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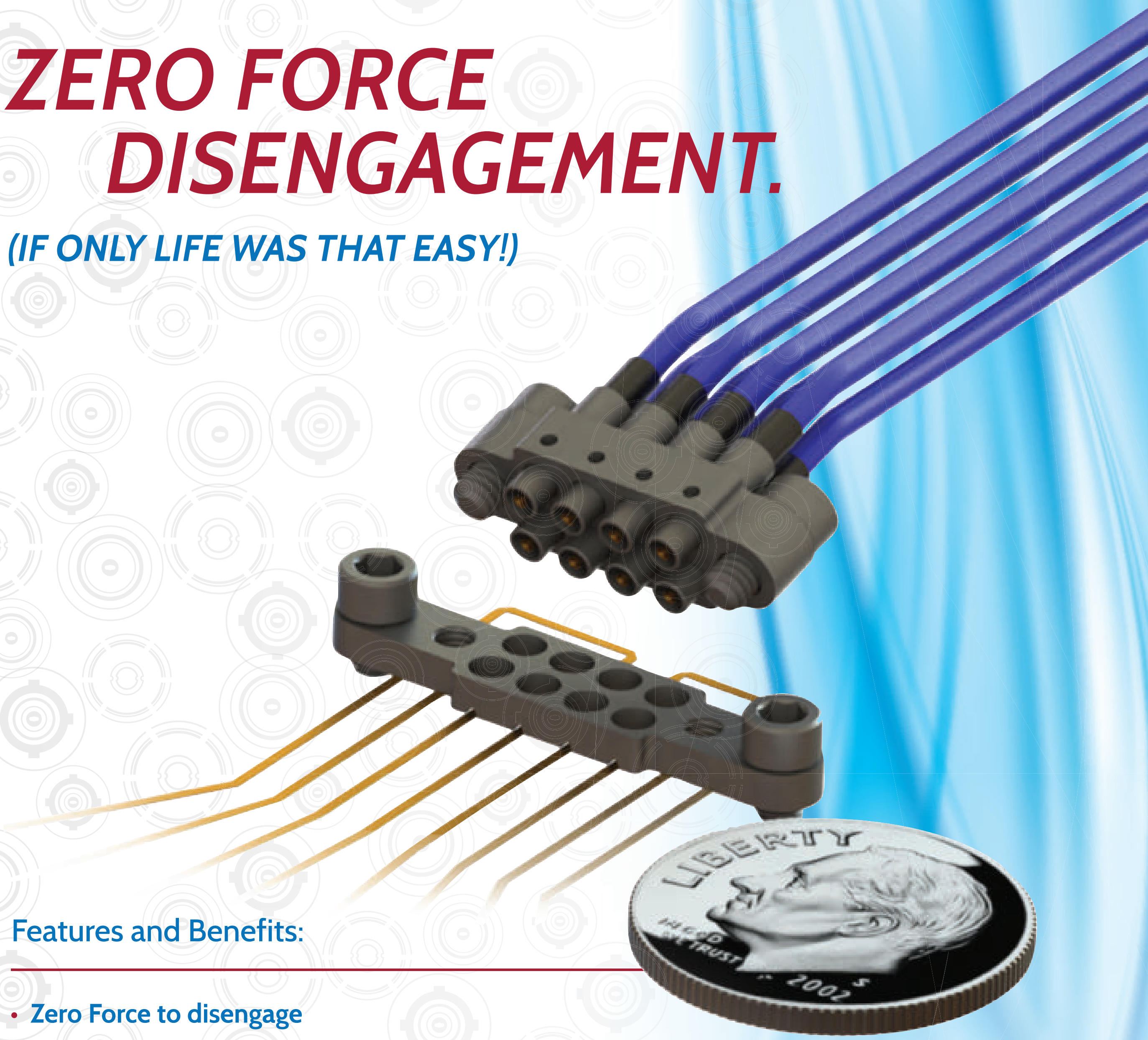

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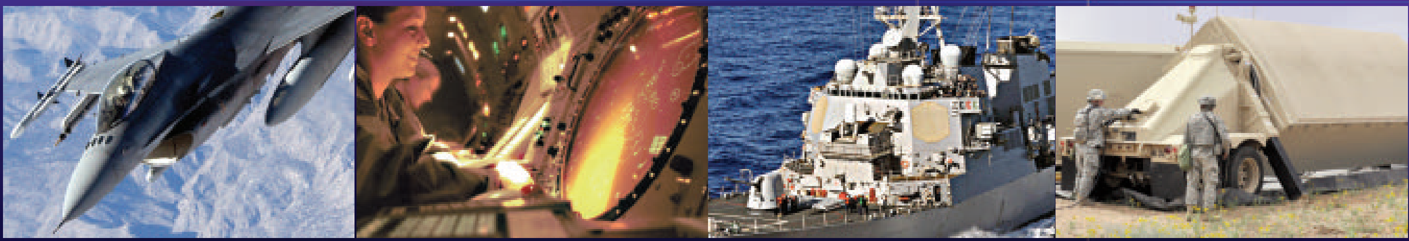

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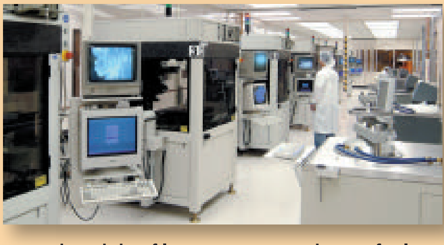

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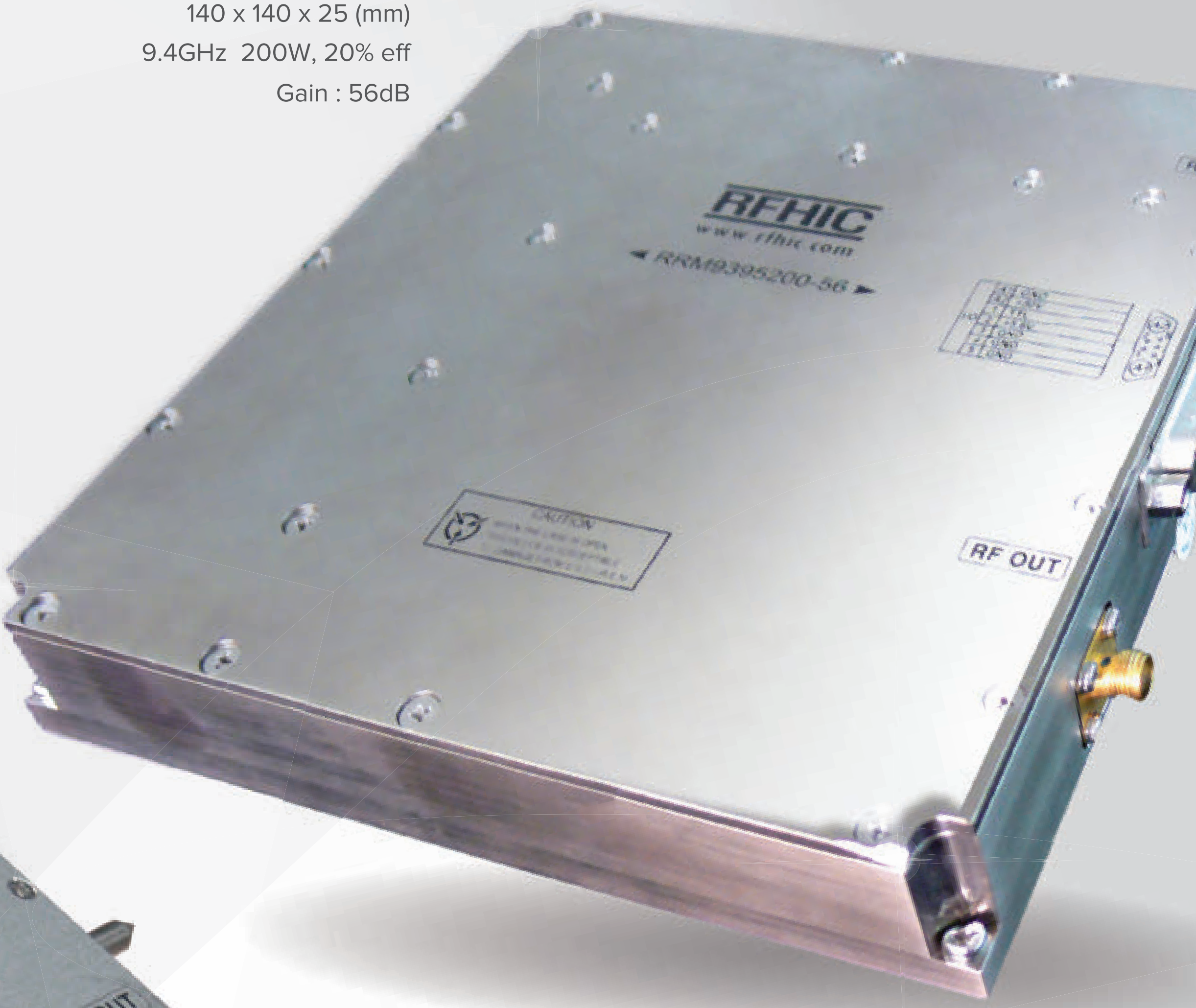

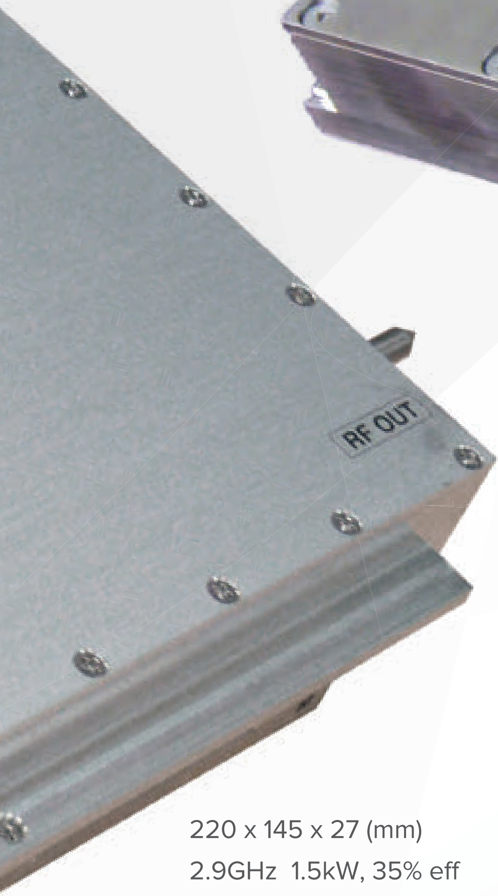

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Modular Platform Approach for UWB Radar System Design and Verification Challenges

Bertalan Eged, Raffaele Fiengo and David A. Hall
National Instruments, Austin, Texas

Ever since the 1940s, the design of radar systems has been subject to continuous innovation and experimentation. Today, radar systems use technology ranging from ultra-wide bandwidths (UWB)[1] to phased arrays and even passive radar. Some of the emerging technologies under investigation from the radar community include: cognitive radar[2], waveform diversity[3] and compressive sensing.[4] In addition, multifunction radars, such as DMPAR,[5] can be employed for meeting the requirements of multiple scenarios and challenges.

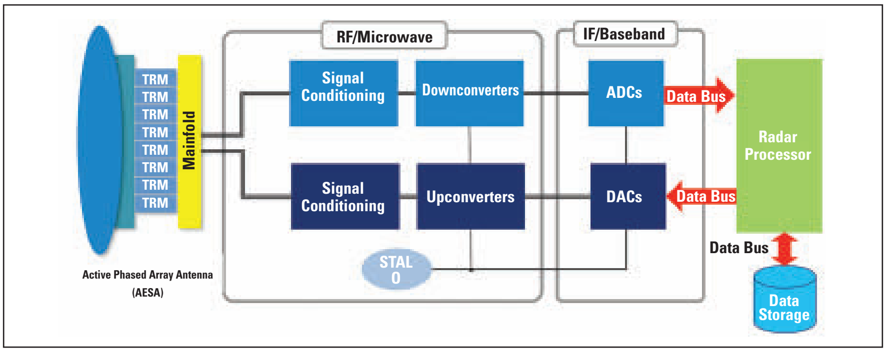
In the defense industry, there is a continuous contest between radar and electronic support measures (ESM) systems. Radar scientists are looking for new technologies that will improve the low probability of intercept (LPI) properties of radar and prevent ESM receivers from detecting and classifying signals transmitted by radar. In these applications, the requirement of ambiguity-free radar has increased interest in noise or pseudo-noise radar systems[6] that use digital transmitters and receivers with hundreds of MHz of instantaneous bandwidth.

UWB radar technology remains an attractive technology because of its ability to increase obstacle detection and tracking resolution of traditional radar systems. More importantly, UWB systems do this while spreading power over a wider signal bandwidth. As a result, they inherently transmit a lower power in any narrow band and reduce the likelihood of detection. IEEE Standard 686[7] defines ultra-wideband as any signal that either occupies more than 25 percent of the bandwidth of the carrier (called 'percentage bandwidth') or has a bandwidth greater than 500 MHz.

This article will discuss some of the design and test challenges associated with UWB radar systems with a focus on system verification and RF testing, trends in radar architecture, approaches to system design and prototyping, and typical RF measurements.

EVOLUTION TO SOFTWARE-DEFINED ARCHITECTURES

As the design of modern radars has adopted an increasingly sophisticated software-defined architecture, advanced signal processing algorithms have become an essential element of modern radar systems. ***Figure 1*** illustrates a general block diagram of a modern radar system. In this figure, high sample rate digital-to-analog converters (DAC) and analog-to-digital converters (ADC) support wide input signal



▲ *Fig. 1 Software defined radar systems.*

bandwidth. In microwave radar systems, these components enable wide instantaneous bandwidths of the radar system. In some cases, use of high sample rate DACs and ADCs also enables the design and deployment of direct sampling transmitters and receivers for L-Band radars.

In phased array radar systems, having multiple channels of the analog signal conditioning and ADCs/DACs is a key requirement. In these applications, providing tight synchronization between these elements using low-phase noise local oscillators and sampling clock sources is crucial to ensuring a high degree of system performance.

In addition to synchronization between channels, today's software defined radio systems require synchronization within elements of the processing chain, including DDCs, DUCs and channelization algorithms. The ultra-wideband architecture use of a large number of channels, in conjunction with high sampling rate converters, produces an immense amount of data. As a result, transferring this data (often multiple gigabytes/sec) introduces additional challenges in the system architecture design and verification.

The software-defined approach to radar system design is an important enabling technology in modern radar system design because it allows the engineers and scientists to continually evolve radar systems with new waveforms and architectures. As a result, engineers are increasingly adopting software defined radio platforms as a design tool for next-generation radar algorithms.

DESIGNING MODERN RADAR SYSTEMS

The instantaneous bandwidth requirements of modern UWB radar systems add considerable difficulty to the challenges of designing and prototyping modern radars. For example, with signal bandwidths of up to 500 MHz, the data associated with the single physical channel ranges from 2 to 4 GB/s – depending on ADC and DAC resolution. Not only do these extremely high data rates present a significant challenge in the design of the deployed radar, but they also introduce significant challenges when

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prototyping. In order to better understand these challenges, it is worth explaining the typical design process used in the design of a radar system and how engineers are dealing with the large amount of data that modern radar systems produce.

