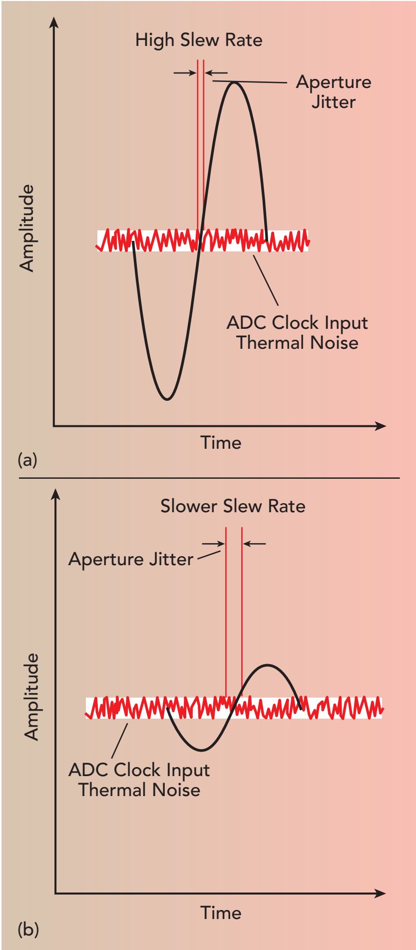


Fig. 2 ADC aperture jitter is lower with a high slew rate clock (a) than with a clock with a slower slew rate (b).

of the input signal. In the frequency domain noise analysis, the total clock noise is scaled by 20log (input frequency/clock frequency) during the sampling process. The higher the frequency of the input signal, the larger the clock noise contribution. System designers are well aware

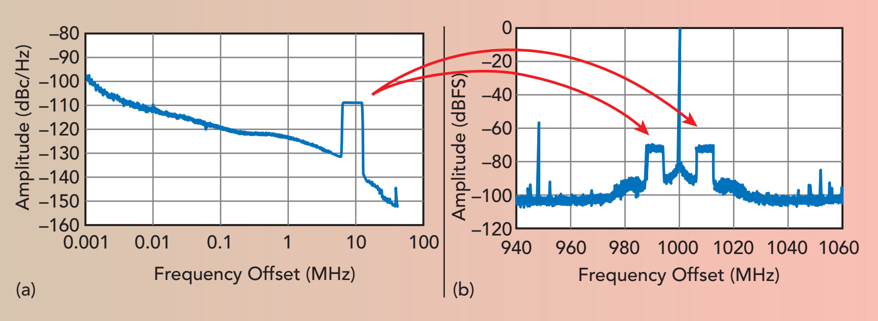


Fig. 3 Clock phase noise with pedestal offset (a) and resulting FFT with F_{IN} = 1 GHz and F_S = 3 GSPS (b).

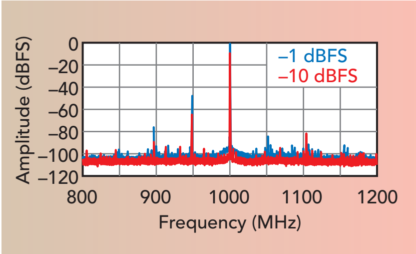


Fig. 4 FFTs with input amplitude at –1 dBFS and –10 dBFS, with F_{IN} = 1 GHz and F_S = 3 GSPS.

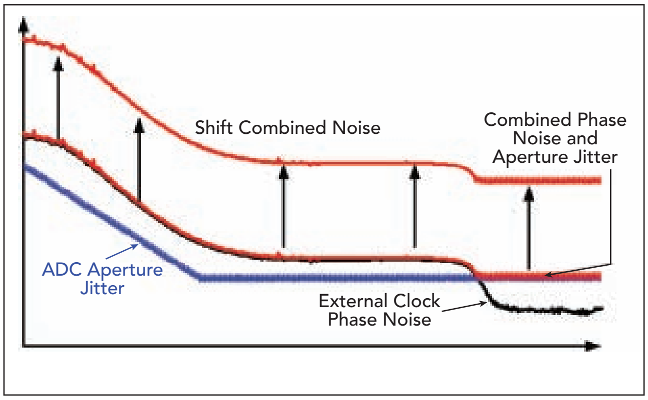


Fig. 5 Data converter clock noise after combining ADC aperture jitter with the external clock phase noise and shifting it.

of this concept in the time domain, where the noise contribution due to jitter scales with input frequency is SNR = 20log(2π × F_{IN} × T_{Jitter}).[4]

Input signal amplitude—Clock noise gets modulated onto the input signal; hence, the lower its amplitude, the lower the actual modulated clock noise contribution. The automatic gain control loop in the receiver tries to maintain the input signal level close to the ADC's full scale to maximize the signal chain gain. Adding some back-off reduces the risk of saturation but also reduces the noise degradation from clock noise. ***Figure 4*** shows that the clock noise contribution improves directly when reducing the input signal amplitude.

ADC NOISE ANALYSIS

For a more accurate specification of the external sampling clock phase noise requirement at specific frequency offsets, follow these steps to analyze the data converter noise contribution in the frequency domain:[5]

1. Obtain the external clock phase noise and ADC aperture jitter in the frequency domain in decibels relative to the carrier frequency (dBc/Hz). The frequency bin sizes and frequency steps must be identical. Typically, the clock phase noise data is in a log-type format. If the ADC aperture jitter is not assumed flat across frequency, some data interpolation may be necessary to match the data format of the clock phase noise. As discussed earlier, the ADC aperture jitter is clock amplitude dependent, which needs to be considered.
2. For each frequency bin, combine the external clock phase noise and the ADC aperture jitter using Equation 1. This addition is illustrated in ***Figure 5***.

$$PN_C = 20\log\left(\sqrt{\left(10^{\frac{PN_E}{20}}\right)^2 + \left(10^{\frac{PN_A}{20}}\right)^2}\right) \text{ dBc/Hz} \qquad (1)$$

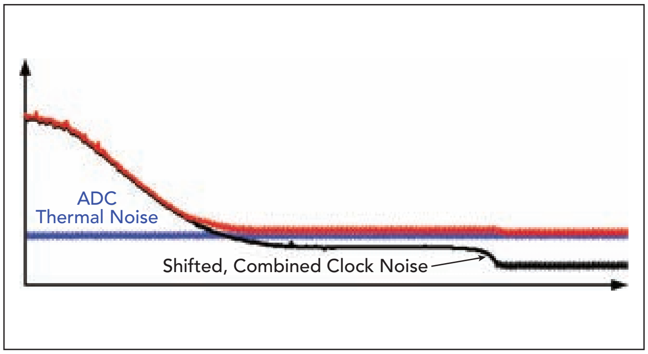


Fig. 6 Total ADC noise after adding data converter thermal noise.

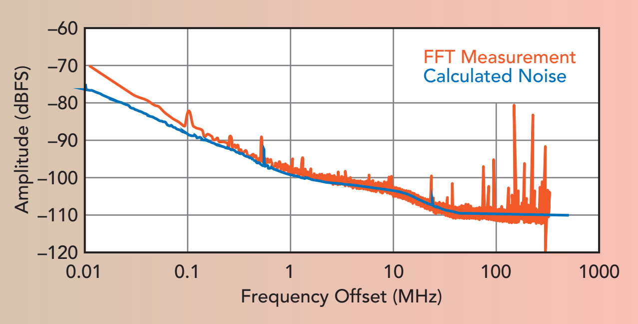


Fig. 7 Comparison of calculated data converter noise and FFT measurement (262,144 points, 100x averaging, F_{IN} = 1 GHz and F_S = 3 GSPS).

3. Adjust the clock noise by accounting for the signal input frequency. The noise in each frequency bin is shifted by Equation 2

$$PN_{FIN} = PN_C + 20\log\left(\frac{F_{IN}}{F_S}\right) \qquad (2)$$

where F_{IN} is the signal input frequency and F_S is the ADC sampling rate. As the signal input frequency increases, SNR degradation due to clock noise increases as well.

4. Account for the amplitude of the input signal. The clock noise contribution is reduced when the signal amplitude is less than the ADC full scale. For example, a 3 dB back-off (A_{in} = -3 dBFS) reduces the noise power in each frequency bin by 3 dB.
5. Calculate the total ADC noise contribution by adding the ADC thermal noise. The last step is to combine the final clock noise with the inherent thermal noise of the data converter. This results in the expected total noise contribution from the ADC for specific frequency offsets from the input signal (see ***Figure 6***).

This analysis matches typical observations. For example, as the signal input frequency increases, the clock noise increases by $20\log(F_{IN}/F_S)$. Depending on the actual setup, the far-end noise floor increases above the ADC thermal noise, and a broad noise floor increase is observable (see Figure 4). Similarly, the clock noise contribution reduces as the input signal amplitude is decreased.

CALCULATION VERSUS MEASUREMENT

Using the aperture jitter profile information of the TI ADC32RF45, along with the phase noise information of both the clock and input signal generators, the total noise is calculated for a clock frequency of 3 GSPS with an input signal of 1.8 GHz at -1 dBFS amplitude. The result in ***Figure 7*** shows a very close match, considering that other contributors such as power supply noise and temperature are not included.

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Digital Phase Noise Generator

Noise eXtended Technologies (Noise XT)
Elancourt, France

In the RF and microwave world, low phase noise is a major aim—alongside higher bandwidth, greater analysis of the environment, better detection of potential threats—and of course, all achieved wirelessly. However, the road to achieving this aim is not smooth, with one particular barrier being the design tools available.

Although phase noise analyzers are becoming increasingly important in engineering laboratories, they come in various types and sizes and use traditional analog techniques or digital signal processing. Researchers have tried to assess such instruments, usually by comparing their phase noise floor limits, but almost none have tried to compare their accuracies. A key element of a phase noise analyzer's accuracy relates to calibration, and the most popular technique to calibrate them relies on the generation of calibrated spurious signals that can be swept in offset frequency and amplitude. This way, the accuracy of the instrument can be traced back to a national institute, such as NIST, LNE, NIM or NPL depending on the country where the instrument is used, as the spurious generators are themselves traceable.

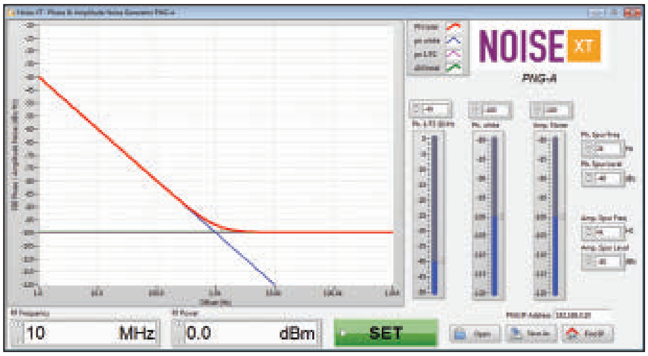


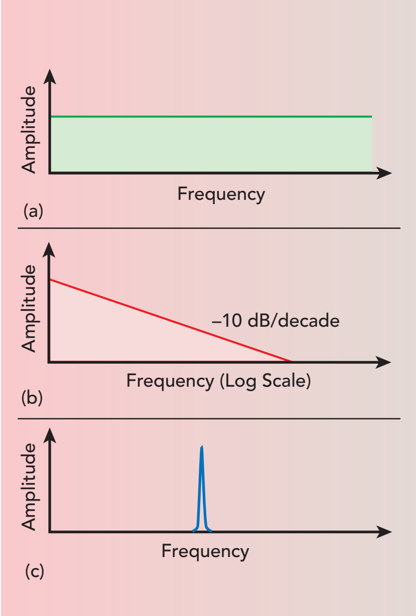
Fig. 1 The GUI of the PNG-A phase noise generator.

Calibrating signal source analyzers, phase noise analyzers or spectrum analyzers for phase noise is usually a time consuming process, requiring that the user extract the instrument from its operating environment and ship it to an external calibration provider—with the customs risks and delays that might occur. Such issues could be reduced or eliminated if it were possible to verify the accuracy on-site with a simple, independent solution, which is why Noise XT has developed the PNG-A phase noise generator, which has the added advantage of including

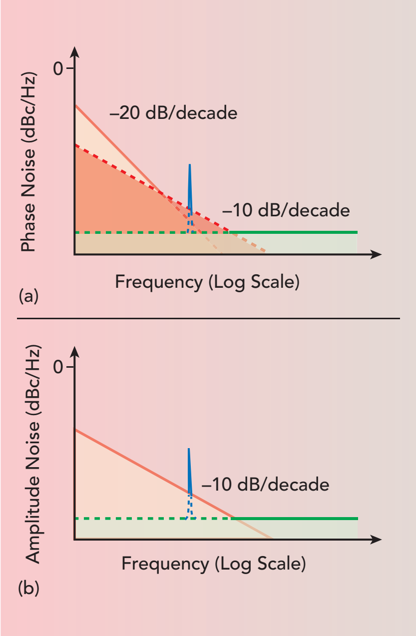
amplitude noise generation in the same package. This device is completely independent from any analyzer or any manufacturer's current design, and is claimed to be very affordable.

The PNG-A, with its internal processor, computes the perfect sine wave in real-time and adds the exact amount of random and discrete phase and amplitude noise. Thanks to the graphical user interface (GUI) (see ***Figure 1***), the user defines noise profiles that can be programmed to reflect the best application where the calibration has to be done. Those profiles are not just basic white noise from a diode or a resistor. The main issue with these techniques is that the reference level is difficult to tune, as the noise will be proportional to $4k_BTB$, where kB is the Boltzmann constant, B is the bandwidth in Hertz and T is the temperature in Kelvin. The level of this signal phase noise depends on external parameters such as temperature, aging, VSWR and nonlinearity in the chain, which might experience long term fluctuations. Accuracy in such analog solutions would be fully based on another calibration process involving another set of accuracies.

Numerical generation circumvents these issues. By applying



▲ **Fig. 2** Modulation signal profiles available from the PNG-A: white noise (a), flicker noise (b) and spurious (c).



▲ **Fig. 3** The PNG-A generates phase (a) and amplitude (b) noise profiles that can be combined with a CW signal.

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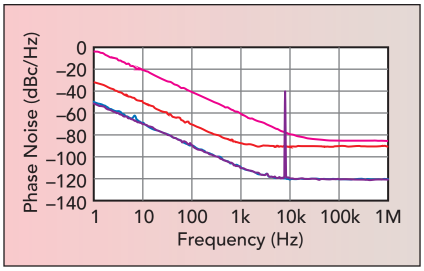

▲ **Fig. 4 PNG-A phase noise measured using the NXA-6 phase noise analyzer.**

deterministic contributions on the phase, amplitude and frequency of a sinusoidal modulation, the user can generate a signal with a well-defined phase noise profile. A CW signal, on top of which the user can add several tunable random or sinusoidal modulations (see ***Figure 2***), is generated inside the Xilinx Zynq system on a chip. Later, in the FPGA fabric, the amplitude and phase noise are mathematically combined, such as shown in ***Figure 3***, then converted to RF. Thus, the noise does not depend on measurement conditions. A purely designed noise profile matches the real world, as its noise density reduces as the offset increases, as in all frequency sources currently available. The PNG-A generates both the sine wave and its relative noise with the same digital-to-analog converter; this guarantees that the small index AM and PM noises will always be at the correct calibrated level. Experimental measurements made with the NXA-6 phase noise analyzer, shown in ***Figure 4***, match expectations well.

