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March 2016

Microwave Journal

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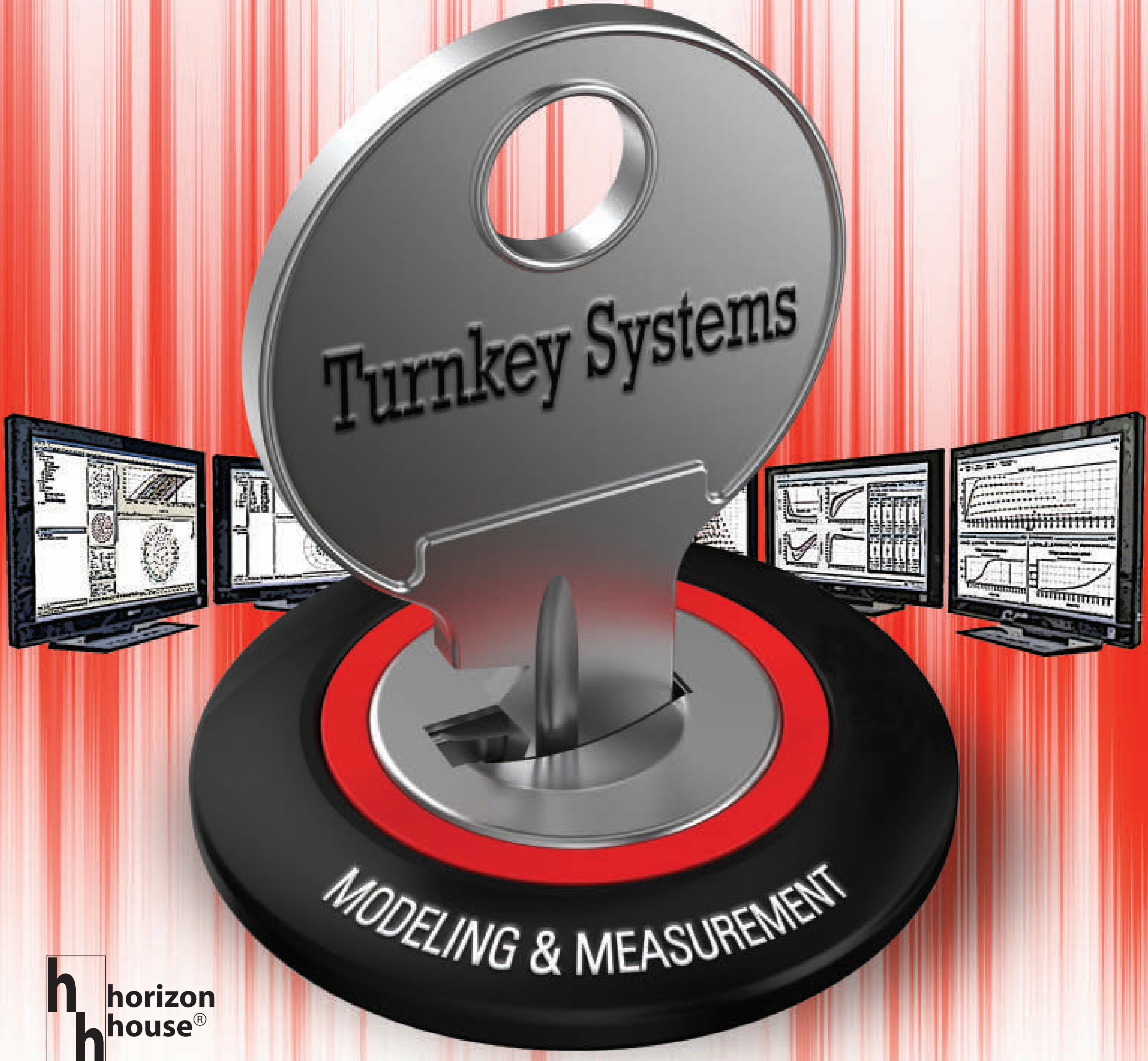

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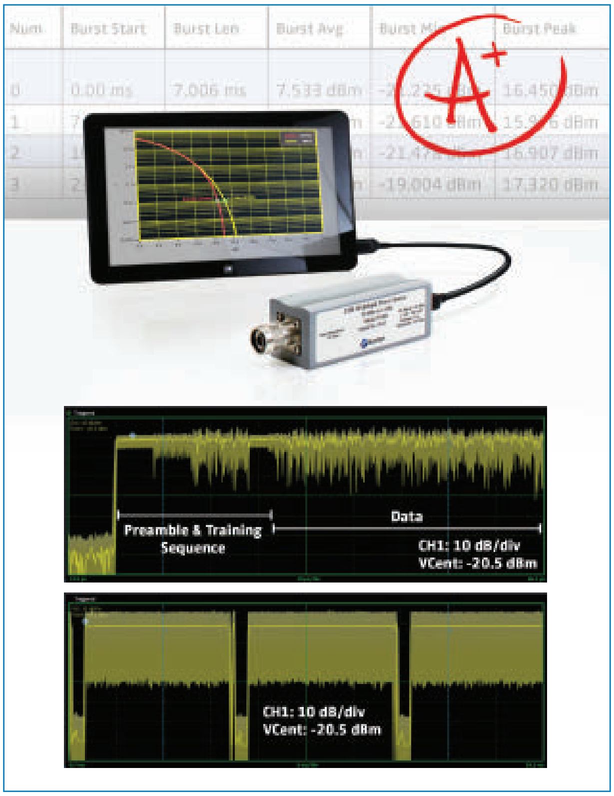

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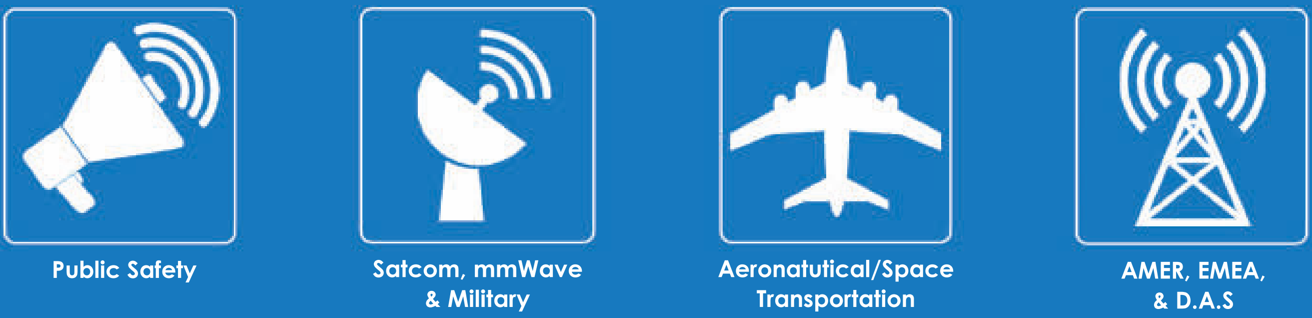

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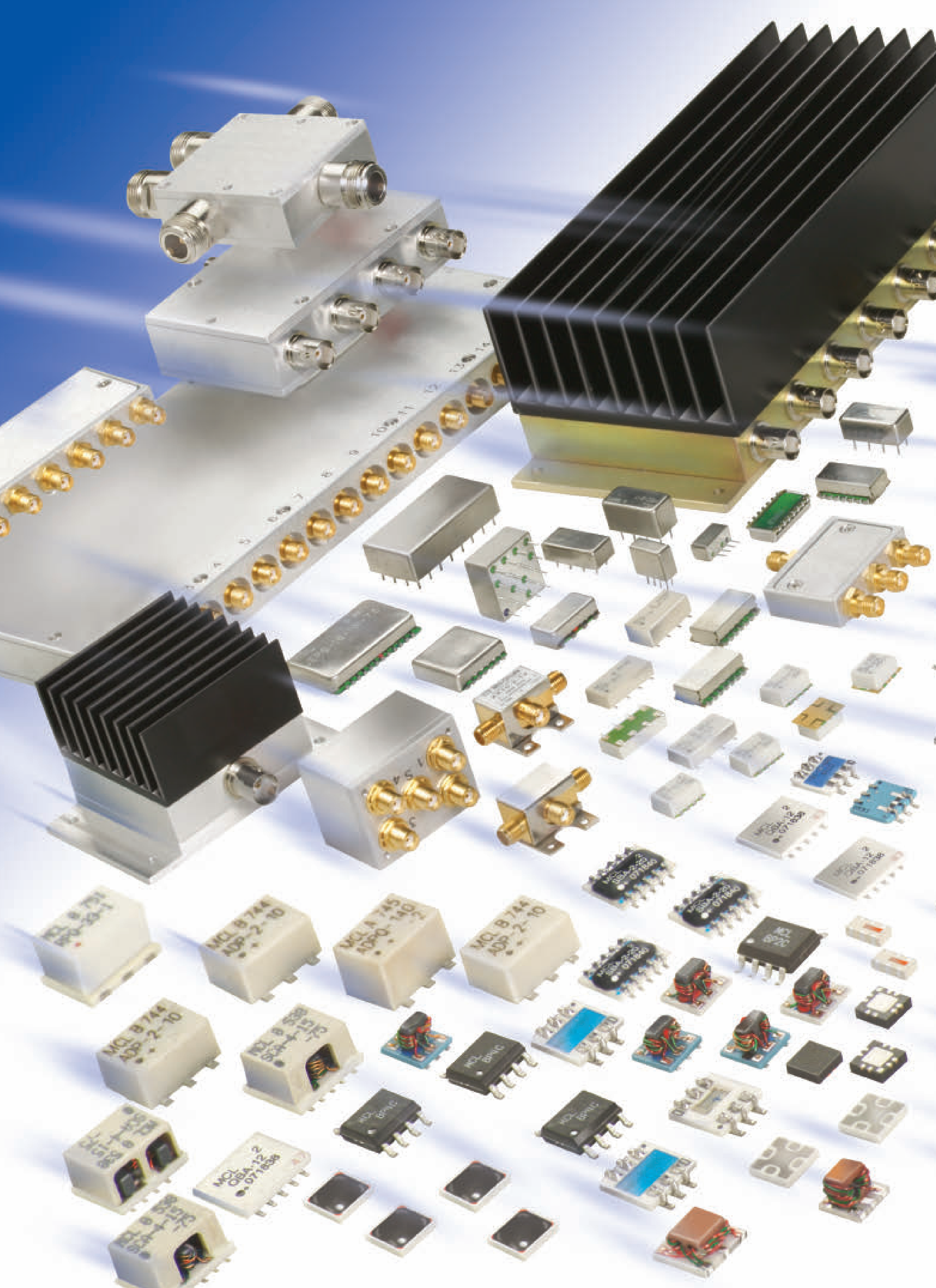
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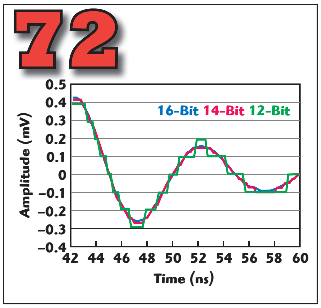

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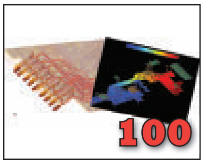

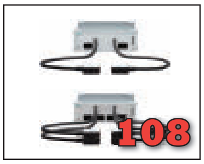

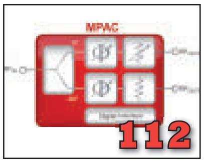

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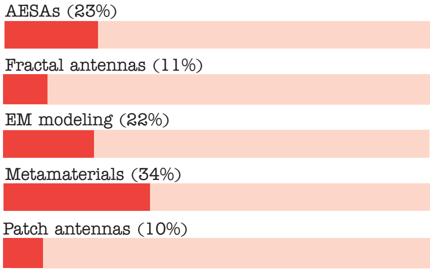

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David Brown, president of **Berkeley Nucleonics**, discusses the company's background, strategy for the RF/microwave test and measurement market and what BNC uniquely offers its customers.

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Integrated, Turnkey Modeling and Measurement Systems

Editor's Note: As time-to-market demands have increased and modeling/measurement systems have become more complex and difficult to assemble, companies have been seeking fully integrated, turnkey system solutions. *Microwave Journal* asked some leading software and measurement companies to review their offerings in this area including their advantages for customers. Keysight Technologies, National Instruments, Maury Microwave and Focus Microwaves review their capabilities in the area of integrated modeling/measurement solutions, many made up of software and hardware components from multiple companies teaming up to offer a full turnkey system solution.

Turnkey Solutions for Semiconductor On-Wafer Measurements

Yoshiyuki Yanagimoto,
Keysight Technologies, Santa Rosa, Calif.

As semiconductor technology continues to evolve, time-to-market cycles are shrinking and the need for even greater accuracy is increasing. Unfortunately, those trends often run counter to the need to properly characterize semiconductor components and devices during their development and manufacture. One issue is the time that is required to configure and assemble a measurement system to handle this task. In a typical wafer-level measurement system for mmWave measurements, for example, over 25 to 30 cables must be properly configured and assembled. The semiconductor test engineer may spend several months evaluating, ordering, assembling and verifying that system. And because it is so complex, there is a greater likelihood that a cable, connector or mechanical component will be missed, further delaying its commissioning.

The software used in the measurement system can also create challenges for the engineer. Such systems, which typically include a probe station, measurement instruments and calibration, are generally controlled by multiple pieces of software. That means that the engineer is forced to deal with different user interfaces just to operate one system. Even highly skilled engineers have to spend months or even years working to establish measurement automation. According to one recent customer survey, the need for a software solution capable of efficiently controlling both the prober and instruments, while maintaining the necessary flexibility to address diverse measurement needs, was identified as a "top three" priority.

These challenges demand an integrated, turnkey system that can quickly and accurately perform advanced DC, RF/microwave/mmWave, high power and flicker noise measurements on semiconductor components and devices. Keysight Technologies and Cascade Microtech set out to deliver this type of system in June 2014 and launched wafer-level measurement solutions (WMS). WMS provides fully configured and validated RF measurement solutions to satisfy the ever increasing

▲ *Fig. 1 Typical WMS configuration with Keysight measurement instruments and Cascade Microtech probe station.*

demands, both technically and volume-wise, of on-wafer measurements (see ***Figure 1***). To date, over 80 configurations have been tested and over 1,800 calibrations performed. Since WMS was first announced, an increasing number of semiconductor test engineers developing and manufacturing semiconductor components and devices are asking for a complete solution, rather than a collection of individual parts from various suppliers.

INTEGRATED, TURNKEY SOLUTION

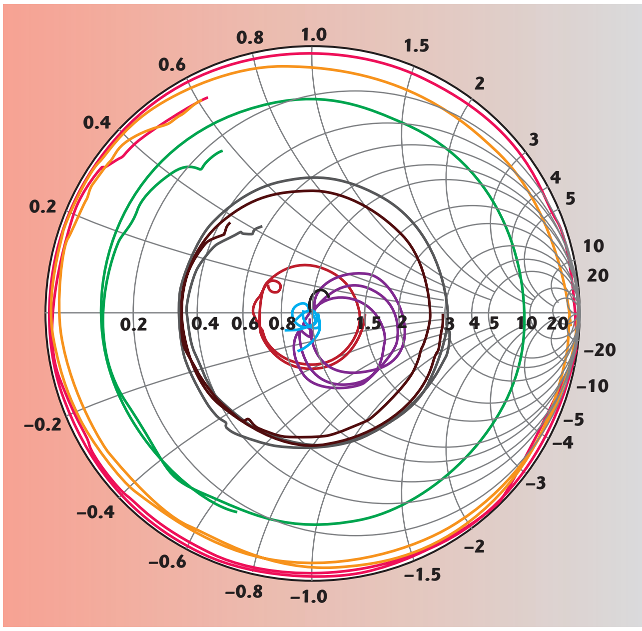
Providing an answer to that demand for a "solution," the WMS program delivers a turnkey solution for on-wafer measurements through three key deliverables: guaranteed configuration, guaranteed installation/verification and guaranteed support. These deliverables are critical to ensuring the measurement system is not only turnkey, but can quickly and accurately make the measurements today's semiconductor test engineers demand.

With guaranteed configuration, Keysight and Cascade Microtech also guarantee that if there is a missing piece in the delivered system, it will be provided free of charge. One way they ensure a complete system is delivered is through a three-way joint meeting; essentially a Keysight/Cascade Microtech sales team meeting that takes place with the engineer at the beginning of any new engagement. The three-way joint meeting eliminates the need for the engineer to meet with the sales teams from each company separately. This is not only a much more efficient use of time, but makes sure that the end system will satisfy the engineer's needs with the most reasonable and reliable configuration. It also helps ensure that there are no missing components in the system or careless mistakes made; something which can easily occur when different parties are involved in separate meetings.

Guaranteed installation allows engineers to request a variety of services at purchase, such as installation service, on-site functional qualification, measurement consultation, application training, and complete system verification and performance — all provided by application experts. These services eliminate the headaches and worries an engineer normally faces when installing a measurement system and drastically shortens the time-to-first measurement. Keysight's WaferPro Express software was specifically designed to enable engineers to quickly setup and execute automated measurements, as well as the system performance verification. The WMS program's guaranteed support means that engineers gain a single point of contact for support, rather than having to wonder which company to contact when a system level issue is encountered.

PRE-CONFIGURED SYSTEM OPTION

To further simplify the process of making on-wafer measurements and speed the actual time-to-first measurement, the companies spent a tremendous amount of time evaluating commonly used combinations of measurement instruments, including Keysight's B1500A Semiconductor Device Parameter Analyzer, N6705B DC Power Analyzer, PNA and PNA-X Network Analyzers and mmWave Extenders, and Cascade Microtech's multiple probe stations (e.g., the Summit™/Elite300™/CM300 series probe stations) and probes (e.g., Infinity® probes). As a result of these efforts, a number of pre-configured systems are now available with guaranteed performance. When one of these systems is purchased, the companies provide a system specification that serves as an acceptance criteria at installation.



▲ *Fig. 2 The Keysight Verification Substrate verifies a system with a higher coverage of the Smith Chart.*

ENABLING SYSTEM PERFORMANCE VERIFICATION

A key benefit of the WMS program is that the complete on-wafer measurement system performance is not only specified, but verified during installation. As an example, the WMS program verifies the DC leakage and noise of the entire system. Previously, DC leakage and noise could only be specified separately at the front connectors of the Keysight B1500A Semiconductor Device Parameter Analyzer by itself and at a stand-alone Cascade Microtech probe station.

For RF measurements, an application expert performs S-parameter verification at the tips of the probes using a newly developed Keysight verification substrate (KVS) up to 110 GHz. The KVS contains multiple devices, such as a mismatch line (Beatty Standard) and 25 and 100 ohm series resistors, as well as the open, short, load and line standard to more confidently verify S-parameter measurements (see ***Figure 2***).

One reason KVS is able to produce a more confident verification is that its verification standards cover a wider area of the Smith Chart. In contrast, traditional verification uses the open,

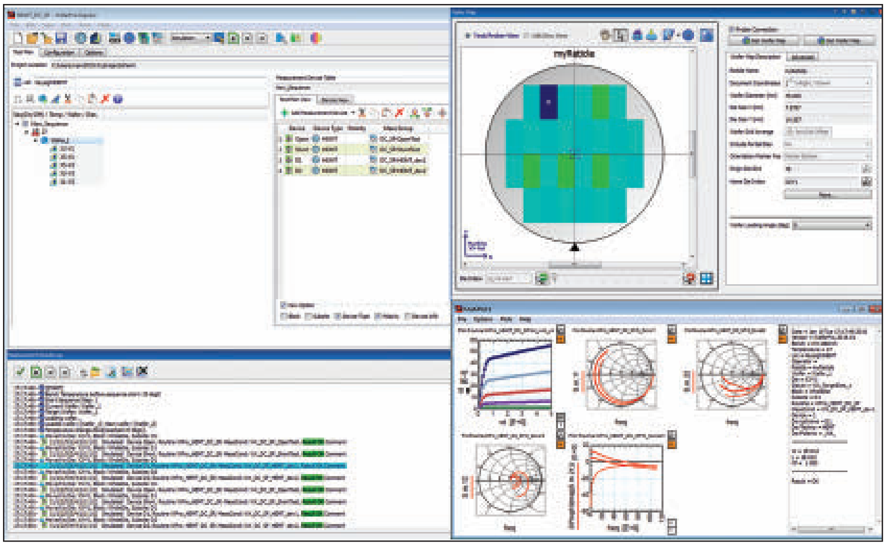


Fig. 3 *WaferPro Express software enables turnkey automated measurements as well as full customization.*

short, load and line standard, which only runs on the outer circle of the Smith Chart or stays at the center dot, making it much more limited. By verifying the complete measurement system using KVS and via DC leakage and noise, engineers gain greater confidence in the overall performance of their measurement system.

REDUCING MEASUREMENT SETUP COMPLEXITY

Keysight and Cascade Microtech jointly developed a software platform that interfaces with all the needed pieces of an on-wafer measurement system. Called WaferPro Express, the platform enables automated characterization of wafer-level devices and circuit components (see ***Figure 3***). It features over 50 measurement turnkey drivers and many test examples so that an engineer can immediately perform the needed measurements. Engineers can start an operation and write an automation program without having to waste time learning multiple pieces of software. By efficiently controlling all of the components in a wafer-level measurement system—instruments and wafer probers—WaferPro Express is able to reduce the engineer's measurement setup complexity and provide a unified platform for efficient automated measurement and data management.

With its guaranteed configuration, installation/verification and support, KVS-enabled verification and WaferPro Express software, the WMS program offers a compelling turnkey solution for on-wafer measurement needs; whether being performed on the semiconductor factory floor or by R&D teams measuring high-volume data for applications such as device modeling, process monitoring, reliability and component characterization. Engineers performing such tasks can no longer afford the time it would normally take to evaluate, order, assemble and verify a traditional measurement system. For today's semiconductor test engineers, the benefits of the WMS program are accurate and repeatable testing, faster time-to-first measurement, and assured data correlation between multiple locations—all of which are essential to allowing today's semiconductor test engineers to perform accurate and fast advanced DC and RF measurements on both components and devices to get their products to market on time.

Customized Advanced Modeling through PXI-Based High Speed Nonlinear Measurement Systems

David Vye and Marc Vanden Bossche, National Instruments, Austin, Texas

Device modeling, specifically transistor characterization at RF frequencies and above, has been the ongoing focus of R&D for well over 40 years. Initially driven by early mil/aero funding for MMIC development, device modeling enables design innovation by bridging the gap between known transistor technology (through measurement) and unknown circuit performance (through simulation). In the earlier days of device characterization and circuit design, measurement technology, equation-based predictive modeling and simulation took shape through a mix of independent and collaborative efforts to characterize and predict the electrical behavior of new semiconductor processes.

Today, the goal for the device modeling remains the same: support basic device development and provide the design engineer with an accurate representation of how that device will behave when operating within the design network under real-world conditions. As RF semiconductor technologies mature, many transistor development and modeling techniques will be addressed with existing commercial turnkey solutions. For newer semiconductor technologies targeting applications that require models based on a broader characterization region (i.e., wideband, dynamic, thermal), the need to advance measurement speed, accuracy and customization will continue.

DEVICE MODELING

Understanding the factors driving development in device characterization starts with an examination of how data is measured and used to create predictive models. The three most common types of models used are physical models, compact models and behavioral models. Models for silicon devices such as BJTs and CMOS are commonly based on semiconductor physics. Industry standard compact models for compound semiconductor such as GaAs and GaN are typically based on empirical equations describing currents and charges as a function of the applied voltages and temperature. Behavioral models use direct measurements to represent the device with component responses to specific controlled stimuli captured in a "black-box" table or data file. Behavioral models are only valid under the operating conditions measured. This model type is actively

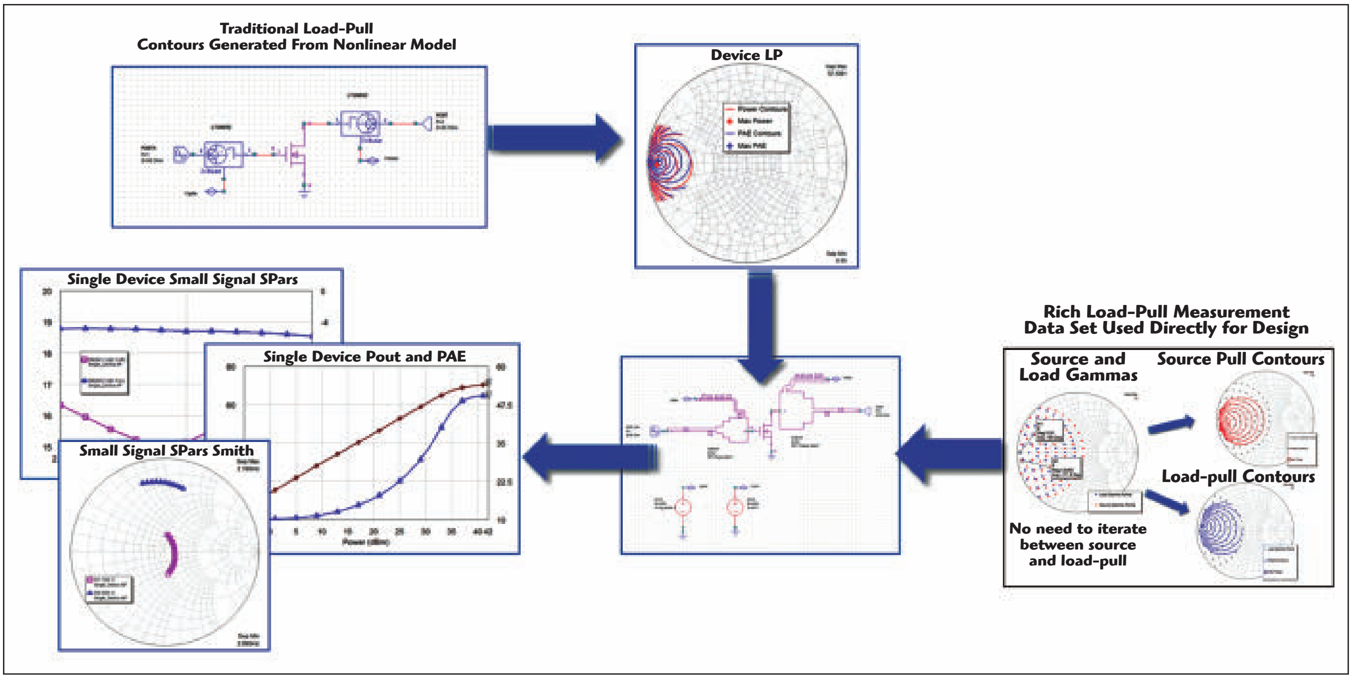


Fig. 4 New design flow replacing load-pull contours generated from nonlinear models with direct load-pull measurement sets.

under development and has recently been improved to take memory effects into account.

The compact transistor model is widely used to model the III-V semiconductor devices which are the mainstay of RF/microwave applications. Compact models extracted from measured IV, quasi-isothermal pulsed IV, S-parameters and pulsed S-parameter data, with validation from load-pull characterization, can take into account complex phenomena such as electro-thermal and trapping effects. Most of today's PAs are fed by modulated signals such as versatile pulses in the case of radars or highly modulated signals in the case of telecommunication applications. It is essential to assess the dynamic behavior of RF devices fed by these large modulated signals. Contrary to CW conditions, low frequency and high frequency memory effects created by trapping and thermal effects must be included to accurately predict the device response to complex modulated signals (such as EVM or ACPR).

To accurately predict RF (and digitally modulated) nonlinear behavior, advanced compact and behavioral models require a considerable amount of measured data, which significantly increases the time it takes to fully characterize a single device and validate the model through load-pull verification. Rapid measurement systems are required to reduce data acquisition time and to make the modeling practical. Today, the speed and flexibility of PXI-based systems make it practical to obtain massive data sets for device modeling, targeting design work as well as production test.

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MODULAR PLATFORM SOLUTION

PXI is a PC-based platform for measurement and automation systems that are compact, fast, cost-effective, adaptable and accurate, and enable many features that were previously available only to high-end and expensive setups. National Instruments supports the development of state-of-the-art device characterization systems through cooperation around solutions from Maury Microwave, Anteverta-mw (now part of Maury Microwave), Focus Microwaves and Mesuro (now part of Focus Microwaves). For these load-pull solutions, vendors are combining their expertise with NI PXI hardware and system design software, like LabVIEW, to overcome the increasingly time-consuming source and load-pull characterization requirements placed on microwave power amplifiers.

Load-pull characterization is an essential tool to increase the efficiency of power amplifiers. Due to time and cost, vendors have historically performed load-pull only during design. Today, however, the speed and flexibility of a PXI-based system make it possible to verify power amplifier performance during design verification and production test (see ***Figure 4***).

The LabVIEW reconfigurable I/O (RIO) architecture is part of the NI PXI platform. It includes the latest computing technologies, such as multicore CPUs and FPGAs, and a single, common development approach and language. Maury, Focus and their acquired companies are benefitting from this architecture, along with their unique approaches, to help their customers simplify test and decrease time to market.

Maury Microwave (with Anteverta), utilizes the high speed and broadband modulation capabilities from the NI PXI form factor to create a solution that is ideal for power amplifier characterization during development, pre-production and production testing. These systems allow broadband impedance synthesis which is becoming more important to design power efficient and linear amplifiers. The resulting large amount of test data can be managed through NI's LabVIEW, which is a graphics-driven programming environment for developing test systems. It is possible to compress all the data into a measurement-based behavioral model which can then be used with NI AWR Design Environment for circuit design.

Using the latest generation of commercial, off-the-shelf NI PXI hardware, Focus (with Mesuro) developed its RAPID load-pull system that employs a "quasi closed loop" approach, which maintains the speed of a closed loop active load-pull system but removes the inherent stability issues that limit its application. The output signal from the device is fed to a circulator or coupler and passed to the PXI chassis, where the signal is down-converted, modified to set the desired impedance, up-converted and then injected back to the test device to set an invariant impedance. Due to the system feedback, changes in the device output due to a drive level shift will be automatically compensated for in the feedback signal. This results in extremely fast impedance changes and a fast calibration process.

Even the use of a passive tuner in combination with the PXI-based vector signal transceiver (a combination of a VSG, VSA with a common FPGA architecture) and possibly a PXI SMU, speed up the classic source and load-pull. LPLite is an open-source LabVIEW application, provided by NI as reference architecture that supports an intuitive source- and load-pull application using passive tuners from both load-pull companies. LPLite stores this characterization data away in a NI/AWR compatible data format. This reference architecture can be extended easily with ET and DPD where again one benefits from the synchronization and speed of the PXI. All of these options provide a flexible system that can meet the needs of most any engineer.

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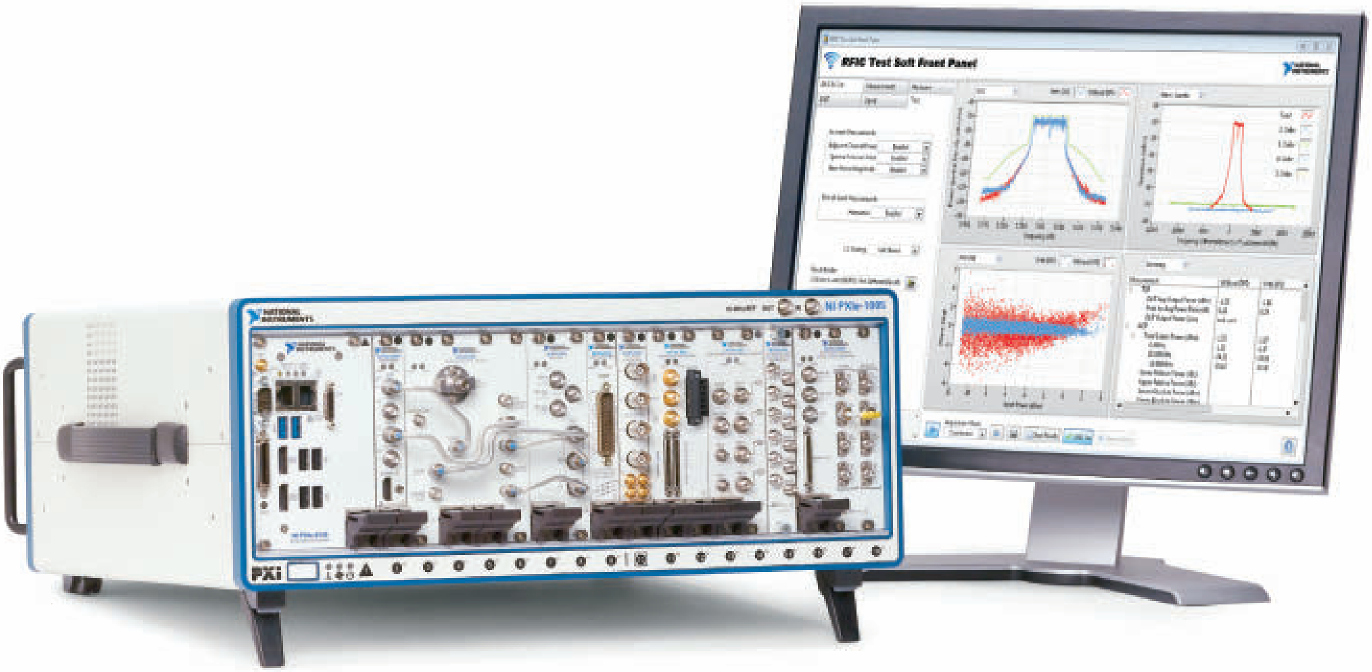

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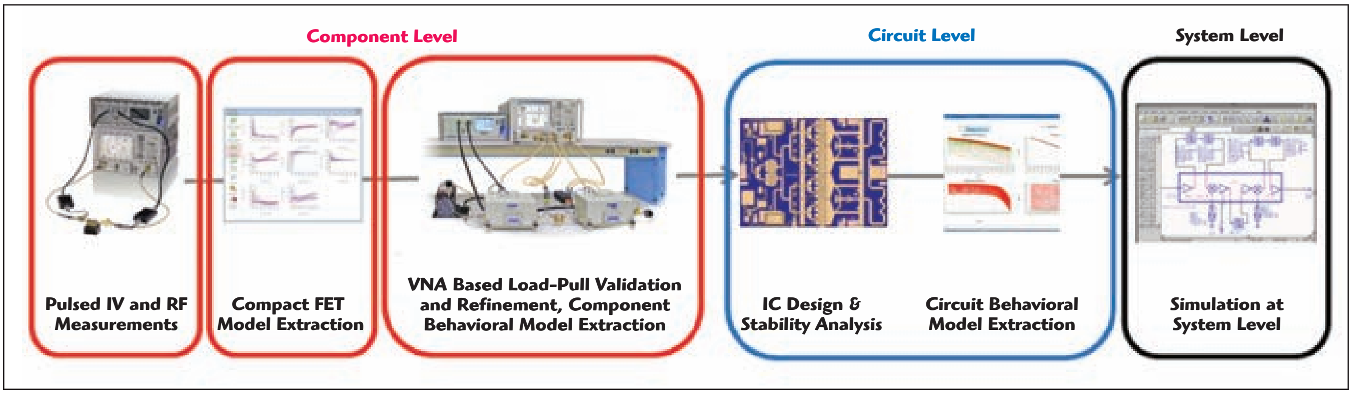

Fig. 5 Design flow to extract component- and circuit-level compact and behavioral models.

Addressing Time-to-Market with Turnkey Measurement and Modeling Systems

Steve Dudkiewicz, Maury Microwave, Ontario, Calif.

As companies become more vertically integrated, they take on greater responsibilities for accurate and robust device modeling and associated measurements across multiple product levels (IC, die, package, etc.). With time-to-market an important organizational goal, the need for a highly efficient, turnkey component-to circuit-to system-level measurement and modeling device characterization solution has never been more critical. Maury Microwave and AMCAD Engineering have partnered to address this need with a turnkey design flow (see ***Figure 5***) that includes the instrumentation and software necessary to take measurements and extract, validate and refine compact and behavioral models, all from within a single intuitive software platform.

TRANSISTOR MODELS

The first step in developing a comprehensive line of state-of-the-art transistors is to create highly accurate and reliable compact transistor models. Compact models include elements associated with linear, nonlinear, electro-thermal and trapping circuits and are extracted from synchronized pulsed IV/S-parameter measurements using an AMCAD BILT pulsed IV system, Keysight PNA-X and Maury IVCAD software suite (see ***Figure 6***). Linear compact models are extracted using S-parameters to determine the extrinsic parasitic ele-

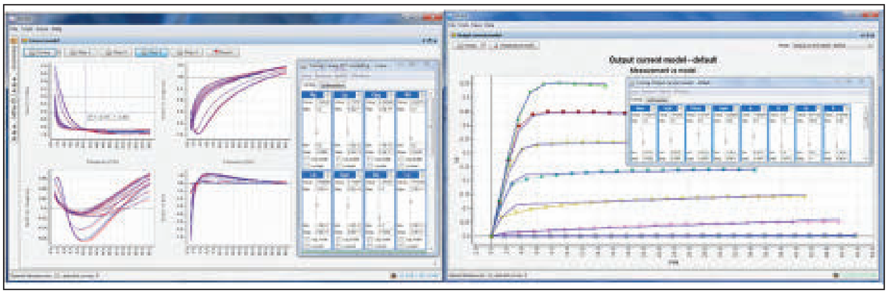

Fig. 6 Linear and nonlinear model extraction optimization in IVCAD.

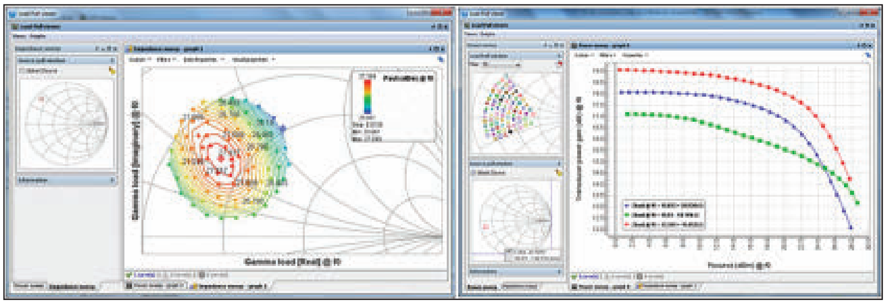

Fig. 7 *Load-pull iso-contours and gain compression curves under nonlinear operating conditions.*

ments, from which the resulting data is used to extract frequency-independent intrinsic parameters.

