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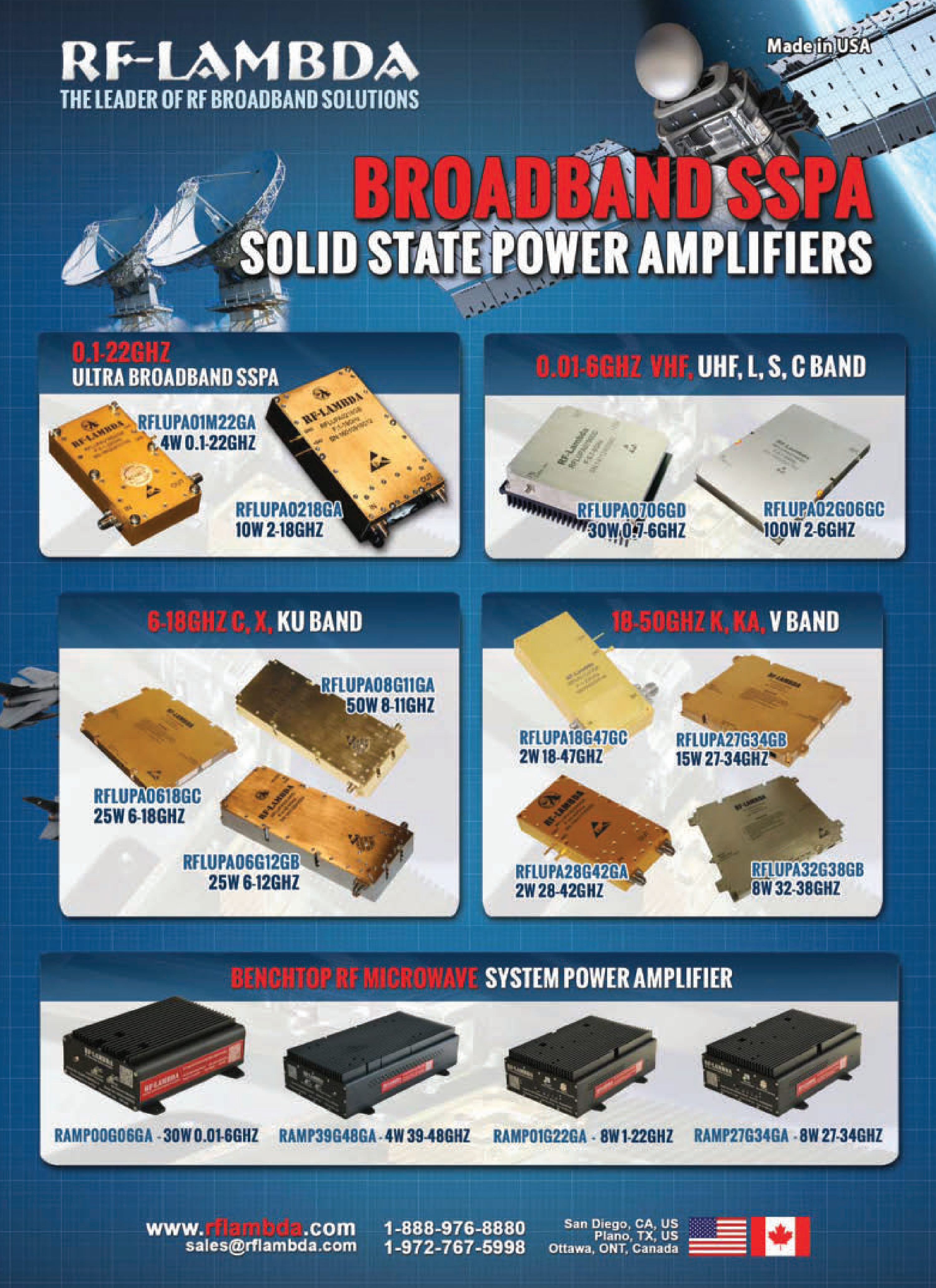

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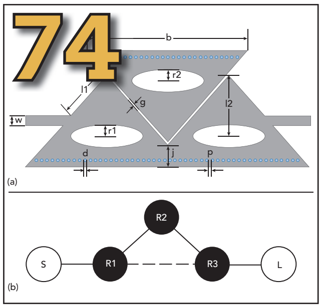

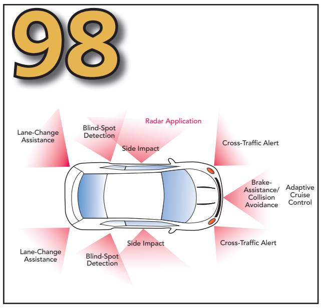

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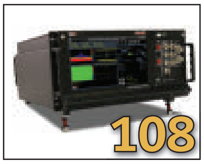

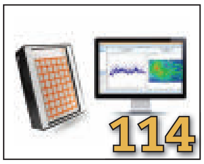

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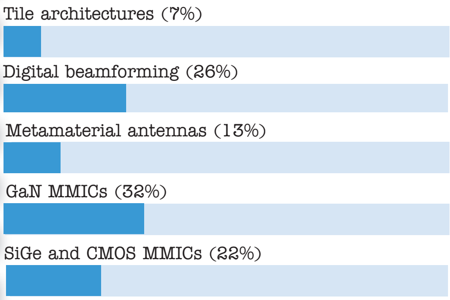

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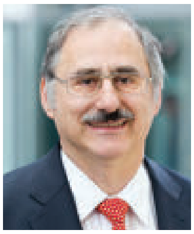

Roland Steffen, executive vice president test and measurement and vice president market segment wireless communications at **Rohde & Schwarz**, explains how a family-owned company founded in 1933 has developed technologies, forged a global presence and continues to innovate for future generations.

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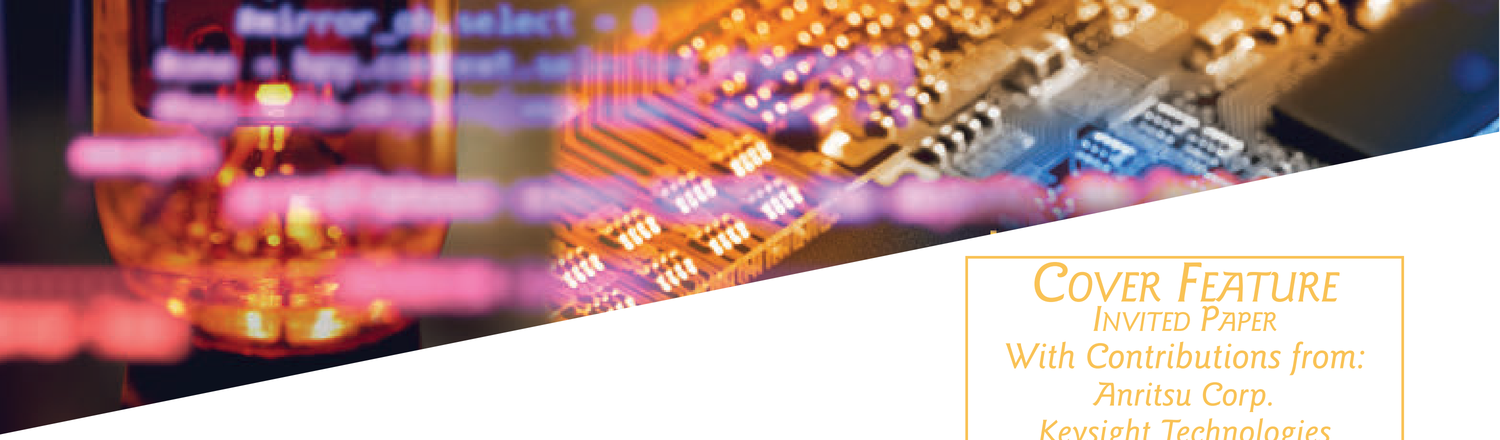

Cover Feature
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Editor's Note: Microwave Journal *recently reached out to some of the leading test and measurement companies to learn more about the innovative measurement equipment being deployed to meet the industry's upcoming challenges in the areas of 5G/Massive MIMO, automotive radar/sensors, signal integrity and millimeter wave communications.*

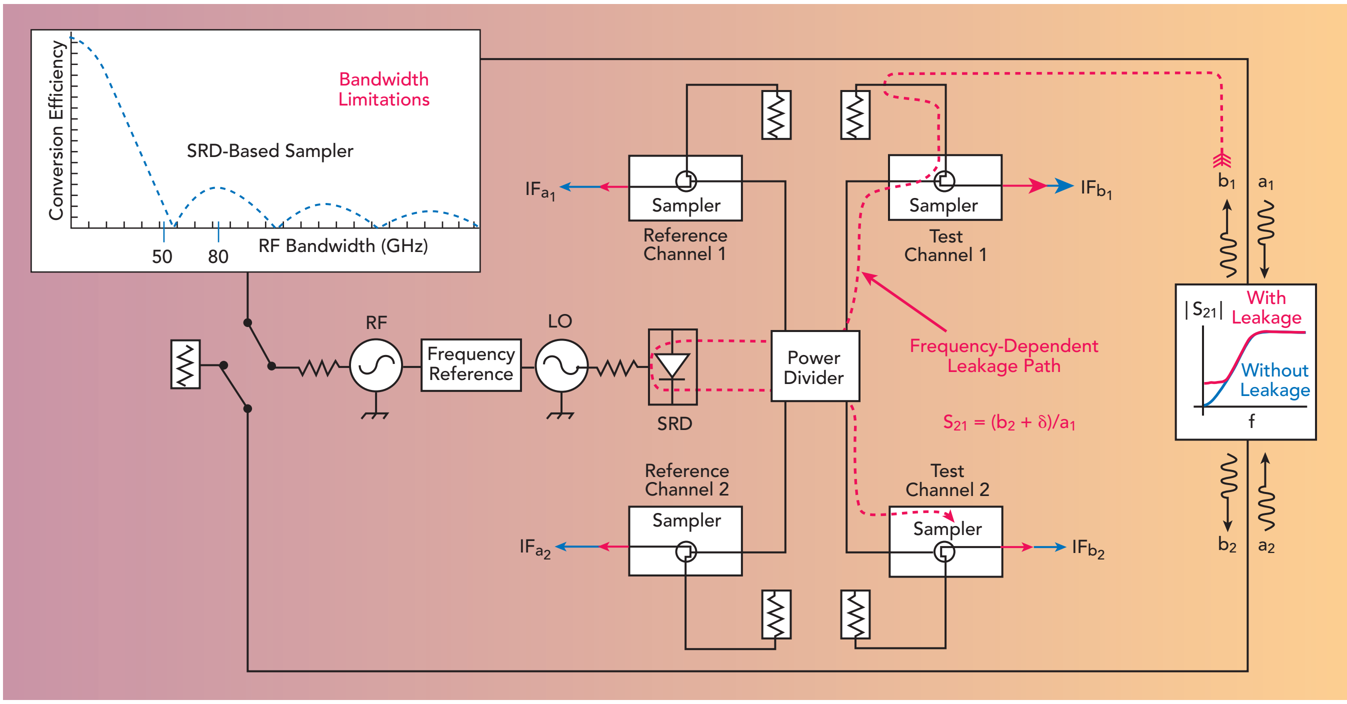
Innovations in Test and Measurement to Meet Today's Challenges

The innovative application of nonlinear transmission line (NLTL) technology in vector network analysis and other test instrumentation has delivered high performance, robust, frequency scalable and cost-effective test solutions. Today the value of that testing innovation has never been greater. The future growth engine for test and measurement is the move toward mass market applications at microwave and millimeter wave (mmWave) frequencies—whether it is for high data rate 5G wireless communications, multi-gigabit per second speed WiGig technology, higher frequency radars for advanced driver assistance systems or even signal integrity applications at wireline data centers. NLTL technology redefines the level of performance and size of instrumentation while reducing the higher costs usually associated with high frequency test and measurement equipment. Anritsu's patented application of this technology enables the next wave of microwave and mmWave instruments—accelerating next generation product development and lowering production costs with the added portability to be able to install and maintain next generation radio systems.

SRD HARMONIC SAMPLER-BASED VNAs

To understand the advantages of NLTL technology, its application in a VNA is explored. Microwave and mmWave VNAs are based on the use of either harmonic mixers or samplers. In traditional sampling VNAs (see ***Figure 1***), short pulse waveforms are used in the VNA receivers to sample stimulus and response signals. These waveforms are also used as harmonic generators to multiply the frequency of internal VNA signals that are used for both the stimulus source and receiver local oscillator. Traditionally, the short pulses are generated with a step-recovery diode (SRD) circuit. However, VNAs utilizing SRD-based harmonic samplers face a number of challenges. SRD-based harmonic samplers have bandwidth limitations. In addition, there is often leakage between test channels, limiting the VNA dynamic range. When extending beyond the fundamental bandwidth of the SRD-based harmonic samplers, short- and long-term stability and quality of broadband VNA measurements may also be challenged due to the following:

- Physically large and inhomogeneous measurement structures utilizing discrete components such as reflectometers, receivers, signal conditioning devices, interconnect cables or waveguides
- High-frequency multiplexing schemes
- Complex receiver structures such



▲ **Fig. 1** Harmonic sampler-based VNA utilizing step recovery diodes (SRD).

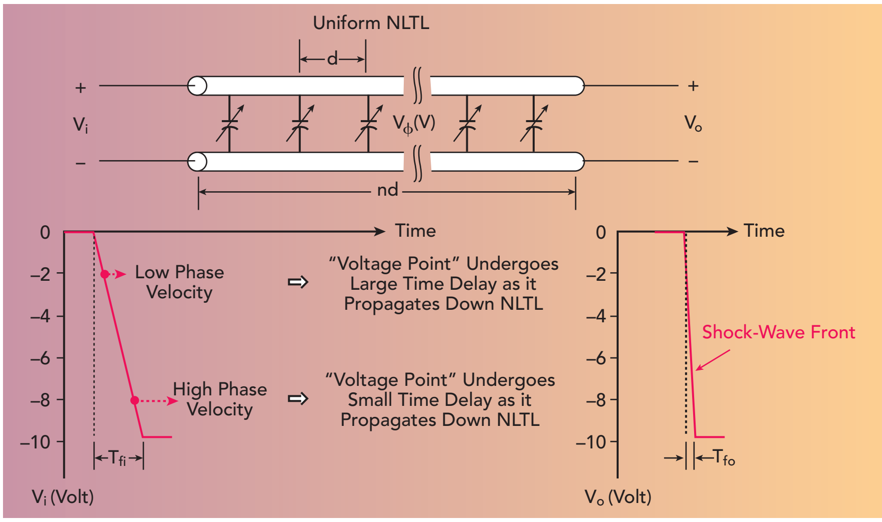
as harmonic frequency converters and complex LO (local oscillator) distribution networks

NLTLs can be used in place of the SRD to overcome the limitations and challenges faced by SRD-based systems.

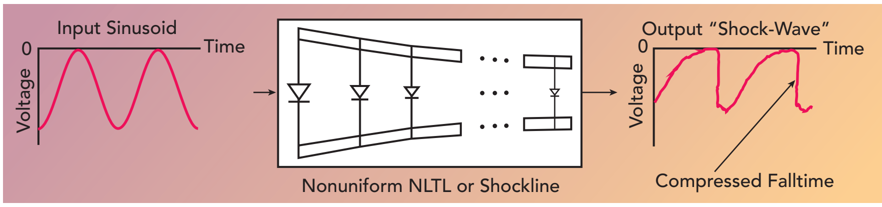
NLTL TECHNOLOGY

In their most basic form, NLTLs consist of high-impedance transmission lines loaded with varactor diodes that form a propagation medium whose phase velocity, and thus time delay are a function of the instantaneous voltage across the diodes. The lower the voltage, the lower the phase velocity and the longer the time delay of a waveform propagating along the nonlinear transmission line. Conversely, the higher the voltage, the greater the phase velocity and the shorter the time delay. When acting on a section of a trapezoidal voltage waveform applied to its input, an NLTL compresses the waveform's front, resulting in a step-like voltage that is highly rich in harmonics (see ***Figure 2***).

Non-uniform NLTLs further enhance fall time compression, and result in a train of step-like waveforms when driven by a CW signal. By leveraging the fall-time compression characteristics of an NLTL, a train of very narrow gating pulses can be generated at microwave and mmWave frequencies for sampling receivers starting from a CW signal (see ***Figure 3***); the fall times are about 10 times faster than a pulse generated with an SRD. In addition, broadband distributed harmonic generation is achieved by leveraging the "harmonic growth" characteristics of NLTLs. Since two primary functions of any VNA are generating signals and sampling them, NLTL technology is especially well suited for use in such instruments.



▲ **Fig. 2** The falling edge of an electrical wave undergoes compression as the wave propagates along the nonlinear transmission line.



▲ **Fig. 3** Resulting waveform after utilizing non-uniform NLTL (or Shockline) technology.

TABLE 1 NLTL TECHNOLOGY ADVANTAGES		
Parameter	***NLTL-Based VNA Advantage***	***Benefit***
Simplified VNA Architecture	Monolithic reflectometer design reduces number of discrete parts and connectors	Lower maintenance cost, reduced down time and operating costs
Stability	Integrated chip design greatly reduces the temperature variation across reflectometer constituents	Longer intervals between calibrations, better measurement accuracy and repeatability
Bandwidth	Extremely wide RF harmonic sampler bandwidth allows one sampler to cover broad frequency range	Lower cost for making high-performance measurements over broader frequency ranges
Dynamic Range	Over 100 dB across all frequency ranges	Better characterization of highly reflective devices and weak crosstalk
Size	High performance in a very small form factor	Direct connection to wafer probes, smaller footprint in manufacturing, lightweight field solutions
Cost	Improved capability-to-cost ratio enables new applications	Dramatic cost reduction for high frequency testing in engineering, manufacturing and field

COMMERCIALIZATION OF VNAs USING NLTL

In 2009, Anritsu introduced the VectorStar series of VNAs signifying the first commercial introduction to NLTL technology into a VNA and has continued to apply its semiconductor, component and miniaturization capabilities to include NLTL technology in a complete line, ranging from VNAs with highest levels of performance to solutions for cost-sensitive applications including testing of microwave systems in field applications. ***Table 1*** shows the advantages and benefits of NLTL technology.

TEST INNOVATIONS ENABLED BY NLTL TECHNOLOGY

Broad Frequency Range

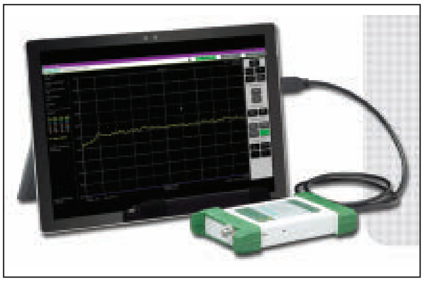
NLTL-based VNA mmWave systems combined with external mmWave modules now enable measurement of frequencies from 70 kHz to 110/125/145 GHz in single coaxial connection. These systems are excellent for device characterization and high data rate signal integrity applications. In addition, the small size and lightweight, high-frequency reflectometers enhance maneuverability and probe positioning in applications such as on-wafer measurements and near field scanning of antennas and circuits. This enables direct connection to the DUT, broadband dynamic range of 107 dB to 110 GHz and calibration stability of 0.1 dB and 0.5° for S_{21} over 24 hours.

Cost-Effective E-Band VNA

A low cost NLTL-based VNA family consists of a base chassis and small tethered source/receiver modules capable of measuring from 55 to 92 GHz. It is an integrated system ready to operate right out of the box providing high value and enabling mass market production of E-Band components.

Handheld Cable and Antenna Analyzer up to 40 GHz

Microwave handheld analyzers offer field technicians, engineers and wireless network installers industry-leading dynamic range, directivity and durability so that they can conduct highly accurate measurements during the installation, maintenance and troubleshooting of microwave communication systems operating to 40 GHz.



▲ Fig. 4 Anritsu MS2760A handheld millimeter wave spectrum analyzer.

Ultraportable Instrumentation

An ultraportable spectrum analyzer sets a new standard for cost, size and performance associated with traditionally large form-factor instruments to more efficiently advance technology development. A pocket sized VNA with good performance including industry leading dynamic range, sweep speed and amplitude accuracy has been developed with this technology. Its ultraportable size enables direct connection to almost any DUT, eliminating the need for cables or antennas. The Anritsu MS2760A is the first handheld mmWave spectrum analyzer to provide continuous coverage from 9 kHz up to 110 GHz in this form factor (see ***Figure 4***). It is poised for use in the growing 5G network development market, as well as other fast growing mmWave applications, like 802.11ad/WiGig, E-Band microwave wireless communications, satellite communications, electronic warfare and automotive radar.

A new power meter is the first frequency selectable mmWave power analyzer. It is an ultraportable USB-powered instrument that measures the RF power of signals up to 70 GHz and as low as -90 dBm. Unlike spectrum analyzers that are bulky, expensive and complex, or power meters that are not frequency dependent selectable and have limited dynamic range, this unit enables simple, numeric, frequency-based amplitude measurements of up to six signals from 9 kHz to 70 GHz in a package slightly larger than a cell phone and at an extremely affordable price.

CONCLUSION

Nonlinear transmission line technology redefines the level of performance and size of instrumentation while breaking down the cost barriers usually associated with high

frequency test and measurement equipment. Anritsu's patented application of this technology enables the next wave of microwave/mmWave instruments by accelerating next generation product development and lowering production costs — with the added portability to easily install and maintain next generation radio systems.

5G Coexistence in a Satellite World

Greg Jue
Keysight Technologies
Santa Rosa, Calif.

Today's sub-6 GHz spectrum is crowded, complex and congested with limited available spectrum. In contrast, centimeter and millimeter wave frequency bands offer the potential for larger swaths of contiguous spectrum for 5G high data throughput applications. For this reason and more, regulators are opening up more spectrum. In July 2016, the U.S. Federal Communication Commission (FCC) allocated 11 GHz of spectrum for wireless broadband in the high-band spectrum to enable rapid development and deployment of next generation 5G technologies and services.[1] This includes 3.85 GHz of licensed spectrum and 7 GHz of unlicensed airwaves: Upper Microwave Flexible Use service in the 28 GHz (27.5 to 28.35 GHz), 37 GHz (37 to 38.6 GHz) and 39 GHz (38.6 to 40 GHz); and a new unlicensed band at 64 to 71 GHz.

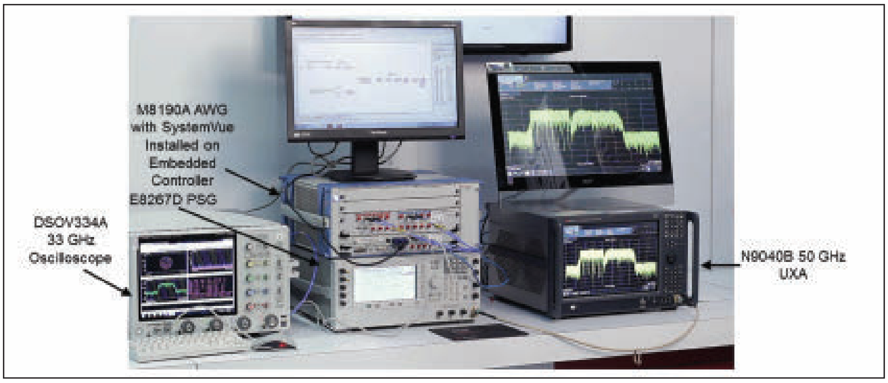
Sharing licensed spectrum is a key element of future policy, as evidenced by the FCC announcement. The 28 GHz band is an existing Fixed-Satellite Services (FSS) licensed band for Earth-to-space applications.[2]

The potential sharing of spectrum between satellite and 5G applications poses questions on how they might peacefully coexist. This may become an increasingly important area of research in uncovering potential issues. A flexible testbed to explore many different coexistence signal scenarios in the R&D lab environment could be beneficial, before actual field testing and deployment of hardware systems.

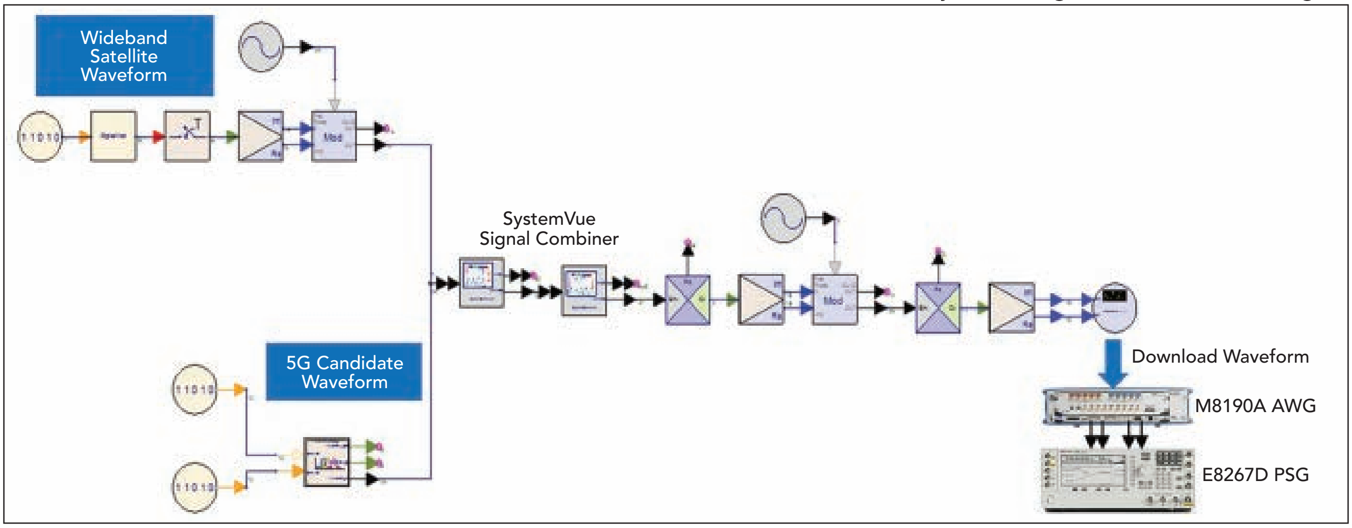
This article shows a new testbed that can be used in the 28 GHz frequency band to explore potential 5G and satellite coexistence scenarios. Flexibility in generating signal scenarios is enabled by using simulation software, combined with wideband high-frequency test equipment. A case study will be explored with candidate 5G waveforms and satellite waveforms in the 28 GHz frequency band to evaluate their coexistence for several different scenarios. The testbed is scalable, and can also be used for sub-6 GHz coexistence case studies as well as mmWave applications.

COEXISTENCE TESTBED

To generate the wideband 28 GHz satellite and 5G candidate test signals, a vector PSG with wideband IQ inputs is used in combination with a wideband precision arbitrary waveform generator (AWG). ***Figure 5*** shows the testbed that will be used for the 28 GHz case study. The AWG generates I and Q, which is modulated on to the approximate 28 GHz carrier frequencies using the vector PSG. This combination of the AWG and the vector PSG can generate test signals up to 44 GHz with up to 2 GHz of modulation bandwidth. The test signals are analyzed using either a 50 GHz signal



▲ **Fig. 5** **Testbed used for 28 GHz coexistence case study.**



▲ **Fig. 6** **Simulation schematic to generate and download the 28 GHz coexistence test signals.**

analyzer with 1 GHz of bandwidth, or with a 33 GHz oscilloscope. Design simulation software is installed on the embedded controller for the AWG. This will be used to generate the coexistence scenario which will be examined next.

28 GHz COEXISTENCE CASE STUDY

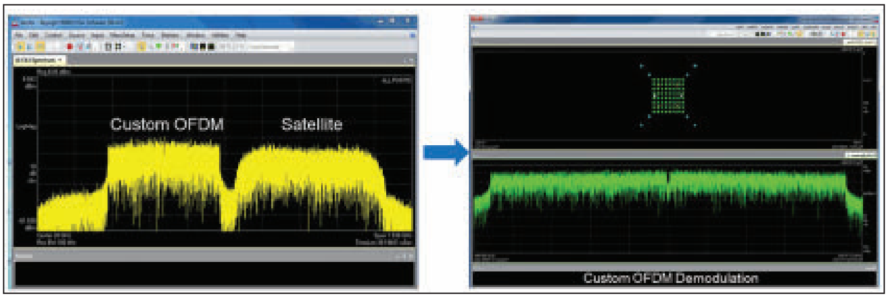
The design simulation schematic in ***Figure 6*** was used to generate the 28 GHz coexistence signal scenario. For this coexistence scenario, a wideband amplitude and phase-shift keying (APSK) waveform was used as an example satellite waveform. The APSK simulation signal source is shown in the upper-left of Figure 6. For the 5G candidate waveform, a wideband custom orthogonal frequency-division multiplexing (OFDM) waveform was used, and is shown on the lower-left of the figure. For both of these simulation sources, there are a number of parameters that can be set to configure the waveform characteristics. Both of these waveform types were chosen to illustrate a coexistence scenario concept, but the user can replace them with other types of waveforms for the actual application of interest.

A signal combiner element in simulation design software is used to resample and combine the satellite waveform and 5G candidate waveform. This element is an enabler in combining multiple input waveforms with different center frequencies, bandwidths and sample rates to create a single composite output waveform that can be downloaded to test equipment to generate coexistence test signals.

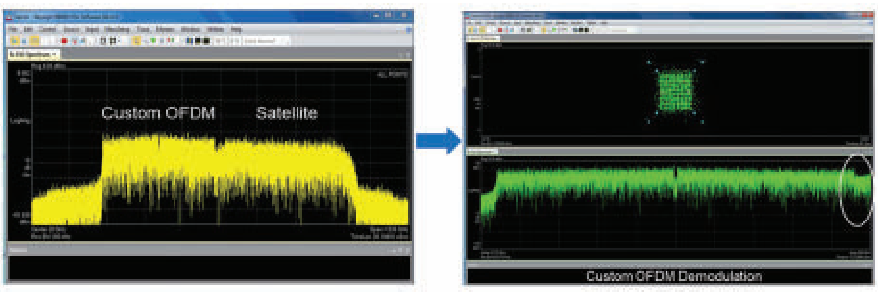
The AWG downloader element is used on the right of the simulation schematic. The I and Q of the composite complex waveform is automatically downloaded to the AWG upon completion of the simulation. The I and Q outputs of the AWG are routed to the wideband rear-panel IQ inputs on the vector PSG signal generator to modulate them onto an approximate 28 GHz carrier frequency.

The resulting test signal is shown in ***Figure 7***. The custom OFDM waveform is shown on the left of the spectrum display, and the satellite APSK signal is shown on the right. For this scenario, the center frequencies and bandwidths were set such that there is sufficient guard band between the two signals.

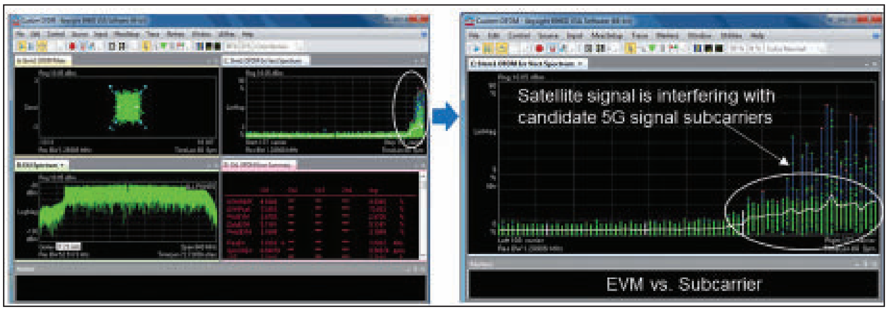
The coexistence for this scenario is demonstrated by using vector signal analyzer software on the test equipment to demodulate the custom OFDM waveform. For this



▲ **Fig. 7 Good coexistence between the candidate 5G waveform and satellite waveform.**



▲ **Fig. 8 Poor coexistence between the candidate 5G waveform and satellite waveform.**



▲ Fig. 9 EVM vs. subcarrier and close-up examination of the interference.

scenario, the OFDM constellation looks relatively clean, indicating good coexistence between the two waveforms. The signal scenario is then modified by changing the frequency separation between the two signals. ***Figure 8*** shows that satellite signal is now encroaching on the custom OFDM waveform and there is insufficient guard band between the two signals.

The coexistence performance impact of this scenario can be observed in the VSA measurement. The constellation shows significant dispersion as a result of the satellite signal interfering with it. A closer examination of this interference can be observed by measuring the EVM vs. subcarrier, as shown in ***Figure 9***.

On the left VSA display, the EVM vs. subcarrier on the upper right shows the impact of the satellite signal, especially on the subcarriers near the upper band edge. The EVM result on the lower right corner of the left VSA display shows a relatively high EVM, indicating that there is poor coexistence between the candidate 5G custom OFDM waveform and satellite waveform for this scenario. This EVM number is an average across the entire acquisition time and bandwidth of the signal, but the VSA software can provide a breakdown of errors versus frequency (or subcarrier) or errors vs. time (or symbols).

On the VSA display to the right, the x-axis has been scaled to zoom into the subcarriers impacted by the satellite interferer. The white trace is the average EVM versus subcarrier. It can be observed that it increases significantly at the upper band edge where the satellite signal is interfering with the candidate 5G OFDM signal. The blue and green vertical lines represent the distribution of EVM results at each subcarrier versus symbol.

CONCLUSION

Coexistence may become an increasingly important topic of interest as 5G continues to evolve, as well as spectrum policy. This article discussed a flexible testbed which can be used to investigate potential coexistence issues under various signal scenarios. Although simulation software was combined with wideband test equipment, scenarios could be evaluated in simulation stand-alone (e.g., coexistence impact to simulated bit error rate). Although not shown in this article, this testbed has also been used to generate coexistence signal scenarios in the 39 GHz frequency band. A demonstration video can be viewed from the video link at www.keysight.com/find/5G.

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RF Hardware-in-the-Loop Technologies Drive Embedded System Test

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Austin, Texas*

As wireless technology continues to become more embedded in "mission critical" applications like automotive radar and machine-to-machine communication, new test practices are emerging to ensure system reliability. One emerging test technique for RF-enabled systems is hardware-in-the-loop (HIL) testing—a category of "real-time" testing. The principle of HIL test, the idea that test engi-

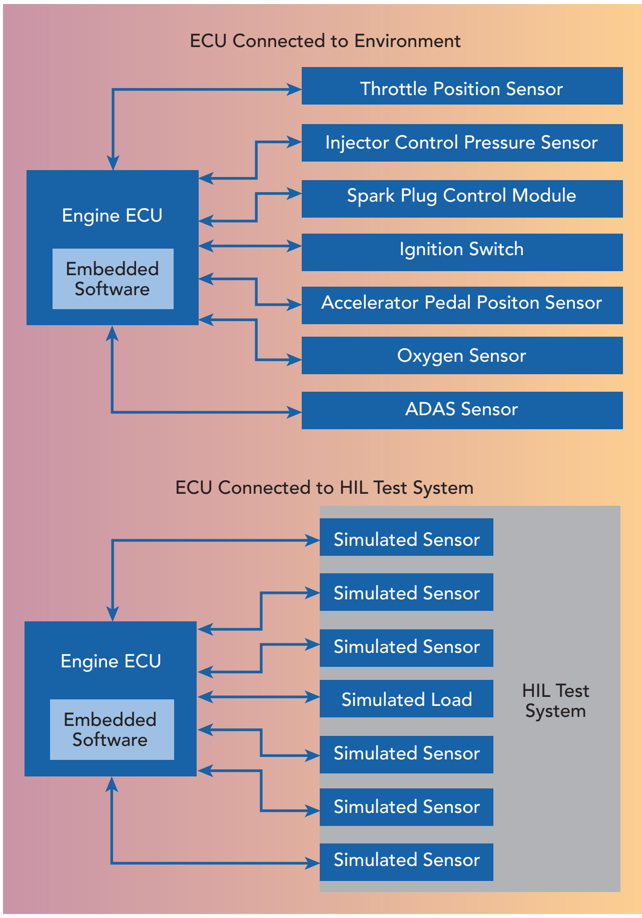
neers build test systems that can emulate physical systems typically present in the real world, is not new. However, the growing prevalence of RF technology in mission-critical systems like automotive radar has made HIL testing an increasingly common test technique for wireless applications.

ARCHITECTURE OF AN HIL TEST SYSTEM

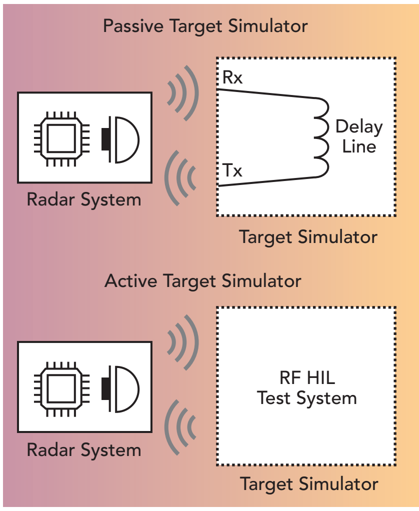
The idea of HIL testing first emerged as a mechanism for testing complex control systems in both the aerospace and automotive industries. In a typical application, an engineer might use a HIL system to test an engine's electronic control unit (ECU) by using the HIL test system to model the electrical signals and behavior of an engine. In this application, the test system combines analog and digital analog interfaces for input and output (often referred to as "I/O") along with deterministic processing elements to effectively emulate the system (see ***Figure 10***).

In recent years, the use of RF technology as both a critical sensing and a communications technology has driven many RF system engineers to use a similar test approach. In a typical RF HIL test system, relatively low-speed analog-to-digital converters (ADC) and digital-to-analog-converters (DAC) have been replaced with a vector signal generator and analyzer. In fact, the HIL test systems used in these applications often architecturally resembles a software-defined radio (SDR). However, many of the embedded processing elements remain the same. Common applications for RF HIL systems include channel emulation channel sounding, real-time GNSS simulation, radar target generation and cognitive test.

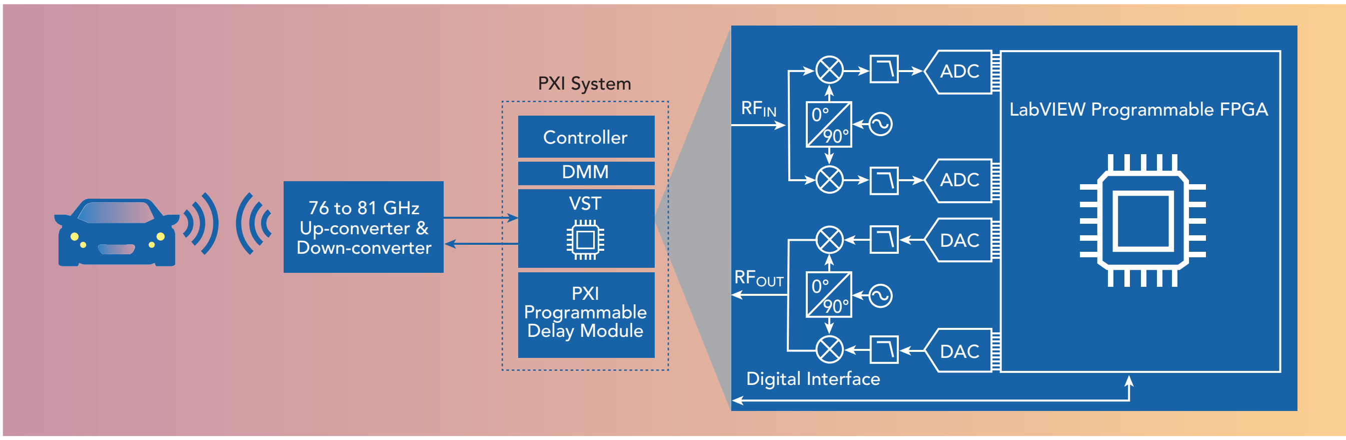
One of the most exciting real-time test applications is in the testing of automotive radars—both as a stand-alone product and as part of a more complex Advanced Driver Assistance System (ADAS). Modern ADAS technology uses a combination of radar (historically at 24 GHz and increasingly at 77 and 79 GHz), cameras, ultrasound and LIDAR technology to sense the world around them. ADAS designs range in complexity from the more simplistic blind-spot detection warning indicator to fully autonomous driving systems. Although many of today's critical automotive sensing technologies are relatively old (in fact, the first prototype automotive radars go



▲ **Fig. 10 Block diagram of a typical HIL test system.**



▲ **Fig. 11 Passive vs. active radar target generator.**



▲ **Fig. 12 Block diagram of Audi's Active Target Emulation System.**

back to the late 1950s)—improvements in sensor size and cost along with advances in signal processing technology have made autonomous driving systems much more practical.

HIL TESTING FOR AUTOMOTIVE RADAR APPLICATIONS

Testing a radar sensor requires engineers to validate both the electromagnetic and functional characteristics of the device. For example, typical RF measurements might include output power and pulse linearity (measured by demodulating the FMCW output). Equally important are functional characteristics that include range accuracy, range resolution, and the ability to detect an object in the presence of interference.

In order to test both physical and functional characteristics, a growing trend in radar test is to utilize test equipment that can be configured both as a measurement instrument and as a radar target generator. In this case, the test system uses its real-time signal processing elements to essentially trick the radar sensor into believing that it sees an object or target when in fact it merely sees a piece of test equipment. This process, called "target emulation" or "target generation," uses signal processing to recreate the electromagnetic response of a radar stimulus bouncing off an object.

Figure 11 illustrates two approaches to radar target generation. In the first approach, considered "passive target generation," a delay line is used to simulate the round-trip propagation time of a radar stimulus. The second approach is considered "active target simulation" and uses an HIL test system to digital recreate the radar system's environment. In a typical active target simulator, a wideband vector signal analyzer receives the stimulus from the radar sensors. Onboard the instrument, an embedded processor applies a delay to simulate distance and Doppler shift to simulate velocity. Finally, a vector signal generator generates this digitally created radar environment as a signal back to the radar sensor.

For a given application, either passive or active radar target simulation might be preferable depending on the type of object one is trying to simulate. For example, passive simulators tend to better simulate short-range targets, while active simulators can simulate more sophisticated driving scenarios like a lane change or an object crossing the road.

AUDI AUGMENTS DRIVE TESTING USING HIL TEST

NI has been working in conjunction with several leading automotive manufacturers to refine next generation radar test technologies. More specifically, NI has recently been working with Audi AG in Ingolstadt, Germany as they pioneer research efforts to develop fully autonomous vehicles.