One of the key advantages of this digital modulation is the flicker noise generation. This 1/f noise is difficult to produce with analog filters or analog modulation and is seen as a major issue for many applications. As a cherry on the pie, all these parameters can be tuned in "real-time," making this device stand out and useful in a dynamic calibration process.

The PNG generates a 5 to 35 MHz sine wave which may, at first, seem limited. However, the purpose of this calibrated source is to validate the phase and amplitude noise accuracy, not the whole frequency coverage of an analyzer. Traditional calibrations will not verify operation at all frequencies, as the analyzer "core" is common and its inherent accuracy is basically the same across its complete input frequency range. Calibrating at 10 MHz from 1 Hz offset to 1 MHz offset will be sufficient in 95 percent of the applications, which lowers the cost. The PNG approach to phase noise calibration is particularly relevant in two situations: one, calibrating on-site and in-lab in a matter of minutes, where the hassle of going through an "old fashioned" solution is not really an option, and two, where having the capability for an independent low-cost solution to verify that the data is "real" will satisfy the customer's expectations.

Noise eXtended Technologies (Noise XT)
Elancourt, France
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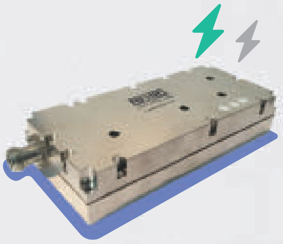

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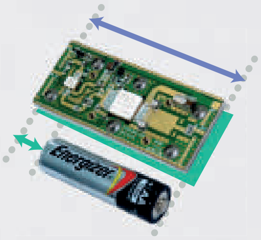

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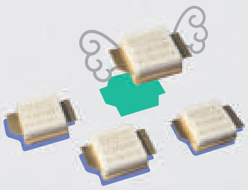

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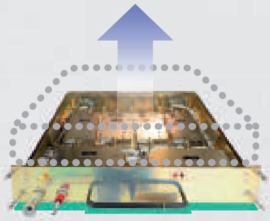

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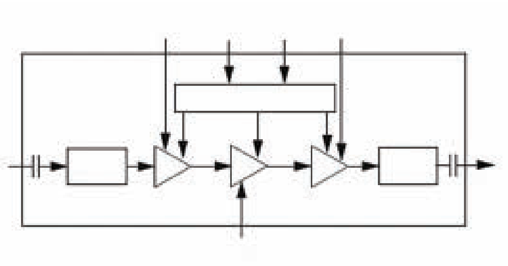


Small (Cell) Steps to 5G Evolution

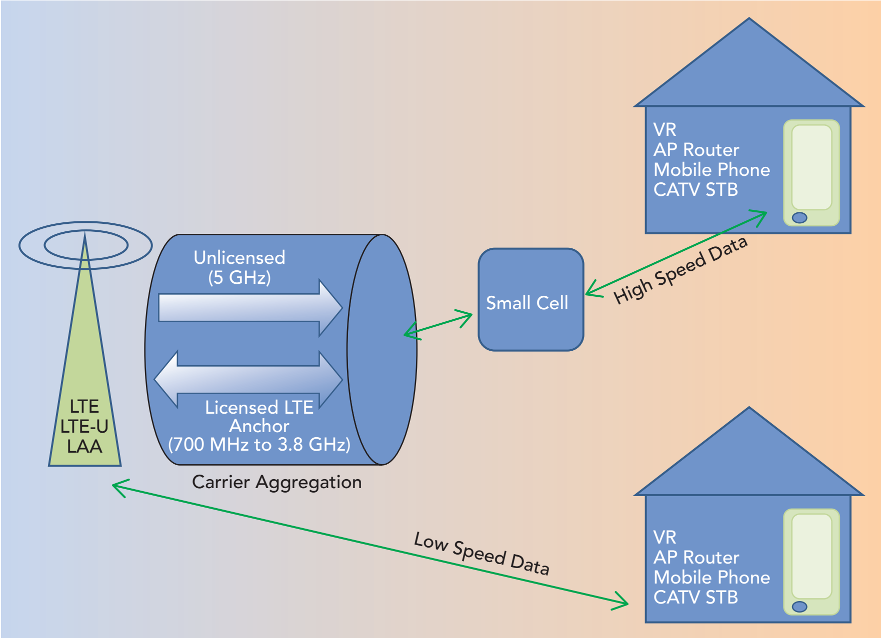
Skyworks Solutions, Inc.
Woburn, Mass.

While playing a virtual reality (VR) game can be surprisingly entertaining, it has one major drawback: the multitude of wires needed to operate the system. Keeping those wires from getting tangled can be quite a challenge, often requiring several pauses during the game. Part of the difficulty is the amount of data VR systems require. Data must be sent to the user's goggles to enable high resolution video and a dynamic experience; the VR goggles must also stream real-time data regarding the user's movements and positions back to the system. Because of this, high data capacity cables are needed to connect the user to the VR system and transfer the data. VR systems will eventually evolve into wireless devices. One way to eliminate the wires is with a high efficiency network capable of streaming large amounts of data, e.g., one that employs small cells. Small cells are not just good for improving VR systems; they are also a key enabler of 5G.

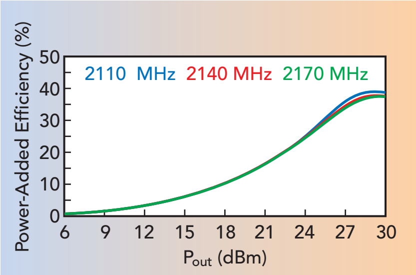
Today, small cells are often installed by cell phone providers to help end users combat connectivity issues. Generally, the providers use a single, narrowband small cell system. However, to realize increased data rates for 5G, next-generation small cells must support ever wider bandwidths. This can be achieved by using wideband systems and taking advantage of carrier aggregation (CA) technology. CA increases data capacity by streaming on a licensed anchor channel and using additional channels, either within the same frequency band or a different band. The result is an increase in the overall data rate.

Use of CA is fairly widespread. The cell phone or tablet used to read this article likely already supports CA. However, some networks have not fully taken advantage of the technology or even deployed it, due to its high cost. Another factor impeding its use is that multiple bands inside one small cell box requires additional power amplifiers (PA) to support the different frequency bands, which means increased power consumption and, often, thermal issues. Highly efficient small cells can overcome many of these limitations. Thanks to new innovative techniques, next-generation small cell boxes with two to three bands and a multiple-input-multiple-output (MIMO) configuration for enabling multiple data streams are now possible. They allow enormous amounts of data to be streamed to a smartphone, tablet or VR device (see ***Figure 1***).

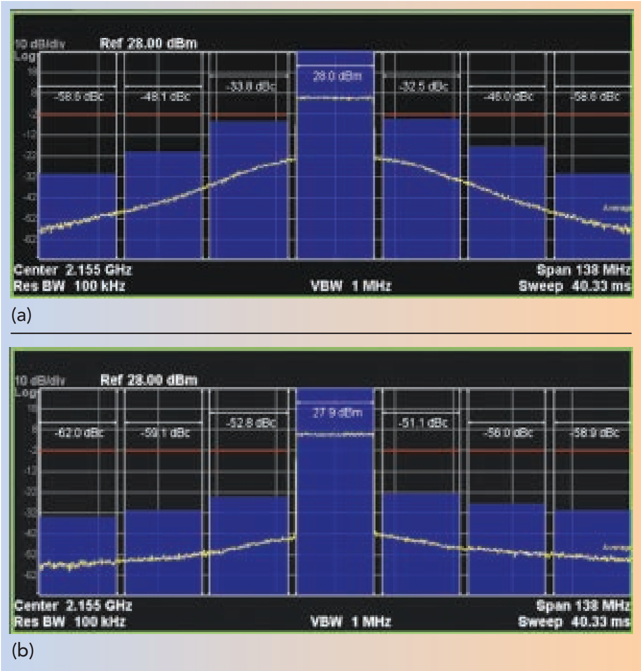
A big chunk of the power budget in a small cell is allocated to the PAs—the devices responsible for transmitting data in an ever extending range—while maintaining data purity. Close collaboration between PA vendors and system-on-chip or transceiver vendors has led to highly efficient systems. One such family of high efficiency PAs hails from Skyworks Solutions. Its SKY6629x family of small cell enterprise PAs offers power-added efficiency (PAE) of 30 to 40 percent and covers the major 3GPP bands from 700 MHz to 6 GHz, including the new band 48 from 3.5 to 3.7 GHz—also known as the CBRS band—and band 46, the licensed as-



▲ **Fig. 1** Small cells will densify the wireless network and increase data rates to users.



▲ **Fig. 2** Skyworks' SKY66294-11 PA achieves a PAE of 36 percent at +28 dBm output, biased with a 5 V supply.



▲ **Fig. 3** The linearity of the SKY66294-11 PA before (a) and after (b) DPD.

sisted access (LAA) or LTE-U band, which operates from 5.15 to 5.925 GHz. While traditional linear PAs have a typical efficiency of 10 percent, the SKY6629x PAs offer 3x efficiency improvement. The increased efficiency enables small cell developers to either design a box with very low power consumption or one with more channels (i.e., more frequency bands for CA). That means no more 1 × 1 systems, as the industry has moved to 2 × 2, 4 × 4 and higher-order MIMO systems.

For example, the SKY66294-11 band 66 PA achieves 36 percent PAE at the rated output power of +28 dBm, biased with a 5 V supply (see ***Figure 2***). The output of the PA has an uncorrected adjacent channel leakage ratio (ACLR) of −33 dBc with a 20 MHz, 8 dB peak-to-average input signal (using crest factor reduction). By applying low complexity digital predistortion (DPD), the PA can be linearized to more than -50 dBc, a full 5 dB lower than the -45 dBc specified by the 3GPP standard (see ***Figure 3***). This improvement in performance saves power, reduces thermal effects on the overall system and provides more than 5 dB margin for linearity.

Higher efficiency PAs reduce the total cost of small cell development and deployment. Current small cell boxes are single band systems. Even with only one or two PAs per box, the inside temperature can increase to between 85°C and 90°C. To cool the boxes, developers usually incorporate metal heat sinks and sometimes fans. Lowering PA power consumption with Skyworks' SKY6629x family eliminates the need for additional metal or fans, providing small cell developers with a viable solution to help minimize power dissipation and solve heat problems.

While the obvious application for these high efficiency PAs is in small cells, they have other uses. They can be used in distributed antenna systems, vehicle to everything (V2X) infrastructure for car-to-car communication and self-driving vehicles and consumer electronics products such as high definition wireless cameras and drones. Given their efficiency and ability to be linearized, the PAs in Skyworks' SKY6629x family have been used as driver amplifiers for higher power, outdoor small cell systems and in the early development of massive MIMO systems for 5G.

Without a doubt, small cell deployment is moving toward 5G and will help to enable a seamless handover from large macro base stations to indoor small cells. Densification of heterogeneous networks (HetNet) is critical to the realization of 5G and will be aided by next-generation small cells. For the industry, these small cells will deliver key benefits, including ease of deployment and smaller, less conspicuous base stations. Because higher efficiency PAs reduce power consumption, "green" technology small cells offer added benefits that the cellular industry can leverage.

VENDORVIEW

Skyworks Solutions, Inc.
Woburn, Mass.
www.skyworksinc.com

RF Power Transistors Increase BTS Efficiency

Specifically designed to meet the cellular industry's demands for more power efficient base stations, the Gen10 series of LDMOS RF power transistors reduces power consumption, shrinks the size and weight of the power amplifier (PA) and lowers the operating temperature of infrastructure equipment. Thanks to an innovative implementation of internal decoupling, the Gen10 series enables wideband operation, where a single PA can cover a complete LTE band simultaneously.

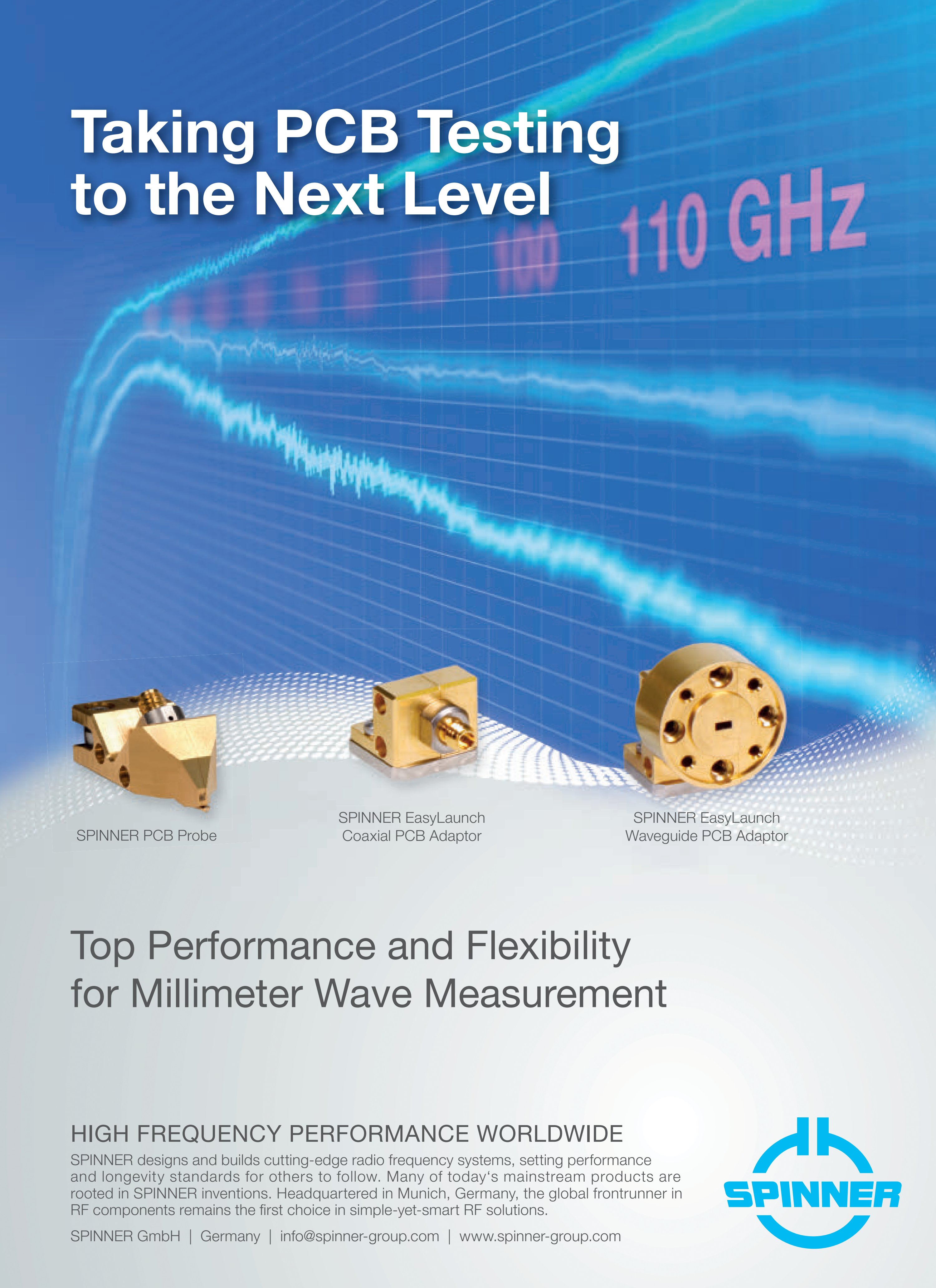
The Gen10 series of RF power transistors includes the:

- BLC10G18XS-320AVT—In a Doherty PA covering 1805 to 1880 MHz, this transistor provides 47.5 dBm average power and an efficiency > 51.5 percent.
- BLC10G20LS-240PWT—In a three-way Doherty covering 1805 to 1880 MHz, the PA provides 47.5 dBm average power and > 52 percent efficiency.
- BLC10G22LS-100AWT—The transistor provides 42 dBm average power and > 49.3 percent efficiency over 2110 to 2200 MHz.
- BLC10G22XS-400AVT—This device provides 49.4 dBm average power and > 48.6 percent efficiency over 2110 to 2200 MHz.
- BLC10G27XS-320AVT—Covering 2500 to 2700 MHz, the transistor delivers 47.1 dBm average power and > 47.5 percent efficiency.