Nonlinear model extraction uses pulsed IV measurements to study the effects of temperature-dependent performance in safe operating regions and to study the breakdown area of a transistor. Pulse widths and duty cycles are chosen to maintain quasi-isothermal operating conditions. Pulsed IV measurements are used to extract the current diodes, and synchronized pulsed IV/S-parameters to extract the nonlinear capacitance model.

Electro-thermal circuits are used to model transistor performance as a function of device temperature and device self-heating. A transistor's thermal resistance is extracted using the differentiation between continuous and short-pulsed bias conditions. Thermal capacitance is extracted using longer pulses and studying current decrease with time. Thermal impedance is modeled from several thermal resistances and capacitances representing various time constants.

Trapping effects, surface trapping (gate lag) and buffer-trapping (drain lag) are modeled from sets of pulsed IV measurements at multiple quiescent bias points. Quiescent bias points are specifically chosen such that the difference between IV characteristics can be entirely attributed to either gate or drain lag.

MODEL VALIDATION

Following the turnkey compact model extraction flow, the 58 electrical equivalent parameters are automatically determined and result in ready-to-use III-V or MOS compact transistor models. Since the nonlinear compact transistor model was extracted from linear S-parameter measurements, nonlinear vector-receiver load-pull (see ***Figure 7***) can be used to validate and refine the model based on nonlinear fundamental and harmonic load-dependent measurements as a function of impedance, power compression and bias.

Vector-receiver load-pull uses a VNA to measure frequency-selective a- and b-waves from which separate and accurate fundamental and harmonic input and output powers are calculated. Since the large-signal input impedance of the transistor is measured in real-time, delivered input power

can be calculated as well as operating power gain and gain compression that are directly related to the intrinsic transistor's performance independent of source match. Vector parameters such as AM/PM and droop, and multi-tone parameters such as intermodulation distortion products and intercept points can be measured and compared against simulated data.

Fig. 8 IVCAD measurement and modeling device characterization software suite.

Certain VNAs, such as Keysight PNA-Xs, allow for nonlinear VNA time-domain voltage and current waveforms to be measured. When de-embedded to the intrinsic transistor reference plane, measurements can be compared against simulated data and used to refine and enhance the compact model.

CW and pulsed-RF powers can be swept using programmable signal sources to study the device's performance under small-signal to highly-compressed operating conditions. DC and pulsed biases can be adjusted using programmable power supplies or pulsed-bias (pulsed IV) systems. Impedances can be presented at the fundamental and/or harmonic frequencies using Maury's LXI™ certified passive single or multi-harmonic automated impedance tuners, active tuning chains or a combination of both. Nonlinear vector-receiver load-pull plays a critical role in validating any nonlinear model by presenting actual nonlinear operating conditions to the modeled transistor, and is useful for refining the model as needed.

BEHAVIORAL MODELS

Once a nonlinear compact model has been extracted, or if a compact model is unavailable, it is often useful to have a component-level behavioral model available for circuit design use. Unlike compact models which expose the workings of the transistor, behavioral models are "black-box" and based on a behavioral response to a set of stimuli. Nonlinear load-pull measurement data can be converted to various behavioral models, including Keysight's X-Parameters and AMCAD's Enhanced PHD (EPHD). These models can be used to quickly simulate the behavioral response of a transistor and are useful for circuit design and evaluating the transistor performance versus operating conditions. Certain behavioral models, such as the AMCAD multi-harmonic Vollterra (MHV) model can be useful for system design, taking into account low frequency and high frequency memory effects and accurately simulate ACPR and EVM using wideband modulated signals.

Amplifier and MMIC designers will often find that their designs suffer


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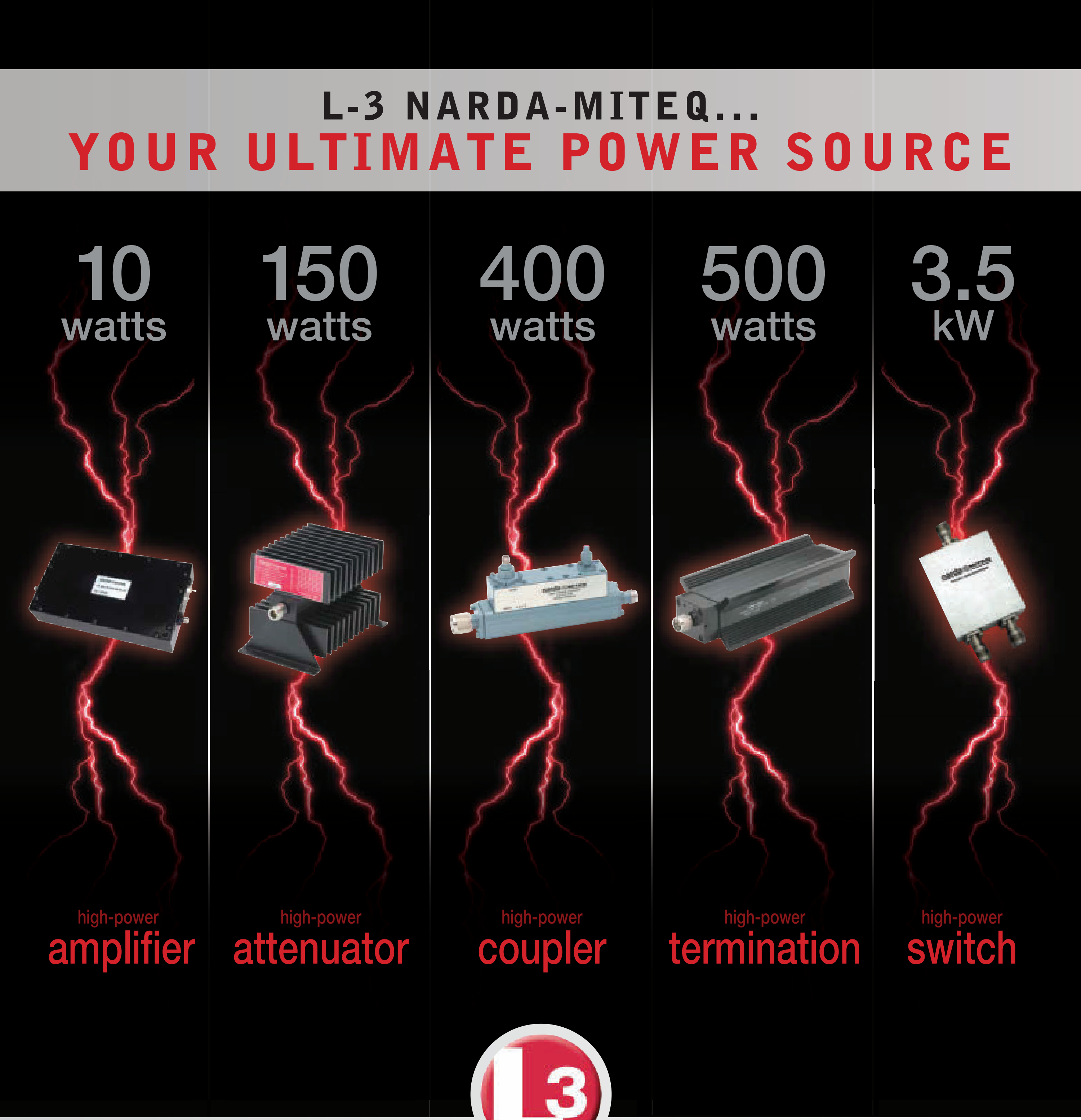
from spurious oscillations, only discovered after a circuit has been fabricated — resulting in the necessity of multiple spins. To avoid costly redesigns, stability analysis is an important step in the design flow, and STAN (STability ANalysis) can determine the nature of oscillations under both small-signal and large-signal operating conditions. Based on the pole-zero identification technique, oscillations are analyzed as a function of bias, power, impedance and manufacturing tolerances at multiple nodes of a circuit. Without a single fabrication, oscillation avoidance using the minimum number of stabilization networks can be compared against RF performance and result in the ideal compromise, leading to first-pass design success.

Without a single software platform covering the entire design flow, one runs the risk of incompatible formatting, missing measurement data and lost time. IVCAD (see ***Figure 8***) is a single suite which includes modules for synchronized pulsed IV and pulsed S-parameter measurements, compact transistor model extraction for III-V and MOS technologies, passive, active and hybrid-active fundamental and harmonic load-pull for model validation, refinement and design, multiple behavioral model extraction techniques, stability analysis of microwave circuits, with advanced visualization and data analysis, full scripting and automation capabilities. IVCAD measurement, compact model and behavioral model file formats are compatible with commercial simulation tools for easy transition from measurement and model to simulation.

All-in-One Measurement and Modeling Systems

Vince Mallette, Focus Microwaves, Montreal, Canada

Today's design engineers are looking for systems that can do it all. Integrated nonlinear measurement solutions can help designers gener-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ate compact models resulting from accurate linear pulsed S-parameters. They can also perform all the required measurements to generate a robust measurement-based behavior model calculated from wave-based harmonic load-pull measurements.

Load-pull measurements will continue to be an integral part in the design flow for RF and microwave power devices for the foreseeable future. Collection of a rich load-pull data set can shorten design cycles. Early last year, Focus added to their portfolio high power pulsed IV testing from AURIGA Microwave and behavior modeling tools from MESURO.

PULSED IV

Depending on what model extraction method designers prefer, there are various solutions to reach the end result. Pulsed IV (current-voltage) measurements have emerged as one of the popular methods of capturing current-voltage characteristics of active devices such as field effect (FET) and bipolar junction (BJT) transistors. With the growing popularity of high-power devices, like GaN HEMTs, LDMOS, SiC and graphene, current and voltage requirements are being increased.

The Auriga AU4850 is a full-featured characterization platform capable of measuring DC IV and pulsed IV curves, expandable to pulsed S-parameters and pulsed load-pull. With rise times as fast as 30 ns, measurements can be made near the instant of activation to mitigate channel, self-heating and memory effects. With pulse widths as narrow as 70 ns, the system is well suited for isothermal testing of devices. Advanced in-situ calibration features allow for correction and accuracy at the DUT reference plane.

LOAD-PULL

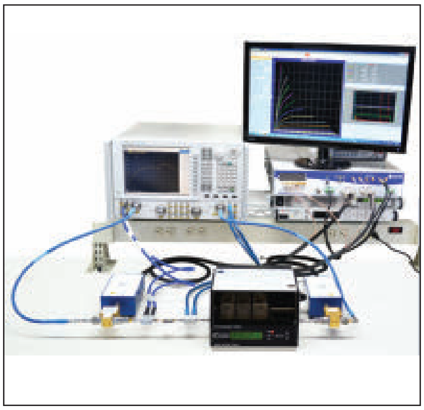
Using the vector receiver architecture, fundamental and/or harmonic load-pull can be undertaken using a variety of configurations, either employing internal VNA sources or external RF sources and a PLL interface. Focus' MPT series of wideband harmonic tuners simplifies and reduces the cost of highly complicated harmonic load-pull setups.

CoverFeature

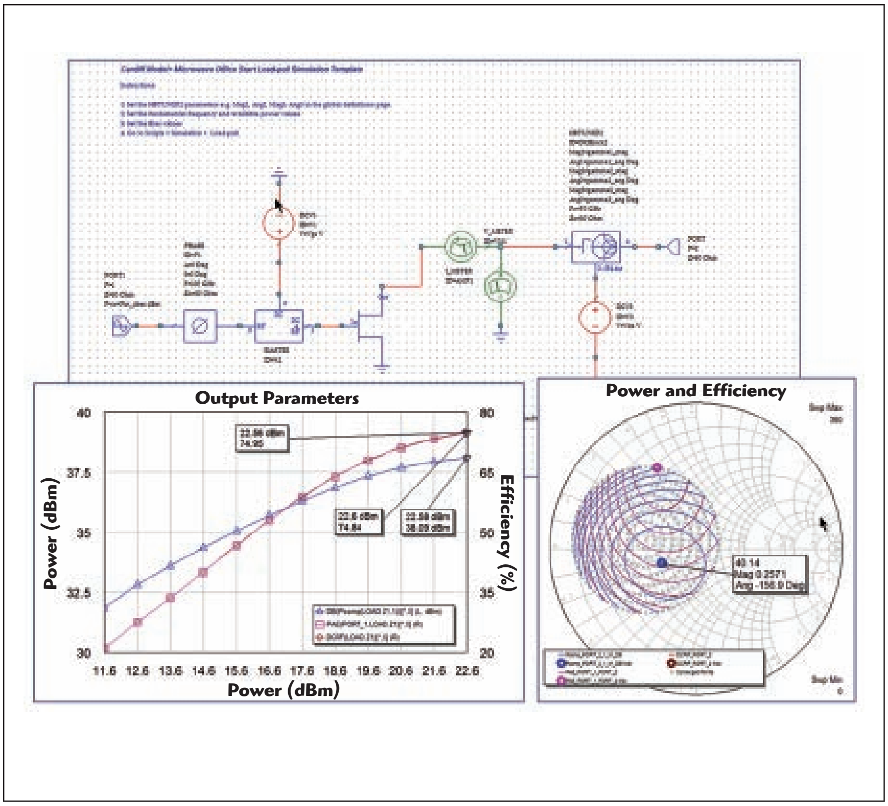
Multi-purpose tuners (MPT) use three independent wideband probes, allowing independent control of the amplitude and phase of the reflection factor at all three harmonic frequencies. The MPT can be used to pre-match impedances at the fundamental and the harmonic frequencies to reduce amplifier power by an average factor of 10 dB, and the corresponding cost when used in active systems to reach the edge of the Smith Chart. The MPT can also be used for static passive harmonic tuning in a high speed active setup with a single fundamental injection source. The active harmonic load-pull setups configured this way are marketed as model HAILP (Hybrid Active Injection Load-Pull, with one injection source) and HAILP+ (with two or three harmonic injection sources). ***Figure 9*** shows Auriga's high power pulsed IV and 8 to 50 GHz multi-harmonic tuner, driven by both Focus' and Mesuro's device characterization software, performing the measurements and generating a device model — providing a complete measurement and modeling system.

BEHAVIORAL MODELS

Nonlinear measurement data has been exploited in various ways to create behavioral models for high frequency components. These include frequency domain descriptive behavioral models, such as poly harmonic distortion (PHD) models, S-function and Keysight's X-parameters. Formulations of these models have been defined in terms of the travelling waves, with a desire to represent nonlinear behavior of high frequency transis-



▲ *Fig. 9 Auriga's AU4850 high power Pulsed IV and MPT-5080 8 to 50 GHz multi-harmonic tuner driven by Focus' and Mesuro's device characterization software.*



▲ *Fig. 10 Example results generated from an imported model.*

tors through a direct extension from the linear S-parameters. ***Figure 10*** shows the results generated from an imported model.

The Mesuro model portfolio has a number of solutions that range from the direct data look-up approach of the Cardiff DWLU model, for recreation of measured data; to the Cardiff Model Lite, where the desired output is a local model; to the Cardiff Model+ formulation, which incorporates higher-order mixing terms with perfect accuracy over the entire impedance plan.

The Cardiff Model+ is a generalized solution using an nth order "mixing" parameter formulation that can be applied as a fundamental only mode or using the harmonic content and then easily extracted using the model generation tool and used within the EDA simulation environment. The measurement data can then be exported in a file format as required by the user, such as .XNP or .MDF, to be used within the available EDA tools.

The Cardiff Model+ is a polyharmonic distortion (PHD) model. The ideal analyzing set is generated by varying one parameter at a time and analyzing the effect on the frequency components. The MPT tuner simplifies the control of three independent impedances at the given frequencies.

More than ever, a combination of companies like Focus Microwaves together with MESURO and AURIGA are providing one-stop shopping for design engineers. If we go back only a few years the typical load-pull system was a scalar solution and was considered "high-end" when you could tune harmonics for a very narrowband frequency range. Now most systems delivered by Focus are compatible with the widest range of available instrumentation, offer a wide bandwidth, tune harmonics passively and actively both on the input and the output, support wave-based receiver measurements and are capable of producing robust behavior models. ■

Ground-Based Midcourse Defense System Conducts Successful Flight Test

The U.S. Missile Defense Agency, in cooperation with the U.S. Air Force 30th Space Wing, the Joint Functional Component Command for Integrated Missile Defense and U.S. Northern Command, recently conducted a non-intercept flight test of the Ground-based Midcourse Defense (GMD) element of the nation's Ballistic Missile Defense System (BMDS). A long-range ground-based interceptor was launched from Vandenberg Air Force Base, Calif., successfully evaluating the performance of alternate divert thrusters for the system's Exoatmospheric Kill Vehicle.

During the test, a target representing an intermediate-range ballistic missile was air-launched from a U.S. Air Force C-17 aircraft over the broad ocean area west of Hawaii. An Army Navy/Transportable Radar Surveillance and Control Model 2 (AN/TPY-2) radar in Forward Based Mode, located at the Pacific Missile Range Facility, Kauai, Hawaii, detected the target and relayed target track information to the Command, Control, Battle Management and Communication system. The Sea-Based X-Band radar, positioned in the broad ocean area northeast of Hawaii, also acquired and tracked the target. The GMD system received track data and developed a fire control solution to engage the target. The test also included a demonstration of technology to discriminate countermeasures carried by the target missile.

Source: MDA

A three-stage Ground-Based Interceptor was launched from Vandenberg AFB, performed fly-out, and released a Capability Enhancement-II Exoatmospheric Kill Vehicle. The kill vehicle performed scripted maneuvers to demonstrate performance of alternate divert thrusters. Upon entering terminal phase, the kill vehicle initiated a planned burn sequence to evaluate the alternate divert thrusters until fuel was exhausted, intentionally precluding an intercept.

Program officials will evaluate system performance based upon telemetry and other data obtained during the test. Engineering data from this test will be used to increase confidence for future GMD intercept missions.

New Chips Ease Operations in Electromagnetic Environs

Competition for scarce electromagnetic (EM) spectrum is increasing, driven by a growing military and civilian demand for connected devices. As the spectrum becomes more congested, the Department of Defense (DoD) will need better tools for managing the EM environment and for avoiding interference from competing signals. One recent DARPA-funded advance, an exceptionally high-speed analog-to-digital converter (ADC), represents a major step forward. The ADC could help ensure the uninterrupted operation of spectrum-dependent military capabilities, including communications and radar, in contested EM environments. The advance was enabled by 32 nm silicon-on-insulator (SOI) semiconductor technologies available through DARPA's ongoing partnership with GlobalFoundries, a manufacturer of highly-advanced semiconductor chips.

The EM spectrum, whose component energy waves include trillionth-of-a-meter-wavelength gamma rays to multi-kilometer-wavelength radio waves, is an inherently physical phenomenon. ADCs convert physical data — that is, analog data — on the spectrum into numbers that a digital computer can analyze and manipulate, an important capability for understanding and adapting to dynamic EM environments.

Today's ADCs, however, only process data within a limited portion of the spectrum at a given time. As a result, they can temporarily overlook critical information about radar, jamming, communications, and other potentially problematic EM signals. DARPA's Arrays at Commercial Timescales (ACT) program addressed this challenge by supporting the development of an ADC with a processing speed nearly ten times that of commercially available, state-of-the-art alternatives. By leveraging this increased speed, the resulting ADC can analyze data from across a much wider spectrum range, allowing DoD systems to better operate in congested spectrum bands and to more rapidly react to spectrum-based threats.

How fast is fast? The new ADC samples and digitizes spectrum signals at a rate of over 60 billion times per second (60 GigaSamples/sec). That's fast enough to directly detect and analyze any signal at 30 GHz or below — a range that encompasses the vast majority of operating frequencies of interest. Whereas scanning through these frequencies today requires costly application-specific hardware with long development cycles, the new ADC can provide a "one-stop shop" for processing radar, communications and electronic warfare signals.

Desirable as these blazing sampling speeds are, they also pose challenges. The amount of data generated is staggering, reaching nearly a terabyte per second. This high data rate requires on-chip data-management circuitry that allows signals to be processed locally on the ADC, reducing the amount of data that must be communicated to neighboring electronics. This on-board digital signal processing

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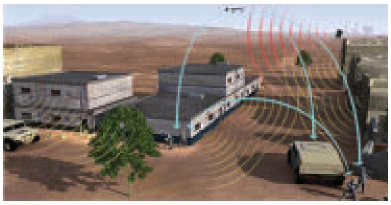

Source: DARPA

burns quite a bit of power and also demands state-of-the-art transistors. The 32 nm SOI technology offered by Global Foundries, the only certified DoD supplier of this circuit technology, provided ACT with the leading-edge transistors needed to sample and process the RF spectrum without exceeding power or data-transfer limitations.

Upcoming ACT designs will go further. By using GlobalFoundries' even more advanced 14 nm technology, ACT's next generation of ADCs aim to reduce power requirements by an additional 50 percent and enable yet smaller and lighter systems that can sample even greater swaths of the spectrum.

Successes and Hardware Stack up for Raytheon's AMDR

VIEW VIDEO

Raytheon Co. recently announced that its AN/SPY-6(V) Air and Missile Defense Radar (AMDR) team has completed the first full radar array, fully populated with component Line Replaceable Units (LRU), including more than 5,000 Transmit/Receive elements, in 140 days. In less than two years, the radar has been designed, built and transitioned to test; the Engineering and Manufacturing Development (EMD) phase of the program is now more than 66 percent complete. The program remains on track to begin production and deliver on time to the FY16 authorized DDG 51 Flight III destroyer.

"As each milestone is completed, development of the SPY-6 radar progresses on schedule," said U.S. Navy Captain Seiko Okano, major program manager, Above Water Sensors (IWS 2.0). "With this array, now built and operational in the near field range, we're proceeding to plan and commencing full-scale integration and test of AMDR's unprecedented capability."

SPY-6(V) is the next-generation integrated air and ballistic missile defense radar for the U.S. Navy, filling a critical capability gap for the surface fleet. It is the first scalable radar, built with radar building blocks (RMA). Each RMA, roughly 2' × 2' × 2' in size, is a stand-alone radar that can be grouped to build any size radar aperture, from a single RMA to configurations larger than currently fielded radars. All cooling, power, command logic and software are scalable, allowing for new instantiations without significant radar development costs.


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Airbus Defence and Space and OneWeb Create OneWeb Satellites

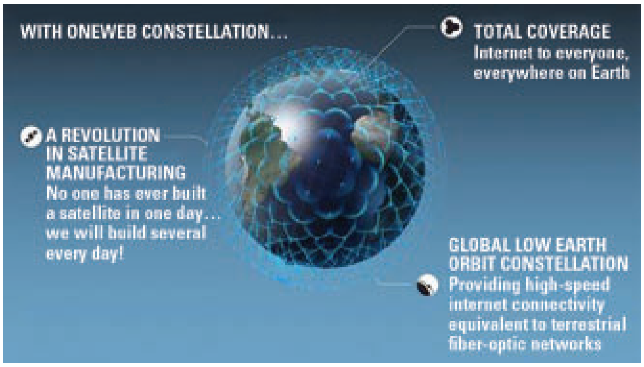
Airbus Defence and Space and OneWeb, which is building a new global satellite communications system, announced the creation of OneWeb Satellites. The new joint venture, equally owned by the two companies will design and build the 900 satellites of the OneWeb constellation, which will offer high speed internet with global coverage.

The new company, which will be led by Brian Holz as CEO, will also be able to build satellites, platforms and equipment to be marketed by Airbus Defence and Space to other operators of future constellations.

"The next stage of the OneWeb adventure is here! On both sides of the Atlantic, our teams are now working under a common flag to meet the incredible challenge: to mass-produce 900 satellites for the OneWeb constellation," said Eric Béranger, head of Programmes Space Systems. "For several months now, we have been working on the design of this unprecedented constellation and how we are going to manufacture them — both ground-breaking in their own way. The next step will be to set up a prototype line in Toulouse for production of the first 10 satellites. This will also be used to test the industrialisation method for the series production of the other satellites."

"Airbus is a key partner to our success as we move forward and are very happy to have them being a part of OneWeb and our new joint venture. We are benefitting from Airbus Defence and Space's manufacturing and assembly knowledge as we look to initiate services," said Matt O'Connell, CEO of OneWeb.

OneWeb Satellites will undertake design activities for the entire satellite fleet and the manufacture of the first 10 flight models will take place in France, with the first ever mass production of the operational satellites planned for North America. Each satellite will weigh less than 150 kg and will operate in low Earth orbit. They will be launched by Arianespace and Virgin Galactic starting from 2018 and reach their orbital positions using electrical propulsion.



Courtesy: OneWeb

Internet of Things Could Be Low-Cost 'Connectivity Key'

A new report from the International Telecommunication Union (ITU) and Cisco identifies the Internet of Things (IoT) as a major global development opportunity that has the potential to improve the lives of millions and dramatically accelerate progress towards the UN Sustainable Development Goals.

The joint report, titled "Harnessing the Internet of Things for Global Development" argues that strong demand for IoT technologies has created a huge array of IoT devices that are readily available, affordable and scalable for developing countries, providing an ideal platform to energize growth in emerging economies and improve people's quality of life significantly – all with minimal investment.

> "...huge potential for disruption and transformation..."

"The Internet of Things is one of the most exciting areas of our fast-evolving ICT industry, offering huge potential for disruption and transformation. In the context of global development challenges, this means we have the potential to surmount long-standing hurdles in basic services like health care, both quickly and affordably. IoT could prove the long-awaited new approach that will help turn-around developing economies and greatly improve millions of people's day-to-day lives," said ITU Secretary-General Houlin Zhao.

Interconnectedness will be the key to increased usage, the ITU/Cisco report stresses. Thanks to the efforts of international standards-makers like ITU, global interoperability between devices is now increasing, making operating and synchronizing a variety of formerly incompatible devices both possible and practical.

Driverless Cars Technology Receives £20 Million Boost in UK

Eight new projects have been awarded £20 million in funding to research and develop enhanced communication between vehicles and roadside infrastructure or urban information systems, including new 'talking car technologies'.

The projects are the first to be funded from the UK government's £100 million Intelligent Mobility Fund. They range from developing autonomous shuttles to carry visually-impaired passengers using advanced sensors and control systems, to new simulation trials for autonomous pods to increase uptake and improve real-world trials. Trials to test driverless cars on the streets are currently being worked on in Bristol, Coventry and Milton Keynes, and Greenwich.

The UK has a rich fabric of scientists and engineers who have established the UK as pioneers in the research and de-

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...talking car technologies...

velopment of connected and autonomous vehicles. This funding will help strengthen the UK as a global centre for the fast-growing intelligent mobility market, estimated to be worth £900 billion per year globally by 2025.

Roland Meister, head of Transport at the UK's innovation experts Innovate UK, said, "The UK is rapidly becoming one of the best places in the world for companies to develop their Intelligent Mobility business. He added, "Driven by our work with the Centre for Connected and Autonomous Vehicles this competition has connected together the UK's fantastic automotive industry, the research base, the insurance sector, public authorities with high growth businesses working in human behavioural science, telematics, information technology, communications, simulation, advanced sensor systems and machine learning."

ETSI Creates Standardization Group for Next Generation Protocols

The European Telecommunications Standards Institute (ETSI) has opened a new Industry Specification Group to commence work on Next Generation Protocols, looking at evolving communications and networking protocols to provide the scale, security, mobility and ease of deployment required for the connected society of the 21st century.

The telecommunications industry has reached a point where forward leaps in the technology of the local access networks will not deliver their full potential unless, in parallel, the underlying protocol stacks used in core and access networks evolve. The development of future 5G systems presents a unique opportunity to address this issue, as a sub-optimal protocol architecture can negate the huge performance and capacity improvements planned for the radio access network.

...concerted standardization action can take place...

The ETSI Next Generation Protocols Industry Specification Group (NGP ISG) will provide a forum for interested parties to contribute by sharing research and results from trials and developments in such a way that a wider audience can be informed. An action plan to engage other standards bodies will be developed so that parallel and concerted standardization action can take place as a further step in the most appropriate standards groups.

Andy Sutton, chairman of NGP ISG said, "The TCP/IP protocol suite has undoubtedly enabled the evolution of connected computing and many other developments since its invention during the 1970s. NGP ISG aims to gather opinions on how we can build on this momentum by evolving communication systems architectures and networking protocols to provide the scale, security, mobility and ease of deployment required for the connected society of the 21st century."

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[i] See datasheet for suggested application circuit.
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In-Building Mobile Data Traffic to Grow More Than 600 percent by 2020

With the majority of mobile traffic either originating or terminating indoors today, Wi-Fi is now a robust access technology for mobile data offload. In 2015, Wi-Fi offload traffic from mobile devices continued to exceed 4G mobile traffic, and, by 2018, Wi-Fi traffic is set to exceed all 2G, 3G and 4G cellular traffic combined. In a recent market study, ABI Research forecasts that rapidly increasing adoption of 4G and Wi-Fi will drive monthly in-building traffic to 53 exabytes per month by 2020.

"Mobile network operators, neutral host providers, building, enterprise and venue owners can all leverage this growth in 4G and Wi-Fi traffic," says Nick Marshall, research director at ABI Research. "Video traffic volume outstrips all other traffic types and will grow tenfold between 2015 and 2020. The enterprise and commercial segments, sports venues, transportation and healthcare verticals continue to transport the most traffic, with shopping malls and hospitality coming in at a close second place."

In-building wireless data traffic will grow at a double-digit rate to reach 53 exabytes per month worldwide in 2020. Report findings show that the Asia-Pacific region will continue to consume almost half of the worldwide in-building wireless traffic throughout the forecast period. This is due to the region's large population and extensive Wi-Fi and 4G deployments.

> On track to reach 53 exabytes per month worldwide in 2020.

"With more than 80 percent of all traffic originating or terminating indoors, Distributed Antenna Systems (DAS) have now become a must-have for handling mobile and Wi-Fi traffic," concludes Marshall. "As such, DAS and mobile equipment vendors remain poised to benefit from this traffic explosion."

North America continues to show the most DAS spend, followed by the Asia-Pacific region and then Europe. Leading companies in the DAS market include Alcatel-Lucent, Cobham, Cisco, CommScope, Corning, Dali Wireless, Ericsson, JMA Wireless, Nokia Networks, Wireless Telecom Group and Zinwave. These companies and others will benefit from increased DAS spending as mobile broadband operators densify networks to meet this mobile traffic surge.

Global LTE Subscriptions Pass One Billion

LTE subscriptions passed the one billion subscription mark during the final quarter of 2015 and are set to continue strong double-digit growth for the next five years, according to global analyst firm Ovum.

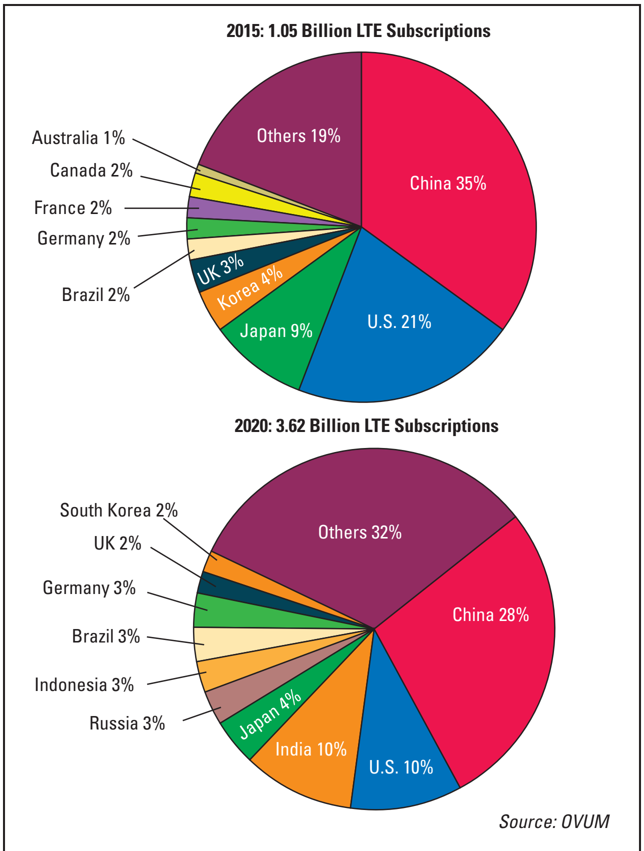
Ovum's latest research reveals that the overall count is top heavy, with five countries accounting for nearly three-quarters of all subscriptions. China is by far the biggest driver for growth, accounting for half of net additions during the last quarter and 35 percent of the total.

Growth will remain robust through 2020, as China's fellow BRIC members and Indonesia rise into the top 10 to dominate net additions and maintain annual LTE subscription growth rates well above 20 percent. Of particular significance is the rapid rate of LTE adoption, which has taken around half as long as W-CDMA to reach various milestones.

> LTE adoption has taken around half as long as W-CDMA to reach various milestones.

Ovum's chief research officer, Mark Newman, notes, "Reaching 1 billion LTE subscriptions has taken less than six years compared with more than 10 years required for W-CDMA. This highlights just how critical wireless data speeds have become, as operators aggressively roll out 4G networks to meet consumer demand for capacity, which continues unabated."

"We also see LTE subscriptions doubling by 2017 and tripling by 2019 as smartphones become cheaper and mobile broadband services become more and more indispensable. Indeed, today's majority 2G subscribers will become a rarity, with 3G and 4G accounting for 85 percent of all subscriptions by end-2020," concludes Newman.



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Scan page using layar app

Consumer Drone Shipments to Exceed 90 Million Units and Generate $4.6B in Revenue by 2025

VIEW VIDEO

The consumer drone market continues to exhibit dramatic growth as users look to use them to enrich their pastimes and activities. ABI Research predicts more than 90 million consumer unmanned aerial vehicles (UAV) will ship during 2025, up from 4.9 million in 2014 with a CAGR of 30.4 percent over the same period. Consumer drone revenues in 2025 are forecast to reach $4.6 billion.

According to research findings, toy/hobbyist drone shipments accounted for 30 percent of consumer UAV revenue in 2014, while the prosumer segment captured 69 percent. ABI Research anticipates that toy/hobbyist UAV revenue will surpass prosumer UAV revenue beginning in 2017, and will account for more than two-thirds of the $4.6 billion consumer drone market in 2025.

"For the study period, the overwhelming majority of consumer UAVs shipped will be toy/hobbyist UAVs, followed by prosumer UAVs, while kits and custom UAVs will remain a small market," says Phil Solis, research director at ABI Research. "Overall, growth in the consumer drone sector will remain strong, spurred by the creation of new use cases and the adoption of the technological advancements generated by well-funded market leaders such as DJI, 3DR, Parrot, and Yuneec, among others."

> Forecast for continued, steady growth for both the toy/hobbyist and prosumer UAV sectors.

Additionally, the report finds that as the complexity of technology in the toy/hobbyist segment continues to increase, consumer UAVs with at least one camera can expect higher shipments than those without any cameras from 2019 onward. These cameras will not be limited to taking pictures and video, but will also be utilized for machine-vision applications, such as motion tracking, obstacle avoidance and other advanced functionalities.

"It will be interesting to watch what happens as consumer UAV technology continues to evolve," concludes Solis. "The future challenge will lie in finding ways to keep the products interesting. By transforming consumer UAVs into flying smartphone-like platforms, product vendors will be able to add innovative technological functionality into the devices with an eye on more open application development to enable innovative use cases. This will enable products to hold consumer interest longer, increase product value and extend product lifespan."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Sony Corp. announced that it has reached an agreement with **Altair Semiconductor** and its major shareholders to acquire the company. The purchase price is $212 million (approximately 25 billion yen), and Sony expected to complete the acquisition in early February, 2016. Altair, an Israel-based company, owns modem chip technology and related software for LTE, a 4G cellular standard for mobile devices. Altair develops and sells products focused on LTE technology, and its modem chips stand out for their low power consumption, high performance and competitive cost.

TowerJazz has completed its previously announced acquisition of an 8-inch wafer fabrication facility in San Antonio, Texas from **Maxim Integrated Products Inc.** This acquisition will expand TowerJazz's current worldwide manufacturing capacity, cost-effectively increasing its production by about 28,000 wafers per month. The companies signed a long-term supply agreement of 15 years, under which TowerJazz will manufacture products for Maxim in the San Antonio facility, in quantities which will allow for a gradual ramp of third party products. As previously announced, Maxim received as consideration $40 million paid with approximately 3.3 million ordinary shares of TSEM, representing approximately 3 percent of the company's fully diluted share count.

Nokia and **Alcatel-Lucent** celebrated their first day of combined operations in January, marking the completion of Nokia's latest transformation and the creation of a global leader in technology and services for an IP connected world. Following the integration of the former Nokia Siemens Networks, the divestment of Nokia's Devices & Services business, the sale of HERE and the acquisition of Alcatel-Lucent, Nokia is now a business focused on network equipment and wireless technology. The celebration marked the culmination of months of preparatory planning by teams from Nokia and Alcatel-Lucent, with Nokia employees welcoming their new colleagues and, together, setting their sights on the exciting next stage of Nokia's journey.

Smiths Microwave announced the restructuring of three companies in its portfolio into a single integrated business. Organized as **Smiths Microwave Subsystems**, the business unit includes **Millitech** in Northampton and South Deerfield, Mass., **TECOM Industries** in Thousand Oaks, Calif., and **TRAK Microwave** in Tampa, Fla. The integration is designed to provide enhanced value to customers through a more integrated product offering and improved performance of all areas of the business. The team will continue to use the established brands of Millitech, TECOM and TRAK and remain as three separate legal entities to ensure continuity in the contracting process.

Honeywell has completed the acquisition of Ontario, Canada-based **COM DEV International**, a satellite and space components provider of switches and multiplexers. COM DEV will be part of the company's defense and space business and will drive continued growth across Honeywell's connectivity initiatives, benefitting the company's military, civilian and commercial aviation customers. The acquisition complements Honeywell's existing space business and enhances its radio frequency and microwave engineering competencies.

Würth Elektronik iBE GmbH, headquartered in Thyrnau, Germany, has acquired the family-run **Büchele Group**. With the merger, Würth Elektronik iBE further strengthens their position as a market and technology leader in the automotive sector. As a result of this acquisition Büchele will get access to the internationally oriented distribution structure of Würth and the Würth Elektronik eiSos Group.