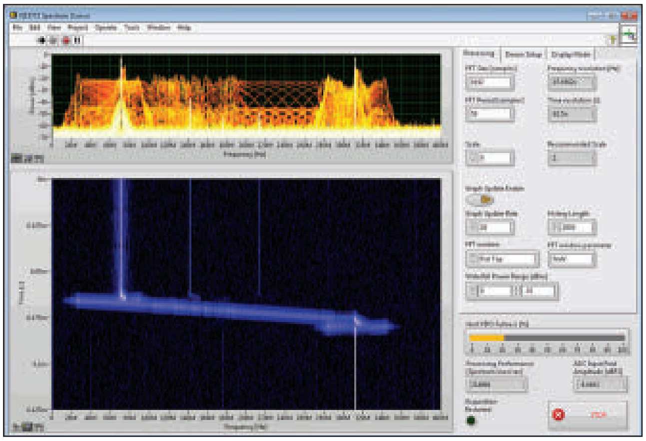
Historically, radar systems had typically been designed and integrated by a small team of hardware engineers. However, today's increasingly complex, software-defined radar systems require a mix of software, digital and analog designers. As a result, engineers face an increasing need for a highly integrated tool chain that enables them to prototype radar systems early during the design process.

An increasingly common approach to radar system verification and prototyping is the use of software defined radio technology to design and test the signal processing algorithms used in modern radar systems. When developing such systems, engineers are tasked with the challenge of designing and testing signal processing algorithms, often before the front end design is complete. An increasingly common approach to radar validation is to use instrumentation as the radio front end to validate the behavior of signal processing.

VALIDATING RADAR SIGNAL CHARACTERISTICS

Validating radar subsystems or building prototypes using instrumentation requires extremely wideband instrumentation. Not only can engineers use instrumentation to validate the behavior of complex radar signals, but they can also use it to emulate the behavior of the radar itself at either baseband or RF frequencies.

For example, consider the use of real-time spectrum analysis tools to validate the creation of a hopped or chirp waveform. At baseband frequencies, one can use an IF digitizer such as the NI PXIe-5624R IF with up to 1.7 GHz of analog bandwidth with a digital downconverter capable of up to 800 MHz of instantaneous bandwidth. Engineers can use this instrument or similar ones as either as an IF digitizer connected to existing RF front ends or as a direct sampling digitizer in L-Band radar systems. At RF frequencies, engineers can use a vector signal analyzer (VSA) such as the NI PXIe-5668R VSA that has more than 500 MHz of RF bandwidth at frequencies up to 26.5 GHz. As illustrated in ***Figure 2***, both of these instruments offer real-time spectrum analysis capabilities that execute a wideband FFT on samples. As a result, the behavior of a radar pulse can be validated using displays such as the persistence plot or the real-time spectrum analyzer.



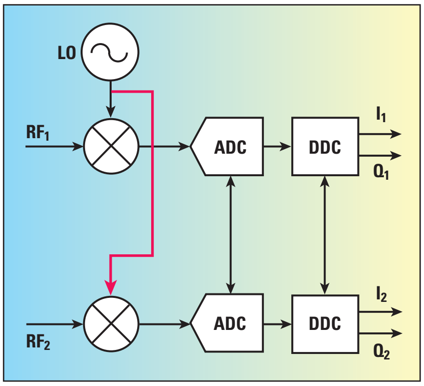
▲ *Fig. 2 Analyzing radar chirp on a real-time spectrum analyzer.*

MULTI-CHANNEL ANALYSIS

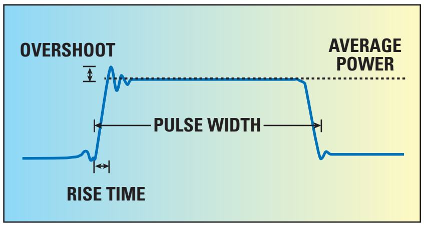
A second key verification technique of advanced UWB radar systems is the use of multi-channel instruments to verify radar behavior. Modern radar systems, that often use active electronic scanned array (AESA) technology, are increasingly utilizing multi-channel architectures. Common multi-channel implementations include phased-array and multiple-input multiple-output (MIMO) radar systems with co-located antennas.

Although the two approaches use similar radio configurations, there is a distinct difference between phased-array and MIMO radar systems. A phased-array radar transmits scaled versions of the same waveform whereas a MIMO radar system transmits different waveforms from different transmit antennas in order to achieve a large virtual array size.[2] Due to the constraints of MIMO radar design, several alternate transmission schemes have attracted much interest including: FDMA, TDMA, randomized TDMA, Doppler DMA and slow-time CDMA.

The complexity of multi-channel radar systems creates significant challenges for engineers tasked with verifying the performances of the radar system. In fact, phase-coherent RF signal acquisition systems require sophisticated synchronization technology to ensure that each downconverter/digitizer shares all timing signals, including local oscillators (LO), sample clocks and start triggers. As we observe in ***Figure 3***, a two-channel RF signal analyzer requires each channel to share a common LO.



▲ *Fig. 3 Architecture of a simplified two-channel RF signal analyzer.*

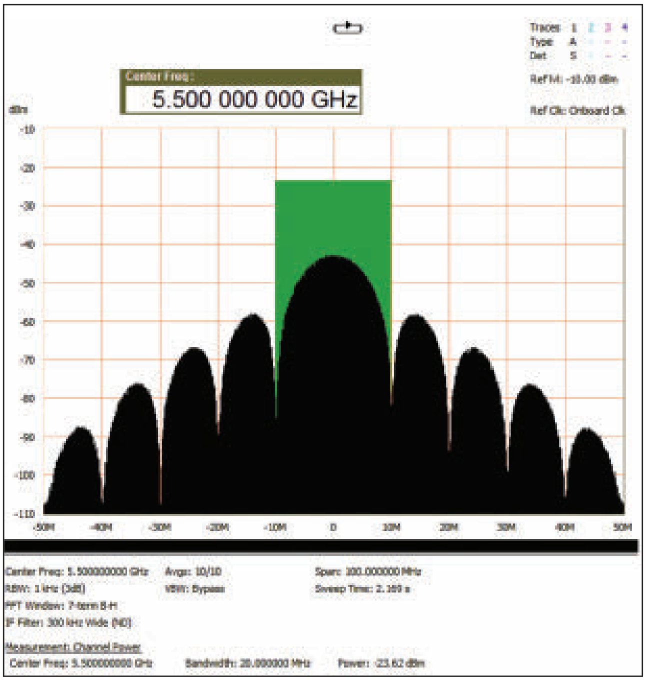


▲ *Fig. 4 Typical radar pulse measurements.*

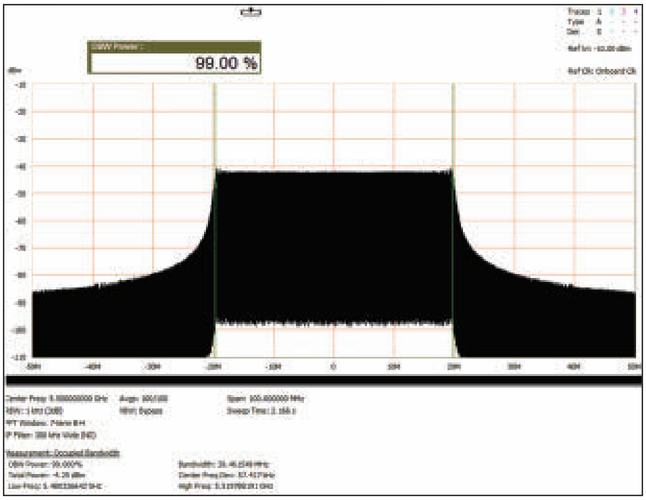
Modular instruments such as PXI have become an increasingly popular approach to testing multi-channel radar systems because of their native support of tight channel-to-channel synchronization. For example, up to 16 IF channels of a digitizer can easily be synchronized in a single PXI chassis. At RF frequencies, modular PXI RF signal analyzers feature the ability to share local oscillators between each channel. As a result, using multiple PXI chassis, it is possible to synchronize 2, 4, 8 or even more RF channels using the native synchronization characteristics of PXI.

RADAR TESTING

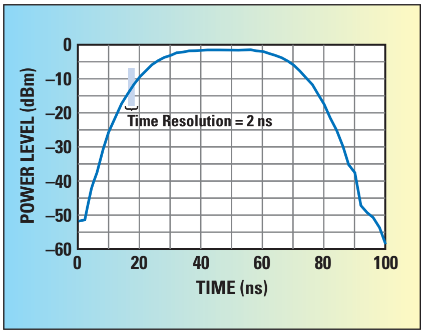
A final challenge of modern UWB radar testing is associated with the bandwidth requirements of wideband



▲ *Fig. 5 Main power lobe of a 50 ns pulse is contained within a bandwidth of 20 MHz.*



▲ *Fig. 7 Example FM chirp occupying approximately 40 MHz of bandwidth.*



▲ *Fig. 6 Time domain of a 50 ns pulse using 500 MHz of instantaneous bandwidth.*

pulsed transmissions. Today's radar systems can require extremely wide bandwidths either through extremely short pulse widths or through pulse compression. Common radar pulse measurements include rise time, fall time, overshoot and pulse width. Although extremely short pulses with a shorter pulse repetition interval (PRI) improve radar resolution (at the expense of range), they inherently require RF signal analyzers with very wide instantaneous bandwidth. All of these measurements, illustrated in ***Figure 4***, are performed using the zero span mode of an RF signal analyzer, which displays power as a function of time.

Pulsed radar signals are typically characterized by a sinc function in the frequency domain. As a result, when measuring extremely wide pulses, wide instantaneous bandwidth is required to accurately measure rise time. In ***Figure 5***, observe the frequency domain of a 50 ns pulse. The main power lobe of a 50 ns pulse is contained with 20 MHz of bandwidth. However, substantial power exists in each of the adjacent side lobes. Thus, accurately measuring pulse time also requires capturing the side lobes as well. A general rule of thumb for measuring pulse rise time is that the instrument's instantaneous bandwidth must be three times wider than 1/rise time.

For example, in order to measure pulse rise times as low as 6 ns, the required instrument instantaneous bandwidth would be 3/(6 ns) or 500 MHz. In ***Figure 6***, we observe the same 50 ns pulse from Figure 5 in the time domain using 500 MHz of instantaneous bandwidth. This configuration shows the rise time of 20 ns given an extremely wide bandwidth and short time-domain resolution of 2 ns.

In addition to measuring short pulse rise times, engineers are increasingly using wideband instruments to test the effectiveness of pulse compression algorithms. Pulse compression techniques such as an FM chirp, shown in ***Figure 7***, can be an extremely effective mechanism to spread transmission power over an extremely wide bandwidth. However, the use of increasingly wide modulation bandwidths for modern pulse compression techniques can often push the measurement limits of modern RF signal analyzers.

For example, because an FM chirp spreads signal power over frequency, it is important to measure power variation over the duration of the pulse to ensure that transmitted power is not frequency dependent. In a traditional spectrum analyzer in swept mode, approximate pulse power is measured by averaging spectrum over a large number of traces and scaling the measured power according to the duty cycle of the transmission.

However, modern wideband vector signal analyzers often allow engineers to capture an entire wideband pulse in a single acquisition. Using this technique, engineers can measure power versus frequency and time more accurately, as well as measure additional pulse characteristics such as the linearity of an FM chirp or characterize LPI signals.

CONCLUSION

The needs and challenges of the design and verification of UWB radar systems require engineers to use sophisticated tools for radar design and test. Today, engineers are using a combination of advanced software and hardware that includes complex scenario generators, wideband signal analyzers and multi-channel modular instruments. These tools allow engineers to quickly prototype and validate advanced radar systems using a common set of hardware. ■

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A Cost-Effective Approach to Simulation for Electronic Warfare Systems

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Electronic Warfare (EW), in general, involves denying an enemy use of the Electromagnetic Spectrum (EMS) or gathering intelligence of an enemy's intended actions or capabilities through analysis of electromagnetic (EM) signals they may transmit, either intentionally or unintentionally. Simulation of the spectral environments encountered by an EW system in the field is a complex undertaking and the need for an effective and validated operational test capability cannot be underestimated, while tight budgets introduce a new dimension of complexity. This article discusses the EW environment, the EW test and evaluation process, and off-the-shelf alternatives for simulation requirements.

EW comprises three areas of application: Electronic Attack (EA), Electronic Protection (EP) and Electronic Support (ES) and operates with other types of systems – specifically Intelligence, Surveillance and Reconnaissance (ISR), and radar (see ***Figure 1***). Electronic attack includes jamming of threats using everything from high power barrage techniques to selective deception techniques that offer the advantage of not jamming your own side's systems as well as your adversaries. Weapon systems are also part of electronic attack in the form of High Speed Anti-radiation missiles (HARM) in addition to actively transmitting decoys. Electronic protection involves managing the spectrum you are using to find clear and safe areas of operation and to ensure your own systems are not overly vulnerable to electronic attack from your adversaries. It also involves control of your own emissions such that your own sig-

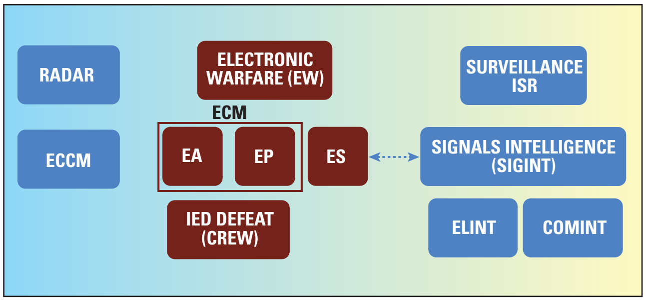

Fig. 1 The application space and sub-elements of EW.

nals don't provide a beacon for enemy fire. Electronic support includes systems that are termed Electronic Support Measures (ESM) that provide threat warning, Signal collection and cataloging, and direction finding (DF) where we'll use the adversary's emissions to locate them.

Radar can pose a threat in the form of a tracking or fire-control radar or a radar signal from a guided missile. The EW system must identify the threat and take mitigating action. Collectively this is known as electronic countermeasures or ECM. Processing by the radar and the actions to overcome ECM or jamming are known as electronic counter-counter measures or ECCM.

The EW application and specifically ES is closely related and overlaps with the SIGINT or signals intelligence area. The collection, identification and cataloging of various threat signals is a critical part of the EW process and receivers are specifically designed to support this mission. SIGINT is divided into several different sub-areas depending on the type of signals in which we are interested. ELINT and COMINT are the two largest with ELINT or electronic intelligence covering radar signals and COMINT dealing with communications signals.

ELECTRONIC ORDER OF BATTLE

There are many terms, abbreviations and acronyms associated with EW technology and operations. One that warrants a closer look is the EOB or Electronic Order of Battle. This refers to all the activity in the EM spectrum occurring at any given time in the theater of a conflict. Generating an EOB requires the identification of all emitters in an area of interest using SIGINT techniques to determine their geographic locations or ranges of mobility, characterizing their signals, and wherever possible, determining their roles in the broad organization and configuration of the conflict. The EOB details all known combinations of emitters and platforms in a particular area of responsibility for both sides of the conflict. The simulation and analysis systems that provide this capability are large and expensive. The magnitude of the signal environment they are designed to simulate drives complexity, making them difficult to modify and program. The solution described here is somewhat simpler but also less capable. The assumption is that many of the steps in the test and evaluation process of different types of EW systems do not need to simulate an entire electronic order of battle but various subsets at any one time.