Significantly, Gen10 devices are assembled using Ampleon's ACP3 packaging, which is being rolled out across the company's entire LDMOS and GaN product portfolio. The ACP3, a copper flanged air cavity package, is claimed to offer double-digit cost savings compared to previous packaging platforms and typically 25 percent lower thermal resistance. The ACP3 format enables higher power capability along with improved reliability, gain and efficiency characteristics.

Key applications for ACP3 devices like the Gen10 series include PAs for LTE radio access networks, where the commercial pressures of cost, size and power consumption are paramount.

Ampleon
Nijmegen, Netherlands
www.ampleon.com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Compact, Cost-Effective Two-Port, Two-Path VNA

Many the RF/microwave designer can recall days having to roll a cart with a heavy, shared vector network analyzer (VNA) to measure S-parameters. Those days may soon be over with the introduction of the compact, cost-effective TTR500 series VNA from Tektronix. With a price point 40 percent less than benchtop alternatives with equivalent performance, the TTR500 series offers a full two-port, two-path S-parameter VNA for such applications as measuring passive and active components, antennas and matching networks, RF modules, test cables and adapters. It features a solid set of specifications, including 100 kHz to 3 or 6 GHz frequency range, 122 dB dynamic range, less than 0.008 dB trace noise and −50 to +7 dBm output power, all in a compact package weighing less than four pounds.

For powering active devices, the TTR500 includes a built-in bias tee that handles 0 to ± 24 V and 0 to 200 mA on both ports. The TTR500 works with a Windows PC or laptop using a USB 2.0 connection and new VectorVu-PC software to control and calibrate the instrument. The software offers touch and point and click usability, along with an offline mode for data analysis. Output file formats are compatible with common electronic design automation (EDA) simulation tools. For automated test systems in design or manufacturing, VectorVu-PC offers programmatic support for standard commands for programmable instruments (SCPI) and legacy VNA compatibility. Rounding out the solution, the TTR500 series is available with a complete set of accessories: a sturdy carrying case, rack mount kits, rugged phase-stable cables, attenuators, adapters and calibration kits.

Prices are just $9,000 MSRP for a 3 GHz instrument and $12,000 for a 6 GHz instrument—which includes a three-year warranty—making for a reliable and cost-effective alternative to rental or shared VNAs.

Tektronix
Beaverton, Ore.
www.tek.com

Software and Mobile Apps

AR App of Knowledge Mobile Device App

VENDORVIEW

AR RF/Microwave's mobile app is available as a free download from Apple iTunes and Google Play. Search for "AR App of Knowledge". This app is a quick and easy tool to access various content from AR. Home screen icons give you easy access to basic and full product descriptions, app notes, AR's literature library, YouTube videos, contact information and social media icons. Visit the site to download the app.

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Antenna Magus, Version 2017.2

VENDORVIEW

AntennaMagus
Explore.Design.Deliver.

The latest update to Antenna Magus, version 2017.2, is now available. Its database of 321 antennas can be explored to choose the optimal topology, designed to meet the system criteria and exported to seamlessly integrate with your design workflow. This update also features several new antennas. For each of these antennas, Antenna Magus offers detailed information, synthesis algorithms, performance estimations and ready-to-run simulation models. Visit the CST website to learn more and download a trial version of Antenna Magus.

Computer Simulation Technology
www.cst.com/products/antennamagus

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

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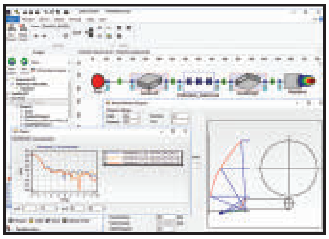
µWave Wizard 8.1



Mician introduces version 8.1 of their hybrid full-wave EM-software tool, µWave Wizard. This release adds radiating boundary conditions to their 3D FEM solver, enabling the simulation of antennas with arbitrary shape and material distribution, like slotted waveguide and dielectric resonator antennas. Outer geometries of waveguide horn antennas can be modeled exactly. The new version allows the simulation of single and dual offset reflector antennas using real feed data, including tracking mode support. It includes a graphical design tool for standard reflectors and allows shaping with user supplied analytical functions.

Mician GmbH
www.mician.com

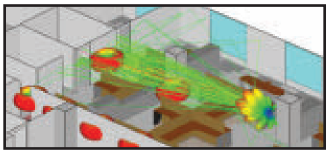
The Modelithics® COMPLETE Library™ v17.1

VENDORVIEW

The latest release of the Modelithics COMPLETE Library for NI AWR Design Environment, version 17.1, contains 44 new models and introduces several new model features. New advanced scalable simulation models for RF and microwave components from 20 different vendors have been added to the v17.1 release. It is compatible with the latest v13 release of NI AWR Design Environment, specifically Microwave Office circuit design software, and includes multiple new features that add even more flexibility and control while using the models in Microwave Office designs. To request a free trial, please visit the website.

Modelithics
www.modelithics.com

Diffuse Scattering Simulation for Wireless InSite®



Remcom announces diffuse scattering prediction in the latest release of Wireless InSite®, its site-specific radio propagation software for the analysis of wireless communication systems. This update greatly improves simulation accuracy for mmWave systems being developed for 5G, WiGig and other emerging technologies. Wireless InSite® simulates the detailed multipath of large numbers of MIMO channels while overcoming the increased level of computations required for traditional ray tracing methods. The diffuse scattering model is available in the professional and MIMO versions of Wireless InSite®.

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EDI CON 2017

EDI CON USA BOSTON

EDI CON USA Brings the High-Frequency Revolution to Boston

Janine Love, *Microwave Journal* Contributing Editor

If you joined us at our inaugural EDI CON USA last year in Boston, we have greatly increased the educational, networking and demonstration opportunities available. If you are joining us for the first time, be sure to thank the alumni attendees for their input in helping to grow EDI CON USA!

This year, the three-day conference of in-depth educational and training opportunities (September 11-13) is matched by an impressive array of industry-leading exhibitors demonstrating high-frequency and high-speed products on the show floor from September 12-13.

Conference Highlights

The conference opens on September 11 with a day of intense short courses, designed to stretch conference attendees' capabilities and provide new methods, techniques and understanding to help get the job done. Here are some of the planned short courses:

- **Practical Antenna Design for Wireless Products**
  presented by Henry Lau, Lexiwave Technology Inc.

- **Radar, Phased-Arrays, Metamaterials and MIMO—Basics, Advances and Breakthroughs**
  presented by Dr. Eli Brookner, Retired, Raytheon

- **Power Integrity 101**
  presented by Steve Sandler, Founder, Picotest

- **Transferring Board Design into PCB Design: Get it Right the First Time**
  presented by Shalom Shlomi Zigdon, iTech iCollege Israel

- **Five Steps to Engineer Transparent Vias in High-Speed Circuit Boards**
  presented by Eric Bogatin, *Signal Integrity Journal* Editor and Dean of Signal Integrity Academy; sponsored by Mentor Graphics, a Siemens Company

- **Practical Board Level Power Integrity Measurement and Design Principles**
  presented by Eric Bogatin, *Signal Integrity Journal* Editor and Dean of Signal Integrity Academy; sponsored by Teledyne LeCroy

- **RF & Bench Essentials for IoT Device Debugging**
  presented by Greg Bonaguide; sponsored by Rohde & Schwarz

On Tuesday and Wednesday, the conference provides peer-reviewed technical sessions across 10 tracks, including test & measurement, power integrity, low-power RF/IoT design, RADAR/defense, signal integrity, 5G, EMC/EMI, RF/microwave, broadband and antenna design. All of these abstracts were reviewed, rated and recommended by members of the EDI CON USA Technical Advisory Committee, which was led by Dr. Istvan Novak, Senior Principle Engineer, Oracle, and Dr. Thomas Cameron, CTO, Analog Devices.

Tuesday and Wednesday will also see panel sessions take place, led by intrepid members of *Microwave Journal*'s editorial team. These sessions will feature industry experts who will discuss the latest technological trends and field questions from the audience. Panel sessions include:

- **Look Ma—No Steering Wheel! The State of the Self-Driving Car**
  moderated by Gary Lerude

- **Bandwidth or Bust—Commercializing 5G mmWave Technology Today**
  moderated by Patrick Hindle

- **The Ferrari of Amplifiers: How Can We Maneuver Around the Current Challenges Facing High Performance GaN**
  moderated by Patrick Hindle

Engineering experts from the show floor will take to the podium during sponsored workshops, which are in-depth talks from industry-leading vendors on technologies and techniques. Workshops will be presented from representatives of Analog Devices, Rohde & Schwarz, Anritsu, National Instruments, RF-Lambda, ANSYS, Cadence and Copper Mountain Technologies, among others.

Those working on high-speed designs should be sure to check out the High-Speed Digital Symposium on Tuesday afternoon, for can't-miss sessions on materials characterization and challenges from leading thinkers in signal integrity. Led by *Signal Integrity Journal* editor and renowned SI guru, Eric Bogatin, this symposium will also include a panel Q&A after the expert presentations. Presenters include Brandon Gore and Scott McMorrow, SAMTEC Inc.; Chris Caisse, Allen F. Horn and Patricia LaFrance, Rogers Corp.; Alfred P. Neves, Wild River; Jason Ellison, The Siemon Company; and Bert Simonovich, Lamsim.

See the online technical program for a full listing of presentations

Conference attendees working on high-frequency designs should plan on attending the European RADAR Summit, which will also be held on Tuesday afternoon. Led by session chair Alfonso Farina, Selex ES retired (Italy), this special event is sponsored by *Microwave Journal* and includes papers from European engineers working on the latest in radar systems, architectures and phased arrays.

EDI CON 2017

EDI CON USA BOSTON

Exhibition Highlights

While the sessions highlighted are available exclusively to conference pass holders, EXPO pass holders can take advantage of a number of excellent educational and networking events. Conference pass holders are also welcome in all of the events outlined below.

The EDI CON EXPO experience kicks off with the plenary session keynotes on Tuesday, September 12 at 10:30 a.m. This year's invited speaker is Scott McMorrow, CTO of Samtec, whose talk is entitled, “Betting Your Job—Finding Your Voice and Being a Change Agent in a Corporate World.” McMorrow will bring his perspective on how we can be the ones to make things happen, including some heartening horror and success stories. McMorrow will be joined by Thomas Cameron, CTO of ADI, who will speak on 5G, while Faride Akretch from Rohde & Schwarz promises a look behind the scenes of test and measurement.

The EXPO opens on Tuesday directly after the plenary session and will feature up to 100 industry-leading vendors working in high-frequency and high-speed digital. Have a design challenge? Bring it to EDI CON USA! In addition to the ad hoc networking that happens all over the show floor and in the conference halls, EDI CON USA has scheduled some specific networking times for attendees to catch up with peers, suppliers and competitors. These include a Monday Training Day Luncheon and Welcome Reception, a Tuesday Welcome Reception in the Exhibit Hall (5-7 p.m.), and Coffee Breaks in the Exhibition Hall.

For those on the show floor looking for some educational opportunities, the Frequency Matters Theater offers ongoing speed trainings, case study analysis, student R&D papers and panel sessions. The High-Speed Zone offers demo pods from vendors working in the high-speed digital industry, and is also home to the SI/PI Measurement Lab, sponsored by Picotest and Rohde & Schwarz. Bring your boards to test, or, if yours are too secret, borrow the donated boards to learn how to make a particular measurement—this measurement lab comes with a "no sales pitch" promise.

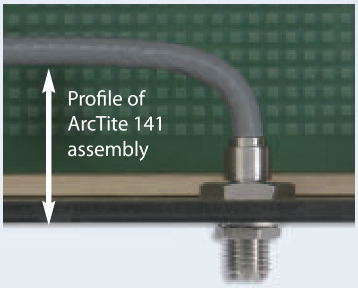
So, whether you opt for the full-conference pass or the EXPO pass, EDI CON USA has plenty to offer engineers working in high-speed and high-frequency designs. It's time to make your travel plans, put together your schedule and make the most of your time at EDI CON USA! *Microwave Journal* subscribers can save 20 percent off the conference pass price with the code READ20MWJ. Local attendees can sign up for luxury charter busing from Quincy, Newton and Woburn during registration. Partner programs for exploring Boston are also available, including a Whale Watching Tour and Trolley Tour. See you in September!

EDI CON 2017

Monday, September 11, 2017

Room	107	108	109	110
8:00 - 5:00	On-Site Registration			
	Short Courses/Hands-On Training			
9:30 - 12:30	Streamline Flexible System Designs with RF Data Converters (sponsored by ADI) *Del Jones and Michelle Viani*	Practical Board Level Power Integrity Measurement and Design Principles (sponsored by Teledyne LeCroy) *Eric Bogatin*	Transferring Board Design into PCB Design: Get it Right the First Time *Shalom Shlomi Zigdon*	Practical Antenna Design for Wireless Products *Henry Lau*
12:30 - 1:30	Luncheon, Room 111 Reservation Required in Registration			
1:30 - 4:30	RF & Bench Essentials for IoT Device Debugging (sponsored by Rohde & Schwarz) *Greg Bonaguide*	Five Steps to Engineer Transparent Vias in High-Speed Circuit Boards (sponsored by Mentor Graphics) *Eric Bogatin*	Power Integrity 101 *Steve Sandler*	Radar, Phased-Arrays, Metamaterials and MIMO–Basics, Advances and Breakthroughs *Dr. Eli Brookner (Raytheon, retired)*
2:30 - 2:45	Coffee Break			
4:30 - 5:30	Reception			

Can your cables bend over backwards?