Quadrant Management announced they have acquired **MI Technologies LLC** and will merge MI with its portfolio company NSI. Merging these two premier microwave measurement companies into a single entity will allow them to combine their resources to bring quality, cost effective products and systems to their customers. The name of the new company is **NSI-MI Technologies LLC** doing business as NSI-MI Technologies and their website is www.nsi-mi.com. Going forward, their customers will benefit from product and cost improvements that will result from this merger of these two microwave companies.

COLLABORATIONS

M/A-COM Technology Solutions Holdings Inc. announced a teaming agreement that establishes MACOM as **Northrop Grumman Corp.'s** exclusive teaming partner for the development and manufacture of radar arrays that use MACOM's active antenna technology to target a wide range of defense programs and platforms. Northrop Grumman and MACOM have agreed to collaborate on systems that offer customers increased system performance while also focusing on affordability, and doing so across a number of domains.

Ericsson and **Huawei** have agreed to extend their global patent license agreement between the two companies. The agreement includes a cross license that covers patents relating to both companies' wireless standard-essential patents (including the GSM, UMTS and LTE cellular standards). Under the agreement, both companies are able to access and implement the other company's standard essential patents and technologies globally. Huawei will make on-going royalty payment based upon actual sales to Ericsson from 2016 and onwards. Further details of the agreement are confidential.

Based on common understanding of market and customer needs, **TeliaSonera** and **Ericsson** will together develop 5G use-cases and service scenarios, including both communication and Internet of Things (IoT) services with the purpose to address new business opportunities. The partner-

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ship will bring 5G services to customers in 2018 by combining the TeliaSonera network with Ericsson technology. Stockholm and Tallinn — two of the most connected cities in the world will experience 5G services by 2018. 5G will amplify the value of digitalization and connectivity as it is designed to be the industrial internet.

NEW STARTS

Tektronix Inc. launched a new logo and brand strategy, marking the most significant change in its visual identity in 24 years. On the heels of the company's 70th anniversary, the refreshed logo pays homage to this heritage while pointing the way toward the next phase of the company's evolution, one focused on accelerating the realization of innovative, world-changing technologies. The legacy Tektronix logo has been refashioned, with the angle incorporated within the logotype as an upwards gesture of progress. The sans-serif type is given character by subtly clipping the 'T' letterforms, echoing the blue angle. Simple, definitive lines reflect the company's promise of performance.

RJR Polymers, a developer of high performance liquid crystal polymer (LCP) air cavity semiconductor packaging (ACP), announced that it has changed its name to **RJR Technologies Inc.** The new name reflects the company's growing role as a leading developer and high volume manufacturer of high performance LCP Air Cavity plastic packaging for RF and microwave applications. The company will begin operating under its new name and from a new website, www.rjrtechnologies.com, immediately.

ACHIEVEMENTS

W. L. Gore & Associates Inc. has received a Supplier Appreciation Award from Space Systems Loral Palo Alto, Calif., a provider of geostationary commercial satellites, in recognition of Gore's dedication in supporting SSL programs. SSL has a long history of producing reliable satellites and spacecraft systems for commercial and government customers around the world and currently has more geostationary commercial capacity in orbit than any other manufacturer. Gore has been providing SSL with its high-reliability GORE® Spaceflight Microwave/RF assemblies for more than 20 years. The supplier appreciation award recognizes the dedication of Gore's employees and management in supporting SSL programs.

Efficient Power Conversion announced that its CEO ***Alex Lidow*** was selected as the recipient of the 2015 SEMI Award for North America for the innovation of power device technology, enabling the commercialization of GaN. Dr. Lidow was honored for his work in the area of process and technology integration. Established in 1979, the SEMI Award was designed to recognize significant technological contributions to the semiconductor industry and to demonstrate the industry's high esteem for the individuals or teams responsible for those contributions.

Agile Microwave Technology Inc. passed the rigorous standards for quality management systems to earn certifi-

cation to ISO standard, ISO 9001:2008 for the design and manufacture of RF and microwave circuits, hybrids, modules, MCMs, multi-function modules and MMIC assemblies. Agile Microwave has again demonstrated its commitment to continuous improvement and to bringing out the best in every facet of its operations.

CONTRACTS

Harris Corp. has received a $316 million cost-plus-award-fee contract modification to build two payloads for the fourth and fifth weather satellites in the National Oceanic & Atmospheric Administration's (NOAA) Joint Polar Satellite System (JPSS) program. Known as the Polar Follow-on extension JPSS-3 and JPSS-4 missions, the contract was awarded to Exelis Space Systems, a wholly owned subsidiary of Harris, by the NASA Goddard Space Flight Center in Greenbelt, Md., on behalf of NOAA. The Cross-track Infrared Sounder (CrIS) instrument produces high-resolution, three-dimensional temperature, pressure and moisture profiles used to enhance weather forecasting models.

Altamira Technologies Corp. has been awarded a $35 million contract to provide classified development of advanced analytic innovation, creation and deployment efforts supporting the **U.S. Department of Defense**. Work performed under this five year CPFF contract, awarded in the first quarter of this year, will expand Altamira's Tampa-based operations and its reach into the local community. In addition to providing management, engineering and analysis services, the scope of work on this contract also includes advanced visualization of big data, data science, logistics and subject matter expertise in military operations.

Comtech Telecommunications Corp. announced that its Orlando, Fla.-based subsidiary, **Comtech Systems Inc.**, has been awarded contracts valued at $11.8 million for spare parts and system upgrades. This includes two orders totaling $11.3 million from its North African customer to provide spare parts and training in support of their troposcatter network previously delivered by Comtech. Comtech Systems was selected for these projects due to the superior performance of its system, a long history as a world leader in troposcatter technology. The systems carry digital voice, video and data traffic.

Anaren Inc. announced that it has received a $7 million contract award from **Airbus Defence and Space** for an advanced beam forming assembly to be deployed on the Eutelsat Quantum Satellite program, which Airbus Defence and Space is developing for Eutelsat, as part of a Public-Private funded partnership with the European Space Agency. The Eutelsat Quantum program will feature the world's first fully reconfigurable commercial satellite, allowing Eutelsat to adapt the satellite in response to new demands in coverage, bandwidth, power, frequency, and even changes in its orbital position. Anaren will deliver its first flight-set hardware to Airbus Defence and Space in calendar year 2017, with additional system tests and production anticipated over subsequent years.

Around the **Circuit**

Mercury Systems Inc. announced it received a $3.7 million follow-on order from a leading defense prime contractor for high-performance digital signal processing modules for a manned airborne synthetic aperture radar (SAR) application. The order was booked in the company's fiscal 2016 second quarter and is expected to be shipped by its fiscal 2016 fourth quarter. In other news, Mercury Systems was awarded four "Superior" security ratings in recent vulnerability assessments conducted by the U.S. Department of Defense's Defense Security Service (DSS). Currently, fewer than 10 percent of the approximately 13,500 facilities overseen by the DSS receive a Superior rating.

SKY Perfect JSAT Corp. has awarded **Lockheed Martin** a contract for JCSAT-17, a satellite based on the A2100 common design. JCSAT-17 is the eighth satellite SJC has awarded to Lockheed Martin, beginning with NSAT-110, JCSAT-9 through JCSAT-13 and most recently JCSAT-110R. The satellite will be manufactured in Denver, Colo. and delivered in 2019. The modernized A2100 is built on a flight-proven bus that is the foundation for more than 40 satellites in orbit today. Through an internally funded, multiyear modernization effort, Lockheed Martin enhanced the spacecraft's power, propulsion and electronics, while also adopting the latest advanced manufacturing techniques to decrease production costs and timelines.

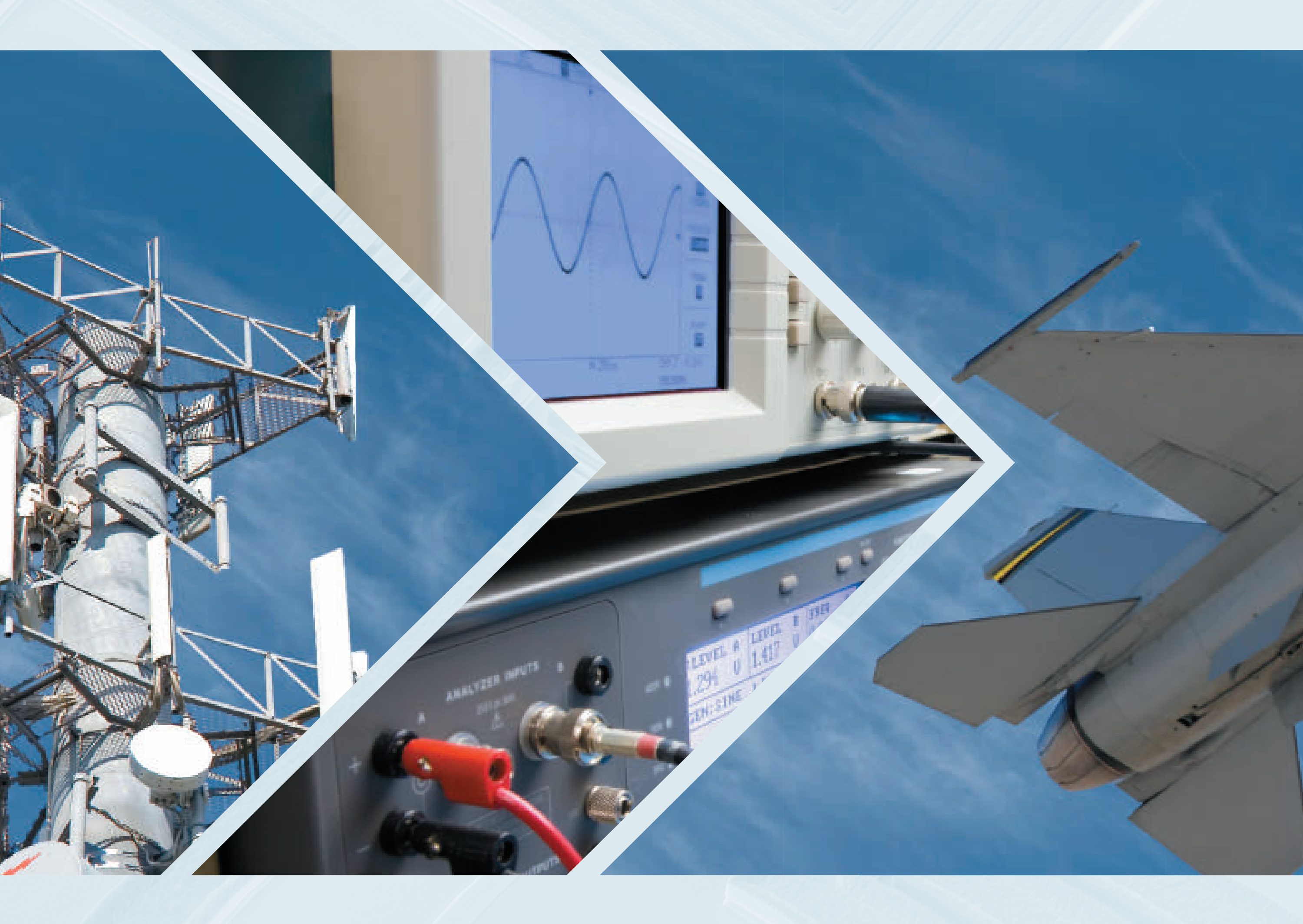
PEOPLE

▲ *Dr. Ulrich L. Rohde*

The IEEE Microwave Theory and Techniques Society (MTT-S) has awarded the 2016 Microwave Application Award to **Dr. Ulrich L. Rohde**, for his significant contributions to the development of low-noise oscillators. The Microwave Application Award recognizes an individual, or a team, for an outstanding application of microwave theory and techniques, which has been reduced to practice nominally 10 years before the award. Dr. Rohde is a regular contributor to *Microwave Journal*. His recent three-part series on Möbius Strips, in collaboration with Ajay Poddar of Synergy Microwave Corp., has been well received by our readers. Dr. Rohde will be presented his award at the annual IEEE MTT-S International Microwave Symposium Awards banquet held in San Francisco, Calif., May 22-27, 2016.

▲ *Jeff Waters*

Isola Group announced that its board of directors has appointed **Jeff Waters** as president and CEO, effective immediately. Waters succeeds interim CEO Jeffery McCreary, who was brought in to enable leadership continuity after Ray Sharpe's retirement in August 2015. McCreary will continue to serve on Isola's board of directors, a position he has held since 2006. Waters brings 25 years of experience in the semiconductor industry, having held senior leadership positions at Altera, Texas Instruments and National Semiconductor.



Around the **Circuit**

▲ *Lisa R. Davis*

Northrop Grumman Corp. announced that its board of directors has elected **Lisa R. Davis**, corporate vice president, communications, effective immediately. Davis will succeed Darryl M. Fraser, who has announced his intention to retire. Davis will have responsibility for the corporation's worldwide communications strategy and execution, including media relations, employee communications, advertising, executive communications and branding/corporate image. She will report to Wes Bush, the company's chairman, chief executive officer and president, and become a member of the company's corporate policy council. Davis joined Northrop Grumman in 2014 and currently is vice president, communications for the Mission Systems sector.

▲ *Greg Rodgers*

Zentech Manufacturing announced that **Greg Rodgers** has joined the Zentech team as director, business development/Delaware Valley Region. Rodgers is widely respected in the Delaware Valley Region (DVR) market and beyond for driving innovative engineering solutions to solve the most challenging of printed circuit board electro-mechanical assembly requirements during his 20 plus years servicing the region. The Delaware Valley Region is comprised of the states of Pennsylvania, New Jersey and Delaware. Rodgers' primary responsibility will be leading Zentech's growth initiatives in the mil-aero, industrial and medical markets in the DVR and leveraging Zentech's certifications and past performance as a mission-critical provider the U.S. Armed Forces while opening additional markets.

REP APPOINTMENTS

Communications & Power Industries LLC, Beverly Microwave Division (CPI BMD) announced it has signed an agreement with **C-Wave**, a manufacturer's representative located in Los Angeles, Calif. Founded in 1948, CPI BMD produces components which generate and control RF power in radar systems and radar-based sensors. CPI BMD is a strategic supplier of microwave components and assemblies to U.S. and foreign markets. They design and manufacture a broad range of RF and microwave products for radar, communications, electronic warfare and scientific applications. C-Wave, founded in 1997, is a microwave products manufacturer's rep covering all of Southern California. C-Wave calls on all microwave companies including military, aerospace and all other manufacturers and service providers.

RFMW Ltd. and **Ampleon** announce the continuation of their distribution relationship coinciding with the formation of Ampleon's global business operations. Ampleon is the RF Power Business Unit recently spun-off from **NXP Semiconductors**. Under the agreement, RFMW contin-

Around the **Circuit**

ues their franchise agreement for the entire RF Power business activity, including sales and support of the complete line-up of Ampleon's LDMOS and GaN RF Power products.

Richardson Electronics Ltd. announced a new global distribution agreement with the **Tecate Group**, a global supplier of electronic components and assemblies. The agreement aligns with both companies' pursuit of supplying and supporting solutions that satisfy even the most demanding applications. The Tecate Group supplies high quality ultracapacitors, capacitors and electronic assemblies to customers worldwide from its corporate headquarters and distribution center in San Diego, Calif., as well as from stocking locations in Asia and Europe. Founded in 1947, Richardson Electronics is a global channel partner for world-class electron devices, power electronics, and RF and microwave components.

e2v inc., global leader in the high reliability semiconductor market, and **Peregrine Semiconductor**, have signed a strategic reseller agreement. According to this agreement, e2v will be the sole provider of Peregrine's high reliability integrated circuits (IC) for the worldwide space market. This strategic RF relationship combines Peregrine's expertise and proven track record in high reliability RF and power management products with e2v's leadership position in aerospace and defense qualified semiconductor products. The result is a broad e2v product offering that spans the signal chain from RF to back-end, including data converters, memory and high performance data processing.

PLACES

Averna, provider of test solutions and services for communications and electronics device-makers worldwide, announced the opening of an RF and FPGA Innovation Lab at its U.S. Headquarters in Atlanta, Ga. Fully equipped with the latest National Instruments equipment, the lab will focus on bringing more RF and FPGA innovations to market by assessing a multitude of designs and ideas, accelerating new product development, and further deepening ongoing research. The Atlanta office will act as Averna's Centre of Excellence for all projects related to ITAR, RF signal processing, and LabVIEW FPGA & VHDL.

Tango Wave, a global provider of satellite communications (SATCOM) power amplifier products, announced the relocation to a new state-of-the-art design and manufacturing facility. Responding to the anticipation of future business opportunities in the high-power SATCOM uplink communications markets the facility will house the company's design, manufacturing, testing and QA operations for its TWTA-based power amplifiers and subassemblies. Tango Wave's new facility is located at 320 Soquel Way, Sunnyvale, CA, 94085 and is centrally located in the heart of Silicon Valley close to major freeways, hotels and the San Jose International Airport.

EDI CON China 2016 Features More EMC, Radar and Semiconductor Content

Patrick Hindle, *Microwave Journal* Editor

EDI CON China 2016 has added two new industry leading conferences to the event this year. The China Electrotechnical Society's EMC China and the China Radar Industry Association conference, in partnership with the China Council for the Promotion of International Trade (CCPIT), will co-locate with EDI CON China 2016, greatly expanding the technical program and audience. All three events will hold their conferences together at the China National Convention Center (CNCC) in Beijing, April 19-21, forming the largest high frequency/high speed design conference and exhibition in Beijing. Delegates will be able to attend five parallel tracks in the EDI CON China program, four parallel tracks in the EMC China program and a two-day radar conference organized by the China Radar Industry Association, offering something for every engineer involved in the area of high frequency and high speed design.

EDI CON China 2016 has scheduled 80 paper sessions, 30 workshops, seven keynotes and two panel sessions for the conference. The first day, Tuesday April 19th, features a new track on silicon-on-insulator (SOI) semiconductor technology. The SOI semiconductor track will feature a keynote talk by Peter Rabbeni, senior director of RF business development and product marketing at GLOBALFOUNDRIES, who will discuss the emergence of SOI in the RF/microwave industry. Sessions from Peregrine, Skyworks, AnalogSmith Design Solutions and Shanghai Jiao Tong University will follow the keynote on SOI. There is also a track on GaN amplifier design including a two hour short course given by Zhancang Wang, author of the book, "Envelope Tracking Power Amplifiers for Wireless Communications," and former employee of Microsoft/Nokia. He will teach "What is New after 80 Years: The Doherty Amplifier and His Load Modulation Pals."

There are also tracks on testing for Satellite Applications and PCB/Packaging Modeling plus full day tracks on System Level Measurement/Modeling and Systems Engineering. Tuesday concludes with the keynote talks starting with EDI CON China 2016 Chairman, Dr. Wai Chen, chief scientist and general manager, Internet of Things Research Institute at China Mobile, followed by EDI CON China's premier sponsors: Keysight Technologies, Rohde & Schwarz and National Instruments.

Wednesday features a full day 5G Forum that will kick off with planned keynote speakers from China Mobile plus a panel session about the latest accomplishments in 5G research with panelists from China Mobile, Keysight Technologies, Rohde & Schwarz, National Instruments and Analog Devices. There will also be featured tracks on Amplifier Modeling/Measurement, IoT Design, mmWave Applications, High Speed Digital Design, EMC/EMI Measurement/Modeling and System Level Measurement (LTE, Wi-Fi/802.11xx, radar, satellite communications and GNSS).

Also starting on Wednesday, the China Radar Industry Association conference begins its two-day seminar with planned keynote talks addressing the latest advances in radar, phased arrays and space-based radar given by high-profile experts in the industry from China and the United States. Dr. Eli Brookner, a leading radar expert who worked for Raytheon for more than 50 years, will give an update on "Advances in Radar and Phased Array Technology" and Dr. Ben De from the Chinese Academy of Engineering will discuss "Airborne Fire Control Radar Development and Trends." Dr. Eli Brookner will also give a two-hour short course entitled, "Review of Basics and New Advancements in Phased Arrays and MIMO Radar" that afternoon.

The Thursday conference tracks cover mmWave Measurement/Modeling, RF/High Speed/EMC Measurement/Modeling topics and Systems Level Design and Measurement. The China Radar Industry Association and EMC China conferences continue on Thursday finishing up the three-day program of events that will include talks from many of the Chinese Institutes such as CETC 10, 14 and 38.

The EMC China conference includes four parallel tracks taking place Tuesday through Thursday. The EDI CON poster sessions will include about 20 papers and be on display during the full event with the authors on site to answer questions right after lunch time on Tuesday and Wednesday. The tea breaks will include lucky draws with a grand prize given away during the Thursday morning break. In addition, Thursday afternoon will include an awards session for various papers and poster sessions given at the conference.

EDI CON China has grown quickly by consistently adding relevant content, securing key partnerships and speakers, and attracting companies with worldwide reach. Please join us in Beijing, April 19-21, 2016 at the CNCC for this exciting three-day event that now includes EMC China and the China Radar Industry Association conference. Visit www.ediconchina.com/registration to secure your registration to attend.

EDI CON

Tuesday, April 19, 2016

	Measurements & Modeling Track: Satellite Focus	Semiconductor Track: SOI Technology	High Frequency & HSD Design Track	System-Level Measurements/ Modeling Track	Systems Engineering Track	
	Room 401	Room 402A/B	Room 403	Room 405	Room 406	
	General Technical Sessions					
10:00 - 10:20	TU_101 - Accuracy Enhancements by Satellite Based Augmentation System (SBAS) in GNSS *Frank-Werner Thuemmler, Rohde & Schwarz (34)*	TU_102 - **Featured Keynote**: RF SOI: Revolutionizing Radio Design Today and Driving Innovation for Tomorrow *Peter Rabbeni, Dir. RF Bus. Dev., **GLOBALFOUNDRIES** (132)*	TU_103 - A New Approach of SerDes Channel Simulation with HSpice+Verilog A & IBIS AMI Models *Yongguang Lu, Lenovo/Keysight Technologies (129)*	TU_104 - High-Speed Serial Communication Physical Layer Network Fault Injection Testing *Wang Qi, Pickering Interfaces (36)*	TU_105 - Introduction to 802.11ax: High Efficiency Wi-Fi *David Hall, National Instruments (40)*	Exhibition Hours 10:00 to 18:00
10:20 - 10:40	TU_201 - Wideband Satellite Component Test Solutions *Mark Lombardi, Keysight Technologies (99)*	TU_202 - Optimizing Beam Forming Through Intelligent Integration *CK Sun, Peregrine Semiconductor (51)*	TU_203 - Supporting PAM-4 Optical Link Development *Beate Hoehne, Keysight Technologies (104)*	TU_204 - Extended Phase Noise Measurement of Direct Spectrum Analyzer Method *Wei Lin, National Instruments (7)*	TU_205 - Navigating DDR4 and LPDDR4 for System Debug and Validation *Jennie Grosslight, Keysight Technologies (89)*	
10:40 - 11:00	Tea Break - South Foyer					
	Measurements & Modeling Track: PCBs/Materials		High Frequency Design Track: Amplifier/GaN Focus			
11:00 - 11:20	TU_301 - Industry Materials Measurement Methods for Permittivity and Permeability *Ryoji Takizawa, Keysight Technologies (100)*	TU_302 - Linearity in CMOS Power Amplifiers *Malcolm Smith, AnalogSmith Design Solutions (80)*	TU_303 - A Band Selecting UHF Class-AB GaN Power Amplifier with 40 dBm Output Power *Sinan Alemdar, Bilkent University (2)*	TU_304 - Identify and Remove Crosstalk from Your Oscilloscope Waveforms *Min Jie Chong, Keysight Technologies (91)*	TU_305 - Phase-Coherent Vector Signal Analyzer Systems for MIMO Applications *Wei Lin, National Instruments (3)*	
11:20 - 11:40	TU_401 - Innovative Electrical-Thermal Co-Design of Ultra High-Q TPV-Based 3D Inductors in Glass Package *Min Suk Kim, GA Tech (109)*	TU_402 - Three Port CMOS/SOI Power Amplifier *Florinel Balteanu, Skyworks Solutions (57)*	TU_403 - Integrated High Power Envelope Tracking Supply Modulator with Wideband Current Sensing for RF PAs *Zhancang Wang, Nokia (46)*	TU_404 - QAM Signal Quality Simulation Model *Maxwell Huang, Cisco Systems (9)*	TU_405 - RF Design Techniques for Improving the Dynamic Range of Base Station Receivers and Transmitters *Alastair Upton, IDT (110)*	
11:40 - 12:00	TU_501 - Optimizing Diamond Heat Spreaders for Thermal Management of GaN HEMT Hotspots *Thomas Obeloer, Element Six Technologies (23)*	TU_502 - A Tunable Matching Network for TD-SCDMA Power Amplifier in 0.18-µm SOI CMOS Technology *Li Peng, Shanghai Jiao Tong University (47)*	TU_503 - Optimizing Doherty Amplifier Yield & Performance Through Integrated Phase & Amplitude Control *CK Sun, Peregrine Semiconductor (53)*	TU_504 - How to Evaluate Signal Integrity Performance for Your High-End Real-Time Oscilloscopes *Min Jie Chong, Keysight Technologies (94)*	TU_505 - LTE-A RF Test with R12 and R13 New Features *Shanshan Cong, Keysight Technologies (115)*	
12:00 - 13:00	Lunch Break - Exhibition Floor					
	Workshops					
13:00 - 13:40	WS_TU101 - Enabling the R&D of New Nanomaterials for Nanoelectronics - Complete Solution to Nanoscale Materials Characterization *Keysight Technologies (83)*	WS_TU102 - Why High Frequency RF Applications Need CMOS Technology *Peregrine Semiconductor (52)*	WS_TU103 - **Paid Educational Course**: What is New After 80 Years: The Doherty Amplifier and His Load Modulation Pals *Zhancang Wang, Microsoft/Nokia*	WS_TU104 - Advanced Techniques for Phase Noise and AM Noise Measurements *Schmaehling, Rohde & Schwarz (64)* and New Technique for Pulse Phase Noise Measurement *Zhong, Rohde & Schwarz (81)*	WS_TU105 - RF Solid-State Energy Paving the Way for Innovations in Consumer Whitegoods *Ampleon (formerly NXP) (122)*	
13:40 - 14:20	WS_TU201 - High Frequency Laminate Solutions for mmWave Applications *Taconic (125)*	WS_TU202 - RF SOI Process Innovations and Advanced Design Kit Enablement *Tower Jazz (151)*		WS_TU204 - How to Measure RF Signals with an Oscilloscope *Li Kai, Keysight Technologies (95)*	WS_TU205 - High Power Electromagnetic Threats and Immunity Testing Methods, *Corad (150)*	Poster Session: Exhibition Floor 13:30 - 15:30
14:20 - 15:00	WS_TU301 - Circuit Material Choices for Millimeter-Wave Frequencies *Rogers Corp. (123)*	WS_TU302 - Small Cells and Software Defined Radio (SDR) Design *Richardson RFPD (130)*		WS_TU304 - Developing Flexible and Reusable Automated Test Systems with Fast Turnaround Times *Mini-Circuits (138)*	WS_TU305 - Benefits of Multi-Tone Immunity Testing *AR Worldwide (121)*	
15:00 - 15:30	Tea Break - Exhibition Floor					
15:30 - 17:30	PL_TU - Plenary Session - Featuring Dr. Wai Chen, China Mobile - IoT; Keysight, Rohde & Schwarz and National Instruments Keynotes - Auditorium, Level 4					
18:00 - 20:00	VIP Reception and Dinner - Ballroom, Level 1/S					

Wednesday, April 20, 2016

	Design & Measurement Track: Antenna Focus	5G Forum	Measurement & Modeling Track: Amplifier Focus	System-Level Measurements/ Modeling Track: Radar Focus	HSD and EMC/EMI Measurement and Modeling Track		
	Room 401	**Room 402A/B**	**Room 403**	**Room 405**	**Room 406**		
09:00 - 09:20	WE_101 - Performace Analysis for Printed Antennas with Conductive Inks *Giovani Bulla, UNISINOS (73)*	WE_102 - **Featured Keynote**: 5G Vision at China Mobile *Dr. Chih-Lin I, Chief Scientist,* ***China Mobile***	WE_103 - Understanding, Designing and Calibration of a Microwave Variable Complex Load Tuner *AmiyaKumar Mallick, Narula Institute of Technology (15)*	WE_104 - Advancements in Automated Radar T/R Module Testing with Temperature and Module Control *Fabricio Dourado, Rohde & Schwarz (72)*	WE_105 - High Speed Channel Optimization with DOE Method *Kezhou Li, ANSYS (86)*	**Exhibition Hours 09:00 to 17:00**	
09:20 - 09:40	WE_201 - Test Modules That Provide Low Cost, High Quality Antenna Measurements *Darren Jones, Millitech (17)*	WE_202 - **5G Panel Session**: *Keysight Technologies, Rohde & Schwarz, National Instruments, ADI and China Mobile (142)*	WE_203 - High Speed Load Pull for First Pass Model and Design Success *David Li, Maury Microwave (98)*	WE_204 - Design of Multi-Technology Based Transceiver for Active Phased Array Radar System *Anil Pandey, Keysight Technologies (48)*	WE_205 - Model Decomposition for System Level Antenna and EMC Simulations *Peter Futter, Altair Development (29)*		
09:40 - 10:00	WE_301 - Design and Comparison of Switched Beam ESPAR Antennas *Tayyab Hassan, CESAT (56)*		WE_303 - High Power Tuners for Load Pull Systems *Christos Tsironis, Focus Microwaves (77)*	WE_304 - An Integrated Model-Based Platform for Radar Design and Test *Shivansh Chaudhary, National Instruments (37)*	WE_305 - Optical Signal Property Synthesis at Runtime – A New Approach for Coherent Transmission Stress Testing *Beate Hoehne, Keysight Technologies (105)*		
10:00 - 10:30	**Tea/Coffee Break - Exhibition Floor**						
	Design and Modeling Track: IoT Focus						
10:30 - 10:50	WE_401 - End-to-End Communication Analysis of a ZigBee IoT System *Peter Futter, Altair Development (30)*	WE_402 - From Theory to Practice: 5G Massive MIMO Exploration and Verification *Yi Liang, Keysight Technologies (82)*	WE_403 - Next Generation Power Amplifier Test Challenges and Measurement Solution *Yu Qian, Keysight Technologies (112)*	WE_404 - 16 Channel Phase Coherence Transmitter and Receiver System *Jinjie Wang, Keysight Technologies (103)*	WE_405 - Addressing RF Test Requirements for DOCSIS 3.1 Upstream Signals *Xiang Feng, Keysight Technologies (10)*		
10:50 - 11:10	WE_501 - Technology for Increasing Spectral Efficiency and Data Through-put Delivers Better Connectivity for IoT and M2M Vendors *Quanxin Wang, Ethertronics (19)*	WE_502 - 5G Channel Sounding Test Solution *Yu Feng, Rohde & Schwarz (16)*	WE_503 - An Active, PXI Based RAPID Load-Pull Tuner *Tudor Williams, Focus/Mesuro (79)*	WE_504 - Reproducing Correlated Radar Sea Clutter Using Vector Signal Generators *Steffen Heuel, Rohde & Schwarz (13)*	WE_505 - High-Speed EMI Tests for Automotive Products - Measurement Method of Critical Disturbance Signals *Volker Janssen, Rohde & Schwarz (12)*		
11:10 - 11:30	WE_601 - Smart End-to-End Testing for IoT Devices Using LTE-M and NB-IoT *Joerg Koepp, Rohde & Schwarz (74)*	WE_602 - 8 x 2 MU MIMO Wireless Communication System Based on NI Platform *Xi Yang, Southeast University (35)*	WE_603 - Wideband Amplifier Power Synthesis Technology *Gengye Liu, Maury Microwave (90)*	WE_604 - Using Hardware in the Loop Techniques to Accelerate System Level Characterization *Abhay Samant, National Instruments (45)*	WE_605 - Full Vehicle EMC Simulation Method *Zhenghao Chu, ANSYS (96)*		
11:30 - 11:50	WE_701 - Intelligent Wearable Design - Simplifying IoT Design *Cong Li, ANSYS (97)*	WE_702 - Design & Implementation of OOK Visible Light Wireless Communication System *Anis Abousaada, Suk Ajoumaa Higher Institute (5)*	WE_703 - Introduction to a 1200 V Precision Pulse Test Head *Tsironis, Focus Microwaves (76)*	WE_704 - Realization of DRFM Radar Target Simulator Based on General Instruments *Peng Zhang, Rohde & Schwarz (75)*	WE_705 - EMC Simulation for the Power Filter Design *Gao Ding, Ericsson (21)*		
12:00 - 13:00	**Lunch Break - Exhibition Floor**						
	Workshops & Panels						
13:00 - 13:40	WS_WE101 - MIMO OTA Mobile Device Antenna Test *Hanglu Bai, Keysight Technologies (117)*	WS_WE102 - Radio Testing of 5G Modulation Scheme Candidates *Martin Schmaehling, Rohde & Schwarz (63)*	WS_WE103 - From Wave-Based Load-Pull to Behavioural Nonlinear Models -Cardiff Model + *Focus/Mesuro (78)*	WS_WE104 - **Paid Educational Course**: Advancements in Phased Array and MIMO Radars *Eli Brookner, retired Raytheon*	WS_WE105 - Streamlining High-Speed Channel Design with Simulation *Klaus Krohne, CST (119)*		**Poster Session: Exhibition Floor 13:30 - 15:30**
13:40 - 14:20	WS_WE201 - Solving Electrically Large Complex System RF Interfer-ence (RFI) Simulation *ANSYS (113)*	WS_WE202 - 5G Channel Measurement Solutions *Keysight Technologies (88)*	WS_WE203 - Advances in Harmonic-Balance Based Simulation Load-Pull and Data Visualization *National Instruments/AWR (42)*		WS_WE205 - *Comsol Workshop*		
14:20 - 15:00	WS_WE301 - Advances in Integration of EM Simulators in Microwave Circuit Design Software: The EM Socket Concept *National Instruments/AWR (54)*	WS_WE302 - From Concept to Prototype - Introduction to 5G Research Platform Based on LabVIEW Software Defined Radio *National Instruments (133)*	WS_WE303 - A High Efficiency GaN on Si Doherty Amplifier for LTE Base Station Applications *Macom (128)*		WS_WE305 - Designing High Performance and Multi-band Signal Chains for Cellular Basestations *Analog Devices (140)*		
15:00 - 15:30	**Tea/Coffee Break - Exhibition Floor**						
15:30 - 16:10	WS_WE401 - Visualize Wireless Power Transfer Efficiency with Network Analyzers *Keysight Technologies (135)*	WS_WE402 - GaN vs. LDMOS for Cellular Applications *NXP (formerly Freescale)*	WS_WE403 - Full-Band UWB Microwave Up/Down Frequency Conversion Technology *Sample Technology (120)*	WS_WE404 - Wideband Signal Generation for Automotive Radar *Heuel, Rohde & Schwarz (14)* and Radio Testing and Troubleshooting Automotive Radar E-Band Systems *Schmaehling, Rohde & Schwarz (62)*	WS_WE405- EMS Immunity Test System Solution and Crystal Oscillator Development for High Speed Radar Systems, *Mitron (92, 139)*		
16:10 - 16:50	WS_WE501- *CETC41 Workshop*	PA_WE502 - **Special Panel Session: Realizing the Full Potential of GaN**: Incorporating Efficiency, Linearity, Bandwidth and Size Improvements for RF Power Amplifiers *Richardson RFPD - Macom, NXP, Qorvo, Microsemi, New Edge (131)*	WS_WE503 - Multi-Channel Coherent Signal Generation Measurement & Calibration, *Zheng, Rohde & Schwarz (20)* and Generation and Measurement of Phase Coherent Signals *Bednorz, Rohde & Schwarz (68)*	WS_WE504 - Radar Prototyping and Test Systems Using PXI *National Instruments (134)*	WS_WE505- *IC Technologies, Xiamen Sanan*		

Thursday, April 21, 2016

	Measurement & Design Track: mmWave Focus	RF Measurement & Modeling Track	EMC & HSD Measurement/Modeling Track	System-Level Design and Measurement Track	
	Room 401	**Room 403**	**Room 405**	**Room 406**	
09:00 - 09:20	TH_101 - Techniques for Extending Microwave Frequency Instruments for mmWave Measurements *Abhay Samant, National Instruments (41)*	TH_102 - Review of Power Electronic Device Models *Ma Long, Keysight Technologies (85)*	TH_103 - Signal Integrity and Shielding Analysis of PCBs *Peter Futter, Altair Development (31)*	TH_104 - Applying TDOA RF Sensor Network For Discovering the Geo-Locations of Interference Sources in Airport *Andrew Ko, Keysight Technologies (59)*	**Exhibition Hours 09:00 to 14:00**
09:20 - 09:40	TH_201 - Accurate and Repeatable Phase Noise Measurement of Millimeter-Wave Oscillators *Hai-Peng Fu, Tianjin University (27)*	TH_202 - Performing VNA Measurements on a MIPI Device with a RFFE Interface *Tanja Menzel, Rohde & Schwarz (67)*	TH_203 - Overcoming the Measurement Challenges for Characterizing Ultra-low Loss Capacitors in Temperature Chambers *Andrew Ko, Keysight Technologies (114)*	TH_204 - Compact Multilayer Analog Complex Correlator Design for Interferometric Imaging *Muhammad Kashif, Beijing University of Aeronautics and Astronautics (107)*	
09:40 - 10:00	TH_301 - An Ultra-Broadband Planar Up-Converting Millimeter-Wave Mixer with RF Bandwidth Covering 37 to 70 GHz *Scott Hsu, National Instruments (39)*	TH_302 - Optimizing RF Measurement Automation for Parallelism and Test Speed *Shivansh Chaudhary, National Instruments (38)*	TH_303 - Baseband Section in a Vector Signal Generator: Requirements, Challenges and Applications *Frank-Werner Thuemmler, Rohde & Schwarz (32)*	TH_304 - Based on Frequency Agile PDM Signal Source Applications in Electronic Warfare Tests *Qin Zhang, Keysight Technologies (118)*	
10:00 - 10:30	**Tea/Coffee Break - Exhibition Floor**				
	Design Track				
10:30 - 10:50	TH_401 - Reflectionless Filters Improve Linearity and Dynamic Range in Microwave Systems *Mini-Circuits (136)*	TH_402 - In Situ De-Embedding *Ching-Chao Huang, AtaiTec Corp. (137)*	TH_403 - Ten Common Mistakes to Avoid in High-Speed PCB Design *Bruce Wu, Edadoc (101)*	TH_404 - PCB Design with a Common Microwave and Satellite Communication Teaching Experiment Box *Lishan Wang Du Yan, Nanjing Yuma Communication Technology Institute (22)*	
10:50 - 11:10	TH_501 - A Compact Broadband Impedance Transformer on GaAs MMIC Technology *Shi Weiyi, LDC Microelectronics (6)*	TH_502 - Frequency Conversion Measurements Combining Coaxial Ports of a VNA and a Connected Waveguide Converter Module *Tanja Menzel, Rohde & Schwarz (66)*	TH_503 - High-Speed Circuit Simulation Test Conjoint Analysis *Bruce Wu, Edadoc (102)*	TH_504 - Signal Detection and Location Based on RF Sensors *Zhixun Guo, Keysight Technologies (108)*	
11:10 - 11:30	TH_601 - Development of Compact Wideband Broad Side RMSA Suitable for On-Board Applications *Qaisar Fraz, COMSATS (43)*	TH_602 - Broadband Noise Measurement and Modeling Solution *Li Fei, Keysight Technologies (106)*			
12:00 - 13:00	**Lunch Break - Exhibition Floor**				

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

Common Digitizer Setup Problems to Avoid

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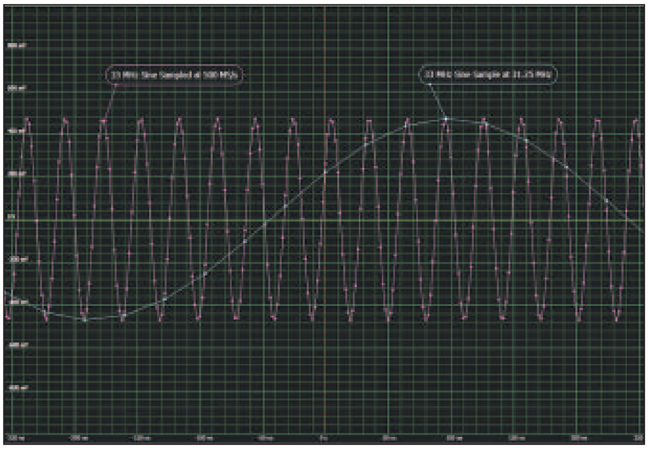
When it comes to making measurements with modular digitizers, it is important to be aware of some common setup problems that will result in bad data and lost time. Setup issues that can arise include aliasing, insufficient amplitude resolution, incorrect amplitude range selection, improper coupling, improper termination, poor trigger setup and excessive noise and spurious pickup. This article will consider each of these issues and provide insight into how to prevent these errors from occurring.