One example of an EW system we want to characterize the performance of is the Radar Warning Receiver (RWR). The primary purpose of the RWR is to issue a warning when a radar signal that might be a threat is detected. The warning can then be used, in conjunction with other systems, to manually or automatically evade the detected threat. Radar warning systems are often capable of classifying the source and type of radar by the signal's strength, phase and waveform type.

EW SYSTEM TEST AND EVALUATION

The test and evaluation of an EW system involves several distinct steps (see ***Figure 2***) that progress through different levels of integration with the system by itself and then the system within the host platform such as an

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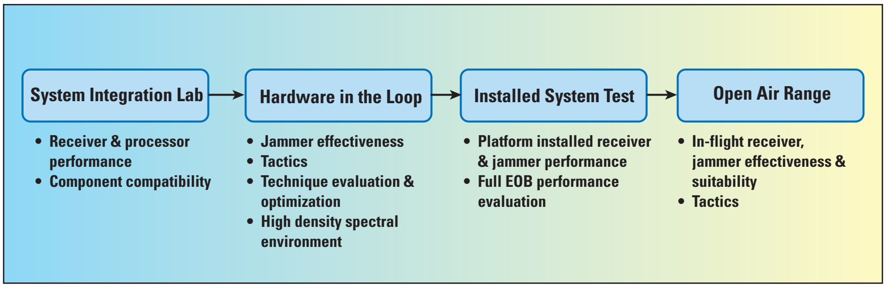

Fig. 2 The EW system test and evaluation process.

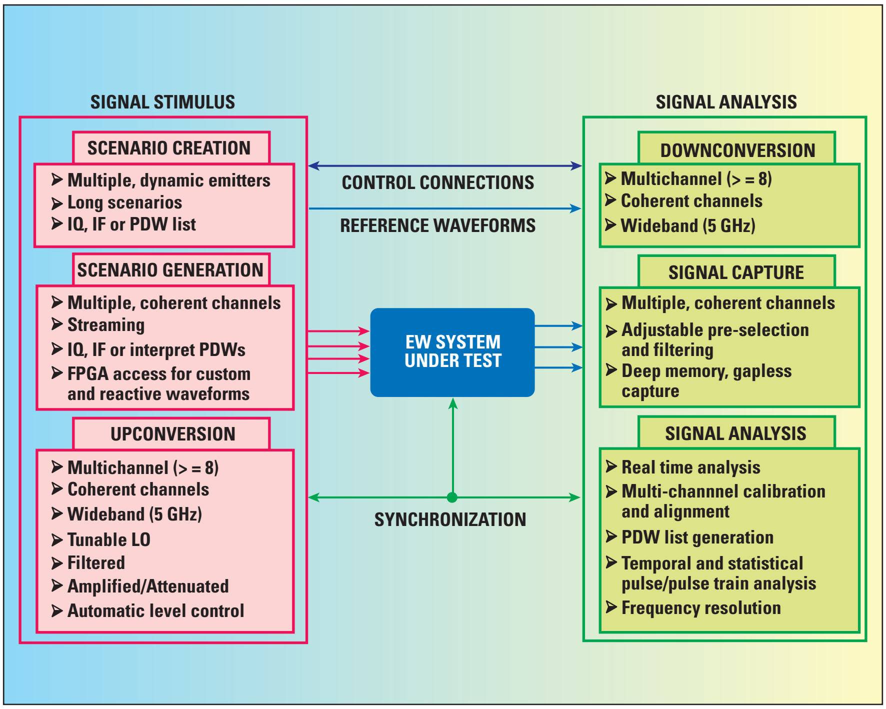

Fig. 3 The basic building blocks of an off-the-shelf EW simulation and analysis solution.

aircraft or ship. As we move up this continuum of integration the simulation becomes more complex until a full EOB environment is simulated or operational testing is conducted in the field or on a test range. It starts in the systems integration lab where we ensure the various components and subsystems interoperate together and that system performance meets specification in terms of RF and environmental parameters. The next step is hardware-in-the-loop (HWIL) testing where the full EW system is stimulated with a high fidelity RF scenario providing a simulation of the operational spectral environment to functionally characterize its performance. This is also a good point at which to optimize EW algorithms and evaluate different jamming tactics. After HWIL testing, the system is installed on the operational platform(s) and functionally stressed in a full EOB environment. Finally, testing moves to an open air range to ensure high performance operation in all situations using a variety of tactics. This stage of testing is very costly and the also the least repeatable, so it is critical to push as much of the evaluation activity as possible to the earlier stages of the test process.

The types of test systems and measurements methods used through the process vary beginning with the use of discrete off the shelf instruments in the system integration lab such as spectrum and network analyzers, oscilloscopes and signal generation equipment. Moving into the HWIL stage a higher degree of automation is applied to construct the needed spectral scenarios, synchronize measurements and record results. At the installed system test facility generally large and somewhat customized test systems are used to generate the very complex and dynamic spectral environment required. At the open air range a variety of equipment is employed from off the shelf instruments to customized automated systems.

Complex multi-emitter simulators are well suited for EW testing in a complex electromagnetic environment and perhaps an entire EOB; however they can be overkill for simple and iterative system integration and HWIL testing or RWR/ESM threat identification evaluation. Scheduling time on such a system may be difficult as such an expensive asset may be in use up to 24 hours a day. ***Figure 3*** shows the elements required in an EW test system to support a variety of EW receivers and jammer types. These elements can be realized with current off the shelf technology. The core of the simulation side of the system is the arbitrary waveform generator (AWG) enabling playback of any waveform file that can be generated mathematically with software or recorded. Multiple coherent AWG channels may be needed to provide appropriate environment simulation for distributed aperture systems. Upconversion to the frequency range of operation is a critical step in the simulation process as the fidelity of the signals must be maintained.

Often the signal scenarios used for EW testing are long and take time to evolve. Waveform memory will be used up quickly when bandwidths are wide and sample rates are high. This means a huge amount of waveform memory beyond what is available internal to the AWG may be required to play the scenario. Different methods of streaming the waveform data may be employed to expand the possible signal scenario length to seconds, minutes or hours. The waveform data could be stored on a deep memory device such as a RAID (redundant array of independent disks) that allows access to a very large memory space. The rate at which data can be streamed is generally limited by the interface between the AWG and the RAID such that the signal bandwidth is well below what is needed for a wideband multi-emitter simulation. Another method is to describe the different pulsed signals contained within a waveform by their temporal parameters such as pulse width and amplitude. This becomes a compressed set

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A recent study conducted for the aerospace industry showed that more than 29 percent of microwave assemblies fail during installation, and aircraft manufacturers have accepted the practice of simply replacing them. However, with the need to decrease costs, they can no longer afford the total cost associated with assemblies that cannot withstand the installation process and the extreme conditions of aerospace. Manufacturers need assemblies that provide the same level of electrical performance before and after installation as well as throughout their service life.

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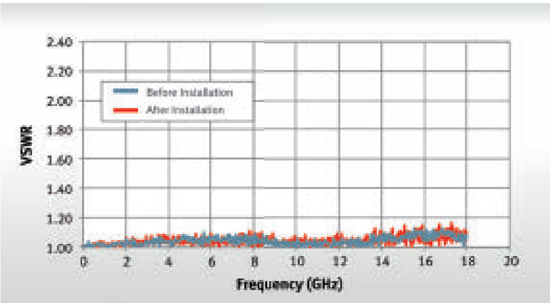
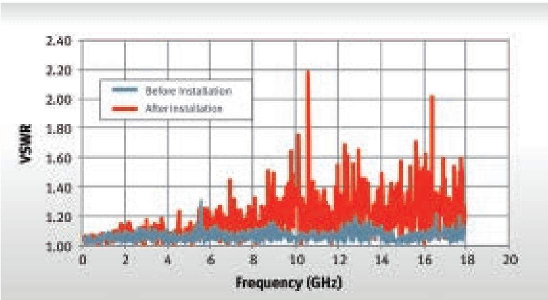
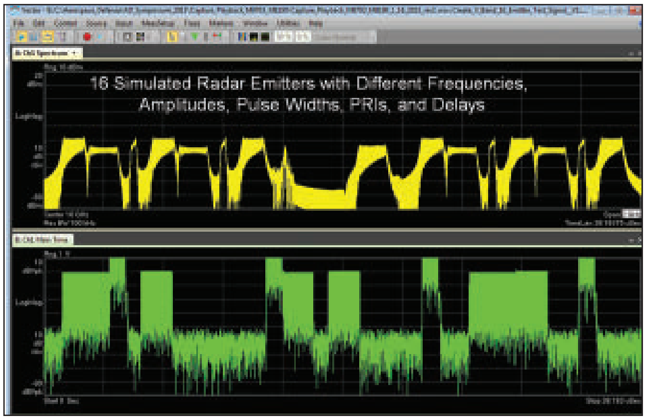
GORE-FLIGHT™ Microwave Assemblies, Series 6 VSWR

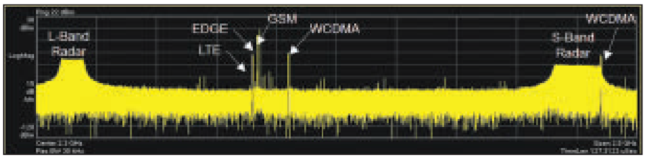


Alternative Airframe Assembly VSWR





▲ *Fig. 4 16 radar emitter waveforms combined and generated from a single AWG channel.*



▲ *Fig. 5 Mixed communications and radar emitters combined into a single waveform file.*

of information of what is termed pulse descriptor words (PDW) which are much more manageable, particularly for off-the-shelf tools.

Multiple threat emitters with different characteristics are shown in ***Figure 4***. Here the 16 unique signals have different frequencies, amplitudes, bandwidths and pulse repetition intervals (PRI). The drawback of adding multiple uniquely modulated emitters to a single AWG waveform file is that the dynamic range of the generated signal will be reduced.

Figure 5 shows a measured multi-emitter spectral environment on an oscilloscope using vector signal analysis (VSA) software. The L-Band radar signal is on the far left. Several communication signals including LTE, EDGE, GSM, and WCDMA signals are near the middle of the spectrum, and the S-Band radar signal is on the far right. A second WCDMA signal has been placed within the S-Band radar's bandwidth. This will allow potential interference effects between the radar signal and the WCDMA signal to be investigated using the VSA software. These various emitters were generated using a single AWG by combining multiple waveform files created using both SW tools and recordings. This was all accomplished using off-the-shelf equipment and software tools.

CONCLUSION

Very sophisticated threat signal and scenario simulation can be produced using commercially available off-the-shelf equipment and software tools; however, there are limitations when attempting to create scenarios with a very large number of threat emitters. In this case, a more costly custom system capable of generating perhaps thousands of emitters may be needed; but for many simpler EW simulation needs, a cost effective solution is right there waiting on the shelf. ■

Co-existence Tests for S-Band Radar and LTE Networks

Steffen Heuel and Andreas Roessler
Rohde & Schwarz, Munich, Germany

Air traffic control (ATC) radar, military air traffic surveillance (ATS) radars and meteorological radars operate in the S-Band frequency range. The excellent meteorological and propagation characteristics make the use of this frequency band beneficial for radar operation – but not just for radar. These frequencies are also of special interest to 4G wireless communications systems such as UMTS long-term evolution (LTE). The test and measurement of co-existing S-Band radar systems and LTE networks is absolutely essential, as performance degradation of mobile devices and networks or even malfunction of ATC radars has been proven.

The Third Generation Partnership Project (3GPP) and standardization body behind LTE started its work on this new technology back in 2004. Four years later, in December 2008, the work on the initial version of the standard was finished and published as part of 3GPP Release 8 for all relevant technical specifications. As of February 2014, 263 LTE networks are on air in 97 countries. The majority of Time-Division (TD) LTE frequency bands are in the S-Band frequency range where ATC, ATS and meteorological radars operate. A dedicated co-existence study for TD-LTE and S-Band radars is therefore recommended.

This article describes potential issues concerning S-Band radar systems and LTE networks from base stations, mobile devices and radar operating in close proximity to one another. It addresses frequency allocation of these systems, explains the performance degradation or malfunction that can be expected and describes measurement solutions for interference testing of radar and LTE networks. Measurements completed at airports demonstrate possible interference and significant performance degradation of both radar systems and LTE networks.

SPECTRUM ALLOCATION

The S-Band has been defined by IEEE as all frequencies between 2 and 4 GHz. Besides aviation and weather forecast, several other maritime radars worldwide also operate in this frequency band. LTE is supposed to operate in two different modes, frequency division duplex (FDD) and time division duplex (TDD). Both duplex modes use different frequency bands worldwide. The latest version of the LTE standard specifies a total of 29 frequency bands for FDD and 12 frequency bands for TDD.

Table 1 lists the LTE FDD frequency bands, whereas the ones in the S-Band frequency range are marked in light blue. The frequency bands that are fairly close to any op-

TABLE I

LTE FDD FREQUENCY BANDS; FREQUENCY BANDS WITHIN THE S-BAND ARE MARKED IN BLUE

E-UTRA Band	Uplink in MHz	Downlink in MHz
1	1920 to 1980	2110 to 2170
2	1850 to 1910	1930 to 1990
3	1710 to 1785	1805 to 1880
4	1710 to 1755	2110 to 2155
5	824 to 849	869 to 894
6	830 to 840	875 to 885
7	2500 to 2570	2620 to 2690
8	880 to 915	925 to 960
9	1749.9 to 1784.9	1844.9 to 1879.9
10	1710 to 1770	2110 to 2170
11	1427.9 to 1447.9	1475.9 to 1495.9
12	699 to 716	729 to 746
13	777 to 787	746 to 756
14	788 to 798	758 to 768
17	704 to 716	734 to 746
18	815 to 830	860 to 875
19	830 to 845	875 to 890
20	832 to 862	791 to 821
21	1447.9 to 1462.9	1495.9 to 1510.9
22	3410 to 3490	3510 to 3590
23	2000 to 2020	2180 to 2200
24	1626.5 to 1660.5	1525 to 1559
25	1850 to 1915	1930 to 1995
26	814 to 849	859 to 894
27	807 to 824	852 to 869
28	703 to 748	758 to 803
29	N/A to N/A	717 to 728
30	2305 to 2320	2345 to 2360
31	452.5 to 457.5	462.5 to 467.5

erational S-Band radar system are highlighted in dark blue. One of the highlighted bands in Table 1 is Band 7, which is used throughout Europe. Due to the rapid deployment of base stations and the addition of small cells to increase system capacity, for example at airport terminals; the co-existence of LTE base stations and ATC radar is of major interest.

Another example in terms of LTE and radar co-existence is the anticipated commercialization of the 3.5 GHz spectrum in the U.S. by the Federal Communications Commission (FCC). The FCC hosted a technical workshop this past January that explored the possibilities of using 100 MHz of spectrum in the 3550 to 3650 MHz band for small cell deployment based on shared spectrum access.[1] Today, this spectrum is owned by the Department of Defense (DoD) and is being used, for example, by maritime radar.[2]

The 2.5 to 2.69 GHz band is allocated by terrestrial mobile services organized in two 70 MHz blocks of paired spectrum (FDD) and one 50 MHz block of unpaired spec-

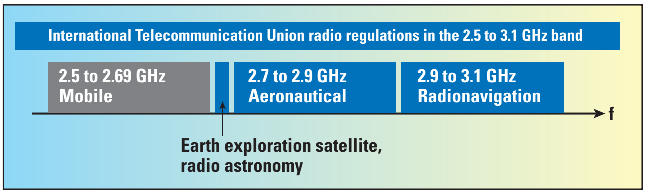


Fig. 1 International Telecommunication Union radio regulations in the 2.5 to 3.1 GHz band.[3]

trum (TDD), see ***Figure 1***. With FDD, the uplink communications frequencies that could be used by the mobile device to transmit to the base station are allocated from 2500 to 2570 MHz. The 2570 to 2620 MHz block is reserved for TDD, and the 2620 to 2690 MHz block is intended for the downlink, where the base station would transmit to the mobile device. 3GPP adopted these frequencies as band 7 (FDD) and as band 38 (TDD). The 2.7 to 2.9 GHz frequency band is primarily allocated to aeronautical radio navigation, i.e., ground-based fixed and transportable radar platforms for meteorological purposes and aeronautical radio navigation services, shown in Figure 1.