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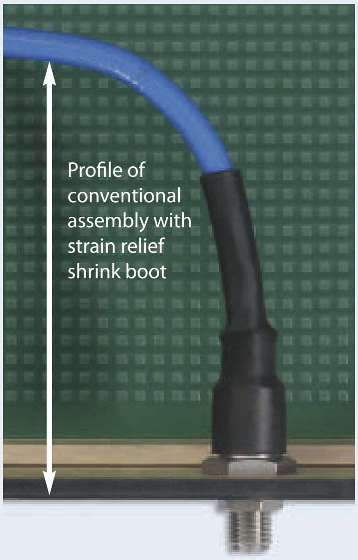

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Tuesday, September 12, 2017

Room	107	108	109	110	111	
8:00 - 6:00	Registration					
TRACK	Test & Measurement	Power Integrity	RF & Microwave	RF & Microwave	RF&MW: Packaging	
9:00 - 9:30	Making Advanced Jitter Measurements with Oscilloscope *Al Gosselin, Keysight Technologies (6)*	Transient Load Tester for Time Domain PDN Validation *Ethan Koether, Oracle Corp. (18)*	Challenges and Benefits of Implementing UWB Digital Pre-Distortion (DPD) in Cable Distribution Systems *Patrick Pratt, Analog Devices (56)*	Practical RF PCB Design *Henry Lau, Lexiwave Technology Inc. (22)*	Overcoming Assembly Challenges with Bottom Termination Components *Brook Sandy-Smith, Indium (85)*	
9:45 - 10:15	Demystifying Phase Coherent Signal Generation *Mathieu Caillet Rohde & Schwarz (38)*	Correlation of Power Integrity to LPDDR4 and DDR4 Memory Activity *Al Gosselin, Keysight (21)*	How Complex Modulation, Zero IF and Advanced Algorithms Enable Next Generation Transceiver Radios *David Frizelle, Analog Devices (58)*	Rapid Prototyping of an 8x8 Butler Matrix Beamforming Network for Phased Array Antenna Application *Jiyoun Munn, COMSOL*	Reliability Without Hermeticity: Vapor Deposited Coatings for Environmental Protection of High-Frequency RF Micro-Electronics *Austin Nowak, GVD (84)*	
10:15 - 10:30	Coffee Break					
10:30 - 12:00	**Plenary Keynote, Room 302: Betting Your Job–Finding Your Voice and Being a Change Agent in a Corporate World, *Scott McMorrow, SAMTEC, Inc.* 5G Five Years From Now–How Do We Get There?, *Thomas Cameron, ADI* 'Delivering Value' Everybody Says It, But What Does It Mean–A Look Behind the Scenes of Test & Measurement *Faride Akretch, Rohde & Schwarz***					
12:00 - 1:00	Lunch Break & Dedicated Exhibit Time—Exhibition Floor					Exhibition 12:00 - 7:00
TRACK	Test & Measurement	Power Integrity	Low-Power RF/ IoT Design	Radar	Signal Integrity	
1:00 - 1:30	Advanced Techniques for Spurious Search in RF and Microwave Devices *Laura Sanchez, Rohde & Schwarz (41)*	Designing Power for Sensitive Circuits *Steve Sandler, Picotest (1)*	Practical Small Antenna Design for Wireless and IoT Products *Henry Lau, Lexiwave Technology (23)*	**EUROPEAN RADAR SUMMIT** *Alfonso Farina, Moderator:* Enhanced Target Detection and Localization by Cueing in Multistatic Passive-Active Radar Systems *Tadeusz BRENNER, PIT-RADWAR SA;* Design Aspects for Dual-Polarized Phased Array Antennas with Low X-pol Contribution *Dennis Vollbracht, Selex-ES GmbH;* Innovative Algorithm for Wide Band Digital Signal Processing in Modern AESA RADAR Architecture *Roberto Lalli, Leonardo Company S.p.A.;* Technology Trends for Future Radar *Johannes Pieter Bezouwen, HENSOLDT; Michael Brandfass, HENSOLDT;* A Family of Secondary Surveillance Radars Based on Conformal Antenna Array Geometries, *Leopoldo Infante, Leonardo SpA*	**HIGH SPEED DIGITAL SYMPOSIUM** *Eric Bogatin, Editor SI Journal:* Insitu Glass Fabric Characterization, *Brandon Gore, SAMTEC Inc.;* Extraction of Frequency-Dependent Dielectric Constant: Loss and Conductor Effects of High-Speed Digital Laminate Materials for High-Speed Channel Simulation, *Chris Caisse, Rogers Corp.;* Test Vehicle Development for Systematic Development and Verification of Materials Models to 50 GHz, *Al Neves, Wild River,* A Case Study of Effective Surface Roughness Acquisition, *Jason Ellison, The Siemon Company,* Practical Modeling of High-Speed Channels Based on Data Sheet Input *Bert Simonovich, Lamsim Enterprises*	
1:40 - 2:10	Architecting GHz Wide Bandwidth RF Record and Playback Systems *Michael Schneider, National Instruments (71)*	Calculate Measurement Uncertainty in Power Measurements *Lawrence Wilson, Rohde & Schwarz Inc. USA (37)*	Designing an IoT Dual-band Compact Wi-Fi MIMO Array Using Antenna Synthesis *Derek Linden, National Instruments (29)*			
2:20 - 2:50	Advanced Phase Noise Measurement Methods for High-Power, Very High Frequency, and Pulsed Signals *Laura Sanchez, Rohde & Schwarz (42)*	Current Sharing Measurements in Multi-Phase Switch Mode DC-DC Converters *Peter Pupalaikis, Teledyne LeCroy (34)*	Engineering the Internet of Things Within the Smart City Streets Lighting Design *Laila Salman, ANSYS (30)*			
2:50 - 3:20	Coffee Break					
3:20 - 4:00	**Workshops & Panels** PANEL: Look Ma—No Steering Wheel! The State of the Self-Driving Car *Gary Lerude, MWJ, Moderator (75)*	Workshop: Overcoming Power Integrity Challenges through a Team-Based Approach *Cadence (81)*	Workshop: Using Vector Network Analyzers to Measure RF and Microwave Material Properties *Copper Mountain (36)*			
4:10 - 4:50		Workshop: Fixture De-Embedding: Practical Advantages and Limits of Simplified Methods *Anritsu Co. (80)*	Workshop: Advanced Load Pull for Linear Power Amplifier Design *National Instruments (12)*			
5:00 - 7:00	Welcome Reception (Show Floor)					

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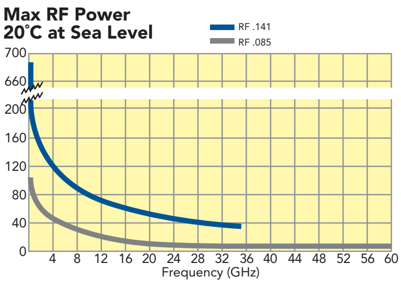

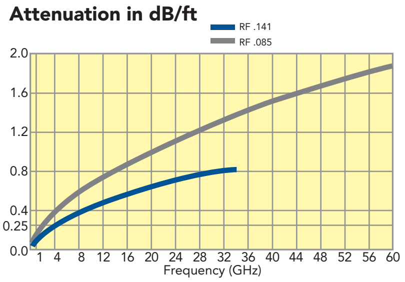

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EDICON 2017

Wednesday, September 13, 2017

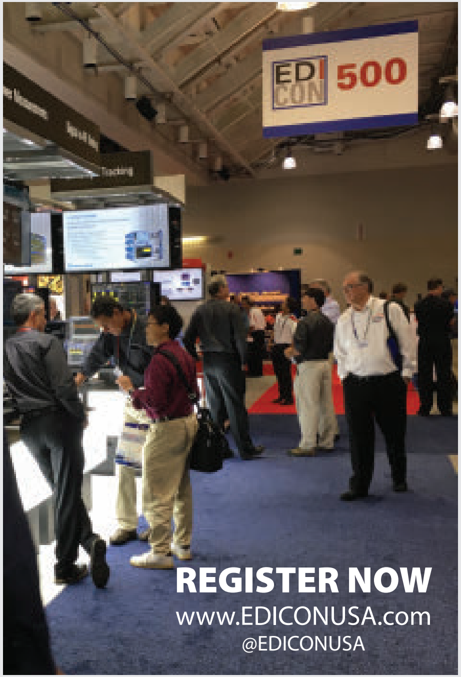
Room	107	108	109	110	111	
8:00 - 5:00	Registration					
TRACK	5G	Radar/Defense	Signal Integrity	EMC/EMI	Diamond Sponsor Workshops	
9:00 - 9:30	Massive MIMO and "Beamforming": The Signal Processing Behind the 5G Buzzwords *Claire Masterson, Analog Devices (57)*	EM/Circuit Co-Simulation of T/R Front-End Module and Actively Scanned Antenna Array *John Dunn, National Instruments/AWR (15)*	Signal Integrity Methodology for Double-Digit Multi-Gigabit Interfaces *Ken Willis, Cadence (30)*	Shielding Effectiveness Simulation of SMT EMI Gaskets *Charlotte Blair, ANSYS & Chris Kerwien, W.L. Gore & Associates (32)*	9:00 - 10:00 AM Workshop 1: New Technologies to Address Wideband Signal Generation and Analysis *Rohde & Schwarz (43)*	Exhibition 9:00 - 5:00
9:40 - 10:10	Simulation of BER, EVM and ACPR Performance Under Proposed 5G Modulation Waveforms *Andy Hughes, National Instruments/AWR (13)*	Applications of Additive Manufacturing to Defense Electronics Systems *William Villers, TEN TECH LLC (8)*	Address DDR5 Design Challenges with IBIS-AMI Models *Todd Westerhoff, SiSoft (69)*	Shielding Effectiveness Comparison of Small Sized Board-Level Shields Obtained by Near and Far-Field Measurement Techniques *Mohammad Ali Khorrami, Laird Technologies (50)*		
TRACK	5G	Radar/Defense	Signal Integrity	Antenna Design	10:10 - 11:10 AM Workshop 2: Phase Noise–New Architecture for Phase Noise Measurements with Unparalleled Accuracy and Speed *Rohde & Schwarz (44)*	
10:20 - 10:50	MIMO and Beam Steering Modeling in Support of 5G Applications *John Dunn, National Instruments/AWR (14)*	Addressing Phase Noise Challenges in Radar and Communication Systems *Paul Blount, Custom MMIC (4)*	Method to Analyze Low-Margin, High-Speed SERDES Channels *Granthana Rangaswamy, Juniper Networks (62)*	Miniature Broadband Antenna for Wireless Handheld Device *Edward Liang, MCV Microwave (61)*		
TRACK	Test & Measurement	RF & Microwave	Signal Integrity	Antenna Design		
11:00 - 11:30	Iterative Direct Digital Predistortion (DPD) *Laura Sanchez, Rohde & Schwarz (39)*	Transmit LO Leakage (LOL)–An Issue of Zero IF That Isn't Making People Laugh Out Loud *Frank Kearney, Analog Devices (59)*	Debugging High Speed SERDES Links in Multi-Board Interconnect Systems *Syed Bokhari, Fidus Systems Inc. (33)*	Introduction to Helical Antennas *Dan Orban, Orban Microwave Inc. (16)*		
11:30 - 1:00	Lunch Break & Dedicated Exhibition Time					
	Workshops & Panels			Host Sponsor Workshop	Diamond Sponsor Workshop	
1:00 - 1:40	Panel: Bandwidth or Bust–Commercializing 5G mmWave Technology Today *Patrick Hindle, MWJ, Moderator (76)*	Workshop: Simplifying the Thermal Analysis of Microwave Systems *ANSYS (90)*	Workshop: From Milliwatts to Kilowatts: Advanced Material Science Enables High-Temperature, High-Power Micro-Mechanical Switches *Menlo Micro (99)*	All-Electronic Phased Array Design Challenges *ADI (96)*	1:00 - 2:00 Workshop 3: Best Practices in Wafer-Level Millimeterwave and THz Testing *Rohde & Schwarz (46)*	
1:50 - 2:30		Workshop: RF Systems on Platforms *ANSYS (92)*	Workshop: Highly Integrated RF and Digital Architectures: Challenges, Benefits and Acceptance *Mercury (100)*	Arrow's Arria10 SOC Data Acquisition Kit, Using Technology from Intel and Analog Devices *ADI (94)*		
2:30 - 2:45	Coffee Break					
2:30 - 3:10	Workshop: Addressing the Challenges of Multi-Channel Phase-Aligned or MIMO RF Systems *National Instruments (72)*	Workshop: 110 GHz Spectrum Analysis in the Palm of Your Hand *Anritsu (87)*	Panel: Solid-State RF Energy in 2017: How Far Have Applications Come and What Still Needs to Be Attained? *Dr. Klaus Werner, Moderator (101)*	How ADI's MEMS Switches Solve Difficult Problems in RF Test Instrumentation and Automatic Test Equipment *ADI (93)*	2:00 - 3:00 Workshop 4: Signal Integrity Debugging Techniques Using Vector Network Analyzer *Rohde & Schwarz (82)*	
3:20 - 4:00				Integrated DPD for Small Cell and Massive MIMO *ADI (95)*		

Details in this conference matrix were accurate at the time of going to press. They are subject to change.

For up-to-date information visit www.ediconusa.com.

EDI CON USA 2017: The Conference- September 11-13

Technical Program Co-Chairs: Istvan Novak, Principal Engineer, Oracle & Thomas Cameron, CTO of ADI.



Use code READ20MWJ for 20% off a Full-Access Conference Pass or a free EXPO pass

Monday, September 11—Training Day

Short Courses:

- Power Integrity 101 (Steve Sandler)
- Practical Antenna Design for Wireless Products (Henry Lau)
- Five Steps to Engineer Transparent Vias in High-Speed Circuit Boards (Eric Bogatin)
- Radar, Phased Arrays, Metamaterials & MIMO (Eli Brookner)
- Transferring Board Design Into PCB Design (Shalom Shlomi Zigdon)
- RF and Bench Essentials for IoT Device Debugging (Greg Bonaguide)
- Practical Board-Level PI Measurement (Eric Bogatin)
- Luncheon & Reception

Tuesday, September 12

Plenary Keynote: Scott McMorrow, CTO Signal Integrity Group at Samtec Inc

- Workshops from ADI, Rohde & Schwarz, Anritsu, National Instruments, Cadence, Copper Mountain Technologies, ANSYS, and others
- Peer-reviewed Technical Sessions
- High-Speed Digital Symposium (Eric Bogatin, Chair)
- European RADAR Summit (Alfonso Farina, Chair)
- Autonomous Automobile Panel

Wednesday, September 13

Frequency Matters Theater Keynote: 3 Critical Considerations for 5G Wireless Network Antennas, Ray Butler, VP Wireless Network Engineering, CommScope

- 5G Panel
- Peer-reviewed Technical Sessions
- Workshops from ADI, Rohde & Schwarz, Anritsu, National Instruments, Cadence, Copper Mountain Technologies, ANSYS, and others
- Outstanding Paper Award

EDI CON 2017

EDI CON USA EXHIBITOR LIST

These booth numbers are complete as of July 14, 2017. Exhibitors in red have an ad in this issue.

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Anokiwave	439
Anritsu	509
ANSYS	209
Applied Thin-Film Products	338
AR RF/Microwave Instrumentation	508
ARC Technologies	332
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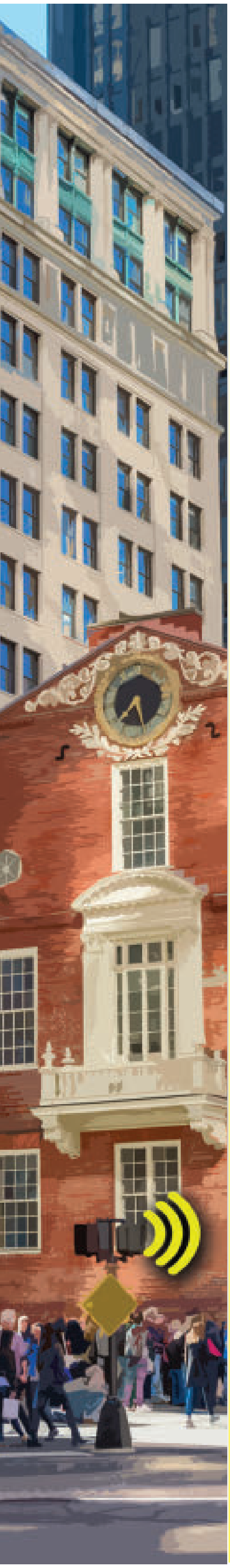
EDI CON USA FLOORPLAN



These booth numbers are accurate as of July 21, 2017.