ALIASING, BANE OF SAMPLED DATA SYSTEMS

Since the advent of sampled data acquisition systems, aliasing has been an ever present problem due to under sampling input signals. Based on the sampling theorem, sampled data instruments such as digitizers and digital oscilloscopes require that analog signals be sampled at greater than two times the highest frequency component present at the input. If this criteria is not met, aliasing can result. Current digitizer designs generally incorporate sampling rates that are greatly in excess of analog bandwidth. By combining this with long acquisition memories, these digitizers minimize this classic problem. Still, users should be aware of aliasing.



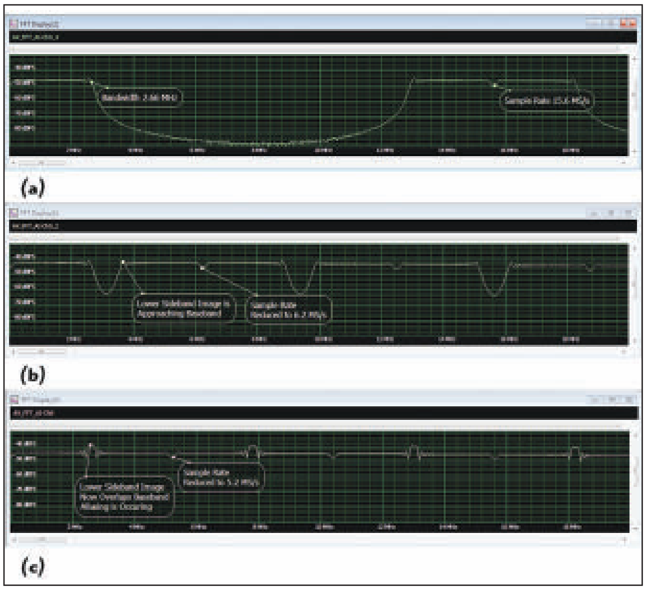
▲ *Fig. 1 A 33 MHz sine wave sampled at 500 Msps and 31.25 Msps. The properly sampled signal reflects a frequency of 33 MHz, while the signal sampled at 31.25 Msps is aliased and shows an incorrect frequency of 1.75 MHz.*

Sampled data systems sample the input signals and store the resulting numeric data. If the sample rate meets or exceeds the rule of the sampling theorem, then the signal can be reconstructed without loss of any information. If the analog input waveform is sampled at less than twice its maximum frequency, then the resulting reconstruction of the digital samples results in a waveform at a frequency lower than the original. An example is shown in ***Figure 1***.

The same effect can be seen in the frequency domain (see ***Figure 2***), where the input signal is a sine sweep with a maximum frequency of 2.66 MHz. Sampling is a mixing process that results in the baseband signal (0 to 2.66 MHz) being duplicated about multiples of the sampling frequency. ***Figure 2a*** shows the input signal sampled at 15.6 Msps, where the baseband signal appears on the left. The baseband region is duplicated as upper and lower sideband images about the marked 15.6 MHz sample frequency. As the sampling rate is decreased to 6.2 MHz (see ***Figure 2b***), the lower sideband image approaches the baseband signal. ***Figure 2c*** shows the spectrum when the

sample rate has been reduced to the Nyquist limit (twice the maximum input frequency or 5.2 Msps). At this sampling frequency, the lower sideband image about the sampling frequency interferes with the baseband signal, and aliasing has occurred.

Aliasing generally results in a waveform with a lower frequency than the original signal. It is good practice to know the frequency of the measured signal and then verify it to ensure that it has not been aliased. If the digitizer is triggered from the input signal, then an aliased signal will also appear unstable. This occurs because the digitizer is triggered on the signal and the alias, being at a lower frequency, has multiple trigger points, causing the instability. It is a good procedure to view all unknown signals at the highest sample rate available and then to decrease the sampling rate, if required. If aliasing occurs, the frequency of the signal drop will decrease when a lower sampling rate is selected.



▲ *Fig. 2 A frequency domain view of a sampled signal, where the sampling rate is well above the Nyquist frequency (a) and approaching the Nyquist frequency (b). Aliasing occurs when the sampling rate is below the Nyquist frequency (c).*

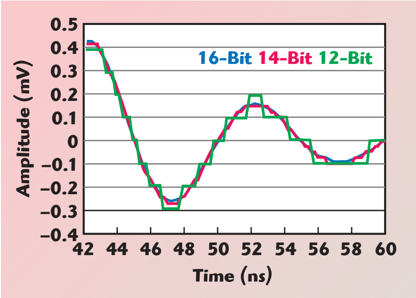
INSUFFICIENT AMPLITUDE RESOLUTION

Digitizers convert the samples of an analog signal into digital values using analog-to-digital converters (ADC). The resolution of the ADC is the number of bits it uses to digitize the input samples. For an n-bit ADC, the number of discrete digital levels that can be produced is 2^n. Thus, a 12-bit digitizer can resolve 2^{12} or 4096 levels. The least significant bit (LSB) represents the smallest interval that can be detected; in the case of a 12-bit digitizer, the LSB is 1/4096 or 2.4×10^{-4}. To convert the LSB into a voltage, the input range of the digitizer is divided by 2^n.

Resolution determines the precision of a measurement; the greater the digitizer resolution, the more precise the measurement values. A digitizer with an 8-bit ADC divides the vertical range of the input amplifier into 256 discrete levels. With a vertical range of 1 V, the 8-bit ADC cannot ideally resolve voltage differences smaller than 3.91 mV, while a 16-bit ADC digitizer with 65,536 discrete levels can resolve voltage differences as small as 15.2 μV.

One reason to use a high resolution digitizer is to measure small signals. Based on the way the minimum voltage level is computed, a lower resolution instrument and a smaller full-scale range can be used to measure smaller voltages. However, many signals contain both small-signal and large-signal components. Thus, for signals with both large and small voltage components, a high resolution instrument with a large dynamic range and a digitizer able to measure small signals and large ones simultaneously is needed.

Figure 3 illustrates how a waveform would look if passed through digitizers with different resolutions, comparing ideal 12-, 14- and 16-bit digitizer responses to a segment of a ±200 mV damped sine waveform. The segment selected is near the end of the waveform and has small amplitude. The 14- and 16-bit digitizers still have sufficient resolution to render the signal accurately. The 12-bit digi-



▲ *Fig. 3 A comparison showing how digitizer resolution affects measurement fidelity.*

tizer, with 100 μV resolution (based on a full-scale level of ±200 mV) is unable to resolve levels smaller than 100 μV. The error in reading, for any resolution, will increase with decreasing signal amplitude. This is an ideal case, and noise will limit the accuracy and precision in the real world.

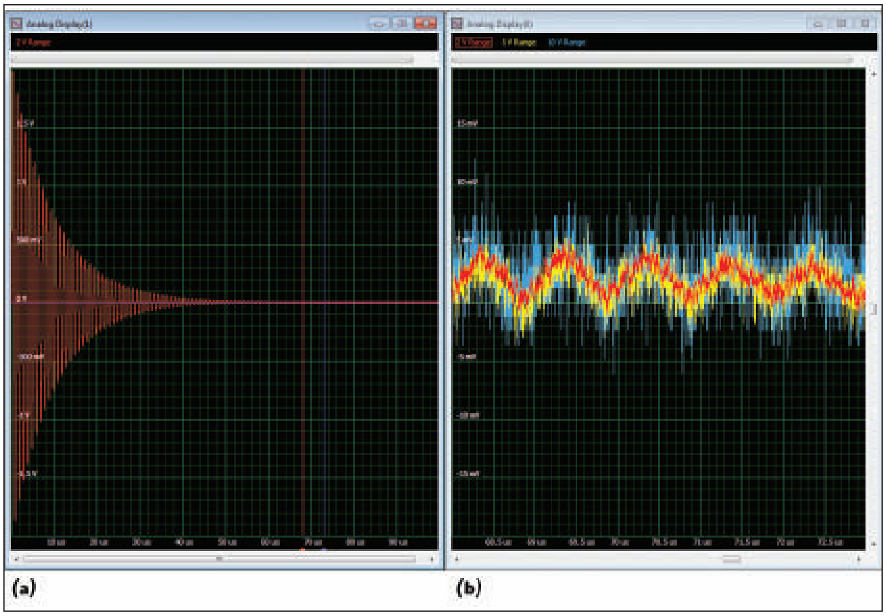
While signal processing tools like filtering and averaging can improve the resolution of a digitizer, it is still important to consider the dynamic range requirement of any measurement prior to selecting a digitizer; then select one with an appropriate resolution.

AMPLITUDE RANGE SELECTION

Quality modular digitizers offer a wide selection of input voltage ranges to accommodate multiple measurement scenarios. The general rule to follow in selecting an amplitude range is to have the signal span the greatest portion of the digitizer's full scale input range. If possible, aim for utilizing 90 to 95 percent of the available range. Doing so maximizes the available dynamic range and the signal-to-noise ratio. The most common problem is to use only a small percentage of the digitizer's dynamic range — having a signal with a ±2 V range and acquiring it with a range of ±5 V.

Consider the signals shown in ***Figure 4***. The input is a damped sine with a ±2 V range. It is acquired using the ±2, ±5 and ±10 V ranges. The full signal acquisition using the 2 V range is shown in ***Figure 4a***. A small section of the lower amplitude portion corresponding to the vertical red and blue cursor lines is expanded in ***Figure 4b***. The waveform acquired on the 2 V range (red trace) has the lowest noise level. The waveforms acquired on the 5 V (yellow) and 10 V (blue) ranges have higher noise levels.

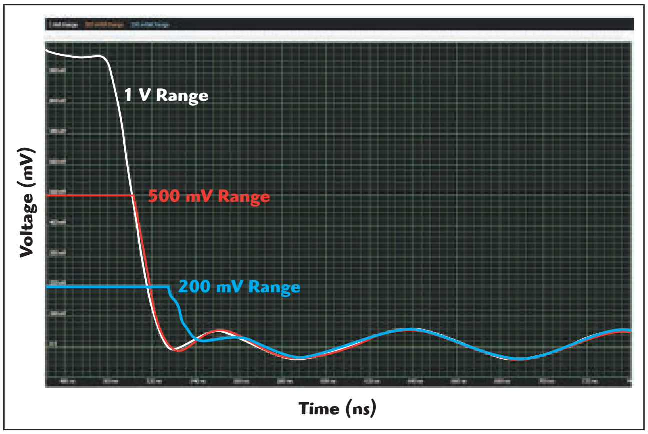
One issue that appears when attenuators are in the signal path is that the instrument's internal noise amplitude scales (relative to the input of the attenuator) with the front-end attenuation. For example, a 10:1 attenuator added to a digitizer with a 58 μV rms noise level has a noise level of 580 μV referenced to the input. The noise level is still the same relative to the percentage of the attenuated full-scale range; however, for a lower signal level – say 5 V on the 10 V range – using one half of the range reduces the dynamic range by 6 dB, and the signal to noise ratio has been decreased.



▲ *Fig. 4 Matching the digitizer's measurement range with the amplitude of the signal affects the noise of the measurement. Full waveform (a) and magnified low signal region (b).*

The other common setup issue is to acquire the signal on too low a range. If the signal exceeds the full scale range then clipping or limiting will result. If the overload exceeds the maximum voltage range for the digitizer, it may be damaged. Information will be missing in the overloaded areas, and this portion of the waveform is not useful. Some signal processing functions such as the fast Fourier transform (FFT) and digital filtering will produce incorrect results based on overloaded data. Sections of the waveform inside the range may be distorted depending on the overload recovery specifications of the digitizer.

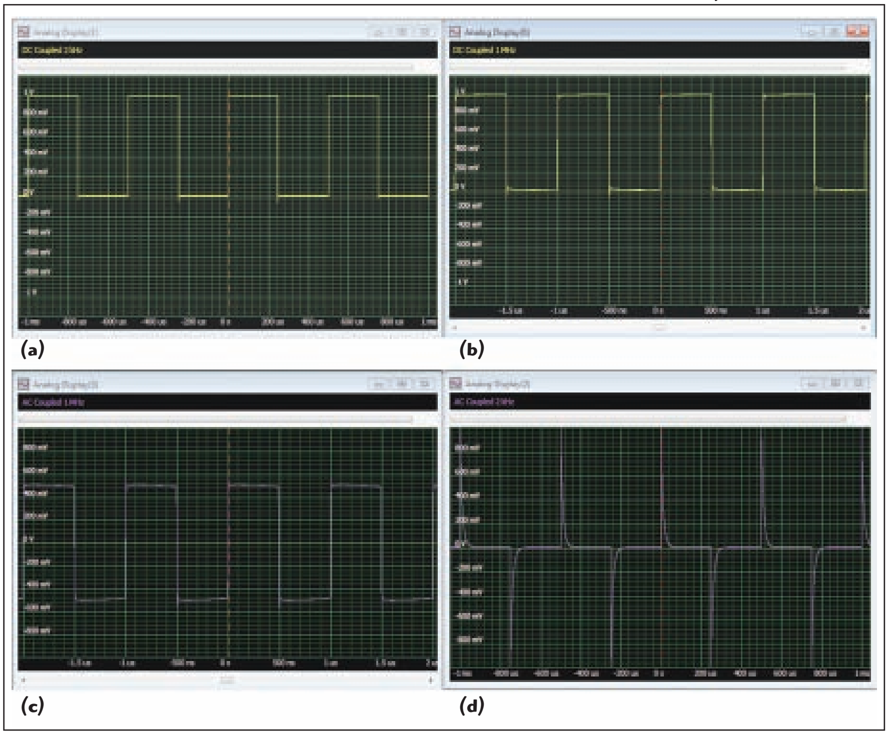
If using this technique to see small signals in the presence of larger ones, it is important to verify that the low level signals are not being distorted (see ***Figure 5***). This example shows a 1 V square wave with a 50 mV sine added to it. The digitizer response on the 1 V range is shown as a reference waveform (white trace). The response on the 500 mV range (red trace) shows a slight initial delay but quickly recovers in about 20 ns. When the input is overloaded by 5× (200 mV range, blue trace) the delay is initially about 10 ns with full recovery taking 70 ns. The measured waveform is distorted during the overload recovery time of the digitizer and the distortion depends on the degree of overload. It is better to use a digitizer with greater dynamic range and magnify the acquired signal using zoom than to overload the front end of the digitizer.



▲ *Fig. 5 Overloading the digitizer will impair measurement accuracy during the overload and until the instrument recovers.*

IMPROPER INPUT COUPLING

Input coupling in a digitizer offers the ability to AC or DC



▲ *Fig. 6 AC coupling will affect the signal integrity of waveforms with frequency components near or below the lower cutoff frequency (a) and (d), while AC coupling has little to no effect on much higher frequency signals (b) and (c).*

couple the instrument to the source. DC coupling shows the entire signal, including any DC offset (non-zero mean signals). AC coupling eliminates any steady state mean value (DC). AC coupling is useful for measurements such as ripple on the output of a DC power supply. Without the AC coupling, the DC output would require a large signal attenuation, which would make the ripple harder to measure accurately. With AC coupling, a higher input sensitivity can be used, resulting in a better measurement of the ripple component.

The key specification for AC coupling is its low frequency cutoff (-3 dB point) of the AC coupled frequency response. This determines how much a low frequency signal will be attenuated by the AC coupling. It also relates to the recovery time, the time it takes for the input level to settle after the DC level changes. Generally, the lower the cutoff frequency, the larger the coupling capacitor and the longer the settling time. Problems with AC coupling generally involve trying to measure signals which have low frequency components near or below the lower cutoff frequency of the digitizer's AC coupling. Consider two square wave input signals with non-zero mean values. One has a frequency of 2 kHz (see ***Figure 6a***), the other 1 MHz (see ***Figure 6b***). Both are applied to a digitizer's AC coupled input. The 1 MHz square wave has the DC offset removed when using AC coupling (see ***Figure 6c***). The 2 kHz square wave, which is below the 30 kHz cutoff frequency of the digitizer, is differentiated: the coupling circuit passes only the high frequency components, i.e., only the edges of the square wave (see ***Figure 6d***). As the signal frequency is increased, the effect of AC coupling is diminished. Frequencies near the lower cutoff exhibit "tilt," meaning the top of the square wave will tilt down and to the right.

It is important to know the lower cutoff frequency of the digitizer's AC coupling. The lower cutoff frequency of the digitizer using the 1 MΩ input termination is 2 Hz and this provides a better range of signal frequencies with good signal fidelity.

IMPROPER TERMINATION

A measuring instrument should terminate the source properly. For most RF measurements this is a 50 Ω termination. A matching termination minimizes signal losses due to reflections. The figures of merit for matching are return loss or voltage standing wave ratio (VSWR). Either of these indicates the quality of the impedance match. If the source device has a high output impedance then it is more properly matched with a 1 MΩ high impedance termination, which minimizes circuit loading. The 1 MΩ termination also allows the use of high impedance oscilloscope probes, which further increase the load impedance. Impedance matching to other standard terminations, like 75 Ω for video or 600 Ω for audio, can be accomplished by using a 1 MΩ termination combined with a suitable external termination.

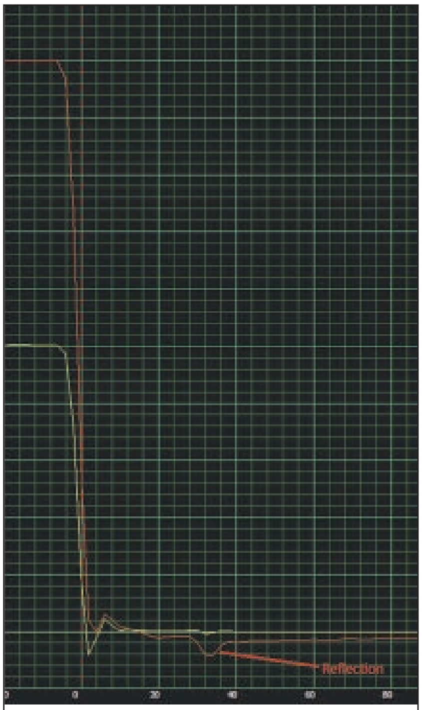
Choosing an incorrect termination can cause some interesting effects, as shown in ***Figure 7***. The source for this example is an arbitrary waveform

generator (AWG) with a 50 Ω output impedance. When the 50 Ω termination (yellow trace) is selected on the digitizer, the input shows a step voltage going from 1 V down to 0 V. This is the signal amplitude selected in the AWG. When the 1 MΩ termination is selected (red trace), the amplitude doubles (as expected from an unterminated 50 Ω source), with a reflection 32 ns after the negative step. This reflection is due to the mismatch at the digitizer side of the test setup. Selecting the 1 MΩ termination caused two signal integrity errors, which, if observed by an inexperienced engineer, might cause needless troubleshooting. It is best to always terminate the signal being measured with the correct load impedance.

TRIGGER SETUP

Triggering is an essential function for any instrument that acquires and digitizes signals. The most common trigger method uses the signal that is input into one of the digitizer's channels. The basic principle is that a defined point on the waveform is detected, and this "trigger event" is marked as a known position on the acquired data. The function of triggering is to link the time measurements to a known point in time. For repetitive signals, the trigger must be stable to enable measurements from one acquisition to be compared with others. The wide variation in possible signal waveforms, levels and timing requires that the digitizer's trigger circuit be extremely flexible. The principal trigger input sources contain dual trigger level comparators and support multiple trigger modes. All modern digitizers include single and dual slope edge triggers, rearm (hysteresis) triggers, window triggers and, for the multiple source trigger, there are related trigger gate generators.

Given the large number of possible trigger modes and settings, it is often difficult to select a good trigger strategy. The most common problems are using the incorrect trigger level and failing to deal with multiple trigger events in a waveform. Both of these issues can be dealt with by actually looking at the trigger signal. Software can aid trigger setup by allowing users to see the trigger levels overlaid on top of the trigger waveform.



▲ *Fig. 7 Improper matching of digitizer and system impedances can yield measurement artifacts.*

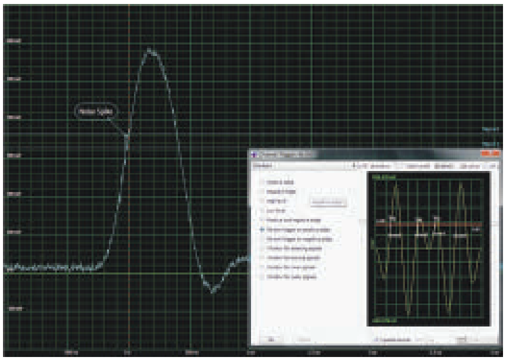


Fig. 8 The choice of trigger is essential for accurate and stable measurements of noisy signals.

Viewing the trigger source waveform facilitates selection of the proper trigger levels. A descriptive pop-up window explaining the trigger setup in detail is shown in ***Figure 8***. In this example, a positive rearm or hysteresis trigger mode is being used, as the trigger source is a noisy pulse waveform. The goal is to trigger the digitizer on the signal while minimizing the effects of the noise. There are two trigger levels in this trigger mode: the first (TrigLvl1) arms or enables the trigger; the second (TrigLvl0) will trigger the digitizer acquisition when the waveform exceeds this level with a positive slope. This is explained in the channel trigger pop-up shown in the figure. The rearm trigger is used to trigger reliably in the presence of noise. The difference between the two trigger levels is the trigger hysteresis, which is set to be

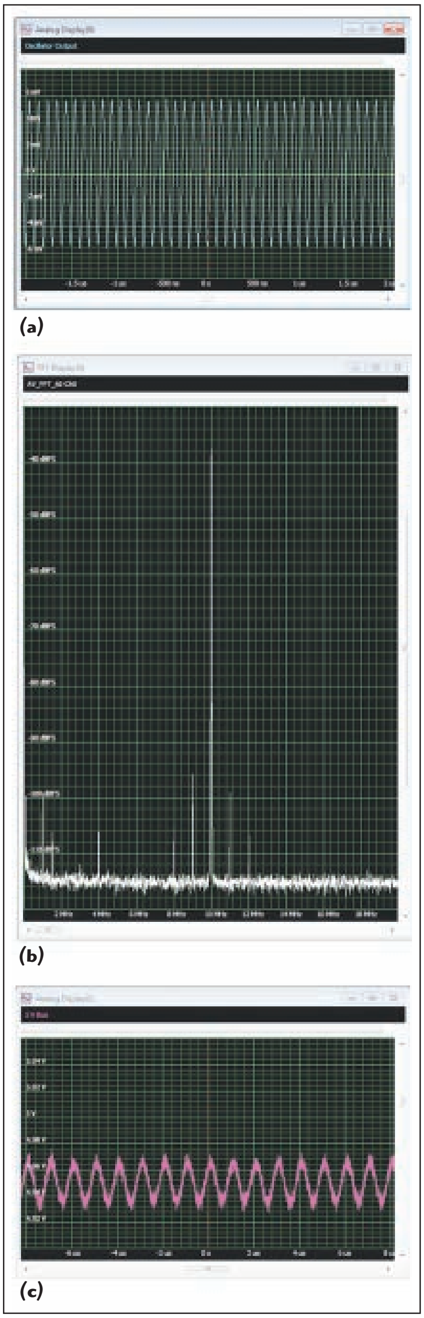
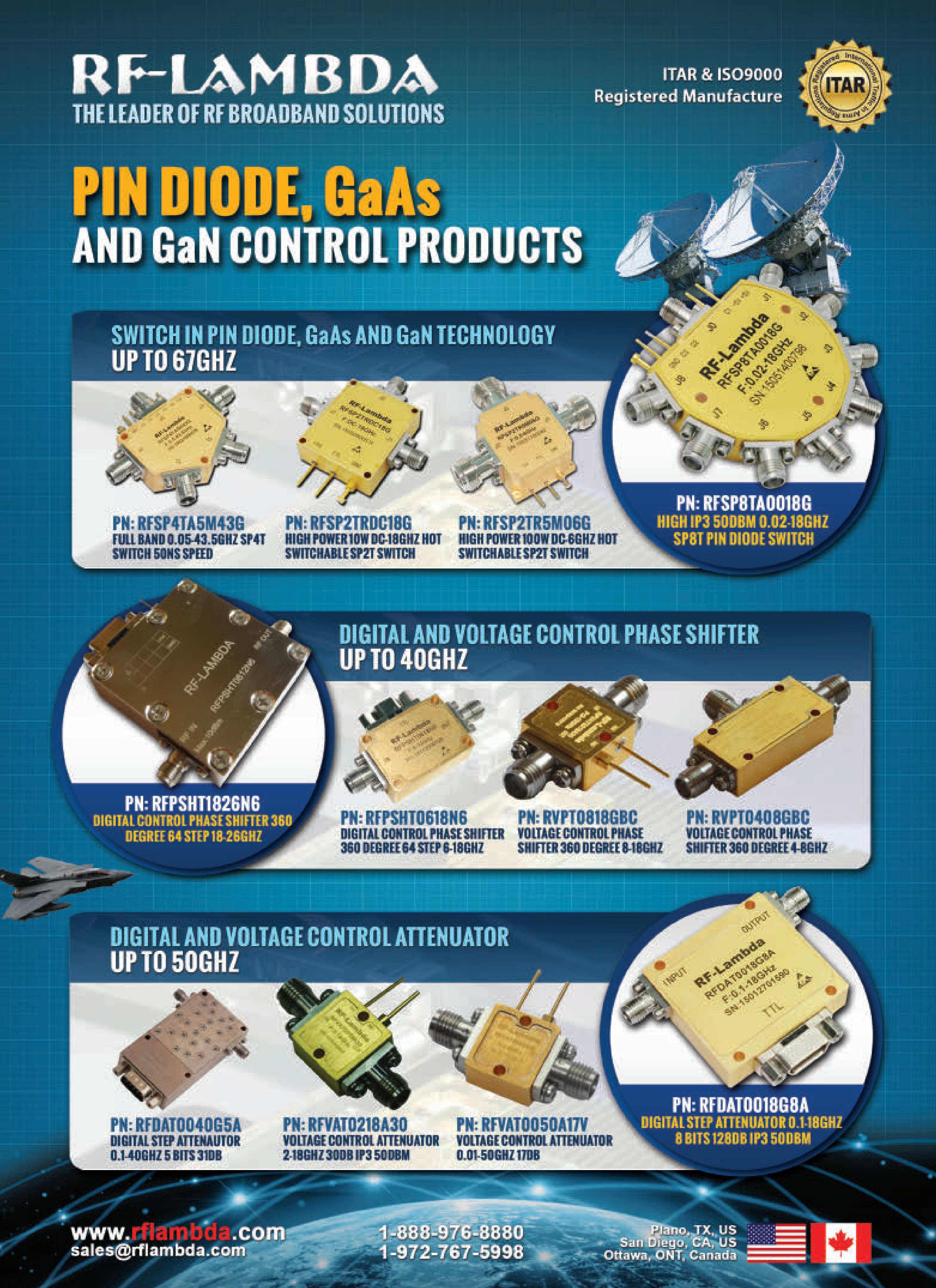


Fig. 9 A 10 MHz oscillator (a) contains an unwanted 1 MHz signal (b) from the 5 V power bus (c).



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UP TO 40GHZ
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PN: RFPSHT0618N6
DIGITAL CONTROL PHASE SHIFTER 360 DEGREE 64 STEP 6-18GHZ
PN: RVPT0818GBC
VOLTAGE CONTROL PHASE SHIFTER 360 DEGREE 8-18GHZ
PN: RVPT0408GBC
VOLTAGE CONTROL PHASE SHIFTER 360 DEGREE 4-8GHZ
DIGITAL AND VOLTAGE CONTROL ATTENUATOR
UP TO 50GHZ
OUTPUT
INPUT
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SN:15012701590
TTL
PN: RFDAT0040G5A
DIGITAL STEP ATTENAUTOR 0.1-40GHZ 5 BITS 31DB
PN: RFVAT0218A30
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greater than the typical noise spikes on the waveform. In this case, the digitizer ignores the noise spike between the arm and trigger levels. The digitizer trigger was armed on the lower trigger level but the noise spike amplitude did not exceed the hysteresis, so the digitizer triggered when the waveform resumed its rise.

NOISE AND INTERFERENCE

High resolution modular digitizers are designed to minimize internal noise and, because of their large dynamic range, it is important to make sure that extraneous noise and interfering signals do not contaminate the measurements. Interfering signals can be coupled into measurements via either conducted or radiated signal paths.

Conducted noise is most generally due to ground loops in which two or more circuit elements are referenced to different grounds. Proper grounding is essential for accurate measurements. Most commonly, ground loops induce 50 or 60 Hz and related harmonics into a system. These can sometimes be filtered out, but it is better to avoid them if possible. Other conducted paths include spurious signals coupled from power buses. An example of this type of interference is shown in ***Figure 9***, using the output of a 10 MHz oscillator (see ***Figure 9a***). The FFT of the oscillator output (see ***Figure 9b***) shows sidebands spaced at 1 MHz intervals from the 10 MHz carrier, indicating that the oscillator output is being modulated by a 1 MHz source. The 5 V power bus which feeds the oscillator has a 1 MHz ripple with an amplitude of 40 mV peak-to-peak (see ***Figure 9c***), confirming the source of the 1 MHz modulation on the oscillator output.

Radiated noise can be from capacitive, inductive or RF coupling. Interference is "broadcast" from a source directly into the wiring of the circuit under test. The effects of this interference depend on the nature of the coupling and the circuit structure. External noise and interference are not digitizer issues; however, users should be aware that the measurement setup can contribute to uncertainty in the measurement.

CONCLUSION

Many techniques are useful for reducing noise and spurious pickup in a measurement system. Summarizing the most useful:

- Use low impedance terminations (50 Ω)
- Use the minimum bandwidth necessary for accurate measurements
- Use shielded cables connected to a low noise ground at one end, preferably at the measuring device end
- Use differential cables and digitizers with differential inputs for low speed signals
- Keep radiating sources as far from the circuit under test
- Use magnetic shielding to reduce inductive pickup near motors and other electromagnetic devices
- Ground all measuring instruments to a common, low noise ground
- Use high quality, low loss cables
- Secure cables so that they cannot move or vibrate, to reduce "triboelectric" generation.
- Properly filter all power connections in the circuit under test.

Note: The measured data for the examples in this article were obtained with a Spectrum 14-bit, 500 Msps digitizer. Screenshots were taken using Spectrum's SBench 6 software. ■

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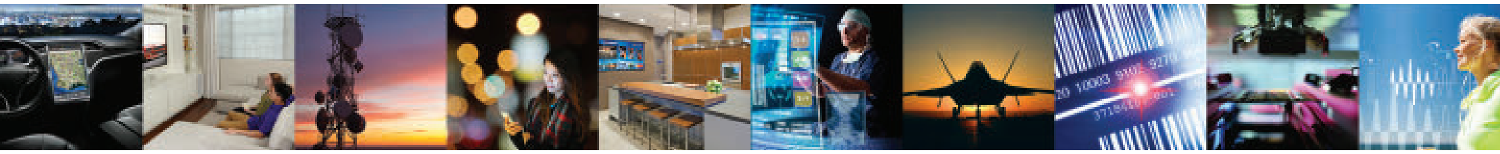

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INVITED PAPER

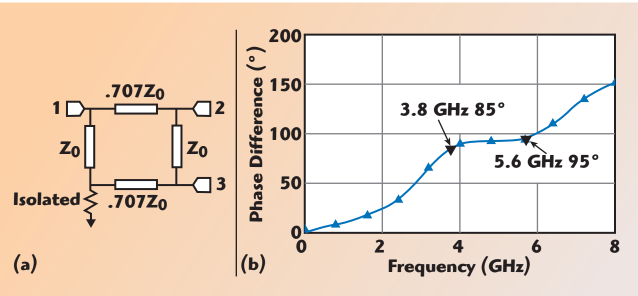
Implementing I/Q, Single Sideband and Image Reject Mixers

Marki Microwave
Morgan Hill, Calif.

In "An Introduction to Passive I/Q, Single Sideband and Image Reject Mixers," published in the December 2015 issue of Microwave Journal*, we highlighted the difficulty in maintaining high performance over a broad bandwidth in these special mixers. High performance requires precise amplitude and phase balance over the bandwidth of operation. Any imperfection in the phase balance of the LO or the amplitude or phase balance of the I/Q channels will lead to imperfect sideband cancellation in a single sideband (SSB) or image reject (IR) mixer or imperfect rejection of the unwanted channel in an I/Q mixer. Maintaining this balance is the subject of ongoing research and development. In this article, we review the state-of-the-art in quadrature phase shift generation. We will also discuss techniques to compensate for inevitable imperfections in quadrature signal generation and combination.*

The following approaches to creating a quadrature phase shift are discussed, listed from worst to best and judged by the following characteristics:

- Achievable balance over the bandwidth
- Size and achievability in planar or integrated forms
- Suitability for data (i.e., on the RF/IF port in addition to the LO port)
- Insertion loss, isolation and power handling
- Difficulty and cost to implement.



▲ *Fig. 1 Branchline coupler schematic (a) and phase response (b).*

POWER SPLIT WITH DELAY LINE

Easy to implement but extremely narrowband, this is the trivial case where you simply pass the signal through a power divider and then time delay one side. For any application with a fixed frequency LO, this is a straightforward way to obtain a very accurate 90 degree phase differential, especially if you can tune the delay. It works only at a single frequency, so it is unsuitable for data, yet great for a single frequency LO.

BRANCHLINE COUPLER

Slightly broader band and easy to implement in a planar microstrip circuit, the basic branchline coupler consists of four quarter-wave microstrip sections arranged in a square ring, with different impedances on adjacent sides (see ***Figure 1***). This can theoretically provide perfect quadrature phase, but only over a small bandwidth. The single stage coupler has a 33 percent bandwidth with a 5 degree phase difference (see ***Figure 1b***). This performance

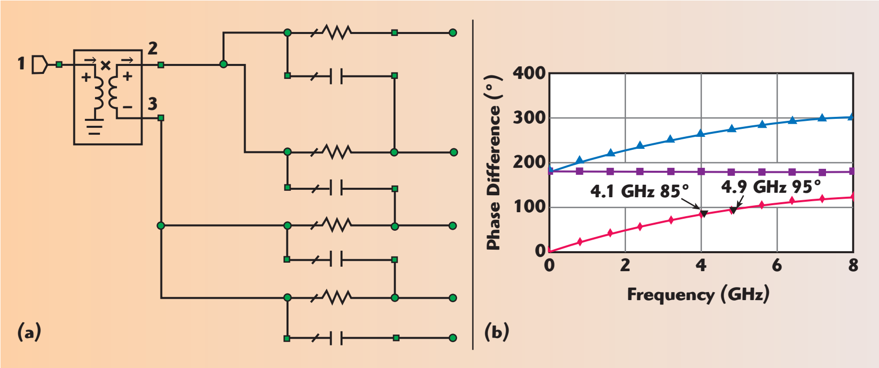


Fig. 2 Polyphase filter quadrature splitter schematic (a) and single stage phase response (b).

is adequate for many communications applications as it can pass narrowband data with high power.

SCHIFFMAN PHASE SHIFTER

The Schiffman phase shifter is an unconventional but powerful technique for some applications. It applies a broadband 90 degree phase shift (not a time shift) to one signal, while another signal is passed through a matched time delay. It can provide multi-octave bandwidths with some difficulty and has a high power handling capability. It works for LO signals and IF/RF data as well. It is somewhat esoteric and can be challenging to design.