The team at Audi has recognized safety and reliability are key concerns with next-generation autonomous vehicles. Because of this, Audi

uses HIL testing as a mechanism to simulate an ADAS system's environment in a laboratory environment. By simulating a typical drive test in the lab, Audi was able to improve the reliability of their embedded software much earlier in the design process—even catching bugs that might not otherwise have been caught until a physical drive test.

Audi's target emulation system, illustrated in ***Figure 12***, combines NI's second-generation vector signal transceiver (VST) with specialized up-converters and down-converters designed for the 79 GHz radar band. In this scenario, the VST functions like a software-defined radio and its LabVIEW-programmable FPGA executes real-time signal processing routines to emulate a radar target. Dr. Neils Koch, radar component owner at Audi AG, added that "with the PXI VST, the combination of wide bandwidth and low-latency software has allowed us to identify critical bugs in our radar module that we could not detect before."

TRENDS IN ADAS

Going forward, the trend in ADAS design is to combine multiple sensing technologies to take advantage of the comparative benefits of each technology. For example, radar is often one of the most accurate technologies for measuring range to an object, even at night or in foggy conditions. However, technologies like camera-based image recognition are more accurate at determining the exact position of an object. By combining inputs from multiple sensors as part of a "sensor fusion" architecture, ADAS systems benefit from an improved ability to sense the world around them (see ***Figure 13***).

The use of sensor fusion, combined with the growing reliance on inherently less predictable algorithms like neural networks to detect objects, will continue to drive the importance of embedded software test long term. In the future, engineers will increasingly integrate radar testing with the testing of other embedded sensors technology in highly synchronized and extremely flexible HIL test beds.

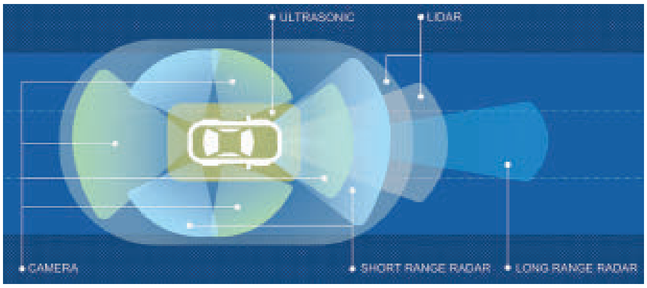
ADDITIONAL APPLICATIONS FOR RF HIL TESTING

Although radar target emulation is an HIL application that will likely affect us as consumers in the short term, it is one of only several emerging applications for RF HIL test systems. For example, in the defense industry, engineers use similar test strategies to simulate the environment of advanced electronics. Also, in the wireless industry, engineers are using similar HIL techniques for increasingly complex real-time channel sounding.

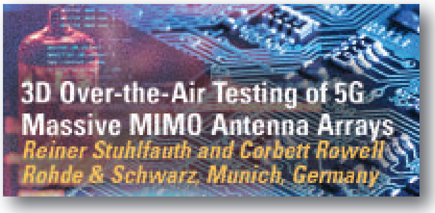
Today's RF HIL test systems bear a striking architectural resemblance to the advanced software-defined radio technology that engineers are using to prototype 5G communications systems. Similar to radar target emulation, wideband RF front-ends and intense signal processing elements are necessary to interpret and react to a stimulus signal in real-time. As a result, many of the same technology innovations that are allowing companies like Nokia, Intel and Samsung to prototype 5G systems are the same technologies used by a much broader set of RF HIL test applications.

CONCLUSION

Increasingly complex systems of systems like autonomous vehicles are quickly rewriting the rules for how test and measurement equipment vendors must design instrumentation. In the past, an instrument was merely a mechanism to report on the analog characteristics of a signal. Today, instruments are being used to report on the functional characteristics of a system as well. Going forward, software is the critical technology that allows engineers to construct increasingly complex measurement systems capable of characterizing everything from the simplest RF component to a fully autonomous vehicle. Software remains a key investment area for test equipment vendors—and the ability to differentiate products with software will ultimately define the winners and losers in the industry.



▲ **Fig. 13 Autonomous vehicles integrate multiple sensing technologies.**



5G will apply multiple antenna systems and combine them with enhanced spatial multiplexing to provide data for multiple users, known as Massive MIMO. One consequence is that performance evaluation of radiation patterns cannot be done in a conducted way, so connection over-the-air will be essential. This article presents technical aspects on how to measure three-dimensional antenna patterns using an over-the-air testing setup.

The upcoming 5G standard promises more throughput, capacity and implementation flexibility while achieving lower operational expenses (OPEX). Other goals include ultra-reliable low-latency communications (uRLLC) and massive machine type communications (mMTC). Software-defined networks (SDN) and Massive MIMO multiple antenna scenarios are likely technology choices for achieving these goals.

To obtain the wider bandwidths for higher throughput, 5G systems will use frequencies in the centimeter and millimeter wave ranges. One drawback to this approach is higher free-space path loss. Antenna arrays that provide a much higher antenna gain can compensate for free-space path loss. To maintain the same Rx power at a frequency of 28 GHz compared to 900 MHz means increasing the antenna gain by 30 dB. Using a high number of antenna elements and steering the energy pattern, known as beamforming, can achieve this goal.

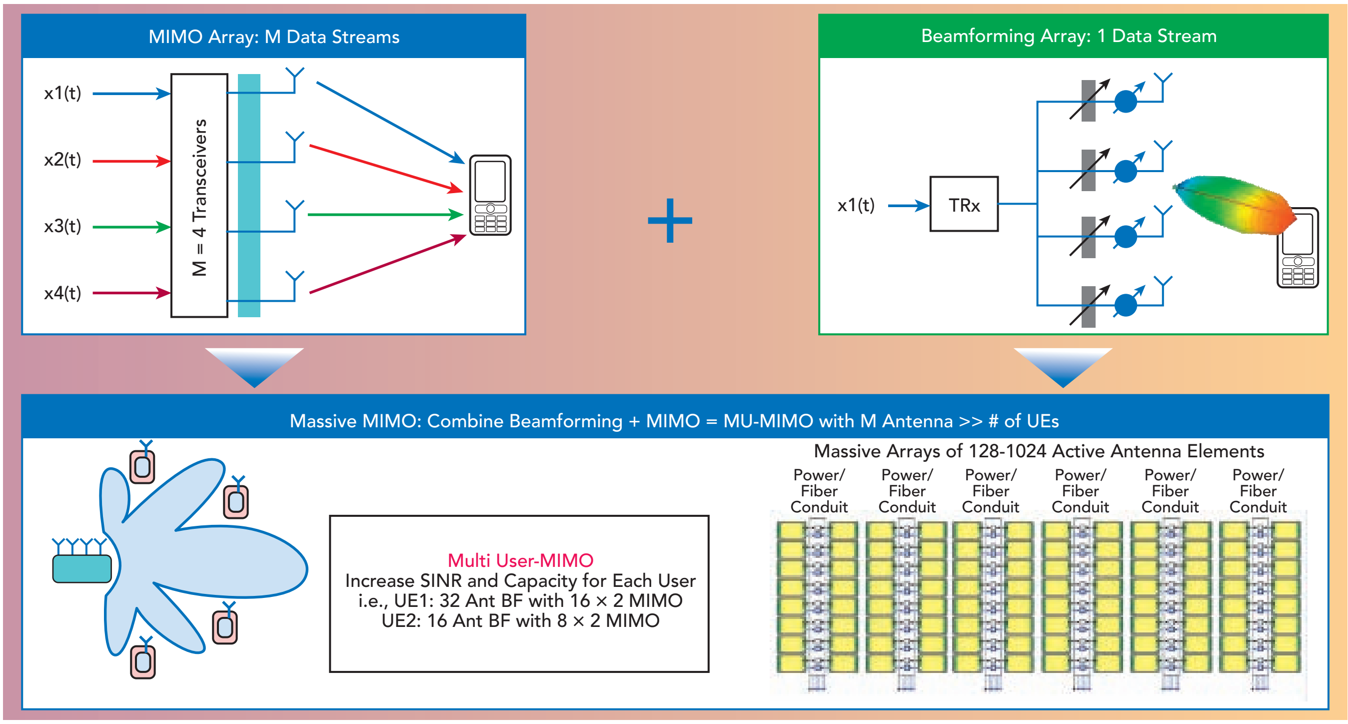


Fig. 14 Massive MIMO: Combination of beamforming and spatial multiplexing.

Beamforming also significantly reduces the energy consumption by targeting individual user equipment (UE) with their assigned signal. In a base station without beamforming, energy not received by the UE can create interference for adjacent UEs, or, is simply lost.

Current standards like LTE or WLAN employ MIMO to obtain a higher capacity through spatial multiplexing. Multi-user MIMO extends MIMO by sending data to different UEs simultaneously using beamforming. The term Massive MIMO describes the combination of beamforming and spatial multiplexing of many antennas in a dynamic manner depending on hardware configuration and channel conditions (see ***Figure 14***).

CHALLENGES FOR MASSIVE MIMO

While Massive MIMO offers many advantages, there are also several challenges including:

1. High throughput for fronthaul interface connection
2. Antenna array calibration
3. Mutual coupling between antenna elements
4. Irregular antenna arrays
5. Antenna array complexity

Massive MIMO introduces similar challenges for characterizing signals and measuring antenna array power that cannot be met by the traditional conductive interface with

a cable. Meaningful characterization can only be accomplished using Over-The-Air (OTA) testing. Major reasons include: cost, high losses and coupling experienced at higher frequencies make cable testing unfeasible; and, Massive MIMO systems integrate the radio transceivers into the antennas, which results in the loss of RF test ports. What are the consequences of this paradigm change?

3D OTA MEASUREMENTS

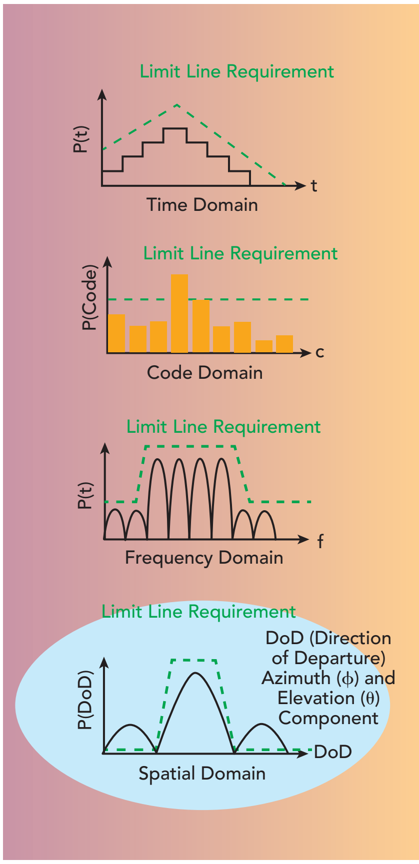
In the past, power was measured as a function of time, spectrum or code (CDMA systems). The addition of beamforming adds another dimension: Space or power vs. direction of departure. ***Figure 15*** gives an example of a power measurement. OTA measurement parameters can be divided into two general categories: R&D and certification or conformance testing for more complete investigation of the DUT radiated properties, and production for calibration, verification, and functional testing.

The primary test parameters for antenna designers include gain patterns, radiated power, receiver sensitivity, transceiver/receiver characterization and beam steering/beam tracking. Each has its own implications for OTA measurements. Beam steering/beam tracking is of special interest; however, because of the frequencies employed by Massive MIMO. Although static beam pattern characterization is used for existing cellular technology, mmWave systems will require dynamic beam measurement to characterize beam tracking and beam steering algorithms accurately.

PRODUCTION TESTING

Conformance and production testing have many aspects. Three that are of particular importance include:

- **Antenna/relative calibration:** To form beams accurately, the phase



▲ **Fig. 15** Power measurements as a function of time, frequency, code and space.

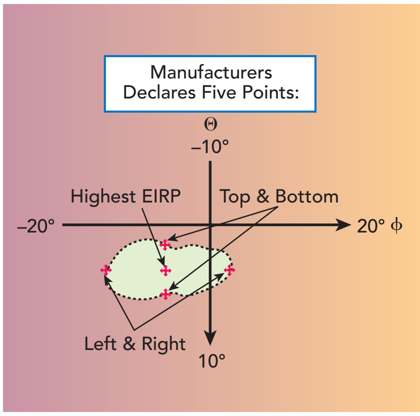


Fig. 16 Five point test based on manufacturer declaration of five measurement points.

misalignment between RF signal paths must be less than ±5°. This measurement can be performed using a phase-coherent receiver to measure the relative difference between all antenna elements.

- **Five-point beam test:** According to 3GPP, the active antenna system (AAS) manufacturer specifies a beam direction, maximum EiRP, and an EiRP threshold for each declared beam. In addition to the maximum EiRP point, four additional points are measured at the declared threshold boundary, i.e., a central point with highest EIRP and the remaining four points declaring the left, right, top and bottom boundary, as *Figure 16* illustrates.
- **Final functional tests:** Performed on the completely assembled unit in production, this can consist of a simple radiated test, a five point beam test and aggregate transceiver functionality, such as an EVM measurement of all transceivers.

NEAR AND FAR FIELD MEASUREMENTS

OTA measurement systems can be classified according to which part of the radiated field is being sampled. ***Figure 17*** illustrates the near and far fields from a base station antenna array (eight circular microstrip antenna patches at 2.70 GHz with uniform excitation). The near field and far field regions are defined by the Fraunhofer distance R = 2*D2/λ, where D is the maximum antenna aperture or size. In the near field region, at distances less than R, the field consists of both reactive and radiated components; whereas the far field of an antenna has only the radiated component.

Precise phase and magnitude measurements over a three-dimensional surface surrounding the DUT are required for the mathematical transformation to the far-field region, resulting in the antenna 2D and 3D gain patterns. A measurement in the far field region needs only the magnitude to calculate the beam pattern of the antenna and can be measured at a single point in space, if desired.

For small devices (in terms of wavelengths), such as UEs, the re-

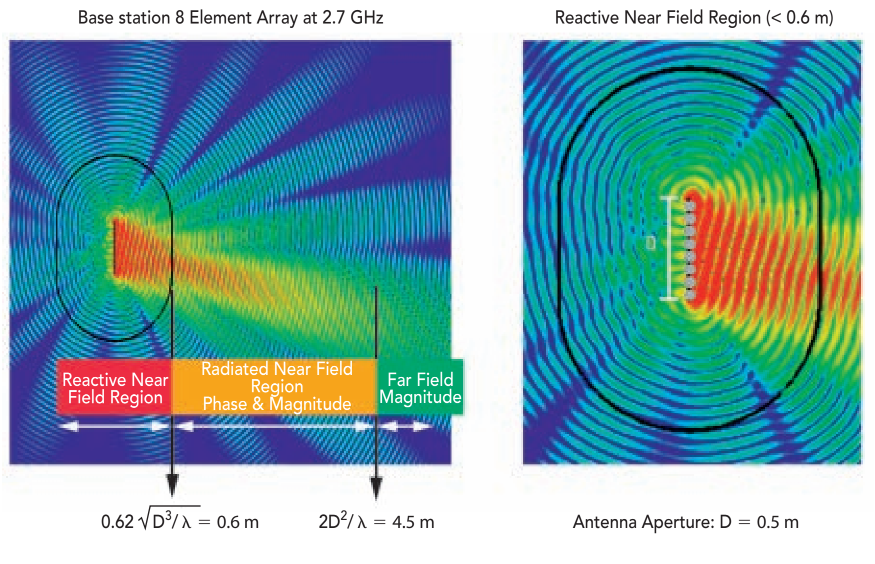


Fig. 17 Electromagnetic fields from a base station antenna array.

quired chamber size for far field conditions is dominated by the measurement wavelength. For larger devices, such as base stations or Massive MIMO, the required chamber size may become very large. Chamber sizes can be reduced significantly as long as the measurement system accurately samples the phase and magnitude of the electromagnetic field on the entire enclosing surface.

Measuring in the far field region requires a direct measurement of the magnitude of the plane waves and such chambers are generally quite large where the length is set by a combination of the DUT size and the measurement frequencies.

Although the far field is generally measured at a suitable distance from the DUT, it is possible to manipulate the electromagnetic fields such that a near field chamber can be used to directly measure the plane wave magnitudes. There are two techniques:

- Compact range chambers, which are most often used for large DUTs such as aircraft and satellites; and,
- Plane Wave Converter (PWC): A planar wave is created at the DUT is to replace the measurement antenna with an antenna array. Similar to using lenses in an optics system, the antenna array can generate a planar far field at a targeted zone in the region of the DUT.

NEAR FIELD MEASUREMENTS

Measurements in the near field region require both the field phase and magnitude sampled over an enclosed surface (spherical, linear or cylindrical) in order to calculate the far field magnitude using Fourier spectral transforms.

This measurement is usually performed using a vector network analyzer such as the R&S ZNBT20 with one port at the DUT and the other port at the measurement antenna. For active antennas or Massive MIMO, there are often no dedicated antenna or RF ports, so the OTA measurement system must be able to retrieve the phase in order to complete the transformation into far field. There are two methods of performing phase-retrieval for active antenna systems:

- Interferometric: A second antenna with a known phase is used as a reference. The reference signal is mixed with the DUT signal with unknown phase. Using post-processing, the phase of the DUT signal can be extracted and used for the near-field to far-field transformation.
- Multiple surfaces or probes: A second surface volume is used as the phase reference with at least one wavelength separation between the two measurement radii. Instead of multiple surfaces, two probes with different antenna field characteristics can be used. The two probes need to be separated by at least half-wavelength to minimize mutual coupling.

When selecting a vector network analyzer (VNA), true multiport VNAs, such as the R&S ZNBT20, have an additional advantage for measuring coupling between antenna elements. Having multiple receivers—instead of using switches —to perform tests simultaneously reduces test duration and does a better job of performing complete mutual coupling measurements.

CONCLUSION

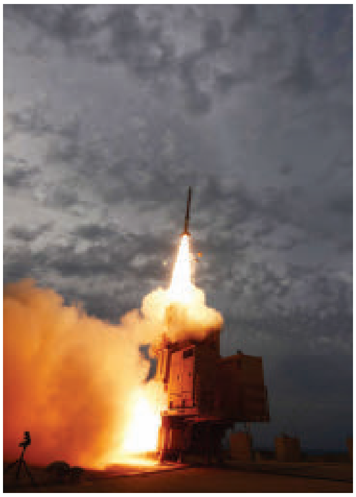
Antenna arrays will play an essential role in future wireless communication. But challenges in their development, design and production make thorough testing essential to achieving optimal performance. The elimination of RF test ports and the use of frequencies in the centimeter and millimeter wave length region make OTA an essential tool for characterizing the performance of not just Massive MIMO arrays, but the internal transceivers as well. This will drive a high demand for OTA chambers and measurement equipment to measure the strict radiation properties of antennas and transceiver measurements.■

Israel and U.S. Successfully Complete David's Sling Weapon System Intercept Test Series

The Israel Missile Defense Organization (IMDO) of the Directorate of Defense Research and Development (DDR&D) and the U.S. Missile Defense Agency (MDA) successfully completed a test series of the David's Sling Weapons System, a missile defense system that is a central part of Israel's multi-layer anti-missile array.

This test series, designated David's Sling Test-5 (DST-5) was the fifth series of tests of the David's Sling Weapon System. This test series was conducted at Yanat Sea Range, operated out of Palmachim Air Base, Israel.

"This test campaign is a critical step in ensuring Israel has the capability to defend itself from a very real and growing threat," said U.S. Missile Defense Agency Director Vice Adm. Jim Syring. "We remain strongly committed to supporting Israel's development of a missile defense system."



Source: MDA

The test examined capabilities and performance of the entire David's Sling Weapon System. Threat-representative targets were launched and successfully intercepted by Stunner missiles. The Multi-Mission Radar (MMR) detected the target after launch and transferred flight information to the Battle Management Center (BMC), which calculated the defense plan. The interceptors were successfully launched, performed all flight phases and engaged the targets as planned. Preliminary analysis indicates that test objectives were successfully achieved.

The information collected during the test is being analyzed by program engineers and will be used for ongoing development and fielding of the David's Sling Weapon System. This test series provides confidence in future Israeli capabilities to defend against large-caliber rockets and other developing threats.

The prime contractor for the David's Sling Weapon System Program is Rafael Advanced Defense Systems, with Raytheon Missile Systems as a sub-contractor. The MMR is developed by Elta, a subsidiary of Israel Aerospace Industries. The BMC, known as the Golden Almond, is developed by Elisra, an Elbit subsidiary.

DARPA's Spectrum Collaboration Challenge: Let the Games Begin!

Unveiled in March 2016, DARPA's Spectrum Collaboration Challenge has reached an early milestone by choosing 30 contenders for the first of the three-phase competition, slated to culminate at the end of 2019 with a live match of finalists who have survived the two preliminary contests. In addition to 22 teams from academia and small and large companies, eight individuals have made it into the competition.

The Spectrum Collaboration Challenge (SC2) aims to ensure that the exponentially growing number of military and civilian wireless devices will have full access to the increasingly crowded electromagnetic spectrum. Competitors will reimagine spectrum access strategies and develop a new wireless paradigm in which radio networks will autonomously collaborate and reason about how to share the RF spectrum, avoid interference and jointly exploit opportunities to achieve the most efficient use of the available spectrum. SC2 teams will develop these breakthrough capabilities by taking advantage of recent advances in artificial intelligence (AI) and machine learning, and the expanding capacities of software-defined radios. Ultimately, this competition aims not only to challenge innovators in academia and business to produce breakthroughs in collaborative AI, but also to catalyze a new spectrum paradigm that can help usher in an era of spectrum abundance.

Six of the chosen teams for the first preliminary competition earned their slots in the "Proposal Track," which includes $500,000 of contract funding. Twenty-four teams, including all of the individual contenders, are participating by way of the "Open Track," which means they had to pass technical hurdles specified by SC2 organizers but will pay their own costs. A total of 113 candidates vied for a spot via the Open Track option.

"SC2 sets out to bring the software defined radio and artificial intelligence communities together to fundamentally rethink 100 years of spectrum practice, and tackle the original and enduring spectrum grand challenge: efficient coexistence of all wireless communications," said Paul Tilghman, a program manager in DARPA's Microsystems Technology Office and administrator of the Spectrum Collaboration Challenge. "I'm excited to see these two communities combine their efforts to take on such an important problem. The teams participating in Phase 1 are all well-poised to see this vision through to fruition."

All 30 of the chosen teams now will have to meet several requirements throughout the year to prepare for the Preliminary Event #1 Competition this December. A still to be specified number of top-performing teams in this first phase of the competition will receive $750,000 and will automatically proceed to the second phase of SC2, which will end with another similarly run preliminary competition in December 2018. The finale will take place at

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the end of 2019 with prizes of $2 million, $1 million and $750,000 going to the top three finishers, respectively.

NextGen Aegis BMD System Successfully Engages Medium Range Ballistic Missile Target

The USS JOHN PAUL JONES, supported by the U.S. Navy, Missile Defense Agency and Lockheed Martin, used the latest evolution of its Aegis Combat System to detect, track, engage and launch a missile to intercept a Medium Range Ballistic Missile target.

This exercise marked the first shipboard demonstration of the Aegis Baseline 9.2 (BMD 5.1) Ballistic Missile Defense (BMD) tracking and engagement capabilities against more complex threats with increased battle space in support of the U.S. Phased Adaptive Approach to protect Europe from ballistic missile attack.

The test, called Standard Missile-3 Block IIA Cooperative Development Flight Test Maritime – 1 (SFTM-1), demonstrated the integrated capabilities of the Aegis Weapon System and how it has continually evolved to counter advanced threats. SFTM-1 is a development test that supports BMD 5.1 certification expected in 2018.

U.S. Navy Photo

BMD 5.1 is the third generation of Aegis BMD capability and delivering the program to the Navy and the Missile Defense Agency is critical. Under this baseline configuration, Aegis merges BMD and anti-air warfare into its Integrated Air and Missile Defense (IAMD) capability using commercial-off-the-shelf and open architecture technologies.

This test builds upon joint research investments by the United States and Japan. Lockheed Martin is developing a Baseline 9/ BMD 5.1 variant computer program, referred to as J7, for deployment on Japan's Aegis destroyers. This test also builds on prior Baseline 9 successes, when Aegis demonstrated its advanced IAMD capabilities and was certified by the Navy and Missile Defense Agency. As the targets and threats have become more advanced, Aegis BMD has evolved over the last 20 years from a tracking experiment to today's capability in which it can detect, track and engage targets.

EPSRC Grant to Develop GaN-on-Diamond Microwave Technology

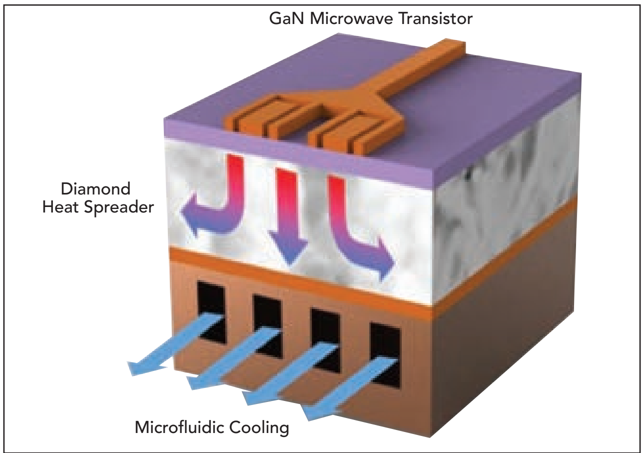
The University of Bristol has been awarded a £4.3 million grant from the Engineering and Physical Sciences Research Council (EPSRC) to lead an important new project to develop Gallium Nitride-on-Diamond microwave technology.

This next generation technology will underpin future high power radio frequency and microwave communications, space and defence systems, paving the way towards 5G and 6G mobile phone networks and much more comprehensive radar systems. Bristol will work with a consortium of four other UK universities (Cardiff, Glasgow, Cambridge and Birmingham) and leading industry partners during this five-year project.

The vision of this new project is to develop transformative GaN-on-Diamond High Electron Mobility Transistors (HEMT) and Monolithic Microwave Integrated Circuits (MMIC), the technology step beyond current microwave devices. These devices will allow the implementation of future communications networks and radar systems with capabilities beyond what is presently possible.

The outcome will be devices with a spectacular > 5x increase in RF power compared to the current state-of-the-art GaN-on-silicon carbide HEMTs, presently commercially available. Alternatively and equally valuable, a dramatic 'step-change' shrinkage in MMIC or power amplifier (PA) size is possible, delivering an increase in efficiency through the removal of combining networks as well as a reduction in power amplifier cost.

This represents a disruptive change in capability that will allow the realization of new system architectures—for example, for radio frequency seekers and medical applications, and enable the bandwidths needed to deliver 5G and beyond. Reduced requirements for cooling/increased reliability will result in major cost savings at the system level.



Ultra-high power GaN-on-Diamond microwave device transforming communication and radars.

First 5G Federated Network Slicing Grants Global Reach

Deutsche Telekom (DT), Ericsson and SK Telecom have jointly built and demonstrated the world's first intercontinental 5G trial network. DT and SK Telecom network slices are now available in the other operator's footprint, and Germany and Korea are connected. A proof-of-concept has been implemented and successfully evaluated, featuring the creation and roaming extension of network slices optimized for Augmented Reality (AR) and maintenance services.

The successful demonstration was hosted at DT's corporate R&D centre in Bonn, Germany and SK Telecom's 5G Testbed at Yeoungjong-do (BMW driving centre), South Korea.

In 5G, network slicing will allow the operator to configure an end-to-end network that provides the desired overall functionality and service parameters. Federated network slicing for 5G roaming extends this concept to a visited network. This technology will make it possible for an operator to provide a network service globally, making sure that the customer does not need individual agreements with different operators for a global service experience.

"Our customers are demanding global connectivity with a unified service experience," said Bruno Jacobfeuerborn, CTO Deutsche Telekom. "Network slicing is envisaged as a key enabler to support multiple services in the 5G era. Today's breakthrough shows we can extend that concept to ensure optimized service experiences with global reach for our customers."

Ulf Ewaldsson, senior vice president, chief strategy and technology officer at Ericsson said, "5G is the network for all industries. Network slices in the context of 5G will be like 'virtual networks on-demand.' With this world's first intercontinental 5G trial network, we truly demonstrate the provisioning of network slices to global customers when abroad."

Saab and Aalto University Sign Cooperation Agreement

Saab and Aalto University, Helsinki, Finland, have signed an agreement for a 10-year programme with the aim of strengthening their research cooperation, especially in long-term sensor technology research. They have been working together in this field for some time, and the newly signed agreement, which has a total value of approximately €20 million, further strengthens this cooperation.

Aalto's partnership with Saab focuses on future technologies, while Saab is especially interested in

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developing radio and signal processing technologies, which are among Aalto University's core strengths.

The scientific inquiry concentrates on the development of cognitive systems, microwave systems and sensor technologies, as well as hydroacoustics. The emphasis is on long-term sensor technology development. During the 10-year agreement period, the collaboration programme is expected to be expanded with new topics.

"With the collaboration with Aalto University, Saab will strengthen our cutting edge technological expertise in sensors and communications. Our sensor technology is at the top of its class, and we want to remain continuously ahead of the field. We expect the collaboration to give us new technology to support our research and development. The collaboration also aims to strengthen the Finnish industrial ecosystem and international visibility in this field," said Håkan Buskhe, president and CEO of Saab.

SmallGEO's First Flight Reaches Orbit

The European Space Agency's (ESA) new small telecom platform has been launched. The Hispasat 36W-1 satellite, based on the SmallGEO platform, lifted off on a Soyuz from Europe's Spaceport in Kourou, French Guiana. The three-tonne satellite will provide broadband services to Europe, South America and the Canary Islands.

SmallGEO is Europe's response to the market demand for more flexible, modular telecommunications platforms. It marks the first time the German satellite manufacturing company OHB System AG has been the prime contractor for a telecommunications satellite mission and its Hispasat payload marks the first ESA partnership with a Spanish operator.

> "...flexible, modular telecommunications platforms."

"The launch of this first SmallGEO platform marks another major success for ESA's programme of Advanced Research in Telecommunications Systems, known as ARTES, which aims to boost the competitiveness of its Member State industry through innovation," noted Magali Vaissiere, ESA's director of telecommunications and integrated applications.

Carlos Espinós Gómez, CEO of Hispasat, said, "Hispasat 36W-1 is not only the first mission of the new SmallGEO platform, but also incorporates an advanced regenerative payload that will provide the satellite with greater flexibility and signal quality thanks to its reconfigurable antenna and onboard processor, thus improving the telecommunications services it will provide to our clients."

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CMA-82+	DC-7	15	20	42	6.8	5	8.95
CMA-84+	DC-7	24	21	38	5.5	5	8.95
CMA-62+	0.01-6	15	19	33	5	5	7.45
CMA-63+	0.01-6	20	18	32	4	5	7.45
CMA-545+	0.05-6	15	20	37	1	3	7.45
CMA-5043+	0.05-4	18	20	33	0.8	5	7.45
CMA-545G1+	0.4-2.2	32	23	36	0.9	5	7.95
CMA-162LN+	0.7-1.6	23	19	30	0.5	4	7.45
CMA-252LN+	1.5-2.5	17	18	30	1	4	7.45

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Surging Wi-Fi Traffic and IoT Applications to Spike Wireless IC Shipments

Short-range wireless connectivity market technologies—including ZigBee, Thread, Bluetooth Low Energy (BLE), Z-Wave, Wi-Fi and NFC—will continue to evolve to meet new market demands, as evident with various new and upcoming enhancements. These include Bluetooth 5 and Bluetooth Mesh, the ZigBee Alliance's reveal of dotdot language for the IoT, Wi-Fi HaLow (802.11ah), WiGig (802.11ad), new Z-Wave security enhancements and the growth of ICs that combine several of these connectivity solutions.

"The proliferation of multi-protocol ICs and devices will allow for much simpler product creations and quicker times to market regardless of the deployed technology," says Andrew Zignani, industry analyst at ABI Research. "A prime example is Qorvo's recent GP695 SoC product announcement that integrates multiple communication protocols, including IEEE 802.15.4, ZigBee and BLE. The technology collaboration reduces complexity for IoT device designers by enabling them to take advantage of a single SKU development platform."

> Multi-protocol ICs and devices enable simpler product creations and quicker times to market.

Specifically, Bluetooth 5 speed enhancements will benefit wearables and other handheld devices that will sport quicker performance times, quicker data transfers and syncing and faster firmware updates, all while keeping power consumption down. The higher speeds will also lead to improvements in future wireless audio applications. Mesh, which Bluetooth SIG remains set to standardize in 2017, will become increasingly vital to the support, creation and enhancement of use cases that include smart lighting control, building automation and condition monitoring. Mesh will help enable Bluetooth to compete in areas in which other technologies previously held the competitive advantage.

Wi-Fi's continued evolution will come in the form of several new protocols. 802.11ax will focus on overall network efficiency improvements rather than simply boosting peak speeds. 60 GHz WiGig (802.11ad) will improve Wi-Fi's suitability for 4K streaming, docking and VR applications. The sub-1 GHz HaLow standard (802.11ah) will open up new opportunities in low-power and in an extended range of IoT applications.

Wi-Fi chipsets that incorporate 802.11ax, WiGig or HaLow technologies will make up 60% of wireless IC shipments by 2021. Both WiGig and HaLow represent a new direction for Wi-Fi and will face unique challenges in creating a new ecosystem in different bands.

mHealth Wearables Boost Patient Healthcare Both Inside and Outside the Hospital

A surge in healthcare patient monitoring wearables will soon help reduce readmission risks and better prevent the occurrence of serious medical traumas, alleviating growing performance pressures on healthcare services. ABI Research forecasts the patient monitoring wearable market, which includes remote and on-site devices, will grow from 8 million shipments in 2016 to 33 million in 2021. Device types are diverse and include staples like blood pressure monitors, continuous glucose monitors and pulse oximeters, as well as newer devices like Fatigue Science's fatigue monitoring wearable.

"While previously professional-grade patient monitoring largely limited itself to a doctor's rounds, new wearables allow medical professionals to remotely and continuously monitor patients in the hospital and beyond," says Stephanie Lawrence, research analyst at ABI Research." The devices send real-time alerts regarding any condition deteriorations or fluctuations, in effect reducing response times to potentially life-threatening changes and saving the healthcare system resources in the long term."

On-site professional healthcare monitoring wearables, such as those by Philips Healthcare, allow medical professionals to work with a larger base of patients, as the devices continuously update doctors throughout the day on patients' vitals and overall conditions without the need for physical check-ins. The wearables also, in effect, help to ensure that doctors do not overlook any slight changes in condition before granting patients release.

> Remote patient monitoring devices will see strong growth of nearly 35 percent by 2021.

Beyond the hospital, remote patient monitoring wearables, such as blood pressure monitors and telemedicine products by A&D Medical, then provide healthcare professionals with continued access to their patients' health, which would have otherwise been inaccessible once they left the confines of the hospital. As such, doctors can now, like with on-site treatment, monitor their patients' conditions and better diagnose any treatment adjustments necessary on the path to recovery.

A&D Medical, Medtronic, Nonin Medical and Philips Healthcare lead the market, while start-ups like Fatigue Science, Health Care Originals and Qardio are beginning to challenge the incumbents and diversify the competitive landscape in offering solutions to treat specific medical conditions.

For More Information

Visit mwjournal.com for more commercial market news.

Automotive Cellular V2X Communications to Challenge IEEE 802.11p/DSRC Standard

With the LTE-V2X (LTE vehicle-to-everything) standard finalized and 5G standardization impending, the use of cellular technology for low-latency Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) applications is now a realistic prospect—one that will challenge the legacy IEEE 802.11p Dedicated Short-Range Communications (DSRC) standard. Autonomous level 4 and driverless level 5 vehicles will require V2V and V2I capabilities to achieve ultra-high reliability levels with carriers like Deutsche Telekom, Orange, SK Telecom, Telefonica and Vodafone already performing trials on automotive 4G and/or 5G use cases.

"The evolutionary path offered by cellular technologies and their large supporting mobile ecosystem is an attractive option for automotive suppliers and OEMs eager to execute early implementations of autonomous functionality," says Dominique Bonte, managing director and vice president at ABI Research. "While cellular antagonists claim DSRC is more mature, reliable, secure and ready to deploy, it remains to be seen whether it will survive the onslaught of the cellular ecosystem or continue to coexist with future cellular alternatives."

The legacy IEEE 802.11p DSRC standard allows reliable low latency communication of basic safety messages between vehicles and between vehicles and roadside infrastructure. While a DSRC mandate seems imminent in the U.S., ABI Research expects cellular V2X to show steady growth, initially through LTE-V2X, reaching 300 million global subscriptions by 2030. At that point, 5G V2X will surpass it. Longer term, automotive OEMs will start to offer network-based low-latency, end-to-end automotive services.

> Cellular ecosystem powerhouses will lobby for significant spectrum share despite legacy DSRC reservations.

"The main challenge for cellular V2X is to get hold of dedicated spectrum needed for the Device-to-Device, or D2D, V2V protocol," concludes Bonte. "While the intelligent transportation systems spectrum in the 5.9 GHz band was made available in the U.S., Europe and other regions more than a decade ago, it remains reserved for DSRC. But this could change if, or more likely when, cellular giants like Ericsson, Qualcomm and Samsung, unite and fight for lobbying power."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Keysight Technologies Inc. and **Ixia** announced a definitive agreement for Keysight to acquire Ixia in an all-cash transaction of approximately $1.6 billion, net of cash. The boards of directors of both companies unanimously approved the transaction, which is expected to close by the end of October 2017. The deal must be approved by Ixia shareholders and requires government anti-trust review. Ixia shareholders will receive $19.65 per share in cash, a premium of approximately 45 percent to Ixia's closing stock price on December 1, 2016 — the last trading day prior to media reports that Ixia was considering strategic alternatives.

MACOM Technology Solutions Holdings Inc., commonly known as **MACOM**, completed its acquisition of **Applied Micro Circuits Corp.** on January 26, 2017 for approximately $770 million. The acquisition strengthens MACOM's portfolio for the data center market, adding OTN framers, MACsec Ethernet networking components and a single-lambda PAM4 platform. MACOM will not retain all of Applied Micro's products and plans to divest the compute segment, which is not aligned with MACOM's strategy for the optical market.

JADAK LLC, a global leader and supplier of Radio-frequency Identification (RFID), optical data collection and machine vision technologies, announced it has acquired the assets of **ThingMagic** (formerly a Division of Trimble). ThingMagic, based in Woburn, Mass., provides Ultra High Frequency (UHF) RFID Reader Modules and Finished RFID solutions to original equipment manufacturers (OEM) for a wide range of applications, including in the medical, retail, logistics and airline industries. RFID technology has emerged over the last decade as an efficient means of detecting and tracking retail products, medical consumables, airline baggage and many other types of tangible goods.

ETI Tech Inc., of Dayton, Ohio, was acquired by majority investor **Soaring Pine Capital** (SPC), a Simon Group Holdings (SGH) company in Birmingham, Mich. Founded in 1996, ETI is a provider of more than 200 flight hardware parts for military aircraft and ground support equipment for the aerospace defense industry for fixed and rotary wing aircrafts, and unmanned aerial vehicles, including the F-35, C-130, F-16 and C-5B, among others.

COLLABORATIONS

Qualcomm Inc. and **TDK Corp.** announced the completion of the previously announced joint venture under the name RF360 Holdings Singapore PTE. Ltd. (RF360 Holdings). The joint venture will enable Qualcomm's RFFE Business Unit to deliver RF front-end (RFFE) modules and RF filters into fully integrated systems for mobile devices and fast-growing business segments, such as Internet of Things (IoT), automotive applications, connected computing, and more. The business being transferred constitutes a part of the TDK SAW Business Group activities.

Huawei, together with **China Unicom Group**, completed field verification of the industry's first FDD-based massive MIMO technology using the existing two-antenna receiving terminal and 20 MHz of spectrum. With the rapid development of mobile Internet applications, such as high-definition video and online games, massive broadband (MBB) networks face a huge challenge in capacity. Massive MIMO can help operators greatly enhance wireless network capacity and user experience by maximizing existing sites and spectrum resources. Massive MIMO is one of the key solutions for Huawei's 4.5G Evolution.

IBM and **Ericsson** have created a compact silicon-based millimeter wave (mmWave) phased array integrated circuit operating at 28 GHz that has been demonstrated in a phased array antenna module designed for use in future 5G base stations. This research breakthrough could accelerate the launch of 5G communications networks and support new mobile enterprise and user experiences enabled by very high data rates, including IoT, connected vehicles and immersive virtual reality. 2017 has been described as a defining year for 5G.

Telit is collaborating with **Yokogawa**, a global leader in the industrial automation and control, test and measurement, aviation and other business segments, on a brand new Industrial Internet of Things architecture created with the goal of propelling Yokogawa's business model into a connected future. By combining Telit's robust technological portfolio of communication modules, sensor onboarding, and device management capabilities with their 100+ years of experience in providing devices, analytical instruments, and other industrial solutions, Yokogawa will be able to create new value for its customers.

NEW STARTS

Signal Integrity Journal, a new sister publication to ***Microwave Journal*** covering signal integrity, power integrity and EMC/EMI related topics, has secured seven sponsors to start the new year. The Platinum Level sponsorships are sold out for 2017 with industry leaders Rohde & Schwarz, Anritsu, Mentor Graphics and CST filling the top sponsorship level. Joining them are Cadence and Samtec at the Gold Level and Passives Plus at the Silver Level. Six Gold and nine Silver Level sponsorships are still available. Each sponsorship level is 12 months in duration and includes a website banner ad, e-newsletter sponsorships, Buyer's Guide enhanced listing, sponsored content positions and webinar(s). Other sponsorship options are available.

ACHIEVEMENTS

Analog Devices Inc. announced that the company has been honored with the 2017 IEEE Corporate Innovation Award "for sustained innovation and leadership in

For More Information

For up-to-date news briefs, visit mwjournal.com.

the development of high-performance data converter technology and products." This award was established in 1985 to recognize outstanding innovation by organizations across the world, and recipients are honored for their resolve to discover, extend, or complement technological advancements in education, industry, research and service in IEEE fields of interest.