EDI CON 2017

AISLE 200

PRODUCT SHOWCASE

The following booth numbers are complete as of June 29, 2017.

Mini-Circuits — Booth 202

20 dB DC Pass High Power Bi-Directional Coupler

Mini-Circuits' ZGBDC20-33H+ broadband high power bi-directional coupler offers excellent performance across a wide range of popular frequency bands. Built using low loss suspended substrate construction, the ZGBDC20-33H+ can pass up to 3A of DC current from input to output and handle up to 50 W CW. Rugged sealed construction makes this coupler ideal for use in field applications or remote monitoring sites; however, it is also ideal for high power lab testing.

DC Pass, High Power Bi-Directional Coupler

Mini-Circuits BDCH-10-63 ultra wide band high-power bi-directional coupler covers frequencies from 2000 to 6000 MHz with high power handling up to 100 W and insertion loss of 0.1 dB Typ. The ultra wide band supports a wide variety of applications from S-band and C-band radar through various cellular base station applications, UHF and SHF power monitoring up to 6000 MHz. The coupler is designed into an open printed laminate (0.2" × 0.56" × 0.08") with wrap-around terminations for good solderability and easy visual inspection.

Surface Mount Voltage Variable Equalizer

The VAEQ-1220+ is a 50Ω Voltage Variable Equalizer built into a shielded case (size of .394" × .394" × .150", 10 × 10 × 3.8 mm). This model offers excellent performance over a wide frequency range of 50 to 1220 MHz with the variable slope providing great flexibility in a small 10 mm package. The VAEQ-1220+ is often used to compensate RF chain gain flatness or cable loss versus frequency.

Coaxial Matching Pad

Mini-Circuits' UNMP-R5075-33+ is a coaxial 50/75Ω matching pad covering the DC to 3000 MHz frequency range, supporting impedance matching in a wide range of systems. This model is ideal for 50/75Ω impedance matching in systems where minimizing overall signal loss is a priority. The matching pad is housed in a rugged unibody construction with N-Male (50Ω) to N-Female (75Ω) connectors.

Coaxial Power Splitter/Combiner

Mini-Circuits' ZC10PD-26W+ is a 10-way 0° splitter/combiner providing 10W RF power handling as a splitter across the 2250 to 2800 MHz range, covering a variety of applications including cellular, ISM and more. It provides a high port-count with low insertion loss, high isolation and low amplitude unbalance, making this model ideal for systems requiring distribution of signal into many channels. The splitter/combiner comes housed in a rugged aluminum alloy case (6.13 × 3.00 × 0.53") with SMA connectors.

USB/RS232/SPI Programmable Attenuator

Mini-Circuits' RUDAT-13G-60 is a general purpose, single channel programmable attenuator suitable for a wide range of signal level control applications from 10 MHz to 13 GHz. The attenuator provides 0 to 60 dB attenuation in 0.5 dB steps. Its unique design maintains linear attenuation change per dB, even at the highest attenuation settings. The attenuator is housed in a compact and rugged package with SMA female connectors on the bi-directional input and output RF ports, a standard 9 pin D-Sub and a USB type Mini-B power and control ports.

FLEX TEST Armored Test Cable

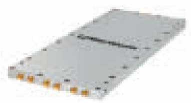
Mini-Circuits' APC-4FT-SMNM+ is a wideband, armored test cable supporting a wide range of applications from DC to 18 GHz. APC-series test cables feature extra-rugged, crush resistant construction, ideal for demanding production floor environments where heavy machinery is used. This model is 4 ft. in length with SMA-Male to N-Male connectors and provides low insertion loss, excellent return loss, and superior stability of insertion loss, VSWR, and phase versus flexure. Like all Mini-Circuits test cables, the APC-4FT-SMNM+ has been performance qualified to 20,000 bend cycles and comes with our 6 month guarantee.

USB/Ethernet RF Switch Matrix

Mini-Circuits' RC-1SP6T-A12 is a general purpose RF switch matrix controlled via either USB or Ethernet-TCP/IP (supports HTTP and Telnet protocols). The model contains an electro-mechanical SP6T, absorptive fail-safe RF switch constructed in break-before-make configuration and powered by +24 VDC with switching time of 25 ms typical. The RF switch operates over a wide frequency band from DC to 12 GHz, has low insertion loss (0.2 dB typical) and high isolation (90 dB typical) making the switch matrix perfectly suitable for a wide variety of RF applications.

DC Pass, Ultra-Thin Power Splitter/Combiner

Mini-Circuits' ZN6PD1-63SMP+is a 6-way 0° splitter/combiner supporting a wide variety of applications from 600 to 6000 MHz. This model is capable of handling up to 20 W RF input power as a splitter and provides low insertion loss, high isolation. It comes housed in an ultra-thin, aluminum alloy case (9.50" × 4.25" × 0.43") with SMP snap-on connectors, saving space in crowded system layouts.



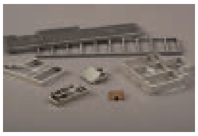
DC Pass Power Splitter/Combiner

Mini-Circuits' ZN4PD-02183+ is a 4-way 0° ultra-wideband splitter/combiner supporting a wide range of applications from 2 to 18 GHz. This model is capable of handling up to 30W RF input power as a splitter with low insertion loss across its full frequency range, providing excellent signal power transmission from input to output. It delivers nearly equal output signals with low amplitude unbalance and low phase unbalance, and excellent isolation minimizing interference between channels.

VENDORVIEW

www.minicircuits.com

Orbel — Booth 117
Materials



Since 1961, Orbel's custom design and manufacturing process has enabled unique engineered solutions for a variety of applications and industries. From conception through delivery, Orbel offers today's most effective EMI/RFI shielding, photo-etched precision metal parts, precision metal stampings and electroplated metal foils. Areas of specialization include aerospace, telecommunications, electronics, medical, automotive and manufacturing.

www.orbel.com

Ophir RF Inc. — Booth 204
Solid State Broadband High-Power RF Amplifier

The 5304050 is a 10 W broadband amplifier that covers the 6 to 18 GHz frequency range. This small and lightweight amplifier utilizes class AB linear GaN devices that provide an excellent third order intercept point, high gain and a wide dynamic range. Due to robust engineering and employment of the most advanced devices and components, this amplifier achieves high efficiency operation with proven reliability. Like all Ophir RF amplifiers, the 5304050 comes backed by Ophir RF's commitment to total customer satisfaction.

www.ophirrf.com

Maury Microwave — Booth 205
Measurement and Modeling Device Characterization Solutions

Exceptional companies have superior labs—complete your lab with Maury Microwave! Maury, a leader in measurement and modeling device characterization solutions, VNA calibration accessories and interconnections, will be showcasing active and hybrid-active harmonic load pull solutions, LXI™-certified mechanical impedance tuners, pulsed IV/RF compact transistor modeling as well as coaxial and waveguide VNA calibration kits and metrology adapters, in-stock color-coded precision and daily-use adapters and test-port, phase-stable and value cable assemblies. Visit us for details, demos, deals and NPIs!

www.maurymw.com

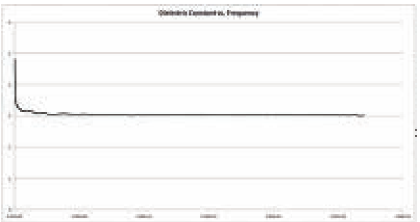
MCV Microwave — Booth 206
Removable Connectors for Drop-In

VENDORVIEW

MCV Microwave high frequency cavity and planar filters for 5G system integration include very wideband bandpass filter covering from 10 to 30 percent bandwidth, having low insertion loss and moderate rejection. MCV Microwave also offers extremely narrow-band notch filters, as narrow as 0.3 percent bandwidth, having very sharp roll-off and high rejection. Excellent ultimate rejection and good passband matching or 14 dB return loss are achieved in both surface mount and drop-in packages in a very small footprint for X-, Ku- and Ka-Band.

www.mcv-microwave.com

RCL Microwave Inc. — Booth 207
Non-Destructive Broadband Thin Film Dielectric Characterization



RCL Microwave Inc. specializes in non-destructive broadband thin film dielectric characterization. We use the phase differential method to achieve a high degree of accuracy for a wide range of dielectric constants and loss tangents. Material thicknesses from 20 to 1000 microns can be accommodated in the company's non-destructive test fixture. Please contact RCL today at 877-387-6125 for a free quote.

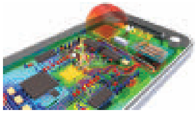
www.rclmicrowave.com

WEST·BOND Inc. — Booth 208
Wedge Bonder/Ball Bonder Combination Machines

West•Bond offers wedge bonder/ball bonder combination machines, as well as die bonders that combines both epoxy and eutectic methods in one chassis. Between these two series you can bond most any product in the microelectronic industry. Since 1966, West•Bond has been a design and manufacturer of assembly and test equipment for the microelectronic industry, including automatic, semiautomatic and manual ESD protected bonders with ultrasonic, thermosonic and thermocompression wire/ribbon capability.

www.westbond.com

ANSYS — Booth 209
Electro-Thermal Design Flow



ANSYS will demonstrate its new electro-thermal design flow developed to support high-frequency design from layout, inclusion of signal integrity, power integrity, EMI, thermal and structural reliability. As power density within digital electronics and microwave systems continues to increase, the ability to accurately predict electro-thermal effects within a design becomes paramount. The new design flow allows engineers to perform electromagnetic, thermal, stress, shock and vibration analysis from a seamless integration of HFSS, SIwave, Icepak and ANSYS Mechanical.

www.ansys.com

Gowanda Electronics — Booth 210
Broadband Conicals to 5 A DC

Gowanda Electronics will feature conical designs including the C550FL series of high-current, thru-hole, wirewound broadband conical inductors providing a current rating to 5 A DC. As with Gowanda's other conicals, this newest series provides predictable frequency response and repeatable performance from 40 MHz to 40 GHz and is specifically designed for high frequency applications where ultra-low insertion loss is a design requirement. Gowanda Electronics, Dyco Electronics, Butler Winding, Communication Coil, TTE Filters, Microwave Circuits and Instec Filters are affiliates of GCG (GowandaComponentsGroup.com).

www.gowanda.com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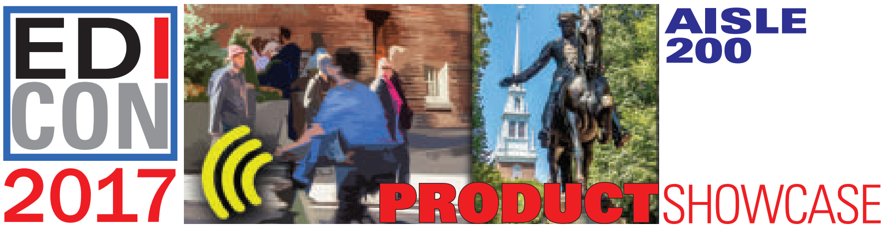


TTE — Booth 210

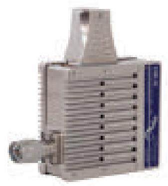
Bias Tees to 40 GHz

Shipping from stock (in prototype quantities), TTE's bias tees are available for frequencies from 10 MHz to 40 GHz and current handling capabilities to 7 A DC. They offer superior broadband performance, low insertion loss, minimal return loss, desirable VSWR characteristics, extremely flat gain response and RoHS-compliant options. TTE's RF and microwave filters are available to 40 GHz. Built-to-order lead times are as short as five days. TTE Filters, Microwave Circuits, Instec Filters, Gowanda Electronics, Dyco Electronics, Butler Winding and Communication Coil are affiliates of GCG (GowandaComponentsGroup.com).

www.tte.com

Copper Mountain Technologies — Booth 216

1-Port VNA Cable and Antenna Analyzer



The new R180 1-port VNA cable and antenna analyzer from Copper Mountain Technologies is the first 18 GHz 1-port VNA that can connect directly to DUT, improving measurement accuracy by eliminating practical limitation of RF cables. R180 can be controlled and powered through a USB-C port or through an external 5 VDC power supply. The unit delivers high accuracy results in a wide variety of measurement formats including time domain measurement. The frequency range is 1 MHz to 18 GHz.

www.coppermountaintech.com

Analog Devices Inc. — Booth 217

Wideband GaN MMIC Amplifier

Analog Devices' wideband GaN power amplifier offers best-in-class performance within a compact design. Covering the 300 MHz to 6 GHz spectrum, the highly integrated HMC8205 provides significant benefits for system designers of applications such as wireless infrastructure, radar, public mobile radio and general-purpose amplification test equipment that require pulse or continuous wave (CW) support. The HMC8205 GaN MMIC amplifier offers unmatched integration, gain, efficiency and wide bandwidth in a small footprint.

www.analog.com/en/products/rf-microwave/rf-amplifiers/power-amplifiers/hmc8205.html

Berkeley Nucleonics — Booth 218

Microwave Signal Generator

VENDORVIEW

The Model 855 Series is a multi-channel, phase coherent, fast switching, low phase noise microwave signal generator with output frequency ranges from 10 MHz to 6, 12 or 20 GHz in any combination from 2 to 8 outputs in one system. Frequency and power switching sweep times down to 10 μs with excellent phase noise makes this instrument line ideally suited for a broad range of applications where very high signal quality, accuracy and wide output power range is required.

www.berkeleynucleonics.com

Cernex Inc. — Booth 220

Benchtop Amplifiers

VENDORVIEW

Cernex's BenchTop Amplifiers are designed for use in a wide range of general purpose applications, such as laboratory test equipment, instrumentation and other applications. Reliable operation is achieved using rugged stripline circuit construction with selected GAsFETs, PHEMTs and MIMICs.

www.cernex.com

RelComm Technologies Inc. — Booth 222

High Performance 1P12T Relay

RelComm Technologies compliments its product line by offering a low cost high performance 1P12T relay configured with "SMA" type connectors, providing exceptional RF performance to 18 GHz. The relay measures 2.25 in square and is less than two inches tall. It is fitted with standard DA15P header for ease of installation. The relay is available in failsafe configuration with 12 and 24 V DC operation. Options include TTL control input.

www.relcommtech.com

PA&E — Booth 225

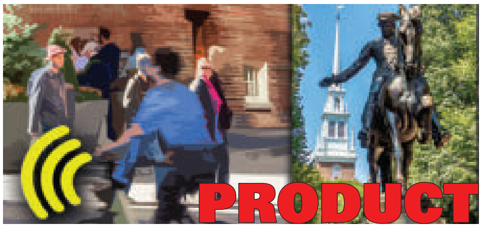
Hermetic 38999 BMA RF Connector

Design engineers can now leverage the utility of a 38999 format high-speed RF connector in harsh environment applications, following PA&E's release of its new hermetic 38999 Blind Mate Attach (BMA) RF connector line. Available in laser-weld or jam-nut configurations with 1, 2, 4, 6 or 8 contacts, they provide RF performance of ≤ 1 dB insertion loss at 18 GHz and have a hermetic leak rate of ≤ 1 x 10^{-9} cc He at 1 ATM. Visit PA&E in Booth 225 to learn more.