POLYPHASE FILTER QUADRATURE SPLITTER

This quadrature phase splitter makes the list for one significant reason: it is probably the most ubiquitous quadrature splitter on the planet. CMOS chip makers frequently tie polyphase splitters with Gilbert cell mixers to create billions of inexpensive I/Q modulators for cellular and Wi-Fi applications (see ***Figure 2***). They are perfect for CMOS implementation because they use lumped elements, have differential inputs and occupy a small area; however, the high loss and frequency limitations of CMOS circuits make them unsuitable for microwave applications.

The polyphase filter is fairly complicated (see ***Figure 2a***), yet because of its popularity, there is a tremendous amount of information available about both analog and digital forms. One major drawback is loss. In addition to the 6 dB splitting loss (for a four-way split), a single stage polyphase filter has about 4 dB of additional loss while creating only a narrowband quadrature signal

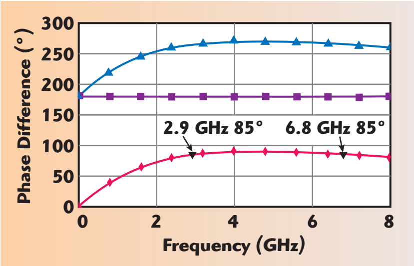


Fig. 3 Two stage polyphase splitter phase response.

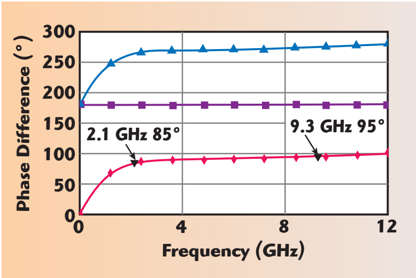


Fig. 4 Three stage polyphase splitter phase response.

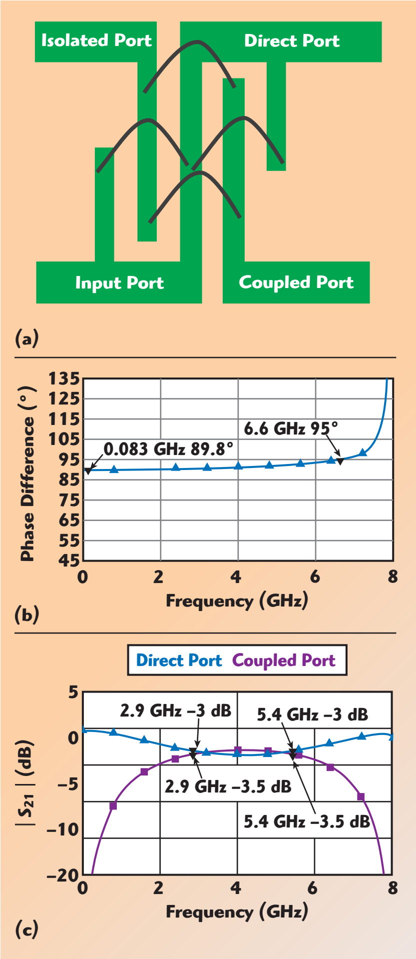
(see ***Figure 2b***). Bandwidth can be improved by adding a second stage (see ***Figure 3***) and a third stage (see ***Figure 4***) to create a very broadband phase shift; however, the cost is that each stage adds another 3 to 4 dB of insertion loss. The broadband three stage phase shifter has over 10 dB of insertion loss in addition to the 6 dB splitting loss.

LANGE COUPLER

Due to the Lange coupler's quasi-planar nature, it is the most common device used with balanced MMICs such as amplifiers and I/Q mixers. The fundamental problem with planar couplers is that edge-coupled microstrip lines are very weakly coupled unless the gap between them is very small. This is limited by the fabrication tolerances of the process, so 3 dB couplers are difficult to realize. Lange couplers solve this problem by using wire bonds or air bridges to connect

different fingers of an interdigitated coupling structure (see ***Figure 5***).

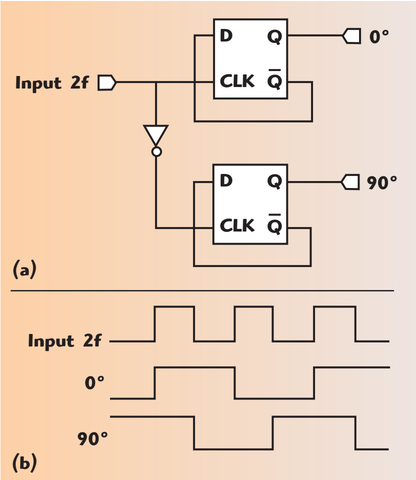
The four finger Lange coupler shown in ***Figure 5a*** has very good phase and amplitude balance and low insertion loss and covers slightly more than an octave bandwidth. Amplitude balance can be improved by adding more fingers, but this comes at the expense of phase balance. Overall, the Lange coupler is an excellent choice, especially for a quasi two-dimensional structure. It can be used for a broadband LO signal or RF/IF data, can be cheaply printed onto a MMIC or other planar circuit and is relatively easy to design. The only major drawbacks are lower power handling, due to its wire bonds or air bridges, and slightly less bandwidth than the previous two options.



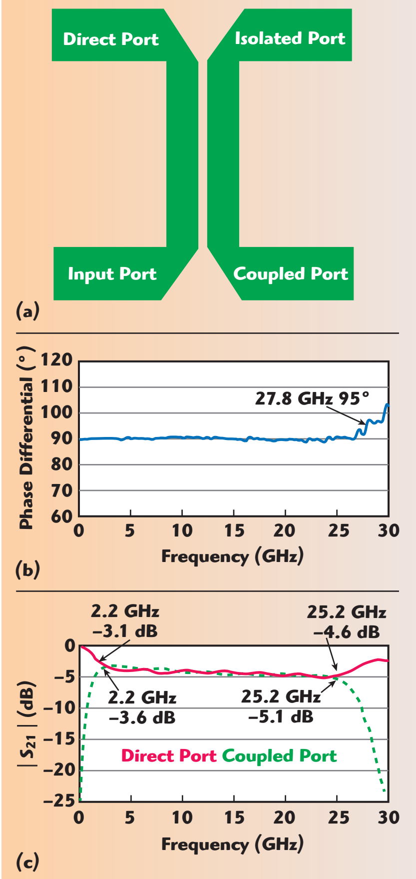
▲ *Fig. 5 Lange coupler layout (a) phase response (b) and insertion loss (c).*

DIGITAL FREQUENCY DIVIDER

For a perfect quadrature ultra-broadband phase shift, it is difficult to beat a digital frequency divider. The digital circuit is very simple: it just takes a double rate clock and switches one output on the rising edge and one on the falling edge, resulting in two outputs in quadrature with each other. It is implemented with two D



▲ *Fig. 6 Digital frequency divider schematic (a) and phase response (b).*



▲ *Fig. 7 3 dB quadrature hybrid coupler layout (a) phase response (b) and insertion loss (c).*

flip-flops, with the inverted signal connected to the input of one (also called a T flip-flop) as shown in ***Figure 6***. Since it is fabricated in fast, differential SiGe, it can provide all four phases of the output signal from DC to as high as 30 GHz. In addition to needing a double rate clock, there are a few other drawbacks. Since the circuit is limiting, it is not suitable for analog inputs, so it cannot be used as the IF hybrid in an IR/SSB mixer. If there is any amplitude noise, duty cycle distortion or amplitude distortion on the input, it will show up as phase noise or distortion on the output.

In general, this is not a very good device as a quadrature splitter, but it is perfect for creating a quadrature LO drive for an I/Q mixer. This is what is frequently used in low frequency silicon RFICs for LO clock generation, which means it is also ubiquitous.

3 DB QUADRATURE HYBRID COUPLER

The 3 dB quadrature hybrid coupler is the "gold standard" for quadrature signal generation. It can operate across a broad bandwidth (e.g., 2 to 26 GHz), has excellent balance in both amplitude and phase and can be used as the RF or IF hybrid of an image reject or single sideband mixer for better than 20 dB of rejection. Ideally, it is built in a tri-plate stripline construction, which has the physical advantage of matching the dielectric constant around the circuit while handling 20 W or more of CW power. ***Figure 7*** shows the basic coupler layout, along with the phase deviation and loss performance that can be achieved.

All stripline directional couplers can provide a 90 degree phase shift, but it is difficult to achieve strong enough coupling to create the 3 dB split necessary for amplitude balance.

TABLE 1

ADVANTAGES AND DISADVANTAGES OF QUADRATURE GENERATION TECHNIQUES

Structure	Bandwidth	Suitable for RF/IF Data	Size and Planar Integration	Insertion Loss	Power Handling	Isolation	Difficulty to Design	Cost
Power Split/ Delay Line	Single Frequency	No	Medium, Possibly Planar	Low	High	No	Very Low	Moderate
Branchline Coupler	Narrow	Yes	Medium, Possibly Planar	Low	High	Yes	Low	Moderate
Schiffman Phase Shifter	Multi-Octave	Yes	Large, Not Planar	Moderate	High	Depends on Power Divider	Very High	Very High
Polyphase Filter	Narrow	Yes	Small and Planar	Very High	Very Low	Depends on Power Divider	Low	Very Low
Lange Coupler	Octave	Yes	Medium, Quasi-Planar	Moderate	Moderate	Yes	Moderate	Low
Digital Frequency Divider	Ultra-Broadband	No	Very Small and Planar	N/A	N/A	N/A	Low	Very Low
3 dB Quadrature Coupler	Multi-Octave	Yes	Very Difficult in Planar	Moderate	High	Yes	High	High

Integration requires broadside coupling for a high coupling coefficient in a system with good dielectric properties. The combination of stringent materials requirements and high design difficulty have limited their realization in a multi-octave planar form to just the Microlithic[1] series of mixers.

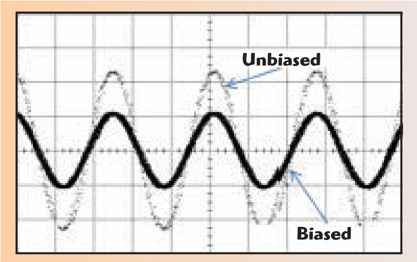
Table 1 summarizes the advantages and disadvantages of the quadrature generation techniques discussed.

COMPENSATING FOR I/Q-SSB-IR IMBALANCE

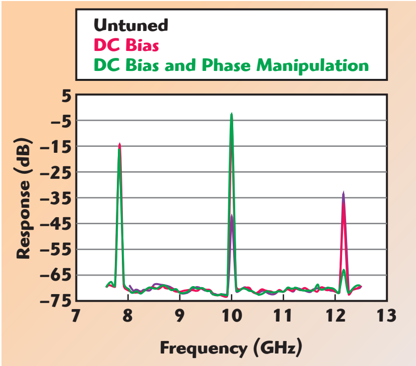
Unfortunately, even the best quadrature phase shift achievable will always have some imperfections due to fabrication tolerances, design limitations, material variability over temperature and aging over time. Fortunately, any imbalance in the LO phase of an I/Q-SSB-IR mixer can be compensated on the IF side, and vice versa. What follows is a description of several techniques, beyond component design and selection, that are commonly employed to overcome these limitations.

DC OFFSETS

The application of a DC voltage to the IF port of a double balanced mixer changes the bias conditions of the diode rings inside. Specifically, two of the diodes turn on at a higher voltage, and two of them turn off at a higher voltage. ***Figure 8*** shows an oscilloscope screenshot of the output of a microwave double balanced mixer with no DC bias and with +0.5 V applied. The DC voltage degrades conversion loss without changing the phase, allowing easy variation of amplitude balance on one side of an IQ mixer.[2]



▲ *Fig. 8 Double balanced mixer output when biased and unbiased.*



▲ *Fig. 9 Trade-off between sideband and LO suppression.*

Unfortunately there is a trade-off. The application of a DC voltage also degrades LO-to-RF isolation; as sideband suppression is improved, LO suppression is reduced. Since the LO is always closer than the unwanted sideband, this generally doesn't make sense for a single sideband mixer. With the mixer shown in ***Figure 9***, sideband suppression is increased from about 19 to 23 dB by adding an offset voltage, then again to approximately 50 dB by combining phase manipulation with the DC offset. The penalty is increasing LO feedthrough from -30 to -3 dBm, overpowering even the desired sideband. This technique can be used without penalty for image reject mixers, however, since the LO is out of the band of the IF output. If phase balance is much better than amplitude balance, to begin with, then this technique can yield improvement. In most situations, the benefits will be quite limited, however.

LO PHASE MANIPULATION

The error terms for sideband elimination are all dependent on φ and ε, meaning that the LO phase can be manipulated to completely eliminate the erroneous sideband. This can be done without the penalty to LO feedthrough that comes with DC biasing, since the phase of the incoming LO does not affect LO to RF isolation. The problem, however, is that this cannot always be done in a convenient manner. If the I/Q mixer is built as a bolt-together solution, then the phase can be manipulated by varying line lengths or using a phase trimmer. If the I/Q mixer is integrated, however, it is more difficult. For a mixer in a planar integrated form,[3] LO phase can be trimmed by applying ceramic, absorber or other microwave tuning elements while observing the sideband suppression.

ADC/DAC PHASE AND AMPLITUDE CORRECTION REGISTERS

This is the predominant approach for analog I/Q compensation (see ***Fig-***

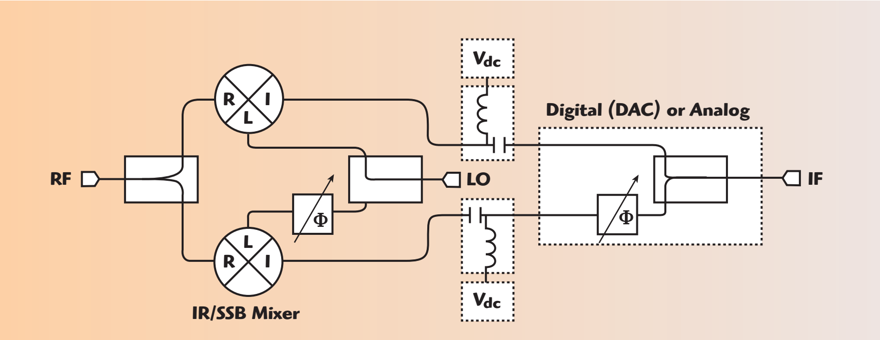


Fig. 10 ADC/DAC phase and amplitude correction.

ure 10). Amplitude and offset correction registers are generally built into DACs that are designed for communications, arbitrary waveform generation and software defined radios. This makes them readily accessible for IF amplitude and phase manipulation. The phase can also be manipulated in digital implementations. Since the amplitude and phase terms are sufficient to completely eliminate the sideband error terms, the only limit to the achievable sideband suppression is the quantization noise of the DAC and the time, temperature and frequency variations between the calibration point and the transmitted signal.

Some ADCs are also designed to receive I/Q data and perform another down-conversion, particularly those intended for software defined radios. The phase control in these ADCs may be performed on the internal oscillator. For more information, one can consult the (usually very detailed) datasheet of a dual channel high speed ADC.

DIGITAL COMPENSATION

This is the ultimate in I/Q compensation techniques. As we have seen with fiber optic links, wireless links and other modern data standards, it is easier and less expensive to use millions of transistors to digitally compensate for a bad signal than to create the analog channel necessary for a good signal. Any deterministic impairment can be pre- or post-compensated, and sideband suppression is definitely deterministic. The basic approach for sideband suppression is to simply receive both I and Q channels, estimate the distortion coming from the Q channel to the I channel and then subtract this estimate from the I channel.

There are numerous methods to perform this digital compensation with different cost tradeoffs. For example, some techniques are "blind," meaning they do not require a separate receiver to estimate the error vector magnitude; some require training sequences, while others do not; and some are capable of compensating for errors in addition to I/Q imbalance, such as fading and DC offset. There are many references on this topic, including several books. Most contain dense math and advanced digital signal processing algorithms. One excellent resource is Marcus Windisch's thesis,[4] in particular Chapter 4.

CONCLUSION

This article covered two topics central to the design and performance of passive I/Q, single sideband and image reject mixers: quadrature signal generation and compensation of amplitude and phase imbalance. Several ways to generate quadrature signals were described, with the 3 dB hybrid coupler demonstrating the greatest capability. It is broadband, has excellent amplitude and phase balance and can be used as the IF hybrid of an image reject or single sideband mixer to obtain high rejection. What the future holds for high performance I/Q-SSB-IR mixers is uncertain; it is likely to lean heavily on digital LO generation and digital compensation techniques. ■

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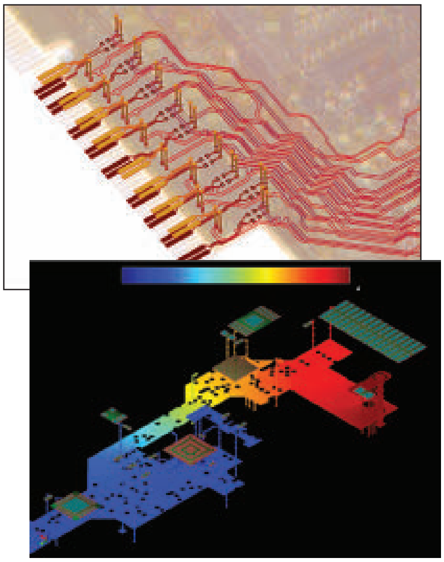
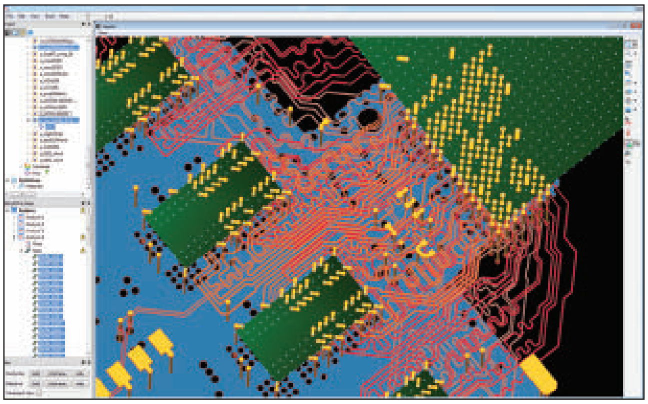


Redefining Signal and Power Integrity Analysis with ADS SIPro and PIPro Solutions

Keysight Technologies Inc.
Santa Rosa, Calif.

Design engineers face an incredible array of challenges to deliver multi-gigabit data rates for high performance consumer products, network infrastructure and devices that have become so commonplace. Savvy consumers expect that these devices and systems will work as promised. Making that possible, however, requires reliable high speed links. That means engineers have to perform a remarkable number of signal integrity (SI) and power integrity (PI) simulations and analyses, often as two separate design tasks. Keysight Technologies recently introduced two innovative technologies in the newest version of its Advanced Design System (ADS) electronic design automation software — ADS 2016 — that have redefined SI and PI analysis, by creating a cohesive workflow for both tasks that delivers higher accuracy and faster results (see ***Figure 1***).



▲ *Fig. 1 The newest version of ADS includes SIPro and PIPro, which provide a cohesive workflow in one environment.*

SI and PI are critical contributors to the quality and reliability of devices and systems. Engineers who don't accurately simulate and analyze their designs may fail to identify and address problems early and risk their devices and systems not performing as expected in the field. Many hours troubleshooting an intermittent problem on the bench, trying to find the root cause, could easily have been identified by simulation. Crosstalk and stub resonances are usual suspects.

The challenge is that while SI and PI are closely interrelated design tasks with the same end goal — to ensure high speed link performance and system-level reliability — they are typically treated as separate design tasks. Usually they are performed using separate, general-purpose electromagnetic (EM) design tools, possibly from different simulation vendors. The key disadvantage of this approach, beyond the sheer cost of each point tool, is that the design engineer has to learn two different interfaces. During the design process, the engineer must switch back and forth between the tools, a time consuming and error-prone process. Because

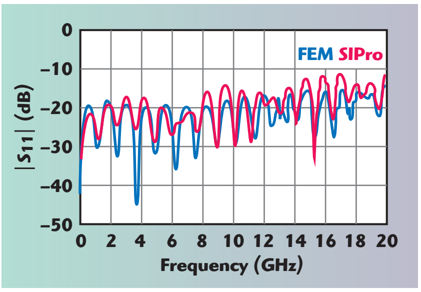
the two analyses may be performed by different engineers using different tools, collaboration is difficult at best. A further complication — engineers typically have to spend hours manually simplifying or reducing the size of their designs, since general-purpose EM tools have limited capacity and speed. Often, this is accomplished through a slow and cumbersome process of "cookie cutting" and removing layers and nets.

FASTER AND MORE ACCURATE

Unlike today's general-purpose EM design tools, ADS's new SIPro and PIPro solutions are specifically designed to help SI and PI engineers improve high speed link performance in printed circuit board (PCB) designs. SIPro focuses on enabling full EM analysis and model extraction for high speed links on large, complex PCBs. PIPro is used for full EM analysis of power distribution networks (PDN), including DC IR drop, AC PDN impedance and power plane resonance analysis. Both solutions are utilized within the ADS environment and deliver faster results than general purpose EM tools, while maintaining high accuracy.

SIPro utilizes a composite EM technology to ensure high frequency accuracy and the speed and capacity needed to analyze densely-routed, advanced PCB designs. Through simulation, engineers can characterize "all at once," i.e., the loss and coupling of signal nets, power nets and complete ground nets. Via-to-via coupling and via transition effects can also be characterized, and ground return paths, cut-outs and drills in ground/power planes are accurately modeled. The accurate, extracted EM model seamlessly flows into an ADS transient simulation and channel simulation for complete channel analysis. Since SIPro is based on a net-driven use model geared for SI and PI, it is much faster to set up and much more efficient than general-purpose EM tools. Because it leverages multiple EM technologies, it delivers accuracy approaching that of industry-standard 3D EM solvers — something that can be achieved in just a fraction of the time it would take to complete a full-wave 3D EM simulation. When compared to finite element method (FEM) simulation, the industry's gold standard, it demonstrates very good agreement at a small fraction of the time and memory consumption, even at high frequencies (see ***Figure 2***).

Like SIPro, PIPro is an EM-based solution. It provides accurate and efficient net-driven analysis utilizing three specialized simulation engines. A DC IR drop simulator provides a



▲ *Fig. 2 SIPro achieves accuracy approaching 3D EM solvers, yet in much less time. In this case, the 3D EM simulation took 12 min per frequency and consumed 8 GB of memory, while the SIPro analysis took 6 sec per frequency and required only 1 GB of memory.*

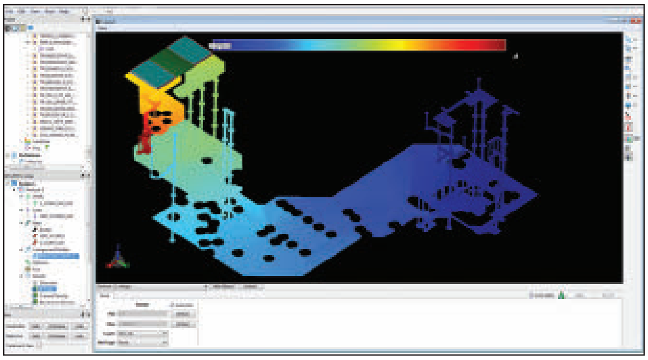


Fig. 3 PIPro provides 3D visualization of voltages, current density and power dissipation on the power and ground nets.

table of DC voltages and currents for each via, pin, sink and voltage regulator module in the PDN. Using this information, engineers can predict the DC voltage at the pins of the ICs sinking the current. A 3D visualization of the design's voltages, current density and power dissipation on the power and ground nets enables engineers to easily identify trouble spots in the PCB (see ***Figure 3***). With the AC PDN impedance simulator, the frequency dependency of the PDN can be calculated with decoupling capacitors (decaps) in place. After tuning decap values, the PDN impedance can be quickly re-analyzed without additional EM simulations. The resulting S-parameter model extraction of the PDN can be back-annotated to the schematic, along with circuit models of the components, to enable further tuning and optimization. Additionally, the simulator provides greater visibility into the PDN with its 3D field and current density plots. A power plane resonance simulator can be used to identify the PCB layout's self-resonant frequencies. It also helps engineers visualize the PCB's electric and magnetic fields to better understand where resonances are originating. Layout areas with the highest field strength can be further examined, aiding the placement of decaps.

COHESIVE WORKFLOW

A key benefit of ADS's new SIPro and PIPro solutions is that they share the same analysis environment, including a common GUI, workflow, model database and visualization results via a native 3D viewer. This allows engineers to visually inspect nets prior to simulation and view post-processed field visualizations in 3D; it also creates a cohesive workflow for both SI and PI design tasks (see ***Figure 4***). Rather than having to switch between point tools, engineers can now use a single user interface for both PI and SI analyses. One EM setup can be easily copied from one analysis to the other and vice versa, with simulations run in the same environment.

The setup itself is completely net driven. This allows engineers to select only those nets they want to simulate, with no engineering effort or time required to manually manipulate layout objects prior to simulation. With the

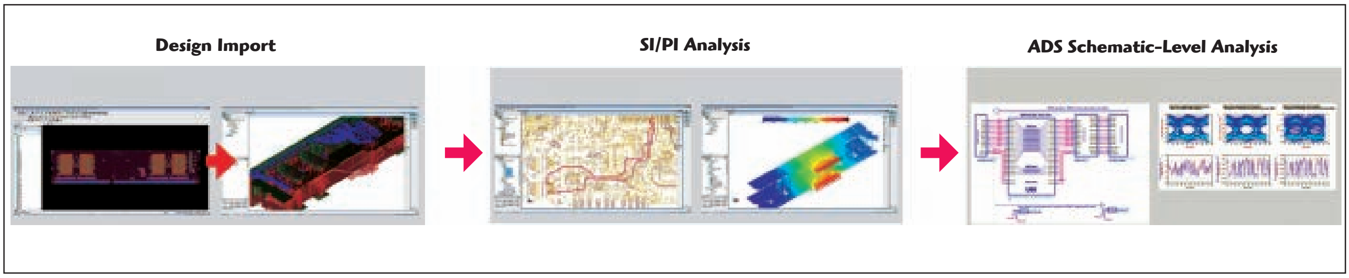


Fig. 4 ADS's new cohesive workflow redefines SI and PI analyses by eliminating the limitations from treating SI and PI as separate design tasks and using general-purpose EM tools for analysis.

high capacity EM solvers in SIPro and PIPro, engineers can tackle more nets at once. With ADS's cohesive new workflow, engineers can literally go from layout to results in less than 20 clicks. The workflow automatically generates schematics to prepare EM models for immediate use with ADS's channel, DDR bus and transient simulators. Using them, engineers can perform SI analyses (e.g., BER contour measurements) and complete design verification with standard-specific compliance test benches.

CONCLUSION

Accurate signal and power integrity analyses are critical to ensuring optimal high speed link performance in PCBs. While general-purpose EM tools can be used to accomplish these tasks, the process requires much more manual intervention and is not conducive to engineering collaboration. ADS's new SIPro and PIPro solutions overcome these limitations with powerful new EM technology that delivers accuracy approaching industry-standard 3D EM solvers, while delivering results in a fraction of the time. A cohesive workflow seamlessly transfers EM characterized models back into the schematic and promotes better collaboration. Together, these capabilities raise the bar on performance, accuracy and efficiency for SI and PI simulation and analysis. Design engineers now have the capabilities they need to address their toughest design challenges in the fastest way possible.

VENDORVIEW

Keysight Technologies Inc.
Santa Rosa, Calif.
www.keysight.com

E-Band Test Makes Component Design and Manufacturing More Affordable

Anritsu
Morgan Hill, Calif.

Growing demand for driver assistance radar and multi-gigabit wireless communications (e.g., WiGig) and the impending demand for 5G small cell networks are driving higher performance requirements for E-Band components — while challenging suppliers to lower their costs. Component test falls squarely in the crosshairs. The recent introduction of an E-Band frequency option to the MS46522B and MS46524B series of Performance ShockLine™ Vector Network Analyzers (VNA) provides manufacturers of passive E-Band devices such as antennas, filters and duplexers with high quality measurements at a more affordable price than previously available.

TABLE 1

PERFORMANCE SUMMARY MS46522B AND MS46524B WITH OPTION 82

Operational Frequency Range	55 to 92 GHz, Extended E-Band
Dynamic Range	120 dB (10 Hz IFBW, 60 to 90 GHz)
Trace Noise (RMS)	4 mdB (100 Hz IFBW, 60 to 90 GHz)
Port Power	Up to 0 dBm leveled power, 50 dB adjustment range
Measurement Speed	30 µs/point, typical (widest IFBW)
Remote Control	LAN
Calibration	SOLT, SOLR, SSLT, SSST, LRL/LRM, WG, Microstrip, Thru update
Frequency Sweep Type	Linear, Log, CW and Segment
Maximum Number of Points	20,000

Note: All specifications typical.

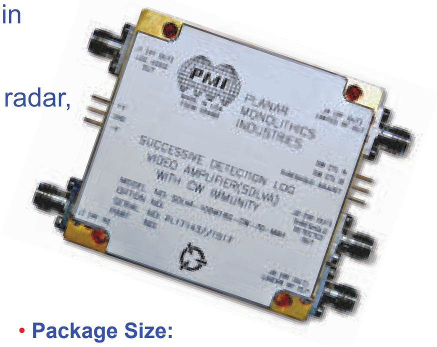
The new ShockLine E-Band option utilizes Anritsu's NLTL technology, complemented with novel monolithic broadband directional bridges, multiplexers and other key components, resulting in NLTL-based samplers and distributed harmonic generators that provide outstanding performance and a lower price than alternative approaches. For example, ShockLine performance enables filter manufacturers to take advantage of 120 dB of dynamic range to meet higher selectivity requirements. The same NLTL-based technology is also inherently stable over temperature and time, which results in less drift and downtime for performing calibrations. Less downtime means higher utilization and lower test cost. The novel architecture of the E-Band option provides multiple advantages:

Planar Monolithics Industries, Inc.

CW-Immune Successive Detection Log Video Amplifier (SDLVA), 100 MHz - 18 GHz

- Amplifiers
- Attenuators - Variable
- DLVA & ERDLVA & SDLVA's
- DTO's & Frequency Synthesizers
- Filters
- Form, Fit & Function Products
- IFM's & Frequency Discriminators
- Integrated MIC/MMIC Modules
- I/Q Vector Modulators
- Limiters & Detectors
- Log Amplifiers
- Pulse & Bi-Phase Modulators
- Phase Shifters
- Rack & Chassis Mount Products
- Receiver Front Ends & Transceivers
- Single Sideband Modulators
- SMT & QFN Products
- Solid-State Switches
- Switch Matrices
- Switch Filter Banks
- Threshold Detectors
- USB Products

PMI Model SDLVA-100M18G-CW-70-MAH SDLVA features a SPST on the RF output that allows for the RF to be blanked when the input signal is below the externally adjustable threshold. A 3.3 V TTL-compatible output is also provided for time-gating or sampling to assist in digital system integration.



- Ideal for EW, ELINT and IFM receivers, DF radar, ECM, broadband test & measurment and missile guidance applications.
- SMA Connectors & Gold Finish.
- Military or Stringent Screening is available.
- Small Quantity Requirements accepted.
- Specialized Testing & Custom designs welcome!

- **Package Size:** **2.30" x 2.20" x 0.36"**
- **DC Voltage:** **+12 VDC @ 310 mA, -12 VDC @ 95 mA**

SPECIFICATIONS

Frequency Range:	100 MHz to 18.0 GHz
Frequency Flatness:	±2.0 dB max. - measured ±1.0 dB
TSS:	-68 dBm min., -70 dBm typ. - measured -68 dBm
Limited Output Power:	8.0 dBm ± 3.0 dBm max., - measured +8 ± 2.5 dBm (Input Power $\geq$ -65 dBm)
VSWR:	2.0:1 max. - measured 1.97:1
Linear Output Gain:	43 dB ± 3.0 dB max. - measured 43 to 45.7 dB
Linear Output Psat:	3 dBm ± 3.0 dB max. - measured 0.9 to 4.0 dBm
V0 (Video Comparator Signal Amplitude):	3.3 V typ. - measured 2.25 V
Video Comparator Delay:	50 ns typ. - measured 45 ns
Video Comparator Threshold Level:	Adjustable with Analog Voltage, -60 dBm ± 3.0 dB max.
V1 (Log Video Signal Amplitude):	1 Volt max. - measured 0.807 Volt
Log Slope:	10 mV/dB into 50 Ω Load ±1 mV max. - measured 10 mV/dB
Log Range:	-65 to +5 dBm min.
Log Linearity:	±1.75 dB (-40 °C to +85 °C) - measured 0.92 dB
Pulse Range:	100 ns to 250 µs
Rise Time:	35 ns max. - measured 20 ns
Settling Time to ±1 dB:	50 ns typ. - measured 41 ns
Recovery Time:	350 ns max. - measured 220 ns
SDLVA-100M18G-CW-70-MAH	TSS to -45 dBm (1 dB degradation) - measured 0.7 dB
Pulse Considered "CW":	1 ms typ. - measured 0.7 ms
Rejection Time:	1 ms typ. - measured 0.5 ms
Droop:	1 dB max. - measured 0 dB
SPST Isolation:	70 dB typ. - measured $\geq$70 dB
Switching Speed:	20 ns typ. - measured 20 ns

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Only pay for the frequency range needed. Unlike alternative solutions that provide E-Band measurement capability through broadband approaches, the MS46522B and MS46524B equipped with option 82 is a dedicated E-Band VNA covering 55 to 92 GHz. This focus allows the elimination of components needed to cover unused frequency ranges, enabling a significant cost reduction and a price tag that is a fraction of a broadband system.

Lower cable losses and gain greater configurability. The ShockLine E-Band solution incorporates small millimeter wave modules that are tethered to the instrument through 1 m cables. With the millimeter wave measurement capability located in the modules rather than the base instrument, high frequency cables losses and cable instabilities are reduced, enabling the VNA to provide more power with higher dynamic range at the device under test (DUT). The source and receiver modules are small and lightweight enough to connect directly to the DUT, ideal for use in applications like antenna range measurements.

Reduce downtime and errant measurements. The MS46522B and MS46524B with option 82 come pre-configured with tethered modules already attached and ready to make measurements. Alternative solutions frequently require complicated cabling and configuration, which can cause extended downtime and lead to errant measurements. ShockLine VNAs are supported by Anritsu's easyTest™ software. easyTest is a free tool for Anritsu VNAs that allows users to create work instruction files on a PC, deliver these files by e-mail and then display work instructions on supported instruments and modes. These easyTest files provide guided step-by-step instructions for both the test setup and instrument operation. One easyTest file can be uploaded into multiple VNAs, reducing the cost of training personnel and lowering the chance of incorrect measurements.

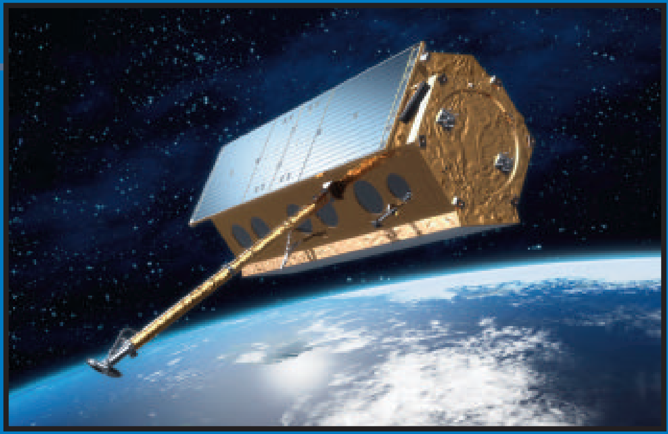
Increase capacity or eliminate floor space while spending less. The ShockLine E-Band solution includes a 3U tall chassis, which is smaller than many E-Band VNA alternatives. Users can either increase capacity without adding factory floor space or reduce the floor space while maintaining capacity. The chassis also helps save money. Utilizing commercial off-the-shelf components (e.g., the built-in computer and power supply) rather than proprietary components, savings from economies of scale can be passed on through lower pricing. The chassis is more reliable because it does not include fragile buttons or keypads, nor a display that is easily damaged. When needed, users can attach a touch screen monitor for manual testing.

Table 1 summarizes the performance of the MS46522B and MS46524B with option 82.

VENDORVIEW

Anritsu
Morgan Hill, Calif.
www.anritsu.com

Instantly Improve the Performance of Your Phased Array Radar!

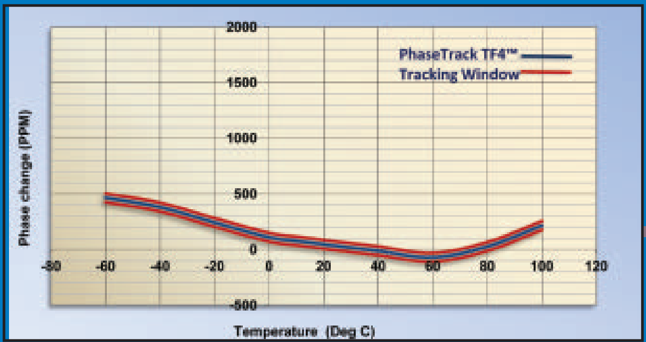


Phased Array Radar system performance has long been limited by the phase change over temperature of coaxial cables.

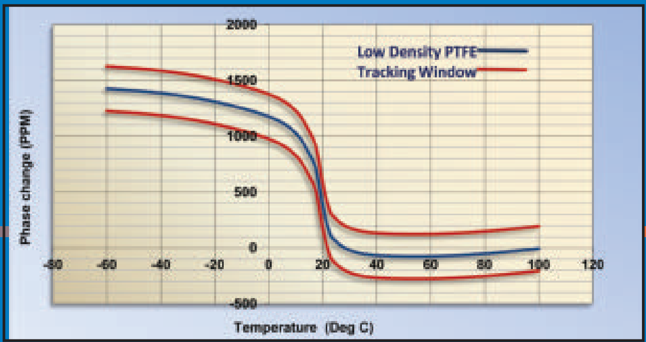
Not anymore!

TF4™ - our proprietary, ultra stable dielectric material significantly improves Phased Array Radar system performance by reducing the phase change of the interconnecting coaxial cables.