Inmarsat announced a key infrastructure milestone for its European Aviation Network (EAN), following the successful test and validation of the EAN Satellite Access Station (SAS). This makes it the first solution in the world to integrate connectivity from a satellite, operated by Inmarsat, and a LTE-based ground network, operated by Deutsche Telekom. EAN will now be able to provide a true in-flight broadband experience for millions of airlines passengers travelling throughout Europe. The SAS (Satellite Access Station) is located in Nemea, Greece and operated under an agreement with OTE, the largest telecommunications provider in Greece and member of the Deutsche Telekom Group.

CONTRACTS

Boeing and **Jeju Air** announced an order for three Next-Generation 737-800s. The order, valued at nearly $300 million at current list prices, will become the airline's first direct-purchased airplanes from Boeing and will fuel the airline's continued expansion within Asia's rapidly growing air travel market. The order was previously attributed to an unidentified customer on Boeing's Orders & Deliveries website.

The **U.S. Navy** awarded **Raytheon Co.** $235 million for Standard Missile-6 all-up round production missiles and spares. Raytheon will begin delivery in 2018. The missiles will be deployed on Aegis cruisers and destroyers to support U.S. Navy fleet operations. The award funds the fourth year of full-rate production for the multi-mission missile, which recently accomplished significant testing milestones and achievements. The contracted missiles will include an anti-surface capability, which was demonstrated in early 2016 during a highly successful tactical demonstration event off the coast of Kauai. The SM-6 also set a new record for maximum down-range and maximum cross-range intercepts in over-the-horizon missions.

Elbit Systems Ltd. announced that a Brazilian subsidiary, **Ares Aeroespacial e Defesa S.A.**, was awarded a framework contract, in a total value of approximately $100 million, to supply 12.7/7.62 mm Remote Controlled Weapon Stations (RCWS) to the Brazilian Army. The contract includes associated equipment and services. The RCWS, named REMAX, will be supplied over a five-year period. An initial production order, valued at approximately $7.5 million, has been received. Specifically designed by Ares to meet Brazilian Army requirements as part of the VBTP program, Ares' REMAX systems have been successfully tested and fielded in Brazilian Army Guarani 6x6 vehicles.

Around the Circuit

Harris Corp. has been awarded a $91 million IDIQ contract by **Warner Robins Air Logistics Center** to provide AN/ALQ-211 Advanced Integrated Defensive Electronic Warfare Suite (AIDEWS) systems to the Royal Moroccan Air Force (RMAF). The contract was awarded during the second quarter of Harris' fiscal 2017. Harris will supply AIDEWS systems, spares and support equipment and services to Morocco to help protect the RMAF F-16 aircraft fleet against current and evolving electronic threats. The combat-ready ALQ-211(V)4 EW system is a low-risk, modular solution that provides powerful capabilities and mission-based adaptability that have made it the top choice for 5 other international allies.

Phonon Corp. has received a $7.2 million order from a leading defense prime contractor for SAW radar pulse compression modules, for 2017 and 2018 delivery, for an air defense system. Phonon Corp. designs and builds custom SAW devices and modules for defense and space.

Mercury Systems Inc. announced it received a $2.4 million follow-on order from a leading defense prime contractor to supply frequency conversion modules for an Electronic Warfare (EW) service life extension program. The order was booked in the company's fiscal 2017 second quarter and is expected to be shipped over the next several quarters.

Antenna Systems Solutions S.L. (Celestia Technologies Group) announced that it has won a contract to supply a high accuracy positioning system for an RCS measurement project to **Thales UK** in Wells. A string reel positioning system and a curved floor arch will be used for state of the art radar cross section measurements of scaled models. This solution is based on ASYSOL's state of the art positioners and automated slides.

Defence and security company **Saab** has received a contract for production and delivery of the man-portable weapon system Carl-Gustaf. The order value is approx. MSEK 334 and deliveries will take place during 2017. The order will be booked in the fourth quarter 2016. The contract includes weapon systems of the Carl-Gustaf M3 version. The industry's nature is such that depending on circumstances concerning the product and customer, further information regarding the customer will not be announced. Saab's world-leading weapon system Carl-Gustaf has a long and distinguished service history all around the world.

Starting in 2018, **Thales** will provide French forces up to 210 mini reconnaissance UAVs. The Spy'Ranger is the new 'eye in the sky' for the combined arms tactical group, able to be operated in a standalone mode or connected to a C4I system. The Spy'Ranger is specifically tailored to the needs of the armed forces, as well as to those of essential operators.

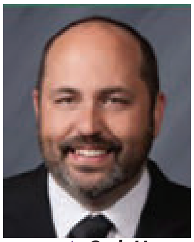
PEOPLE

▲ *Herbert Merz*

Radio Frequency Systems (RFS), a global designer and manufacturer of cable, antenna and tower systems providing total-package solutions for wireless and broadcast infrastructure, has appointed **Herbert Merz** as the company's new president and chief executive officer. Merz will assume global leadership responsibilities effective immediately. Herbert Merz brings a deep level of business knowledge with 15 years of experience in the telecommunications industry.

Skyworks Solutions Inc. announced that **Steven C. Machuga** has been promoted to vice president of worldwide operations for Skyworks. Machuga has been with the company since 1999 and most recently served as Skyworks' vice president of external manufacturing and operations engineering. During his years at Skyworks, he has held positions of increasing responsibility in process and product development, operations strategy and execution. Prior to joining Skyworks, Machuga worked for Motorola in various semiconductor engineering and manufacturing management roles.

The board of directors of **Raytheon Co.** has elected **James A. "Sandy" Winnefeld Jr.** as a director, effective immediately. Winnefeld, 60, is a retired United States Navy admiral who served as the ninth Vice Chairman of the Joint Chiefs of Staff. He previously served as Commander, U.S. Northern Command (USNORTHCOM) and Commander, North American Aerospace Defense Command (NORAD). Winnefeld's operational commands include serving as Commander, U.S. Sixth Fleet and Commander, Allied Joint Command Lisbon. He retired from the Navy in 2015 after over 37 years of service. Winnefeld graduated from the Georgia Institute of Technology with a Bachelor of Science degree in Aerospace Engineering and received his commission via the Navy Reserve Officer Training Corps program.



▲ *Seth Homer*

Indium Corp. has hired **Seth Homer** as product manager for Engineered Solders – IGBT. Homer will specialize in the power electronics markets for engineered solders, including automotive, renewable energy, industrial motor drives and consumer appliances. Homer worked for Indium Corp. for nearly 25 years prior to taking a one-year break. He recently rejoined the company to take on this new role.

AtlanTecRF has appointed **Mike Andrioff** as its new North American sales manager who will be responsible for expanding the company's North American business with a specific focus on growing its already successful Satcom RF Testing Equip-

ment sales. His expertise includes general manager and director of sales at Amawave Inc., new business development manager at Micro-Coax Inc. and an RF & Petro-Chemical Cable sales engineer at Meggitt Safety Systems. Andrioff has also worked in the U.S. Navy on Weapon Systems Electronics and holds an MBA from San Diego State University.

REP APPOINTMENTS

Anokiwave Inc., an innovative company providing highly integrated IC solutions for mmW markets and active antenna based solutions, announced that they have signed a representative agreement with **InResonance** in Sweden. The agreement aligns with Anokiwave's goal to support new customers and opportunities for its highly-integrated Active Antenna Core IC solutions in Sweden. InResonance has a wide experience in both microwave design as well as sales and marketing and is focused on the Swedish wireless market, specializing on in-design of RF and microwave components of strategic importance.

International Manufacturing Services announced the appointment of **Fahrner-Miller Associates** (FMA) as the exclusive sales representative for northern California and northern Nevada. FMA will be instrumental in helping IMS strengthen and extend its presence in this region. FMA's extensive expertise in increasing market share and market presence fits nicely with IMS' strategic plan for the territory. FMA founded in 1975, is a full service, technically trained sales organization. Their focus is to provide manufacturers with sales, marketing and branding expertise focusing on networking, medical, smart energy, military and wireless/RF markets.

Modelithics Inc. announced a new representation partnership with **Aktif Neser Elektronik Ltd.** in Istanbul, Turkey for regional sales of Modelithics' simulation model library and high frequency precision measurement and consultation services. Larry Dunleavy, president and CEO of Modelithics, and Neslihan Yasav, managing director of Aktif Neser Elektronik, have signed a representation and reseller agreement for new business in Turkey. Aktif Neser Elektronik will offer sales and coordination of support for Modelithics' exceptional RF and microwave simulation model libraries and measurement services in the representation area.

Wireless Telecom Group Inc. announced an agreement with **AR Europe** for the distribution of its Boonton Electronics and Noisecom products throughout Europe. AR Europe's RF expertise and instrumentation experience along with their sales and distribution reach will place the full Boonton and Noisecom product portfolios of RF power meters, USB power sensors, and noise generation devices in front of design and test engineers, system integrators and field service technicians across Europe. Wireless Telecom Group is committed to working with Europe to provide the highest quality customer service, technical support and RF instrumentation solutions.

EDI CON 2017 Electronic Design Innovation Conference 电子设计创新大会 CHINA

EDI CON China Comes to Shanghai

Janine Love, Technical Program Director, EDI CON China 2017

In its fifth year, EDI CON China 2017 will take place April 25-27, at the Shanghai Convention & Exhibition Center of International Sourcing in Shanghai, China. This year's event promises to bring its renowned learning and training opportunities to engineers in the Shanghai area, while offering a show floor of exhibitors demonstrating the latest in RF, microwave and high-speed digital products and services during the three days of the conference.

As the new technical program director for EDI CON China 2017, I am responsible for programming the conference sessions, workshops and plenary talks for this year's event. The technical program features sessions selected from abstracts submitted through our Call for Papers process. In addition to my work on EDI CON China, I am also event director for EDI CON USA and a contributing editor to *Microwave Journal*, *Microwave Journal China*, and the new *Signal Integrity Journal*. I look forward to seeing you in Shanghai. Here are some highlights of what we have planned:

Day one of the conference will begin with in-depth technical workshops followed by the opening plenary session. The keynote speaker will be Peter Rabbeni, senior director, RF BU business development and product marketing at GLOBALFOUNDRIES. Recognized as a global thought leader in semiconductor technologies, Rabbeni will bring his insights to bear on the latest developments in semiconductor technology and how they can support the latest design needs and market trends for RF and high-speed digital applications. The plenary session will also feature insightful talks from representatives of Keysight Technologies, Rohde & Schwarz and National Instruments. Keysight's Satish Dhanasekaran, general manager & vice president, wireless devices & operators industry solutions, will specifically address design challenges in deploying mmWave frequencies for commercial use.

The afternoon will provide simultaneous technical presentations from different technical tracks, allowing attendees to specialize in their conference experience and ask industry experts specific questions. Planned tracks for this year's event include: RF & Microwave Design, High-Speed Digital Design, Measurement & Modeling, Systems Engineering, 5G Advanced Communications, EMC/EMI, IoT Design, Radar Communications and Semiconductors. After a tea break on the exhibition floor, the conference day will end with in-depth training in 40-minute workshops followed by a welcome reception from 6 to 8:30 p.m. sponsored by Keysight Technologies. Days two and three of the conference will also include in-depth technical workshops and technical sessions.

Current workshop sponsors include: CST, Focus Microwaves, Keysight Technologies, Maury Microwave China, Mini-Circuits, National Instruments, Richardson RFPD, Rohde & Schwarz (China) Technology Co. Ltd., Sichuan YiFeng Electronic Science & Technology Co. Ltd., Xiamen San'an Integrated Circuit Company Ltd. and Ampleon.

EDI CON China 2017 will also feature panel discussions that focus on critical industry topics. This year's planned panels include, "Which Technology is Better for the First 5G Systems: Massive MIMO sub-6 GHz or mmWaves?" Moderated by *Microwave Journal* editor Patrick Hindle, this panel will compare the advantages and disadvantages of massive MIMO sub-6 GHz and mmWave 5G next generation cellular systems. Attend this event to hear what panel experts think are the advantages and disadvantages of each system. At the end of the session, the audience will vote for which technology will be used first.

Another panel, "Trends in Mobile Infrastructure," moderated by *Microwave Journal* technical editor Gary Lerude, will explore the impact of the latest mobile network protocols on the base station transmitter, including inroads by GaN vs. LDMOS and which flavor of GaN is winning (silicon or SiC).

In a special session, the RF Energy Alliance's Klaus Werner will speak on "Solid-State RF Energy in 2017: The Volume Breakthrough Is Finally There, Is It Not?," followed by a panel of industry leaders for discussion and questions regarding RF energy.

EDI CON China 2017 will once again partner with the China Radar Industry Association (CRIA) Conference. This successful partnership began at EDI CON China 2016, and continues with specialized radar technical sessions over the three days of the conference. In addition, EDI CON China 2017 is partnering with Universal Prosperity Exhibition & Convention (Beijing) Co., Ltd. (UPEC) to present an EMC Forum with presentations across all three days, focusing on medical, automotive and EMC technology topics.

This year EDI CON China 2017 will also host two 5-hour training sessions from the American Certification Body (ACB) Inc. The training will provide education for Chinese test engineers, R&D personnel as well as certification/regulatory professionals in the wireless/RF and EMC industries. Day one will be 5-hour regulatory training focused on basic knowledge of FCC/ISED/CE rules and current updates to the regulations. Day two will be a 5-hour session on iNARTE EMC training, providing EMC fundamentals to help attendees prepare for the iNARTE EMC exam. All of these special partner programs are available in the EDI CON China 2017 registration portal.

We have a great deal of technical information and training planned for you in Shanghai this April, as well as exciting demonstrations and new products on the exhibition floor. Registration is open, and hotels are now available. We look forward to seeing you in Shanghai!

Tuesday, April 25, 2017

Time	Room 305A	Room 305B	Room 307A	Room 307B	Room 302A	
08:00 - 17:00	**Registration On Site**					
	Workshops					
09:20 - 10:00	**Sponsored Workshops**					**Exhibit Hall Open 10:00 - 17:30**
10:00 - 10:20	**Tea Break (Exhibit Hall)**					
10:30 - 12:00	**Plenary Session Room 302: Featuring Keynote Speaker Peter Rabbeni, GLOBALFOUNDRIES. Guest Speakers: Satish Dhanasekaran, Keysight Technologies; Corbett Rowell, Rohde & Schwarz; Jason White, National Instruments.**					
12:00 - 13:00	**Lunch Break**					
	Technical Sessions					
	5G	**Test & Measurement**	**Radar/Communications**	**Amplifiers**	**RF/Microwave**	
13:00 - 13:20	TU_101: Polar Code for 5G Mobile Communication *(24) Shi Xiaofeng, Rohde & Schwarz*	TU_102: Advanced Materials Measurement Techniques for Permittivity and Permeability *(5) Ryoji Takizawa, Keysight*	TU_103: Microstrip Component Based Leakage Canceller Circuit For FMCW Radar Applications *(52) Anjali Lahoti, Keysight*	TU_104: High Linear CMOS Power Amplifier and Tracker for LTE Advanced Applications *(4) Florinel Balteanu, Skyworks*		
13:25 - 13:45	TU_201: Ultra-Wideband Signal Phase and Amplitude Calibration Method for High Performance 5G mmWave Device Testing *(35) Ryoji Takizawa, Keysight*	TU_202: De-Skew, Gating, Fixture Removal, and Correlation Analysis *(66) David Feng, Molex*	TU_203: EM/Circuit Co-Simulation of T/R Front-End Module and Actively Scanned Antenna Array *(44) Milton Lien, AWR*	TU_204: A Novel Impedance Flattening Network for Wideband Doherty Power Amplifier at 3.4 to 3.8 GHz *(82) Rui Ma, Mitsubishi Electric Research Labs*	TU_205: Embedded Thin Film Planar Resistors in 5G Power Dividers for Improved High Speed Signal Integrity *(19) Helena Li, Shanghai Gentronics Electronics. Ltd.*	
13:50 - 14:10	TU_301: MIMO OTA Certification Testing Solution: Multi-Probe Method *(71) Andy Zhang, Hwa-Tech Information System Co.*	TU_302: New Method for Debugging Crosstalk Issues in Your Design *(40) Min-Jie Chong, Keysight*	TU_303: RF Environment Generation for Radar and Receiver Test *(99) Steffen Heuel, Rohde & Schwarz*	TU_304: A Design of High Efficiency GaN on Si 3 Way Doherty Amplifier for Base Station Application *(116) Xin Liu, MACOM*	TU_305: Solid-State RF Energy in 2017: The Volume Breakthrough is Finally There, is it Not? *Klaus Werner, RF Energy Alliance, Presentation and Panel*	
14:15 - 14:35	TU_401: RF SOI Technology for Reliable 5G Beamforming *(92) Charles Gui, Peregrine Semiconductor*	TU_402: LNA Integration and Noise Figure Measurement at Higher Data Speeds *(51) Gu HongLiang, Keysight*	TU_403: Automotive Radar Interference Test *(100) Steffen Heuel, Rohde & Schwarz*	TU_404: The New Frontier in Solid State Power Amplifiers: The Spatial Power Amplifier *(60) Maurizio D'Antoni, University of Rome*		
14:40 - 15:00	TU_501: 5G Device Design Verification and Test Challenges *(28) Li Xin, Keysight*	TU_502: New Approach of Building RF PA/FEM Test Systems *Jianhui Wang, Keysight*	TU_503: Modeling Large Phased-Array Antenna Systems With an Advanced Behavioral Model and Simulated/ Measured Radiating Elements *(43) Gent Paparisto, AWR*	TU_504: Design of MMIC Class- E Adaptive Bias Power Amplifier with Built-In Linearizer using 0.5 µm GaAs E-pHEMT Technology *(111) Shanthi. P, R.V. College of Engineering*		
15:00 - 15:20	**Tea Break: Exhibition Floor**					
	Workshops					
	Measurement & Modeling	**5G**	**High-Speed Digital**	**Semiconductors**	**Test & Measurement**	
15:20 - 16:00	WS_TU201: From Wave-Based Load-Pull to Behavioral Nonlinear Models *(11) Focus Microwaves*	WS_TU202: Verizon 5G and 3GPP New Radio (NR) Generation and Analysis *(102) Rohde & Schwarz*	WS_TU203: Via Structure Optimization for Pre-layout PCIE Channel Design *(53) ANSYS*	WS_TU204: E-Foundry Model Provides New Opportunity *(133) Chengdu HiWafer Semiconductor*	WS_TU205: New High Performance Test Cable Assemblies, Millimeter Wave Integrated Multi-Pin Connector Harness Assemblies & Aerospace High Speed Data Master Cable Assemblies *(138) Mitron*	
16:05 - 16:45	WS_TU301: Load Pull: A Critical Tool For Model Extraction, Validation and Design *(48) Maury Microwave*	WS_TU302: Portable MIMO Testing Platform Based on the Technology of Software Defined Radio *(128) Sample Technology Shanghai*	WS_TU303: Interfacing FPGA with High-Speed Data Converter Using Parallel and Serial Interface *(108) e2V*	WS_TU304: The Future Outlook of RF GaN: Applications and Performance *(150) Richardson RFPD*	WS_TU305: Massive MIMO Prototype and MIMO OTA Test *(136) Keysight*	
16:50 - 17:30	WS_TU401: Accelerating Design Cycle Time of Key RF FEM Circuit Blocks Through Innovative Modeling Methods *(81) GLOBALFOUNDRIES*	PN_TU402-PANEL: Which Technology is Better for the First 5G Systems: Massive MIMO sub-6 GHz or mmWaves? *Moderator: Patrick Hindle, MWJ*	WS_TU403: High-Speed Simulation & Measurement *(137) CST*	WS_TU404: GaN RF Power Devices *(146) Dynax Semiconductor*	WS_TU405: Multiport Automatic Testing System Based on Switch Matrix with High Reliability *(141) Mini-Circuits*	
17:30	**Welcome Reception for Conference Delegates (Badge & Ticket Required)**					

Wednesday, April 26, 2017

	Room 305A	Room 305B	Room 307A	Room 307B	Room 302A	
08:00 - 05:00	Registration On Site					
Technical Sessions						
	Test & Measurement	Systems Engineering	IoT	5G	RF & Microwave	
09:00 - 09:20	WE_101: Techniques for Extending Microwave Frequency Measurement Instruments for mmWave Measurements *(78) Wei Lin, National Instruments*	WE_102: Addressing Multi-Channel, Wide-Band Test and Data Management in 5G *(25) Sheri DeTomasi, Keysight*	WE_103: Electromagnetic and Structural Co-Design of a Smart Watch *(91) Cier Siang Chua, CST*	WE_104: New Wireless Technologies for Tomorrow's Connected Devices *(55) David Hall, National Instruments*	WE_105: Advanced Techniques for Spurious Search in RF and Microwave Devices *(6) Martin Schmaehling, Rohde & Schwarz*	Exhibition Hours 09:00 to 17:30
09:25 - 09:45	WE_201: 802.11ax Introduction and How to Overcome the Test Challenges *(95) Xiang Feng, Keysight*	WE_202: Building a Multi-GHz Real-Time RF Streaming System *(98) Shivansh Chaudhary, National Instruments*	WE_203: Channel Emulation for RFID Baseline Test *(112) Hui Shao, JX Instrumentation Co. Ltd.*	WE_204: Compact Phased Array with Beamforming Network for 5G MIMO System at 60-GHz on Liquid Crystal Polymer Substrate *(3) Anil Kumar Pandey, Keysight*	WE_205: A Multi-Offset PLL Synthesizer with Phase Detector Noise Floor Degeneration *(29) Dr. Alexander Chenakin, Micro Lambda Wireless Inc.*	
09:45 - 10:05	Tea/Coffee Break - Exhibition Floor					
	High Speed Digital	Test & Measurement	EMC/EMI	5G	RF & Microwave	
10:10 - 10:30	WE_301: Timing Mistakes in High-Speed PCB Design *(9) Wu Jun, Edadoc*	WE_302: Novel Modeling Method Based on Field Measurement Data in OTA Chamber for UE Performance Test *(74) Huaizhi Yang, Keysight*	WE_303: Real-Time Measuring Equipment Optimized for Faster Detection of Critical EMI Signals *(18) Volker Janssen, Rohde & Schwarz*	WE_304: Introduction to 802.11ax: High Efficiency Wi-Fi *(83) Alejandro Buritica, National Instruments*	WE_305: High Performance Material Considerations for Use in Wireless Communications Infrastructure *(126) Art Aguayo, Rogers Corp.*	
10:35 - 10:55	WE_401: Fast and Accurate Measurement of PCB Quality Parameters *(63) Yang Hongwen, Rohde & Schwarz*	WE_402: Advanced PA Test Techniques: Advanced Technologies for DPD, ET and Measurement Acceleration *(85) Alejandro Buritica, National Instruments*	WE_403: Protecting the Next Generation Technologies-5G, IoT and Automotive Through EMC Solutions *(94) Sangam Baligar, AR RF/Microwave Instrumentation*	WE_404: Software Defined Radio Techniques Applied to 5G Emulation *(77) Tom Higgins, Keysight*	WE_405: CMOS and SOI for RF Modules *(33) Malcolm Smith, AnalogSmith Design Solutions LLC*	
11:00 - 11:20	WE_501: Signal Integrity Measurement Using a Vector Network Analyzer *(38) Fei Yu, Rohde & Schwarz*	WE_502: Millimeter Wave OTA Test Challenges *(89) Prasadh Ramachandran, Keysight*	WE_503: SmartTone Proposal of EMC *(69) Andy Zhang, Hwa-Tech Information System Co.*	WE_504: 5G Antenna for Mobile Terminal Device Application *(113) Bin Yu, Speed Wireless Technology Co. Ltd.*	WE_505: Very High Efficiency High Power Schottky Diode Frequency Doubler Operating at 180 to 190 GHz *(75) Tomasz Waliwander, Farran Technology*	
11:25 - 11:45	WE_601: PAM-4 Challenges and Testing in 400G Ethernet *(22) Li Kai, Keysight*	WE_602: Distortion Measurements on Radio Front-End (RFFE) Components and Chains *(121) Gareth Lloyd, Rohde & Schwarz*	WE_603: Discussion of EMC Test Technology for Automotive Electronics *(101) Cinya Tu, Institute of EMC & Electronic Measurement, EVERFINE Instrument Co. Ltd.*	WE_604: Verification of Beamforming Devices with OTA (Over-the-Air) Power Sensors *(115) Frank W. Thümmler, Rohde & Schwarz*	WE_605: Broadband Microwave Frequency Doublers with Improved Harmonic Suppression Based on Quasi-Vertical GaAs Shottky Diodes *(50) Nikolay Drobotun, TUSUR*	
12:00 - 13:00	Lunch Break - Exhibition Floor					
Workshops						
	RF & Microwave	5G	RF & Microwave/IoT	RF & Microwave		
13:00 - 13:40	WS_WE101: Design Flow and Simulation Technologies Supporting Multi-Technology RF Modules for Wireless Applications *(42) National Instruments*	WS_WE102: 60 GHz Wireless Systems with Circuit/EM Co-Simulation *(64) ANSYS*	WS_WE103: Challenges and Test Solutions in IoT *(134) Keysight*	WS_WE104: High Performance Material Considerations for Use in Wireless Communications Infrastructure *(151) Rogers Corporation*		
13:45 - 14:25	WS_WE201: Simulation of a Large Cassegrain Antenna with an FSS Subreflector *(46) ANSYS*	WS_WE202: 20 W Fully Integrated 3.5 GHz GaN Doherty MMICs for 5G Applications *(132) Ampleon*	PN_WE203_PANEL: Trends in Mobile Infrastructure *Moderator: Gary Lerude, MWJ*	WS_WE204: New Challenges for Next-Generation Vehicles *(127) National Instruments*		Poster Session 14:00 to 15:00
14:30 - 14:50	Tea/Coffee Break - Exhibition Floor					
	RF & Microwave	Measurement & Modeling	5G			
14:50 - 15:30	WS_WE301: Designs of GaN on Silicon Doherty PAs for Commercial Base Station Application *(61) MACOM*	WS_WE302: VNA Based Measurements and Nonlinear Modeling for Efficient RF PA Circuit Design *(47) Maury Microwave*	WS_WE303: Wideband Amplitude and Phase Control Matrix for 5G MIMO Channel Simulation *(139) Mitron*			
15:35 - 16:15	WS_WE401: Monolithic Alternatives to PIN Diodes – RF SOI Power Limiters & Switches *(93) Peregrine Semiconductor*	WS_WE402: Characterization and Test Challenges for Multimode Multiband Power Amplifiers and Duplexer Modules *(65) Keysight*	WS_WE403: 5G Over-the-Air Measurements *(142) Rohde & Schwarz*			
16:20 - 17:00	WS_WE501: Wide Bandwidth, Low-Current Consumption Amplifier for 5G Massive MIMO Applications *(119) IDT*	WS_WE502: Challenges of Evaluating RF Performance of High Frequency Wide Bandwidth Devices *(87) Keysight*	WS_WE503: Addressing the Test Challenges of 4.5G PA and Device Measurements *(148) National Instruments*			

Thursday, April 27, 2017					
	Room 305A	Room 305B	Room 307A	Room 307B	
08:00 - 14:00	Registration On Site				
Workshops					Exhibition Hours 09:00 to 13:00
09:00 - 09:40		WS_TH102: Revolutionary Filter/IPD Technology for 5G Application *(140) Mini-Circuits*	WS_TH103: RF & Microwave Coaxial Switches, How to Reach 10 Million Cycles With an Electromechanical Device *(145) Shanghai Radiall Electronics Co. Ltd.*	WS_TH104: Pave Your Way for the 5G Era *(147) National Instruments*	
Technical Sessions					
	Systems	High-Speed Digital Design	Test & Measurement	RF & Microwave	
09:45 - 10:05	TH_101: WiGig: 802.11ad is Coming, Test Equipment Closes Behind and What Does it Mean to Us? *(10) Wei Lin, National Instruments*	TH_102: Modeling and Calibration of High-Speed Passive Channels *(12) Wu Jun, Shenzhen EDADOC Technology Co. Ltd.*	TH_103: Measurements of Phase Noise at Frequencies Above 50 GHz *(120) Wolfgang Wendler, Rohde & Schwarz*	TH_104: Design & Build Intelligent Switching Management System for Large-Scale RF Switching *(118) Wang Qi, Pickering Instruments*	
10:10 - 10:30	TH_201: Minimizing Uncertainty in Noise Figure Measurements *(79) Wei Lin, National Instruments*	TH_202: Power and Signal Integrity Insight for DDR4/LPDDR4 Systems *(20) Jennie Grosslight, Keysight*	TH_203: An Innovative Methodology for Probe Pin Characterization with Vector Network Analyzer *(105) Yuk Choi Andrew KO, Keysight*	TH_204: An RF Solution With Design Flexibility for Mid-Tier Smartphones *(125) Locker Jiang, Qorvo*	
10:30 - 10:50	Tea/Coffee Break - Exhibition Floor				
	Test & Measurement	Radar	RF & Microwave	RF & Microwave	
10:50 - 11:10	TH_301: Understand Smearing-Effect of Time-Domain Pulse-Waves Radiated from a Wire Antenna *(17) Shi Pu, Wuhan University of Technology*	TH_302: Automotive Radar Target Simulator *(45) Tie Hieng Ling, Keysight*	TH_303: System Accuracy Verification for Real-Time Hybrid Load Pull System Under Large Mismatch Condition *(36) Xianfu SUN, Focus Microwaves*	TH_304: 5G Simulation Using Phased Array *(67) Zhang Shuai, Keysight*	
11:15 - 11:35	TH_401: On-Wafer Measurement and Analysis of Flicker Noise and Random Telegraph Noise *(26) MA Long, Keysight*	TH_402: Sophisticated Pulse Scenarios. How to Achieve Long Signal Play Time with High Sample Rate when ARB Size is Limited? *(114) Frank-W. Thümmler, Rohde & Schwarz*	TH_403: Applying Crest Factor Reduction (CFR) for the Partial Band of DOCSIS 3.1 System *(107) Maxwell Huang, Cisco Systems*	TH_404: Design of a High-Conversion-Efficiency X-Band Rectifier for Microwave Wireless Power Transmission *(76) Feifei Tan, Chengdu University of Information Technology*	
11:40 - 12:00	TH_501: The New Method of Nonlinear Parameter of Measurements *(49) Zong Huiqing, Rohde & Schwarz (China) Technology Co. Ltd.*	TH_502: Tackling the Test Challenges of Next Generation ADAS Vehicle Architectures *(84) Alejandro Buritica, National Instruments*	TH_503: Circularly-Polarized Antipodal Fermi Tapered Slot Antenna for Millimeter-Wave Applications *(110) A. Sebak, Concordia University*	TH_504: Using Software-Centric Solution to Build Cloud Based Test *(123) Shanshan Cong, Keysight*	
12:05 - 12:25	TH_601: Introduction to Real-Time Spectrum Monitoring *(88) Fangze Tu, National Instruments*	TH_602: 900 W GaN-HEMT Transistor for L-Band Radar Applications *(23) Weishu Zhou, Microsemi*	TH_603: Practical Considerations for Load-Dependent X-Parameters Extraction with Harmonic Impedance Control of a 10 W GaN Power Transistor *(68) Di Liu, Keysight*	TH_604: Very High Efficiency High-Power Schottky Diode Frequency Doubler Operating at 180 to 190 GHz *(70) Michael Crowley, Farran*	

Details in this conference matrix were correct at the time of going to press. They are subject to change.
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Miniaturized Bandpass Filter Using Quarter SIW Resonator With Elliptic Defected Structure

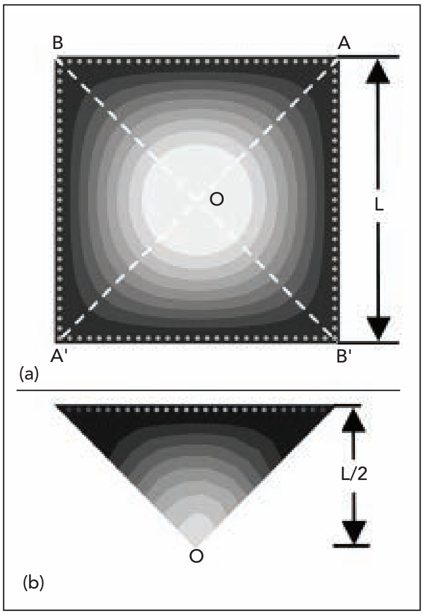
Sheng Zhang, Hai-Ting Wang, Yi-Kang Zhang and Hai Liu
China University of Mining and Technology, Xuzhou, China

Fa-Lin Liu
University of Science and Technology of China, Hefei, China

A novel quarter substrate integrated waveguide resonator (QSIWR) with an etched elliptic defected structure (EDS) to reduce its resonant frequency employs electric coupling in the main path and magnetic coupling in the cross-coupled path to realize a miniature cross-coupled bandpass filter (BPF) with a size reduction greater than 88 percent. The filter possesses a transmission zero (TZ) in the upper stopband, which improves selectivity.

Various kinds of substrate integrated waveguide (SIW) filters have been reported in the recent decade,[1-4] with the advantages of high Q, light weight and ease of fabrication/integration. Compared with other planar filters, however, SIW filters are generally larger in size.[1] Although advanced multilayered technologies can reduce their dimensions, the fabrication process is costly and complicated. To realize miniaturized filters in a single layer, the concepts of half-mode,[2] quarter-mode,[3] and even eighth-mode[4] SIW resonators (SIWR) can greatly reduce the size of SIWRs. Based on EM simulation, many kinds of miniaturized SIW filters using these resonators have been reported, but the coupling mechanisms, especially the cross-coupling theory, are still being explored.

In order to further reduce the size of SIWRs,[4] a new QSIWR with EDS is described here. Compared with conventional SIWRs, the resonant frequency drops dramatically. A cascaded triplet QSIWR with EDS filter is designed using cross-coupling technology. Compared with a cascaded triplet SIWR filter, the size is reduced by more than 88 percent. A TZ is implemented with cross-coupling technology in the upper stopband to improve selectivity. Experimental results agree well with simulation.



▲ **Fig. 1** Electric field distribution of a square SIW resonator (a) and QSIWR (b).

FREQUENCY CHARACTERISTICS OF QSIWRS WITH EDS

Figure 1a shows the electric fields of a square TE101 mode SIWR. Cutting along AA' and BB', leaves a QSIWR as shown in ***Figure 1b***.[3] Because the open sides of the QSIWR are nearly equivalent to perfect magnetic walls, there is little wave leakage along the two walls. So, the QSIWR can be used to design various cavity filters with 75 percent size reduction.

The QSIWR with EDS is shown in ***Figure 2***. The elliptic defected structure is etched in upper metallic layer. The elliptic major axis is parallel to the hypotenuse of the isosceles right triangle, with the axial ratio fixed at 3.3. The length of minor axis is r. ***Figures 2a*** and ***b*** indicate the surface current distributions of the QSIWR with and without EDS, respectively. As the surface current is disturbed by the EDS, the equivalent electric length of the QSIWR with EDS is extended. The resonant frequency of the etched QSIWR is determined by both the sizes of the resonator and EDS. ***Figure 3*** shows the influence of r on

resonant frequency, while the size of the QSIWR remains unchanged. With increased r, the resonant frequency decreases, i.e., for the same resonant frequency, the QSIWR with EDS is smaller.

CROSS-COUPLED BPF DESIGN

The BPF utilizing cross-coupling technology is shown in ***Figure 4a***, while ***Figure 4b*** depicts its coupling topology. The main coupling path is realized with a cascaded triplet QSIWR, which is indicated in solid lines. A TZ is implemented with cross-coupling between Resonator 1 and Resonator 3, indicated by a dotted line. The I/O feed lines are directly coupled with the cascaded triplet QSIWR, which determines the coupling with external circuits. The filter is specified to work at 3.6 GHz with a fractional bandwidth of 8.5 percent. The TZ is tuned to 3.98 GHz. The coupling matrix and the external quality factor are calculated as follows:[5]

$$M = \begin{bmatrix} -0.0195 & 0.0905 & -0.0194 \\ 0.0905 & 0 & 0.0905 \\ -0.0194 & 0.0905 & -0.0195 \end{bmatrix},$$

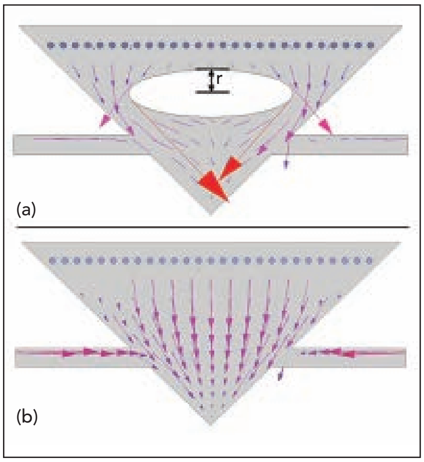
$$Q_{e1} = Q_{e3} = 9.5348 \qquad (1)$$

where M_{ij} denotes the coupling coefficient between resonator i and resonator j, while Q_{e1} and Q_{e3} represent the input and output external quality factors, respectively.

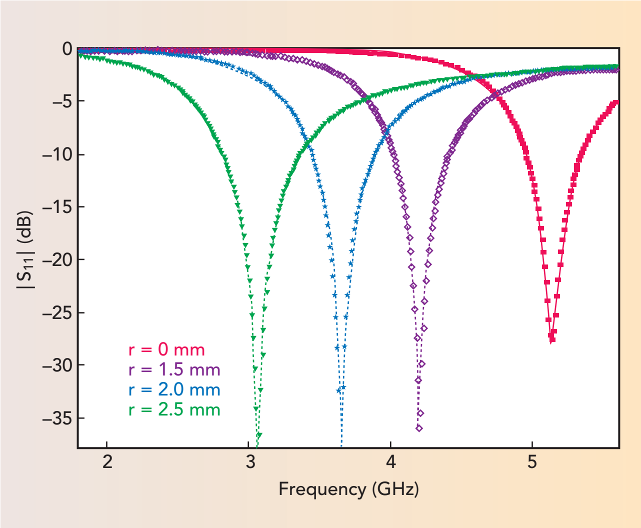
According to odd-even mode theory[5] and EM simulator analysis, the direct-coupling structure is electric in nature, while the cross-coupling structure is magnetic. The cross-coupling strength has a distinct relationship with the TZ. As shown in ***Figure 5***, the coupling strength is determined by parameter j. As j is increased, the coupling strength also increases, pulling the TZ closer to the passband, and thus improving selectivity in the upper stopband.

RESULTS AND DISCUSSION

The filter is fabricated on Rogers RT/duroid® 5880 substrate with dielectric permittivity ε_r = 2.2 and thickness h = 0.508 mm (see ***Figure 6***). The optimized dimensions are w = 1.6 mm, l_1 = 9.3mm, l_2 = 10 mm, r_1 = 2 mm, r_2 = 1.92 mm, j = 4 mm, b = 30mm, d = 0.5mm, p = 1mm and g = 0.62 mm. The total size of the filter is about 20 mm x 53 mm including the 50 Ω microstrip feed lines. Assuming that a conventional SIWR is used in the design of a cascaded triplet filter, its total dimensions would be no less than 95 mm x 95 mm; therefore, the cross



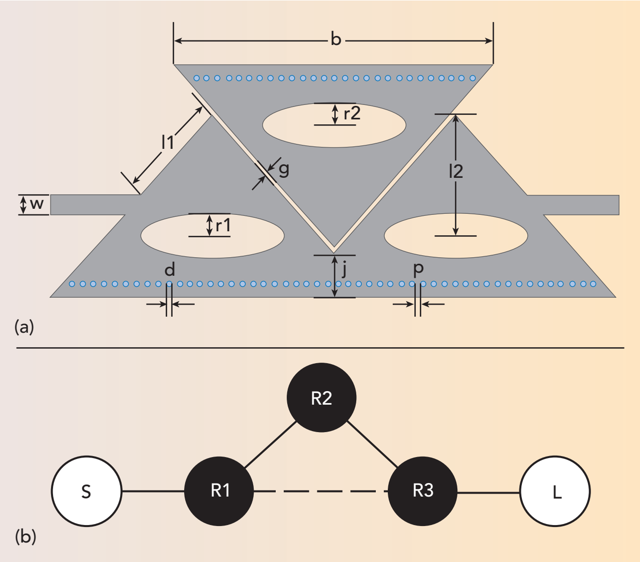
▲ **Fig. 2 QSIWR surface current distribution, with (a) and without (b) EDS.**



▲ Fig. 3 $|S_{11}|$ vs. r.

coupled filter is a more compact structure, with greater than 88 percent size reduction.

Figure 7 shows good agreement of measured results with simulation. The measurements are obtained with a Rohde & Schwarz ZVA40 vector network analyzer. Insertion loss is approximately 1.2 dB and return loss is better than 23 dB in the passband. A TZ with attenuation of 57.8 dB is implemented at 4.02 GHz, which greatly improves selectivity in the upper stopband.



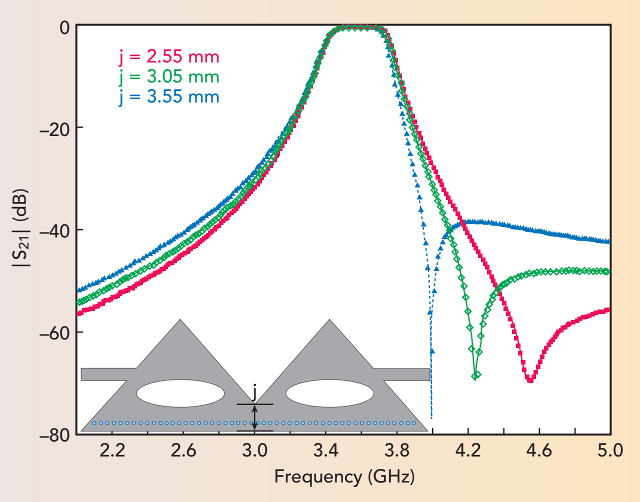
▲ Fig. 4 Cross-coupled cascaded triplet bandpass filter (a) and coupling topology (b).

CONCLUSION

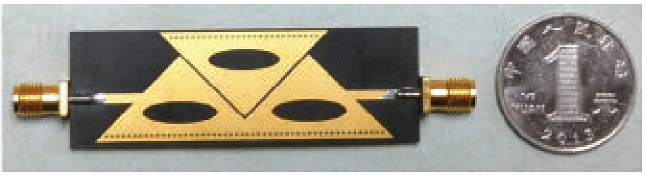
A novel QSIWR with etched EDS lowers its resonant frequency. A cascaded triplet QSIWR BPF built utilizing cross-coupling technology and a TZ in the upper stopband has a compact structure with greater than 88 percent size reduction compared to a conventional triplet SIWR filter. ■

ACKNOWLEDGMENT

This work is supported by the fundamental research funds for the central universities (2014QNA85).