Carrier frequencies of the radars mentioned are assumed to be uniformly distributed throughout the S-Band.[4] As depicted in Figure 1, the two frequency bands for mobile communications and aeronautical radio navigation are located very close to each other. As an example, some ATC radar systems operate at 2.7 to 2.9 GHz; others, such as the AN/SPY-1 radar operated by the U.S. Navy, operate at a frequency of 3.5 GHz. Most of these types of radar apply pulse and pulse compression waveforms.

After pulse transmission, the radar switches from transmitter to receiver and receives the radar echo pulses from targets inside the observation area. Receivers use low noise front ends because echo signal power is extremely low. This high sensitivity makes receivers susceptible to interference signals. LTE networks using nearby frequencies can cause these interferences and may significantly degrade the radar performance.

CO-EXISTENCE OF LTE AND S-BAND RADAR

Disturbance of LTE networks may occur through S-Band radar, such as degradation of performance due to lower throughput, indicated by an increasing block error rate (BLER). On the first view, this is not a major drawback, but spectral efficiency, power reduction and cost are of great importance for any mobile network operator.

3GPP specifications find solutions, e.g., dynamic frequency selection or transmit power control, in order not to disturb other signals. However, radar parameters such as transceiver bandwidth, spurious emissions, transmit power, transmit antenna pattern, polarization and waveform may limit the performance of mobile services, because these systems obey different regulations.

ITU Recommendation M.1464-1[4] mentions ATC radar systems operating in mono-frequent or frequency diversity. The RF emission bandwidth of these radars ranges from several kHz to 10 MHz while transmitting power of up to 91.5 dBm. Since the mobile network has standardized filtering in line with 3GPP, disturbance must not occur. Yet measurement results show that 4G user equipment and base stations are influenced by radar signals and should be tested to ensure proper functionality, efficient power and spectrum usage.

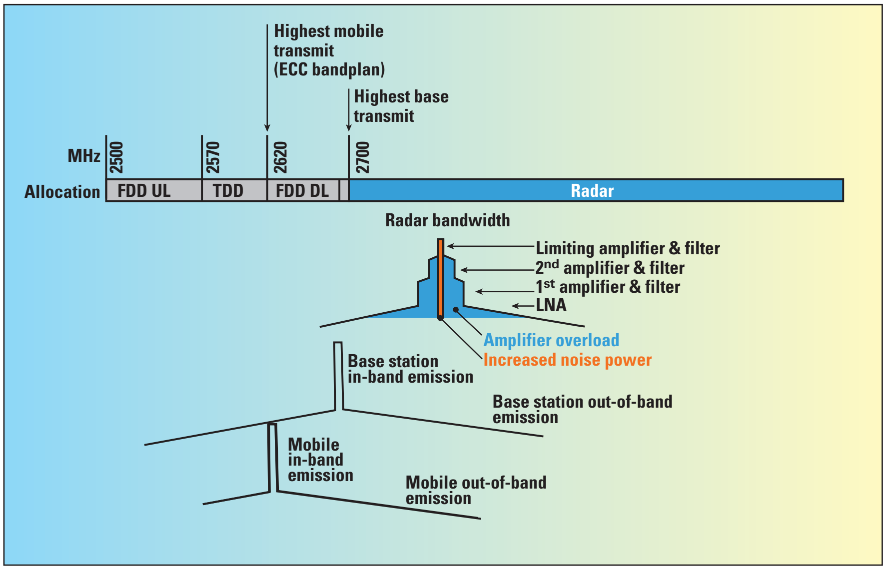


Fig. 2 Radar amplifier chain in the frequency domain and out-of-band and in-band interference.

On the other hand, the presence of LTE signals and less selective filters in the radar receiver can cause significant interference or even damage to the radar system. This may be indicated by false target detection or by the high power state of the receiver protector. The latter can occur when LTE signals and spurious emissions are very strong and received by the radar. In the case of weaker signals or signals outside the nominal receiver bandwidth, the radar could go into compression and produce nonlinear responses or react by raising the constant false alarm rate (CFAR) threshold (see ***Figure 2***). Targets that are present can thereby be lost in consecutive measurements and targets with low power echoes cannot be detected.

The performance degradation depends strongly on the type of signal disturbing the radar. Continuous-wave or noise-like modulation signals with constant power disturb azimuth sectors of the radar in which the interferer is located. Pulsed interference strongly depends on synchrony with the radar and the design of the receiver, signal processing and mode of operation, e.g., frequency agile radar systems may be less influenced than non-frequency agile ones.

Interference entering the receiver chain and finally the detector of the radar is depicted in Figure 2. While in-band interference will raise the noise floor, out-of-band interference may overload the amplifiers and decrease the signal power. Either way, the signal-to-noise ratio (SNR) of a target echo signal at the detector is reduced, which is why the probability of detection is reduced.

According to 3GPP Technical Specification (TS) 36.101 and TS 36.104, LTE base stations are allowed to transmit a maximum of 46 dBm with additional antenna gain of approximately 15 dBi. Antenna height may be up to 30 m above ground. To estimate the disturbance of radar caused by mobile services, technical radar parameters such as radar receiver sensitivity, noise figure, recovery time, bandwidth, antenna pattern and polarization have to be known.

The large variety of radar systems, their inherent design and technical parameters cause different and nearly unpredictable reactions to LTE signals in their environment. Additionally, antenna steering direction and output power of base stations can increase radar interference. Radar, as an extremely security-relevant system, therefore has to be tested in the presence of 4G networks.

TEST SOLUTIONS AND MITIGATION

Test and measurement solutions have been developed to apply different synthetic as well as recorded signals to both LTE networks and S-Band radar systems. These test solutions allow verification of proper functionality and, in the case of interference or even malfunction, development of mitigation techniques.

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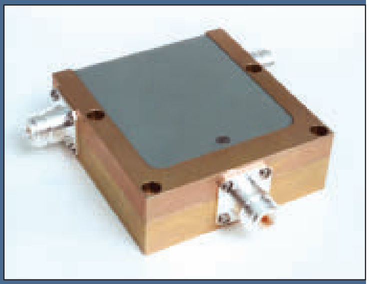

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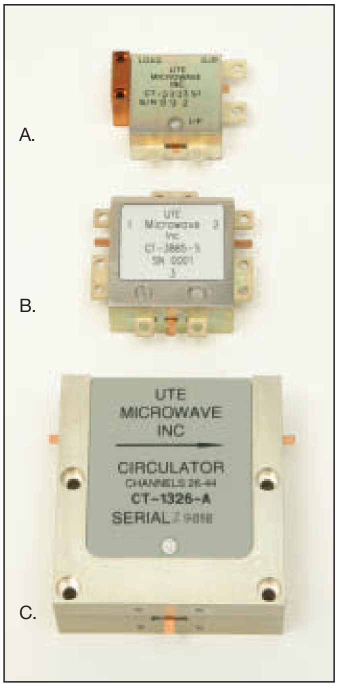

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CT-3838-N	5 Kw Pk 500 W Av	N Conn.	2.7–3.1 GHz
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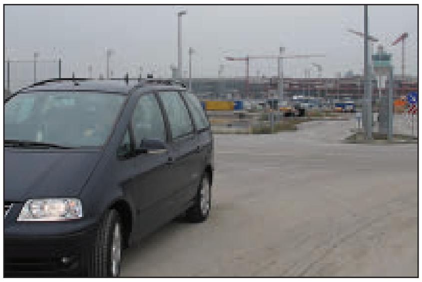


▲ *Fig. 3 Vehicle with measuring equipment recording I/Q data at a German airport.*

Performance and Interference Testing of LTE Terminals

For chipset and wireless device testing, a wideband radio communication tester is widely used. Engineers use it for protocol, signaling and mobility tests as well as for RF parametric tests of transmitter and receiver performance of a mobile terminal. 3GPP has defined multiple test cases for all three test areas: protocol/signaling, mobility and radio resource management (RRM), as well as RF conformance.

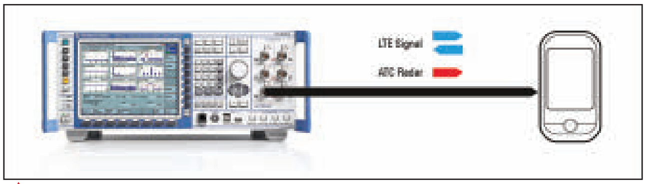
This ensures minimum compliance with the current 3GPP standard. However, the majority of receiver and performance tests for LTE only assume the presence of another LTE signal or 3G signals, such as WCDMA (UMTS). There are no tests defined by 3GPP for the presence of an S-Band radar signal in adjacent frequencies to the received signal from an LTE base station.

In order to test real-world conditions, it would be beneficial to record an S-Band radar signal and play it back on an adjacent frequency while performing a throughput test or receive sensitivity test on an LTE-capable terminal that is, for example, operational in Band 7 (detailed description in reference 8). The ATC radar signal from an airport could be recorded. Therefore a universal network scanner would be tuned to the desired S-Band radar frequency to capture the RF signal, perform the downconversion and thus convert the RF signal to I/Q data. ***Figure 3*** shows a picture taken at the airport recording an ATC radar signal.

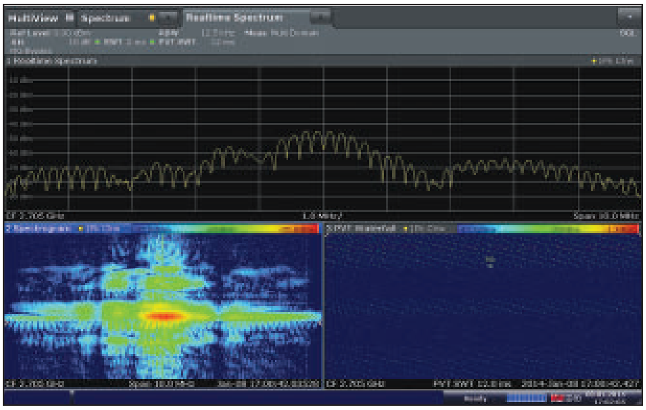
The recorded I/Q data can now be used in the lab and played back as an arbitrary waveform (ARB) using the embedded signal generator functionality in the wideband communication tester. At the same time, the wideband communication tester acts as a network emulator, simulating an LTE cell at e.g. frequency Band 7, where the device under test (DUT) registers in (see ***Figure 4***).

To carry out a co-existence test, the recorded radar signal can now be applied during a receive sensitivity level test of the DUT, while measuring the BLER for a given LTE signal. To verify the above assumptions of LTE and S-Band radar interfering with each other, several measurements were carried out. The recorded radar signal that was used for these tests originated from an operational ATC radar at a distance of approximately 1.5 km from a major German airport.

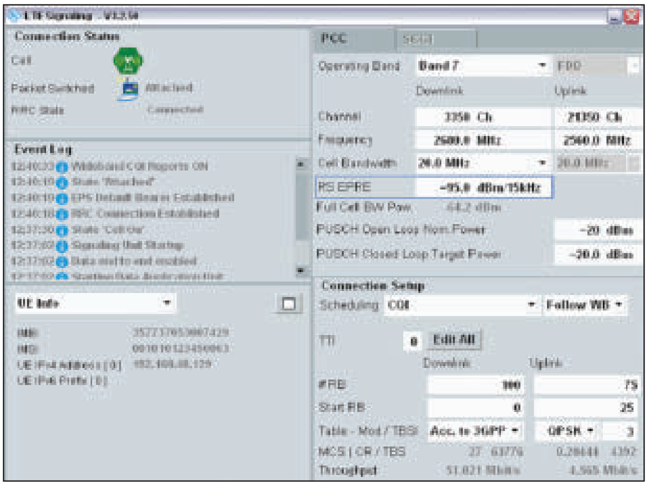
As described, the I/Q data is played back using ARB functionality embedded in the wideband radio communication tester at a carrier frequency of 2.69 GHz and in a second test at 2.693 GHz. The measured radar transmitted consecutive pulses at different frequencies using a total bandwidth of 10 MHz. As the radar rotates during operation, radar signals arrive at the receiver in an equidistant time of 1.1 ms (see ***Figure 5***). In the measurement data, a maximum power level of 0 dBm was detected by the spectrum analyzer, and the total SNR varied between 10 to 70



▲ *Fig. 4 Test setup for LTE and S-Band radar co-existence tests, using a wideband radio communication tester.*



▲ *Fig. 5 Captured S-Band radar signal (10 MHz) analyzed with R&S FSW signal and spectrum analyzer in real-time mode.*



▲ *Fig. 6 LTE signaling configuring for modified reference sensitivity level test (BLER measurement).*

dB depending on the measurement position.

To analyze receiver performance of an LTE-capable terminal in the presence of an S-Band radar signal, the receive sensitivity level test estimated with help of a BLER measurement and described in section 7.3 in 3GPP's TS 36.521-1 for UE RF conformance was adopted and slightly modified. The test described in this section requires the device to transmit at maximum output power, which is defined for LTE for all commercial frequency bands with +23 dBm.

In addition, the orthogonal channel noise generator (OCNG) on the downlink has to be enabled to emulate other users being active within this bandwidth. In general, the receive sensitivity test is designed to verify QPSK modulation only for a full resource block (RB) allocation in the downlink, but no MIMO. Dependent on the frequency band and bandwidth being tested, the reference sensitivity level varies.

For Band 7 and 20 MHz, it corresponds to a reference signal power level of -91.3 dBm full cell bandwidth power. In the

uplink, an allocation of 75 RB is used with an offset of 25 RB and is as close as possible to the downlink. The following sensitivity test is based on a BLER measurement. The wideband radio communication tester counts the reported acknowledged (ACK) and non-acknowledged (NACK) data packets, from where an average throughput is calculated.

For the test, specific test signals (reference measurement channels (RMC) for the downlink and uplink), are standardized. These test signals allow a maximum throughput based on the specified signal configuration in terms of bandwidth allocated, modulation scheme being used and transport block size (TBS). The standard test is only specified for QPSK modulation, where the maximum achievable throughput is relatively low, compared with any higher-order modulation scheme. Higher modulation schemes would require a better SNR.

Any interference would impact the achievable throughput using, for example, 16QAM and/or 64QAM – which would result in a much higher BLER and a much lower throughput. To verify this assumption, the standardized test in 3GPP TS 36.521-1, section 7.3, was changed in such a way that the scheduling type was changed from RMC to channel quality indicator (CQI) and, in particular, follow wideband CQI mode (see ***Figure 6***). This ensures more real-world conditions during the tests.

With this test method the LTE device measures the channel quality on the downlink signal using the embedded reference signals. The measured signal receive quality is translated to a CQI value that is reported back to the network. The scheduler in the LTE base station can now use this feedback to basically adopt the resource allocation, modulation and coding scheme being used based on actual channel conditions as seen by the device. This results in better performance, namely average throughput.