Typical PhaseTrack TF4™ Performance



Typical Low Density PTFE Performance



- Available NOW in various flexible coaxial cable and semi rigid coaxial cable assembly sizes
- Perfect for all Ground, Naval, Airborne or Spaceflight Phased Array Radar applications
- Frequency ranges to 40 GHz
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- Best Phase Tracking and Absolute Phase Change performance available

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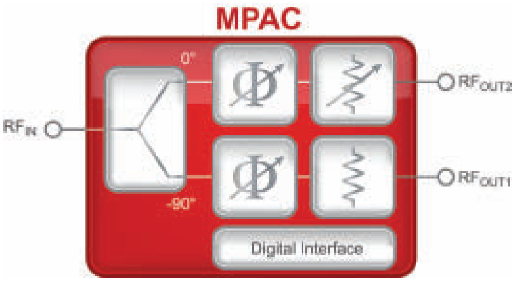


Monolithic Phase and Amplitude Controllers Optimize Doherty PAs

Peregrine Semiconductor
San Diego, Calif.

Anyone who's been tasked with implementing a Doherty power amplifier (PA) for a wireless base station transmitter can attest to the difficulties that lie in Doherty amplifier optimization. There are the manufacturing variances, the manual tweaking of each module, the discrete components and their own variances, not to mention the lack of flexibility after optimization. Any mismatch or misalignment in phase and amplitude between the Doherty architecture's carrier and peaking paths can quickly contribute to higher costs and degradation of the overall performance. If the carrier and peaking amplifiers are not in sync, the final output will not reach the output performance as designed.

Today, most macrocell RF engineers manage this complexity using discrete components to tune the phase and amplitude for each one of the carrier and peaking paths. Unfortunately, these discrete components require substantial engineering time and expertise, because optimization is both manual and laborious. Engineers must determine the discrete component values and how to put them on the board. Once the discrete components are on the board, there is no flexibility to make changes for unexpected power transistor variances. The RF engineer is also left with no way to optimize the phase and amplitude. Doherty PA optimization is a time-consuming challenge — time that is also an investment cost for the company.

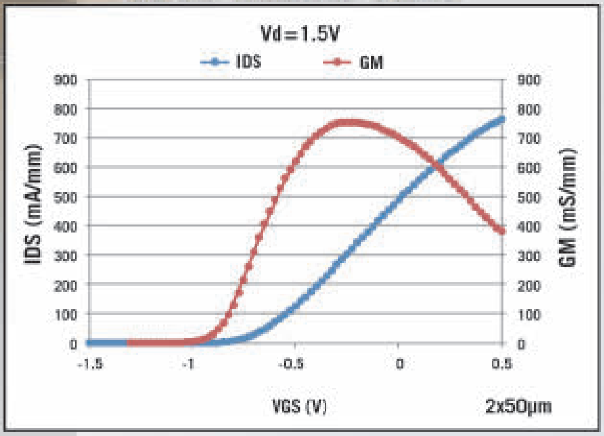
Despite these challenges, the Doherty amplifier continues to dominate the wireless infrastructure equipment market. Why? The answer is the amplifier's ability to accommodate high peak-to-average ratios (PAR). With the advent of quadrature amplitude modulation in wireless and the worldwide rollout of LTE and LTE-A, the PAR required is around 9 dB. A Doherty configuration uses load modulation to achieve very high efficiencies under back-off conditions. The back-off efficiencies are key to keeping the overall system efficiency of the PA module high for LTE signals. Most wireless base stations — macro, micro and picocells — implement a Doherty architecture to improve PA efficiencies, especially when quadrature amplitude modulation is used.

Aware of the challenges in Doherty PA optimization, Peregrine Semiconductor developed a solution, announced at the International Microwave Symposium (IMS) in May 2015. Peregrine's PE46120 was the first product in the UltraCMOS® MPAC (monolithic phase and amplitude controller) family. Peregrine is now add-

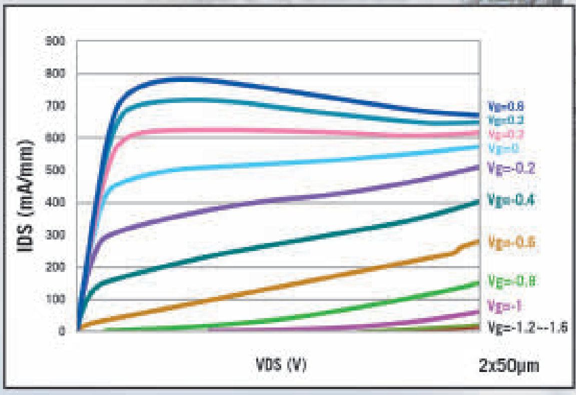
PP10-10/-11 0.1µm Power pHEMT

- 0.1µm high performance power / low noise process
- 50µm and 100µm thickness are standard
- Useable gain to 110GHz
- 4V operation - Psat > 800mW/mm, > 50% PAE, and 13dB Gain at 29GHz

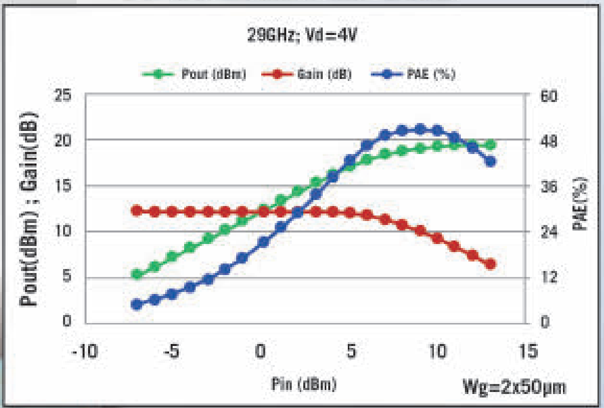
PP10 Transfer Curve



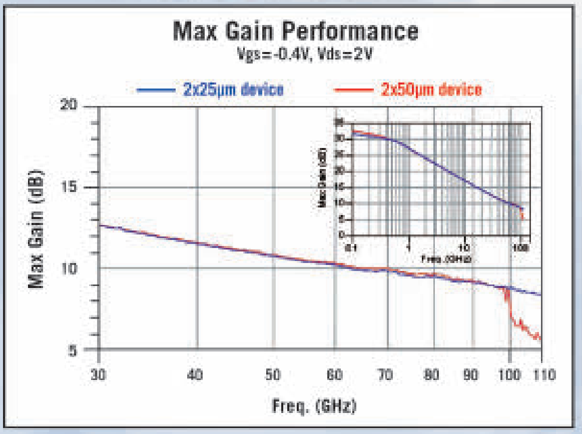
PP10 I-V Curves



PP10 Load Pull Data



PP10 Max Gain



WIN SEMICONDUCTORS CORP. Tel:+886-3-397-5999 Fax:+886-3-397-5069 http://www.winfoundry.com

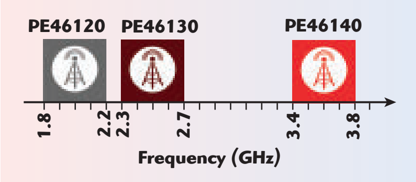
ing two new controllers: the PE46130 and PE46140. The three MPAC products in the family enable alignment of the phase and amplitude between the Doherty amplifier's carrier and peaking paths through a digital interface. Each monolithic controller integrates a 90-degree phase splitter, 5-bit digital phase shifter, 4-bit digital step attenuator and a digital serial peripheral (SPI) interface (see block diagram).

ADVANTAGES

The PE46120, PE46130 and PE46140 eliminate the need for multiple discrete components and can be used to optimize Doherty power amplifiers using either laterally diffused metal oxide semiconductor (LDMOS) or gallium nitride (GaN) devices. When used for Doherty amplifier optimization, the monolithic controllers offer the following benefits to wireless infrastructure vendors:

- **Better performance.** Power-added efficiency, linearity across frequency and Doherty bandwidth improve through better matching and increased effectiveness of the digital predistortion (DPD) loop. If a company is not already investing in module-by-module tuning, engineers can expect to see a three to four percent efficiency increase — a huge improvement.
- **Reduced bill of materials (BOM) cost** by improving the overall yield of expensive Doherty power amplifier assemblies.
- **Improved system reliability** and increased transceiver yield from better uniformity and repeatability of transceiver paths.
- **Maximum tuning flexibility** to adjust the phase and amplitude in real-time for operational and environmental factors.

As the controllers are built on an UltraCMOS silicon on sapphire (SOS) monolithic die, RF engineers can trust the uniformity and manufacturing reliability of the process. Only UltraCMOS technology enables intelligent integration, a unique design capability that enables the integration of RF, digital and analog components onto a single die. Peregrine uses this design capability to offer benefits such as configurability, flexibility, enhanced performance, ease-of-use and a reduced form factor.



▲ *Fig. 1 The PE46120, PE46130 and PE46140 cover various cellular bands.*

PERFORMANCE

Designed for the LTE and LTE-A wireless infrastructure transceiver market, the three monolithic controllers cover several cellular frequency bands (see ***Figure 1***). The PE46120 provides excellent phase and amplitude accuracy from 1.8 to 2.2 GHz, the PE46130 covers 2.3 to 2.7 GHz and the PE46140 covers 3.4 to 3.8 GHz. Although they cover different frequency ranges, the PE46120, PE46130 and PE46140 are similar in features and performance advantages. The controllers provide a phase range of 87.2 degrees in 2.8 degree steps and an attenuation range of 7.5 dB in 0.5 dB steps. They deliver high linearity, 60 dBm IIP3, and handle 35 dBm input power with only at 0.1 dB compression. Port-to-port isolation is 30 dB, and current consumption is only 0.35 mA. UltraCMOS technology enables the controllers to withstand ESD of at least 1 kV on all RF pins and operate over an extended temperature range to +105°C and a power supply range from 2.3 to 5.5 V. Each controller is offered in a RoHS compliant, 32-lead, 6 × 6 mm QFN.

Compared to GaAs-based module solutions, the PE46120, PE46130 and PE46140 offer:

- > 20 dB better linearity (IIP3)
- 2.5× the resolution at twice the range of phase control
- >10 dB increased port-to-port isolation
- 4 dB more RF input power (CW)
- Wider power-supply operation.

In addition to Doherty amplifiers, the MPAC family can optimize the performance of other dual path, dynamically load-modulated amplifier architectures. The RF controllers can also be utilized for vector generation in feedforward amplifiers, beam forming networks and dual-polarized alignment/generation applications.

Peregrine Semiconductor
San Diego, Calif.
www.psemi.com

Pulse Generators for High Speed Digital and Microwave Test

Pico Technology
St Neots, U.K.

In wide bandwidth test and measurement applications, it is common to use a fast transition pulse as a stimulus to the device under test (DUT). With its broad spectral content, such a pulse can, in a single instant, drive a component, transmission path or system with all the frequencies that it will likely encounter. By gathering the response of the DUT, either from instrumentation within the device itself or using a wideband oscilloscope to capture its output, fast and detailed device characterization can be performed. However, very fast transition pulse generators can be relatively hard to find and can be expensive. The same can be said of broadband oscilloscopes, because the generation, delivery and recapture of pulses with transition times of a few hundred picoseconds or less is quite challenging.

▲ *Fig. 1 PicoSource PG900 high speed pulse output viewed on a PicoScope 9341 4-channel 20 GHz oscilloscope.*

Pico Technology specializes in these technologies, supplying fast pulse generators with transition times down to 40 picoseconds within its 12 and 20 GHz sampling oscilloscopes. With the launch of the PicoSource PG900 USB controlled pulse generators, those technologies are available at a lower cost and in the flexible format of a stand-alone differential pulse source. The products are suited to the characterization of microwave and gigabit devices, lines, networks and systems for signals up to 10 GHz and 20 Gbps. These pulse generators are high speed, low cost instruments for use in single-ended and differential pulsed measurement applications, such as time domain reflectometry (TDR) and radar system, semiconductor, gigabit interconnect and port testing. The generators are typically used to drive broad spectral content into a 50 Ω cable, connector, RF semiconductor or other DUT. The reflected or transmitted pulse can then be monitored and displayed by a broadband or sampling oscilloscope (see ***Figure 1***). TDR or time domain transmission (TDT) analysis are alternatives to vector and scalar network analysis and widely used to speed the development, evaluation and testing of high speed data paths (e.g., Ethernet, USB, HDMI, SATA) and RF, radar and microwave devices, cables, networks and equipment. Figure 1 shows the responses to a pulse applied to a 50 Ω controlled impedance, differential line on a printed circuit board. Channels 3 and

4 (i.e., the purple and green traces) display the launch pulse, and channels 1 and 2 (i.e., blue and yellow traces) show the effects of crosstalk on an adjacent differential line about 3" along the PCB.

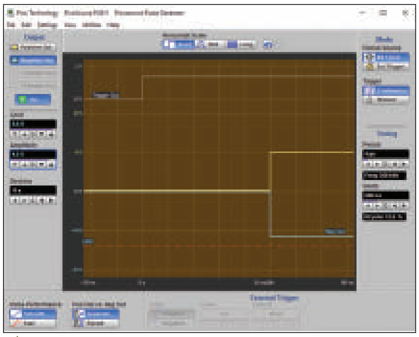
PicoSource PG900 generators are compact USB devices that connect to a PC running Microsoft Windows, with the advantages of

- Leading microwave performance in a compact and portable instrument
- High resolution graphical display
- Easy setup via keyboard, mouse or touch screen.

***Figure* 2** shows the software screen used to set the pulse generator parameters.

DESKEWABLE DIFFERENTIAL OUTPUTS

The pulse generators have deskewable differential outputs adjustable to 1 ps resolution, which allows timing inequalities in test connections and fixtures to be nulled – or the deliberate introduction of timing skew to stress test the system. Each of the outputs can also operate in a single-ended mode. The PG900 Series offers two triggered step-generation technologies to suit different applications. The PG911, with integral step recovery diode outputs, offers a transition time of less than 60 ps with a large and adjustable output swing of 2.5 to 6 V on each output. These pulses can support high dynamic range and long distance measurements, exercising all signal amplitudes in most transmission systems and devices. The PG912 uses external tunnel diode pulse heads to deliver a faster transition time of less than 40 ps with fixed 200 mV amplitude at the interface plane. A third model, the PG914, combines both technologies in one space-saving, economical unit. All models feature low jitter, external trigger input and output and an internal trigger clock with comprehensive width, period and hold-off adjustments. Pulse edge jitter with respect to the trigger input and output is less than 3 ps RMS.

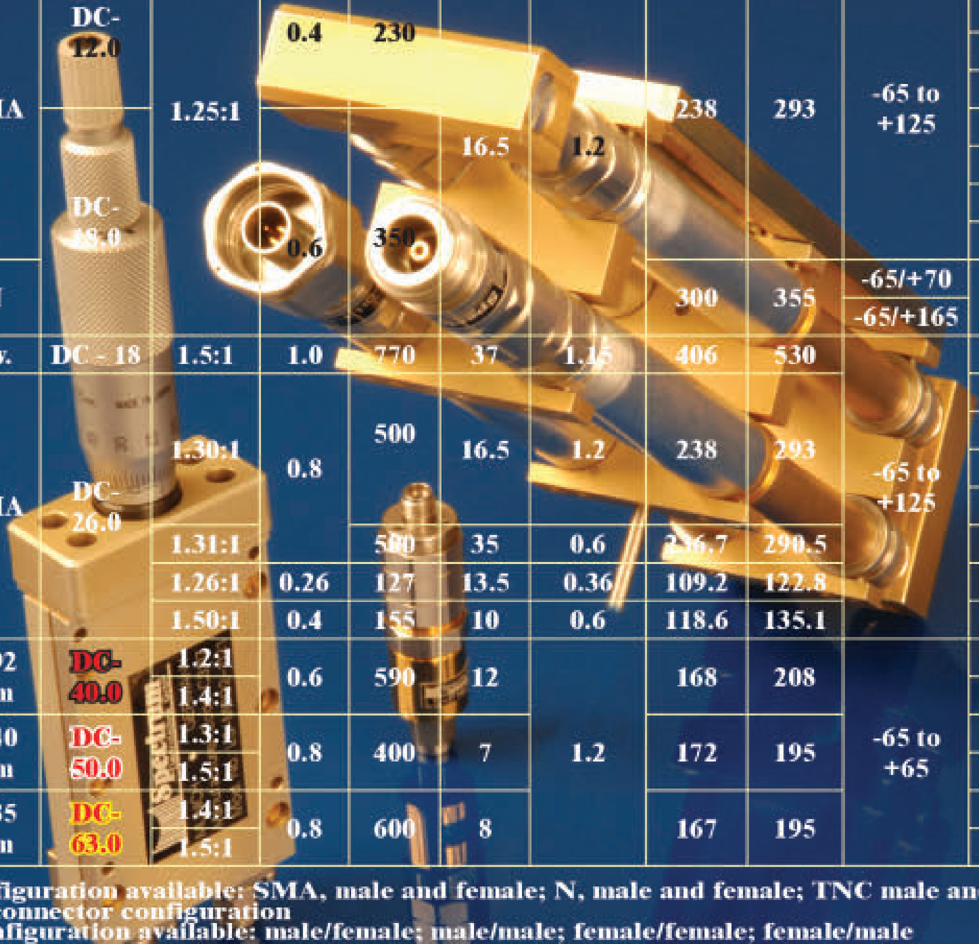


▲ *Fig. 2 PicoSource PG900 software screen used to set pulse parameters. Three timescales are available to display pulses.*

The portability and low cost of the PG900 generators can bring RF and microwave testing out of the lab and into the world of on-site measurement. Typical applications include: TDR/TDT network and match analysis, spectral and flatness measurements and timing, jitter and crosstalk determinations. The PG900 pulse generators can partner the PicoScope 9300 20 GHz sampling oscilloscope in many of these applications.

Pico Technology
St Neots, U.K.
www.picotech.com

Phase Adjusters



Part Number	Connectors	Frequency Range (GHz)	VSWR max.	Insertion Loss max. (dB)	Phase Shift min. (°)	No. of Turns	Phase Shift Deg/GHz/Turn	Time Delay min. (psec.)	Time Delay max. (psec.)	Temperature (°C)	Weight max. (g)
LS-0002-YYYY[1]	div.	DC - 2	1.2:1	0.3	85	37	1.15	393	516	-65 to +125	98-220[2]
LS-0103-6161	Nf	DC - 3	1.15:1	0.4	540	cont.		1826	2328		700
LS-0203-6161				0.9	1080			3693	4694		1200
LS-0012-YYYY[1]	div.	DC - 12	1.3:1	0.8	520	37		406	530		114-234[2]
LS-0112-XXXX[3]	SMA	DC-12.0	1.25:1	0.4	230	16.5	1.2	238	293	-65 to +125	70
LS-A112-XXXX[3]											47
LS-0212-1121											70
LS-A212-1121											47
LS-0118-XXXX[3]		DC-18.0		0.6	350						70
LS-A118-XXXX[3]											47
LS-0218-1121											70
LS-A218-1121											47
LS-0118-5161	N							300	355	-65/+70	105
LS-U118-5161										-65/+165	
LS-0018-YYYY[1]	div.	DC - 18	1.5:1	1.0	770	37	1.15	406	530		98-220[2]
LS-0121-XXXX[3]	SMA	DC-26.0	1.30:1	0.8	500	16.5	1.2	238	293	-65 to +125	70
LS-A121-XXXX[3]											47
LS-0221-1121											70
LS-A221-1121											47
LS-0321-1121			1.31:1		580	35	0.6	236.7	290.5		30
LS-0170-1121			1.26:1	0.26	127	13.5	0.36	109.2	122.8		9
LS-S008-1121			1.50:1	0.4	155	10	0.6	118.6	135.1		20
LS-P140-KFKM	2.92 mm	DC-40.0	1.2:1	0.6	590	12	1.2	168	208	-65 to +65	51
LS-0140-KFKM			1.4:1								49
LS-P150-HFHM	2.40 mm	DC-50.0	1.3:1	0.8	400	7		172	195		55
LS-0150-HFHM			1.5:1								53
LS-P165-VFVM	1.85 mm	DC-63.0	1.4:1	0.8	600	8		167	195		55
LS-0165-VFVM			1.5:1								53

1) div.: Connector Configuration available: SMA, male and female; N, male and female; TNC male and female
2) Weight depends on connector configuration
3) SMA Connector Configuration available: male/female; male/male; female/female; female/male

Spectrum Elektrotechnik GmbH

when Quality is needed

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Synthesizers Lead in Phase Noise, Spectral Purity and Volume

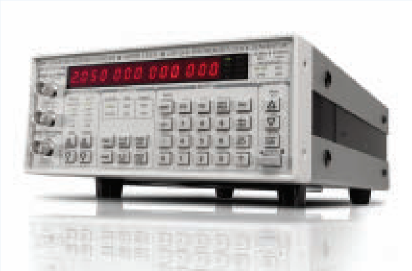
Holzworth Instrumentation's latest HSX series RF synthesizers are phase coherent, multi-channel signal sources that offer industry leading phase noise (-142 dBc/Hz at 1 GHz, 10 kHz offset) and spectral purity of better than -85 dBc (spurious signals). The current product offering operates from 10 MHz to 6 GHz with 0.001 Hz resolution. 12 and 24 GHz models will be released during 2016. The internal configuration supports better than -110 dB isolation between loaded channels, and the synthesizers have a Z540 calibrated dynamic range of +20 to -110 dBm. The output power can be set with 0.01 dB resolution and ±1 dB accuracy at -110 dBm.

Users can select factory configurations from one to four phase coherent channels in a single 1U chassis. The compact 1U form factor is ideal for this class of frequency source, as test system rack space comes at a high premium. The phase coherent relationship between loaded channels is also an advantage for many applications, as channel-to-channel (tone-to-tone) relative drift can result in measurement errors. The use of phase coherent channels for tone and clock generation helps reduce and potentially eliminate unnecessary test margins, often increasing yields in product test applications.

Few signal sources can meet the CW performance levels achieved by the HSX series, and the prices of those competitors are approximately 2× higher per channel than HSX pricing. Also, competitive form factors require at least 2U of rack space per channel, or 8U for four channels, versus 1U for the HSX. The HSX series has a three-year product warranty, reflecting the high reliability and quality standards that Holzworth's customers rely upon.

VENDORVIEW

Holzworth Instrumentation
Boulder, Colo.
(303) 325-3473
www.holzworth.com



High Resolution, Low Jitter, Fast Transition Clock Generator

With exceptionally low phase noise and high frequency resolution, Stanford Research System's CG635 clock generator provides a stable clock signal for developing and testing digital components, systems and networks. It can also replace RF signal generators in many applications.

The CG635 generates extremely stable square wave clocks between 1 μHz and 2.05 GHz — 16 digits of frequency resolution — with random jitter less than 1 ps RMS. The standard crystal time base has a stability of better than 5 ppm. Two options allow better frequency stability: an oven-controlled crystal oscillator (OCXO) will provide about 100× better stability and a rubidium source will provide 10,000× better stability. A 10 MHz time base input allows the instrument to be phase-locked to an external reference, and two CG635s can be locked using the 10 MHz output signal.

Clock phase resolution is 1 degree for frequencies above 200 MHz and increases by a factor of 10 for each decade below 200 MHz, to a maximum resolution of 1 nanodegree. This allows the clock edges to be positioned with a resolution of better than 14 ps at any frequency between 0.2 Hz and 2.05 GHz.

Two front panel BNC outputs provide complementary square waves at standard logic levels (ECL, PECL, LVDS or +7 dBm). The amplitude may be set between 0.2 and 1.0 V, with an offset from −2 to +5 V. These outputs have transition times of 80 ps and can drive 50 Ω loads. The levels double when the outputs are unterminated.

Stanford Research Systems
Sunnyvale, Calif.
www.thinksrs.com

HIGH POWER

5 - 500 WATTS PRODUCTS

POWER DIVIDERS

RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.] ¬	Package
2-WAY								
CSBK260S	20 - 600	0.28 / 0.4	0.05 / 0.4	0.8 / 3.0	25 / 20	1.15:1	50	377
DSK-729S	800 - 2200	0.5 / 0.8	0.05 / 0.4	1 / 2	25 / 20	1.3:1	10	215
DSK-H3N	800 - 2400	0.5 / 0.8	0.25 / 0.5	1 / 4	23 / 18	1.5:1	30	220
P2D100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	2	329
DSK100800	1000 - 8000	0.6 / 1.1	0.05 / 0.2	1 / 2	28 / 22	1.2:1	20	330
DHK-H1N	1700 - 2200	0.3 / 0.4	0.1 / 0.3	1 / 3	20 / 18	1.3:1	100	220
P2D180900L	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	2	331
DSK180900	1800 - 9000	0.4 / 0.8	0.05 / 0.2	1 / 2	27 / 23	1.2:1	20	330
3-WAY								
S3D1723	1700 - 2300	0.2 / 0.35	0.3 / 0.6	2 / 3	22 / 16	1.3:1	5	316
4-WAY								
CSDK3100S	30 - 1000	0.7 / 1.1	0.05 / 0.2	0.3 / 2.0	28 / 20	1.15:1	5	169S

¬ With matched operating conditions

HYBRIDS

RoHS

Model #	Frequency (MHz)	Insertion Loss (dB) [Typ./Max.] ◊	Amplitude Unbalance (dB) [Typ./Max.]	Phase Unbalance (Deg.) [Typ./Max.]	Isolation (dB) [Typ./Min.]	VSWR (Typ.)	Input Power (Watts) [Max.]	Package
90°								
DQS-30-90	30 - 90	0.3 / 0.6	0.8 / 1.2	1 / 3	23 / 18	1.35:1	25	102SLF
DQS-3-11-10	30 - 110	0.5 / 0.8	0.6 / 0.9	1 / 3	30 / 20	1.30:1	10	102SLF
DQS-30-450	30 - 450	1.2 / 1.7	1 / 1.5	4 / 6	23 / 18	1.40:1	5	102SLF
DQS-118-174	118 - 174	0.3 / 0.6	0.4 / 1	1 / 3	23 / 18	1.35:1	25	102SLF
DQK80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	113LF
MSQ80300	800 - 3000	0.2 / 0.4	0.5 / 0.8	2 / 5	20 / 18	1.30:1	40	325
DQK100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	326
MSQ100800	1000 - 8000	0.8 / 1.6	1 / 1.6	1 / 4	22 / 20	1.20:1	40	346
MSQ-8012	800 - 1200	0.2 / 0.3	0.2 / 0.4	2 / 3	22 / 18	1.20:1	50	226
180° (4-PORTS)								
DJS-345	30 - 450	0.75 / 1.2	0.3 / 0.8	2.5 / 4	23 / 18	1.25:1	5	301LF-1

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS

RoHS

Model #	Frequency (MHz)	Coupling (dB) [Nom]	Coupling Flatness (dB)	Mainline Loss (dB) [Typ./Max.]	Directivity (dB) [Typ./Min.]	Input Power (Watts) [Max.] ¬	Package
KFK-10-1200	10 - 1200	40 ±1.0	±1.5	0.4 / 0.5	22 / 14	150	376
KDS-30-30	30 - 512	27.5 ±0.8	±0.75	0.2 / 0.28	23 / 15	50	255 *
KBS-10-225	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	255 *
KDS-20-225	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	255 *
KBK-10-225N	225 - 400	10.5 ±1.0	±0.5	0.6 / 0.7	25 / 18	50	110N *
KDK-20-225N	225 - 400	20 ±1.0	±0.5	0.2 / 0.4	25 / 18	50	110N *
KEK-704H	850 - 960	30 ±0.75	±0.25	0.08 / 0.2	38 / 30	500	207
SCS100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	361
KBK100800-10	1000 - 8000	10.5 ±1.5	±2.0	1.2 / 1.8	8 / 5	25	322
SCS100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	321
KDK100800-16	1000 - 7800	16.8 ±1.5	±2.8	0.7 / 1.0	14 / 5	25	322
SCS100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	12 / 5	25	321
KDK100800-20	1000 - 7800	20.5 ±2.0	±2.0	0.45 / 0.75	14 / 5	25	322
KEK-1317	13000 - 17000	30 ±1.0	±0.5	0.4 / 0.6	30 / 15	30	387

* Add suffix - LF to the part number for RoHS compliant version.

¬ With matched operating conditions

Unless noted, products are RoHS compliant.

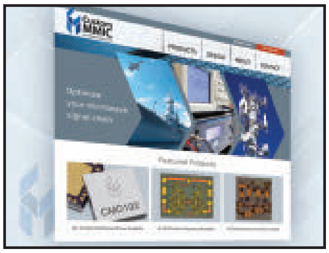
SYNERGY®
MICROWAVE CORPORATION

Phone: (973) 881-8800 | Fax: (973) 881-8361
E-mail: sales@synergymwave.com
Web: WWW.SYNERGYMWAVE.COM
Mail: 201 McLean Boulevard, Paterson, NJ 07504

Web & Video Update

New Website

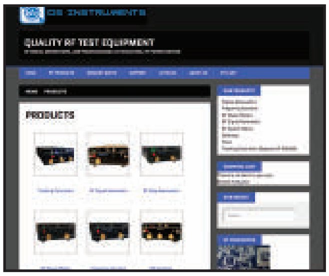
VENDORVIEW



Custom MMIC has launched a new website featuring over 80 products from their catalog and over a dozen recently released high performance, GaAs and GaN low noise amplifiers, distributed amplifiers, power amplifiers, driver amplifiers, attenuators, mixers, multipliers, phase shifters and switches. The site also includes free signal chain optimizing design calculators, including a thermal profile calculator for printed circuit boards, an attenuator calculator for digital attenuators, an image rejection calculator for mixers and a cascade analysis calculator for your entire microwave subsystem.

Custom MMIC
www.CustomMMIC.com

RF Web Store



DS Instruments' new RF equipment web store is open for business. The website, in addition to excellent affordable products, includes educational articles and links to helpful video tutorials. DS Instruments designs and manufactures simple yet powerful unique RF test equipment including signal generators, digital attenuators, power meters, RF switches, tracking generators and frequency counters. DS Instruments is now fully registered with Dun & Bradstreet and the Defense Logistics Agency to provide quality RF Test equipment to government, research and defense clients.

DS Instruments
www.dsinstruments.com/store

X-Series Video

VENDORVIEW

Keysight Technologies' new 90-second video introduces the new X-Series signal analyzers. You'll see how they are the benchmark for accessible performance that puts you closer to the answer by easily linking cause and effect. You'll also get a look at Keysight's new industrial design that includes a multi-touch user interface that streamlines measurement setup and creates a solid foundation for new solutions. X-Series applications with multi-touch simplify complex operations with proven, ready-to-use measurements for pulse analysis, analog demodulation, noise figure, phase noise, LTE/LTE-Advanced and W-CDMA.

Keysight Technologies Inc.
www.keysight.com/find/X-Series

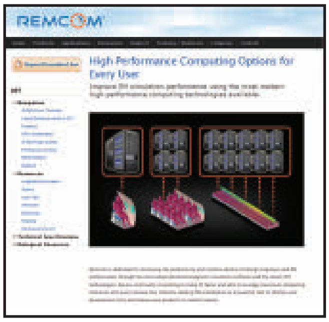
The Cable Creator

VENDORVIEW

Design and buy online with the Pasternack Cable Creator™. Customize over 250,000 possible RF cable assemblies to your exact specifications with the new Pasternack Cable Creator. This easy to use tool provides instant pricing, detailed datasheets and online ordering with same day shipping on any cable assembly built from our inventory of 1,300 connectors and 120 cable types. Pasternack is your source for any RF cable assembly requirement.

Pasternack
www.pasternack.com

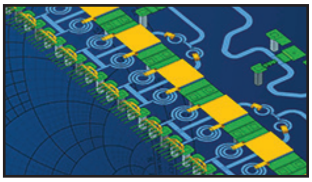
High Performance Computing



Remcom has worked hard to provide the latest high performance computing technology to all users, regardless of how large or small their computing environment. We know time is money, and engineers are under pressure to complete designs quickly. XFdtd is unrivaled in efficient simulation of complex problems, due to GPU acceleration technology and the ability to distribute calculations across clusters (either CPU or GPU clusters). Visit the high performance computing page on their website at www.remcom.com/high-performance-computing to learn about these solutions.

Remcom Inc.
www.remcom.com

Tutorial Videos



Release 16 tutorial videos are now available on Sonnet's website. Of particular interest are the Polygon Boolean Operations and Sonnet Cadence Virtuoso Interface videos. The first shows the union and subtraction of metal polygon geometries, demonstrating the four new Boolean commands. In the Sonnet Cadence tutorial, Sonnet is used entirely from within the Cadence environment through the Sonnet Cadence Virtuoso Interface. The tutorial starts with drawing an initial layout and progresses to the creation of an entire model for use in Cadence simulations.

Sonnet Software Inc.
www.sonnetsoftware.com/resources/videos

Web & Video Update

Broadband RF and Microwave Products

Weinschel Associates designs and manufactures high-quality broadband RF and microwave products for commercial and military markets domestically and internationally. Their updated website features an interactive catalog of products including fixed and variable attenuators, terminations, power dividers and splitters, DC blocks, RF adapters and directional couplers. The new website also includes an online request for quote system. Visit www.weinschelassociates.com today and start the RFQ on your next project by browsing products or creating an account.

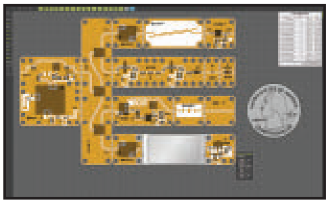
Weinschel Associates Inc.
www.weinschelassociates.com

Ethernet Cables

W. L. Gore & Associates Inc. (Gore) has launched an enhanced website to provide easier access to product information and performance data. The site simplifies the design process by providing connector compatibility data along with cable termination instructions that enable visitors to evaluate the performance of their high-speed interconnects. Visitors can access technical documentation and multimedia such as: cable-connector compatibility, cable-connector termination instructions, selecting the right Ethernet cables to increase high-speed data transmission and demonstration videos.

W. L. Gore & Associates Inc.
gore.com/aerospace-ethernet-cables

Get on the Grid!



X-Microwave offers an innovative system for RF and microwave design from simulation to prototype to production hardware. After using the free online simulator powered by Keysight's Genesys Spectrasys, designers can move to the online mechanical layout tool (MLT) to arrange system blocks called X-MWblocks on the grid. The X-MWblocks including mixers, amplifiers, multipliers, filters, splitters, couplers and switches are easily cascaded along with bias control boards and machined housings. A hybrid and a layout view are provided for valuable insight into the design.

X-Microwave LLC
www.xmicrowave.com

eLEARNING center

Presented by: Microwave Journal

March Short Course Webinars

Technical Education Training
Millimeter Wave and E-Band Vector Network Analyzer Solutions
Sponsored by: Anritsu
Live webcast: 3/2/16

Technical Education Training
Doherty at Eighty
Sponsored by: National Instruments
Live webcast: 3/9/16

Keysight Technologies Webcast
Using a Multi-Touch UI to Streamline Signal Analyzer Measurements
Live webcast: 3/10/16

Register to attend at mwjournal.com/webinars

Scan page using layar app

Past Webinars On Demand

Technical Education Training Series

- Large Signal Device Characterization for RF Power Amplifier Design
- RF and Microwave Heating Simulation and Application Design
- Critical Aspects of Dielectric Constant Properties for High Frequency Circuit Design
- Demystifying MIMO Radar and Conventional Equivalents
- Passive Intermodulation (PIM) in Printed Circuit Boards: Mechanisms and Mitigation
- Port Tuning -- EM Accuracy and Circuit Theory Speed
- Antenna Simulation with COMSOL
- Breakthroughs in Phased Arrays and Radars
- Very-Near-Field Scanning Solutions for Pinpoint Diagnosis of EMC Compliance Problems
- GaN Technology in Mainstream RF Energy Applications
- RF PCB Design
- VCO Fundamentals
- Preview of FEKO 14.0 Under Altair HyperWorks
- Highly Integrated Silicon ICs -- A Disruptive Technology for Phased Arrays
- Microwave and Millimeter-Wave High Frequency Circuit Material Performance (up to 110 GHz)
- Reducing VNA Test Costs and Decreasing Test Times
- Simulation of Radio Frequency Interference (RFI) in our Wireless World
- Developing Flexible & Reusable, Automated Test Systems with Fast Turnaround Times
- Addressing Electrically Large Antenna System Design with ANSYS HFSS Hybrid Simulation

RF/Microwave Training Series

Presented by: Besser Associates

- Passive Components: Dividers, Couplers, Combiners
- Introduction to Radar
- RF Components for Aerospace & Defense

CST Webinar Series

- Hybrid Simulation for Electrically Large Aerospace Platforms
- Simulation of Implanted Medical Devices
- Advanced PCB Rule Checking for Signal Integrity and EMC
- Graphene-Enhanced Devices: Simulation-based Design from Microwave to Optical Frequencies
- Precise High Frequency Modeling of SMD Components
- Electromagnetic Simulation Supporting Aircraft Certification
- Phased Array, FSS and Polarizer Design

Innovations in EDA

Presented by: Keysight Technologies

- 5G Physical Layer Modeling: A Communication System Architect's Guide
- Designing X-Band PAs Using SMT Plastic Packaged GaN Transistors
- How to Design Broadband Impedance Matching Networks
- How to Design Power Electronics: HF Power Semiconductor Modeling

Keysight Technologies Webcast

- Best Practices to Optimize Power Meter Sensor Measurements
- 5G Channel Sounding Challenges and Test Approaches
- Achieving Fast, Accurate Multi-Channel Power Measurements Over a Wide Dynamic Range

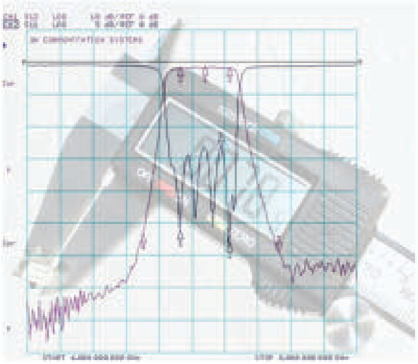
NEW PRODUCTS

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

COMPONENTS

C-Band Nano Filter

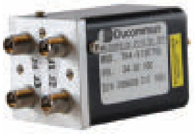
VENDORVIEW



3H's new C-Band Nano bandpass filter offers low in-band insertion loss of <2 dB over 10% bandwidth and >50 dB attenuation at ± 900 MHz from Fo. The filter size is 0.65" × 0.20" × 0.08, is suitable for automated assembly processes and meets Mil-Std-202 conditions. For more information contact: sales@3hcomm.com or call (949) 529-1583.