▲ Fig. 5 $|S_{21}|$ vs. j.



▲ Fig. 6 Filter fabricated on Rogers RT/duroid 5880 substrate.

References

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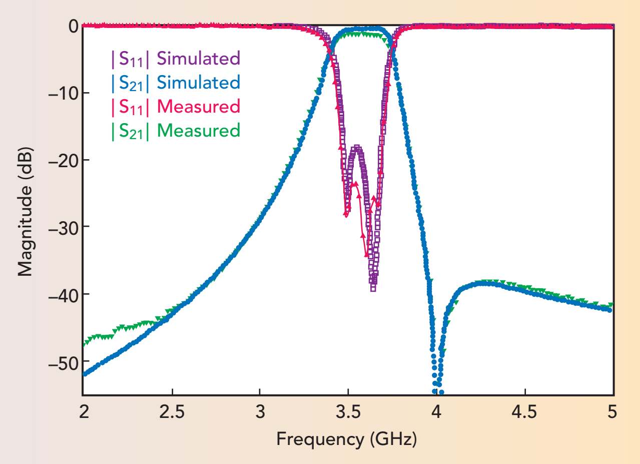
4. S. Sam and S. Lim, "Electrically Small Complementary Split-Ring Resonator Antenna on Eighth-Mode Substrate Integrated Waveguide," *Electronic Letters*, April 2013, Vol. 49, No. 8, pp. 519–521.
5. J. S. Hong, "*Microstrip Filters for RF/Microwave Applications*," Wiley, New York, 2011.



▲ Fig. 7 Measured vs. simulated filter responses.

Editor's Note: A complementary article introducing some of the new radar applications using the technologies described in this article is included in the online issue of Microwave Journal *and can be viewed at www.mwjournal.com/radarapplications.*

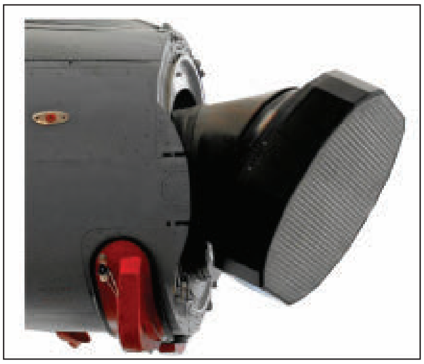
INVITED PAPER

Radar Technology Advancements and New Applications

Pasternack
Irvine, Calif.

Recent breakthroughs in radar technology combined with the demand for compact, affordable and high precision radar for military and commercial applications, has led to a renaissance in the methods and use of radar. Many of the upcoming sectors of technology growth, namely autonomous vehicles, unmanned aerial vehicles (UAV) and various commercial/civilian applications, rely upon solid-state radar and new methods of fabrication and programming. This resurgence is a byproduct of escalating advancements in radar, stealth and jamming technologies for defense that is driving conventional radar solutions into obsolescence.[1] A wide accessibility to sophisticated digital-signal processing (DSP), agile RF transceivers and cutting-edge antenna techniques is fueling this accelerating change.

A contributing factor to enhanced capabilities and decreased costs is the development of new antenna and radar fabrication technologies. Among these, GaN power transistors, low noise amplifiers (LNA) and active electronically steered array (AESA) antennas have been central to recent radar and radar jammer military contract awards and system deployments around the globe. Radars employing these technologies outperform conventional radar systems and have spurred a flood of new and innovative radar design and fabrication approaches. New AESA technologies have enabled an evolution to higher (millimeter wave) frequencies providing greater resolution with smaller phased-array antennas, while modular design approaches enable rapid adoption of new digital processing and computation techniques.



▲ **Fig. 1** Many fighter jets have been retrofitted with newer AESA radar technology, eliminating mechanical steering.[2]

Active Electronically Steered Array (AESA)

In prior decades, phased array antennas greatly improved the form factor and performance of conventional radar. A more recent enhancement is enabled by greater DSP and computational methods. Active electronic beam steering (or beamforming), leverages the performance benefits of phased array antennas and introduces active steering, greatly reducing the maintenance costs and failure rates of mechanically steered radar antennas while increasing radar scanning speed and accuracy[2] (see ***Figure 1***). Among the industry leaders are Raytheon, Northrop Grumman, Lockheed Martin and Thales; but, there are many other companies with active development in this area. AESA radar is in high demand for the retrofit, upgrade and replacement of legacy radar technology.

In the latest breed, the transmit/receive (TR) modules can be configured to operate either independently or in clusters. This enables the generation of multiple beams operating at different frequencies in order to devote scanning resources dynamically and intelligently. This highly adaptable con-

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JUST ADDED CG2164X3	DPDT	6.0	0.50	0.65	25	17	+32 @ P0.5dB	+30 @ P0.5dB	(1.5 x 1.5 x 0.37)
CG2176X3	Absorptive SPDT	6.0	0.45	0.55	30	22	+37.5 @ P0.5dB	+37.5 @ P0.5dB	(1.5 x 1.5 x 0.37)
CG2179M2	SPDT	3.0	0.45	N/A	26	N/A	+30 @ P0.1dB	NA	(2.0 x 1.25 x 0.9)
CG2185X2	SPDT	6.0	0.35	0.40	28	26	+29 @ P0.1dB	+29 @ P0.1dB	(1.0 x 1.0 x 0.37)
CG2214M6	SPDT	3.0	0.35	N/A	25	N/A	+30 @ P0.1dB	NA	(1.5 x 1.1 x 0.55)
JUST ADDED CG2409M2	SPDT	3.8	0.45	N/A	27	N/A	+37.5 @ P0.1dB	NA	(2.0 x 1.25 x 0.9)
JUST ADDED CG2409X3	SPDT	6.0	0.40	N/A	26	N/A	+37.5 @ P0.1dB		(1.5 x 1.5 x 0.37)
CG2415M6	SPDT	6.0	0.35	0.45	32	26	+31 @ P0.1dB	+31 @ P0.1dB	(1.5 x 1.1 x 0.55)
CG2430X1	SP3T	6.0	0.50	0.60	28	25	+28 @ P0.1dB	+28 @ P0.1dB	(1.5 x 1.5 x 0.37)

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figuration helps to reduce the probability of intercept compared with passive array radars. Additionally, directional reception and frequency agility reduce susceptibility to jamming, particularly if wideband.

The modular AESA design also enhances reliability, as any failures in the TR modules will not disable the whole system and repairs/maintenance can readily be accomplished by swapping modules. TR modules for AESA radars are essentially highly capable software-defined radios (SDR) that can also be configured for radio communication with extremely high data rates. The highly directional beamforming capability also provides communication security by confining communication to receivers within the beam's focused path.[4]

AESA radar antennas typically have maximum scanning angles less than 120 degrees. For 360 degree coverage, a common solution is to mount them on mechanically rotating platforms. Full 360 degree coverage has recently been demonstrated with fixed arrays using back to back antenna panels. An example is Raytheon's self-funded prototype designed as an upgrade to the Patriot Missile system. Other systems use several panels linked to the same radar system (three or more) to provide omnidirectional scanning and tracking capabilities Notably, the cost of an AESA system is roughly proportional to the size and performance of the array, and the number of TR modules.

MIMO

In order to reduce the size, weight, power and cost (SWAP-C) of AESA radars and increase scalability, researchers are developing sophisticated techniques that leverage sparsely populated arrays that are combined to form larger virtual arrays using multiple-input multiple-output (MIMO) technology similar to techniques being developed for 5G wireless communications. MIMO radar leverages spatial diversity with multiple separate transmit and receive antennas that use computational algorithms to calculate radar reflections and achieve compound resolution.[5] These antenna systems can also operate at several frequencies, or over a wideband set of frequencies simultaneously without interfering, to further enhance discrimination of legitimate targets over radar clutter.

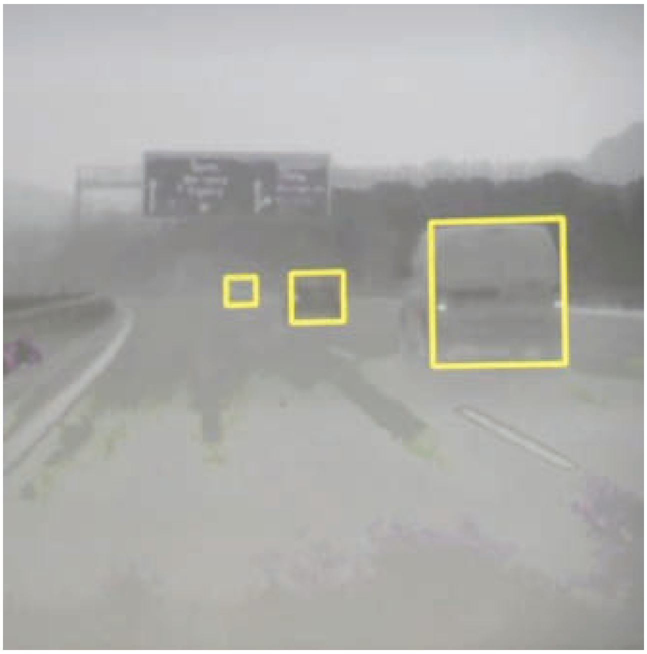
There have been claims that MIMO radar systems might outperform analogous conventional phased-array radar systems.[6] Though this has yet to be conclusively demonstrated, there are applications where the SWAP-C benefits of compact sparsely populated MIMO antenna arrays might enable high precision radar capabilities where a phased-array radar would be too costly, heavy, large or power consuming to be deployable; for example, on SWAP-C restricted platforms such as a small UAS, satellite or rapidly deployable mobile radar station. Some recent research has shown potential improvements in synthetic aperture radar (SAR) MIMO radar systems for ground moving target indication (GMTI) applications that have exceeded phased-array radar target geolocation accuracy for fast and slow moving targets with fewer false alarms and potentially higher jamming resistance.[7] Highly sophisticated DSP and digital waveform generation technologies are necessary, and must be effectively applied, considering the environmental conditions and radar signature of the target, in order to realize the performance benefits.

MIMO radar research also focuses on omnidirectional antenna systems, which suffer from higher losses than phased-array antennas. This loss may be associated with waste energy depleted outside of a target area of interest. Nevertheless, there are methods being proposed to use cognitive radio systems to augment MIMO radar and mitigate these drawbacks.

ULTRA-WIDE BANDWIDTH MILLIMETER WAVE RADAR

To avoid the spectrum congestion at lower microwave frequencies, and to achieve high-precision and high resolution capabilities many applications have moved beyond 20 GHz. Fortunately, at millimeter wave frequencies there are several

frequency bands that are designated with 0.5 GHz, 1 GHz and even 4 GHz of available bandwidth. Radiation at millimeter wave frequencies tends to suffer higher atmospheric losses, but is more directional than at sub-6 GHz microwave frequencies. Millimeter wave radars benefit from reduced noise, greater resolution due to ultra wide bandwidths, and reduced size.[8]



▲ **Fig. 2** Millimeter wave radar has the ability to penetrate dust and fog, which enables it to accurately detect and identify other vehicles and road hazards.

Many of the latest automobile radars leverage the 79 GHz millimeter wave frequency band that can penetrate sufficiently in adverse conditions, such as fog, dust and rain that are impenetrable by optical sensors (see ***Figure 2***). Operation in this band also enables increased resolution and better hazard detection features. The benefits of millimeter wave radar translate to other applications as well, including detection and surveillance of UAS/drones and even medical monitoring. For example, multi-channel radar for perimeter surveillance (MCRPS) and scanning surveillance radar systems (SSRS) using FMCW principals, with 1 GHz of bandwidth and 100 mW at 94 GHz, have been used to achieve 15 cm range resolution and classification of UAS/drones based on their rotor typologies. Also, 24 GHz band radar has been used in remote heart rate monitors able to discriminate and characterize a heartbeat accurately and efficiently with less than 7.17 ms of RMS error.[9]

The benefits seen for military applications (e.g., better range, resolution and greater FMCW-based object identification) may be leveraged for new applications in a wide range of fields from scientific, medical and security. The reduced susceptibility of millimeter wave radar to light conditions, weather and clutter provides surveillance advantages over visual spectrum and IR camera technology, as well. For example, security and safety management technology for concealed threat detection has been developed that can reliably detect threats at a standoff distance of 100 ft.[10] This currently uses W-Band (75 to 110 GHz) frequencies and has been implemented in a handheld version with over 30 ft. effective standoff range.

RADAR DESIGN AND FABRICATION

Many of the latest advancements and applications of radar technology may have been possible with legacy radar technology; however, the SWAP-C benefits and advances of digital computation have enabled a more rapid adoption in the growing radar industry, as they have proven to be cost-effective and capable. New fabrication techniques and semiconductors are being developed to spur further growth.

GaN Technology's Impact on Radar

Many of the latest U.S. DoD contracts and military development in other countries have required GaN-based TR modules for retrofits and upgrades to legacy radars.

The main reason is that GaN power amplifiers (PA) in the TR modules of AESA radar have power densities, reliabilities, frequency capabilities and bandwidths far exceeding other solid-state technologies. They compete with TWTs as well, but without the accompanying reliability, size and maintenance issues. Like other class III-V semiconductor materials, such as GaAs and indium phosphide (InP), GaN semiconductors have a very high electron mobility/velocity compared to silicon and silicon carbide (SiC).

GaN also demonstrates extreme physical ruggedness, radiation resistance, high voltage survivability and very high thermal stability. Consequently, GaN power electronics exhibit impressive power densities, and in the case of PAs, high power-added efficiencies (PAE) compared with other solid-state technologies. GaN is also used for low noise amplifiers (LNA) with similarly rugged characteristics as the GaN PAs, providing sensitive receiver technology that is not easily jammed, damaged or otherwise impacted by the limited dynamic range due to a low input voltage threshold.

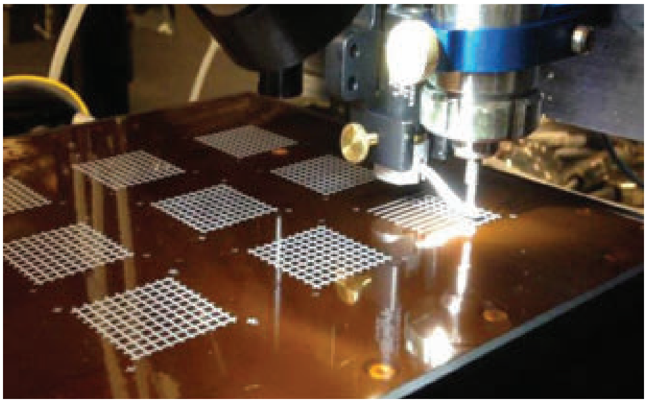


Fig. 3 3D printed antenna arrays will reduce the cost and weight of AESA radars, using plastic substrates and other low weight and low temperature fabrication components.

The benefits of GaN technology for reducing SWAP-C aspects of telecommunications, satellite and other power electronics has been explored by many industries with the aim of increasing wafer sizes and improving GaN processes. Methods of improving heat dissipation have also led to higher power levels and smaller, more cost effective devices. GaN is developing into a mainstream technology that will lead to radar and communications systems with much higher bandwidths and performance to meet lower cost thresholds and bring about new radar and radio applications.

3D Printed Radar Components, Modular Radar Design and Magnetic Material Enhancements

To further reduce radar component SWAP-C, advances in 3D printing of electronics, modular RF/microwave component design techniques and the use of magnetic material enhancements are being investigated by research institutions, industry and the DoD. Smaller, more efficient, scalable and flexibly manufactured radar components, including antennas and RF/microwave passive components, will lead to more sophisticated manpack, UAS and commercial radar systems. Such techniques must be able to print the antenna, phase-shifters, filters and transmission lines on a low-cost substrate. A research group at the Raytheon UMass-Lowell Research Institute is pursuing such a project, using plastics, 3D printed conductive ink, frequency-selective surfaces and actively tunable varactor diodes (see ***Figure 3***).[11]

Raytheon is also collaborating with the Army Research Laboratory (ARL) on the Scalable, Agile, Multimode, Front-End Technology (SAMFET) program for the Army's Next Generation Radar (NGR).[12] The Army proposes using an open architecture for NGR to reduced iterative development cycles and upgrades, while encouraging modular component development, new radar designs and new fabrication techniques as well. RF/microwave and digital technologies, such as OpenVPX and OpenRFM will also enhance the modular design and development of high performance military electronics that rely on tightly coupled digital and RF/microwave systems.

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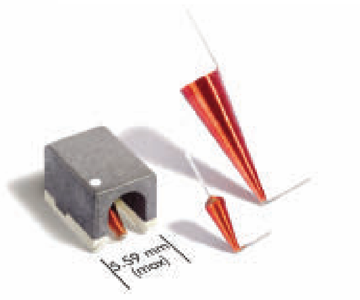

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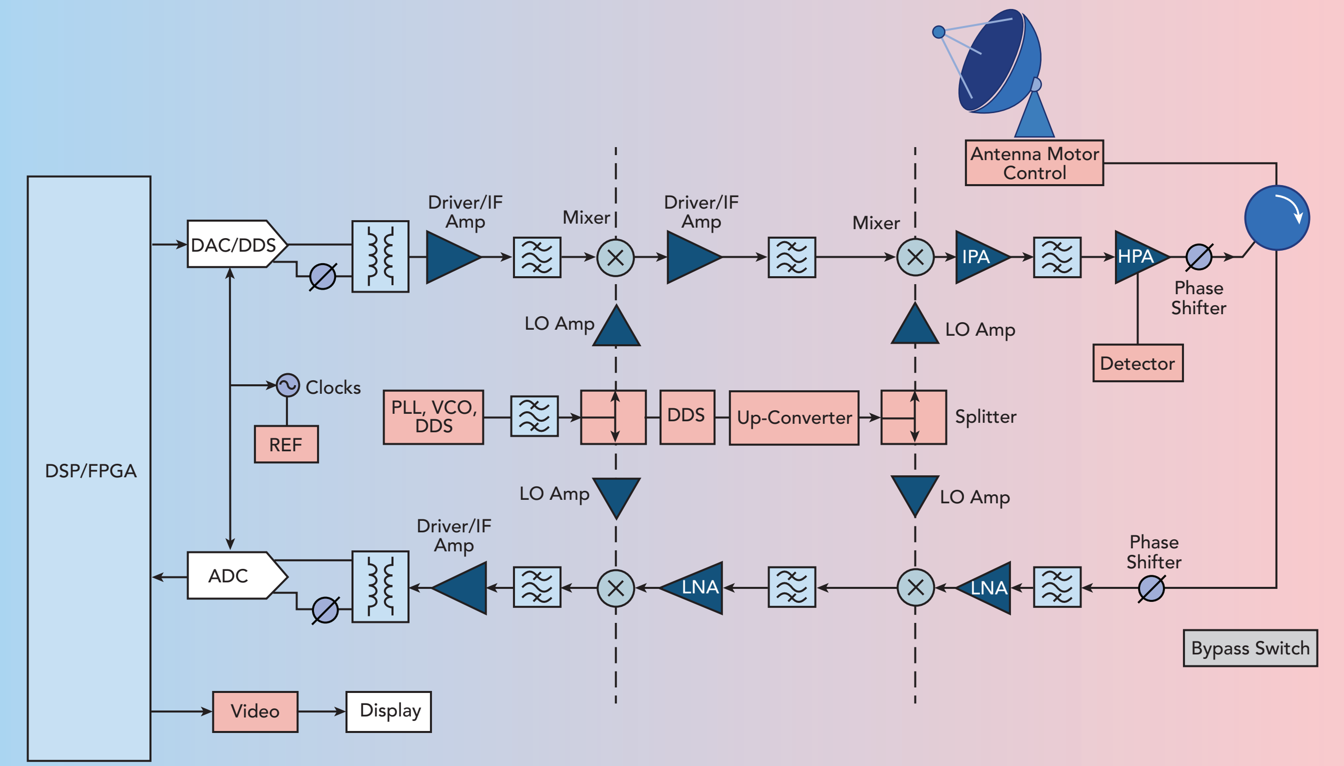


Fig. 4 A modern radar signal chain employs many RF and microwave components.

TABLE 1

ELEMENTS OF A RADAR SYSTEM

Analog/Digital Electronics	*RF/Microwave Electronics*	*Design and Test Equipment*	*Fabrication and Assembly*
FPGAs	Power Amplifier	Vector Signal Generator	Radome
Microprocessors	Low Noise Amplifier/ Bidirectional Amplifier	RF Oscilloscope	Installation Hardware
General Purpose Processors (GPP)	Power Combiners/Dividers	Network Analyzer	RF Laminates for PCBs
Application Specific ICs (ASIC)	Phase Shifters	Real-time Spectrum Analyzer	PCB Coaxial Connectors
Digital Signal Processors (DSP)	Mixers	Delay Lines	Waveguide Hardware
Digital-to-Analog Converters (DAC)	Signal Generator/Frequency Synthesizer	Anechoic Chamber	3D Printers
Analog-to-Digital Converters (ADC)	Local Oscillators (LO)	Long-Range RF Test Field	Conductive Inks
I/Q Detectors	Voltage-Controlled Oscillators (VCO)	Digital/Analog/ RF Design Software	Aluminum/Steel/Brass/Kovar/ Invar Electronics Housings
Display Technology	Phased Array Antenna	IC Design Suites	EMI Gaskets
Processing Software	Coaxial Cables	EM Simulation Software	
Embedded Computers	Waveguide	Precision Antenna	
Power Supplies	Power Detectors	Environmental Chambers	
Data Acquisition Controller	Phase Detectors	Vibration Tables	
Solid-State Drives (SSD) for Long-Term Storage	Switches/Switch Banks	EMC/EMI Test Facilities	
RAM	High, Low and Bandpass Filters		
Phase Locked Loop (PLL)	Pulse Modulator		
Voltage Controlled Oscillators (VCO)	Modulation/Demodulation Circuitry		
Oscillators	IF Amplifiers		
Chokes	Driver Amplifiers		
Electrostatic Discharge (ESD) Protection Circuits	Gain Block Amplifiers		
	Baluns		

Approaching SWAP-C reduction from another angle, DARPA has initiated a research project with the aim of integrating magnetic components into RF and digital integrated circuit (IC) processes. The Magnetic Miniaturized and Monolithically Integrated Circuit (M3IC) project's goal is to shrink the size of communications, radar and electronic warfare (EW) systems and enable new methods of control/functionality.[13] It is unclear from the DARPA program information if the project is open to the use of metamaterial technologies, as some have proven to demonstrate magnetic properties.

IMPACT ON COMPONENTS AND DEVICES

The latest radar and radio systems are complex and highly integrated assortments of digital, analog and RF/microwave electronics controlled and interpreted by sophisticated computer systems (see ***Figure 4***). The SDR technology that powers most modern radar can also be found in Wi-Fi routers, smart phones, cars and cellular base stations. The differentiating factor between aerospace, defense radar and these modern commercial radios is the sophistication, bandwidth and power of the RF and digital electronics, along with the size and power handling capability of the antennas.

As consumer and industrial radio and radar technology advances, however, the lines are blurring in terms of capability and sophistication. To maintain its lead, the DoD continues to invest in developing the next generation of components and devices for aerospace and defense radar. This impacts the components and devices themselves, as well as the equipment used to design, test and fabricate them.

Analog/Digital Electronics

Advanced DSP and digital waveform generation technology enhances programmability and flexibility to provide next-generation radar waveforms. Commercial FPGAs have become extremely powerful—with over 20 TMACs of fixed-point performance and 10 tera floating point operations per second (TFLOPS) of single-precision floating point performance; and unlike CPUs and GPUs, FPGAs can be reconfigured as requirements change. In a military scenario, this facilitates and enables flexible adaptation to evolving threats, especially considering their capabilities with respect to latency, parallelism, input/output (I/O) speed and computational intensity.[14]

However fast the processing capability, analog data must first be converted to digital data to take advantage of these benefits. Hence, the development of analog-to-digital converters (ADC) and digital-to-analog converters (DAC) has been to increase the speed of ADC/DAC components to enable direct RF sampling/synthesis at gigahertz frequencies. Although direct RF synthesis and sampling at higher microwave and millimeter wave frequencies is currently not feasible for most deployed systems, there are several 2.4 GHz ISM (or S) Band ADC/DACs used in SDRs that have this capability. Higher frequency digital synthesis and sampling eliminates stages

of up-conversion and down-conversion, avoiding the performance limitations associated with mixers in the signal chain for high microwave and millimeter wave frequency radar, while increasing bandwidth.

With the increasing demand for FPGAs, general purpose processors (GPP) and ADC/DACs, associated components and technologies are also needed. This includes high speed RAM, longer-term memory storage, such as solid-state drives (SSD), embedded computers and data acquisition control systems.

RF/Microwave Electronics

Similar to radio hardware, radar signal chains combine multifaceted transmit and receive capabilities that can handle extreme power levels, wide bandwidths and complex signal modulations, while an array of switched filter banks and phase shifters is also required. The transmit/receive (TR) modules powering each antenna array element send to the antenna and return to the receiver microwave or millimeter-wave signals generated or deciphered by the DSP cores. TR modules amplify, filter and up-convert/down-convert the signals in several stages. Coaxial, stripline or waveguide interconnects transfer high-fidelity signals from one subsystem to another with as little loss as possible.

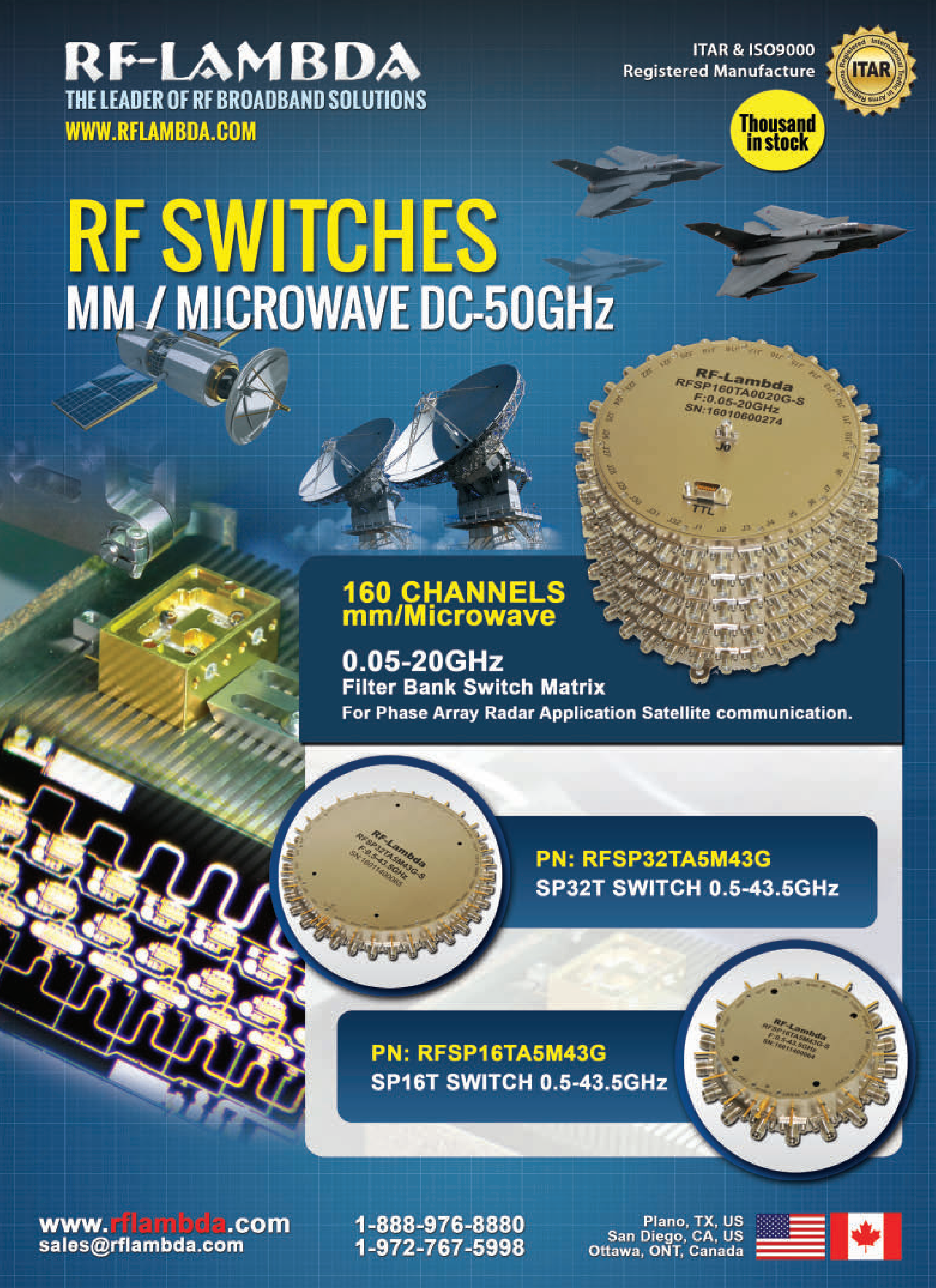
Table 1 provides a shortlist of the RF/microwave components required for a variety of modern radar types. Depending upon the scale of the radar, several to thousands of each of these components may be used in a single aerospace or defense AESA.

TEST AND MEASUREMENT EQUIPMENT AND FACILITIES

Bandwidths of the latest radar technology far exceed the capabilities of commercially available test and measurement equipment; although expensive and highly customized test systems do exist that bridge that gap somewhat. Increased agility and programmability has also made new radar systems impossible to test thoroughly over every operational mode and condition. This is driving the development of more modular and configurable test equipment as well as more advanced EM and design simulation software.[15]

An example is the increased utility of real-time spectrum analyzers (RTSA) paired with vector network analyzers (VNA) for radar characterization. As radar waveforms adapt and change, new methods of identifying friend or foe (IFF) and testing this capability are also required. This demands instruments that are advanced radars themselves, equipped with high levels of diagnostic and reporting capabilities.

Signal generators with far greater bandwidths must supply complex radar waveforms. Furthermore, modern facilities to test the RF, physical and survivability characteristics of radar components are necessary—this includes EMC/EMI facilities, vibration tables, environmental chambers and near/far field test ranges.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CONCLUSION

Fielding of radar systems that meet the latest demands of the modern battle space and a diverse range of new radar applications requires advanced technologies and techniques from digital and RF/microwave hardware, to simulation software and test systems. New material development, sponsored by the U.S. DoD and conducted by industry aerospace and defense organizations, is also needed to enhance SWAP-C. All levels of radar design and implementation are changing to accelerate next generation system development. This is pushing the boundaries of RFIC and monolithic microwave integrated circuit (MMIC) design, DSP techniques, material science and testing.

Lead times and design cycles for aerospace, defense and automotive radar are compressing, placing a greater burden on component and device procurement. Many RF/microwave suppliers require relatively long lead times and PO processing that take weeks or months for approval. This is changing as well, with just-in-time solutions being applied to support the latest radar programs.■

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INVITED PAPER

Solving Millimeter Wave Test Challenges

Tom Brinkoetter
Anritsu Company

Millimeter wave (mmWave) frequencies have traditionally been dedicated to military applications, with some commercial use for point-to-point microwave links. Octave bandwidth waveguide was the preferred transmission line as mmWave capable coaxial cables and connectors were not available. That has changed during the past decade, with technology improvements in semiconductors, components, cables and connectors. As mmWave frequencies are now being used for commercial and consumer electronics, design engineers must be aware of the issues encountered using coax cables within a test system. Reducing test equipment size and using fewer interconnections will yield improved measurement accuracy.

GROWING MARKETS

Several market segments are adopting mmWave frequencies, each with its own design and test considerations:

5G — The demand for mobile data spectrum keeps growing with the increasing number of smartphone users and new applications that require very high data rates. Recognizing this, in July 2016, the U.S. FCC opened up nearly 11 GHz of mmWave spectrum: 27.5 to 28.35 GHz, 37 to 38.6 GHz, 38.6 to 40 GHz and 64 to 71 GHz. While 5G is still evolving, it appears the initial use will be for last-mile residential service. Longer term, mobile devices and base stations will have beamforming antennas to compensate for the higher path losses at mmWave frequencies, enabling these applications to become more common.

Automotive Radar — A cornerstone in the ability to achieve self-driving vehicles is the ability to detect and avoid obstacles (see ***Figure 1***). To support the array of sensors needed for automotive radar, mmWave components are rapidly being developed. Current automotive radar uses the 24, 77 and 79 GHz frequency bands.

60 GHz Wi-Fi (WiGig) — Consumer Wi-Fi applications have expanded beyond what is available from the IEEE's popular 802.11ac wireless local-area network (LAN) standard. 802.11ad taps the 58 to 64 GHz spectrum, which has long been available for unlicensed services and was recently expanded to 71 GHz (FCC Part 15). Examples of applications are high speed wireless multimedia transmission, including uncompressed HDTV and virtually instantaneous music and images.

Point-to-Point Links — For telecommunications, both fiber and microwave back-

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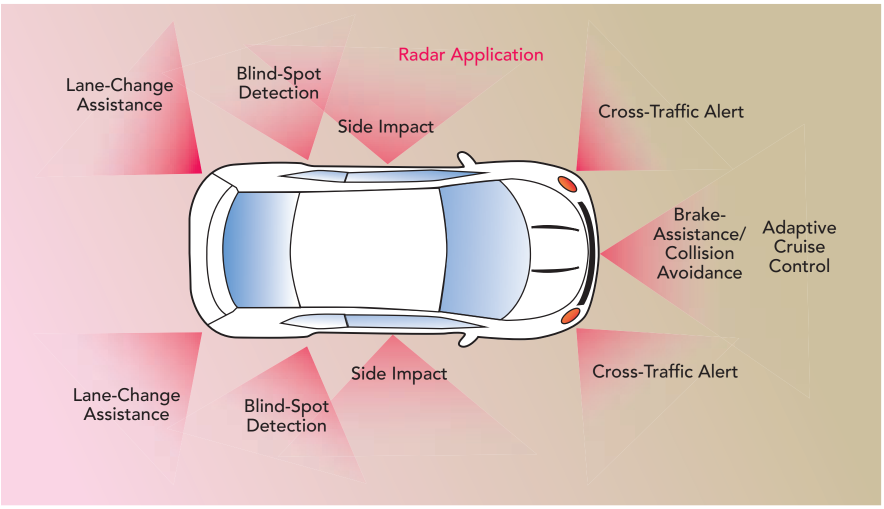
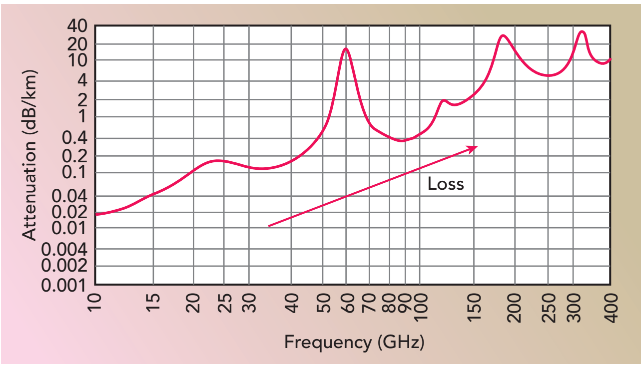


▲ **Fig. 1** **Automotive radar sensor applications.**

haul are commonly used. While fiber is preferred for backhaul because of its higher speed capacity, microwave and mmWave backhaul are widely used in many regions, with mmWave links supporting LTE 4G cellular services in high density areas. They will continue to be deployed, as they are attractive for smaller bases stations such as picocells, microcells and metrocells. The traditional microwave and mmWave backhaul bands are 6, 11, 18, 23 and 38 GHz. Unlicensed 60 GHz backhaul equipment is inexpensive but offers limited range due to high oxygen absorption. Some 80 GHz backhaul units are now available, with the most popular mmWave frequency at E-Band, which covers 71 to 76 GHz, 81 to 86 GHz and 92 to 95 GHz.

Security and Defense — Radar and satellite communication are the main military applications for mmWave systems, with security systems more recent. Advanced imaging technology that leverages mmWave allows detection of metallic and nonmetallic threats, including weapons and explosives, without physical contact. If you have boarded a plane in recent years, you are probably familiar with these systems, now common at U.S. airports.



▲ **Fig. 2** **Atmospheric propagation loss vs. frequency.**

mmWAVE CHALLENGES

As discussed, the advancement of mmWave technology has opened the door for numerous applications. Higher frequency transmission, however, comes with challenges such as higher propagation loss, measurement repeatability and field testing.

The loss of a signal propagating at RF and microwave frequencies is proportional to the frequency (f) and distance (d):

$$\text{Loss} = \left(\frac{4\pi df}{c}\right)^2 \tag{1}$$

At mmWave frequencies, there is additional attenuation from components of the Earth's atmosphere, such as oxygen. ***Figure 2*** shows how propagation loss varies with frequency. Attenuation is particularly pronounced at 60 GHz from oxygen absorption. Using this property, regulators have chosen 60 GHz for unlicensed use to minimize co-channel interference. However, the additional loss presents a testing

- Amplifiers – Solid State
- Attenuators – Variable/ Programmable
- Couplers (Quadrature, 180° & Directional)
- Detectors – RF/Microwave
- DLVAs, ERDLVAs & SDLVAs
- DTOs, VCOs, PLO, DROs, & Frequency Synthesizers
- Filters & Switched Filter Banks
- Form, Fit, Functional Products & Services
- Frequency Discriminators & IFMs
- Integrated MIC/MMIC Assemblies (IMAs)
- IQ Vector Modulators
- Limiters – RF/Microwave
- Log Amplifiers
- Millimeter Wave Components (Up to 50 GHz)
- Miscellaneous Products
- Multifunction Integrated Assemblies (MIAs)
- Phase Shifters & Bi-Phase Modulators
- Power Dividers/Combiners (Passive & Active)
- Pulse Modulators (SPST)
- Rack & Chassis Mount Products
- Receiver Front Ends & Transceivers
- SDLVAs, ERDLVAs & DLVAs
- Single Side Band Modulators
- SMT & QFN Products
- Switch Matrices
- Switched Filter Banks
- Switches – Solid State
- Systems – Fly Eye Radars
- Threshold Detectors
- USB Products

Planar Monolithics Industries, Inc.

Ultra Broadband State-Of-The-Art 360° Digital Phase Shifters

PMI offers the highest quality phase shifters for industrial and military applications in the frequency range of 85 MHz to 10 GHz. These models offer a 360° phase shift with various options available.

Model: PS-200M10G-8B-SFF

http://www.pmi-rf.com/products/phaseshift-biphasemod/phaseshifters/PS-200M10G-8B-SFF.htm

Frequency	200 MHz to 10.0 GHz
Insertion Loss	10.5 dB Typ - Measured 8.0 dB
VSWR	2.4:1 Output, 1.5:1 Input
Amplitude Error	±1 dB Typ. - Measured ±0.1 dB
Phase Accuracy	±0.5° Typ. - Measured ±0.35°
Control	8-BIT TTL Compatible: 15 Pin Sub-D (Male)
Temperature	-55 °C to +85 °C

Package Size: 3.25" X 3.25" X 0.84"
DC Voltage: -15 VDC @ 21 mA
+15 VDC @ 189 mA
Switching Speed: Measured <250 ns

Model: PS-85M4G-9B-SFF

http://www.pmi-rf.com/Products/phaseshift-biphasemod/phaseshifters/PS-85M4G-9B-SFF.htm

Frequency	85 MHz to 4.0 GHz
Insertion Loss	13 dB Max - Measured 10.1 dB
VSWR	1.75:1 Typ - Measured 1.65:1
Amplitude Error	±1 dB Typ. - Measured ±1.91 dB
Phase Shift Error	±10° Max - Measured +13.4°/ -13.1°
Control	10-Bit TTL Compatible: 15 Pin Sub-D (Male)
Temperature	0 °C to +50 °C (Operating)

Package Size: 4.95" X 3.38" X 1.0"
DC Voltage: -15 VDC @ 38 mA
+15 VDC @ 265 mA
Switching Speed: Measured <300 ns

Model: PS-2G6G-8B-SFF

http://www.pmi-rf.com/Products/phaseshift-biphasemod/phaseshifters/PS-2G6G-8B-SFF.htm

Frequency	2.0 to 6.0 GHz
Insertion Loss	10.5 dB Typ - Measured 8.0 dB
VSWR	2.4:1 Output, 1.5:1 Input
Amplitude Error	±1 dB Typ. - Measured ±0.1 dB
Phase Accuracy	±0.5° Typ. - Measured ±0.35°
Control	8-BIT TTL Compatible: 15 Pin Sub-D (Male)
Temperature	-55 °C to +85 °C

Package Size: 3.25" X 3.25" X 0.84"
DC Voltage: -15 VDC @ 21 mA
+15 VDC @ 189 mA
Switching Speed: Measured <250 ns

Model: PS-500M2G-8B-SFF & PS-500M2G-10B-SFF

http://www.pmi-rf.com/Products/phaseshift-biphasemod/phaseshifters/PS-500M2G-8B-SFF.htm
http://www.pmi-rf.com/Products/phaseshift-biphasemod/phaseshifters/PS-500M2G-10B-SFF.htm

Frequency	0.5 to 2.0 GHz	PS-500M2G-8B-SFF	PS-500M2G-10B-SFF
Insertion Loss	13 dB Typ	9.77 dB	8.20 dB
VSWR	1.75:1	1.61:1	1.65:1
Amplitude Error	±1 dB Typ.	±0.61 dB	±0.23 dB
Phase Shift Error	±10° Max	±0.48°	±0.34°
Control	8-BIT TTL 15 Pin Sub-D (Male): PS-500M2G-8B-SFF 10-BIT TTL 15 Pin Sub-D (Male): PS-500M2G-10B-SFF		
Temperature	0 °C to +50 °C (Operating)		

Package Size: 4.95" X 3.38" X 1.0"
DC Voltage: -15 VDC @ 18 mA
+15 VDC @ 249 mA
Switching Speed: Measured <300 ns

West Coast Operation:
4921 Robert J. Mathews Pkwy, Suite 1
El Dorado Hills, CA 95762 USA
Tel: 916-542-1401, Fax: 916-265-2597

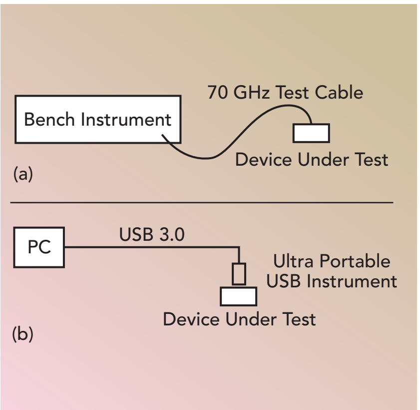
East Coast Operation:
7311-F Grove Road
Frederick, MD 21704 USA
Tel: 301-662-5019, Fax: 301-662-1731

sales@pmi-rf.com • www.pmi-rf.com

ISO9001-2008 REGISTERED

challenge. Test equipment needs higher output power or improved sensitivity for accurate measurements at these bands.