In terms of any interference present, the device would measure a lower received signal quality, translating into a lower CQI value being reported, which would result in the usage of a lower modulation and coding scheme by the base station. ***Figure 7*** shows the results for the first test without the radar signal being present. There was 100 percent acknowledged packets with an average throughput of 13.29 Mbit/s achieved.

In comparison, ***Figure 8*** shows the result for the reference sensitivity level test with the radar signal being present at a carrier frequency of 2690 MHz at an output power of -7.00 dBm, comparable to the power levels measured at an airport. All other test parameters are the same. The NACK rate has increased to almost 3 percent and there is a massive drop in data throughput (blue curve, upper graph) in the presence of a pulse radar signal. The throughput drops when the radar signal points toward the mobile terminal.

For the second measurement, the power level of the base station was increased to -83 dBm/15 kHz. As depicted in ***Figure 9***, the block error rate increased even for a higher output power for the LTE downlink signal. Additional tests showed that the throughput and CQI decreased even when the radar was operating at a frequency of 2700 MHz, depending on the DUTs.

The results presented in Figures 8

and 9 show that there are co-existence issues when an LTE-capable terminal has an active data connection running and comes close to an S-Band radar signal. In the real world, the receive power levels of the serving LTE base station might even be lower than the ones used in the test, in which case we would see a higher BLER resulting in lower throughput or even connection loss and thus impacting mobile services.

▲ *Fig. 7 Reference sensitivity level test (BLER measurement) without S-Band radar signal present.*

▲ *Fig. 8 Modified reference sensitivity level measurement (BLER) while S-Band radar signal is present.*

▲ *Fig. 9 BLER measurement with S-Band radar signal present.*

Radar Interference Test

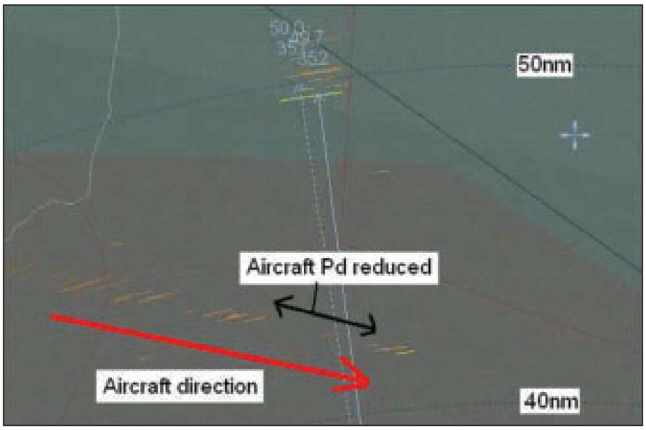
When a radar system is being designed or a 2.6 GHz base station is being set up, several aspects have to be considered to ensure efficient functionality, robustness and co-existence of both systems. For test and measurement, an interference test system for S-Band radar systems to counter interference from LTE signals (see ***Figure 10***) was developed.[5]

The system is able to generate realistic 4G scenarios in the frequency range of 2.496 to 2.69 GHz, including the generation of multiple base and mobile stations. The test system can be set up at a distance of 100 to 300 m in front of a radar system that is in normal operating mode. The radar operator is then able to immediately test and measure the ATC radar in the presence of LTE signals.

Measurements performed using the radar test system have shown that out-of-band and in-band interference mechanisms can become critical and cause ATC radar to become blind in certain azimuth sectors and under certain conditions, e.g., when broadcasting an LTE[6] or WiMAX™ [7] signal towards the radar. This reduces the probability of detection and causes the radar to lose targets. Reference 6 addresses "challenging case" and "typical case" scenarios of 4G networks at airports and describes mitigation techniques.

Dominant interference occurs due to both mobile and base stations, which cause the noise floor to rise. Reference 7 describes tests in which the radar was disturbed using continuous-wave and pulsed signals. The study shows degradation in the probability of detection depending on the applied signal. ***Figure 11*** shows where the probability of detection (Pd) is reduced due to the presence of a 4G signal; the aircraft even disappeared from the radar screen.[7] Due to these results, co-existence of radar and 4G networks should be tested.

▲ *Fig. 10 Radar interference test system R&S TS6650.*



▲ *Fig. 11 4G signal at 2685 MHz.*[7]

Mitigation Techniques

Different approaches can mitigate disturbances on radar and 4G base stations. One approach is to reduce transmit power at the base station and radar. However, this would reduce the maximum range of the radar and coverage of the base station. Another approach would be to increase frequency separation or distance between the two services, but frequency selection may be impossible due to technical restrictions. There are also less expensive techniques, such as not pointing mobile service base station antennas towards S-Band radar. Basic approaches involve improving receiver selectivity, filtering transmitter signals, and reducing unwanted spurious emissions on both sides. These steps would allow co-existence. In order to validate mitigation techniques, test and measurement is necessary.

CONCLUSION

Up-and-coming 4G networks such as LTE and WiMAX™ operate in the 2.6 GHz frequency band, as well as ATC S-Band radar systems. To ensure proper functionality of the radar and efficient 4G networks, co-existence has to be proven. The tests and measurements explained in this article were conducted at airports to test radar as well as LTE mobile terminals in the presence of disturbing signals and found that performance degradation can occur on both sides. This causes reduced probability of detection of the radar and reduced throughput of 4G mobile networks. ■

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Low Loss Configuration for Integrated PIN-Schottky Limiters

Chin Leong Lim
Avago Technologies, San Jose, Calif.

The Schottky-PIN limiter provides better receiver protection than a PIN diode-only limiter because it has a ~10 dB lower limiting threshold; however, its insertion loss has a strong impact on the overall noise figure because it typically precedes the gain stages. The extra diode in the Schottky-PIN limiter results in higher loss than the PIN diode-only limiter. The main loss contributors are the diodes' parasitic capacitances, which load the signal path. In addition, the use of low cost, plastic packaged diodes introduces substantially more loss than either bare chips or hermetically packaged diodes.

Aside from reducing diode parasitic capacitance by either stacking[1] or mesa construction,[2] limiter loss can be minimized using circuit techniques. The loading effect of the Schottky diode on the RF path can be reduced with either a high-impedance, quarter wavelength line[3] or a directional coupler,[4,5] but these passive components add to either the size or cost, and furthermore, they detrimentally increase the limiting threshold. A new design recently demonstrated that a PIN-Schottky limiter's insertion loss can be improved by integrating the two discrete diodes' parasitic capacitances into a lowpass ladder network.[6] The ladder configuration preserves the low limiting threshold, but requires that the PIN diode have two anode connections.

Traditionally, the PIN-Schottky limiter is fabricated using separate diodes, but we recently combined two diodes in a SOT-323 package to achieve greater miniaturization[7] and demonstrated its viability in a microwave limiter application.[8] The three-pin package, however, limits the PIN diode to one anode connection (see ***Figure 1***). To reduce the insertion loss of microwave limiters fabricated with this device, a lowpass π configuration for absorbing the parasitic capacitances was devised. This article summarizes resulting performance improvements using the lowpass π configuration in a 1.8 GHz limiter.

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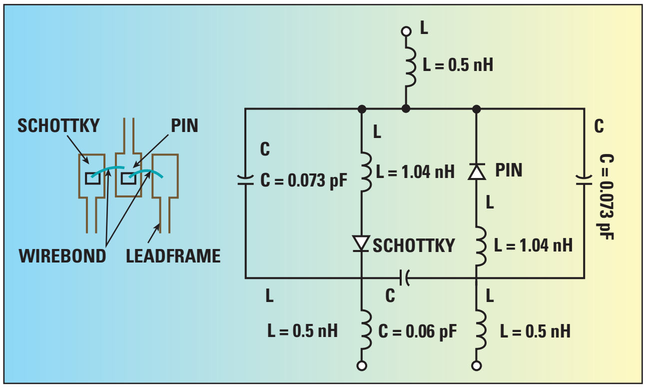
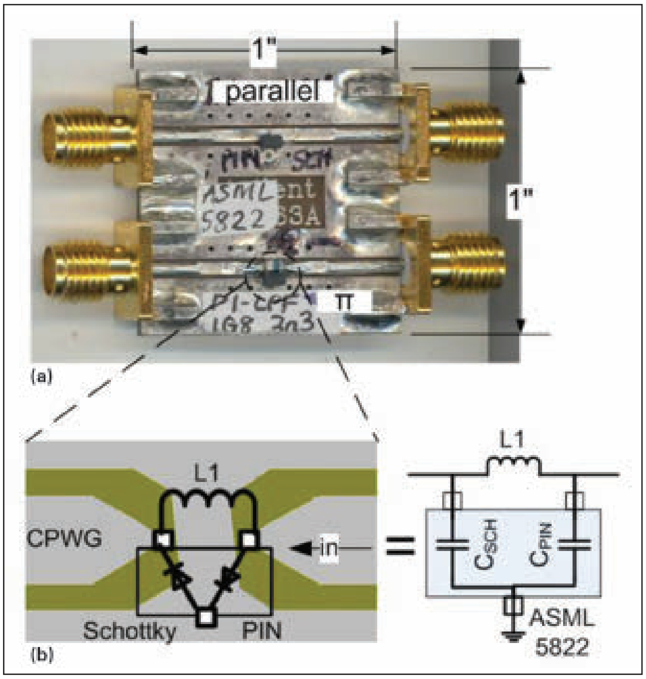


▲ *Fig. 1 SOT-323 packaged PIN-Schottky diode pair (left) and package equivalent circuit model.*



▲ *Fig. 2 Test fixture for evaluating the PIN-Schottky diode pair (a); External inductor (L1) forms a π lowpass network with diodes' parasitic capacitances (b).*

TABLE I
SCHOTTKY DIODE'S SPICE PARAMETERS

Parameter	Mean
n	1.067
Is (A)	1.48E-8
Rs (Ω)	7.8
Cj0 (pF)	0.649
BV (V)	26.7

TABLE II
PIN DIODE'S APLAC PARAMETERS

Parameter	Mean
R_{MAX} (kΩ)	5
I_S (A)	3.80 E-10
N	1.77
TT (ns)	70
C (pF)	0.6
A	0.0337
K	0.513
R_{MIN} (Ω)	0.35
L (nH)	2

HYBRID LIMITER WITH PIN AND SCHOTTKY DIODES

The PIN diode, which forms the signal-attenuating half of the limiter component, can be functionally described by its 1.5 μm I-layer and a 100 μm diameter.[9] The first dimension determines the limiter's turn-on threshold,[10] transient response time[11] and spike leakage;[12,13] whereas, the second dimension caps its power dissipation. The APLAC simulation parameters (see ***Table 1***) complete the PIN diode description. The Schottky diode, which constitutes the signal detecting half of the limiter component, can be described by a 250 mV barrier height at 1 mA[14,15] and a set of SPICE parameters (see ***Table 2***).

Electrical connections between the diode chips and the package leads are made using a combination of conductive epoxy and bond-wires (see Figure 1). A low thermal resistance of 150°C/W, achieved by attaching the diode chips directly to the copper lead-frame, improves power dissipation. The package leads and bondwires contribute ~0.5 and ~1 nH, respectively, to the component's equivalent circuit model. The plastic encapsulation adds ~73 fF parasitic capacitances across the diodes. Measured at the package terminals, the PIN and Schottky diodes' zero bias capacitances at 1 MHz are ~0.9 and ~0.7 pF, respectively. When the two diodes are connected in parallel in the limiter circuit, they present a combined ~1.6 pF capacitance in shunt with the RF path.

EVALUATION FIXTURE

The evaluation fixture consists of a 30 mil thick FR-4 PCB containing two 50 Ω co-planar waveguide (CPWG) with ground transmission lines (see ***Figure 2***). The first line is continuous, but the second line has a narrow gap in the middle. The PIN-Schottky diode pair mounted on the continuous line acts as an experimental control; the circuit arrangement, two diodes connected in parallel, is the one originally envisaged for this component. The second PIN-Schottky diode pair is mounted on the gapped line with its adjacent leads straddling the gap. The diodes' capacitances form the shunt arms of a lowpass π network. A chip inductor L1, which bridges the same gap, forms the series arm. Following the norm for this class of limiter, the PIN diode side is defined as the signal input.

SIMULATION

Through simulation, L1 is optimized for minimum loss at the operating frequency. To model the PIN-Schottky diode pair, APLAC and SPICE parameters from Tables 1 and 2 are combined inside the symbol X3 in ***Figure 3a***. The frequency of 1.8 GHz is chosen for evaluation because it is the device's upper limit. ***Figure 3b*** shows that an inductance of 3.2 nH results in the lowest insertion loss (~0.4 dB), while the best return loss occurs at a slightly higher inductance of 3.4 nH. The physical realization uses a standard value of 3.3 nH from the Toko LL1608 series.

The limiter circuit containing the paralleled diodes is represented by the condition L1 = 0. A higher loss of 1.2 dB is obtained with the diodes mounted in parallel following the datasheet's recommendations. The results include an estimated fixture loss of 0.25 dB.

EXPERIMENTAL RESULTS

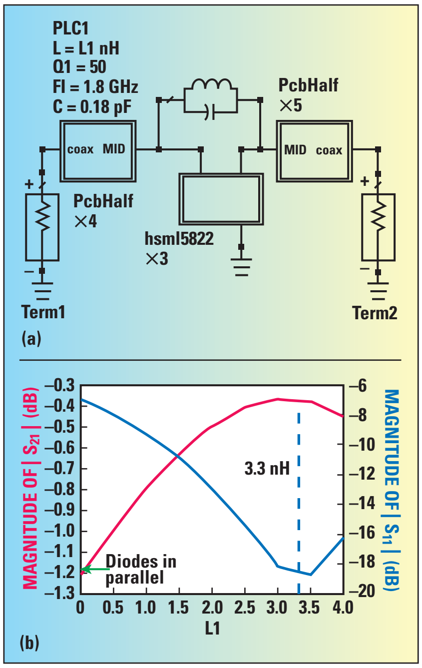
Experimental results confirm im-

proved performance of the π configuration over the parallel connection (see ***Figure 4***). After 0.25 dB of fixture loss is removed from the raw data, a 0.9 dB difference is recorded between the two configurations at 1.8 GHz. Despite optimization at 1.8 GHz, improvement is maintained over a 1 GHz bandwidth.

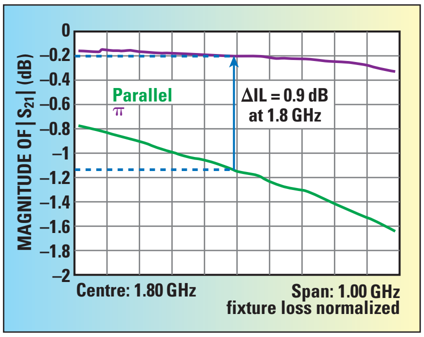
The π configuration can be optimized for reduced loss at other frequencies via L1, however, in addition to increasing insertion loss with frequency, isolation also degrades. Isolation degrades with frequency due to parasitic inductance in series with the PIN diode. This particular Schottky-PIN pair has ~2 nH of parasitic series inductance (see Figure 1). This limits its isolation to approximately 8 to 10 dB at 1.8 GHz. Components with lower parasitic inductance should produce better performance at higher frequencies.