www.pacaero.com

EDI CON 2017 PRODUCT SHOWCASE

AISLES 200-300



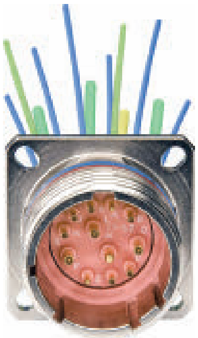
PPG Aerospace-Cuming Microwave Materials — Booth 226

Featuring C-RAM® RF and microwave absorbers, C-RAM® anechoic and free-space materials and C-STOCK® low loss dielectric materials. Custom formulations and configurations available for your specific needs.

www.cumingmicrowave.com

Southwest Microwave Inc. — Booth 233

SSBP High-Performance Multi-Port Cable Harnesses



Save space, reduce panel weight and size and achieve greater bandwidth with Southwest Microwave's size 8, 12, 16 and 20 SSBP coax contacts and cable harnesses to 110 GHz for standard multi-port connectors, such as D-38999, D-Subminiature or Micro-D. Combine RF and microwave coax contacts of varying frequencies in one housing to optimize multi-functionality, packaging design flexibility and cost savings. Miniaturized packaging offers increased density, improved survivability, easier servicing and a more compact footprint.

www.southwestmicrowave.com

AEM Inc. — Booth 305

Tin Whisker Mitigation Process

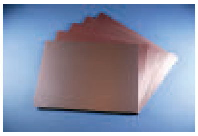
AEM's Tin Whisker Mitigation process utilizing tin-lead conversion with fusion processing ensures system reliability for mission critical programs. AEM's process is suitable for surface mount chips, surface mount molded body packages as well as other unique package styles. Components post tin-lead conversion can then be screened to many MIL-STD and customer source control drawing test requirements.

www.aem-usa.com

Rogers Corp. — Booth 306

RO1200™ Circuit Materials

VENDORVIEW



With channel speeds increasing beyond 50 Gbps, RO1200™ circuit materials are engineered to meet the unique electrical and thermal/mechanical requirements of high speed designs. With a low dielectric constant of 3.05, and a max dissipation factor of 0.0017 at 10 GHz, RO1200 laminates provide outstanding signal integrity, reduced signal skew and reduced cross-talk. Combined with superior thermal/mechanical performance, low CTE and a halogen free UL 94 V-0 rating, RO1200 materials are well suited for the most demanding high layer count applications.

www.rogerscorp.com

Transline Technology Inc. — Booth 307

RF/Microwave, Hybrid and Standard Printed Circuit Boards

Transline serves the RF, microwave, aerospace, defense, medical and satellite industries, among others, to create solutions for ever-advancing concepts and designs. Features and services include RF and microwave applications, hybrid and exotic materials, oversize (large) PCBs, FEP bonding and fusion bonding, Rigi-Flex and Flex PCB, PCB thermal applications, heavy metal back PCB, PCB heat-sink manufacturing and lamination, photo chemical etching and RF shielding products. Also, AS9100C certified, ISO 9001:2008 certified, ITAR registered, SBA SDB 8(a) certified and JCP certification (Cage Code: 3LRM5).

www.translinetech.com

National Instruments — Booth 317

1 GHz Complex I/Q Bandwidth Baseband Vector Signal Transceiver

VENDORVIEW

National Instruments introduces the world's first 1 GHz complex I/Q bandwidth baseband vector signal transceiver (VST), the PXIe-5820. It combines a wideband I/Q digitizer, wideband I/Q arbitrary waveform generator and high-performance user-programmable FPGA into a single 2-slot PXI Express module. Learn how you can tightly synchronize it with the PXIe-5840 RF VST to address a variety of applications including 802.11ac/ax device test, mobile/IoT test, 4.9/5G design and test, RFIC and PA/FEM test, radar test and more.

www.ni.com

NI AWR — Booth 317

NI AWR Design Environment

Visit us at EDI CON USA in Booth #317 to see v13.02 of the NI AWR Design Environment, which includes upgrades and enhancements to Microwave Office, Analog Office, Visual System Simulator™ (VSS), AXIEM and Analyst™ software products. This latest release continues to address design challenges associated with highly-integrated RF and microwave components (power amplifiers, filters and more) commonly found in communications and radar systems. In addition, NI AWR will also be showcasing its newest product addition of AntSyn™ for antenna synthesis and optimization.

www.awrcorp.com/whats-new

EDI CON 2017

AISLES 300-400

PRODUCT SHOWCASE

RF-Lambda — Booth 321

EMC, 140 W, 6 to 18 GHz, Broadband Power Amplifier

RAMP06G18GF is an ultra-wide band solid state benchtop power amplifier covering 6 to 18 GHz with a saturated output power of 140 W. The nominal gain is 45 dB, with a gain adjustment range of 20 dB with a 0.1 dB step size. The units come equipped with multiple protection features such as input over drive, over current and over temperature shutdown, making them ideal for EMC, VSAT, test and radar applications.

www.rflambda.com

MOSIS — Booth 322

Prototype and Volume-Production

MOSIS

For 30-plus years, IC designers have relied on MOSIS for an efficient, affordable way to prototype and volume-produce their devices. Many turn to MOSIS for their special expertise in providing Multi-Project Wafers (MPW) and related services that drive IC innovation. This "shared mask" model combines designs from multiple customers, or diverse designs from a single company, onto one mask set. In addition MOSIS supports clients through to production, minimizing time to market with competitive pricing for new product introduction.

www.mosis.com

TechPlus Microwave Inc. — Booth 326

1 to 18 GHz Suspended Substrate Quintuplexer

The TM2020 operates from 1 to 18 GHz with passbands of 1 to 2, 2 to 4, 4 to 8, 8 to 12 and 12 to 18. This product is one from the company's extensive suspended substrate, catalog of SS designs. TechPlus is a state-of-the-art, innovative, RF and microwave filter supplier specializing in economical, high quality microwave filters and assemblies. Their capabilities include small and large production runs utilizing state-of-the-art test equipment. TechPlus manufactures filters, duplexers and multiplexers for aerospace, defense, commercial and public safety to 40 GHz.

www.techplusmicrowave.com

Barry Industries — Booth 337

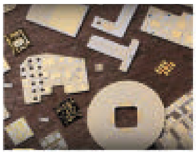
HTCC QFN Packages

HTCC QFN packages from Barry Industries are available in standard 3 thru 8 mm standard JEDEC footprints and feature broadband low-loss transitions for superior performance over frequency. Maximum insertion loss for the 3 mm QFN is 0.5 dB over a DC to 18 GHz range. HTCC construction provides for enhanced mechanical strength and higher thermal conductivity compared with LTCC. These extremely rugged packages are available with either a plain seal or metallized grounded seal ring compatible with epoxy or solder lid attachment techniques.

www.barryind.com

Applied Thin-Film Products — Booth 338

Thin Film Manufacturing

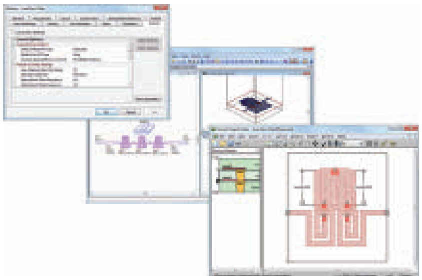


ATP is a leading ISO/AS9100 Certified thin film manufacturer that offers complete in-house circuit fabrication services and engineered solutions. Quick turn engineering prototyping is available as well as mass production jobs. ATP offers a wide range of ceramic/special materials and metallization schemes including solderable and bondable films. Features include laser diode submounts, edge defined wraps, conductors, integrated resistors (with or without laser trimming), hollow and solid filled vias, double-sided patterning, backside burnishing treatment and serialization capabilities.

www.thinfilm.com

Sonnet Software — Booth 401

Sonnet Suites



Sonnet Software maintains a single, dedicated focus on providing the industry's most accurate and reliable high frequency electromagnetic (EM) software, Sonnet Suites. Sonnet utilizes the shielded domain Method of Moments technique to provide model extraction error frequently on the order of one percent or less. Sonnet's newest release, version 16.54, will be available for demo at in-booth workstations. This release features a 64-bit Sonnet Interface for NI AWR Microwave Office v13 which provides a completely integrated "solver on request" interface.

www.sonnetsoftware.com

EUROPEAN MICROWAVE WEEK
NÜRNBERG CONVENTION CENTER
NUREMBERG, GERMANY
8TH-13TH OCTOBER 2017
www.eumweek.com
A PRIME YEAR FOR A PRIME EVENT

EUROPEAN MICROWAVE WEEK 2017

THE ONLY EUROPEAN EVENT DEDICATED TO THE MICROWAVE AND RF INDUSTRY

The EuMW 2017 team are excited to return to Nuremberg, a uniquely fascinating European city, full of medieval charm. Bringing industry and academia together, European Microwave Week 2017 is a SIX day event, including THREE cutting edge conferences and ONE exciting trade and technology exhibition featuring leading players from across the globe. Concentrating on the needs of engineers, the event showcases the latest trends and developments that are widening the field of applied microwaves. It also offers you the opportunity for face-to-face interaction with those driving the future of microwave technology.

EuMW 2017 will see an estimated 1,700 - 2,000 conference delegates, over 4,000 visitors and in excess of 300 international exhibitors (inc. Asia & US).

REGISTRATION TO THE EXHIBITION IS FREE!

Pivotal to the week is the European Microwave Exhibition, which offers YOU the opportunity to see, first hand, the latest technological developments from global leaders in microwave technology.

The exhibition will provide an unrivalled opportunity for visitors to view and ask questions related to the latest products, components and materials from our extensive selection of international exhibitors. It will also feature exhibitor demonstrations, Industrial Workshops and the annual European Microwave Week Microwave Application Seminars (MicroApps).

- **International Companies** - meet the industry's biggest names and network on a global scale
- **Cutting-edge Technology** - exhibitors showcase the latest product innovations, offer hands-on demonstrations and provide the opportunity to talk technical with the experts
- **Technical Workshops** - get first hand technical advice and guidance from some of the industry's leading innovators

BE THERE

Exhibition Dates	Opening Times
Tuesday 10th October	09:30 - 18:00
Wednesday 11th October	09:30 - 17:30
Thursday 12th October	09:30 - 16:30

FAST TRACK BADGE RETRIEVAL

Entrance to the Exhibition is FREE and attending couldn't be easier.

VISITORS

Registering for the Exhibition

- Register as an Exhibition Visitor online at **www.eumweek.com**
- Receive a confirmation email with barcode
- Bring your barcode with you to the Exhibition
- Go to the Fast Track Check In Desk and print out your visitor badge
- Alternatively, you can register onsite at the self service terminals during the Exhibition

Please note NO visitor badges will be mailed out prior to the Exhibition.

EUROPEAN MICROWAVE WEEK
NÜRNBERG CONVENTION CENTER
NUREMBERG, GERMANY
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www.eumweek.com
A PRIME YEAR FOR A PRIME EVENT

EUROPEAN MICROWAVE WEEK 2017 THE CONFERENCES

Don't miss Europe's premier microwave conference event. The 2017 week consists of three conferences and associated workshops:

- **European Microwave Integrated Circuits Conference (EuMIC) 9th - 10th October 2017**
- **European Microwave Conference (EuMC) 10th - 12th October 2017**
- **European Radar Conference (EuRAD) 11th - 13th October 2017**
- **Plus Workshops and Short Courses (From 8th October 2017)**
- **In addition, EuMW 2017 will include for the 8th year, the Defence, Security and Space Forum on 11th October 2017**

The three conferences specifically target ground breaking innovation in microwave research through a call for papers explicitly inviting the submission of presentations on the latest trends in the field, driven by industry roadmaps. The result is three superb conferences created from the very best papers. For a detailed description of the conferences, workshops and short courses please visit www.eumweek.com. The full conference programme can be downloaded from there.

FAST TRACK BADGE RETRIEVAL

Register online and print out your badge in seconds onsite at the Fast Track Check In Desk

CONFERENCE PRICES

There are TWO different rates available for the EuMW conferences:

- **ADVANCE DISCOUNTED RATE** – for all registrations up to and including 8th September
- **STANDARD RATE** – for all registrations made after 8th September

Please see the Conference Registration Rates table on the back page for complete pricing information. All payments must be in € Euro – cards will be debited in € Euro.

Online registration is open now, up to and during the event until 13th October 2017

DELEGATES

Registering for the Conference

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

- Saturday 7th October (16:00 - 19:00)
- Sunday 8th October (07:30 - 17:00)
- Monday 9th October (07:30 - 17.00)
- Tuesday 10th October (07:30 - 17.00)
- Wednesday 11th October (07:30 - 17.00)
- Thursday 12th October (07:30 - 17.00)
- Friday 13th October (07:30 - 10.00)

Once you have collected your badge, you can collect the conference proceedings on USB stick and delegate bag for the conferences from the specified delegate bag area by scanning your badge.

CONFERENCE REGISTRATION INFORMATION

EUROPEAN MICROWAVE WEEK 2017, 8th - 13th October, Nuremberg, Germany

Register Online at www.eumweek.com

ONLINE registration is open from 1st June 2017 up to and during the event until 13th October 2017.

ONSITE registration is open from 16:00 on 7th October 2017.

ADVANCE DISCOUNTED RATE (up to and including 8th September) STANDARD RATE (from 9th September & Onsite).

Reduced rates are offered if you have society membership to any of the following*: Eu*M*A, GAAS, IET or IEEE.

Eu*M*A membership fees: Professional € 25/year, Student € 15/year.

If you register for membership through the EuMW registration system, you will automatically be entitled to discounted member rates.

Reduced Rates for the conferences are also offered if you are a Student/Senior (Full-time students 30 years or younger and Seniors 65 or older as of 13th October 2017).

The fees shown below are invoiced in the name and on behalf of the European Microwave Association. Eu*M*A's supplies of attendance fees in respect of the European Microwave Week 2017 are exempted from German VAT under Article 4 no. 22a German VAT Act.

ADVANCE REGISTRATION CONFERENCE FEES (UP TO AND INCLUDING 8TH SEPT.)

CONFERENCE FEES	ADVANCE DISCOUNTED RATE			
	Society Member (*any of above)		Non Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 470	€ 130	€ 660	€ 190
EuMIC	€ 360	€ 120	€ 510	€ 170
EuRAD	€ 320	€ 110	€ 450	€ 160
2 Conferences				
EuMC + EuMIC	€ 670	€ 250	€ 940	€ 360
EuMC + EuRAD	€ 640	€ 240	€ 890	€ 350
EuMIC + EuRAD	€ 550	€ 230	€ 770	€ 330
3 Conferences				
EuMC + EuMIC + EuRAD	€ 810	€ 360	€ 1140	€ 520

STANDARD REGISTRATION CONFERENCE FEES (FROM 9TH SEPT. AND ONSITE)

CONFERENCE FEES	STANDARD RATE			
	Society Member (*any of above)		Non Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 660	€ 190	€ 930	€ 270
EuMIC	€ 510	€ 170	€ 720	€ 240
EuRAD	€ 450	€ 160	€ 630	€ 230
2 Conferences				
EuMC + EuMIC	€ 940	€ 360	€ 1320	€ 510
EuMC + EuRAD	€ 890	€ 350	€ 1250	€ 500
EuMIC + EuRAD	€ 770	€ 330	€ 1080	€ 470
3 Conferences				
EuMC + EuMIC + EuRAD	€ 1140	€ 520	€ 1600	€ 740

WORKSHOP AND SHORT COURSE FEES (ONE STANDARD RATE THROUGHOUT)

FEES	STANDARD RATE			
	Society Member (*any of above)		Non Member	
	Standard	Student/Sr.	Standard	Student/Sr.
Half day WITH Conference registration	€ 100	€ 80	€ 130	€ 100
Half day WITHOUT Conference registration	€ 130	€ 100	€ 170	€ 130
Full day WITH Conference registration	€ 140	€ 110	€ 180	€ 130
Full day WITHOUT Conference registration	€ 180	€ 140	€ 240	€ 170

Other Items

STATE RECEPTION – 11TH OCT 2017

Tickets for the State Reception are free, but are limited. They are available for delegates on a first-come, first-served basis.