At 70 GHz, the diameter of the coaxial center connector is just 0.5 mm. A center pin diameter is the same size. Connector dimensions are approaching the limits of machine shops, and scratches and dust particles on the connector interface affect the impedance match at mmWave frequencies. mmWave connections require significantly more care than at lower frequencies. Connector interfaces should be inspected with a microscope and cleaned before each use. Connectors should be tightened with a torque wrench to the proper specification (i.e., 8 lbs-in maximum).

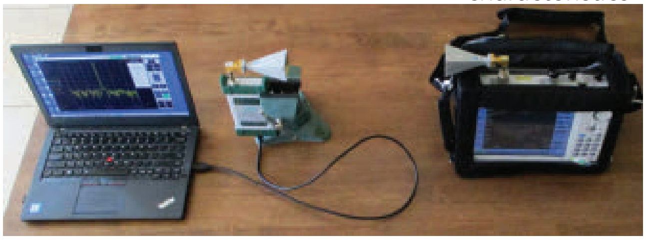


▲ Fig. 3 **Using a benchtop instrument for measurements at mmWave frequencies will likely suffer from high cable losses (a). Using a small, USB-controlled instrument usually allows the instrument to be placed much closer to the device under test (b).**

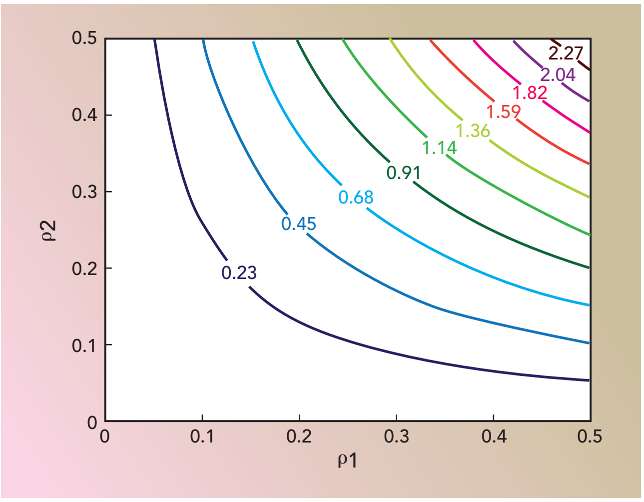
OVERCOMING mmWAVE TEST CHALLENGES

Spectrum analyzers are often used to measure the path loss of a proposed wireless link. The setup comprises a test source with antenna and spectrum analyzer with antenna, placed at realistic locations. At lower frequencies, a bench instrument on a cart with the antenna elevated on a pole and fed with a coaxial cable is used. At mmWave frequencies, a similar approach with a long cable run results in significant loss. For example, at 70 GHz, a 3 m cable has more than 20 dB loss, reducing measurement range and accuracy. Also, the loss and phase characteristics of cables vary with temperature, which adds to the uncertainty. To address this, a portable spectrum analyzer can be connected directly to the antenna and elevated above the control PC, using a USB extender cable to interface with the analyzer (see ***Figures 3*** and ***4***).

Reducing the number of connections in a test system reduces measurement error and the possible points of failure, including dust or dirt affecting the return loss of a connection. It also minimizes the chance for imperfections that cause test system impedance to vary from 50 Ω. Each connec-



▲ Fig. 4 **Link measurement setup at 28 GHz. A 0 dBm, battery-powered portable source drives the transmit antenna, with a handheld spectrum analyzer connected directly to the receiving antenna.**



▲ Fig. 5 **Mismatch uncertainty (±dB) resulting from two interfaces with reflection coefficients ρ_1 and ρ_2.**

tion in the system (male to female connector pair) will add uncertainty, and mmWave connectors and cables are particularly sensitive. They must be handled carefully to ensure accurate measurements.

Power meter and spectrum analyzer measurements are "scalar," meaning the phase of the signal is unknown. Mismatch at the sensor or analyzer will cause a portion of the signal to be reflected back toward the source. Mismatch at the source will cause this reflection to return towards the sensor or analyzer. As the test frequency changes, the mismatch voltages sequentially sum and cancel, introducing amplitude ripple to the results. The measured values can be either above or below the value achieved with ideal 50 Ω components in a 50 Ω system.

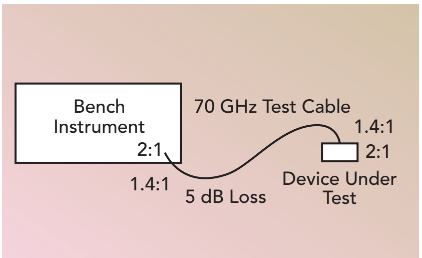
The mismatch uncertainty can be calculated from the voltage reflection coefficient, ρ, of each interface. For two interfaces with reflection coefficients ρ_1 and ρ_2 , the positive and negative uncertainties, u+ and u–, in dB are calculated using the expressions

$$u+ = 10\log_{10}\frac{1}{\left(1-\rho_1\rho_2\right)^2} \qquad (2)$$

$$u- = 10\log_{10}\frac{1}{\left(1+\rho_1\rho_2\right)^2} \qquad (3)$$

ρ can be measured with a vector network analyzer (VNA). A family of uncertainty curves generated from these equations is shown in ***Figure 5***. As an example, if a 70 GHz signal generator with 2:1 SWR ($\rho = 1/3$) is connected to a power sensor or spectrum analyzer having a 2:1 SWR, a 0 dBm power measurement could have worst-case measurement uncertainty range from +0.92 to -1.02 dB. As the number of connections in a system increases, these errors will compound.

Precision, low loss cables can improve system performance. A 2 ft. precision test cable will typically cost more than $1,000 and will still add uncertainty from mismatch and insertion loss (see ***Figure 6***). The issue of cable loss becomes more complicated if multiple cables are used in a system. For example, assume one cable has 5 dB of insertion loss at 30 GHz and 8 dB at 70 GHz. A second cable, from the same manufacturer, has 5 dB insertion loss at 30 GHz but 10 dB at 70 GHz. This scenario, which is not uncommon, makes it difficult to determine the net loss. To properly characterize and remove the impact of the cables, a network analyzer can characterize each cable to discover the net loss at each measurement frequency.



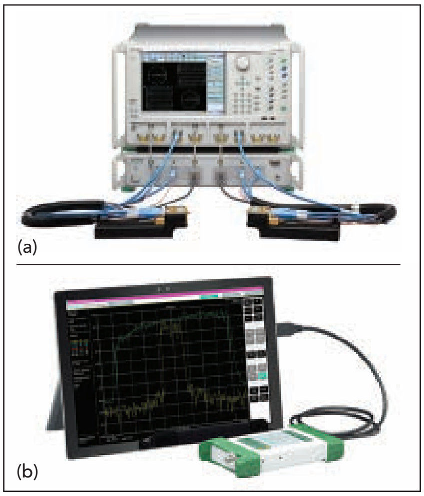
▲ Fig. 6 A precision test cable connecting a measurement instrument to the device being tested will add uncertainty from the cable loss and reflections at the cable interconnects.

This, however, can be complicated, time consuming and costly. The only way to simply and completely remove the impact of cables is to remove them and directly measure the device under test (DUT). In this example, connecting the spectrum analyzer directly to the DUT would improve the sensitivity by 5 dB and reduce measurement uncertainty by approximately ±0.4 dB.

mmWAVE TESTING ADVANCES

Advances in mmWave testing over the years are also enabling more accurate measurements at these frequencies. The introduction of the 40 GHz K connector in 1983, the 70 GHz V connector in 1989 and the 110 GHz W connector in 1997 are examples of such innovations.

Test equipment has also progressed to meet the market need:



▲ **Fig. 7** **Current mmWave test systems: Anritsu VectorStar VNA (a) and MS2760A handheld spectrum analyzer (b).**

VNAs are now available to 145 GHz, as well as spectrum analyzers in ultra-portable form factors (see ***Figure 7***). Some VNAs have very small mmWave frequency extension modules that enable full frequency coverage for on-wafer measurement systems. Using nonlinear transmission line (NLTL) technology allows the probes tips to be mounted directly to the modules, enhancing measurement and calibration stability. A handheld spectrum analyzer using this same technology is slightly bigger than a smartphone and provides performance similar to a benchtop instrument in a much smaller and more affordable design. The small size allows direct connection to almost any DUT.

CONCLUSION

In the past decade, technology improvements in semiconductors, components, cables, connectors and test equipment have helped make it possible for mmWave frequencies to be used for low cost commercial and consumer electronics products and systems. Engineers can ensure the performance of their designs at these higher frequencies by understanding and addressing the issues of connector mismatch error and cable loss, which will yield greater confidence in their products. The continuing evolution of test instruments will significantly reduce mmWave measurement challenges and improve measurement performance and accuracy.■

Modular, Software-Defined Real-Time Spectrum Analyzer

RADX Technologies Inc.
San Diego, Calif.

With their ability to detect, analyze and record elusive signals that are effectively invisible to conventional spectrum analyzers, real-time spectrum (or signal) analyzers (RTSA) have become an essential tool for RF, microwave, radar and electronic warfare applications. As more wideband communication systems incorporate spread spectrum and frequency hopping technologies and since intermittent interference can cause critical interruptions of service in these systems, leading RF test and measurement (T&M) companies now offer advanced, integrated, touchscreen, box instrument RTSAs with real-time analysis bandwidths over 500 MHz, long duration spectrum recording (external), flexible triggering modes and the ability to detect signals with 100 percent probability of intercept (POI) with full amplitude accuracy that are substantially under 15 μs in duration (see ***Figure 1***). One hundred percent POI is a critical metric for assessing RTSA performance, since it prescribes the minimum duration of a signal that can be repeatedly and reliably detected, captured and analyzed by an RTSA. These advanced box instrument RTSAs currently range in price from \$170,000 to over \$300,000, depending on configuration.

THE FIRST MODULAR RTSA

Historically, modular instruments (e.g., VXI, PXI, PXIe) have primarily been employed by integrators in automated test systems (ATS) and by experimenters willing to develop their own applications using example programs from suppliers. Until recently, performance limitations of commercial RF modules and the lack of modular, integrated, touchscreen-optimized, RF T&M platforms precluded the possibility of a commercial off-the-shelf (COTS) modular, advanced RTSA.

That changed in May 2016, when RADX Technologies Inc. (RADX®) introduced the LibertyGT® 1410 real-time vector signal analyzer (LGT1410-RTVSA), the first advanced, integrated, modular, COTS, software-defined, touchscreen-optimized RTSA. The LGT1410 is based on the National Instruments (NI) PXIe-5668R vector signal analyzer (VSA). The NI VSA features exceptional RF capabilities, a 20 Hz to 26.5 GHz frequency range, 765 MHz real-time analysis bandwidth and support for real-time, peer-to-peer streaming of I/Q samples for RTSA processing. The LGT1410 combines the PXIe-5668R with the RADX LibertyGT FPGA-based, real-time, touchscreen-optimized Measurement Science Firmware and Software (MSFS). This combination creates the first modular RTSA that delivers industry-leading performance, ease-of-use and multiple benefits that accrue from the system's modular, software-defined, open architecture. Coupled with a starting price under \$150,000 for a fully-featured, turnkey system, the LGT1410 is also the first modular, advanced RTSA that effectively competes in price, performance and features with proprietary, box instrument RTSAs.

With its dedicated, real-time, FPGA based MSFS, the LGT1410 can process up to 62.5 million fast Fourier transforms (FFT) per second, which is better than the nearest RTSA competitor by over an order of magnitude. The LGT1410 delivers an industry-leading 320 ns minimum signal duration with 100 percent POI at full amplitude accuracy, which is 2x to 10x shorter than its closest rival (see ***Figure 2***).

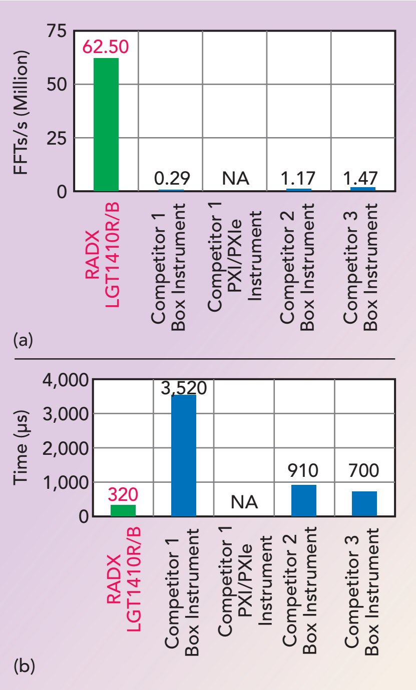
Unlike proprietary, boxed instrument RTSAs, the LGT1410 is truly modular. The LGT1410 is based on

▲ **Fig. 1 A 300 ns pulse eludes detection in a typical spectrum analyzer (a) yet is readily detected by the LGT1410 RTSA (b).**

NI PXIe modules: the PXIe-8880 Intel® Xeon® based embedded controller, PXIe-5668R VSA and PXIe-7976R Xilinx® Kintex®-7 FPGA module (see ***Figure 3***). The modules are deployed in either a reference NI PXIe-1085 24 GB/sec chassis (LGT1410R) or a RADX patent-pending, touchscreen-equipped, 24 GB/Sec PXI/PXIe benchtop enclosure (LGT1410B) that features a unique, hinged front panel for easy access to the PXI/PXIe modules mounted inside.

As a PXI/PXIe-based, software-defined instrument, the LGT1410 supports module-level software and hardware technology insertion that enables seamless, cost-effective upgrades and enhancements, module-level spares, repairs and calibration, and the virtual elimination of life-time-buys for end-of-life subsystems—all of which enable the system to provide superior mean-time-to-repair (MTTR) and reduced total cost of ownership (TCO), compared to monolithic box instruments.

The LGT1410's software-defined architecture enables the system to support multiple LibertyGT applications (apps). The apps are synthesized on the system's hardware, which eliminates the need for additional instruments and reduces system size, weight and power, along with acquisition and operating costs.



▲ **Fig. 2 Comparison of RTSA performance at 26.5 GHz: FFTs/s (a) and minimum signal duration for 100 percent POI (b).**

CAPABILITIES AND OPTIONS

The LGT1410 includes the LibertyGT object-oriented, LabVIEW-based MSFS framework with touch-screen GUI, VISA TCP/IP remote interface, comprehensive applications programming interface (API) and the following standard apps:

- Real-time spectrum analyzer (RTSA-2) with 320 ns minimum signal duration at 100 percent POI with full amplitude accuracy (export license required)
- Spectrum analyzer
- Real-time vector signal analyzer (RTVSA) with standard digital and analog demodulators
- SSD-based narrowband signal and spectrum recording and playback
- Standard DSP-based RF power, RF counter and error meters
- Internal bit error rate (BER) tester, pattern generator and receiver (via RF, Ethernet, RS-232C or USB)
- Internal audio analyzer (via RF and Ethernet)

Because of its modular, software-defined architecture, the LGT1410 supports extensive internal options that enable the LGT1410 to be upgraded to provide a complete benchtop ATS capability. The LGT1410, unlike boxed instruments, does not require additional external subsystems to upgrade, although some may require additional PXI/PXIe modules (noted by *):

- Multi-channel real-time VSA for simultaneous capture, demodulation and analysis of up to 128 channels
- Internal LabVIEW or MATLAB post processing
- Dozens of NI and third party apps available via the LabVIEW Tools Network (see www.ni.com/labview-tools-network)
- Advanced spectrum recording with 8 to 64 TB of internal RAID modules* that supports up to 765 MHz bandwidth
- Internal IRIG-B or GPS time-stamping* for spectrum monitoring
- Second RTSA channel*
- 10 Gigabit Ethernet*
- Internal RF or vector signal generator*

Rosenberger

www.rosenberger.com

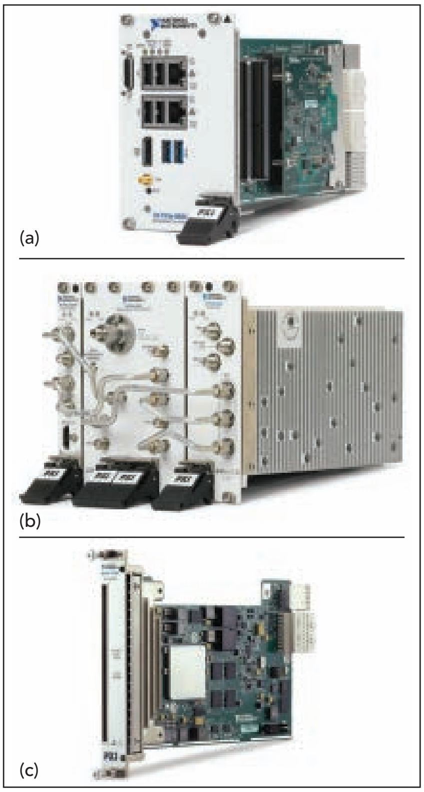
Test, Measurement & Calibration

RF and microwave components from Rosenberger play a key role in a variety of test, measurement and calibration applications. RF high precision connectors, adaptors & devices, PCB connections – solderless, modular system or even spring loaded products – calibration kits, microwave test cables, VNA test port cables or automated test equipment products – renowned companies trust the precision and quality of Rosenberger test & measurement products.

Fields of Application

- Microwave measurements & VNA calibrations
- Lab testing
- Factory testing
- PCB connections
- Semiconductor test applications & high-speed digital testing
- Network testing
- Test & measurement equipment
- Service and support

Rosenberger | Hochfrequenztechnik GmbH & Co. KG
Hauptstraße 1 | 83413 Fridolfing | Germany | Phone +49 (0)8684 18-0 | info@rosenberger.de



▲ **Fig. 3 Modular components of the LGT1410: PXIe-8880 embedded controller (a) PXIe-5668R VSA (b) and PXIe-7976R FPGA module (c).**

- Internal digital storage oscilloscope (DSO)*
- Internal digital multi-meter (DMM)*

All LGT1410 apps are accessible via the system's intuitive HD 1080 pixel touchscreens, standard VISA/TCP/IP remote interface and the included LibertyGT API, which supports programming in LabVIEW, TestStand, Python, C, C++ and Java. The LGT1410 also includes a powerful, Intel Xeon-based embedded controller that eliminates the need for a separate test executive computer for sequencing automated tests. Since all the LGT1410 apps are part of a unified programming environment, test programming on the LGT1410 is greatly simplified.

A fully configured, integrated LGT1410R including RTSA-2 (export license required) starts at $148,500 and is available with an 8 to 12-week lead-time from RADX. LGT1410 kits, including RADX MSFS, accessories and RADX touchscreen PXIe enclosures are available for customers with existing NI purchasing relationships.

RADX Technologies Inc.
San Diego, Calif.
www.radxtech.com

Speed Meets Accuracy in a New EM Scanning Technique

EMSCAN
Calgary, Alberta, Canada

For designers of integrated circuits and circuit boards, electromagnetic emissions are a critical concern. Designers need to ensure the final products comply with international standards for controlling radiated emissions. They must also ensure that a product does not cause self-interference or interference with other devices when part of a larger system. If electromagnetic interference (EMI) and electromagnetic compatibility (EMC) problems are not detected and fixed early in the design process, the consequences can include production delays, missed time-to-market goals and higher costs. To correct EMI and EMC problems early, they must be identified before compliance testing, with detailed information that standard far-field compliance testing cannot provide. Far-field measurements indicate whether a device has passed or failed, but they do not add much value for discovering the root cause of an emissions issue. For this reason, very-near-field tools capable of pinpointing problems are essential; the faster and more accurate the tools, the better.

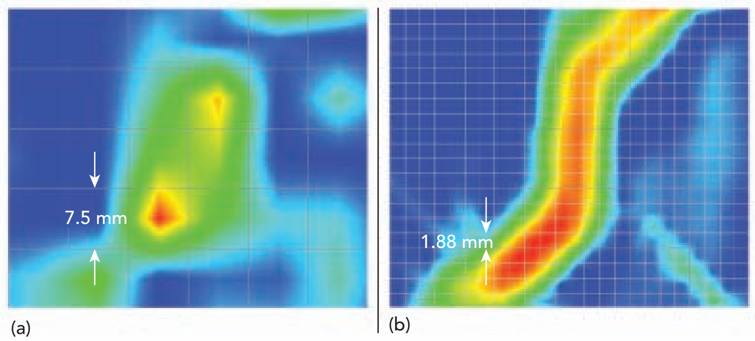


Fig. 1 EMxpert ERX+ spatial scans at levels 1 (a) and 3 (b).

Most available tools emphasize high speed or high precision, not both. A traditional handheld probe is useful for finding sources of emissions, yet it doesn't provide an overall picture of the board and can miss potential sources of emissions. Robotic positioners will individually scan all the features where emissions might occur and with high precision, but they can take hours. A much faster method is using a scanning array that applies multiple probes simultaneously, enabling the user to measure an entire board or section in less than a second. Not only faster, a scanning array is repeatable.

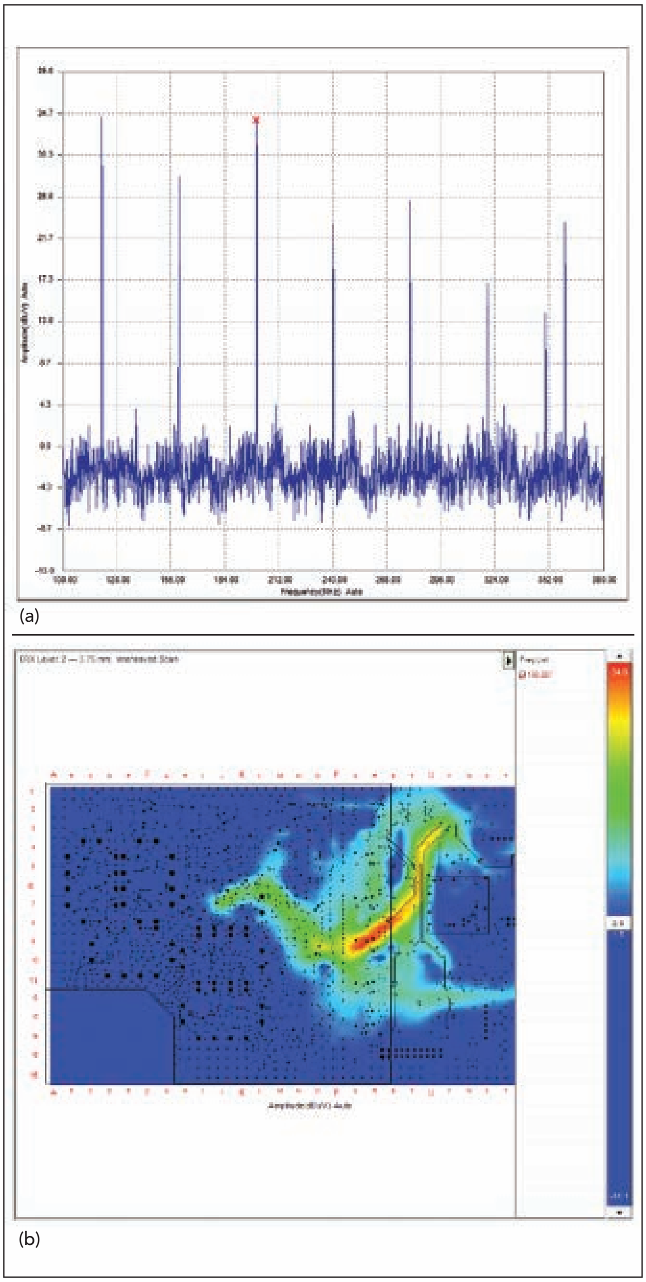
THE BEST OF BOTH

A new scanning technique is available that delivers both speed and accuracy, with the ability to precisely pinpoint emissions in just minutes, even from inside an integrated circuit

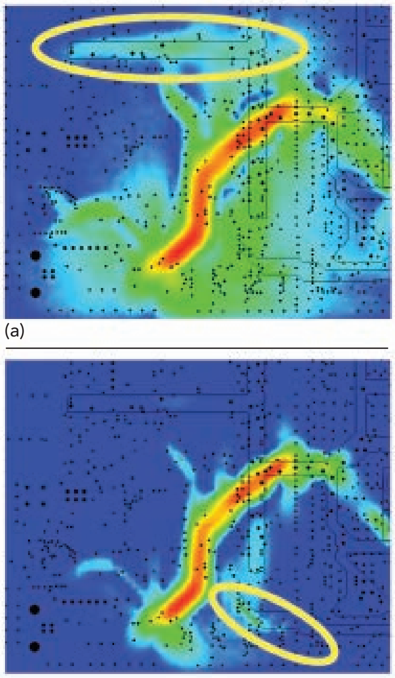
or microchip. The EMxpert™ ERX+™ from EMSCAN™ provides higher resolution by combining a 1218-probe array with a fine and precise mechanical motion. A robotic positioner moves the entire array methodically to fill in the distance between probes. This technique increases the density of points measured—up to 65,000x the number of points—by dividing the scanned area into tighter and tighter grids according to user settings (see ***Figure 1***). The ability to increase density makes a significant difference in the resolution of the spatial image provided by the scan. For example, changing from a level 1 scan to a level 8 scan, the highest density setting, reduces the effective spacing between measurement points from 7.5 to just 0.06 mm. Details of small features become available, even inside components.

The EMxpert ERX+ enables quick sampling of the magnetic field distribution of a product, with a visual display of the results. An embedded spectrum analyzer with intuitive visual imaging provides both a spectral view, to identify the frequencies of emission, and a spatial view, to visualize location (see ***Figure 2***).

A quick scan typically identifies many emissions. The EMxpert ERX+ software allows the scan to "jump around" the board, zoom in and isolate emissions by location or frequency. Overlaying a design file or image of the board on the spatial view makes it easy to correlate the energy shown in the display with specific circuit board features, such as ICs, power planes and control lines (see ***Figure 3***). For multilayer boards, multiple layers can be displayed to follow emissions coming from a trace that starts on one layer and continues deeper. If currents move to an internal layer that is shielded, there will be no fields in the external environment for the EMxpert ERX+ to measure. In this case, the currents are not relevant to a radiated emissions problem. If the shielded feature is the root cause of emissions leaking out of holes in



▲ **Fig. 2** **Spectral (a) and spatial (b) views of a scan.**


(a)
(b)

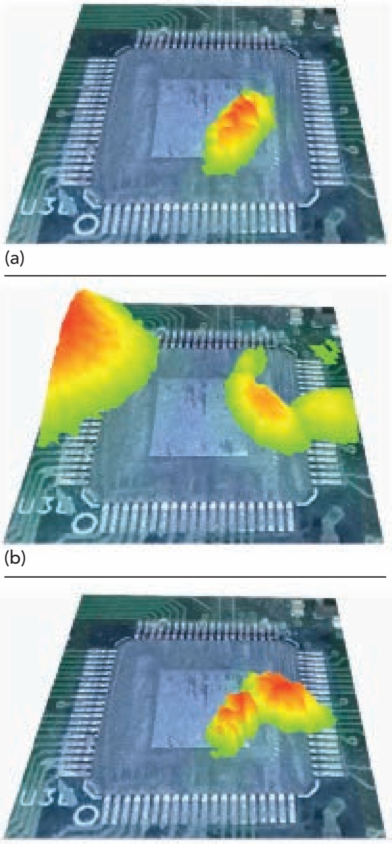
▲ Fig. 3 Energy coupled onto power plane (a) and control line (b).

the shield or at the board edge, the scanner will be able to measure it.

INSIDE AN IC

The extremely high resolution of the EMxpert ERX+ enables it to peer inside an IC and isolate the radiation from individual pins and wire bonds at various frequencies. Spectral and spatial views can be combined to provide a three-dimensional image of the emissions. Looking inside an IC, it is possible to see the sources of radiation, whether they are coming from the die region, from pins on the IC or spilling onto the IC from a different portion of the board (see ***Figure 4***). Using this information with knowledge of the IC design, the user can solve the emissions problem.

The capabilities provided by EMxpert ERX+ add up to faster time-to-market, reduced project cost and increased productivity. EMxpert ERX+ presents real-time scans in seconds that identify spurious and continuous EM emissions. It provides spatial and spectral scans that allow design teams to cut one


(a)
(b)
(c)

▲ Fig. 4 Views of IC emissions at 100 (a) 120 (b) and 130 MHz (c).

to two design cycles out of product development. It also reduces EMI testing time by up to two orders of magnitude. EMxpert ERX+ enables scans to be conducted where designers are located, obtaining results in minutes. Testing a new design in a third-party chamber could require traveling to an offsite test facility for the day, after potentially waiting days or weeks for a chamber to become available. The spatial and spectral scans provided by the EMxpert ERX+ system improve the ability to document new features and can be key elements in product marketing, giving customers graphic proof of a product's EMI characteristics.

**EMSCAN
Calgary, Alberta, Canada
www.emscan.com**

40 and 70 GHz Test Boards Verify VNA Cals

Signal Microwave and GigaProbes have developed a line of 40 and 70 GHz test boards for verifying VNA calibration (cal) and checking for measurement drift. To check a cal, many operators use only a low loss through adapter; however, this only verifies that the system noise was removed. A "golden unit" with a known response over frequency should be used to verify that the cal was successful.

The standard test board design includes a 50 Ω line, a 50 Ω line with a 25 Ω "Beatty" line section to verify time domain measurements and a 100 Ω differential line. Many variations of the board can be created, including differential probe lines with both probe-to-connector and probe-to-probe lines.

The test boards are designed for high performance and ruggedness. The edge-launch connectors, manufactured by Signal Microwave, were designed using 3D modeling and RF transmission line analysis. The board launch, the transition from the board to the connector, has a grounded coplanar waveguide (GCPWG) section incorporating a top ground launch that transitions the ground to an inner layer as it transitions to a microstrip line. Rogers' RO4003 with a thickness of 8 mils and ½ oz. copper is used for the board. The finish on the board is electroless nickel with a top layer of immersion gold (ENIG). The RO4003 is processed by itself, including drilling vias and plating, and is then laminated to an FR4 backer for mechanical stiffness. The board incorporates a custom design standoff with magnets at the end to hold the board securely to a magnetic plate.

Signal Microwave
Chandler, Ariz.
signalmicrowave.com

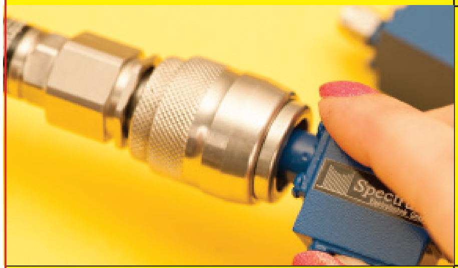
GigaProbes
San Carlos, Calif.
www.gigaprobes.com

Procedure for how to use the N, TNC and 7/16 Push-On male. Push-On Connectors mate with any standard female connector of the same connector style.

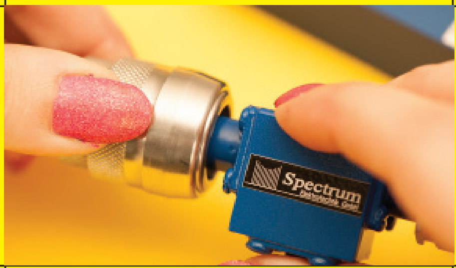
1. Convert your standard Assembly into a Push-On Assembly using the Nf to Nm Push-On Adapter.

2. Put your fingers firmly onto the knurls of the "Lock Nut".

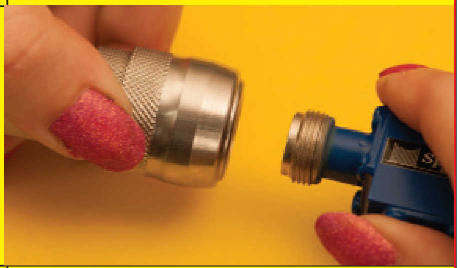
3. Push "Lock Nut" forward and engage the Push-On end of the Adapter with the mating female. Back nut must be released.



4. The Connection has been completed, easy and fast. The connector has been locked on safely.



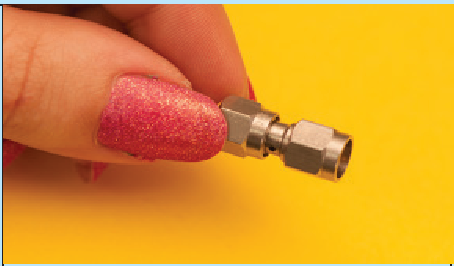
5 . To unlock (when "Back Nut" is in unlocked mode) push the "Lock Nut" forward and stop reverse movement by setting your fingers onto the "Back Nut".



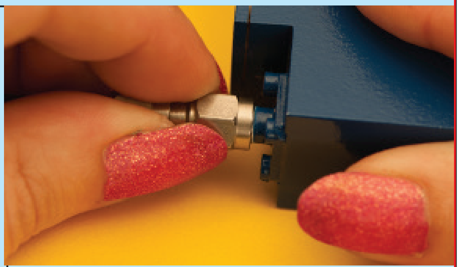
6. Keep fingers on "Back Nut" to ensure that "Lock Nut" cannot slide back and pull the connector off.

Procedure for how to use the SMA male and SMA female Push-On connectors. SMA Push-On Connectors mate with any standard connector of the same but opposite connector style.

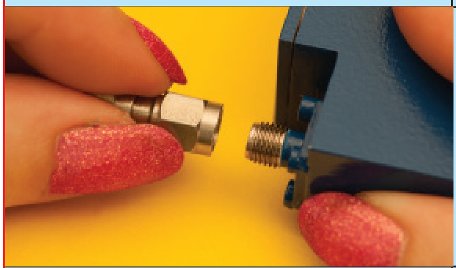
1. Convert your standard cable assembly into a Push-On Assembly by threadening the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted into an SMA male Push-On Assembly.



3. Just slide the Push-On SMA male Connector onto any standard SMA female. The connection is securely completed in seconds.

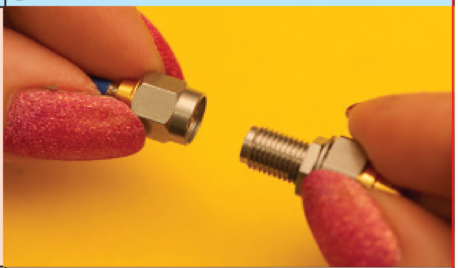


4. To disconnect, just pull the connector off.

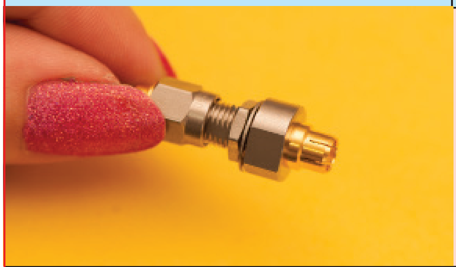
Spectrum Elektrotechnik GmbH

Please contact us at:
www.spectrum-et.com
Email: sales@spectrum-et.com
Phone: +49-89-3548-040
Fax: +49-89-3548-0490

Spectrum Elektrotechnik GmbH

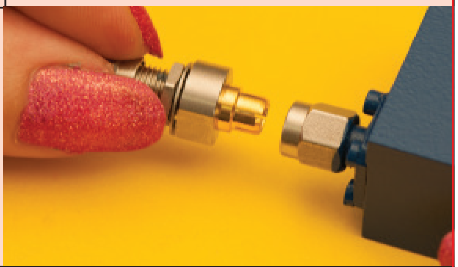


1. Convert your standard cable assembly into a Push-On Assembly by threadening the standard female side of the adapter onto the male connector of the assembly.



2. Your standard SMA male cable assembly is converted to a Push-On SMA female Cable Assembly.

3. Just slide the Push-On SMA female Connector onto any standard SMA male. The connection is securely done in seconds.



4. To disconnect, just pull the connector off.

Web and Video Update

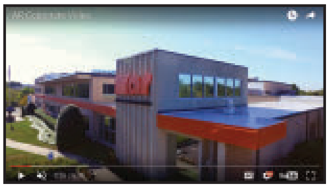
Transmission Line Calculator Tool

Antenova launched a series of tools and resources to help product designers successfully integrate antennas onto new PCB designs simpler and faster. This free Antenna Transmission Line Calculator tool will help designers calculate the Grounded Coplanar Wave Guide trace and optimize antenna performance, based on the key parameters of a PCB design. This is available for download at www.antenova-m2m.com/free-download-antenova-transmission-line-design-tool/. Antenova's other online resources include datasheets, CAD and STEP footprint files, antenna performance and design tips, and videos covering antenna design and implementation.

Antenova Ltd.
www.antenova-m2m.com

New Corporate Video

VENDORVIEW

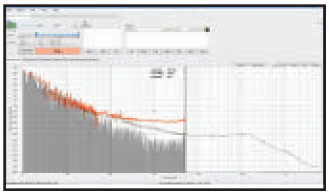


AR was forged on some very powerful ideas and a very simple premise. Products that last are good for the company, and very good for their customers. The AR family of companies make RF & EMC related products—power amplifiers, antennas, systems and components for commercial, military, wireless and EMC. AR pushes technological boundaries and remains the leader in the industry after nearly five decades. The company provides a level of customer care and service that is unsurpassed.

AR RF/Microwave Instrumentation
www.arworld.us/corpVid

"One-Click" Simplicity

VENDORVIEW



Tutorial videos on pulsed phase noise measurements are available on the Berkeley Nucleonic's website. This video shows the advancement in "one-click" simplicity with the model 7000 series with these traditionally complex and cumbersome measurements. The SSA model 7000 series is a complete broadband 2 MHz to 25.6 GHz turnkey system offering absolute and additive phase noise measurements, AM, pulsed, VCO characterization. A fraction of the cost and complexity than any other system in the industry.

Berkeley Nucleonics Corp.
www.berkeleynucleonics.com

Interactive Capability

After months of dedicated hard work, Dow-Key Microwave announced the launch of their newly designed website. The site includes a new mobile friendly platform which can be displayed and supported on any smartphone or tablet to better serve their customers. Dow-Key's goal is to provide a more effective way to access information while providing enhanced interactive capability for better understanding of the company's design, development and manufacturing abilities.

Dow-Key Microwave Corp.
www.dowkey.com

Updated RF Assembly Calculator

VENDORVIEW

The popular HUBER+SUHNER RF assembly calculator has been updated and provides many additional features. The product portfolio has been enhanced with recently launched cable assemblies such as the new SUCOFLEX series (126/229/240/329/340). In the new version, attenuation and CW power can be calculated individually, plus the manual calculation options have been extended. This allows various electrical calculations apart from the HUBER+SUHNER cable portfolio.

HUBER+SUHNER
http://rfcablecalc.hubersuhner.com

User-Friendly Experience

Integrated Microwave Technologies (IMT), a business unit of xG Technology Inc. (xG), announced the launch of its new company website. The new design for www.imt-solutions.com delivers a more streamlined experience that is easier to navigate and provides improved functionality for its current and potential customers. The new website builds on IMT's customer support portal, which was deployed earlier this year. The new pages are organized by application, allowing users to find products that fit their specific needs and highlight full turnkey solutions.

Integrated Microwave Technologies (IMT)
www.imt-solutions.com

Web and Video Update

Low Cost RF Connectors

Intelliconnect (Europe) Ltd. launched a new website offering easier navigation, search facilities and a new "quote basket" that allows customers to request a quote for selected products. Also, the new online cable selector enables customers to build a custom cable assembly and request a quote. Another key element of the new website is the launch of the Taurus Range of RF connectors, a new range of low cost, high quality standard coaxial connectors and adaptors. A brochure detailing all Intelliconnect products is available for download.

Intelliconnect (Europe) Ltd.
www.intelliconnect.co.uk

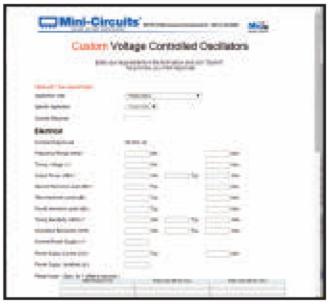
Improved Navigation

K&L Microwave's website provides information and tools, such as the Filter Wizard® web application to speed the identification of custom design solutions from a full range of company products. The latest web update features a new look, mobile device support, social media links and improved LTE band navigation to test set components for broadband emission monitoring. Research capabilities, access datasheets, submit quote requests and download catalog sections. Visit www.klmicrowave.com today.

K&L Microwave
www.klmicrowave.com

Custom VCO Spec Checklist

VENDORVIEW



Need a VCO custom designed for your project? Visit minicircuits.com and try their online custom VCO spec checklist. Simply enter your requirements and a little information about your project, and click submit for a fast response. Mini-Circuits' engineers will review your application, determine feasibility and provide a proposal. They can optimize models for wideband, linear tuning, dual output, low phase noise and more for low cost and with fast turnaround.

Mini-Circuits
www.minicircuits.com

Web and Video Update

Interactive Tools Simplify RF Design

Qorvo's® new website offers tools to support the design process and a simpler e-commerce portal for online ordering. The new Qorvo.com combines all core RF products from Qorvo and its legacy companies, TriQuint and RFMD. Visitors can search the unified catalog by product type or application, then easily access additional details and datasheets, request a sample or quote, or buy products online. Central to the site is the Qorvo Design Hub, where engineers can access how-to information, interactive design tools, videos, e-books and educational blogs.

Qorvo Inc.
www.qorvo.com

New Website is Live

VENDORVIEW

SPINNER Group's new website has gone live. It features a new design that is more clear, contemporary and user-friendly. The website has also been optimized for use across all devices: smartphones, tablets and desktop computers. Content now automatically adapts to the user's screen resolution, so that everything can be viewed on any device without any loss of functionality or quality. SPINNER is thus responding to the accelerating trend toward mobile Internet use.