The π-configured limiter is also significantly less reflective than the parallel-connected 'control' (see ***Figure 5***). At 1.8 GHz, the π configuration achieves ~13 dB lower return loss than the control. The largest improvement occurs at ~2.4 GHz or ~33 percent higher than the design frequency, although we are not able to explain the responsible mechanism.

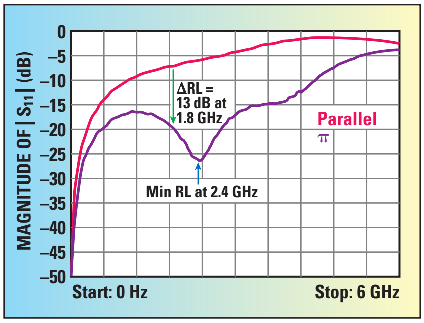
The measured noise figure of a



▲ *Fig. 3 Simulation shows lower loss for the π configuration at 1.8 GHz (a); simulated results (b).*



▲ *Fig. 4 New configuration reduces 1.8 GHz insertion loss by 0.9 dB.*



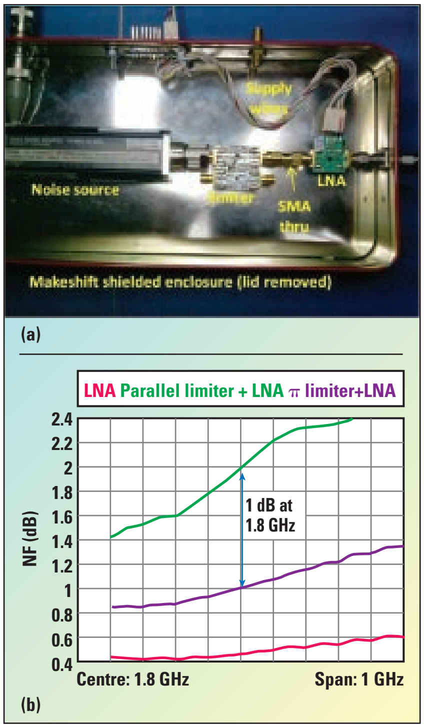
▲ *Fig. 5 New configuration increases 1.8 GHz return loss by 13 dB.*

cascaded limiter and low noise amplifier (LNA) confirms the π configuration's lower loss. The test setup replicates the configuration of a limiter to protect an LNA input. The 1.8 GHz LNA uses a MGA-634P8 GaAs ePHEMT MMIC[16] and has a ~ 0.5 dB NF at its connectors.[17] The first combination of π limiter and LNA achieves ~1 dB NF, whereas, the second combination consisting of a parallel limiter and the LNA is significantly noisier at ~2 dB NF (see ***Figure 6***). The difference between the two can be predicted from the limiters' insertion loss. In a final product, the cascaded NF should be < 0.8 dB because the limiter fixture and the SMA 'through' adapter add ~0.25 dB loss to the experimental results.

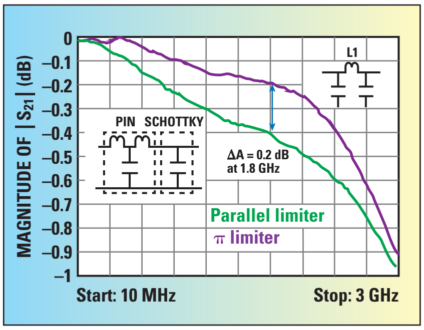
The π configuration also outperforms the alternative loss mitigating scheme based on the ladder network.[6] To ensure a fair comparison, the ladder-configured limiter is fabricated from the same PIN and Schottky diode chips as the π limiter, but the former's diodes are assembled into separate SOT-323 packages so that its PIN diode can have the required dual anodes. At 1.8 GHz, the π configuration has ~0.2 dB insertion loss versus the ladder configuration's ~0.4 dB (see ***Figure 7***). Besides providing lower loss, the π configuration occupies approximately half the PCB space of the ladder configuration.

CONCLUSION

A 1.8 GHz limiter based on a three-pin hybrid Schottky-PIN diode component can benefit from lower loss and better matching when the diodes' parasitic capacitances are configured into a π network, as compared to the manufacturer rec-



▲ *Fig. 6 Cascaded π limiter/LNA NF reduces NF by 1 dB versus parallel limiter/LNA; physical circuit (a), measured performance (b).*



▲ *Fig. 7 π limiter exhibits 0.2 dB lower insertion loss than the ladder limiter at 1.8 GHz.*

ommended parallel diode connection. Although demonstrated with an ASML-5822 PIN-Schottky diode pair, the proposed configuration has general utility. Since most packaged PIN diodes are available only in single-anode styles, (e.g. SOD-323, SOD-523, beam lead and glass diodes) and two anodes are required in the competing ladder configuration, the π configuration expands the number of usable devices. Moreover, the π configuration achieves lower loss than the ladder configuration when fabricated with a similar set of PIN and Schottky diode chips. Future work will investigate large-signal (limiting) and transient performance of the π configuration. ■

ACKNOWLEDGMENT

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Multi-Channel Antenna Calibration Reference Solution

Keysight Technologies Inc., formerly Agilent Technologies electronic measurement business
Santa Rosa, Calif.

Precise cross-element phase and magnitude measurements and increased measurement bandwidth and system flexibility dramatically speed up large antenna array combinations

The market for multi-channel, phased-array antennas is growing and bringing increased pressure on manufacturers to reduce costs and increase test capacity. At the same time, manufacturers of these antennas need to expand test system flexibility to cover broad use cases and provide options for future upgrades, while facing multi-channel phased array antenna calibration and test challenges including:

- An increase in test times and test complexity due to a growing number of array elements
- Phase coherent sampling across all input channels, providing relative amplitude and phase measurements is critical for precise beamforming
- Advancements in antenna and radar technologies require a flexible and upgradeable test system

The multi-channel antenna test Reference Solution, the second in a series of modular-based Reference Solutions introduced by Keysight Technologies earlier this year, is a combination of hardware, software, and measurement expertise providing the essential components of a narrow-band antenna calibration test system. With this Reference Solution, engineers have the ability to meet antenna test and calibration challenges with a new test approach and enhance or modify a test system to meet specific test application requirements. They include scalable channel count, options for downconversion of antenna receive channels, selectable analysis BW and choice of RF/microwave sources and LO. The Reference Solution also allows a test system to be extended to wide-band measurements as needs change. To facilitate evaluation and integration in a test environment the Reference Solution provides test code examples to set up receiver channels, including DDC, make phase and magnitude measurements, add channel-channel correction factors and export measurements for post-processing.

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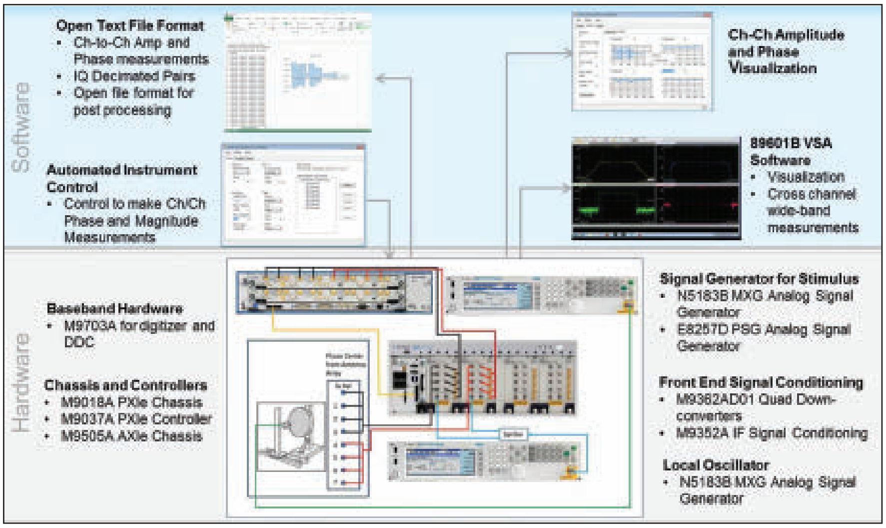
REFERENCE SOLUTION ARCHITECTURE

Antenna Calibration Example Software

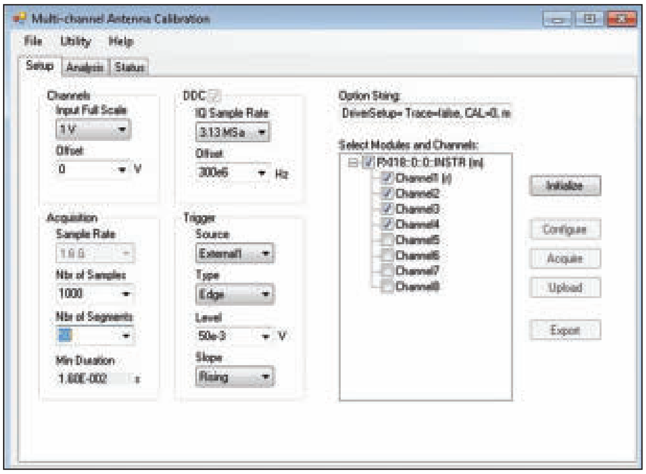
This Reference Solution contains a C# test code example, specifically designed to collect data from an antenna under test and compute cross-channel magnitude and phase data. To accelerate test development and facilitate integration into a test environment, example software source code is provided in the form of a .NET class library. This allows the example to be built-upon (using Microsoft Visual Studio or National Instruments LabVIEW) and the collection and processing of data is customized for specific application needs. The Reference Solution antenna calibration example software provides a number of unique features and capabilities that facilitate and speed calibration and testing, including test setup and control, utility and file functions, cross-channel measurement computation, and measurement interval isolation (see ***Figure 1***).



▲ *Fig. 1 MAC block diagram.*

Test Setup And Control

The Reference Solution's example GUI allows users to set up the measurements made with the M9703A digitizer, including control over DDC parameters (see ***Figure 2***). It includes settings such as initial sample rate, number of samples/segments, trigger control and decimated IQ sample rate. It also allows the user to select which digitizer channels are used for the test and the reference channel for cross-channel measurements. Once the test conditions are set the hardware is configured, data is acquired, and the decimated I-Q data record is uploaded to the host computer (see ***Figures 3*** and ***4***).



▲ *Fig. 2 Test setup and control.*

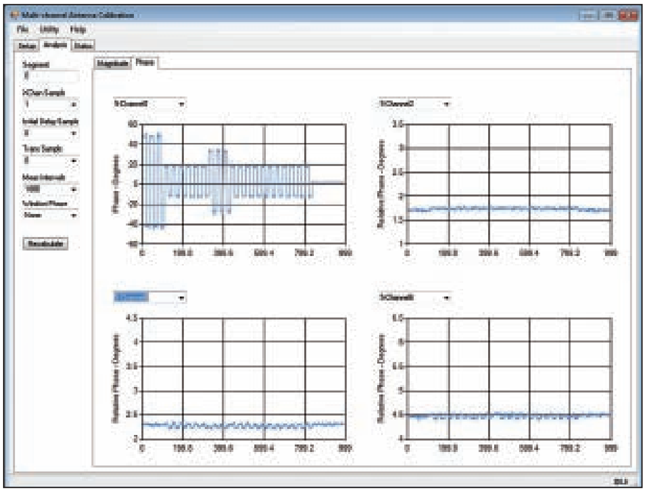
Computing Cross-Channel Measurements

The analysis tab allows quick visualization of absolute or relative phase/magnitude measurements for all measurement intervals in a selected segment.

Isolating Measurement Intervals

The analysis tab also allows mea-

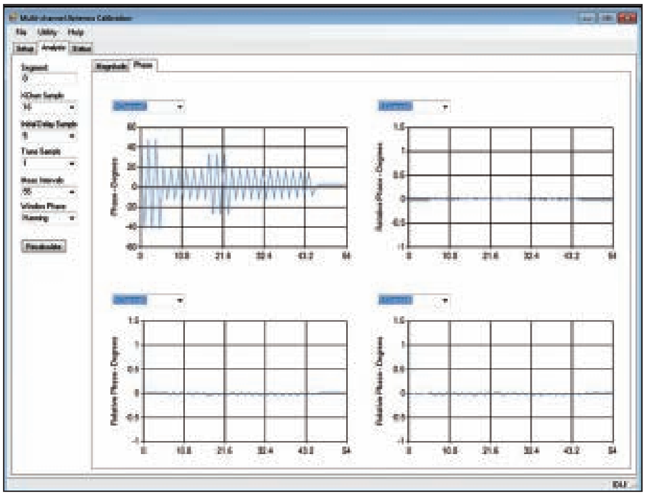
surement intervals to be isolated by selecting the number of samples to integrate over and setting the interval delay and transition time (samples) between intervals. After recalculating, the software will generate a single I-Q measurement for each interval. Again, the plots can be used to visualize either relative or absolute measurements (see Figure 4). Results can also be exported for post-processing in a test environment (see ***Figure 5***).



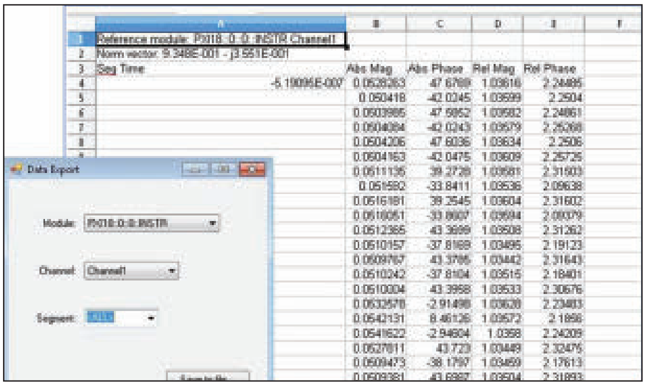
▲ *Fig. 3 Cross-channel phase measurements for all I-Q samples with absolute (reference channel) and relative (other channels) values.*

Utility and File Functions

The example software also has utility and file functions to help improve and utilize test results. For example, a cal table containing channel-channel magnitude/phase correction factors can be loaded for use when calculating the cross-channel measurements. Results can also be exported for post-processing in a test environment.



▲ *Fig. 4 Absolute and relative phase plots, after computing a single I-Q pair for each interval and applying a calibration table.*



▲ *Fig. 5 Exporting cross-channel I-Q measurement.*

CONCLUSION

The Keysight multi-channel antenna calibration Reference Solution provides antenna manufacturers greater testing flexibility for more applications and can be quickly integrated into a receiver channel calibration test environment, using near-field, narrow-band testing of the array. The solution allows antenna manufacturers to meet the demand for reduced costs and increased test capacity by making more antenna measurements per second; measuring multiple, phase-coherent channels in parallel; and optimizing the amount of data though real-time digital downconversion (DDC). ■

VENDORVIEW

Keysight Technologies Inc.
Santa Rosa, Calif.
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Waveguide Noise Figure and Gain Test Extenders

SAGE Millimeter Inc.
Torrance, CA

Many system integrators are recognizing the increasing number of commercial and consumer applications for the millimeter-wave frequency spectrum. Applications like automotive radar, local area and last-mile communication systems, portal security systems, traffic control infrastructures, and UAVs have encouraged those in the millimeter-wave industry to address the manufacturing costs of V-, E- and W-Band – and even higher frequency bands – devices, components and subassemblies. RF performance testing for products is one key part of the manufacturing process and often requires expensive test equipment that drives up costs. While many test equipment leaders continually introduce new test equipment that pushes frequencies higher, noise figure measurement systems are still limited to 50 GHz or lower.