Proceedings on USB Stick

All papers published for presentation at each conference will be on a USB stick, given out FREE with the delegate bags to those attending conferences. The cost for an additional USB stick is € 50.

International Journal of Microwave and Wireless Technologies (8 issues per year)

International Journal combined with Eu*M*A membership:
€ 67 for Professionals or € 57 for Students.

Partner Programme and Social Events

Full details and contacts for the Partner Programme and other Social Events can be obtained via the EuMW website www.eumweek.com.

EUROPEAN MICROWAVE WEEK WORKSHOPS & SHORT COURSES

SUNDAY 8th October		
Half Day	SS-01	EuMC
Full Day	WS-01	EuMC
Full Day	WS-02	EuMC/EuMIC
Full Day	WS-03	EuMC
Full Day	WS-04	EuMC
Full Day	WS-05	EuMC/EuMIC
Full Day	WS-06	EuMC/EuMIC
Full Day	WS-07	EuMC
Full Day	WS-08	EuMC/EuMIC
Full Day	WS-09	EuMC/EuMIC
Full Day	WS-10	EuMC
Full Day	WS-11	EuMC
Half Day	WS-12	EuMC
Full Day	WS-13	EuMC
Half Day	WS-14	EuMC
Half Day	WS-15	EuMC

MONDAY 9th October		
Full Day	WM-01	EuMC
Full Day	WM-02	EuMC
Full Day	WM-03	EuMC
Half Day	WM-04	EuMC
Half Day	WM-05	EuMC
Half Day	WM-06	EuMC
Half Day	WM-07	EuMC
Full Day	WM-08	EuMC

TUESDAY 10th October		
Full Day	WTu-01	EuMC/EuMIC

WEDNESDAY 11th October		
Half Day	SW-01	EuMC/EuRAD
Half Day	WW-01	EuMC
Half Day	WW-02	EuMIC/EuRAD
Half Day	WW-03	EuMC/EuMIC

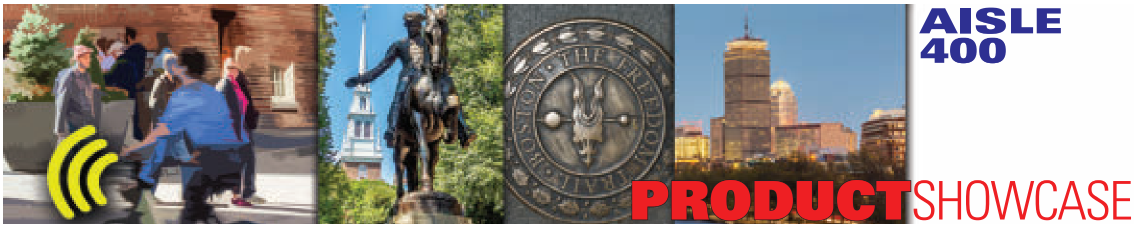
THURSDAY 12th October		
Half Day	WTh-01	EuMC/EuRAD
Full Day	WTh-02	EuRAD
Full Day	WTh-03	EuMC/EuMIC

FRIDAY 13th October		
Full Day	SF-01	EuRAD
Half Day	SF-02	EuMC/EuRAD
Half Day	SF-03	EuRAD
Full Day	WF-01	EuRAD
Half Day	WF-02	EuMC
Half Day	WF-03	EuMC/EuRAD
Half Day	WF-04	EuRAD
Full Day	WF-05	EuMC
Full Day	WF-06	EuMC/EuRAD
Half Day	WF-07	EuMC/EuRAD
Half Day	WF-08	EuMC/EuRAD

SPECIAL FORUMS & SESSIONS

Date	Time	Title	Location	No. of Days	Fee	
Wednesday 11th October	08:30 - 18:30	Defence, Security & Space Forum	St. Petersburg	1	€ 20 for delegates (those registered for EuMC, EuMIC or EuRAD)	€ 60 for all others (those not registered for a conference)
Monday 9th - Wednesday 11th October	08:30 - 17:50	European Microwave Student School	Neu Delhi	3	€ 40	
Monday 9th - Wednesday 11th October	08:30 - 17:50	European Microwave Doctoral School	Singapur	3	€ 80	

EDI CON 2017



AISLE 400

Teledyne Microwave Solutions — Booth 404

Non-ITAR GaN Amplifiers

VENDORVIEW

With dimensions of 2.5 in × 2 in × 0.42 in and 2.1 cubic inches, these modular, non-ITAR GaN amplifiers from Teledyne Microwave Solutions maintain rugged design characteristics needed for harsh airborne and land based requirements in the smallest footprint possible. The calculated MTBF of these amplifiers is greater than 40,000 hours at +85°C, manufactured to optimal thermal requirements to deliver high-reliability and performance for challenging military and commercial applications.

www.teledynemicrowave.com

Teledyne Relays — Booth 404

Electromechanical Relay

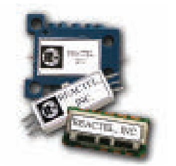
Teledyne Relays introduces the GRF121 electromechanical relay! This magnetic-latching SPDT relay is perfect for broadband, high-repeatability, RF and digital applications—where RF performance from DC to 18 GHz or signal integrity up to 40 Gbps is required. This relay is ideal for ATE, semiconductor/IC testing, high-frequency communication and medical imaging devices, RF switch matrices and other applications requiring broadband signal fidelity and high digital throughput. The GRF121 now includes reversed-polarity coil and ungrounded open-contact options for design flexibility.

www.teledynerelays.com

Reactel Inc. — Booth 410

Form Factor Filters

VENDORVIEW



Reactel introduces their line of small form factor filters. These units are suitable for densely populated boards, portable systems or any application where size is at a premium. Available technologies include discrete component, ceramic, cavity or combline designs. With profiles as low as 1/8 in these robust units pack all of the performance of their larger counterparts into a much smaller package. They are available across a frequency range of 100 MHz to 20 GHz with bandwidths of 5 to 100 percent and are available in 4 to 12 sections.

www.reactel.com

Rohde & Schwarz Inc. — Booth 417

Spectrum Analyzer

VENDORVIEW

Developers of 5G, high-end radar systems and automotive applications need a very large bandwidth to analyze wideband signals. The R&S®FSW Spectrum analyzer is the first test solution that enables 2 GHz wide signal analysis in detail without the need for an external digitizer. It provides 14-bit ADC resolution and wide dynamic range, characterized by excellent SFDR figures. This translates into outstanding performance. The instrument can measure an EVM of around -40 dB with an OFDM signal (792 MHz BW, 300 kHz spacing, 64 QAM, 4096 FFT) at 28 GHz.

www.rohde-schwarz.com

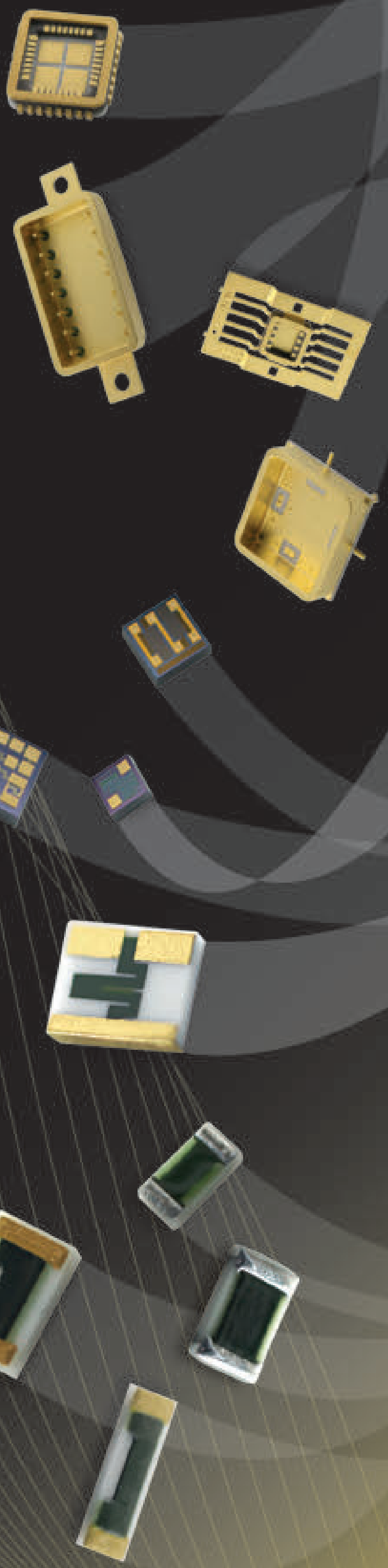
Smiths Interconnect Millitech — Booth 423

High-Power Waveguide Circulators

Smiths Interconnect Millitech brand of high-power waveguide circulators offer frequency range from 18 to 110 GHz. These ferrite-based circulators are four-port, differential phase shift devices which can also be configured as an isolator. They provide exceptional performance for isolation, insertion loss and VSWR (high return loss) make them ideal for use with frequency sources, amplifiers and receivers. All models are rated for 200 W CW.

www.smithsinterconnect.com

PRECISION PASSIVE COMPONENTS & ELECTRONIC PACKAGES



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- Case sizes to 0101
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- Zero failures with over 200 million life test hours
- ISO 9001:2000 certified
- Full line of RoHS compliant products
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  - Surface mount and plug-in packages
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- Custom design available
- RoHS and DFARS compliant

When it comes to today's military, aerospace, and medical applications, the reliability and performance requirements of electronic components have never been so demanding. By delivering superior-quality products for over forty five years, it's easy to see why Mini-Systems is a supplier of choice among design engineers.

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info@mini-systemsinc.com
20 David Road, North Attleboro MA 02761-0069

Passive Plus Inc. — Booth 427
RF/Microwave Passive Components

Passive Plus is a manufacturer of high-performance RF and microwave passive components, specializing in high-Q/low ESR/ESL capacitors, broadband capacitors, non-magnetic resistors and trimmers serving the medical, semiconductor, military, broadcast and telecommunications industries. Capacitor case sizes include 0505, 1111, 2225, 3838; EIA 0201, 0402, 0603, 0805; high-power 6040, 7676 and the new 1313; broadband capacitors, 01005, 0201, 0402. The company is known for their outstanding quality, fast deliveries, competitive prices and superior customer service.

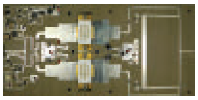
www.passiveplus.com

SignalCore Inc. — Booth 429
Broadband 6 GHz RF Up/Downconverters

SignalCore's high performance triple stage heterodyne 100 kHz to 6 GHz up/downconverters are cost effective, compact and designed for seamless RF integration. Its output IF frequency can be tuned to center between 10 and 500 MHz, and also selectable for 1250 MHz. Flexible IF bandwidths of 80, 160 and 320 MHz can be selected. The devices may be controlled via a computer, laptop or embedded device using USB, SPI or RS232 with a single rail +12 V power supply. Driver and development software with GUI is provided to easily control the units without having to write control software. Also available in PXIe.

www.signalcore.com

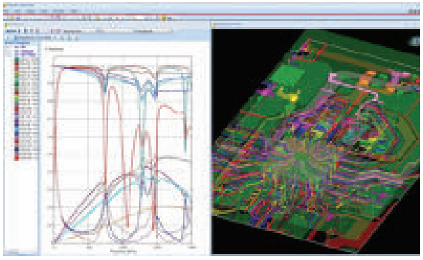
Integra Technologies Inc. — Booth 431
1 KW L-Band Radar Pallet



Integra Technologies, a leader in the design and manufacture of high-power multi-stage, multi-band RF pallets and transistors, is proud to feature IGNP1214M1KW-GPS for L-Band radar applications. The high-power GaN/SiC pallet supplies > 1000 W of peak pulsed output power at 50 V bias, with 13 dB gain and 60 percent efficiency at 300 microseconds, 10 percent pulse conditions and includes gate biasing and sequencing circuitry for easier system integration. Custom versions of this product (and other VHF/UHF, L-, S-, C-, X-Band standard products) are available upon request.

www.integratech.com

Cadence Design Systems — Booth 435
Allegro PCB Design Canvas



Accelerate your PCB design cycle by performing power integrity (PI) and signal integrity (SI) tasks directly from the Allegro PCB design canvas. Using the constraint-driven flow, guide PCB designers on optimizing the power delivery network (PDN) and minimizing signal distortion and crosstalk noise. SI specialists will want to see these compliance kits for the latest multi-gigabit interfaces. Let us show how your design engineers, PCB designers and SI/PI specialists can work collaboratively to create products on time and on budget.

www.cadence.com

Anokiwave — Booth 439
Phased Array Innovator Kit

VENDORVIEW

Ready for 5G? The AWMF-0129 is the world's first commercially available electronically scanned active array enabling fast prototyping and evaluation of 28 GHz 5G applications. Based on highly integrated Si ICs with embedded functions for remote telemetry and low-latency steering™, the AWMF-0129 allows for real-time active beam-steering. With 50 dBmi of EIRP and full flexibility for the user in the choice of waveform stimulus and timing-control, the array is an enabling product for the evaluation and development of 5G networks.

www.anokiwave.com

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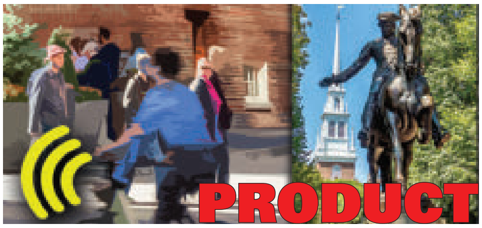
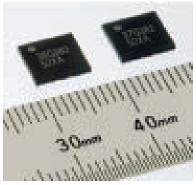


AISLE 500

PRODUCT SHOWCASE

Mitsubishi Electric — Booth 504

GaN Doherty Power Amplifier



Mitsubishi Electric develops ultra-wideband GaN Doherty power amplifiers for next generation wireless base stations. When applying advanced pre-distortion techniques from NanoSemi Inc., the GaN power amplifier achieves high efficiencies with up to 200 MHz instantaneous bandwidth while maintaining ACLR of -50 dBc or better. With this breakthrough, customers gain the ability to design a single flexible LTE power amplifier capable of many carrier aggregation scenarios, even above 3 GHz.

www.mitsubishielectric.com

SemiGen — Booth 505

Schottky Barrier and Detector Diodes

VENDORVIEW

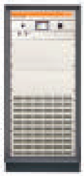
SemiGen's Schottky barrier diodes offer small junction capacitances, low resistances and low I/F noise, along with 0.6 V forward voltage drop and enhanced TSS, ideal for detector, mixer, modulator, power limiter and high speed switch applications. SemiGen's zero-bias Schottky detector diodes exhibit low junction capacitances, high voltage sensitivity, uniform video resistances, high sensitivity—without external biasing. These diodes feature 0.3 V forward voltage drop, incredible TSS and are excellent for waveguide, coaxial, and stripline applications from 55°C to +150°C.