SPINNER GmbH
www.spinner-group.com

Compression Mount Application Note

SV Microwave announced the release of their new Compression Mount Application Note. The application note details the benefits/features and applications of the company's hot selling solderless precision RF compression mount connectors. They are available in high frequency bands including mmWave frequencies. SV Microwave's solderless application makes assembly fast, easy and without damaging the PCB board. Additionally, COTS versions are readily available through distribution. Available for download on their website at www.svmicrowave.com/resources/application-notes.

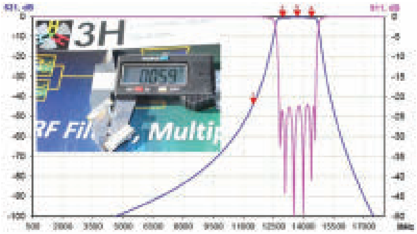
SV Microwave
www.svmicrowave.com

NEW PRODUCTS

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

COMPONENTS/DEVICES

Pico Series Filters



3H's new Pico series filters offers high performance in its new miniature package with sizes starting at 0.65" × 0.20" × 0.060". Their SMT Pico filters are available for tape and reel and can be compliant to RoHS. 3H miniature filters are available from 40 MHz to 19 GHz with selectivity up to 60 dB. Please contact 3H Communication Systems at (949) 529-1583 or email sales@3hcomm.com.

3H Communication Systems
www.3Hcommunicationsystems.com

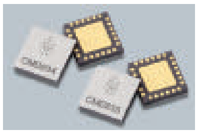
Single Step Programmable Attenuator

Model 651-030-006 is a single step voltage controlled programmable attenuator designed for use in scientific instruments. The frequency range is DC to 1 GHz. Attenuation range is 0 to 6 dB in a 6 dB step with ± 0.4 dB attenuation accuracy. Insertion loss is 0.6 dB nominal while VSWR is 1.30:1 maximum. Input power is 1 W average with supply voltage +15 VDC @ 30 mA nominal. The RF connectors are SMA female and the control solder terminal features a feed-thru capacitor to prevent leakage.

BroadWave Technologies Inc.
www.broadwavetech.com

Non-Reflective Switches

VENDORVIEW



Custom MMIC has added two new GaAs MMIC switches to its expanding product offerings, the non-reflective CMD234C4 and CMD235C4. The CMD234C4 is a DC to 18 GHz broadband MMIC SP3T switch featuring a low insertion loss of 2.4 dB and a high isolation of 40 dB at 10 GHz. The CMD235C4 is a DC to 18 GHz broadband MMIC SP5T switch offering broadband performance with an insertion loss of 2.5 dB and high port-to-port isolation of 40 dB at 10 GHz.

Custom MMIC
www.custommmic.com

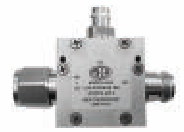
6 GHz RF Digital Step Attenuator

DS Instruments introduced the DAT64F, a compact and full featured RF step attenuator that covers 100 MHz to 6 GHz. The step size is upgraded to 0.25 dB and insertion loss is reduced to just 6 dB. Attenuation can be set manually via front panel controls, or remotely programed over the range of 0 to 63 dB. The USB port is configured as power source and industry standard COM port requiring no additional drivers.

DS Instruments
www.dsinstruments.com

Low PIM Bias Tees

VENDORVIEW



Low PIM (-165 dBc typical), high power (7 amp), bias tees for DAS applications, with rugged construction and excellent performance across all wireless bands from 0.698 to 2.7 GHz make them ideal for in-building or tower top systems. They are available in various Type N configurations as well as custom. Weatherproof IP 67 standard, IP68 available. Made in U.S. and 36-month warranty.

MECA Electronics Inc.
www.e-MECA.com

Dual/Differential Lowpass Filter

VENDORVIEW

Mini-Circuits' DLF-CV-1000+ is a dual lowpass filter with a passband from DC to 1000 MHz designed into a single 1210 ceramic package. The dual filter can also be used as a differential filter in differential circuits where interference and noise must be minimized. This model provides 1.2 dB passband insertion loss, 27 dB stopband rejection with steep roll off, and RF input power handling up to 8.5 W (each filter). It supports a wide range of applications and is ideal for minimizing interference at amplifier inputs and ADC outputs.

Mini-Circuits
www.minicircuits.com

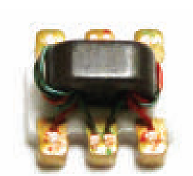
Revolutionary Reflectionless Filter

VENDORVIEW

Mini-Circuits' new XHF2-153+ reflectionless highpass filter has a passband from 15.3 to 30 GHz with a 3 dB frequency cutoff at 14.2 GHz, supporting a wide range of applications including WiMAX, military, space and more. It provides 1.8 dB passband insertion loss, 2.1:1 passband VSWR, 13.7 dB stopband rejection, 2.2:1 stopband VSWR and 1.26 W RF input power handling in the passband (0.16 W in the stopband). It comes housed in a tiny 2 mm x 2 mm QFN package, allowing designers to use it almost anywhere on their PCB.

Mini-Circuits
www.minicircuits.com

SMD Splitters



Are your passives getting performance only some of the time? Then "split" quickly to the MiniRF line of high performance splitters "peas in the pod" performance from the first one to the next >10K units built. MiniRF offers wide bandwidth, excellent isolation, low insertion loss and excellent I/O return loss for superb matching between components. Look for these products and full line of transformers/combiners/couplers on MiniRF's website.

MiniRF
www.MiniRF.com

4-Way Amplified Power Divider Module

VENDORVIEW

PMI Model No. APD-4-20M6G-28V is a 4-way amplified power divider module for use over

the frequency range of 20 MHz to 6 GHz with 3.5 dB of gain, and a typical output P1dB of 9 dBm. This model is designed to have a low noise figure over a broad frequency range. Features include SMA female connectors, 9 pin sub-miniature D (Male) with supplied mating connector. Unit size is 2" × 2" × 0.4".

Planar Monolithics Industries Inc.
www.pmi-rf.com

New**Products**

Miniature 1.5 to 30 MHz Bandpass Filters

Pole/Zero released their new line of HF-ERF™ tunable bandpass filters. HF-ERF™ filters tune using either parallel or Serial Peripheral Interface (SPI) tuning control and are fully pre-aligned by Pole/Zero for labor savings and ease of use. These low-cost bandpass filters are commonly used in applications where small size, low power and high performance are needed such as military handheld radios, radar systems, SATCOM, test and measurement systems and additional commercial applications. Email support@polezero.com for more information.

Pole/Zero
www.polezero.com

SPDT Electro-Mechanical Switch

RF-Lambda multiport switch improves insertion loss repeatability and isolation, which is necessary for higher performance test systems. The repeatability and reliability of this switch is vital to ATS measurement accuracy and can cut the cost of ownership by reducing calibration cycles and increasing test system up time. The RF-Lambda terminated multiport switch provides the long life and reliability required for automated test and measurement, signal monitoring, and routing applications. Highly repeatable switching capability is made possible through RF-Lambda's rigorous design and tight manufacturing specifications.

RF-Lambda
www.rflambda.com

High Power 18 GHz SPDT Switch

RLC Electronics announced the addition of a high power 18 GHz SPDT switch with N connectors to its product capabilities. The switch can handle 1000 W at 100 MHz, 200 W at 4 GHz and 125 W at 18 GHz, and provides high reliability, long life and excellent electrical performance characteristics over the frequency range (including high isolation). Options on the switch include operating mode (failsafe or latching) and coil voltage (12 or 28 VDC), as well as indicator circuitry and a TTL driver.

RLC Electronics Inc.
www.rlcelectronics.com

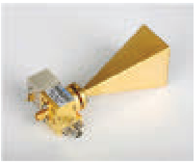
Broadband Circulators and Isolators

VENDOR**VIEW**

To support the ongoing development of E-Band communication, SAGE Millimeter released a new series of broadband circulators and isolators that cover the frequency range of 71 to 76 GHz and 81 to 86 GHz. The circulators, models SNW-7137630818-12-C1 and SNW-8138630818-12-C1, and isolators, models SNW-7137630818-12-I1 and SNW-8138630818-12-I1, provide a low insertion loss of 0.8 dB maximum, a minimum isolation of 18 dB, and a short insertion length for system integration. The input and output ports are WR-12 waveguides with UG-387/U flanges.

SAGE Millimeter
www.sagemillimeter.com

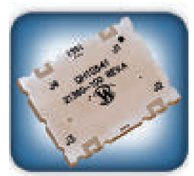
V-Band Frequency Converter



Serving the 5G/WiGig research efforts, Spacek Labs' new V-Band frequency converter, model M64-7X2B accepts an RF input frequency from 57 to 71 GHz. An internal LO X2 multiplier generates the 57 to 71 GHz LO. The IF output frequency is 0.01 to 14 GHz. The mixer conversion loss is 6 dB typ, 8.5 dB max. The RF port is also available in 1 mm coax. In addition, this mixer assembly can be used as an up-converter.

Spacek Labs
www.spaceklabs.com

SMT 90° Hybrid Coupler



Werlatone's newest 90° hybrid coupler covers the full 700 to 6000 MHz band, and is rated at 100 W CW. Ideal for combining at the modular level, the QH10541 operates with less than 0.5 dB of insertion loss and better than 18 dB isolation. Measuring just 0.66" x 0.86" x 0.09", the QH10541 is one of the smallest and most robust SMT 90° hybrid designs available today.

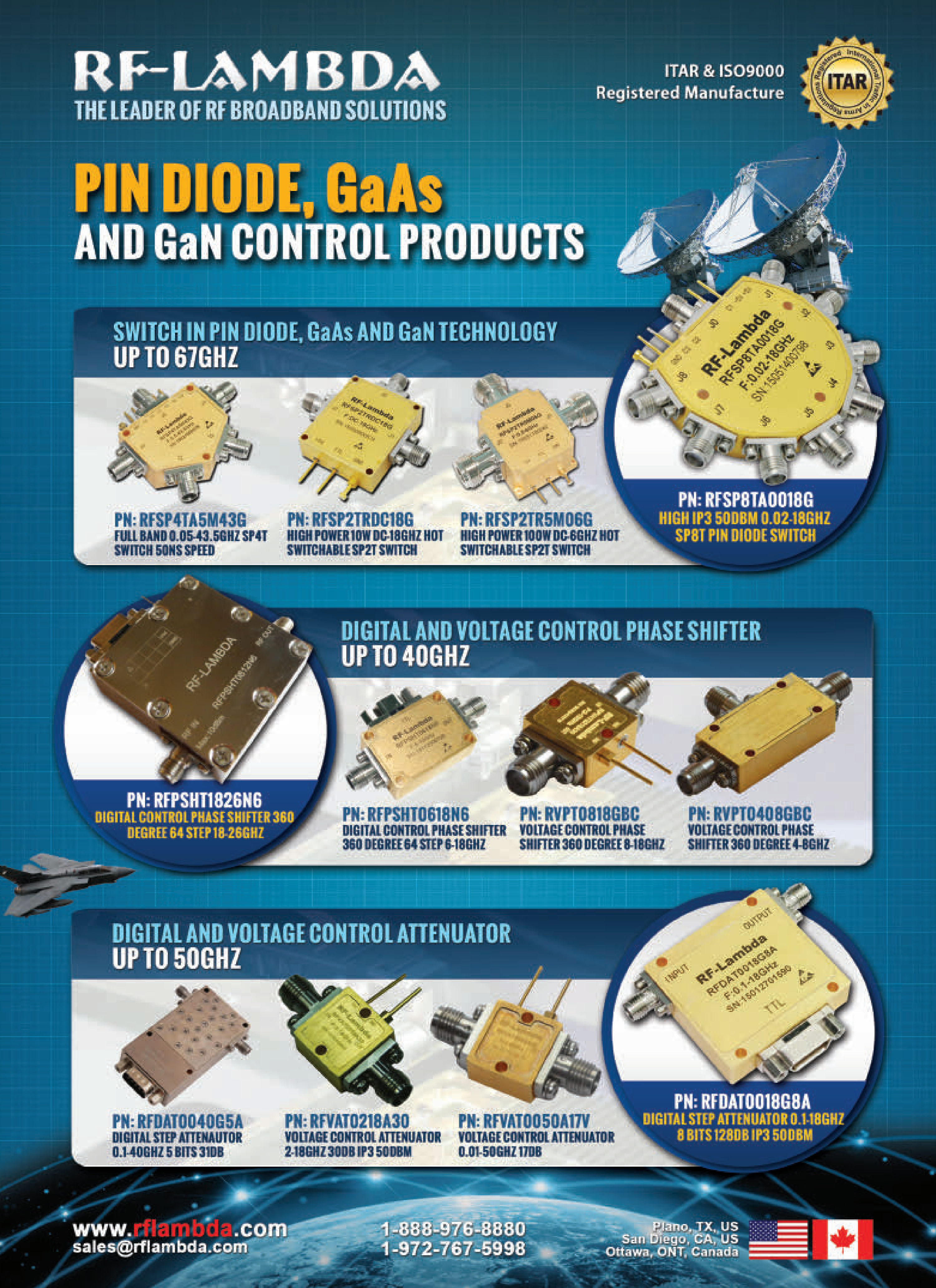
Werlatone Inc.
www.werlatone.com

CABLES & CONNECTORS

MMBX Connectors and Adapters

Fairview Microwave Inc. now offers small form factor MMBX connectors and adapters most commonly used on circuit boards and their associated input/output connections for industrial, telecom and consumer product applications. MMBX-style connectors and adapters are specifically designed to provide versatile and easy PCB-to-PCB connections as well as coax-to-PCB connections. Their mechanical design also allows them to work well in backplane applications.

Fairview Microwave
www.fairviewmicrowave.com


RF-LAMBDA
THE LEADER OF RF BROADBAND SOLUTIONS
ITAR & ISO9000
Registered Manufacture
ITAR
PIN DIODE, GaAs
AND GaN CONTROL PRODUCTS
SWITCH IN PIN DIODE, GaAs AND GaN TECHNOLOGY
UP TO 67GHZ
PN: RFSP4TA5M43G
FULL BAND 0.05-43.5GHZ SP4T SWITCH 50NS SPEED
PN: RFSP2TRDC18G
HIGH POWER 10W DC-18GHZ HOT SWITCHABLE SP2T SWITCH
PN: RFSP2TR5M06G
HIGH POWER 100W DC-6GHZ HOT SWITCHABLE SP2T SWITCH
PN: RFSP8TA0018G
HIGH IP3 50DBM 0.02-18GHZ SP8T PIN DIODE SWITCH
DIGITAL AND VOLTAGE CONTROL PHASE SHIFTER
UP TO 40GHZ
PN: RFPSHT1826N6
DIGITAL CONTROL PHASE SHIFTER 360 DEGREE 64 STEP 18-26GHZ
PN: RFPSHT0618N6
DIGITAL CONTROL PHASE SHIFTER 360 DEGREE 64 STEP 6-18GHZ
PN: RVPT0818GBC
VOLTAGE CONTROL PHASE SHIFTER 360 DEGREE 8-18GHZ
PN: RVPT0408GBC
VOLTAGE CONTROL PHASE SHIFTER 360 DEGREE 4-8GHZ
DIGITAL AND VOLTAGE CONTROL ATTENUATOR
UP TO 50GHZ
PN: RFDAT0040G5A
DIGITAL STEP ATTENAUTOR 0.1-40GHZ 5 BITS 31DB
PN: RFVAT0218A30
VOLTAGE CONTROL ATTENUATOR 2-18GHZ 30DB IP3 50DBM
PN: RFVAT0050A17V
VOLTAGE CONTROL ATTENUATOR 0.01-50GHZ 17DB
PN: RFDAT0018G8A
DIGITAL STEP ATTENUATOR 0.1-18GHZ 8 BITS 128DB IP3 50DBM
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
Plano, TX, US
San Diego, CA, US
Ottawa, ONT, Canada

New**Products**

RF Microwave Coaxial Cable & Cable Assemblies

High Speed Interconnects 141, RF microwave sssemblies are designed to be cut to any length, terminated to 2.92 connectors, and shipped within 1 week. 48" HSI assembly delivers ± 2.5° phase and ±0.05 IL stability (180° flexure), IL 2.4 dB, VSWR 1.25:1 through 40 GHz.

High Speed Interconnects
www.highspeedint.com

SMA Between-Series Adapters

SGMC Size #8 to SMA adapters are precision between-series adapters that feature DC to 18 GHz; VSWR: 1.15:1 Max; blindmate interface; body & contact: heat treated beryllium copper/gold plated; dielectric: PTFE (Teflon); O-rings and fluorosilicone rubber; epoxy captivated. SGMC Microwave's hallmarks are always: quality, performance and reliability. Stock available.

SGMC Microwave
www.sgmcmicrowave.com

AMPLIFIERS

Single Band Amplifier

VENDOR**VIEW**

Model 500S1G6 is a 500 W CW solid-state amplifier that has 57 dB gain, delivers 100% rated output power without foldback over the instantaneous 0.7 to 6 GHz band and can survive output VSWR.

AR RF/Microwave Instrumentation
www.arworld.us

Solid-State Power Amplifier Module

COMTECH PST introduced another new GaN amplifier for X-Band applications. This class AB linear design operates over the full 9 to 10 GHz frequency range and is ideal for use in phase array radar applications, as a TWT replacement or for a microwave communication link. The amplifier features phase and amplitude control, internal DC to DC converters and DC filtering, PA self-test and LED fault indications, unique waveguide coupling circuits, an internal isolator and digital control via a magic tee.

Comtech PST
www.comtechpst.com

NewProducts

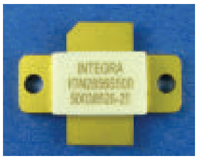
VHF/UHF Amplifier

VENDORVIEW

Exodus Advanced Communications announced the release of its VHF/UHF amplifier model AMP1136, a new 20 to 1000 MHz, 200 W Min CW LDMOS module. It features instantaneous bandwidth with 3 dB peak-to-peak flatness and 24 A max consumption operating from a 32 VDC source. This unit is suitable for all single channel modulations standards and has built in protection circuits. Other notable characteristics are its small form factor, high power density, high reliability and ruggedness. It is designed for EW, EMI/RFI and any other application requiring high power in the VHF/UHF frequency range.

Exodus Advanced Communications
www.exoduscomm.com

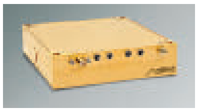
GaN-on-SiC Transistor



Designed for S-Band ISM applications, this high-power GaN-on-SiC HEMT transistor supplies 500 W of peak pulsed output power at 50 V drain bias, with 12 dB of gain and 60% of efficiency at 12 µs, 3% pulse conditions.

Integra Technologies
www.integratech.com

Power Amplifiers



Millitech released a series of power amplifiers leveraging advanced PHEMT MMICs and transistors which yield millimeter wave saturated power as high as 38 dBm at 35.5 GHz and 15.5 dBm at 110 GHz. Frequency ranges for Millitech's AMP devices extend from 18 to 110 GHz with corresponding and standard waveguide or coaxial connector interfaces. The AMP series of amplifiers offers internal bias circuitry that generates gate control voltages, provides proper voltage sequencing, and incorporates reverse voltage protection from a single positive external bias.

Millitech
www.millitech.com

2 W GaN Driver

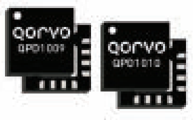
VENDORVIEW

RFMW Ltd. announced design and sales support for a driver amplifier designed to support HPA implementation from 13 to 18 GHz and providing 2 W of saturated output power. The Qorvo TGA2958-SM is compatible with GaN HPA bias conditions allowing it to run from the same supply as the high-power amplifier. The TGA2958-SM, 3-stage driver, has a small signal gain of >25 dB yet draws only 70 mA of CW bias. Ideal for applications in radar, satellite communications and data links, the Qorvo TGA2958-SM is offered in a 4 mm x 4 mm QFN package.

RFMW Ltd.
www.rfmw.com

50 V GaN on SiC RF Transistors

VENDORVIEW



Richardson RFPD Inc. announced the availability and full design support capabilities for two new GaN on SiC RF transistors from Qorvo. The new discrete GaN on SiC HEMTs operate from DC to 4 GHz. The QPD1009 is a 15 W, 50 V device with an output power level of 17 W at 2 GHz, and a linear gain of 24 dB at 2 GHz. The 10 W, 50 V QPD1010 features an output power of 11 W at 2 GHz and a linear gain of 24.7 dB at 2 GHz.

Richardson RFPD
www.richardsonrfpd.com

Compact 25 W Ku-Band Transceiver

VENDORVIEW

TRAK Microwave, a Microwave brand of Smiths Interconnect, announced the addition of the Ku-Band high power transceiver to its wide range of product offerings. TRAK's new HPT functions as a complete airborne Satcom solution, integrating the necessary GaN SSPA, up-converters, down-converters, and digital control technology to offer a highly modular yet easily maintained system complete with advanced interoperability features and multiple built-in-test (BIT) functions.

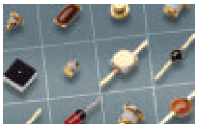
TRAK Microwave
www.trak.com

New**Products**

SEMICONDUCTORS

100 MHz to 30 GHz Limiter Diodes

VENDOR**VIEW**



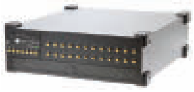
SemiGen Inc. has added a series of new limiter diodes to its expanding product offerings, SLP7100 series. The SLP7100 limiter diodes are processed with a high-resistivity epitaxial wafer (epi) that has thin intrinsic layers. These devices are 2 to 20 microns thick and can be gold doped to achieve specific performance goals. The SLP7100 limiter diodes are used in passive or active limiter designs in the 100 MHz to 30 GHz frequency ranges and feature a low capacitance and resistance as well as a turn-on time as low as 5 ns.

SemiGen Inc.
www.semigen.net

SYSTEMS

Multi-Channel LXI Digitizers

VENDOR**VIEW**



The DN6.44x series of high-speed 14 and 16 bit LXI-based digitizer products comprises 12 new instruments with up to 24 fully synchronized channels. The 16-bit ADC models offer sampling rates of either 130 MS/s or 250 MS/s, while the 14-bit units feature sampling rates of 500 MS/s, making the series suitable for wide-band signal capture. Each channel is also equipped with its own front-end amplifier that features six input ranges (from ±200 mV up to ±10 V full scale), switchable input impedance (50 Ω and 1 MΩ) and programmable positive input offset for unipolar signals.

Spectrum GmbH
www.spectrum-instrumentation.com

SOURCES

Ultra-Low Phase Noise Feature

VENDOR**VIEW**

Berkeley Nucleonics released an ultra-low phase noise feature for their series of compact, portable and 1U rackmount microwave signal generators covering 100 kHz up to 12, 20 and 26.5 GHz. These versatile instruments are offered with a full modulation suite or only as an LO source. At 4 GHz output phase noise is measured at -115 dBc/Hz at a 1 KHz offset. All at a fraction of the cost of contemporary competitive units.

Berkeley Nucleonics
www.berkeleynucleonics.com

Multi-Mode Crystal Oscillators

NDK's NP5032S and NP7050S oscillators combine small size with low jitter performance. The two oscillators have similar performance and capabilities, but offer different

New**Products**

package size options for more flexibility. The wide frequency range of 15 MHz to 2.1 GHz and low jitter makes them suitable for high-speed serial communications applications such as SONET, SDH, Synchronous Ethernet, and other networking devices. Housed in an 8-pin ceramic SMD package, the NP5032S measures only 5 mm × 3.2 mm, with a profile height of 1.2 mm.

NDK
www.ndk.com

High-Performance USB-Controlled PLL Synthesizers

VENDORVIEW

Pasternack launched a new line of USB-controlled phase locked loop (PLL) frequency synthesizers. In RF and microwave communications systems where signal integrity is of prime importance, PLL synthesizers offer high levels of frequency stability and accuracy with exceptional phase noise characteristics that allows components in the signal chain to perform at their optimum levels. These new PLL synthesizers can be useful in applications involving signal generators, benchtop test and measurement, electronic warfare and microwave radios.

Pasternack
www.pasternack.com

C-Band Single Supply PLL Frequency Synthesizer

The surface-mount synthesizer model LFSW400460-1M, operating frequency range of 4000 to 4600 MHz, delivers a powerful performance from just a single +5 V power supply. With its factory preset step size of 10 MHz, this model has low "close-in" phase noise (-90 dBc/Hz at 1 kHz, -95 dBc/Hz at 10 kHz offset, and -100 dBc/Hz at 100 kHz) and a buffered power output of +5 dBm signal minimum.

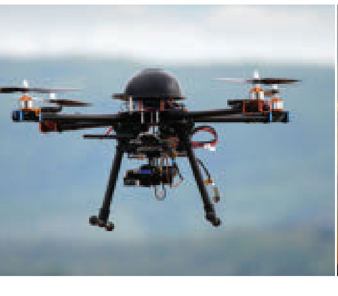
Synergy Microwave
www.synergymwave.com

YIG-based Synthesizer

VENDORVIEW

With a long heritage of innovations in YIG and low phase noise technologies, Teledyne Microwave Solutions has developed the first YIG-based synthesizer that substantially reduces the high cost of acquiring a high-quality, broadband low phase noise source. The new synthesizer simply plugs into a laptop or desktop and yields a fully functional synthesizer that delivers superior performance and ROI to the standard industry alternative, voltage-controlled oscillators (VCOs).

Teledyne Microwave Solutions
www.teledynemicrowave.com




Modern RF and Microwave Filter Design

Protap Pramanick and Prakash Bhartia

Why another book on filter design, you ask? Arguably, filters are the most widely published topic in our industry, reflected in decades of papers and books. What more is there to say? Protap Pramanick and Prakash Bhartia say they wrote this book to solve a nagging problem faced by filter designers: "We were constantly searching through the literature for the specific information we needed. No book on its own covered all the required coupling equations, power-handling details, and so on, for a specific transmission line configuration." So they wrote this text to be a complete yet concise reference for the practicing filter designer, eliminating pure academic theory and impractical ideas. However, the treatment includes the necessary theory to develop a thorough understanding of filter design, including microwave network theory and transmission lines, in all their forms.

Understanding lowpass filters provides the foundation for all other types of filter designs—highpass, bandpass and bandstop—so Pramanick and Bhartia begin here, presenting various lumped element design concepts, such as the Belevitch matrix and transfer function synthesis, impedance inverters, lowpass prototypes using cross-coupled networks and optimizing lowpass prototypes using least squares. Since lumped element designs are not practical in most applications, the authors address the distributed element equivalents of lumped element designs, including transformations from lowpass to highpass and bandstop. The final two chapters are devoted to bandpass filters and multiplexers.

Both authors have extensive experience in the industry and have published widely, and this treatment of filter design seems comprehensive. If you're looking for a reference to guide you from theory to practical implementation, I suggest you start with this volume.

To order the book:

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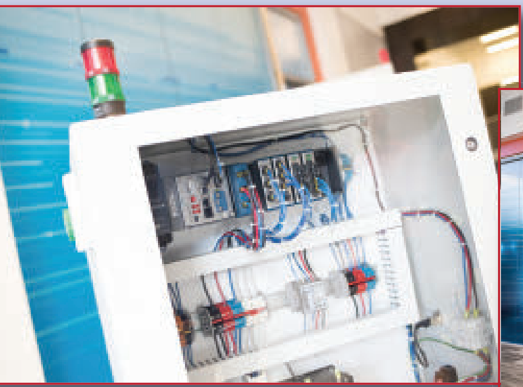
FABS and LABS

NI's Industrial IoT Lab Creates Real World Ecosystems



We hear a lot about the Internet of Things (IoT), a world where "everything" has an IP address and is connected to the cloud. This interconnected web won't happen organically. It will require intense collaboration to establish the technology enablers and failsafe handshakes among a massive number of players: sensors to measure the world, chipsets to process the data, protocols to navigate the networks, security systems to authenticate and verify data and user integrity, spectrum and telecommunications networks to transport the data, data centers to host the applications, and the software that gives it all meaning.

To provide a sandbox where the players in this IoT ecosystem can play and test their pieces of this vast puzzle with other pieces, National Instruments (NI) has established a lab dedicated to the industrial applications of the IoT. Located in Austin, Texas at NI's headquarters, the Industrial IoT (IIoT) lab aims to connect the companies working on the operational and information technology pieces, helping them to learn what they need to know and don't yet know. A lab where companies collaborate fosters interoperability. Companies with expertise in communications protocols, controller hardware, I/O components, processing elements and software platforms can work together to ensure their respective pieces, joined together, create an end-to-end solution. Participants can test these solutions to identify and resolve the challenges of real-world applications. This engaged development process will speed release to the market and adoption by industry.

Initially, the IIoT lab is focusing the collaboration on microgrid control and communication, advanced control for manufacturing and asset monitoring for heavy equipment.

A microgrid is a small electric power system, often with renewable energy sources, that can operate stand-alone yet is usually connected to the main power grid. The lab has a microgrid demonstrator developed by the Industrial Internet Consortium (IIC) that supports testing various approaches for monitoring and controlling microgrids and evaluating interoperability among suppliers and protocol standards.

A second IIC testbed addresses flexible manufacturing that requires time-sensitive networking (TSN). The time sensitivity usually reflects manufacturing process or machine control, where the IoT application is part of a closed loop. Low network latency and jitter are key to maintaining process control and the quality of the output. This IIC testbed currently integrates IoT components from more than 12 companies and is supporting the development of TSN requirements that will be added to the Ethernet standards.

The asset monitoring testbed helps companies use IoT technologies to monitor the operational performance of expensive assets, ensuring consistent performance and timely maintenance — avoiding unexpected, expensive and time-consuming failures and repairs. The asset monitoring demo comprises a pump and motor that uses data acquisition, software analytics and edge computing to monitor the health of the system.

The benefits of collaborating to create an end-to-end IoT environment seem pretty clear, judging by the companies that are sponsoring NI's Industrial IoT Lab: Analog Devices, Avnu Alliance, Calnex, Cisco, Hewlett Packard Enterprise, Industrial Internet Consortium, Intel, Kalypso, OPC Foundation, OSIsoft, PTC, Real-Time Innovations, SparkCognition, Semikron, Viewpoint Systems and Xilinx. By participating in various demonstrations, these companies are sharing experiences and expertise that will lead to more innovative IoT solutions and speed adoption by industry.

www.ni.com/iiot-lab

2017 Cables and Connectors

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Cables and Connectors

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INVITED PAPER

Making Connections – Collaborating to Develop the NEX10 Interface

Richard Mumford, Microwave Journal International Editor
Connects with HUBER+SUHNER, Herisau, Switzerland;
Radiall, Paris, France; and Rosenberger, Fridolfing, Germany

RF coaxial cables and connectors are vital components providing the critical link without which the latest state-of-the-art technology could not function. As the telecommunications industry moves towards smaller equipment and a small cell approach to facilitate higher data speeds, the radios and antennas become smaller, resulting in the need for a small, high performing coaxial RF connector. Here, Microwave Journal *discovers how three leading developers and manufacturers of RF and fiber optic (FO) connectors came together to address the issue and develop the NEX10™ connector interface. This article offers insight into how the companies conceived the new product, collaborated to pool expertise and resources, and managed communication and the division of tasks.*

The appetite for mobile data is ravenous with consumption increasing rapidly across the globe and data speeds expected to further increase with deployments of modern day 4G and the upcoming 5G in the not too distant future. In order to meet these higher data rates, the mobile communications industry is moving mobile radio equipment 'closer to the end user' in order to achieve better coverage. Consequently the desired coverage needs to be delivered by smaller equipment which is lightweight, less obtrusive and can be installed easily at street level, for example on light poles. From the radio and antenna perspective, this requires the development of equipment that is smaller in size and lighter in weight but with the capacity to offer high performance and data speeds up to 1 Gbps.

Critical to the communications channel is the link between remote radio and antennas, which is accomplished by a low loss RF cable. The drawback with using the existing RF connectors that are on the market is that they are either too big or don't meet the electrical requirements of modern day 4G and upcoming 5G mobile networks. For example, the 4.3-10 connector, which has excellent RF performance and is now being commonly used as a standard connector for antennas and remote radio head applications cannot meet the compact size requirement necessary for small cells. On the other hand, smaller RF connectors such as QMA or SMA do not exhibit the required electrical and mechanical requirements such as Passive Intermodulation (PIM) or have the robustness for outdoor use.

Therefore, there is a need for a connector tailored specifically to be installed on radios and antennas with a small pitch, providing high electrical performance in terms of PIM, RL and RF power that is robust and compact with a maximum flange height of 12.7 mm.

THE CHALLENGE

Such a challenge requires confidence, knowledge, experience and expertise, which has been addressed by HUBER+SUHNER, Radiall and Rosenberger who recognized the urgent need for a new high performance RF connector and acted by collaborating to develop a brand new interface —namely, the NEX10™. These three leading connector companies are located within a few hundred kilometers of each other in Switzerland, France and Germany, respectively, and they also share common ground regarding their approach to the collaboration to develop the NEX10. Their priority was to make sure that all the requirements desired by the market were taken into consideration, together with the utilization of the latest and most advanced technologies and concepts for connector development.

Also, commercially, it was considered that through the collaboration potential customers have the confidence that the product has been developed utilizing the resources and expertise of three leading connector manufacturers, giving the users product availability from different sources and enabling them to purchase from their preferred supplier.

THE COMPANIES

HUBER+SUHNER develops and produces high-quality electrical and optical connections. It operates on a global scale, yet with a local approach tailored to each market, enabling it to address customer needs for trans-technological solutions in the communication, transportation and industrial markets. The company provides a one-stop-shop for connectors, cables, cable assemblies, cable systems antennas and lightning protectors.

Radiall was founded in 1952 to make coaxial plugs for the emerging television industry. Today, it is a global manufacturer of high reliability interconnect components for numerous demanding industries including aerospace, defense, industrial, medical and telecommunications.

The Rosenberger Group has more than 7500 employees in its headquarters in Germany, manufacturing plants and sales offices in Europe and Asia as well as in North and South America. For more than half a century, its name has been synonymous with the most advanced technology, quality and creativity. The company is a leading manufacturer of high-frequency and fiber optic connector solutions, with customers including renowned high-tech companies in the cellular technology and telecommunications, data systems, medical electronics, industrial measurement technology, automotive electronics and electro-mobility fields.

THE COLLABORATION

With three major companies involved, each with their own structure, methods and expertise, what were the logistics and procedures for ensuring the collaboration to develop the NEX10 interface was streamlined, efficient and effective?

As might be expected, the design engineers of each company were a vital component of the consortium team. They worked independently on the different packages but shared their ideas during regular meetings between the product management/marketing and design teams, which were either face to face or web based. At every meeting each company took away actions to be explored, with progress reported at the next meeting.

The various work packages were split evenly between all parties for each step of the development process from the first design ideas and the first samples through to the final qualification tests. Individual companies did not have a specific role, but if one design team suggested a new idea/design they would follow it through, taking on board the input and views from the other teams.

DESIGN & DEVELOPMENT

The aim of the collaboration was to design a small, robust and PIM-stable connector. A look at the interfaces currently available on the market showed that achieving this combination would be a challenge. Small connectors like SMA connectors are not PIM-stable and also don't fulfill the requirements regarding robustness which is a prerequisite for a connector that has to be installed in harsh environments. On the other hand, PIM-stable connectors like the 4.3-10 and 7-16 are robust, but are simply too large for small cell applications.

Based on each individual company's many years of experience in connector design, the consortium indentified what design features had to be incorporated in order to achieve good PIM results. It was decided that the easiest design approach was to consider: a downscale version of one of the existing PIM stable connectors. However, it was soon agreed that an interface of this size required specific features to protect the contact elements from damage.

Fig. 1 Notional small cell deployment in an urban setting.

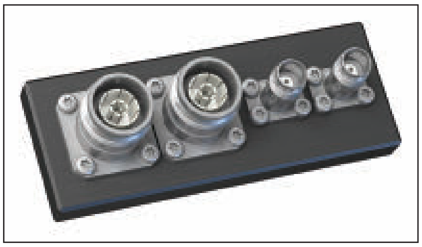


Fig. 2 Size comparison of the 4.3-10 connector and the NEX10 interface.

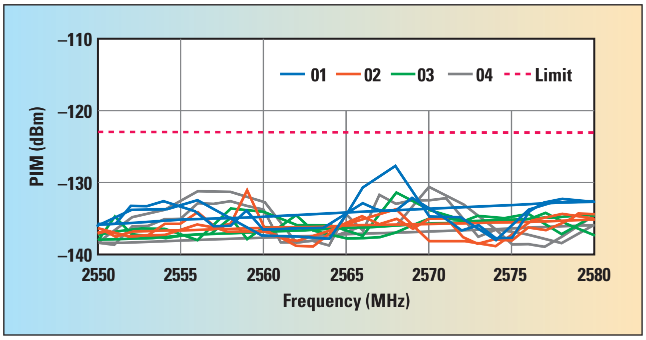
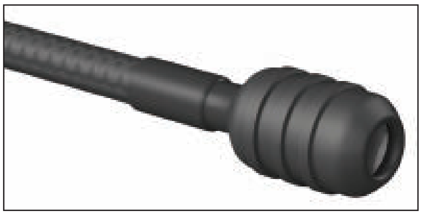


Fig. 3 PIM performance under dynamic test conditions.

Importantly, the center contact on both the female and male side, as well as the slotted outer contact on the male connector, which is needed for a PIM-stable connector independent of the coupling mechanism, has to be protected. Members of the consortium work with small connectors every day and know how to handle them properly. In the final design of the NEX10 a major consideration was to deliver a foolproof design which cannot be easily damaged during installation on site.

THE PRODUCT

The NEX10 interface has great potential for playing a vital role in the future road map of telecom infrastructure. It has been created primarily to address applications requiring PIM stability but in a small size, particularly for small cells (see ***Figure 1***) and MIMO, DAS/in building, antennas, radios and filters.



▲ Fig. 4 An integrated weather protection rubber boot offers IP68 protection for extreme weather conditions.

In small cell applications, the interface is particularly suitable for challenging space restrictions and electrical performance requirements. In low power base stations, the NEX10 can be used for interconnections in the remote radio head as well as the interface on the antenna and on the jumpers. In multi-operator/multiband DAS, it can be used where RF signals have to be combined, terminated or distributed to the antenna.

Several new telecommunications applications require relatively low power combined with an increase in the number of channels in the system. This is exactly where NEX10 can support the future generation of telecom applications in 4.5G and 5G. The compact interface is 50 percent smaller than the 4.3-10 connector—***Figure 2*** shows a comparison with the 4.3-10 connector and the NEX10—and is five times smaller than the 7/16 connector, while meeting all outdoor RF connector specifications.

These include:

- Very low PIM performance independent of torque in dynamic conditions: -166 dBc
- Operates up to 20 GHz with excellent return loss
- 12.7 mm in size
- Mechanically robust design
- Screw and push pull coupling mechanism
- Optimized for cable sizes of up to ¼″ corrugated cables
- IP 68 rated
- Rubber boot design
- Multi-coax version (four contacts in one connector)

To summarize, the NEX10 interface is available in multiple configurations: jack (square flange, bulkhead); plug (straight and right angle); screw-on and push-pull coupling mechanism; multi-coax; additional protection boot for outdoor jumper applications.

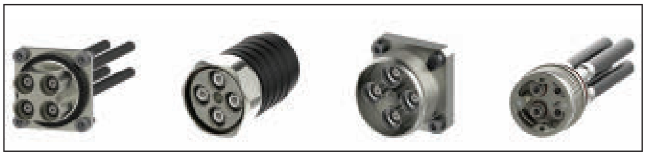


Fig. 5 Multi-coax solutions for the NEX10 interface.

A key design feature of the NEX10 is the separation of the electrical contact from the mechanical contact area, which maximizes intermodulation performance under static, dynamic, vibrations and torque stress conditions. ***Figure 3*** shows a PIM test under dynamic conditions. The interface yields a low PIM and high RL performance independent of the coupling mechanism or applied torque. This characteristic also gives the possibility of offering the connector plug with screw, hand screw and quick lock designs, thus simplifying the installation effort while guaranteeing a very high electrical performance for all coupling mechanisms.

Additionally, the interface has been designed with an integrated weather protection rubber boot protection for extreme weather conditions. The boot, which is part of the interface, shown in ***Figure 4***, offers IP68 protection and is tested against ice and under various temperature cycles. The interface with the rubber boot is available as a standard product for both quick-lock and screw types with a uniform sealing mechanism from all approved NEX10 suppliers.

Also, the separation of electrical and mechanical contact in the interface offers PIM stable multi-coax and blind mate solutions. The multi-coax solution (see ***Figure 5***) is a space saver for dense applications. It consists of up to four connectors integrated in one housing and is available as a standard solution. This solution provides benefits of space reduction and installation time while providing excellent electrical performance and mechanical robustness for outdoor use. The NEX10 blind mate solution is for panel to panel and test and measurement applications.

CONCLUSION

By combining the knowhow of three leading global innovative RF connector companies, the consortium has taken advantage of the expertise and design capabilities of all partners in the design of the interface. Similarly, the companies' expertise and experience was extended to the production processes where the latest advanced manufacturing technologies were utilized to provide a high quality RF connector which meets all the existing standards and future requirements of the telecommunications market.

Significantly too, the consortium also provides the flexibility to enable customers to source the product successfully in any part of the world to satisfy OEM or wireless operators' needs—for example individual connectors or finished RF jumpers. The consortium believes that through close collaboration and team work, NEX10 has the potential to become the new telecom standard for the future.■

Editor's note: *This article is based on a paper presented in Noordwijk, Netherlands at the ESA/ESTEC Passive Components Symposium (www.spcd.space) on October 13, 2016.*

Minimizing Temperature Induced Phase Errors in Coaxial Cables

David Slack
Times Microwave Systems, Wallingford, Conn.