SAGE Millimeter has introduced a series of full waveguide band noise figure and gain test extenders (STG series) to extend industrial standard noise figure test equipment to 50 GHz and higher. ***Figure 1*** illustrates how the noise figure and gain test extender interfaced with standard test equipment. According to the diagram, the noise figure and gain test extender consists of two parts: the full band downconverter (STC series) and the full band noise source (STZ series).

The function of the downconverter is to convert high millimeter-wave frequency (50 GHz or higher) by mixing it with a low frequency signal (20 GHz or lower) to produce IF frequency which can be measured by a

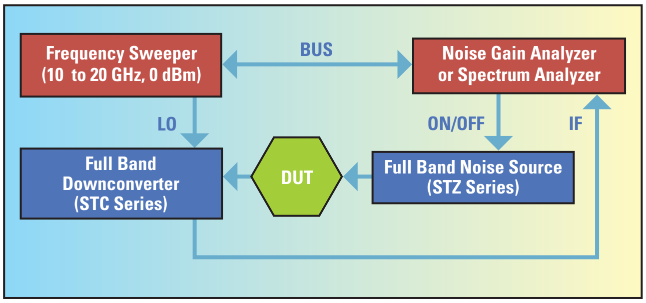
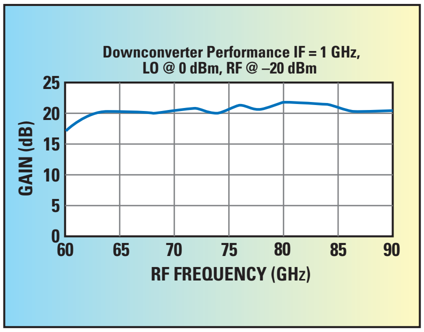
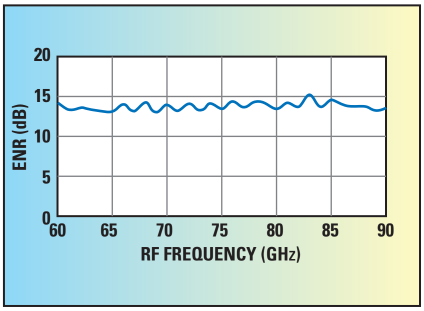


Fig. 1 Interface block diagram.



▲ *Fig. 2 Downconverter gain versus frequency.*



▲ *Fig. 3 Noise source ENR versus frequency.*

TABLE I

SPECIFICATIONS OF STG MODULE

Extender Model Number	STG-15-S1	STG-12-S1	STG-10-S1
Downconverter	STC-15-S1	STC-15-S1	STC-15-S1
RF Waveguide Size	WR-15	WR-12	WR-10
RF Frequency Range (GHz)	50 to 75	60 to 90	75 to 110
LO Frequency Range (GHz)	12.5 to 18.75	10.0 to 15.0	12.5 to 18.33
LO Power (dBm)	0 to +5	0 to +5	0 to +5
IF Frequency Range (MHz)	10 to 1,600	10 to 1,600	10 to 1,600
Noise Figure (dB, typical)	10.0	10.5	11.0
Conversion Gain (dB, typical)	20.0	20.0	20.0
IF and LO Connectors	SMA(F)	SMA(F)	SMA(F)
DC Bias (VDC/mA, typical)	+12/450	+12/450	+12/450
DC Bias Port Connector	Banana Jack	Banana Jack	Banana Jack
Noise Source	STZ-15-I1	STZ-12-I1	STZ-10-I1
RF Waveguide Size	WR-15	WR-12	WR-10
RF Frequency Range (GHz)	50 to 75	60 to 90	75 to 110
ENR (dB, typical)	13.5	13.0	12.5
ENR Variation (dB, Max)	±1.4	±1.5	±1.5
Port VSWR (Max)	1.4:1	1.4:1	1.4:1
AM Modulation Trigger	TTL	TTL	TTL
AM Modulation Rate (kHz, Max)	1.0	1.0	1.0
AM Modulation Connector	SMA(F)	SMA(F)	SMA(F)
Temperature Stability (dB/°C)	0.01	0.01	0.01
Long Term Stability (dB/Day)	0.05	0.05	0.05
Bias (VDC/mA, Typical)	+18 to +28/60	+18 to +28/60	+18 to +28/60
Bias Port Connector	BNC (F)	BNC (F)	BNC (F)

low frequency analyzer or receiver (10 MHz to 1.6 GHz for example). The downconverter includes many high performance SAGE Millimeter components, such as a Faraday isolator (STF series), full band balanced mixer (SFB series), waveguide filters (SWF series), passive and active multipliers (SFP and SFA series) and an IF low noise amplifier (SBL series). While the standard model offers 10 dB input noise figure based on direct downconversion technique, the advanced model with integrated millimeter-wave low noise amplifier is offered as an option to further improve the input noise characteristics. A typical gain versus frequency of an E-Band downconverter is shown in ***Figure 2***, demonstrating very flat gain performance.

The full band noise source is a silicon IMPATT diode-based solid state noise source. The noise source implements high performance diode and proprietary circuit designed to yield high ENR with extreme flatness in the entire waveguide bandwidth. While the standard model offers moderate ENR, the model with higher ENR up to 20 dB is also available as an option. The noise source integrates a Faraday isolator at its output to further improve the port VSWR, resulting in a more stable and reliable noise figure measurement. A typical ENR versus frequency of an E-Band (60 to 90 GHz) noise source is shown in ***Figure 3***. From the curve, very flat ENR figures across the entire E-Band are observed. The flat ENR level is highly desired for any measuring system.

Table 1 shows the main electrical and interface specifications of the featured noise figure and gain test extenders. The RF interface of the extenders is equipped with standard waveguide. SAGE Millimeter's SWC series waveguide to coax adapters can be used to convert the interface to 1 mm coaxial interface.

In addition, the standard extenders can also be tailored to offer lower input noise figure, higher ENR or various conversion gain options.

VENDORVIEW

SAGE Millimeter Inc.
Torrance, Calif.
(424) 757-0168
info@sagemillimeter.com
www.sagemillimeter.com

Compact Waveguide-to-Coaxial Transition

The Neat Adaptor, No Connector (NANo) waveguide-to-coaxial transition is designed to provide a direct, compact transition between a 50 ohm coaxial pin interface and waveguide; replacing the need for the bulky approach of semi rigid cable to conventional waveguide transition. The NANo solution offers improved mechanical integrity and optimizes the signal path while minimizing space envelope and reducing the number of possible failure points.

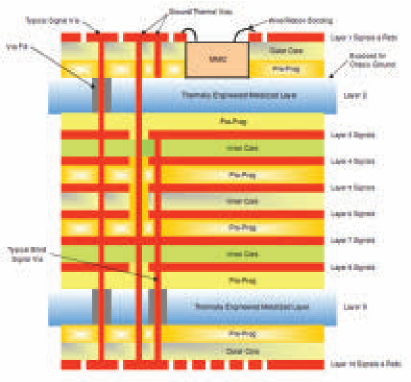
Building on the BSC Ultra Short End Launch Transition (USELT) range, the patented NANo design has comparable performance to precision right-angled transitions with more than 20 dB return loss (VSWR of 1.22:1) for most models. Band-optimized or wideband versions are available, the latter achieving typical bandwidths of above 60 percent of the standard waveguide operating band for the wideband versions.

Typical applications include direct integration of low noise amplifiers to waveguide-based systems. Testing of the LNA can be carried out using field-replaceable coaxial connectors, which are removed and replaced by the NANo. The NANo is then securely fixed to the LNA module, forming one mechanically integrated unit.

The NANo design interfaces directly to a hermetically sealed pin (glass to metal seal) hence fine leak sealing of the LNA or module can be achieved. The standard range of coaxial pin diameters can be accommodated (0.012, 0.015, 0.018 and 0.020 inch).

The NANo range is available in either brass or aluminium with silver plate or passivated finish. Devices can be provided painted, unpainted or primer-finished to allow painting once integrated into the final assembly.

BSC Filters Ltd.
York, England
+44 (0) 1904 694250
www.bscfilters.com



PCB Embedded Cooling Layer System

Cirexx has developed the ECLIPS™ PCB systems based on a Lockheed Martin patented and licensed technology. ECLIPS (Embedded Cooling Layer Interactive Power System) is an advanced PCB system employing a specially developed, thermally engineered, metalized copper graphite composite with a ceramic-matched CTE. The engineered material has superior thermal conductivity properties and CTE values matched with Si, SiC, GaAs and GaN. This provides a reduced overall PCB weight, higher power density and heat dissipation capabilities while maintaining the PCB structure in a stable form for direct die-attach of advanced components, such as GaA and GaN. Due to the stability and construction of the ECLIP PCB, all supporting components are standard SMT plastic packages. This can significantly reduce the cost of advanced designs by allowing for standard SMT assembly and eliminating ceramic die component sourcing, procurement and assembly of non-essential parts.

Cirexx has developed the ECLIPS manufacturing technique and process to incorporate this material into a standard PCB structure.

Common PTFE laminates can be selected to support advanced signal integrity along with variable thickness dielectrics. Heavy copper core layers for additional power and ground use are also available. The thermally engineered composite is currently stocked in 10, 20 and 40 mil thickness for use in PCB structures as a heat sink and stabilizer. Cirexx will help customers design an ECLIPS PCB to solve their high power packaging challenges.

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1 to 6 GHz, 50 W SSPA

Exodus Advanced Communications has introduced an ultra-broadband 50 W minimum SSPA operating from 1 to 6 GHz. It is a Class AB linear GaN design with wide instantaneous bandwidth suitable for all modulation standards. It has power gain of 47 dB minimum and power gain flatness of 3 dB p-p maximum (constant input power) with a return loss of 12 dB minimum. The typical two-tone intermodulation is better than 30 dBc (37 dBm/tone, = 1 MHz), harmonics better than 20 dBc and non harmonics spurious better than 60 dBc. Turn on and off speed is 5 µSec maximum.

The operating voltage is 30 to 32 V with a current of 12 A maximum. Maximum input power is 8 dBm. It has a small form factor (285 × 106 × 27 mm – excluding connectors) and is light weight. The SSPA also features built-in protection circuits with high reliability and ruggedness. Exodus produces high power amplifiers featuring LDMOS, GaN and GaAs-FET discrete transistors and die on ceramic substrates covering frequency ranges from 1 MHz up to 26.5 GHz and power levels exceeding 500 W.

Exodus Advanced Communications
Henderson, Nev.
sales@exoduscomm.com
www.exoduscomm.com

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100MHz to 18GHz Transceiver 3U Open VPX Architecture

- 0.1 to 18.0 GHz Transceiver
- 3U Open VPX Architecture
- VITA 67 RF Interface
- Up to 4GHz Instantaneous Bandwidth
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- BIT Test Mode for Closed Loop Testing
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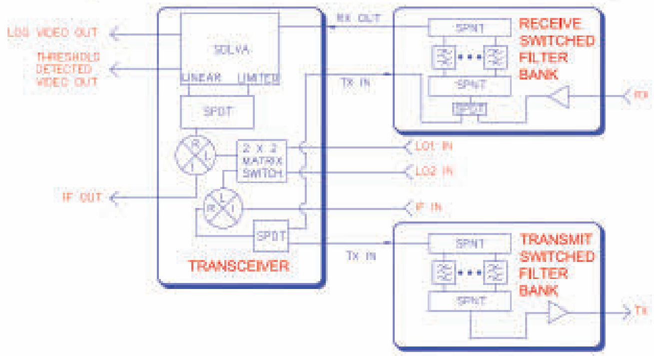
- Input Selection for Two Independent LO
- frequencies (4 to 20GHz)
- -80 to +10dBm Input Power Range
- IF Frequency of 100MHz to 4.0GHz
- LVDS Control Logic
- Ruggedized Construction for Military Applications
- 160mm x 100mm x 12HP per VITA 46 Standards (6.299" x 3.937" x 2.388")

Simplified Functional Block Diagram



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El Dorado Hills, CA 95762 USA
Tel: 916-542-1401 Fax: 916-265-2597
Email: sales@pmi-rf.com

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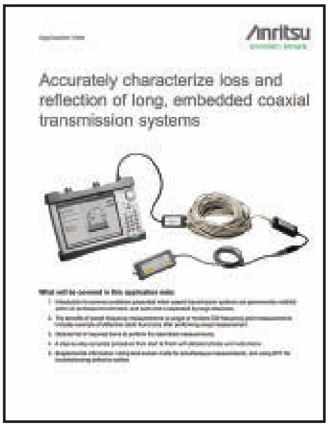
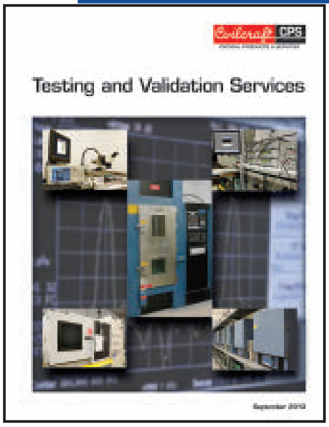


RF Network Testing Application Note

VENDORVIEW

Transmission line and antenna testing has become a common test of RF network integrity over the past few years. This relatively new testing methodology is a result of new test equipment evolutions and the need to fully understand the integrity of RF networks after installation. This application note establishes some basic guidelines for the tests and methods of procedure in an effort to improve these valuable tests and establish consistency in the results and conclusions.

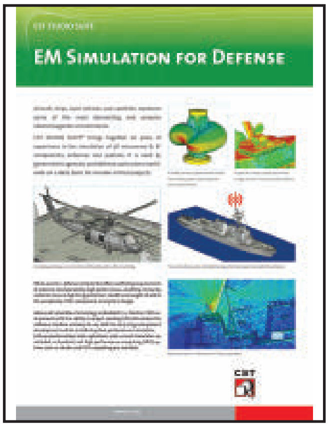
Anritsu
www.anritsu.com/en-US/coaxial-transmission-mwj



Testing & Validation Services

Coilcraft Critical Products & Services (CPS) offers a full range of product testing and validation services to help you determine the reliability, repeatability and/or compliance of the electronic components and assemblies you manufacture or procure. Coilcraft CPS's testing capabilities include vibration and mechanical shock to MIL-STD-202, as well as complete electrical testing, elemental analysis, radiographic inspection, thermal shock and cycling, and other environmental and analytical lab services. Screenings can be modified from an existing Coilcraft document or customized to meet your specific needs.

Coilcraft CPS Inc.
www.coilcraft-cps.com/pdf/testing.pdf



Electromagnetic Simulation for Defense

VENDORVIEW

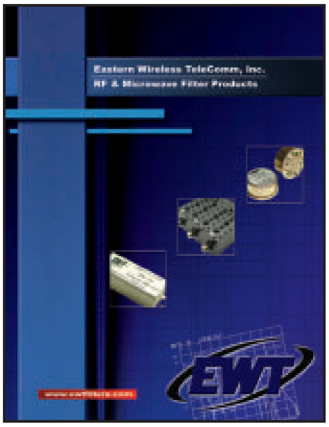
Aircraft, ships, land vehicles and satellites exist in complex electromagnetic (EM) environments. EM simulation tool, CST STUDIO SUITE®, helps development engineers address challenges unique to the field such as radar cross section and electromagnetic pulse. The transient solver, frequency solver, integral equation solver and asymptotic solver are suitable for a broad range of problems. This brochure details the use of EM simulation to analyze antenna placement and co-site interference, electromagnetic environmental effects and radar. Download it at www.cst.com/defenseflyer.