3H Communication Systems
www.3Hcommunicationsystems.com

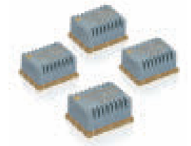
TK4 Series Switches



The TK4 series features K connectors and a frequency range of DC to 40 GHz. This series is available with failsafe, latching self-cut-off or pulse latching functions. Ducommun Inc. RF Products has design engineers who can create custom versions for your specific applications. Contact them at (310) 513-7256 or (310) 513-7200 for more information.

Ducommun Inc.
www.ducommun.com

High-Rel Electromechanical Switches



Fairview Microwave Inc. announced a brand new line of high reliability single pole double throw (SPDT) surface-mount electromechanical RF switches that cover broadband frequencies from DC to 8 GHz. These new RF switches offer exceptional reliability and repeatable performance which make them an ideal solution for demanding industries and applications related to aerospace, defense, industrial, telecom, instrumentation and medical devices. The switches utilize compact surface-mount packages and are designed for high rel performance rated for 2 million life cycles minimum.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Broadband Balun

The HL9407 is the new 67 GHz (at -3 dB) broadband balun from HYPERLABS, a leader in amplitude- and phase-matched precision broadband baluns. With 1.85 mm connectors, this ROHS-compliant balun is ideal for applications such as 40+ Gbps communications systems, modulator drivers, high speed analog-to-digital converters and single-ended to differential data conversion. It is bidirectional, so it can also be used as a high performance signal combiner.

HYPERLABS
www.hyperlabs.com

Ceramic Filters

VENDORVIEW

MCV ceramic filters feature high Q/low loss, high rejection, small size in rugged SMT or connectorized package covering 300 MHz to 10 GHz. High power ceramic filters can handle 10, 20, 30 and 60 W CW. Ceramic bandpass filters, band reject filters and multiplexers are used in 4G LTE small cell, DAS, in-building network, public safety and wireless communication up to 5 GHz. These are an economical option replacing cavity filters at a much smaller size.

MCV Microwave
www.mcv-microwave.com

Rack-mount Power Divider

VENDORVIEW

MECA announced its latest addition to the broadband line of power dividers with the 32-way splitter. Available in Type N & SMA, 30 W Wilkinson power dividers, optimized for excellent performance with industry leading specifications from 500 MHz to 6 GHz. Offering typical VSWR's ranging from of 1.30:1, isolation of 18 dB typical offering phase and amplitude balance typically only seen in narrower/octave band models.

MECA Electronics Inc.
www.e-MECA.com

Voltage-Controlled Phase Shifter

Microwave Solutions Inc. model MSH-4X2XX01-PH analog voltage-controlled phase shifter is a small microwave integrated circuit that provides a continuous variable phase shift at 4.4 to 5 GHz (usable 4 to 6 GHz) controlled with a single voltage from 0 to 10 VDC. Phase shift is 270° min with a phase error of ±10°. The maximum insertion loss is 4 dB and I/O VSWR 2.0:1 max. Operational temperature is -45° to +85°C. Maximum input power is +10 dBm. The unit size is 1.67" × 0.78" × 0.46". Customization is available upon request.

Microwave Solutions Inc.
www.microwavesolutions.com

PIN Diode Attenuator

VENDORVIEW

PMI Model PDVAT-100M20G-30-8B is an 8-Bit programmable 30 dB PIN diode attenuator with a step resolution as low as 0.25 dB over the frequency range of 100 MHz to 20 GHz. This model offers excellent attenuation accuracy and flatness over the entire 100 MHz to 20 GHz frequency range. At 30 dB the measured attenuation accuracy is ±0.09 dB and flatness of ±0.87 dB. It operates on a single +12 VDC to +15 VDC supply at 150 mA maximum/measured at 64 mA.

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

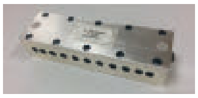
X-Band AESA Core IC Solutions

Richardson Electronics Ltd. announced the availability of the expanded portfolio of core ICs for commercial AESAs from Anokiwave Inc. Anokiwave has added two new devices to complete its family of X-Band AESA core IC solutions for commercial radar and 5G communications markets. Each IC architecture in the family includes an integrated 4-channel beam former, LNA and PA supporting four radiating elements. The ICs feature either a low noise figure or a high input linearity, and they are further divided by dual beam Rx/single beam Tx, or single beam Rx/single beam Tx.

Richardson Electronics Ltd.
www.rell.com

NewProducts

GPO Filters



RLC Electronics introduced a new line of GPO and miniature-GPO connectorized filters. These filters are available in all filter topologies, including tubular, cavity/comb and lumped element, in frequencies up to 26.5 GHz (GPO), 40 GHz (GPPO) and 65 GHz (G3PO). One main benefit of the GPO connector is the ease of mating on the customer board or in the overall system, which potentially eliminates the need for cables. With the GPO connector, RLC is able to offer a more compact filter, resulting in a reduction in overall length.

RLC Electronics
www.rlcelectronics.com

E-Band Sub-Harmonically Pumped Mixer

VENDORVIEW

Model SFS-73336315-12SFKF-E1-M is an E-Band sub-harmonically pumped mixer that utilizes high performance GaAs MMIC chips to offer superior RF performance. The required LO frequency and power are 35 to 38 GHz and +16 dBm, respectively. The mixer exhibits 15 dB nominal conversion loss in the RF frequency band of 70 to 76 GHz. The amplitude unbalance is within ±1 dB and phase unbalance is ±20 degrees typically. IF frequency bandwidth is from DC to 5 GHz. The mixer offers high RF to LO port isolation.

SAGE Millimeter Inc.
www.sagemillimeter.com

Bridge Combiner/Splitter

The BCS7600 is an ultra-wideband, surface-mount bridge coupler that can be used for wide spectrum, low level signal splitting and combining. It is specified to operate optimally from 70 to 5500 MHz over the temperature range of -40° to +85°C. This unique product can find applications from VHF through C-Band and has excellent performance with typical split loss of 6.5 dB and isolation of 25 dB typical. The compact package measures 0.5" × 0.375" × 0.15".

Synergy Microwave Corp.
www.synergymwave.com

SMT 90° Hybrid Coupler

Werlatone's model QH10148, a 90° hybrid coupler, covers the full 2 to 6 GHz band, at 100 W CW, and delivers best-in-class amplitude balance, specified at ± 0.5 dB max. An amplitude balance measuring half that of competing products, ensures that your transistors run more evenly and thus, more efficiently. Measuring just 0.75" × 0.45" × 0.79", the QH10148 is robust and highly repeatable.

Werlatone
www.werlatone.com

CABLES & CONNECTORS

Precision Adapters

Southwest Microwave Inc. has added several new high performance products to their line of precision adapters. Additions include high frequency within-series adapters for Southwest Microwave's 110 GHz 1.0 mm (W) connectors and 67 GHz 0.9 mm SuperMini ultra-miniature threaded coupling coaxial assemblies. Several between-series adapters have also been introduced for interface between 2.92 mm (K) and 1.85 mm (V) connectors, and between 0.9 mm SuperMini and 1.0 mm connectors. Southwest Microwave offers a full range of commercially-priced within-series and between-series adapters with near-metrology grade performance.

Southwest Microwave Inc.
www.southwestmicrowave.com

AMPLIFIERS

300 W, 0.7 to 6 GHz SSPA

VENDORVIEW

Model 300S1G6AB is a solid-state; 300 W class AB amplifier that instantaneously covers 0.7 to 6 GHz in one unit with an input power level of 0 dBm. This wideband output power amplifier is approximately half the size of a traditional class A design, is more efficient and offers a more economical price. Typical uses include wireless and EW applications.

AR RF/Microwave Instrumentation
www.arworld.us/post/300S1G6AB.pdf

RF Amplifier

VENDORVIEW

Empower RF announced it is shipping an RF amplifier system that complements the frequency coverage and power level footprint of its next generation, high power PA product family. Model 2180, covering 1 to 2.5 GHz and delivering an unprecedented 2 kW CW of broadband output power in an 8U, air cooled chassis, is its latest market release.

Empower RF Systems Inc.
www.empowerrf.com

Rack-Mount Variable Gain RF Amplifier

VENDORVIEW

Pasternack introduced a brand new rack-mount variable gain RF amplifier with performance from 100 MHz to 18 GHz. This 19" rack-mounted RF amplifier is designed for lab use and various test and measurement applications. Normally this type of test equipment commands long lead-times for delivery often exceeding several months; however, Pasternack has made this product available from stock for immediate shipment. Pasternack's new rack-mount RF amplifier offers broadband frequency coverage from 100 MHz to 18 GHz with high gain levels of 50 dB minimum over -40° to +85°C.

Pasternack
www.pasternack.com

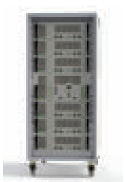
Low Noise Amplifiers

VENDORVIEW

Skyworks introduced two new global navigation low noise amplifiers. The SKY65605-21 and SKY65611-21 are both designed for BeiDou/GPS/GLONASS/Galileo receiver applications and are optimized to operate from 1559 to 1606 MHz. Each device integrates all output matching components, thereby requiring only a single external input matching component. Ideal applications include smartphones, personal navigation devices, wearables, machine-to-machine systems, base stations, asset tracking instruments and professional radios. The devices provide high linearity, excellent gain, a high 1 dB input compression point (1 P1dB), and a superior noise figure. The LNAs use surface-mount technology in the form of quad flat no-lead packaging, allowing for highly manufacturable and low cost solutions.

Skyworks Solutions Inc.
www.skyworksinc.com

Dual-Band Amplifier



MILMEGA introduced a dual-band amplifier designed to exceed the requirements of automotive radar pulse test standards. The AS0104-800/400 has been optimized for maximum power in the two radar bands, 1.2 to 1.4 GHz and 2.7 to 3.1 GHz. This new solid-state amplifier complements MILMEGA's existing 1 to 4 GHz amplifiers. The AS0104-800/400 uses MILMEGA's dual-band philosophy, with each band covering only one octave (1 to 2 GHz and 2 to 4 GHz). This dual-band approach has the advantage that the harmonics of the test frequencies are outside the band of each of the sub-amplifiers and are very poorly amplified.

Milmega
www.milmega.co.uk

6 GHz RF Power Amplifier Module

Triad RF Systems introduced model TA1167, a compact GaAs RF power amplifier module that delivers over 5 W peak power from 6400 to 7200 MHz (other bands available) and is designed for wireless communications applications that require a boost in linear RF power. The TA1167 incorporates circuits that produce over 1 W of linear COFDM power when amplifying a +19 dBm signal. It has gain of 11 dB, return loss of -10 dB (2:1 VSWR), rise and fall times of less than 1 µs, and accepts a maximum RF input of +27 dBm.

Triad RF Systems
www.triadrf.com

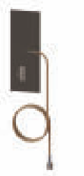
10 MHz to 1 GHz Broadband LNA

Model ABL0100-01-3010 is a low cost, SMA connectorized low noise amplifier offering 30 dB linear gain and 1 dB noise figure over the frequency range from 10 MHz to 1 GHz with excellent gain flatness and input/output return loss. The unit has a built-in voltage regulator and operates with a single DC power supply voltage from +10 to +15 V. The package size is 1.5" × 0.85" × 0.375".

Wenteq Microwave
www.wenteq.com

SOURCES

Dielectric Resonator Oscillator



The EDRO-1000 series dielectric resonator oscillator (DRO) utilizes advanced MIC and MMIC technology to generate precise, reliable and ultra-low noise frequency at microwave and mmWave bands up to 40 GHz. The uni-package is designed to mechanically withstand harsh environmental conditions due to shock/vibration, temperature and humidity. The EDRO-1000 series oscillator is designed using an ultra-low noise amplifier with series feedback at source and dielectric resonator at the gate. High gain, low noise devices are biased and matched precisely to ensure minimum phase noise. The devices are carefully matched for maximum power, minimum phase noise and voltage standing wave ratio (VSWR).

Exodus Dynamics
www.exodusdynamics.com

TCXO

Greenray Industries Inc. announced the availability of the T1241 TCXO. The T1241 temperature compensated oscillator is available from 50 to 100 MHz with squarewave, CMOS output, and features low phase noise and vibration compensation. The T1241 offers low g-sensitivity (down to < 7 × 10^{-11}/g) while providing superior phase noise performance – ideal characteristics for demanding mobile applications, including airborne and instrumentation. Typical phase noise is -155 dBc/Hz at 10 kHz. Supply voltage is +3.3 or +5.0 VDC, and supply current is 30 mA max. EFC (electronic frequency control) is provided for precise tuning or phase locking applications. In addition, the T1241 features a rugged, SMT package.

Greenray Industries Inc.
www.greenrayindustries.com

Broadband Multiplier

VENDORVIEW

Mini-Circuits' RKK-4-112+ frequency multiplier multiplies input frequencies of 200 to 275 MHz by a factor of 4 into output frequencies of 800 to 1100 MHz, supporting applications including synthesizers, local oscillators, satellite up- and down-converters. This model provides RF input power range from +17 to +23 dBm, typical conversion loss of 22.5 dB, and high rejection of unwanted harmonics (F3, 30 dBc; F5, 23 dBc). It comes housed in a miniature shielded surface-mount package (0.50" × 0.50" × 0.18"), ideal for dense circuit board layouts. The RMK-4-112+ is available off-the-shelf for $8.95 each (qty. 10 to 49).

Mini-Circuits
www.minicircuits.com

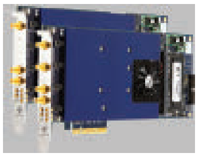
High Performance 20 GHz Signal Source

SignalCore's high performance 20 GHz VCO-based synthesized signal source is cost effective, compact and designed for seamless integration. With frequency spanning 100 MHz to 20 GHz (1 Hz resolution), low phase noise of -115 dBc/Hz at 10 kHz offset at 10 GHz carrier, and amplitude step resolution of 0.01 dB over a -30 dBm to +10 dBm output range, this product is ideal for R&D, academic, military and commercial applications.

SignalCore Inc.
www.signalcore.com

Arbitrary Waveform Generators

VENDORVIEW



The single channel M4i.6630-x8 and dual channel M4i.6631-x8 AWG cards are capable of outputting electronic signals at rates of up to 1.25 GS/s with 16-bit vertical resolution. They can be used to generate almost any waveform, making them suitable for stimulating electronic devices like amplifiers, filters, receivers and digital interfaces. As they can replay real world signals they can also be used to replace or model missing system components. Waveforms can be acquired from a digitizer or other instrument and loaded into the AWG via a number of popular file formats.

Spectrum Systementwicklung GmbH
www.spectrum-instrumentation.com/en

New**Products**

Voltage-Controlled Oscillator

VENDOR**VIEW**

Z-Communications Inc. announced a RoHS compliant voltage controlled oscillator (VCO) model CRO6800Z-LF. The CRO6800Z-LF operates at 6800 MHz within a tuning voltage range of 0.5 to 4.5 VDC. This high performance VCO features a remarkably clean spectral signal of -104 dBc/Hz at 10 kHz offset and a typical tuning sensitivity of 18 MHz/V. The CRO6800Z-LF is designed to deliver +5 dBm of output power into a 50Ω load.

Z-Communications Inc.
www.zcomm.com

ANTENNAS

4G LTE Cellular Omni Concealment Antenna

VENDOR**VIEW**

The 4G LTE Cellular Omni Concealment Antenna (P/N # 1066-012) allows for easy and small spaces, and is ideal for low-profile or covert surveillance use. The penta-band design gives the antenna coverage across all 4G LTE bands, allowing for both domestic and international use. A miniature low loss RF cable and SMA Male connector allow for flexible connection options.

Southwest Antennas
www.southwestantennas.com

TEST EQUIPMENT

6 GHz High Speed VNA

AKELA introduces the only VNA available that can be controlled and programmed directly at the hardware level over LAN or WAN. 6 GHz high speed VNA with libraries of sample software in C++ and Python available on GitHub. The unit, priced at under $10,000, saves both hardware, software and operating cost in both production and remote environments, especially when used in conjunction with a switch matrix.

AKELA
www.akelavna.com

Phase Noise Test System

VENDOR**VIEW**

New GUI update now available for the BNC model 7300 phase noise test system. Key performance features include broadband 5 MHz to 26.5 GHz complete with no additional hardware, absolute and additive noise measurement included in one system, fastest ATE measurements in the industry (< 200 ms complete) and pulse and AM measurements capable. The GUI can be updated by simply by accepting the "Auto Update" notice feature, or by visiting the 7300 product page and see the latest firmware/GUI updates under the 'downloads' section.

Berkeley Nucleonics
www.berkeleynucleonics.com

MICRO-ADS

Antenna and Cable Analyzer

Bird Technologies introduced the SiteHawk SK-200-TC hand-held antenna and cable analyzer that operates from 300 kHz to 200 MHz. The instrument makes it simple to detect problems in coaxial transmission lines and antenna systems and pinpoint their source using distance-to-fault measurements. The SiteHawk SK-200-TC provides all of the measurement capabilities required to evaluate the performance of a communication system's transmission path, and has the same features as its higher frequency counterpart, Bird's SiteHawk SK-4000-TC, which operates over 85 MHz to 4000 MHz.

Bird Technologies
www.birdrf.com

Waveform Generator

The Highland Technology P350 "Wayback Machine" is an Ethernet-based waveform generator designed for aerospace simulation. Its eight analog outputs can be used independently or synchronously. In playback mode, it can store and play multi-gigabyte user waveform files, with programmable playback rates, summing, filtering, scaling/offset and phase/timeshift. Channels can also operate in wavetable mode, playing repetitive standard or arbitrary waveforms. Analog inputs and noise generators are available for modulation or summing.

Highland Technology Inc.
www.highlandtechnology.com

Radio Frequency Interference in Communications Systems

Bruce R. Elbert

With an increasingly crowded spectrum and communications systems often containing multiple radios in close proximity, preventing radio frequency interference (RFI) is a major design challenge. Bruce Elbert, author of "Radio Frequency Interference in Communications Systems" writes, "We have evolved from a time when static and background noise were the main cause of reception problems and connection failures; now, RFI is often the determinant of performance and, importantly, system capacity."

Best practices for solving RFI have historically been learned through the hard-earned experience gained by solving perplexing and persistent problems or from "gurus" with that experience. Elbert is such a guru, with 50 years in radio communications and, because it comes with the territory, RFI. This book condenses his expertise into an authoritative resource that provides a comprehensive strategy with practical approaches for identifying, preventing and fixing RFI.

To mitigate RFI, one must understand how wireless systems operate, how electromagnetic energy propagates and the mechanisms that produce it. Addressing these topics, Elbert organized the book into nine chapters focusing on three areas: radio communication system engineering, radio propagation, and RFI analysis and mitigation. The latter discussion delves into the interference protection ratio (C/I), spectrum analysis and monitoring, interference location, frequency planning, intermodulation and interference cancellation. The final chapter discusses the outlook for resolving RFI, given the trends in wireless systems. He describes new approaches to interference management, cognitive radio and spectrum management.

Elbert received a master's in communications engineering and computer science from the University of Maryland and bachelor's in electrical engineering from the City College of New York. He served as senior vice president of applications systems development at Hughes Space and Communications and is currently president of Application Technology Strategy LLC.

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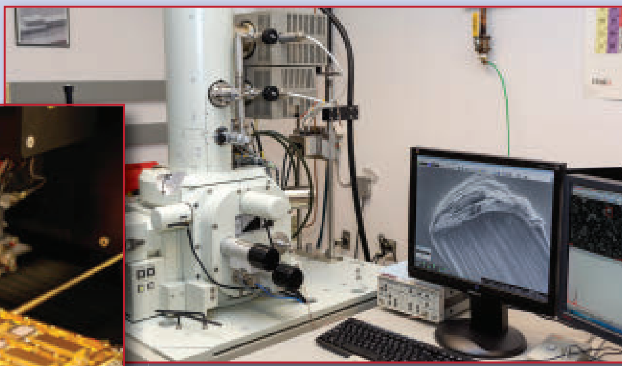
FABS and LABS

Ahead of What's Possible: ADI's Hybrid Module Manufacturing Center



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When Yalcin Ayasli left Raytheon to form Hittite Microwave in 1985, the market for microwave components was military, and GaAs MMICs were still a nascent technology. Ayasli built the small company one MMIC at a time. As the fabless semiconductor firm grew, designers expanded from GaAs to other semiconductor technologies, and Hittite built an enviable catalog of products for virtually all the RF functions in a typical block diagram. With such a large portfolio, from RF to millimeter wave, Hittite's designers found they could combine their MMICs into multifunction modules to solve many of the challenges facing defense systems. As the military community is understandably discreet, only those involved in such programs knew of the formidable module capabilities Hittite was developing. In 2014, Analog Devices (ADI) bought Hittite Microwave to accelerate growth and extend its portfolio from bits to millimeter wave. ADI quickly embraced Hittite's module capability and began expanding its reach.

Bryan Goldstein joined Hittite in 2003 and is now responsible for all of ADI's defense and space business and growth. With the enthusiasm of a proud inventor, he and Everett Cole, the director of the hybrid module manufacturing center, escort MWJ around an unassuming, DoD cleared building in Chelmsford, Mass. The facility occupies 72,000 square feet, of which 20,000 is clean room, and contains all manufacturing steps from incoming to shipment. In an average year, the operation will produce 10,000 integrated modules, 600 subsystems and 250 integrated systems — not high volume compared to mobile phones, yet very impressive considering the complexity, performance and reliability of the products, some of which fly in space.

The core of ADI's value proposition is their ability to build a subsystem using their own MMICs. Drawing from an extensive catalog of devices, they can trade component performance in the block diagram to optimize system performance. While simulating designs before building hardware is now common design practice, ADI is uniquely able to take the next step: quickly building a breadboard by pulling MMICs and evaluation boards from stock. Goldstein says the company's ability to provide measured data is a tremendous advantage when submitting a proposal.

ADI's manufacturing capabilities are extensive: five on-wafer probes characterize devices to 110 GHz and over temperature. Four wafer pick machines pull the good die and can bin them to sort performance. ADI employs both human and automated visual inspection, the choice depending on program requirements. Module assembly capabilities comprise vacuum reflow eutectic and automated epoxy processes for die attach, followed by ball, wedge and ribbon bonding. For space applications, the wire bonders also perform pull testing. As many high reliability applications require hermetic sealing, the facility has laser weld, seam, solder reflow and DAP sealing, as well as leak testing.

All environmental stress screening is performed in-house, including burn-in, temperature cycling, vibration, shock and high G centrifuge. The quality management system is AS9100 certified, with quality assurance and failure analysis capabilities that include real-time X-ray and scanning acoustic and scanning electron microscopes. Automated module test spans all microwave functions, including high power amplifiers, up- and down-converters and low phase noise synthesizers. With systems extending from RF to bits, test capabilities encompass the digital interfaces.

Over the years, ADI's module capability was marketed program by program, customer by customer. Bryan Goldstein wants to change that. "I want all aerospace and defense systems designers to know that we can help them develop the most advanced systems with faster time-to-market and higher ROI. We do this by providing the broadest portfolio of component and system level solutions. ADI provides solutions from the antenna to bits and from the semiconductor to the integrated subsystem. That is a true differentiator."

www.analog.com/adef

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Model	Frequency (MHz)		Power (W CW)		Insertion Loss(dB)	Rejection(dB)	VSWR		Size
	Pass Band	Stop Band	Pass Band	Stop Band	Pass Band	Stop Band	Pass Band	Stop Band	(Inches)
AF10200	0-2.5	4.5-30	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10201	0-4.2	7.5-50	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10202	0-7	12.6-100	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10203	0-12	21-150	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10204	0-19	34-200	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10205	0-30	57-250	500	150	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10502	0-2.5	4.5-25	1,500	400	0.5	45	1.30:1	1.60:1	12 x 5.6 x 3.25
AF10503	0.-4.1	7.4-41	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10504	0-6.7	12.1-67	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10505	0-11	19.8-110	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10506	0-18	32-180	1,500	400	0.5	45	1.30:1	1.60:1	15 x 6.1 x 3.5
AF10507	0-30	54-300	1,500	400	0.5	45	1.30	1.60:1	15 x 4.6 x 3.5
AF9673	1-2.7	3.9-32	1,200	150	0.4	50	1.40:1	1.40:1	15 x 4.6 x 3.5
AF9438	1-30	50-380	5,000	250	0.5	50	1.30:1	1.60:1	20 x 16.9 x 3.4
AF9349	10-150	270-1500	500	25	0.4	50	1.35:1	1.60:1	4.5 x 1.75 x 1.1
AF9187	10-490	850-3000	100	10	0.5	45	1.40:1	1.90:1	2.5 x 1.3 x 1
AF9350	10-500	750-3000	400	25	0.5	45	1.25:1	1.60:1	4.2 x 1.75 x 1.1
AF9960	10-500	750-3000	600	25	0.5	45	1.25:1	1.60:1	4.2 x 1.75 x 1.1
AF9680	10-520	1040-3000	160	10	0.6	60	1.25:1	1.60:1	4.2 x 1.75 x 1.1
AF9313	10-870	1700-4000	100	10	0.6	53	1.30:1	1.60:1	2.5 x 1.3 x 1

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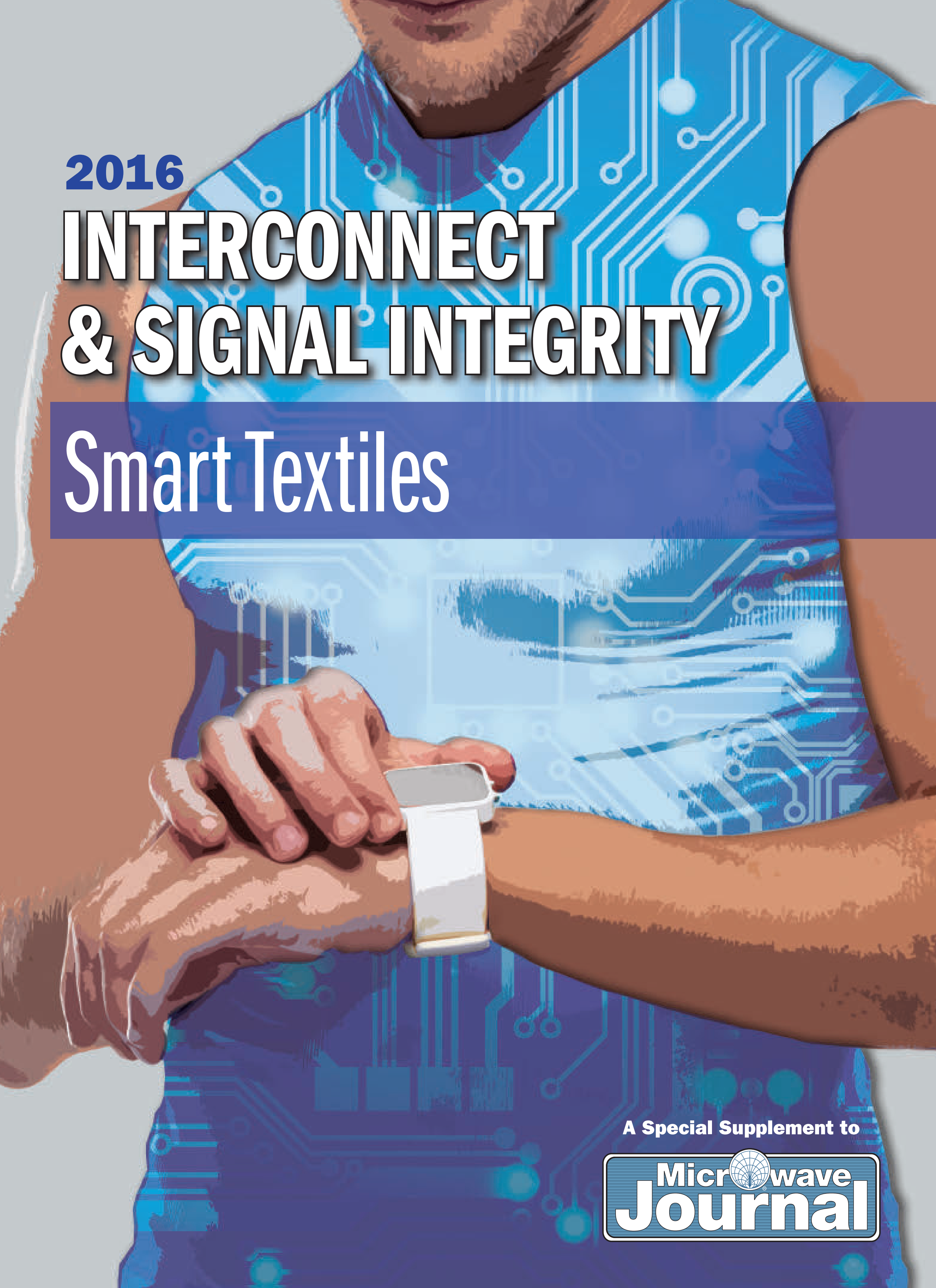


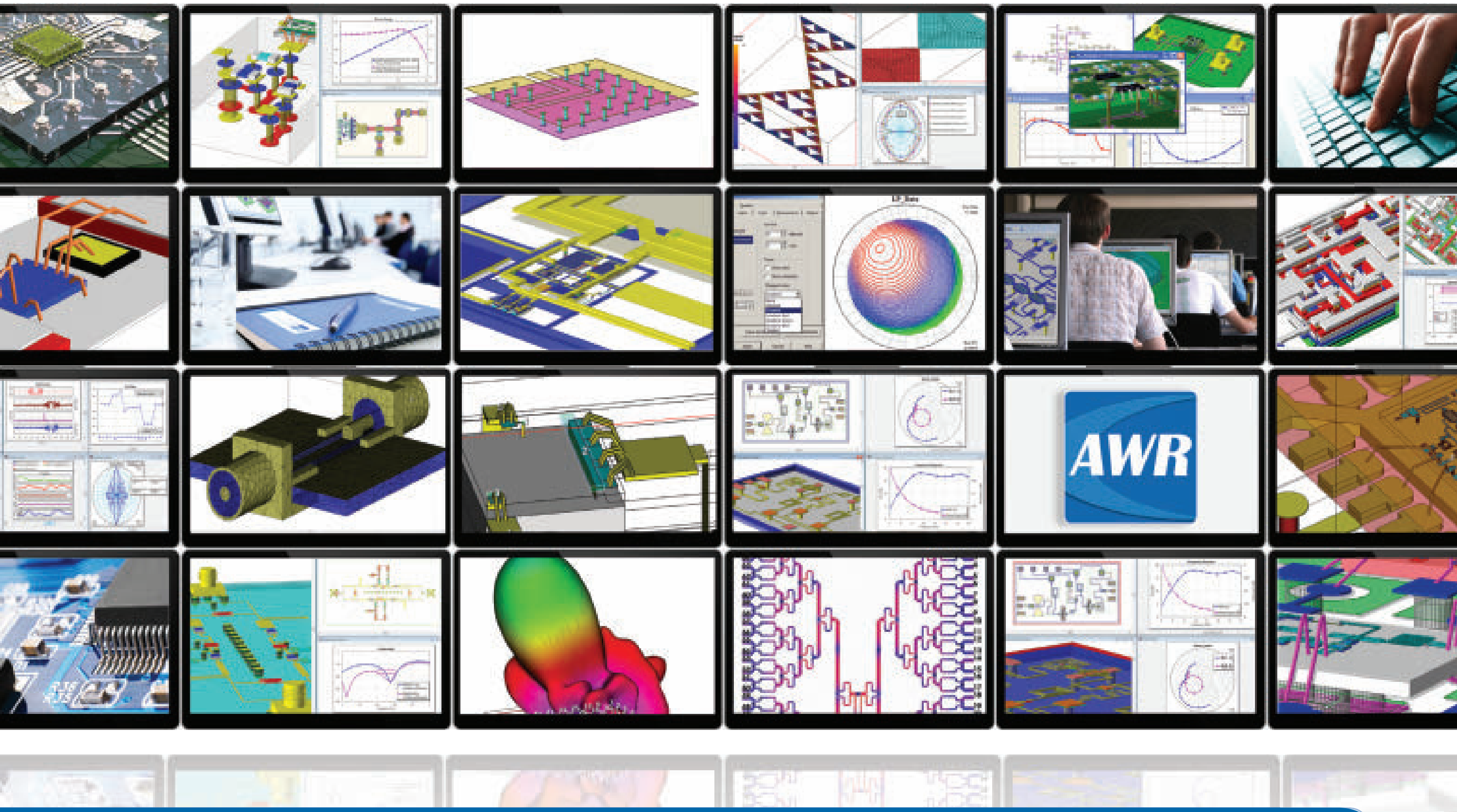
2016

INTERCONNECT & SIGNAL INTEGRITY

Smart Textiles

A Special Supplement to

Microwave Journal



AWR

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Connectivity Challenges in Smart Textiles

Nick Langston, Jr.,
TE Connectivity, Menlo Park, Calif.

In the emerging, amorphous Internet of Things (IoT), we find many expressions of technology: smart home, connected car, even the smart factory. Of all of the nascent markets in which low cost sensors and wireless connectivity are making new products and services possible, none have the potential to impact as many people in such a profound way as smart fabrics. The connected car can make your commute more efficient or productive via autonomous driving; the smart home can improve energy efficiency dramatically and illuminate new ways of improving our use of resources and time; the smart factory can enable faster, more efficient and safer work environments that in turn produce more advanced products at steadily declining costs. Smart fabrics, however, offer the opportunity to measure, analyze and inform the trajectory of our lives.

WHY SMART TEXTILES?

The IoT and 'smart' product movements are simply about enabling the collection and transmission of data to the cloud without human intervention. Textiles, in particular, are a fantastic medium for the integration of bio-metric sensors. There is good logic behind this as advances in flexible and printed electronics have led to the widespread availability of new conductors that are well suited to flexible, stretchable substrates like textiles. When you think about the opportunity for increasing understanding of ourselves and our physiology, textiles are the perfect medium. We are not just in contact with textiles most of every day — we are in contact with textiles most of our lives. There is no better vehicle for unobtrusive sensing of heart rate, breathing, muscle activity — even temperature and motion tracking.

STANDARDS

Wearables in general have a challenge when it comes to standards. While the existence of standard communication protocols like Bluetooth, Wi-Fi, Zigbee and USB have enabled very low cost components and increasingly miniaturized solutions, the connectivity and sensing between the product and its target — us — has endured a confusing array of possible paths. For example, while so many wristbands and smartwatches today are measuring heart rate via photoplethysmography, there is no standard to which any particular product can be certified for this measurement. It's the same for step tracking and motion sensing — each device manufacturer finds a different way of measuring these actions.

If wearables are bad with standards, smart fabrics are worse. While nearly every piece of smart clothing available today offers heart rate monitoring via ECG, there is no standard to which all of the sensors are measured. Additionally, this is not a piece of hardware we are talking about — it's typically a piece of athletic apparel, and standards in the apparel industry are not at all like standards in electronics or software.

CONNECTORS

Mention 'wearables' to someone and they're likely to think of a wristband like the Jawbone Up, Fitbit Charge or even the Apple Watch. Each of these products uses a proprietary external connector primarily for recharging the device's battery. Consumer experience with mobile phones has trained us to keep charging cables within reach — it is not unusual to recharge your phone while in the car or at the coffee shop. A wearable, however, has different expectations. There is no use case for charging something you wear — even more so when it is an article of clothing.

Often when designing a particular connector into an application or product, we are forced to deal with constraints that the available space forces on us. That is, we have a particular volume we can fill in a particular area of the device. Thanks to standards like USB, we know roughly how much space our plug or receptacle is going to fill. There are choices around how the connector is mounted or sealed within the device, and it's these details that normally comprise the bulk of the task of designing in the connector. In wearable devices and smart textiles however, this challenge is turned on its head.

Smart textiles typically rely on a connection to electronics rather than integration with electronics. While LEDs have been placed into textiles for some time, they stand alone as one of the few electronic components that have undergone direct integration. Using conductive elements in a textile for transmission or sensing while leaving discrete electronic components off-board (outside the textile) is much more common. Most of the conductors are in the form of silver threads that may vary in conductivity considerably depending on the particular thread but have a resistance of about 80 ohms per foot. Conductive polymers and pastes are also beginning to see wide use and have similar conductivity as the threads. In some cases, thin gauge copper wire is used as a sensor to measure changes in size or shape, expansion or contraction. In very few cases, there is also the need to deliver power, again via copper wires. With this variety in conductors, the major requirements of the connector are not electrical — they are physical. While the application requirements may differ significantly from one smart textile product to another, nearly all developers agree that the connection should be invisible, flexible and washable.

INVISIBILITY

When we speak of invisibility in textile connectors, we're really pointing toward the need for a solution that is unobtrusive. Because many smart textile products are garments — dresses, shirts, shorts — we need to consider the user carefully. No one wants a big, bulky connector on his or her shirt, especially if it's a tight fitting workout shirt. Today, many of the smart textile products use a simple button snap (see ***Figure 1***) as a connector.

▲ *Fig. 1 Button snap and constituent components.*

They provide a robust connection between the conductor and the electronics box, and they are a known quantity to textile and apparel manufacturers — no special training or tools required. They are, however, a single contact only. If you need multiple or high frequency connections, the solution can quickly become unwieldy.

FLEXIBILITY

In electronics, we are used to working with hard things: PCBs, semiconductors, displays, components of all types that get reflowed onto a board and often placed inside a hard enclosure, whether it is a cell phone, tablet or rack-mounted server. In smart textiles, it is the complete opposite — everything is soft and pliable. Connectors that had been designed to bridge circuits between two hard environments simply fall short when trying to bridge the hard-to-soft transition be-

RF Application

Standard button snaps perform poorly compared to traditional RF connectors for high frequency applications. The typical return loss of an SMA connector is 29 dB at 2.5 GHz while the return loss of a button snap has been measured to be only 10 dB at 1.5 GHz (Tiiti Kellomäki, "Snaps to Connect Coaxial and Microstrip Lines in Wearable Systems," International Journal of Antennas and Propagation, 2012). According to Kellomäki, button snaps are applicable for consumer applications in relatively low frequencies, such as broadcast radio (100 MHz), GPS or Galileo positioning systems (below 1600 MHz), RFID (850 to 900 MHz) and industrial/scientific/medical applications near 430 or 900 MHz, but they do not function well beyond these frequencies.

tween textiles and electronics. What developers have been asking for is a connector system that is physically flexible and can move with the contours of the textile itself when placed on a body or in its final application. The connector should not inhibit the flow or drape of a textile. Flexibility has a second meaning — adaptability. The connector must be physically flexible, but it should also be designed to meet a wide range of uses with a textile application. The ideal connector would be able to handle power, signal and RF within a minimized structure that meets the earlier requirement of being invisible.