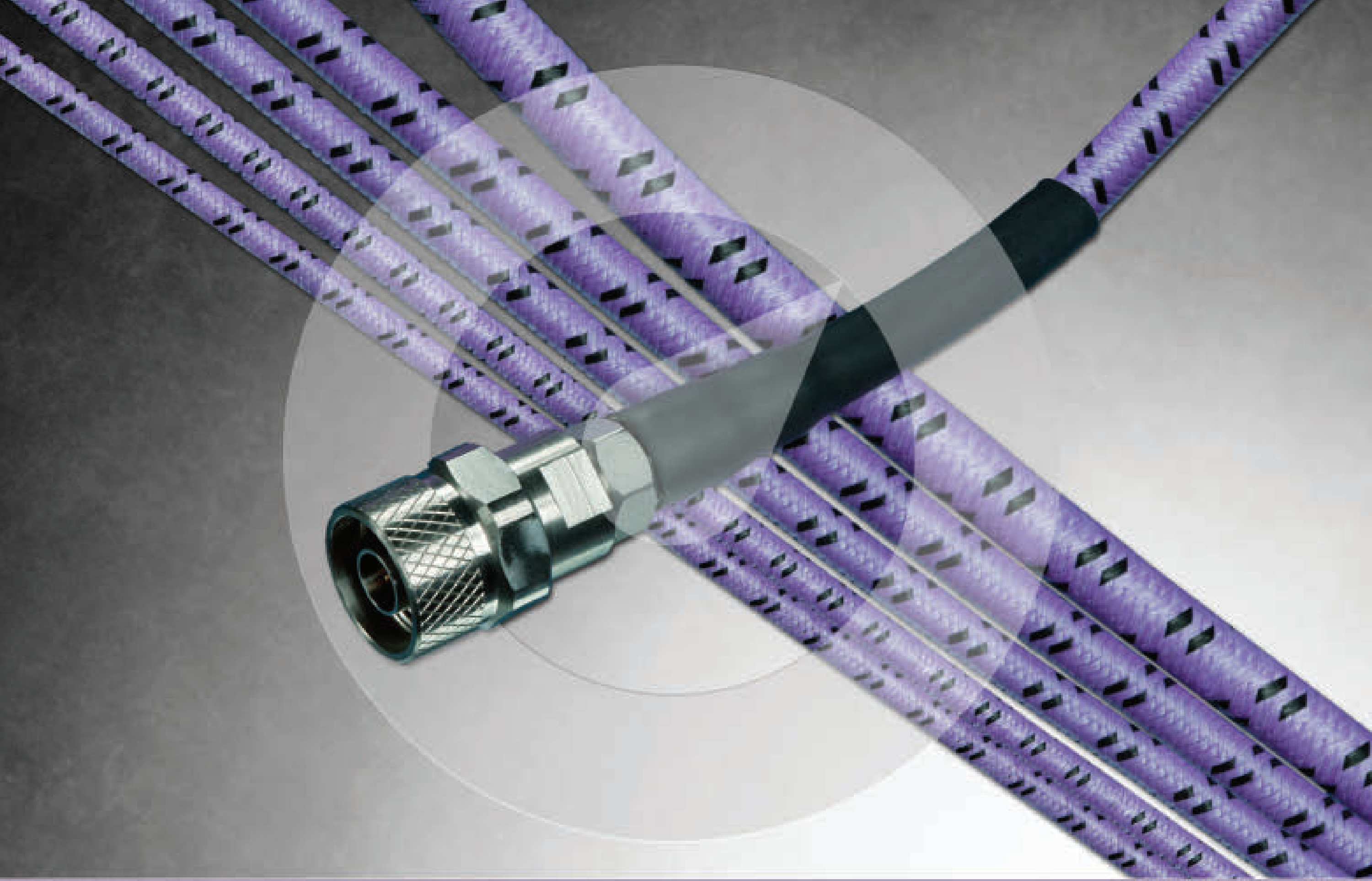
PTFE (Dupont's Teflon®) has been the transmission line dielectric of choice for several decades; however, PTFE undergoes a material phase change at room temperature. It undergoes a virtual "step function" volumetric change and a change in relative permittivity as well as having a "hysteresis" effect on changes in electrical length. These variable material properties and changes in electrical length can be difficult to reliably predict and account for via system software or other means and may contribute to systematic performance degradation. Developments in dielectrics, using both organic and inorganic materials, have yielded dramatic improvements in performance relative to temperature. This article compares and contrasts several coaxial cable technologies for electrical length change as a function of temperature, electrical length tracking of multiple cables as a function of changing temperature, electrical length tracking of multiple cables when transiting through diverging thermal zones and electrical length repeatability versus multiple iterations of temperature cycling. Additive phase noise as a function of mechanical vibration and interactions between conductors and dielectric materials, as they pertain to electrical length parameters, will also be discussed.

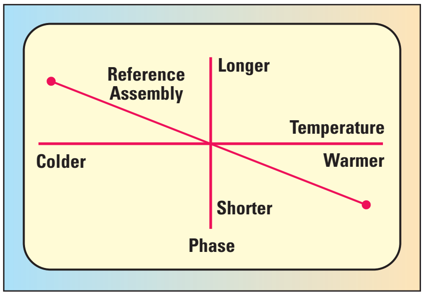
Oliver Heaviside noticed that wrapping a telegraph wire in an insulator improved both the signal quality and effective range of communications signals. In 1880 he patented the world's first coaxial cable. In 1931 engineers at AT&T's Bell Telephone Laboratories patented the first modern coaxial cable. Crude by today's standard it was constructed of two concentric metal tubes separated mostly by air.

In the 1930s gutta percha (a natural form of rubber) was the primary dielectric of choice for early flexible coaxial cables. Polyethylene became the predominant insulator of choice during the World War II years. In the 1950s, "foaming" processes were developed that reduced cable capacitance and loss characteristics.

In the 1960s, solid, full density polytetroflouroethylene (PTFE), or "Teflon®" gained widespread use. Its higher temperature ratings, lower loss tangent, lower dielectric constant and uniform properties over a wide range of temperatures and frequencies made it almost universally desirable as a coaxial cable dielectric.

In the 1970s and 80s manufacturers began using expanded, low density versions of PTFE to further improve its desirable properties. In the 1990s an increasing demand for electrical length stability drove manufacturers to begin using ultra low density PTFE dielectrics. These products were a definite improvement but still had some inherent limitations. Chief among these was a phase vs. temperature "knee"; a step function change in electrical length caused by the base





▲ Fig. 1 Temperature effect on coaxial cable electrical length.

material properties of PTFE molecules. This effect can be minimized but is impossible to eliminate.

In 2004 PhaseTrack® coaxial cable products using TF4® fluorocarbon dielectric technology were introduced to specifically address this problem. In 2015 further refinements and process developments have culminated in an improved TF4 technology with some very clear advantages over PTFE dielectric material in phase sensitive applications.

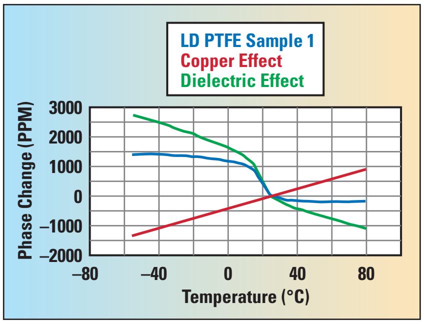
PERFORMANCE METRICS

The ideal microwave cable assembly has zero loss, zero reflected energy and zero electrical length across all environmental conditions that system components would ever see. In our practical world we endeavor to come as close to the ideal as possible. This is certainly true with regard to electrical length changes of a coaxial cable assembly as its surrounding temperature changes.

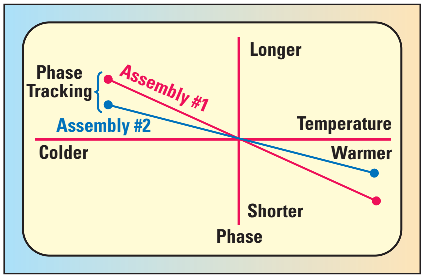
Phase Change as a Function of Temperature

It is commonly known that the metals used to construct coaxial cable assemblies have positive temperature coefficients of expansion and that electrical length and physical length are directly related. It would seem obvious that with an increase in temperature an increase in physical length and thus an increase in electrical length would follow.

In fact, the opposite is true; most microwave cable assemblies exhibit negative temperature coefficients of electrical length, as represented by ***Figure 1***. The axial lengths of the center and outer conductors increase directly with temperature. The diameter of the outer conductor increases as well, in a direct relationship with temperature, causing a small density change in the dielectric core that alters the net relative permittivity. The change in relative permittivity has an effect on electrical length that is opposite to that of the metal expansion/contraction. This is significant, as



▲ Fig. 2 Temperature effect on phase in PTFE-based coaxial cable.



▲ Fig. 3 Phase tracking vs. temperature.

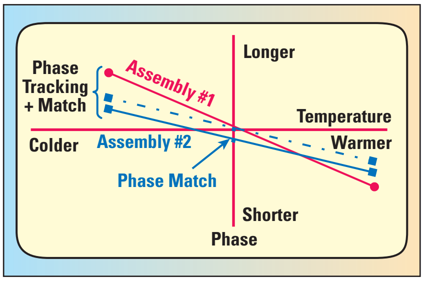
this phenomenon makes it theoretically possible to balance the two effects and achieve zero phase change with respect to temperature.

A practical cable assembly, using PTFE as a propagation medium, will always have a step function change in dielectric constant at room temperature with a corresponding change in electrical length. ***Figure 2*** illustrates the temperature effect on phase. Copper has a positive temperature coefficient of expansion of 17 PPM/°C. For this construction the dielectric has a negative effect on electrical length of 23 PPM/°C. The dielectric also exhibits the PTFE phase transition "knee".

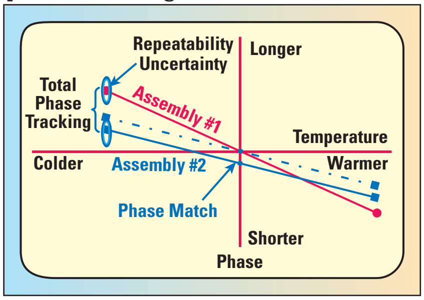
Phase Tracking as a Function of Temperature

In practice, phase matched cable assemblies do not retain their relative phase match as temperature is varied. The degree to which they maintain their initial relative match is referred to as phase tracking. ***Figure 3*** illustrates how two cable assemblies, initially phase matched at room temperature, might track as a temperature changes.

Several factors contribute to good phase tracking performance. Most critical is uniformity per unit length of cable, which includes capacitance, impedance and conductor mechanical uniformity. Worst case phase matching at all temperatures is a function of the initial match plus phase tracking characteristics (see ***Figure 4***).



▲ Fig. 4 Phase tracking with initial phase matching.



▲ Fig. 5 Total phase tracking over temperature is the combination of phase matching, phase tracking over temperature and repeatability. Phase noise can contribute to the uncertainty.

Phase Matching at Room Ambient Temperature

Cable assemblies that are intended for use in phase sensitive applications are phase matched. As environmental temperature changes occur, the ensuing phase change is proportional to the initial electrical length. Assemblies having the same electrical length, and subjected to the same temperatures should, ideally, maintain their phase matched characteristic. In addition to electrical and mechanical consistency, the degree to which a group of cable assemblies is initially matched factors into phase tracking performance.

Phase Repeatability as a Function of Temperature

Virtually all system applications are subject to dozens or hundreds of temperature cycles. It is important to know that each repetition of a specific temperature yields a consistent and repeatable electrical length. Semi-rigid cable tends to be the most reliable in this regard. Well made flexible cables can also be quite repeatable but they have inherent variability due to interactions between expanding and contracting dielectric cores and outer shields. Total phase tracking vs. temperature is the composite of phase matching, tracking over temperature, and repeatability (see ***Figure 5***).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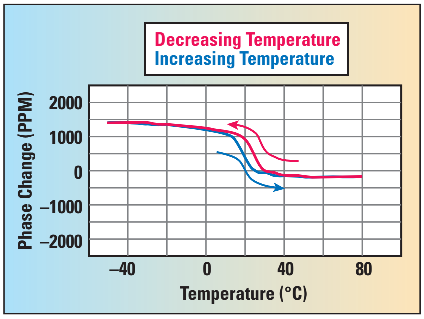

Fig. 6 Hysteresis effect from the PTFE dielectric.

Phase Hysterisis as a Function of Temperature

PTFE has many characteristics that make it highly desirable as a cable dielectric material. A serious drawback, however, is the fact that it undergoes a molecular phase change between 18° and 20°C, further complicating cable phase vs. temperature characteristics with its hysteresis properties (see ***Figure 6***). The phase change equates to a 1.5 percent volumetric change with a corresponding change in dielectric constant, resulting in an abrupt change in cable electrical length. This effect can be reduced by using a less dense PTFE dielectric, but it cannot be eliminated. In addition, the phase change begins at different temperatures for increasing vs. decreasing directions of temperature change, further degrading total phase tracking performance over temperature.

TYPICAL MICROWAVE CABLE PERFORMANCE

PTFE dielectrics are, by far, the most commonly used for the construction of microwave and millimeter wave cable assemblies. They are used mainly in two basic categories, full density (ε_r= 2.01) and low density (ε_r = 1.73). There are also ultra low density PTFE (ε_r = 1.42) cables optimized to the extent of which a phase stable cable can be constructed using PTFE. These cables tend to be highly prone to mechanical damage as the ultra low density construction provides very little mechanical support.

In general, the plastic density per unit length of expanded PTFE dielectrics has consistency variations that translate directly to phase tracking degradation. This is most prominent at the temperature extremes of the cables rated operating temperature. ***Figure 7*** overlays the phase vs. temperature "footprints" of several high performance coaxial cable products.

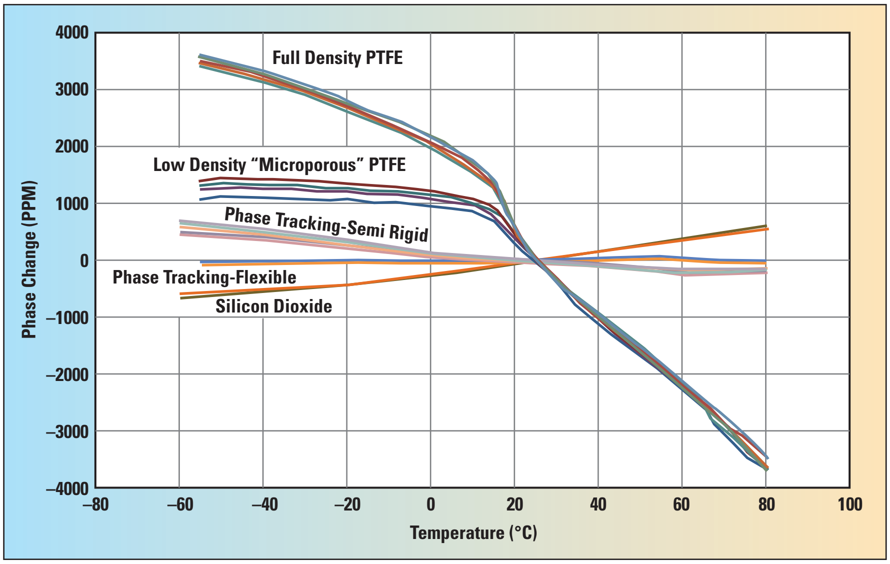

Fig. 7 Phase vs. temperature "signature" of various coaxial constructions.

Solid core, full density PTFE dielectric cables are very mechanically robust. The phase temperature slope is the highest of the variants and the effects of the molecular phase transition is pronounced.

Low density "microporous" PTFE dielectric cores are made in several ways all using variations of a similar process. Full density PTFE material is placed under tension and stretched under controlled conditions and at elevated temperatures. The material is cooled while under tension and the result is an "expanded" PTFE material that can be used to construct a cable dielectric core. These products likely comprise the bulk of cable used in phase sensitive microwave applications. The low density material minimizes the phase temperature slope as well as the "step-function" change in electrical length at the phase change transition temperatures.

PTFE ALTERNATIVES

Several alternatives to PTFE-based coaxial cables have been developed that exhibit significant improvement in system level performance. All of these eliminate the phase temperature "knee" allowing for improved balance of the conductor–dielectric effects on phase vs. temperature performance.

Silicon Dioxide Semi-Rigid Cable Assemblies

Silicon dioxide is a material that has been used as a cable dielectric for a number of years. The silicon dioxide material is extremely hygroscopic. As such, it must be used in cable assemblies

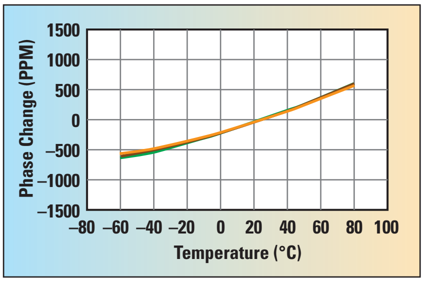

Fig. 8 Typical phase vs. temperature of silicon dioxide semi-rigid coaxial cables.

that are fully hermetically sealed (leak rate less than 5×10^{-8} Atm-cc/sec He). These cable assemblies are semi rigid in construction using copper clad stainless steel jackets welded to stainless steel connector bodies. Given the consistent geometries of the cable and the inorganic nature of the dielectric, these cable assemblies display the ultimate in phase vs. temperature repeatability and tracking performance (see ***Figure 8***). In addition, the materials employed in their manufacture produce extremely robust cable assemblies. The dielectric has the properties of compacted sand providing excellent support for the outer conductor when under mechanical stress. The stainless steel and silicone dioxide materials are both extremely radiation and corrosion resistant, as well. They are suitable for use from absolute zero to well over 600°C and have an impressive pedigree in aerospace applications.

PhaseTrack Semi-Rigid Cable Assemblies Using TF4 Dielectric

A more recent development uses a flouropolymer blend dielectric devel-

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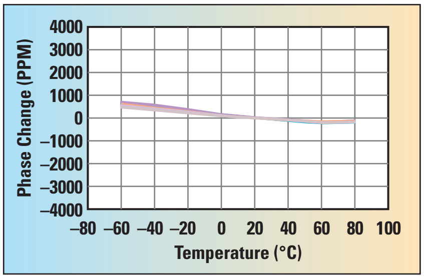
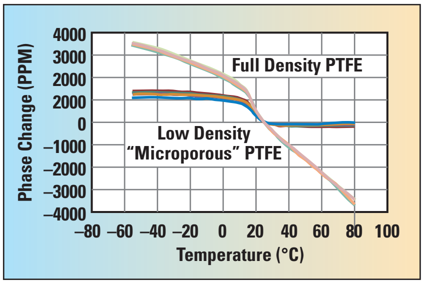
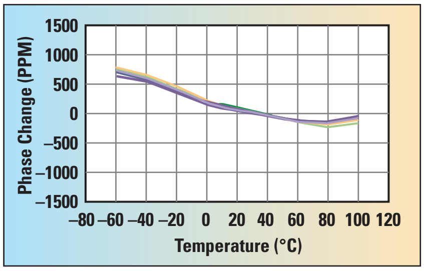


▲ Fig. 9 Typical phase vs. temperature of TF4 semi-rigid coaxial cables.



▲ Fig. 10 Phase vs. temperature of full density and low density PTFE flexible coaxial cables.



▲ Fig. 11 Phase vs. temperature "signature" of TF4 flexible coaxial cables.

oped by Times Microwave Systems. This material has similar temperature ratings as PTFE but does not have the abrupt shift in dielectric constant. Because it can be melt extruded it is much more consistent per unit length than expanded PTFE thus exhibiting improved phase tracking and repeatability. The semi rigid construction uses the same uniform tube structure as silicon dioxide cable assemblies, providing repeatability that rivals silicon dioxide cables without the need for stainless steel conductors and specialized connectors.

Another advantage is the "closed cell" nature of the dielectric core. To achieve a balance between conductor and dielectric effects, a low density PTFE dielectric core must be less dense than what is required to be mechanically robust; however, an ultra low density (velocity factor (Vf) = 84 percent) TF4 dielectric has the same durometer measurement as a standard density (Vf = 76 percent). This allows for a mechanically robust cable without the necessity of heavy and expensive mechanical strength members. ***Figure 9*** shows the phase repeatability and tracking performance of semi rigid coaxial cable assemblies manufactured with the TF4 material.

PhaseTrack Flexible Cable Assemblies

Just as the TF4 dielectric provides a drop-in replacement for PTFE in semi rigid constructions it also provides similar benefits to flexible cables. These cables are sized similarly to PTFE cables. In addition they look and handle almost identically. The benefits are improvements in phase change with temperature, phase tracking with temperature and phase repeatability with temperature.

Figures 10 and ***11*** compare the phase versus temperature characteristics of flexible PTFE and TF4 cable assemblies. Each cable type includes 10 phase matched assemblies to offer not only a comparison of phase versus temperature characteristics but tracking characteristics as well.

PHASE PERFORMANCE

The overlay in Figure 7 of five cable technologies provides a comparison of the relative phase vs. temperature "footprint" of each type. It is evident that cable assemblies made using a dielectric core of solid PTFE have steep phase temperature slopes that become extreme at around room temperature. In the region between +15° and +25°C, the slopes are about -130 PPM/°C. This rate of electrical length change is more than four times greater than at cold temperatures below +15°C. Below room temperature, the temperature coefficient is -30PPM/°C.

A similar change in the phase temperature slope characteristic occurs with all PTFE based cable dielectrics. The magnitude of the slope change can be minimized by reducing the dielectric core density, but it can never be eliminated as it is a fundamental property of the PTFE material. The reasonably optimized "microporous" PTFE product illustrated in Figure 10 demonstrates this effect. The effect of the plastic properties is fairly well balanced against the effect of the expansion-contraction of the metals in the temperature ranges above and below the PTFE material phase transition temperatures. Phase versus temperature slopes are, therefore, relatively flat outside of the room temperature range. It demonstrates a reduced, but still significant phase vs. temperature slope between +15° and +25° C; the phase temperature slope in this zone is about -85 PPM/°C.

Several manufacturers offer products with "ultra" low density PTFE dielectric cores. These products have achieved propagation velocity factors in excess of 85 percent with further reductions in phase temperature slope in the room temperature region. They tend to over compensate the dielectric-conductor balance with a slight positive phase temperature slope above and below the PTFE "knee" and a further reduction in the electrical length slope within the material phase transition temperature band. The characteristics of these products are not discussed in this article as their dielectric cores are so mechanically fragile that they are impractical for all but the most benign applications. When the dielectric offers such little mechanical support it often gives way to mechanical degradation and associated structural return loss and stability problems.

Silicon dioxide and the TF4 dielectric technologies solve both problems without adding size or weight. They have been reasonably well optimized as far as the conductor-dielectric balance without any hint of a slope change at any temperature within the operating range. This is achieved with mechanical durability and handling properties equivalent to, or better than the low density microporous PTFE cable products.

Phase Tracking vs. Temperature

An important cable function is to maintain the relative electrical length relationships of multiple signal paths across an entire system operating temperature range. The degree to which cable assemblies "track" each other is especially critical in regions of the hardware architecture that cannot be calibrated or accounted for via other means. As a general rule the key property of a coaxial cable assembly as it applies to phase tracking is consistency per unit length of cable. Contributors to consistency include dielectric density per unit length, conductor consistency per unit length, material properties, conductor geometries and manufacturing process conditions.

From Figure 7, one can clearly identify two empirical trends. Each of the five examples is illustrated using 10 identical cable assemblies phase matched at room ambient temperature. Solid dielectrics track better than less dense dielectrics and semi-rigid assemblies track better than flexible constructions.

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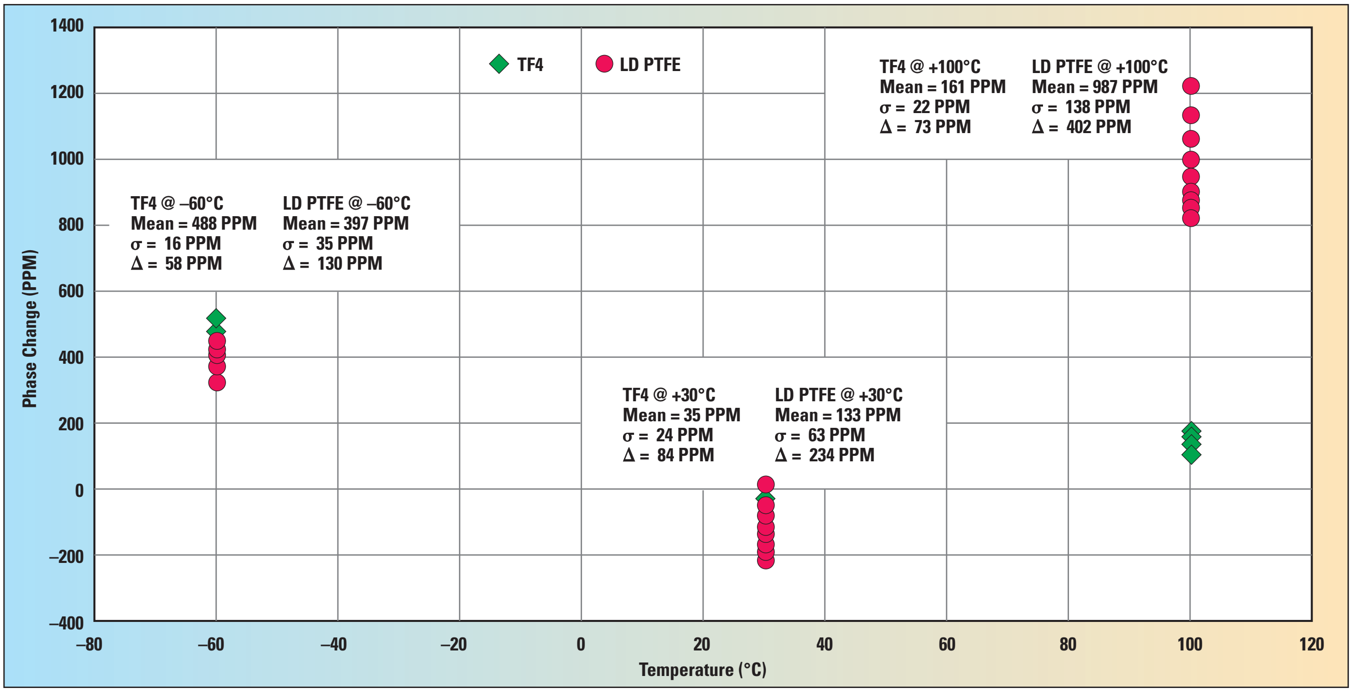


▲ Fig. 12 Phase repeatability vs. temperature of TF4 and PTFE coaxial cables.

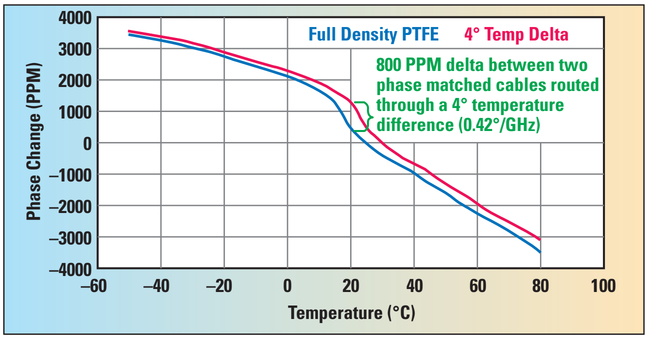
Figures 10 and 11 illustrate the improved tracking performance of the TF4 material over the micro porous PTFE. Both of the cable assembly types that produced the data were identical with the exception of the dielectric material. Both were standard flexible cable designs. The group of PTFE cables tracked to within ±200 PPM around a nominal phase temperature profile. The identically constructed TF4 cables tracked to within ±100 PPM.

When the wire weave "basket" construction of the outer conductor used in a flexible cable is replaced with a solid tube, the tracking performance is further improved to ±50 PPM. The silicon dioxide product, with its solid geometries, inorganic dielectric material and fully welded construction provides the ultimate in tracking performance at ±25 PPM.

Phase Repeatability vs. Temperature

A similar but subtly different attribute of phase temperature performance is phase repeatability. This is the measure of how well a cable returns to a given electrical length over the course of multiple iterations away from, and back to a given temperature. It is closely associated with phase tracking. In fact, without good repeatability, good tracking performance is just a statistical anomaly and a very unlikely event.

Figure 12 illustrates the phase repeatability of an ultra low density PTFE cable assembly and compares it to an identically constructed assembly using a TF4 dielectric. The chart plots the electrical length of the two assemblies, at -60°C, +30°C and +100°C. The red "constellation" of symbols is the PTFE assembly and the green is the TF4 assembly. At each temperature, the variance observed in the TF4 assembly is a fraction of the variance seen in the PTFE assembly. This is one of the attributes contributing to improved phase tracking vs. temperature of a bundle, or network of cable assemblies.



▲ Fig. 13 Phase tracking through mildly diverging temperature zones.

Phase Tracking vs. Diverging Temperature Zones

The previous discussions assumed that all parts of all the cable assemblies are held at the exact same temperature. In practice, this is virtually never true. Quite often cables will have slightly different routings through sections of hardware that are at different temperatures. As long as the cables are exactly matched at a given temperature they maintain their tracking. Once they transit to even slightly different temperature zones the tracking degrades. The larger the phase vs. temperature slope the greater the effect. ***Figure 13*** quantifies the case for two full density PTFE cables in a ±2°C temperature environment. Assuming the overall system experiences the full environmental temperature range, and the thermal consistency of the system hardware results in a 4°C differential between the two cables, then there might easily exist an 800 PPM difference in electrical length between the two cable assemblies. For a lower density PTFE cable this value is reduced to approximately 500 PPM. Of course this maximum difference occurs at the environmental temperature where the phase temperature slope is steepest. It stands to reason that the flatter the phase temperature slope, the less sensitive system performance will be to slight "hot spots" within the system environment. ***Figure 14*** provides a comparison of all the cable technologies discussed with respect to phase tracking with a 4°C temperature differential in the routing of two identical assemblies.

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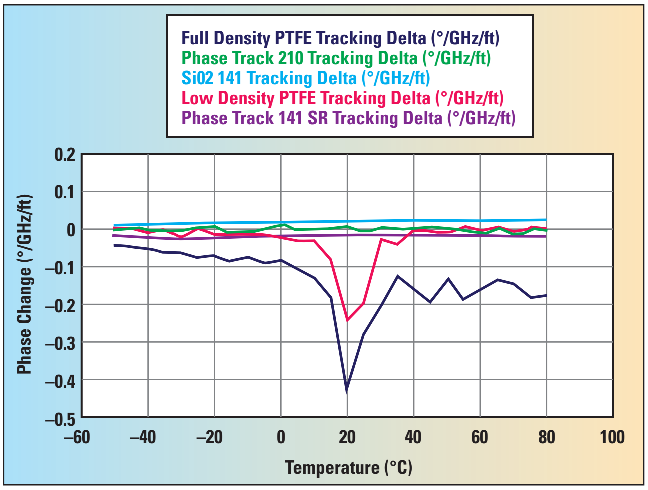


Fig. 14 Comparison of phase tracking through divergent temperature zones.

Product Blending

There may be circumstances where only the absolute minimum of phase change vs. temperature can be tolerated. In these cases technology "blending" techniques have been used with excellent results.

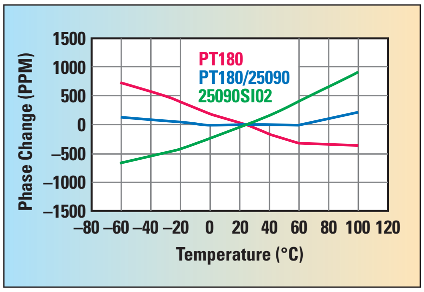


Fig. 15 Technology blending to minimize phase change vs. temperature.

For example, the TF4 dielectric technology has a very slight negative slope in its phase versus temperature characteristic, while for the silicon dioxide technology there is a very slight positive slope. When two cable assemblies, one using TF4 semi rigid and the other using silicon dioxide semi rigid, are connected in series, their phase versus temperature slopes offset each other. The effect is proportional to the overall length of the combined pair. By adjusting the electrical lengths of the two assemblies, the phase temperature slope can be effectively cancelled. In ***Figure 15*** the negative phase temperature slope of a TF4 semi rigid cable is combined with the positive phase temperature slope of a silicon dioxide cable. The result is a virtually flat phase versus temperature response from -40° to +60°C.

CONCLUSION

Excellent phase temperature performance is desirable in phased array antennas and other system architectures. It is also important in achieving and maintaining optimum test equipment calibration.

This is especially true in lab environments that are typically maintained in the worst temperature range for PTFE performance. Going from a cool room temperature to a warm room temperature can have a profound effect on phase sensitive measurements. Regardless of the application, when dealing with phase sensitive equipment it is important to consider the effects that even basic components may have on overall performance. While no existing technology can currently provide the ideal "transparent" interconnect there are more options than may be commonly known.■

Base Station Market Reinventing Connectors

Earl Lum
EJL Wireless Research, Salem, N.H.

Traditional RF connectors for base station antennas, remote radio units (RRU) and jumper/feeder cables have relied upon legacy 7-16 DIN and N-type connector technologies. For legacy 2G/3G networks, these RF connectors performed adequately. However, the migration to 4G networks has prompted the industry to rethink its strategy for addressing one of the significant linearity issues of LTE technology: passive intermodulation—better known by its acronym PIM.

Poor PIM performance from any component in the transmit or receive path within an LTE system causes poor linearity, which ultimately degrades the modulation capability of the overall sector, site and network. Frequency division duplex (FDD) LTE networks are more susceptible to PIM than time division duplex (TDD) LTE networks. FDD-LTE networks have used 7-16 DIN connectors for everything in the transmission line system from the radio to the antenna. TDD-LTE networks have relied on N-type connectors for the transmission line system. The PIM performance of 7-16 DIN connectors is significantly better than that of N-type connectors, yet it is still not what the market would like to see.

To support a single frequency band, each sector of a macro cell site using 2×2 multiple-input-multiple-output (MIMO) requires two RF connectors for the tower-top RRU, four RF connectors for the jumper cables and another two RF connectors on the base station antenna—a total of eight connectors (see ***Figure 1a***). The number of connectors increases by eight for each additional frequency band added to the sector; with 4x4 MIMO, the number doubles to 16 per frequency band per sector.

To meet the market's appetite for ever-higher data rates, the wireless infrastructure will incorporate multiple changes over the next few years:

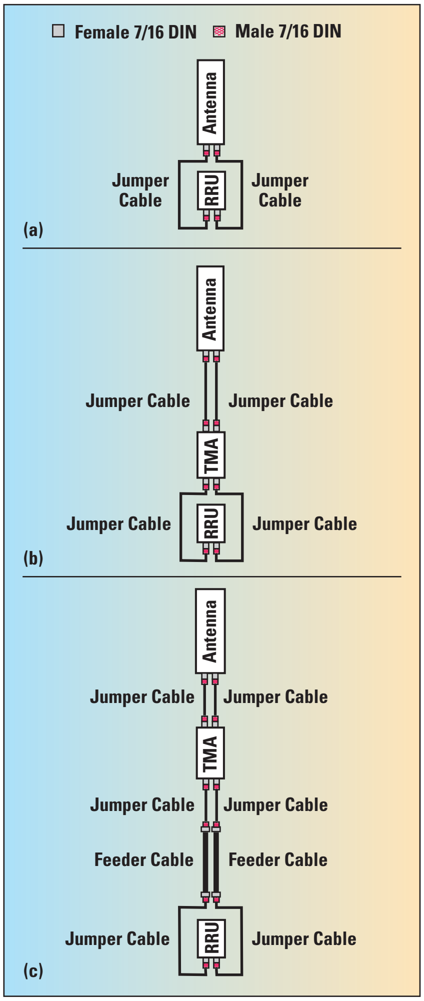
- From 2×2 MIMO to 4×4/4×2 and 8×8 MIMO for FDD-LTE RRUs
- From 6/8-port base station antennas to 12/14 and, in some cases, 24-port antennas
- New LTE spectrum
- RRUs deployed at the bottom of the tower to minimize tower loading
- In-building distributed antenna systems (DAS) for LTE/UMTS coverage
- Massive MIMO for 5G antenna systems.

These changes will increase the connector volume while demanding better connector performance. The following paragraphs discuss each of these drivers.

HIGHER-ORDER FDD-LTE MIMO

The migration to higher order MIMO for RRUs will double the port and RF connector count from two to four for the majority of RRUs shipping in the future. First-generation FDD-LTE MIMO is based on a 2T2R (T = transmit and R = receive) configuration. Second-generation FDD-LTE MIMO has been deployed with some mobile operators in the United States and Canada, along with adoption in Korea and Japan. European operators are lagging behind North America and Asian operators in migrating to 2T4R and 4T4R RRUs. One of the drivers for the 2T4R RRU configuration is to improve uplink (UL) performance as operators deploy voice over LTE (VoLTE). VoLTE reduces UL performance by up to 3 dB, resulting in significant cell shrinkage and a higher rate of dropped calls, as handoffs are not possible with coverage gaps between macro cell sites. Doubling the number of receivers in the RRU extends the macro cell coverage on the UL path, which can limit the required output power from the user equipment (UE)—also improving battery performance.

A potential driver for adopting 4T4R RRUs within an FDD-LTE network is the migration of UE video displays and streaming from 1K to 2K and >4K for iPhones and Android mobile phones and tablets. The Apple iPhone 7 is equipped with a 1K display, while the new iPhone 7+ has a 2K display. The new Samsung Galaxy 8 is reported to have a 4K display. Video services such as Netflix, Amazon Prime, Hulu and YouTube are already streaming 4K video with some level of compression. New mobile phones and tablets will



▲ Fig. 1 Typical configurations for a single sector 2 × 2 MIMO architecture: RRU at the top of the tower (a) RRU and tower mast amplifier (TMA) at the top of the tower (b) and TMA at the top and RRU at the bottom of the tower (c).

drive the penetration of 2K and 4K devices through 2020. The requirements for increased downlink (DL) throughput to support 4K video can be achieved with LTE-Advanced by using a combination of MIMO and multi-band carrier aggregation (CA). The demand from mobile subscribers may force network upgrades to 4×4 MIMO if the bandwidth to support video streaming over mobile networks is not available with the use of CA.

HIGHER PORT ANTENNAS

Site restrictions from weight, wind load and aesthetics are major issues plaguing all mobile operators. Some countries have a strict regulatory environment that limits a macro cell site to only one panel antenna per sector. To meet such requirements, mobile operators need to deploy multiple frequency bands and, potentially, higher-order MIMO on a single sectorized panel antenna. In North America, a mobile operator supporting 2×2 MIMO for LTE at 700, 1900 and 2100 MHz will require two RF connector ports for each spectrum band, or a total of six RF connector ports on a single base station antenna. If the MIMO technology is upgraded to 4×4, 12 connector ports will be needed for the same antenna. Adding 850 MHz spectrum to the mix will require 16 RF connector ports. This example is a simplified version of what really may be required, as it assumes the same electrical tilt can be used for multiple air interfaces (UMTS/LTE) within the same spectrum.

NEW LTE SPECTRUM

Each new spectrum auction adds more RRU deployments for the mobile operators within a country. Currently, the North American market is undergoing an RRU upgrade in the 2100 MHz spectrum, from band 4 to a wider band 66. The eventual conclusion of the FCC's UHF reverse/forward auctions will lead to new RRUs deployed at 600 MHz for the winning mobile operators. Greenfield deployment of the Citizens Band Radio Service (CBRS) at 3.5 GHz will also increase the demand for RF connectors. It's hard to see an end to new spectrum for mobile operators for 4G/4.5G and 5G technology.

TOWER LOADING

Most mobile operators deploy the RRU as close to the base station antenna as possible, to improve UL performance and reduce RF loss through the jumper cables. However, the typical weight of an RRU is approximately 25 kg, and each frequency band requires a different RRU. A three-sector macro site supporting four frequency bands results in a weight load of 300 kg, not including the weight of the sectorized panel antennas and ancillary tower equipment. Current towers were designed to hold base station antennas, and the tower designs did not account for the additional weight of RRUs. In some regions, the towers cannot accommodate the additional weight and wind load, so the RRUs must be deployed at the bottom of the tower. In such a traditional configuration, a jumper cable (two RF connectors) is required for each RRU port to connect to the main feeder cable (another two RF connectors), which is then connected via a jumper cable (two more RF connectors) to a tower mast amplifier (TMA) and then another jumper cable (two more RF connectors) to one RF connector at the base station antenna (see ***Figure 1c***). The TMA and extra jumper cables are required to compensate for the UL losses from the antenna down through the jumper cable/feeder cable to the RRU. The feeder cable can be as long as 100 m in some cases, resulting in approximately 3 dB signal loss.

IN-BUILDING DAS

Typically, the majority of multi-operator active DAS deployments range from a few sectors to more than 50 for a sports stadium. The signaling source for the DAS head-end is an array of macro cell digital baseband units supporting a few to hundreds of macro cell RRUs, depending on how many frequency bands are required and how many operators are supported (see ***Figure 2***). Each output of the RRU requires a jumper cable to a DAS attenuator tray and then another RF cable to the DAS head-end. The majority of DAS attenuator trays today still use the legacy 7-16 DIN connectors; however,

Fig. 2 DAS RRUs (a) and head-end (b). Source: EJL Wireless Research LLC ©2016.

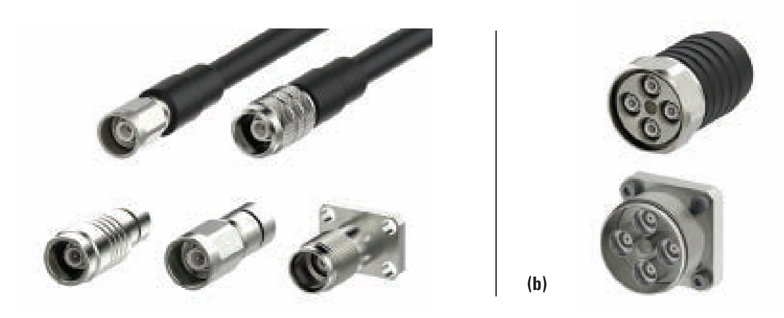


Fig. 3 NEX10 connectors, single (a) and multi-port (b).

next generation products will likely switch to the 4.3-10 DIN connectors. The cable between the DAS attenuator tray and the DAS head-end may use a DIN connector to a smaller QMA type RF connector. The DAS power amplifier nodes (usually one per sector) typically use legacy 7-16 DIN connectors and require one or more jumper cables to the wideband DAS antenna. Passive DAS solutions require even more RF connectors, from splitting the RF signal across multiple paths within a building and the greater use of coaxial cables.