CST
www.cst.com

Power Amplifiers Catalog

CTT announced a new four-page power amplifiers short form catalog. The catalog features more than 75 models developed for radar, EW and multi-function systems design. The amplifiers feature narrowband CW, narrowband pulsed, wideband (CW) and ultra-wideband (CW) coverage. Frequency coverage is from 0.1 to 18 GHz. CTT's family of solid-state amplifiers are finding applications in many of the next generation of high-performance communications, instrumentation and medical systems where high power is required.

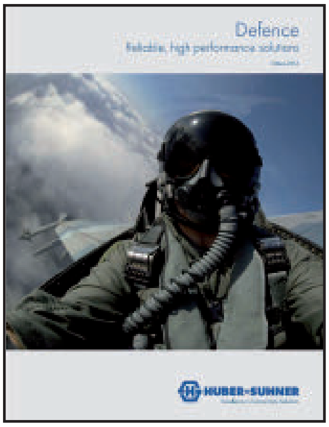
CTT Inc.
www.cttinc.com



Filter Catalog

This new short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial and wireless applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities.

Eastern Wireless TeleComm Inc.
www.ewtfilters.com



New Defence Brochure

As a leading international manufacturer of components and systems for electrical and optical connectivity, HUBER+SUHNER unites technical expertise for the defence market in radio frequency technology, fiber optics and low frequency. The new defence brochure provides an overview of HUBER+SUHNER solutions. The first part particularly focuses on defence-specific applications such as airborne, gimbal, radar, naval, command and vehicles. The second part shows detailed information of the corresponding RF products like SUCOFLEX, minibend, EACON, cable and connectors, lightning protectors and fiber optic solutions.

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www.hubersuhner.com


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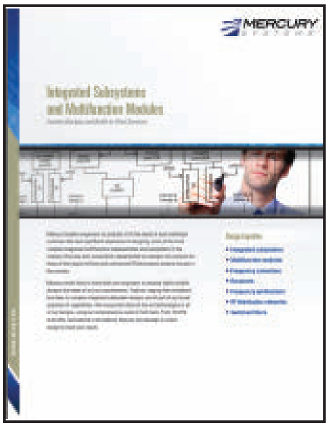
Low PIM Components & D.A.S. Equipment Catalog

MECA's new 12-page catalog features an extensive line of low PIM RF/microwave components with industry leading performance including RF loads, attenuators, directional couplers, power splitters, divider/tappers, adapters, jumpers and D.A.S. equipment. MECA's low PIM loads are considered a benchmark for the industry and are currently the only terminations capable of handling full rated power at 85°C. Visit www.e-meca.com/pdfs/MECA_catalogo-2014.pdf to download a copy.

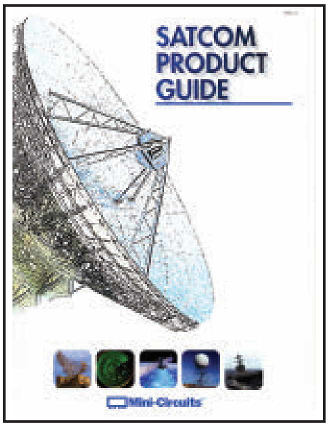
MECA Electronics Inc.
www.e-MECA.com



Integrated Subsystems Flyer

Mercury offers a broad spectrum of design, manufacturing and testing services for complex integrated multifunction assemblies and subsystems. Working hand-in-hand with your engineers, the company helps develop highly reliable designs from 10 MHz to 40 GHz for narrowband or broadband. Manufacturing capabilities include vacuum lamination of substrates, surface mount solder assembly, chip and wire assembly, and hermetic sealing. Test capabilities include static and dynamic phase noise measurements and detailed automated test routines to ensure compliance to all of your requirements.

Mercury Systems
www.mrcy.com/engineering



SATCOM Product Guide

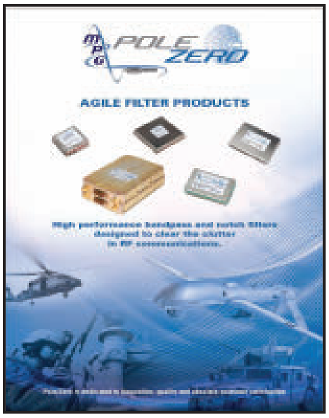
Mini-Circuits has released a new SATCOM product guide in print and for download from their website. This 32-page guide features a full survey of components and assemblies for satellite and earth station systems. With selected products from over 20 different product types to 40 GHz, the guide provides key performance parameters for each product and serves as a handy reference for engineers evaluating parts for their design needs.

Mini-Circuits
www.minicircuits.com

RF and Microwave Filters and Assemblies

NIC celebrates 28 years of uninterrupted service to the military and space markets. This catalog features NIC's design and manufacturing capabilities from DC to 40 GHz and showcases a broad range of filter technologies including: LC, crystal, ceramic, cavity, delay equalized and phase matched filters, as well as NIC's integrated assemblies such as: switch filter banks, filter/amplifiers, and phase shifters. NIC is ISO 9001:2008 certified and AS-9100C certified for aerospace applications.

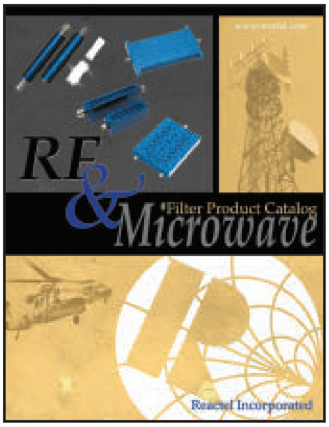
Networks International Corp.
www.nickc.com



Product Brochure

Pole/Zero's latest brochure details their newly-designed, lower-cost Mini-Pole® Series; Extended Range Frequency (ERF™) Series for applications needing a single filter with 30 to 520 MHz tunability and up to 5 W average in-band power handling; MINI/3 ERF filter providing 30 to 520 MHz tunability with enhanced selectivity by use of a three-pole filter architecture; Microwave Series of digital and voltage tuned bandpass filters offering tuning ranges beyond 4 GHz; and MINI-SMT, a surface mount version of the company's Mini-Pole Series.

Pole/Zero Corp.
www.polezero.com



Filters, Multiplexers and Multi-function Assemblies

When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. This catalog features RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request your copy, please email reactel@reactel.com, or visit www.reactel.com.

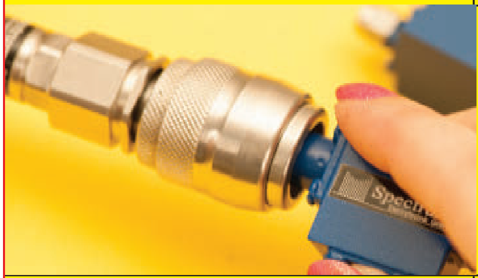
Reactel Inc.
www.reactel.com

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.

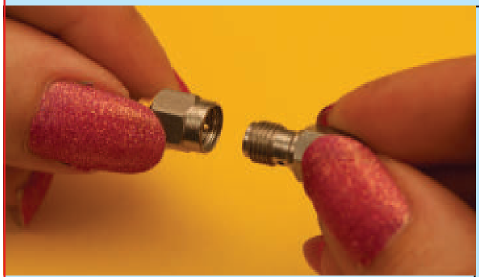


4. The Connection has been completed, easy and fast. The connector has been locked on safely.

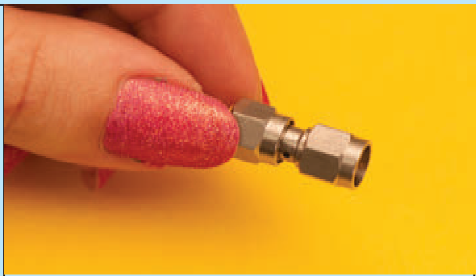
5 . To unlock (when "Back Nut" is in unlocked mode) push the "Lock Nut" forward and stop reverse movement by setting your fingers onto the "Back Nut".

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

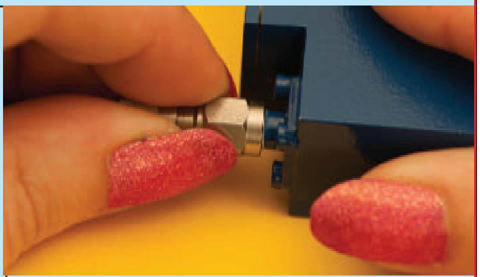
Procedure for how to use the SMA male and SMA female Push-On connectors. SMA Push-On Connectors mate with any standard connector of the same but opposite connector style.



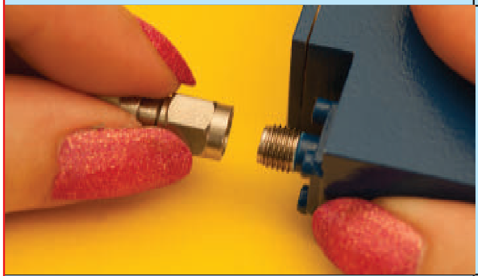
1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



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

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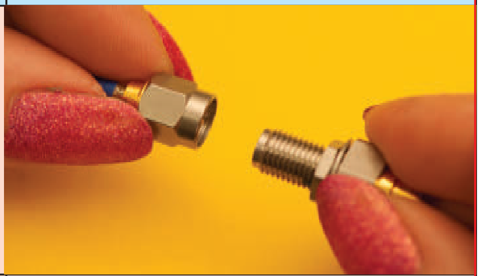
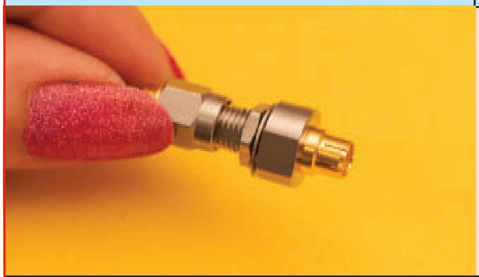
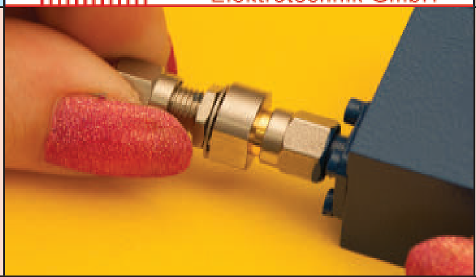


1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



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.

MILITARY MICROWAVES

LITERATURE SHOWCASE

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EM Simulation of Automotive Radar

Trends in automotive safety are pushing radar systems to higher levels of accuracy and reliable target identification. Consequentially, engineers need to better understand how mounting brackets, fascia, paint color and bumper assemblies affect automotive radar systems. This paper outlines the advantages of FDTD EM simulation for analyzing designs that include both the antenna package and the automobile body features surrounding the device. An XFdtd simulation of radar mounted in the rear bumper of a sedan is demonstrated.

Remcom
www.remcom.com/automotive-radar

RF & Microwave Product Selector Guide for Aerospace & Defense

VENDORVIEW

This guide features a broad range of all the latest products by leading suppliers including ADI, Anaren, Freescale, MACOM, Microsemi, Nitronex, Peregrine, Skyworks, STMicroelectronics, TriQuint, UMS, Wavelex and WanTcom. A&D applications supported by these products include electronic warfare, communications, jammers and radar (including commercial). Brought to you by Richardson RFPD, your global source for RF, Wireless & Energy Technologies.

Richardson RFPD / Arrow RF & Power
www.richardsonrfpd.com

Precision Microwave Components Catalog

RLC Electronics is a leader in the design and manufacture of RF and microwave components. In this catalog, you will find standard RLC products, including coaxial switches and filters up to 65 GHz, as well as power dividers, couplers, attenuators and detectors up to and beyond 40 GHz. As you will see, many of these components are available in surface mount or connectorized packages. RLC can also provide customized designs to meet specific customer requirements not shown in the catalog.

RLC Electronics
www.rlclectronics.com

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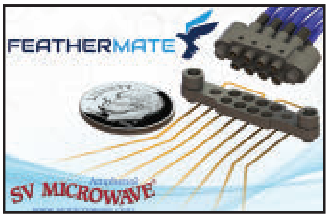
Whatever your job is, you do not always need the ultimate high-end T&M equipment. What you need are precise, reliable, universal measuring instruments. That is what you get with Value Instruments from Rohde & Schwarz: they combine practical features with excellent measurement characteristics; they are easy to use and are easy on the budget. Find out more in the Value Instruments Catalog 2014 from Rohde & Schwarz.

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

Hermetically Sealed Adapters

Spectrum Elektrotechnik GmbH offers a wide range of hermetically sealed adapters to the hermeticity of 10^{-8} atm cm^3/s minimum. The adapters use fused-in glass seals between the center contact and outer conductor. This ensures complete hermeticity of the units. The adapters are normally used at vacuum chambers testing products that are intended for outer space, with the testing equipment and personnel staying at regular environment. Available connector styles 1.85, 2.4 and 2.92 mm; N and TNC.

Spectrum Elektrotechnik GmbH
www.spectrum-et.com



Precision Light as a Feather to Flock Together

SV Microwave's new FeatherMate RF interconnect system combines a high density (0.100" center-to-center spacing), 40+ GHz multiport concept with a zero disengagement force mating mechanism. Direct connection to board trace, solder-free board mounts and small diameter coax cable connectors are available. Ideal for high density, low-force applications. Get more bandwidth and signal density in your application without worrying about destructive demating forces with SV Microwave's FeatherMate.

SV Microwave
www.svmicrowave.com

The 2014 Defence, Security and Space Forum

At European Microwave Week

EuMA

Microwave Journal
Frequency Matters.

Wednesday 8 October • Room Flavia, Fiera di Roma Conference & Exhibition Centre, Rome

A one day Forum addressing the application of RF integrated systems to defence & security infrastructure

Programme

09:00 - 10:40 Microwave Journal Industry Panel Session

The session offers an industry perspective on the key issues facing the defence, security and space sector. In accordance with the theme for 2014, the Panel will address: *Defence and security infrastructure*.

11:20 - 13:00 EuRAD Opening Session

13:10 - 14:10 Strategy Analytics Lunch & Learn Session

This session will add a further dimension by offering a market analysis perspective, illustrating the status, development and potential of the market.

14:20 - 16:00 Integrated RF solutions and its enabling and disruptive technologies on critical infrastructures and civil protection

Speakers from industry and academia present RF solutions and systems that contribute to civil protection, the protection of our critical infrastructures and disaster relief. The topics will be:

- The domino effects in critical infrastructures
- Civil protection, protection of critical infrastructures, disaster relief: vertical applications over a common architecture with heterogeneous communications
- Threats and countermeasures in the homeland security scenario
- Security at European institutional level

The three most highly rated unsolicited papers will complete the analysis of the main session topic.

16:40 - 18:20 EuMW Defence, Security & Space Executive Forum

Two executives from space industry and governmental institutions present their view on defence and space systems for our security. The titles of these two VIP talks will be announced closer to the event on the EUMW2014 website.

These two presentations will be complemented by three pitch presentations:

- Joint Applications of Airborne and Spaceborne Radars
- Instrumented fuzes for aero-ballistics diagnostics of large-caliber projectiles
- New Technologies and Innovative Payload for Space Q/V-Band Telecommunications

The session will conclude with an open forum discussion with all speakers.

18:20 - 19:00 Cocktail Reception

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

Registration fees are €10 for those who have registered for a conference and €50 for those not registered for a conference.

Register online at www.eumweek.com

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