www.semigen.net

AR RF/Microwave Instrumentation — Booth 508

Single Band Amplifiers Cover 0.7 to 6 GHz Frequency Band

VENDORVIEW



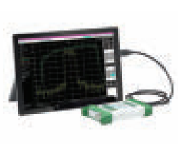
The new 350S1G6 and 500S1G6 are 350 and 500 Wt CW solid-state amplifiers that have 58 and 57 dB gain, respectively. Both deliver 100 percent rated output power without foldback over the instantaneous 0.7 to 6 GHz band and can survive ∞:1 output VSWR. Applications include radiated susceptibility testing, EW jammers and wireless system and device stress screening tests.

www.arworld.us/html/350S1G6-500S1G6.asp

Anritsu Co. — Booth 509

mmWave Spectrum Analyzers

VENDORVIEW

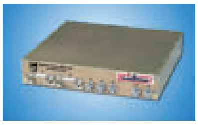


Anritsu has revolutionized the test market with the introduction of the Spectrum Master™ MS2760A family, the world's first ultraportable, mmWave spectrum analyzers, ideal for mmWave 5G and E-Band applications. Leveraging Anritsu's patented NLTL technology, the MS2760A shatters the cost, size and performance barriers associated with traditional larger instruments. In addition to 5G and E-Band, the MS2760A significantly improves test procedures and lowers the cost-of-test in other fast-growing mmWave applications, such as 802.11ad/WiGig, satellite communications and automotive radar.

www.anritsu.com

Wenzel Associates Inc. — Booth 519

OCXO + Rubidium Ruggedized Frequency Source



Wenzel Associates' is now offering QRb Sync Series products, which includes a low noise OCXO coupled with a very stable disciplined Rubidium oscillator, all combined within a small ruggedized housing. This combination offers exceptional phase noise performance as well as excellent stability. There are many options to choose from, depending on the application, including HF and VHF frequencies from 10 to 500 MHz as well as low g-sensitivity and internal vibration isolation.

www.wenzel.com

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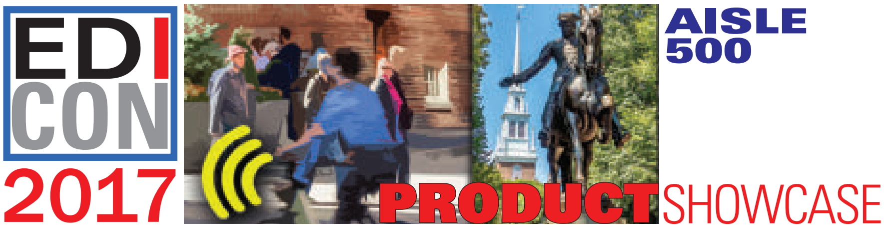
mwjournal.com/EDICON2017


5G

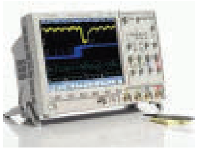
MICRO-ADS

See us at EDI CON Booth 326



Liberty Test Equipment — Booth 521

New and Refurbished Electronic Test Equipment



Liberty Test Equipment is a quality source for buying, renting and leasing new and refurbished electronic test equipment. Their 100 percent customer satisfaction guarantee and commitment to product selection, competitive prices and dedicated customer service distinguishes the company from others. With more than 5,000 products available, Liberty Test Equipment offers test equipment for a variety of applications. The company carries oscilloscopes, spectrum and network analyzers, generators, meters, counters, power supplies, equipment racks and wireless and optical test equipment.

www.libertytest.com

Holzworth Instrumentation — Booth 522

Real-Time Phase Noise Analyzer

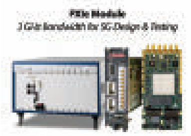
VENDORVIEW

The HA7062C real-time phase noise analyzer is a dual channel, cross correlation system that directly addresses the measurement speed and repeatability requirements of high volume, ATE manufacturing. The versatile design is also popular with product developers due to a reconfigurable analog front end that provides numerous extended capabilities, while also eliminating issues common to digital phase noise test systems. Capable of measuring: absolute, additive, baseband, AM, pulse and much more. See a real-time demonstration at EDI CON USA Booth 522.

www.HOLZWORTH.com

Innovative Integration — Booth 524

PXIe



An ideal platform for complex RADAR/LIDAR, wireless communications or automated test systems. Each chassis combines an multi-core Intel CPU running Windows/Linux with a backplane providing four or eight-lane high-bandwidth PCI Express connections to each payload slot, capable of sustained 3400 to 7000 MB/s data flow. PXIe systems can run the identical application software, drivers and operating-systems as desktop or industrial PCs. PXIe chassis support concurrent use of 6, 9 or 18 plug-in cards, so it is feasible to configure sophisticated systems with myriad I/O connections.

www.innovative-dsp.com/pxie.html

EMSCAN — Booth 525

EMxpert ERX+

EMSCAN's EMxpert ERX+ enables the PCB and design engineers to diagnose EMC/EMI problems between 150 kHz and 8 GHz. ERX+ provides eight levels of resolution (60 microns to 7.5 mm). Level 1 resolution (7.5 mm) allows the engineers to visualize the hot spots, current loops or intermittent problems in real-time. After locating the unintended radiators, engineers can select the resolution level based on the density of their board design. The built-in spectrum analyzer turns ERX+ into a plug-and-play test system.

www.emscan.com

Exodus Advanced Communications — Booth 527

AMP1090 SSPA Module

VENDORVIEW

AMP1090 SSPA module covering the full 2 to 8 GHz frequency band at 10 W min power levels for this frequency range are also available up to 50 W. The AMP1090 uses CW GaN devices and operates from a 32 VDC supply at 3 A max with gain flatness of 3 dB max peak to peak. This module is suitable for use with all modulation standards and features built-in protection circuits. With high-reliability and ruggedness, typical applications would include EMI/RFI, S- and C-Band, RADAR, EW, SATCOM, among others.

www.exoduscomm.com

ConductRF — Booth 528

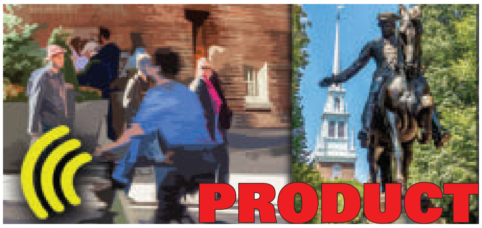
Mil-D38999 RF Solutions

Configurations use industry standard Mil-D38999 multi-port connector system. ConductRF provides solutions from DC to 65 GHz, phase matching between ports and assemblies and more. Using industry standard BMA, SMPM, #8, #12 and #16 Contacts, D38999 assemblies can be configured for varied applications. ConductRF manufactures a broad range of RF solutions from semi-rigid to flexible cables, test & measurement cables, including specialist versions for VNA testing. Enhanced mechanical solutions including armoring, waterproofing and more are available on request.

www.ConductRF.com

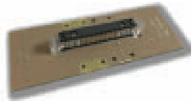
EDI CON 2017 PRODUCT SHOWCASE

AISLES 500-600



Ardent Concepts — Booth 529

Stackable Height RF Interposers



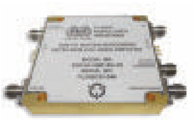
Stackable height RF Interposers provide exceptional signal integrity to 40 Gbps+ in a high density compression mount form factor so engineers can implement the shortest and fastest connector technology in capital equipment designs, radar system, RF communication systems, antenna and a host of other RF applications. Their connectors have the capability to withstand high shock and vibration applications as well as applications requiring extreme temperatures from -50°C to 150°C.

www.ardentconcepts.com

Planar Monolithics — Booth 600

PMI Model No. SDLVA-50M18G-70

VENDORVIEW



PMI Model No. SDLVA-50M18G-70 is an SDLVA (Successive Detection Logarithmic Video Amplifier) operating in the 50 MHz to 18 GHz frequency band. It features a built-in voltage variable threshold detector circuit that is set up to match the video output voltage to within 5 percent. In addition, this model has a TSS of -70 dBm and a dynamic range of 70 dB, VSWR: 2.0:1 maximum, all in a package measuring only 2.3 in × 2.2 in × 0.4 in with SMA female connectors and gold plated finish.

www.pmi-rf.com/Products/SDLVA/SDLVA-50M18G-70.htm

Response Microwave Inc. — Booth 604

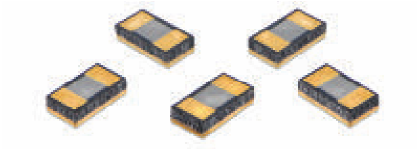
High-Power Quad Hybrid for Radio Applications

Response Microwave, a global specialist in providing RF and microwave customer solutions, is pleased to announce the availability of a new high-power 3 dB 90° hybrid for use in radio applications. Operational from 100 to 450 MHz, the unit offers 0.7 dB insertion loss, 1.3:1 VSWR and 18 dB minimum isolation with N female connectors. Power handling is 100 W CW over the -40°C to +105°C range. Custom configurations are available on request.

www.responsemicrowave.com

Res-Net Microwave — Booth 610

RF Dielectric Material



CVD (chemical vapor deposition) synthetic diamond has outstanding thermal conductivity, 3 to 4x better than copper. In addition, the low dielectric constant makes CVD diamond an excellent RF dielectric material for high frequency and high-power applications. Combining advanced thin-film processing techniques and extensive high frequency design experience, Res-Net Microwave has created a line of high performance CVD components that can withstand even the most challenging space environment. Res-Net Microwave offers the highest quality resistors, terminations and thermal jumpers on diamond substrate.

www.resnetmicrowave.com

Signal Integrity Software Inc. (SiSoft) — Pod 6

Quantum-SI (QSI) 2017

SiSoft's Quantum-SI (QSI) 2017 release extends the world of DDR4/5 timing and signal integrity analysis to include techniques previously limited to multi-gigabit serial channel applications. These techniques allow users to predict eye margins down to probability of 1^{e-15} and include statistical and million bit time-domain simulation, transmit/receive equalization modeling using IBIS-AMI models and aligned pulse response analysis to identify signal quality issues and equalization techniques that can compensate for them.

www.sisoft.com

An Introduction to Packet Microwave Systems and Technologies

Paolo Volpato

Except for the U.S. and China, where fiber is predominant, microwave radio systems provide most of the "back haul" for the global mobile network. During the past decade, since Alcatel-Lucent introduced packet radio technology in 2008 and cellular systems adopted LTE, microwave radios have been migrating to the all-IP packet radio standard. Paolo Volpato helped to usher in this transition while at Alcatel-Lucent. Disappointed by the slower-than-expected adoption of packet radio, he wrote this introduction to "provide a more systemic view of packet microwave… and to remove any remaining uncertainty."

Volpato presents his arguments in eight chapters, beginning with a market view and explanation of packet microwave technology. Since legacy networks use time-division multiplexing (TDM), he addresses introducing packet technology in "hybrid" systems, where the two standards must coexist. A chapter is devoted to the capability of packet radio to scale and accommodate the explosive growth in data traffic. Volpato delves into the architecture of the radio, i.e., how the block diagram is segmented between the indoor and outdoor units, and the topology of a packet microwave network. To provide a real world application, he devotes a chapter to implementing packet radio backhaul for an LTE network, considering both microwave transmission and networking requirements. The book concludes by discussing how packet microwave technology will likely evolve in the future to support the added capabilities of LTE-Advanced: carrier aggregation (CA), coordinated multipoint (CoMP), inter-cell interference coordination (ICIC) and self-organizing networks (SON). Interestingly, there is no mention of 5G, perhaps because the yet-to-be-defined standard was too nebulous when Volpato finished the book.

This introduction was written for network architects and radio engineers, with a hope to bridge the two communities' understandings. Those who design or market components for radio systems will also benefit, gaining insight into the requirements the radio manufacturers flow down.

To order the book:

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www.artechhouse.com
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FABS and LABS

Innovation at Anaren

Innovation never takes a day off at Anaren, Inc. Now celebrating its 50th anniversary as a successful upstate New York manufacturer and employer of approximately 1,100 people, the company continues to advance its engineering expertise and manufacturing processes that improve performance and cost for its customers. Anaren develops many unique products, and over the years has built solid relationships with its customers on a foundation of trust and the spirit of innovation inherent to the culture.

Anaren is well-known for its innovative Xinger® line of hybrid couplers, directional couplers and power dividers. The Xinger was developed in the 1990s during the wireless boom. Anaren engineers stacked multiple layers of stripline circuits separated by nonconductive Teflon® and achieved an order-of-magnitude reduction in size and eliminated bulky RF connectors and interconnects—even the heavy outer cases traditionally used in the industry. To date, the company has shipped well over a billion of these Xinger components to customers throughout the world.

Anaren was formed in the late 1960s, when the U.S. government had an urgent need for technology that could detect, identify and counter radar-guided munitions. Two Syracuse engineers decided to leverage their research and expertise in microwave technology and formed Anaren in the beautiful Finger Lakes region of upstate New York. The founders, Hugh A. Hair and Carl W. Gerst Jr., began Anaren Microwave (aptly named after their wives Anna Marie and Renee) to develop and manufacture instantaneous frequency measurement receivers in a small facility with just a few employees in Syracuse. Despite the company's diminutive size at the time, they caught the attention of defense prime contractors like Hughes, Northrop Grumman and Raytheon, who became some of the first customers and remain customers today. Anaren was careful to focus on innovative, highly engineered, high quality solutions that allowed the company to grow and prosper in the defense industry. With that same focus on innovation, Anaren successfully expanded into the satellite communications and commercial wireless markets.

Anaren's major facilities are located in East Syracuse, N.Y., Salem, N.H. and Littleton, Colo. They all collaborate to meet the needs of their customers, developing the right solution using the best expertise in the company. In most cases, Anaren's technology incorporates proprietary engineering, materials-processing techniques and products that are manufactured in high or low volume (depending on complexity) using current, automated manufacturing in ITAR-compliant, ISO-certified facilities. A wide range of building-block technologies, packaging and substrates for RF/microwave applications—including ceramics (LTCC, thick film, precision thick film), stripline solutions, ferrites and antenna beamforming technology—are core to the company.

In the early 1980s, Anaren expanded its facilities to an 80,000 square foot corporate headquarters in East Syracuse. Another expansion of the East Syracuse facility occurred in 2006 to a 160,000 square foot location. The company's facilities in Salem and Littleton will also be expanding in the fall of this year. The Salem location will be expanding to support the increase in order demand of the LTCC technologies. The Littleton facility will expand to include an additional 10,000 square feet of production area. This update is a response to the recent contract awards and the company's commitment to invest in its manufacturing processes and infrastructure. Recent contract awards include support of the Long Range Discrimination Radar (LRDR) system and RF beamforming assemblies supporting the U.S. Navy's new AN/SPY-6(V) Air and Missile Defense Radar (AMDR). Anaren is considered a strategic partner by several leading defense electronics OEMs through its vertical integration of manufacturing processes and engineering expertise.

Anaren has aggressively pursued automated manufacturing and testing, accelerated product development and marketing throughout the years. Their industry leading manufacturing capabilities include building their own high frequency, high-density circuit boards and ceramic products, and opening an international presence with an operation in Suzhou, China. These core competencies, coupled with Anaren's innovative culture, position them to succeed in new markets, including building a strong foothold in the Internet of Things as they look to the future.

www.anaren.com