5G MASSIVE MIMO ANTENNA SYSTEMS

The 5G era will result in a dramatic departure from traditional low-order MIMO (2/4/8) RRUs to higher order 32/64/128/256 MIMO technology. The actual radiated RF power output remains essentially the same, but the higher-order MIMO dramatically reduces the RF output power per port. For example, a 2×2 MIMO RRU providing 80 W of RF power per channel results in 160 W total to the antenna. To support the same 160 W EIRP to the antenna, a 64x64 MIMO RRU requires only 2.5 W RF output per channel.

With this architecture, the antenna is combined with the RRU and forms a complete integrated transceiver/antenna system, which the industry sometimes calls a massive MIMO active antenna array. Because the antenna is integrated within the RRU, there are not 64 RF connector ports on the outside of the RRU that need jumper cables to connect to a 64 port antenna. Current massive MIMO active antenna designs are based on many large printed circuit boards (PCB) for the antenna arrays and the RF transceiver subsystem. Each antenna array is connected to a corresponding RF transceiver module using small-scale board-to-board RF connectors. For example, a 64×64 massive MIMO active antenna system requires 64 connectors for the RF transceiver PCBs, 64 connectors for the antenna array PCBs and 64 board-to-board connectors—a total of 192 RF connectors per antenna system.

SMALLER, BETTER CONNECTORS

To address these changes in base station configuration and the requirement for better PIM performance, the higher power RF connectors for RRUs, antennas and jumper/feeder cables are in a transition, as the legacy 7-16 DIN connectors are replaced with higher performance and smaller 4.3-10 DIN and the newly developed NEX10™ connectors, as well as the smaller MCX/MMCX connectors for 5G massive MIMO antenna systems.

The 4.3-10 DIN has several advantages over the legacy 7-16 DIN connector, including a smaller footprint and better PIM performance. Pre-LTE systems were more immune to PIM degradation, but the advent of LTE, LTE-Advanced and soon to be deployed LTE-Advanced Pro and 5G require significant linearity from the RF connectors.

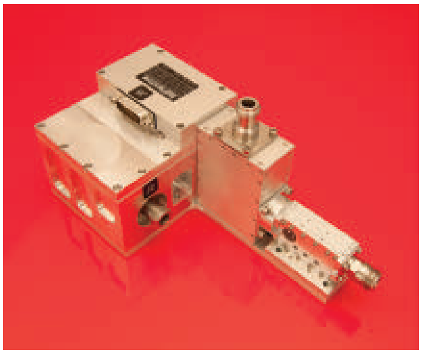
The TDD-LTE market has relied on legacy N-type RF connectors which exhibit poor PIM performance; however, TDD-LTE is more immune to PIM than FDD-LTE systems. The massive TDD-LTE network for China Mobile Communications was built using N-type connectors because of their significantly lower cost than 7-16 DIN connectors. However, the FDD-LTE networks for China Unicom and China Telecom use 7-16 DIN connectors. In North America, Verizon Wireless chose to deploy 4.1-9.5 DIN technology instead of waiting for the 4.3-10 DIN connector to become available. They appear to be the only mobile operator in the world to pick the 4.1-9.5 DIN standard, which may create significant problems for network upgrades in the future.

The advantage of the NEX10 connector is that it offers high PIM performance in both single and multi-port versions and is 50 percent smaller than the 4.3-10 DIN (see ***Figure 3***).

CONCLUSION

As operators move from LTE to LTE-Advanced, LTE-Advanced Pro and, ultimately, 5G massive MIMO, the connector interfaces will migrate from 7-16 DIN to 4.3-10 DIN, NEX10 and MCX/MMCX. The requirements and demand for the RF connectors used throughout the wireless infrastructure network will continue to increase, which makes for a bullish outlook for the global RF connector market over the next several years. ■

Editor's Note: *In this same issue, read "Making Connections – Collaborating to Develop the NEX10 Interface," which describes the development of the NEX10 connector, page 6.*



State-of-the-Art Custom Duplexers

Spectrum Elektrotechnik GmbH
Munich, Germany

High power duplexers, developed and manufactured by Spectrum Elektrotechnik GmbH, operating in L-Band and S-Band are always built to customers' electrical, mechanical and environmental specifications. These units are capable of managing peak transmit power of several kW and long pulses.

When a customer requires a high power duplexer the first decision to be made is on the size and the space the duplexer is allowed to occupy, along with its maximum weight. The next is to specify the exact location of the RF connectors and signal connectors. Devising the most meaningful and effective layout can be complicated and standard connectors at internal connections cannot usually be used. This is where Spectrum can use its expertise to design very specific connections between components. One of the most unique adapters the company has produced, a double right angle, input and output at several degrees tilted, and with a newly designed interface is shown in ***Figure 1***.

This is just one example of the customized duplexer design service offered by the company, which has in-house engineering design centers designing the components required, manufacturing all parts at the numerous CNC centers, and assembly and full testing under the required environment. Also, all the PC-boards are designed by the company, including in-house pick and place, and testing. All of which enables fast response to the customer's specification.

When customizing Spectrum considers all aspects of the duplexer's make-up, specification and applications, paying attention to all the criteria that would impact the product's design and performance.

The classic function of a duplexer is such that the transmit signal enters the circulator, passes through a coupler to the antenna. The receive signal passes through the coupler in the opposite direction, through the circulator to the limiter, while the limiter operates as receiver protection. It needs to provide active limiting capability, triggered with or without a control signal during transmission, and also have passive limiting capability during receiving periods in order to protect the receiver against jamming signals or unwanted reflected signals of high power caused by close objects. The limiter will reject these unwanted signals back into the circulator, which will then lead it to a load, consuming the undesired power.

In certain applications additional bandpass filters and lowpass filters are employed in order to eliminate spurious signals. In certain applications additional components, e.g., low noise amplifiers, etc. may be required.

The duplexer's limiter is the most complex and critical component. In order to operate peak power levels of several kW, a circuit has to be

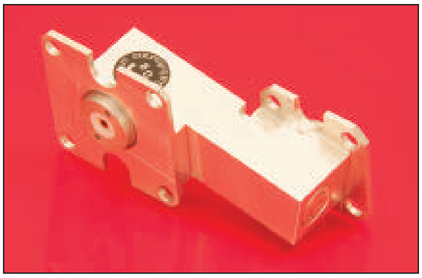


Fig. 1 Double right-angle adapter with new connector interface, designed to connect two components in a duplexer.

Fig. 2 Customized duplexer designed to meet mechanical and electrical performance specified by the customer.

designed using a number of diodes in absolute parallel connection, guaranteeing that every diode receives the same power for equal stress.

In most duplexer specifications Spectrum designers take specific key parameters into consideration. This includes low loss between transmitter and antenna while transmitting and high isolation from transmit to receive mode as well as low loss between antenna and receiver. ***Figure 2*** shows a customized duplexer designed with mechanical and electrical performance as specified by the customer.

Also, modern radar systems will transmit in different pulsed waveforms, pulse spike power, mean duty cycle, or instantaneous duty cycle, resulting in different average peak power, changing pulse duration and sequences of pulses with different lengths.

Important too is fast response circuitry, indicating that the power incident to the limiter stage exceeds the operational limits, activating a signal and providing the system with a message that the transmit power is to be reduced. Should the limiter fail, a signal must be generated so that the system can immediately turn off the transmitter.

A feature is that the limiter's switching response reaches the specified attenuation and the recovery response from full attenuation to a specified level of the insertion loss in a very short time. When activated the attenuation of the limiter at any frequency across the whole operating band needs to provide full protection with or without DC power.

Another consideration when customizing duplexers is that the flat leakage of the limiter towards the output port and certain test ports must not exceed a specified power level for a given characteristic of the input signals. The spike leakage must be limited independent of all specified load conditions of the antenna.

Also, the limiter has to provide forward and reverse video signals associated with the antenna port, which will give the best indication of the power levels provided to the antenna as well as giving the best indication of the reflected power levels from the antenna while maintaining a proportional accuracy level throughout the whole operating band and specified VSWR levels.

It is important for the duplexer to operate in all conditions within any environmental case specified and must have an over temperature sensor that indicates when the maximum operating temperature of the components has been reached or exceeded. Usually two signals are supplied, 'OK' means operating within allowed limits, and 'Fail', indicates that the allowable temperature limits have been reached.

To ensure the correct operation of the unit the input power supply of the duplexer needs to be monitored and a signal sent to the network to indicate a loss of the supply power, or that the voltage has exceeded the allowed tolerance levels, etc.

Also, the duplexer should always monitor its presence in the system, sending signals to the control center to indicate its readiness for operation, or when the transmitter is failing or disconnected. The control and interface unit within a duplexer consists of complex circuitry, which, due to volume restrictions, is usually designed on several PC-boards, combining to form a complex network.

Finally, the duplexer must be able to operate in harsh environments, and withstand mechanical shock, acceleration and bumping during transportation and storage without degradation.

Spectrum Elektrotechnik GmbH
Munich, Germany
www.spectrum-et.com

VNA Test Cables Boast High Abrasion and Crush Resistance

AtlanTecRF
Braintree, U.K.

While it's true that the primary function of an RF coaxial cable assembly is to make an electrical connection between two parts of a system, equipment, sub-assembly or test set up, there is so much more to its specification than just the electrical parameters that define the basic interconnection performance. The environments in which RF coaxial cable assemblies are used are incredibly varied, from static benign, as might be the case in ground-based, room temperature equipment racks, right through to space platforms where the ultimate in reliability is demanded.

It will come as no surprise to the RF test engineer, however, that one of the harshest operating conditions is found in the laboratory, on the test bench. The cable assemblies used to interconnect items of test equipment and connect to the device under test (DUT) may not only be subject to all the environments that the DUT is expected to survive but also to that indefinable form of stress, human handling.

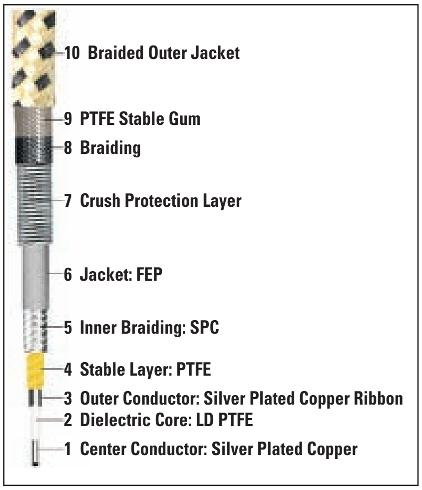
Laboratory test cable assemblies have to withstand extremes of temperature, vibration, shock and handling while delivering a level of electrical performance, which ensures that the measurements of the DUT are minimally compromised. With AtlanTecRF's ACV series of RF test cables the cable construction is built up in multiple layers in order to reduce the compromises and provide the user with the optimum interconnect during the testing routine.

In the ACV-CA40 and ACV-CA50 series, for use at 40 and 50 GHz respectively, the basic electrical performance is provided by the silver-plated solid copper centre conductor, low density PTFE dielectric and silver-plated copper ribbon outer conductor. Together with the PTFE stabilizing layer and the silver-plated copper braid, these five inner layers define and guarantee the impedance, insertion loss, phase and amplitude stability which are so critical when the test set up is subject to constant movement and temperature extremes.

On top of this inner core, the next five layers both reinforce the mechanical and therefore electrical stability and add the vital ingredient of protection against constant handling. The jacket over the braid is FEP and this is further protected but a proprietary crush resistant layer held in place by a further braid and PTFE gum. The final, 10th and outer jacket is of proprietary braided fabric to ensure a high level of resistance to the abrasion potential derived from repeated handling. A complete cross section of the ACV series cable is shown in ***Figure 1***.

The test laboratory contains both expected and accidental stresses on test equipment and this is particularly true of the cable assemblies with high probability of being snagged or caught beneath heavy objects. The two features of crush protection and abrasion resistance, although difficult to quantify, are key in the value provided to the test engineer.

Moving on to the more easily defined electrical and mechanical parameters; the ACV series



▲ Fig. 1 Construction of the ACV series cable.

is available in both standard and custom lengths. The standard, stocked lengths are 0.5, 1, 1.5 and 2 m, being the most popular for bench testing with vector network analyzers (VNA), spectrum analyzers and other items of high performance RF and microwave test gear. Lengths can be customized however for automated test set ups where excess cable length is kept to a minimum.

The two connector series, 2.92 mm for use to 40 GHz and 2.4 mm for use to 50 GHz are among the most common found in today's RF test world and are both precision made in stainless steel. The multi-layer strain relief at the back end of each connector does much to guard against work hardening and fatigue of vital cable elements at this vulnerable point.

The 10 layer construction previously described endows stability under flexure of ±0.03 dB in amplitude and ±5° in phase, both of which are necessary to ensure accuracy and repeatability of RF test results. Basic RF performance is excellent with less than 5 dB insertion loss per meter and an assembly VSWR of typically 1.2:1 at the top end frequencies (see ***Figure 2***).

Over the -55° to +165°C operating temperature range too, these cables show little variation in phase with 1000 ppm being typical. Many laboratory tests need to be carried out in temperature cycling chambers to the full range of the DUT and the test cable's ability to track and maintain performance during such tests is essential.

Once more, the well thought out multi-layer design scores with over 90 dB RF shielding, which is a serious consideration in the test environment. Additional figures in the electrical data listings include a capacitance of 138 pF, withstand voltage of 1000 V, power handling up to 115 W at 12 GHz and insertion loss variation during flexing of no more than ±0.05 dB.

Despite the complex 10-layer construction, great care has been taken to minimize the weight of the cable as this, in itself, can add to the stresses applied. At just 35 g/m therefore, the assemblies are about as lightweight as any that can be found for such a demanding task or many other applications.

With all of the performance and durability so far described, the ACV series of 40 and 50 GHz flexible test cable assemblies have yet another killer asset, a bend radius down to 40 mm, which should grab the interest of RF and microwave test engineers everywhere.

VENDORVIEW

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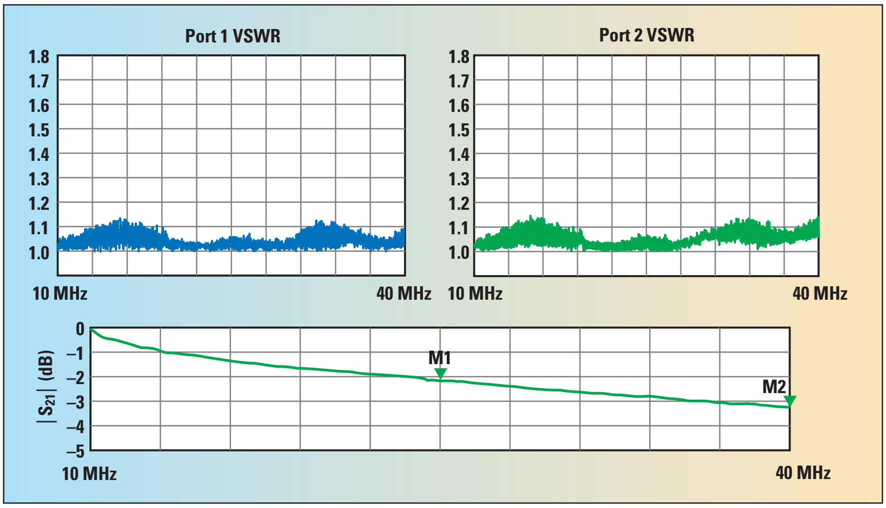
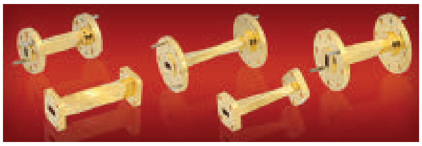


▲ Fig. 2 Loss and VSWR of the ACV series cable.

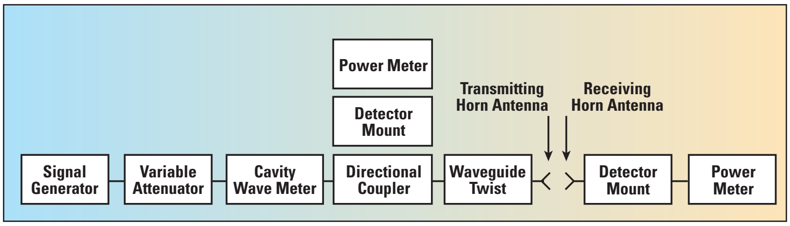


Precision Waveguide Twists For K-, Ka-, V- and W-Bands

Fairview Microwave Inc.
Allen, Texas

Waveguide twists are necessary for waveguide systems and subsystems that require a change in the polarity of a signal to phase match with a load. To support these needs, Fairview Microwave has released a family of waveguide twist assemblies with seven different sizes that operate in distinct bands from 18 to 110 GHz. These waveguide twists cover applications in K-, Ka-, V- and W-Band and are optimally designed for instrumentation, precision measurements, prototyping, characterization and production systems.

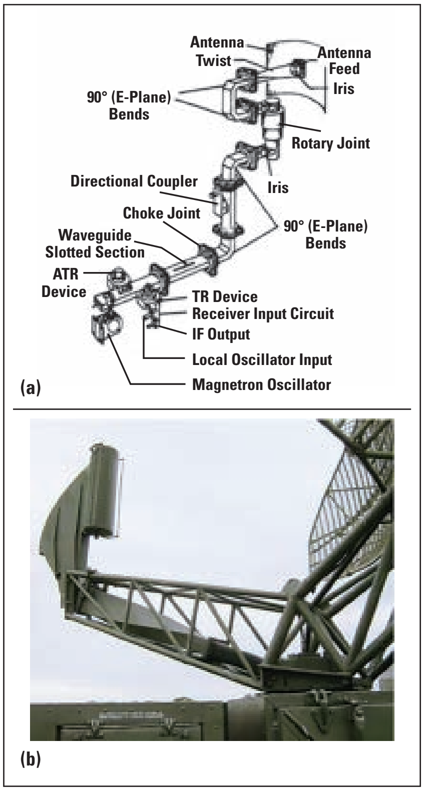
These precision assemblies are available in standard WR-10, WR-12, WR-15, WR-19, WR-22, WR-28 and WR-42 sizes. With compact lengths ranging from 1" to 2.5", these components fit conveniently into any waveguide setup. To support the wide variety of waveguide installations, each waveguide size features 90° and 45° offsets in either the left-hand or right-hand twist plane. Fairview's twist waveguide interconnect family uses brass-body construction with gold plating. Gold plating reduces resistive losses along the interior walls of the waveguide, improving the conductivity and surface condition of the waveguide walls. As the depth at which electrical current travels in a conductor is frequency dependent, a phenomenon known as the skin effect, higher frequency conductors benefit from improved conductivity at the surface, which leads to lower attenuation and less reflection back to the source.



▲ Fig. 1 Using a waveguide twist to test E- and H-plane radiation patterns. Source: Microwave Engineering: Concepts and Fundamentals, Ahmad Shahida Khan.

From K-Band radar antenna feeds to Ka-Band communication satellites to V- and W-Band test systems, the waveguide twists can be integrated in a wide range of waveguide systems. For example, a test bench setup that requires convenient switching between H-plane and E-plane measurements can alternate between a rectangular waveguide twist and a rectangular waveguide. Measuring E- and H-plane radiation patterns with horn antennas just requires the addition or removal of a waveguide twist (see ***Figure 1***). Another illustration of a waveguide twist application is using a twist to change the polarization of the signal in a waveguide antenna feed for military radar (see ***Figure 2***). Waveguide twists are used in front-feed installations to avoid obstructing the aperture of the larger parabolic antenna.

To reliably serve the diverse range of applications, Fairview Microwave fabricates all waveguide in accordance with MIL-DTL-85, which is the military specification for the performance requirements for rigid waveguides with rectangular inside configurations. These standards govern the mechanical and electrical performance of the waveguide. MIL-DTL-85 specifies that any waveguide twist must have at most 1 degree of rotation per foot of length along the axis, as well as defining the maximum allowable surface roughness and scratches, to ensure a conformal waveguide and allow for a continuous impedance



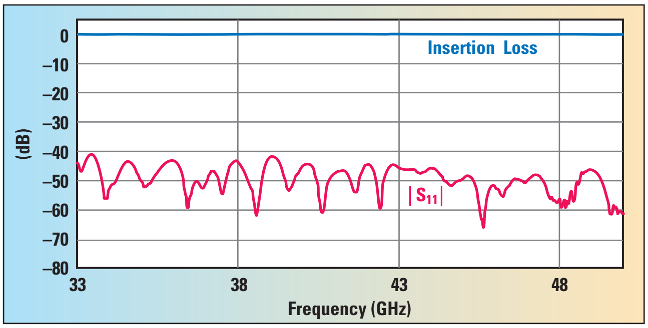
▲ Fig. 2 A waveguide twist (a) used in the antenna feed of a military radar (b). Source: Wikipedia, en.wikipedia.org/wiki/Waveguide#/media/File:Radar_waveguide.jpg, CC BY-SA 4.0.

along the waveguide. The angle of the twist is measured on a flat surface as a reference plane, using an engraved protractor adjusted to a particular angle line. To verify that the waveguide twist meets pressurization standards, it is subjected to forced internal air pressure while submerged in water heated to 68°F for five minutes. A failure occurs in the pressure test if air bubbles are released from the edge seams. VSWR and return loss are also specified to ensure minimum reflection and peak electrical performance.

The insertion loss of Fairview Microwave's 21 different waveguide twists range from 0.2 to 0.75 dB in K- and Ka-Band to 0.5 to 1.1 dB in V- and W-Band. The VSWR can extend between 1.07:1 to 1.25:1 in K- and Ka-Band and from 1.02:1 to 1.43:1 in V- and W-Band. ***Figure 3*** shows the low insertion loss and high return loss of the SMW22TW1001 90° waveguide twist.

Table 1 summarizes the electrical performance and mechanical construction of the waveguide twist family. Seven waveguide sizes are in stock, each with 90°, 45° left-hand and 45° right-hand twists available. Waveguide sizes WR-22, WR-28 and WR-42 are 2" or longer, while WR-10, WR-12, WR-15 and WR-19 are 1.25" to 1.5" in length.

Fairview Microwave's portfolio of waveguide twists are a part of a large suite of precision waveguide. With one of the largest portfolios, Fairview Microwave can serve many "waveguide plumbing" needs across commercial, military and precision test applications.



▲ Fig. 3 The WR-22 90° twist (SMW22TW1001) has a maximum insertion loss of 0.5 dB and VSWR of 1.02:1 between 33 and 55 GHz. The measured $|S_{11}|$ is the reflection from the load used to test the twist.

Fairview Microwave Inc.
Allen, Texas
www.fairviewmicrowave.com

TABLE 1
WAVEGUIDE TWIST FAMILY

Model Number	Waveguide Size	Band	Frequency (GHz)	Twist Plane	Offset Degree	Flange	Length (in.)	IL (dB)	VSWR
SMW10TW1001	WR-10		75 to 110		90	UG-387/U-Mod	1.25	1	1.43:1
SMW10TW1002	WR-10	W	75 to 110	Left-Hand	45	UG-387/U-Mod	1.25	0.75	1.1:1
SMW10TW1003	WR-10		75 to 110	Right-Hand	45	UG-387/U-Mod	1.25	0.75	1.1:1
SMW12TW1001	WR-12		60 to 90		90	UG-387/U	1.25	1	1.12:1
SMW12TW1002	WR-12	V & W	60 to 90	Left-Hand	45	UG-387/U	1.25	1.1	1.16:1
SMW12TW1003	WR-12		60 to 90	Right-Hand	45	UG-387/U	1.25	1.1	1.16:1
SMW15TW1001	WR-15		50 to 75		90	UG-385/U	1.5	1	1.11:1
SMW15TW1002	WR-15	V	50 to 75	Left-Hand	45	UG-385/U	1.5	0.8	1.11:1
SMW15TW1003	WR-15		50 to 75	Right-Hand	45	UG-385/U	1.5	0.8	1.11:1
SMW19TW1001	WR-19		40 to 60		90	UG-383/U-Mod	1.5	0.5	1.22:1
SMW19TW1002	WR-19	V	40 to 60	Left-Hand	45	UG-383/U-Mod	1.5	0.5	1.25:1
SMW19TW1003	WR-19		40 to 60	Right-Hand	45	UG-383/U-Mod	1.5	0.5	1.25:1
SMW22TW1001	WR-22		33 to 50		90	UG-383/U	2	0.5	1.02:1
SMW22TW1002	WR-22	V	33 to 50	Left-Hand	45	UG-383/U	2	0.5	1.02:1
SMW22TW1003	WR-22		33 to 50	Right-Hand	45	UG-383/U	2	0.5	1.02:1
SMW28TW1001	WR-28		26.5 to 40		90	UG-599/U	2	0.5	1.07:1
SMW28TW1002	WR-28	Ka	26.5 to 40	Left-Hand	45	UG-599/U	2	0.2	1.09:1
SMW28TW1003	WR-28		26.5 to 40	Right-Hand	45	UG-599/U	2	0.2	1.09:1
SMW42TW1001	WR-42		18 to 26.5		90	UG-595/U	2.5	0.5	1.07:1
SMW42TW1002	WR-42	K	18 to 26.5	Left-Hand	45	UG-595/U	2.5	0.75	1.25:1
SMW42TW1003	WR-42		18 to 26.5	Right-Hand	45	UG-595/U	2.5	0.75	1.25:1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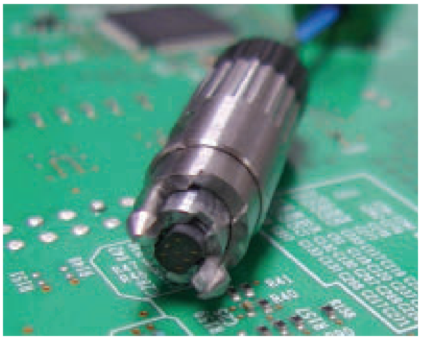
Fax: +886-6-356-6268
E-mail: info@frontlynk.com

Low Loss Coaxial Cables

The Insulated Wire (IW) 480 series of low loss cables operate up to 11 GHz with attenuation values from 0.006 dB/ft. at 0.04 GHz to 0.116 dB/ft. at 11 GHz. The 480 series is constructed with a silver plated stranded copper center conductor with EPTFE dielectric, silver plated copper foil, silver plated copper braid and a FEP outer jacket. Other performance parameters include capacitance of 24 pF/ft., velocity of propagation of 83%, time delay of 1.22 ns/ft., shielding effectiveness (up to 18 GHz) of >90 dB and power handling ranging from about 900 W (at 11 GHz) to more than 1200 W (at 1 GHz); customer testing has proven 17 kW power handling at 13.56 MHz for semiconductor fabrication processes. The cable weighs 2.9 oz/ft. with a minimum bending radius of 2.25 inches. The operating temperature range (cable only) is 65°C to > +200°C. VSWR with two straight connectors is 1.35:1 at 11 GHz. RoHS compatibility is available upon request.

IW's Microwave Products Division designs and manufactures extremely low loss cable assemblies that are optimized for operation in their respective frequency bands from low MHz to 67 GHz. They can accommodate custom assembly configurations, and extrude a broad range of jacketing materials. Their jacketing capabilities enable them to produce assemblies that have extra flexibility, extended flex life, low and high temperature ranges, and resistance to oils and corrosive materials. Their standard assemblies are extruded with FEP but they also provide PFA, Tefzel, silicone rubber and ESTANE® 58244 (low smoke zero halogen) plus others. IW serves a broad range of both military and commercial markets including telecommunications, data links, satellite systems, airborne electronic warfare and counter measures, missile systems, UAV applications, avionics and instrumentation, fire control systems, medical electronics and geophysical exploration.

Insulated Wire (IW)
Microwave Products Division
Bethel, Conn.
(203) 791-1999
info@iw-microwave.com



QUICKLINK Eliminates Surface-Mount Connectors

Ardent Concepts Inc. is aiming to upend the status quo by introducing a solderless twist-to-lock compression-mount connector to replace cumbersome surface-mount connectors, such as SMAs, SMPs and GPPOs.

Unlike surface-mount connectors that require a receptacle on the PCB, Ardent's patented QUICKLINK™ connector combines connector and receptacle and mounts directly to the PCB. The twist-to-lock footprint design requires only two small thru-holes and a printed circuit board footprint. Footprints can be placed anywhere on the board, allowing easy access and rapid connection, with no threading or tools required.

QUICKLINK meets the bandwidth requirements of applications like PAM4 signaling and millimeter wave infrastructure, delivering superior signal integrity from DC to greater than 70 GHz. Insertion loss is 1.5 dB maximum through 40 GHz and 3 dB maximum through 70 GHz. Designed for 50 Ω, return loss is 18 dB or better through 70 GHz. Crosstalk and coupling interference is –70 dB maximum through 70 GHz. A solderless system, QUICKLINK avoids signal distortion and, if not properly connected, is designed to produce an open signal, eliminating the possibility of skewed results from a bad connection. Electrical repeatability is maintained over more than 1,000 mating cycles.

During product development, QUICKLINK's unique design reduces wasted component costs associated with new board revisions, by eliminating soldered surface-mount connectors. In production, QUICKLINK reduces test and manufacturing time, allows for system signal "sniffing" and provides test points for troubleshooting.

Ardent Concepts Inc.
Hampton, N.H.
(603) 474-1760
info@ardentconcepts.com

Best in Class!

2801 Series

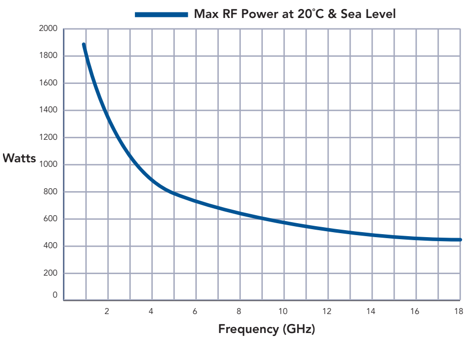
Flexible/High Frequency/Low Loss Cable Assemblies

The **2801 Series** cable assemblies offer the "lowest loss in the industry" at frequencies up to 18 GHz. The cable features a multi-ply concentrically laminated dielectric of expanded PTFE, double shielding and a standard FEP jacket per ASTM D-2116. Options including LOW SMOKE/ZERO HALOGEN polyurethane jacketing and TUF-FLEX internal armoring are available for applications requiring enhanced mechanical protection. SMA, precision TNC and N Type connectors are standard for frequencies up to 18 GHz. C, SC and 7-16 connectors are also offered.

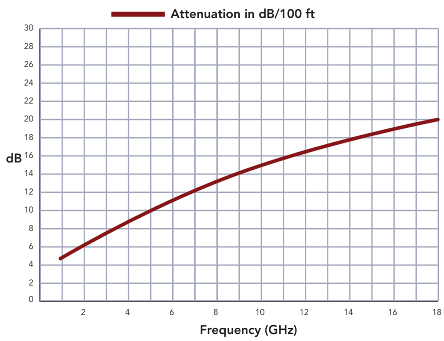
Specifications

Impedance:	50 ohm	**RF leakage, min:**	-100 dB to 18 GHz
Time delay:	1.2 ns/ft.	**Temp range:**	-65°C to +165°C
Cut off frequency:	18 GHz	**Cable outer diameter:**	0.31″
Capacitance:	24 pf/ft.	**Velocity of propagation:**	83%
Weight:	7.8 lb./100 ft.	**Flame retardant rating:**	UL94-V0

Max RF Power in Watts
20°C at Sea Level



Attenuation in dB/100 ft



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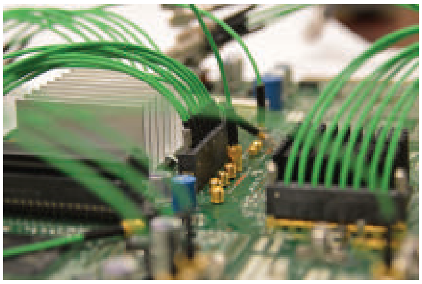


When Signal Integrity and Density Matter

CoreGD™ is a high performance, multi-port, interconnect system that offers excellent signal integrity for complex layouts and crowded PCBs. Despite being optimized for demanding bandwidth applications this interconnect solution delivers significantly lower cost compared to competitive offerings.

The CoreGD system is available in commercial off-the-shelf configurations that include multi-ports (2, 4, 6, 8 or 10) with stackable, side-to-side and back-to-back configurations. Choosing one of these reduces time-to-market and cost. To meet the full range of system needs, the CoreGD can be customized into hybrid designs that combine various RF, digital and power interconnects.

Using SMMP RF connectors, connector pitch is 4 mm, and the RF interconnects operate to 65 GHz. VSWR is less that 1.11:1 (26 dB return loss) up to 26 GHz and increases to 1.4:1 maximum (15.6 dB return loss) at 65 GHz. WMP connectors have 2.5 mm pitch and extend the bandwidth to 100 GHz, with VSWR of 1.35:1 (16.5 dB loss) at 65 GHz and 1.45:1 (14.7 dB return loss) at 100 GHz. Insertion loss is approximately $0.1\sqrt{f(GHz)}$ for the SMMP $0.12\sqrt{f(GHz)}$ and for the WMP.

The innovative design of the CoreGD ensures the consistency of the push-on interface, which eliminates electrical length and phase variation with vibration, shock or other movement. The interconnect system meets MIL-STD-202 for corrosion, vibration, moisture resistance, thermal and mechanical shock, and has an operating temperature range of −55° to +165°C.

Carlisle Interconnect Technologies
St. Augustine, Fla.
www.carlisleit.com

Security Terminations Help Avoid Catastrophe

The accidental removal of a 50 Ω termination will, at best, cause measurement errors or degrade system performance. At worst, it can cause an expensive component such as a power amplifier to fail. To prevent this possibility, Cinch Connectivity Solutions developed a family of "security" terminations that can only be removed with a special tool.

The security termination is a stainless steel, passivated shell that will hold any of three Midwest Microwave's TRM-244x SMA male 50 Ω terminations. The three models in the TRM-244x family provide frequency coverage to 8, 18 or 26.5 GHz with maximum VSWR of 1.11, 1.19 and 1.3, respectively. Average power handling is 0.5 W at +25°C, and the operating temperature range for the family is from −55° to +125°C.

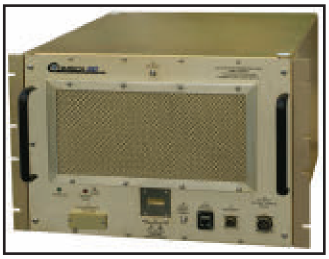
To attach, the security termination is first screwed on the mating connector by hand until the security shell begins to slip. The security termination tool is then aligned with the security termination openings and the insert inside the termination. The tool is turned clockwise by hand until the termination is tight. Using an SMA torque wrench, the final mating torque is applied: 3 to 5 in-lbs for brass SMA interfaces and 7 to 10 in-lbs for stainless steel interfaces. The termination is now secure and can only be removed with the tool. To remove the security termination, the tool is aligned with the termination openings and inserted inside the termination. With an SMA wrench, the termination is loosened by turning in a counter-clockwise direction. Once completely loose, the security termination can be removed by hand.

Not previously available in the market, Cinch Connectivity Solutions' security terminations are being used on test equipment in test labs, production test systems and equipment in the field.

Cinch Connectivity Solutions
Waseca, Minn.
www.cinch.com

Cables and Connectors

Company Showcase



X-Band Radar Solid-State Power Amplifier

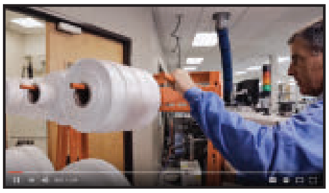
Comtech PST proudly introduces its gallium nitride (GaN) 8 kW amplifier, model BMPC9X89X8-8000, for applications in the X-Band pulsed radar market. The AB linear design operates from the 9 to 9.9 GHz frequency range over any instantaneous bandwidth of 500 MHz. The amplifier design features self protection for load VSWR, duty factor, pulse width, temperature, as well as a graceful degradation in case of a RF power module failure. Custom configurations/features are available as well as specific power levels up to 16 kW.

Comtech PST Corp.
www.comtechpst.com

DynaTest Brochure

DynaTest™ series cable assemblies are designed to deliver repeatable, precision measurements while lowering your overall total cost. These assemblies offer exceptionally low VSWR and insertion loss characteristics across a broad frequency range. This allows a single DynaTest™ cable assembly to be used for the maximum number of measurement requirements. These assemblies are highly flexible, yet maintain phase stability to ensure repeatability without the need for recalibration. DynaTest cable assemblies are available through distribution to support your standard product requirements.

Dynawave Inc.
www.dynawave.com



Introducing VP90

HSI's coaxial cables are processed using solid, foamed and expanded PTFE (VP90) dielectrics—offering high performance coax cable assemblies up to 70 GHz and down to 0.175 mm in pitch. HSI is one of a few custom global manufacturers extruding its own high-performance coaxial cable and ePTFE (VP90). By managing nearly all critical technologies and processes in-house, HSI assures you zero trade-offs when it comes to insertion loss, phase stability, capacitance and velocity of propagation.

High Speed Interconnects
www.highspeedint.com/videos

Solutions for WAN/ Access Networks

VENDORVIEW

Its broad knowledge in different technologies makes HUBER+SUHNER the leading provider of interconnectivity solutions and innovative services in the field of indoor and outdoor Fiber to the Home business (FTTH). This newly launched catalogue showcases the fiber optic portfolio including fiber management systems, enclosures, halogen free cables as well as connectors, adapters, couplers and splitters. In addition, the newly developed fiber optic pre-connectorized solutions allow installers and network suppliers a fast, easy and modular installation of FTTH infrastructure.

Huber + Suhner AG
www.hubersuhner.com

Color-Coded Interconnects

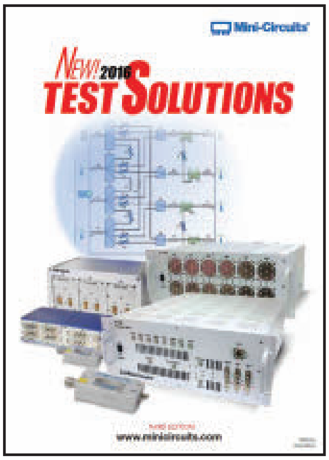
Avoid expensive connector compatibility mistakes? Yes we can! Maury Microwave is the only complete provider of color-coded interconnects which easily identify connector type, frequency and compatibility. ColorConnect includes Stability™ Phase Stable Cable Assemblies, Utility™ General Purpose Cable Assemblies, ColorConnect™ Precision Adapters, precision attenuators, and torque wrenches. Exceptional companies have superior labs—complete your lab with Maury Microwave. Our vision is to be the go-to source for all your lab needs, from adapters and cable assemblies to instrument calibration tools to turnkey measurement and modeling characterization solutions.

Maury Microwave
www.maurymw.com

Microwave mmWave Cable Assemblies

MIcable is a designer and manufacturer of high performance microwave coaxial cable assemblies for a variety of applications, including DC to 50 GHz flexible cable assemblies, hand-formable cable assemblies, semi-rigid cable assemblies and precision test cable assemblies. MIcable also designs and produces various precise adapters and connectors up to 50 GHz. Custom designed cable assemblies are also available. Please email sales@micable.cn for more information.

MIcable
www.micable.cn



Test Solutions Product Guide

VENDORVIEW

Mini-Circuits' line of custom test solutions has expanded with an even wider lineup of capabilities to meet your needs. The third edition of their Test Solutions Product Guide is a 52-page complement to the second edition, featuring a selection of new models developed in 2016 with additional details on applications and companion products. Highlights include a new series of compact modular test systems, N-port mesh network modules and 2x N-port switch matrices.

Mini-Circuits
www.minicircuits.com

Hot New Products

VENDORVIEW

This 24-page product guide provides a complete survey of the hottest Mini-Circuits product releases from the second quarter of 2016. Highlights include everything from ultra-wideband MMIC splitter/combiners, MMIC mixers and MMIC multipliers to their revolutionary reflectionless filters, ultra-sharp cavity bandpass filters, high-power stripline couplers and new portable USB/Ethernet test and measurement devices. Mini-Circuits is continuously innovating new products to meet your needs, and this informative product guide will help you stay up-to-date with their latest model releases.

Mini-Circuits
www.minicircuits.com

NI AWR Design Environment V13

VENDORVIEW

The NI AWR Design Environment software platform addresses design challenges for highly integrated RF/microwave components found in communications and radar systems. New capabilities in the V13 release include enhanced design flow automation for MMIC, RFIC and multi-chip modules, enhanced harmonic balance simulation, new system-level load pull, faster and more robust planar and arbitrary 3D EM solvers, as well as additional component synthesis and wizards supporting OpenAccess and PCB file standards. To learn more, visit awrcorp.com/whatsnew.

National Instruments
awrcorp.com/whatsnew

Test & Measurement Catalog 2017

VENDORVIEW

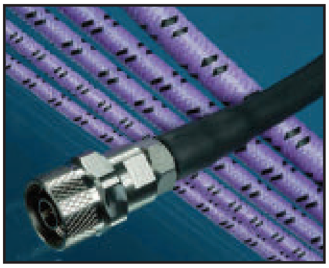
Rohde & Schwarz' Test and Measurement Catalog 2017 features nearly 300 pages of information about Rohde & Schwarz test and measurement instruments, systems and software. It includes a short description and photos of each product, the most important specifications and ordering information. Available for download as a PDF from the Rohde & Schwarz website or customers can order a hard copy from customer support at customersupport@rohde-schwarz.com (order number: PD 5213.7590.42 V 07.01).

Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

Phase Adjuster 2018

Spectrum's Precision Phase Adjusters, also called Phase Shifters, allow the adjustment of the electrical separation between components. A precision mechanical movement provides for smooth and accurate adjustment over the entire frequency range. A secure locking mechanism is furnished with every unit. A wide selection of components is available, offering different mechanical configurations, frequency ranges, electrical lengths and many different connector configurations. Frequency ranges are DC to 2 GHz, DC to 12.4 GHz, DC to 18 GHz, DC to 26.5 GHz, DC to 40 GHz, DC to 50 GHz and DC to 65 GHz.

Spectrum Elektrotechnik GmbH
www.spectrum-et.org



Microwave/RF Test Assemblies

Reliability is crucial for applications that use microwave/RF cable assemblies to ensure consistent, repeatable measurements and to maintain electrical performance. For test applications that require precise, repeatable measurements, GORE® PHASEFLEX® Microwave/RF test assemblies provide excellent phase and amplitude stability with flexure. The rugged, lightweight construction of these assemblies delivers reliable performance with longer service life and reduced equipment downtime, which results in lower costs for testing in laboratory, production and field test environments.

W.L. Gore & Associates Inc.
www.gore.com/test

Cables and Connectors

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