WASHABILITY

Perhaps the most difficult requirement to meet is washability. It is amusing that while the connector industry has matured to provide all types of connection systems for use in deep space, in the depths of the oceans or even inside the human body, we have so few options for the washing machine. The agitation that a connector must endure during a typical wash cycle is very significant and, as a result, the strain relief between the connector and the conductor needs to be carefully considered. Additionally, we want to avoid developing connectors with small cavities that could fill with water or detergent and complicate successful connections after the wash cycle. Encapsulation of connection joints can help protect them but complicates the application by making a permanent connection when most designers are in favor of temporary, removable connections.

INNOVATING IN A MATURE INDUSTRY

Underneath the three requirements of invisibility, flexibility and washability is the implied ease-of-use. While exotic, miniaturized connector structures based on flexible electronics and conductive plastics are exciting and offer new ways of solving the connection problem, we must remember that the apparel industry has a very mature, well-established supply chain. In many cases their manufacturing and assembly techniques have not undergone significant change in decades. If we introduce a product

▲ *Fig. 2 Hexoskin smart apparel.*

▲ *Fig. 3 Conductive thread electrode.*

that requires tools or skills that are outside the norm, we are unlikely to succeed. There are no garment manufacturers training their people in soldering techniques no matter how good or revolutionary the connector may be. It is critical that connectors designed for textile applications also work within the constraints of the textile assembly ecosystem. Laser cutting, heat presses, stitching, and perhaps ultrasonic welding all provide viable paths towards connector assembly.

APPLICATION: SMART SHIRT

Let us consider a smart athletic shirt to see how all these components come together. There are several companies producing versions of these today, and they are gaining some traction with both professional athletes and the early adaptors in the gym. Smart shirts are typically a snug-fitting compression garment intended to be in close contact with the skin. An example is Montreal-based Hexoskin, producing products for athletes and astronauts since 2006. Their shirt is an example of the state-of-the-art in smart athletic wear (see ***Figure 2***).

All the smart athletic shirts today offer heart rate monitoring via electrocardiography. For sensors, the shirts use conductive threads that function as electrodes for the collection of ECG data. As mentioned ear-

Fig. 4 Chest straps with button snaps.

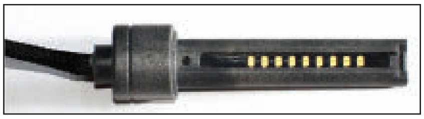

Fig. 5 Hexoskin's proprietary connector.

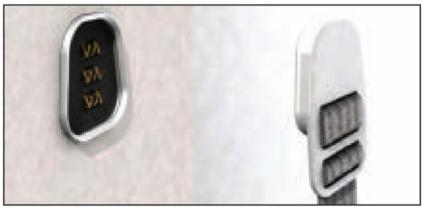

Fig. 6 Ohmatex's textile connector.

lier, these threads are somewhat resistive, but high conductivity is not necessary for sensing heart rate. These types of 'dry' sensors can be somewhat troublesome, in that they cannot get a good signal from the skin through body hair or without sufficient sweat between the thread and the skin to aid conductivity. Carbon nanotube based threads are being considered for these applications, and in some cases, may offer significant advantages due to their higher conductivity, while still maintaining a pliable, thread-like structure. Whichever element is chosen as the conductor for ECG, the requirements for the connector remain basically the same. At least two electrodes are created in the garment by either knitting with the conductive thread (see ***Figure 3***) or embroidering an already-built conductive polymer electrode and transmission line into place.

The transmission lines are most often terminated against a button snap as described earlier. No special treatment is required; the compressive force of the button snap assembly provides adequate electrical contact with the thread. Most of the chest straps available today use these snaps as the connection point to the electronics (see ***Figure 4***).

If we rely on button snaps as the connector, we are limited in how many points of contact we can have while keeping the small form factor or 'invisibility' that developers want. This means fewer lines of sensing, fewer lines for power and fewer opportunities to add the additional functionalities that would create so much value for users.

Hexoskin worked with the ecosystem of electronics suppliers to develop a connector for their shirt but ultimately elected to design and build it themselves (see ***Figure 5***). The resulting connector fits their application perfectly, while achieving cost targets they can live with. Their unique connector is at the end of a textile cable that is integrated into the shirt — this allows the user to connect to the electronic device and place it conveniently into a pocket while working out.

Danish entrepreneur Christian Dalsgaard launched Ohmatex in 2004, specifically to solve the connection and integration issues that he saw around smart textiles. They have developed a line of connectors for textile applications that are well suited for medical, military and aerospace applications — opportunities where the quality and durability of the connector is mission critical, and size is a secondary concern (see ***Figure 6***).

Smart textiles have been around for several years but are gaining momentum as one expression of the IoT and as consumer interest in wearable technologies increases. While many inventive startups have emerged to create new garments and other soft goods that include sensing and interactivity via flexible conductors there still remains a significant challenge in how we connect the hard world of electronics with the soft world of textiles. Clearly, there is an exciting opportunity here for inventive engineers and designers. If the shoe fits...■

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INVITED PAPER

Signal Integrity Tips and Techniques Using TDR, VNA and Modeling

Heidi Barnes, Jeff Most and Mike Resso
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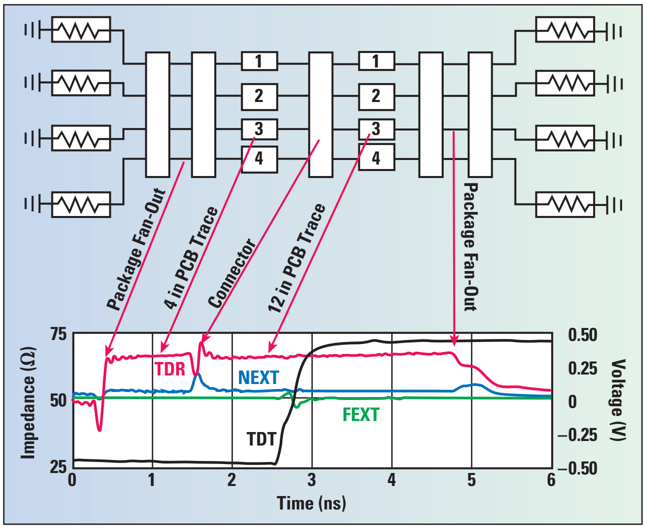
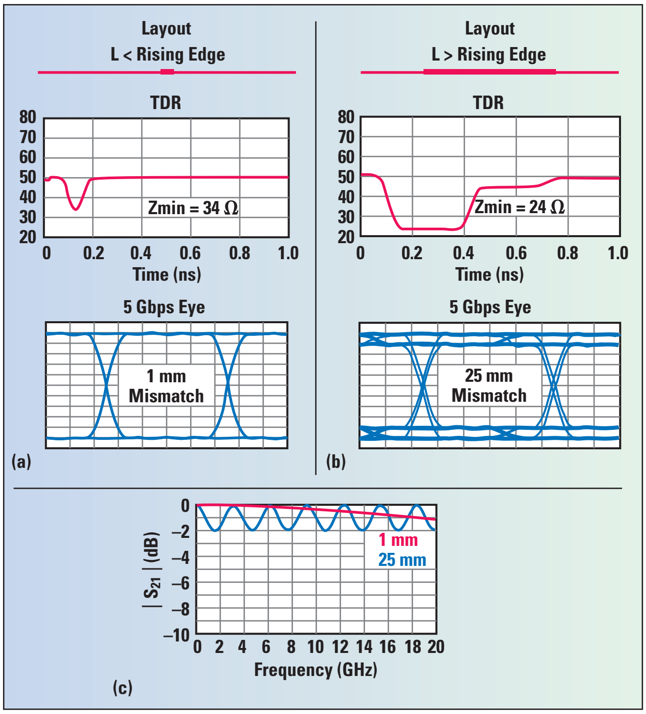
Signal integrity (SI) is all about the losses and types of signal degradation that can happen along the path (channel) between a transmitter and a receiver. In a perfect world, transmitter communication would instantaneously be heard at the receiver and with no change in the signal. Equalization methods exist both in the transmitter and the receiver to help correct for channel losses, but they have their limitations, and the channel must still have some minimal level of performance. SI engineers are faced with the challenge of how to characterize the signal losses that exist in the channel and identify the key elements that are controlling the performance. The use of time and frequency domain analyses for both simulation and measurements is a fast way of becoming an expert on a given channel design.



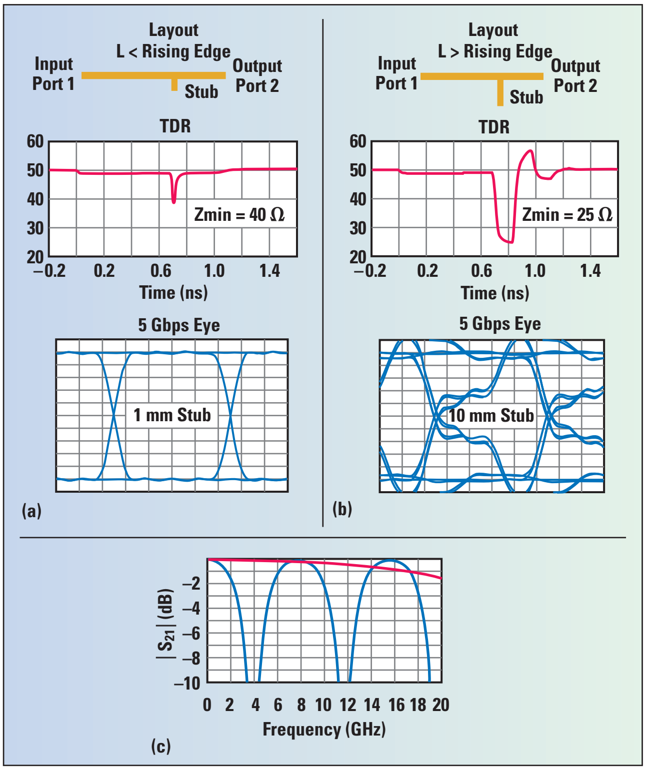
▲ *Fig. 1 Distributed model of the physical channel and the resulting TDR and TDT.*

SIMULATION MODELING

Starting with simulation, one can build a distributed model of the channel with measurements, EM simulations and/or algorithmic models that are cascaded together to predict channel performance. One can look at the output eye diagram to see the aggregate performance and do brute force simulations by varying hundreds of variables to find the best performance. The better option is to run quick time and frequency domain analyses to gain insight and reduce the design space that needs to be simulated. ***Figure 1*** shows how time domain reflectometry (TDR) and transmissivity (TDT) can be used to get spatial information on what is happening to the signal as it travels through the channel. The TDR shows where reflections are occurring, which



▲ *Fig. 2 TDR and eye diagram for series impedance discontinuities shorter (a) and longer (b) than the signal rise time. Insertion loss for the same discontinuities (c).*



▲ *Fig. 3 TDR and eye diagram for stub impedance discontinuities shorter (a) and longer (b) than the signal rise time. Insertion loss for the same discontinuities (c).*

reduces the amount of signal that reaches the transmitter. The TDT shows how the rise time is degraded by material losses in the channel. The near end cross talk (NEXT) on adjacent channels shows which component is the likely source of noise coupling, by being coincident in time with the component's TDR reflection.

This is a very high level look at the power of time domain analysis. To become an expert at reading the TDR/TDT and frequency dependent losses, some very simple simulations can help. The two basic types of impedance discontinuities encountered in a channel are a series change in impedance and a stub that branches off the signal path. Simulating the series impedance discontinuity from a length that is shorter than the rise time of the signal to a length that is much longer shows two very different responses in the time and frequency domain. As the length of the discontinuity gets shorter than the rise time of the signal, the reflection gets smaller and more of the signal transmits through (see ***Figure 2a***). At longer lengths, the double reflections off both ends of the series impedance discontinuity result in a forward traveling wave that is delayed in time and added back into the signal going to the receiver (see ***Figure 2b***). This causes a rippling in the amplitude of the signal versus frequency. The ripple valleys are located at frequencies where the forward traveling waves are 180 degrees out of phase and deconstructively add (see ***Figure 2c***).

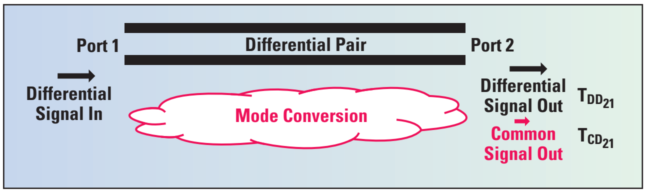
The stub resonator exhibits some of the same behavior. When the stub is much shorter than the rise time, the reflection is reduced, and more of the signal goes through to the receiver (see ***Figure 3a***). A stub longer than the rise time (see ***Figure 3b***) can lead to significant losses, where 100 percent reflection from the end of the stub deconstructively adds with the forward traveling wave (see ***Figure 3c***).

Simulation makes it easy to create a stub and series impedance discontinuity with the same excess capacitance and delta impedance change, to see how these two types of structures compare in the time and frequency domain. It is not just the TDR peak height that matters, but also the subtle information from the double reflection occurring later in time. With these two simple simulations, an SI engineer can look at an eye diagram at the receiver, an S-parameter frequency response or a TDR/TDT time domain response and know whether the problem is a series or stub impedance discontinuity.

FINDING CAUSES OF EMI

The spatial information that TDR/TDT provides can also be used for understanding and troubleshooting EMI problems coming from the physical channel. While there are many potential sources of EMI in high speed serial designs, the most typical is radiation caused by common currents generated by a differential channel. A common signal as small as 10 mV on an external twisted pair can cause an FCC certification test failure. In theory, if the drivers produce a perfect differential signal and the signal passes through a perfect differential channel, there will be no common signal generated. Unfortunately, in practice that is seldom the case.

Assuming the driver is perfect and considering just the channel, any asymmetry in a coupled differential channel will convert some of the differential signal into a common signal. This is known as "mode conversion" (see ***Figure 4***). Mode conversion is typically caused by asymmetries in the coupled lines, such as non-equal line widths and/or lengths,



▲ *Fig. 4 Asymmetry in a coupled differential transmission line will create a common signal at the output.*

different "local" effective dielectric constants, or ground-plane discontinuities. TDR can help in two ways. The first is to determine if mode conversion exists. Using TDR, the channel at port 1 is stimulated with a differential signal and the common mode response at port 2 is measured. ***Figure 5*** shows the measured results from a typical backplane. Three conclusions can be drawn from these test results:

- There is mode conversion in the channel
- The common signal and differential signal travel at similar, yet not exactly the same velocities
- The edge speed of the differential stimulus has a small impact on the mode conversion.

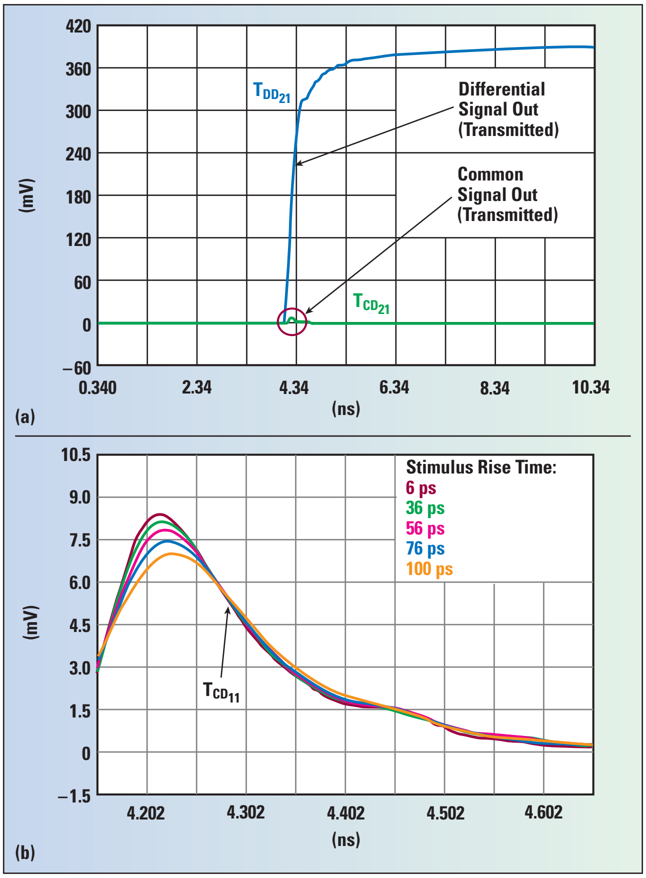
The second way TDR can help is to look at the reflected signal to determine what in the device under test (DUT) is causing mode conversion. ***Figure 6*** shows the measurement when stimulating the DUT with a differential signal at port 1 and measuring both the differential and common reflected signals at port 1. As the stimulus propagates through the channel, any asymmetry encountered will generate a common signal. Some of that common signal will propagate to port 2 and some will propagate to port 1, where it is measured as T_{CD11}. Because the velocity of the common signal is similar to the velocity of the differential signal, features in the impedance profile coincident with the common signal can be used to determine the cause of the mode conversion. In this case, mode conversion is caused by the via fields in the daughter card and backplane.

FIXTURE EFFECTS

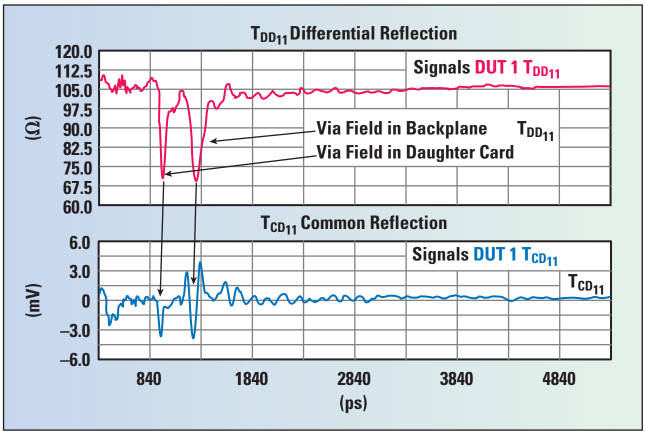
Finally, key to the success of distributed channel simulation and measurement is the ability to measure just the DUT. At high frequencies this can be quite challenging, as the fixture starts to become a significant source of signal degradation, requiring advanced calibration techniques to remove the fixture from the measurement.

Many different approaches have been developed for removing the effects of the test fixture from the measurement; these fall into two categories: direct measurement (a pre-measurement process) and de-embedding (post-measurement processing). De-embedding uses a model of the test fixture and mathematically removes the fixture characteristics from the overall measurement. This fixture de-embedding procedure can produce very accurate results for the non-coaxial DUT without complex, non-coaxial calibration standards. Direct measurement techniques require specialized calibration standards that are inserted into the test fixture and measured. The accuracy of the device measurement relies on the quality of these physical standards (see ***Figure 7***).

The most common calibration methodology is called TRL, for transmission (or thru), reflect and line. The constraints for the TRL standards are that the connectors and



▲ *Fig. 5 Measured TDT response of a backplane, showing the differential and common responses (a) and magnified view of the common responses vs. stimulus rise times (b).*



▲ *Fig. 6 Using TDR to find the cause of mode conversion.*

launches are all identical and all the transmission lines used for the thru and line standards have the same impedance, loss and propagation constant — only varying in length. The number of lines needed will depend on the frequency range covered by the calibration kit. The usable frequency range for each line is determined by comparing the phase of the line standard to the thru standard. Microwave test applications have used TRL calibration techniques for over 40 years with vector network analyzers (VNA). The TRL calibration technique relies only on the characteristic impedance of a short transmission line. From two sets of

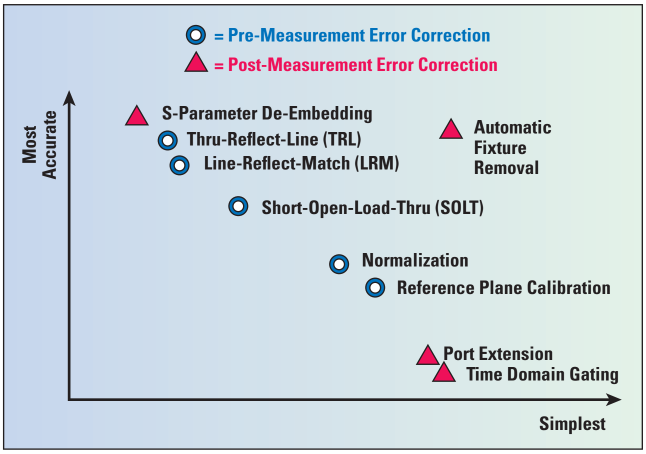
two-port measurements that differ by this short length of transmission line and two reflection measurements, the full 12-term error model can be determined. Due to the simplicity of the calibration standards, TRL can be applied in dispersive transmission media such as microstrip, stripline and waveguide. With precision coaxial transmission lines, TRL has provided the highest accuracy in coaxial measurements since 1975.

A recently developed calibration method called differential cross talk calibration (also referred to as differential TRL) is a differential version of the common, single-ended TRL, using differential instead of single-ended structures. Differential TRL is one of the few calibration algorithms, along with automatic fixture removal (AFR) that accounts for and removes coupling. The same constraints as the single-ended TRL described earlier apply to this differential method. Since these are differential standards, there are additional constraints: mode conversion, whether it be common to differential or differential to common, should be –30 dB or better. The skew between lines needs to be less than 10 degrees. As with single-ended TRL calibration kits, the fixture may be asymmetric (left and right half fixtures do not need to be the same length or impedance), but the fixtures need to be symmetric top to bottom (i.e., one leg to the other leg of the differential pair).

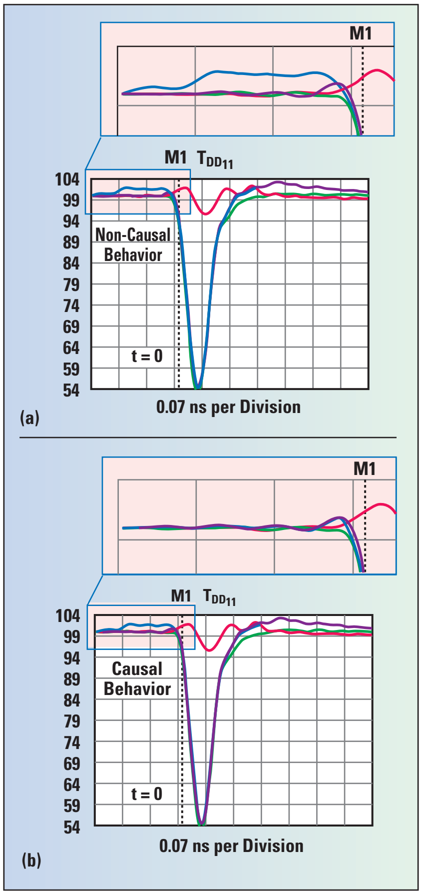
The latest generation AFR algorithms are often referred to as "one-port AFR." This reference to one-port can be either a single-ended port or differential port, but in either case there is no thru measurement required. This enables much simpler and straightforward error correction, because the user can simply use the open ended fixture as a reference standard, saving design time and fabrication costs. Similar to the single-ended AFR, there is a differential automatic fixture removal method. The difference in this method is that the thru is differential; therefore, any coupling that exists in the fixture is also removed in the process. Besides needing to be symmetric (right to left), like the single-ended AFR the thru must also be symmetric top to bottom. Like the single-ended version, this takes less to implement and build than the related multiple TRL structures.

A design case study was conducted to show an application where the 2× thru fixture was manufactured with typical PCB manufacturing tolerances of ±10 percent of the target impedance. This means the differential impedance of 100 V can be as high as 110 V or as low as 90 V, up to a 20 V spread in 2× thru impedance and, more importantly, a significant difference between the fixture to be removed and the 2× thru that is fabricated. Normally, one of the main assumptions in TRL and AFR is that the fixture and calibration 2× thru standard have identical impedance. Another breakthrough in calibration algorithms now exists, where impedance differences between the fixture and the calibration 2× thru standard can be tolerated. This provides new flexibility that improves accuracy and reduces implementation time by avoiding multiple board turns of the calibration 2× thru standard. This enhanced AFR algorithm will take the original measurement of fixture A + DUT + fixture B and compare it to the 2× thru. By specifying that the characterization fixture does not equal the DUT measurement fixture, AFR will use the actual fixture impedance and allow the proper impedance to complete the error correction methodology. The causality problem of having some erroneous response before time t = 0 is greatly reduced (see ***Figure 8***). This novel feature offers another breakthrough for automatic fixture removal and S-parameter accuracy.

Signal integrity engineers have many tools available in the lab to make life easier.[1] Microwave transmission line knowledge, calibration and error correction techniques, and time domain intuition all play an important role in identifying and resolving the root cause of problems. Simulation plus measurement techniques can help provide insight into the success of high speed serial channels. ■



▲ *Fig. 7 Assessment of the numerous error correction techniques for removing fixture effects on the DUT measurement.*



▲ *Fig. 8 Before (a) and after (b) TDR responses, showing the reduction in non-causal behavior using the enhanced AFR algorithm.*

Reference

1. Mike Resso and Eric Bogatin, "Signal Integrity Characterization Techniques," 2nd edition, International Engineering Consortium.

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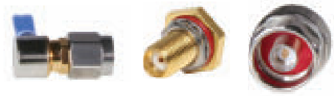

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INVITED PAPER

Streamlining High Speed Channel Design with Simulation

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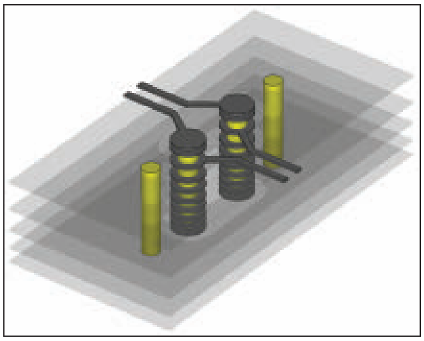
When designing high speed serial channels, engineers often find that multi-Gbps signals behave much the same as RF signals and that the three-dimensional (3D) structure of the transmission channel (vias, reference planes, connectors, etc.) becomes important. High fidelity 3D electromagnetic simulation has been used in the design process by RF engineers for decades, and the same techniques can also be used to model high speed serial channels.

This article will show how 3D electromagnetic simulation can be implemented in the design flow for high speed serial channels. It will show how to optimize reference plane changes and make early design decisions such as layer stack-up, via back-drilling or trace separation that are difficult to change later. At the other end of the design process is the verification/sign-off stage. One problem that plagues sign-off engineers is that not all components of the transmission channel are under their control and high fidelity simulation models of those components can be hard to come by. What to do in such cases and how to make reasonable assumptions about unknown components will be covered.

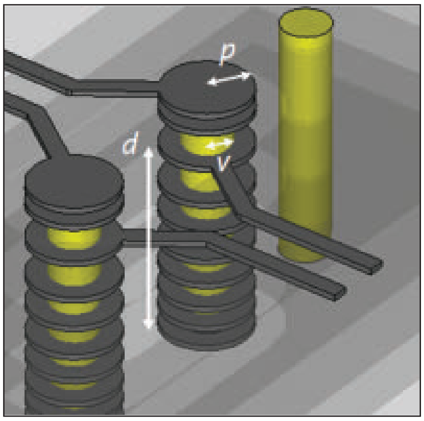
Signal integrity (SI) is of critical importance in modern electronic devices. Increasing speeds and the widespread adoption of mobile devices mean that two trends are increasingly dominating electronic design: an increase in frequency and a decrease in board size. These are changing the design workflow, as engineers need to account for effects that could previously be ignored.

Insertion loss is typically greater at higher frequencies and, to counteract this effect, emphasis and equalization are used. At the transmitter, the signal can either be filtered (de-emphasis) or amplified (pre-emphasis) in such a way that the insertion loss is counteracted. Both have their drawbacks: de-emphasis can cause noise problems by reducing the signal amplitude, and pre-emphasis can lead to emissions issues. For this reason, modern technology increasingly uses equalization where the signal is filtered immediately before the receiver.

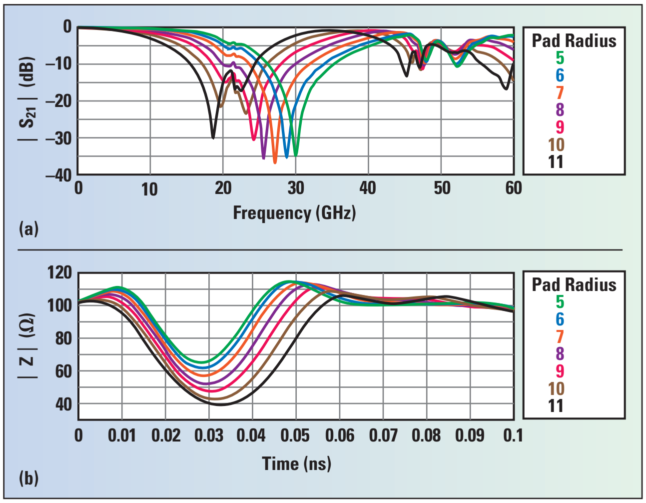
Emphasis and equalization are difficult to implement for parallel channels, since each receiver requires a separate equalizer module, resulting in larger/more expensive ICs and higher power consumption. In addition, parallel channels limit the minimum size of the electronics, and bringing many traces together increases the crosstalk problems. These are some of the reasons modern high speed transmission channels such as PCI, SATA, USB and HDMI are often implemented as serial channels using serializer/deserializer (SerDes) technology. Unlike single-ended parallel transmission lines,



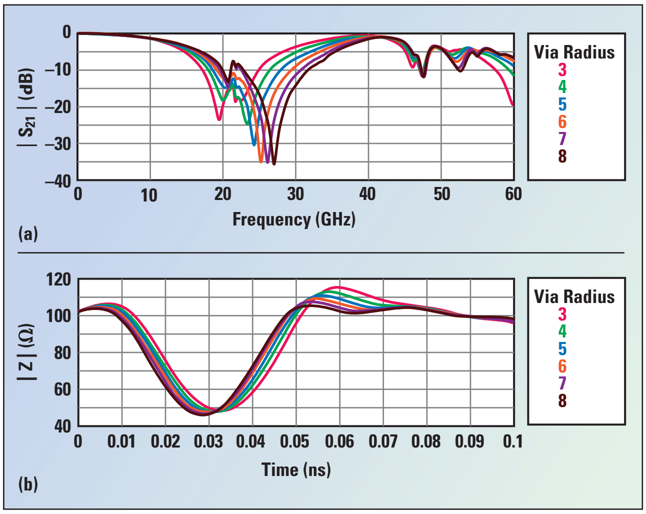
▲ *Fig. 1 A microstrip-to-stripline transition implemented with vias. The two outer vias are stitching vias, which provide a path for the return current.*



▲ *Fig. 2 The three design parameters: pad radius (p), via radius (v) and via stub length (d).*



▲ *Fig. 3 Insertion loss (a) and TDR response (b) vs. pad radius.*



▲ *Fig. 4 Insertion loss (a) and TDR response (b) vs. via radius.*

serial channels are usually differential. This article explains how a serial channel can be designed and characterized using simulation to verify that it meets signal integrity specifications, starting from the design of the vias through the full simulation of the board, including sockets, packages and cross-talk.

VIA DESIGN

Being routed on an inner layer of the PCB helps shield the trace. However, components are mounted on the surface of the PCB, so vias are used as transitions between the surface microstrip and the deeper stripline layers (see ***Figure 1***). The via represents a transition between two transmission lines and must be carefully designed to minimize reflection. A balance must be struck between signal integrity and manufacturing cost.

To investigate how the design parameters affect the performance of the vias, a study was carried out using a time domain EM solver in CST STUDIO SUITE®. The parameters investigated were pad radius, via radius and back-drilling (see ***Figure 2***). In each case, a parameter sweep was performed to calculate how these parameters affect the insertion loss and TDR response (see ***Guide to Terminology sidebar***). The via initially shows a resonance in the insertion loss at around 24 GHz, which could lead to signal integrity problems. Increasing the size of the via pad increases the capacitance of the via (see ***Figure 3***); changing the size of the pad shifts but does not remove this resonance. Changing the via radius has similar effects (see ***Figure 4***), as the via radius controls its inductance.

To deal with this resonance more effectively, back drilling is considered. Back drilling removes the unnecessary via stub, which is the source of the resonance. A simulation shows that back drilling to remove the stub entirely almost flattens the TDR response (see ***Figure 5***). The drawback of back drilling is increased manufacturing cost. As an alternative, the stripline could be routed on a much lower layer of the PCB. This would decrease the effective length of the via stub and reduce the resonance without the additional drilling. The benefit of this from a signal integrity perspective can be seen by looking at a simple channel. If it is assumed that the trace

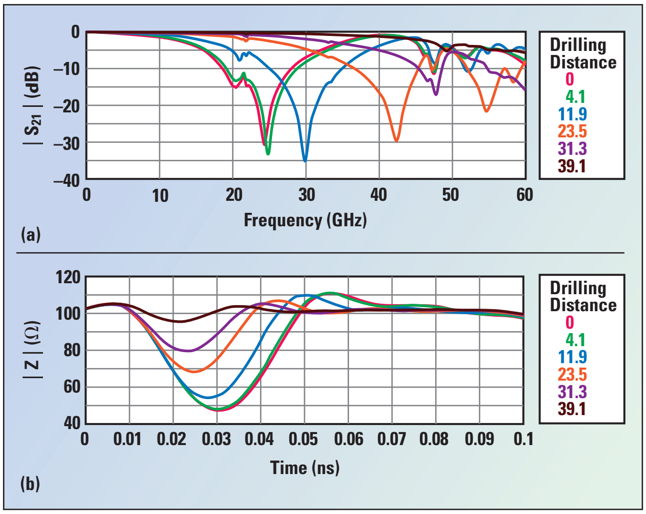
Microwave Meets Electronics: A Guide to Terminology

Because high speed digital channels combine the worlds of electronic engineering and microwave engineering, the terminology sometimes varies. Microwave engineers often work in the frequency domain using S-parameters (return loss and insertion loss).

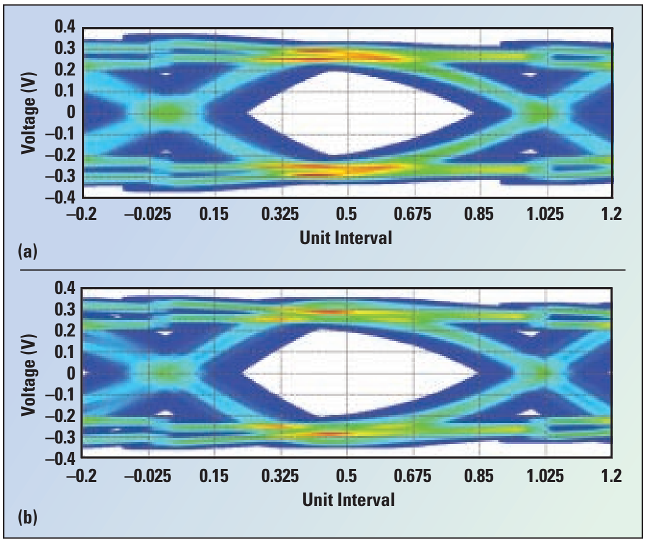
Electronic engineers are more likely to use time domain methods such as time domain reflectometry (TDR). This measures impedance as a function of time, helping engineers to identify discontinuities.

The eye diagram is then produced by injecting a digital signal into the channel and wrapping it around, usually every two intervals. This shows graphically the effect of intersymbol interference and crosstalk caused by the channel and the transmitter and receiver characteristics.

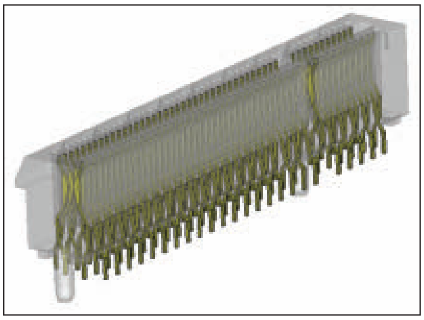
In this article, all of these methods and terms are used.



▲ *Fig. 5 Insertion loss (a) and TDR response (b) vs. drilling distance to vary the stub length.*

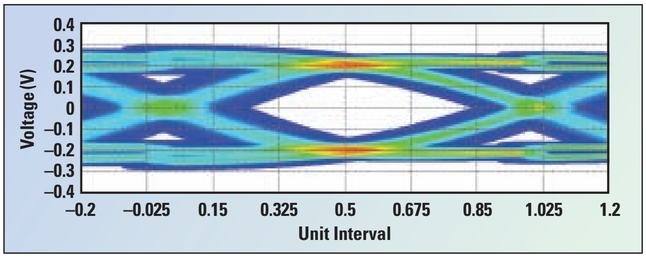


▲ *Fig. 6 Eye diagrams for a simple 8 Gbps channel with two vias before (a) and after (b) via optimization. The eye opening is 75.62 ps wide and 401.8 mV high before optimization, and 78.75 ps wide and 419.3 mV high after.*

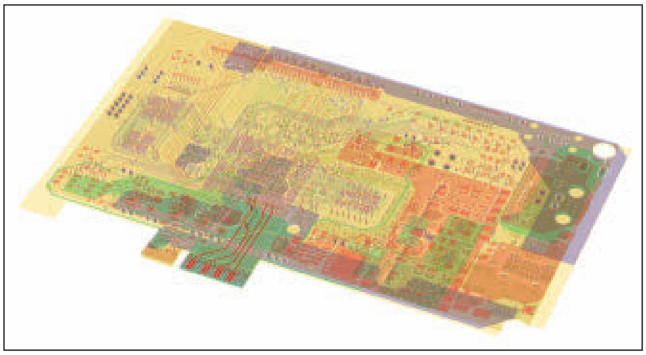


▲ *Fig. 7 Simulation model of a PCI Express connector.*

is a stripline with vias at each end, it can be simulated as a system to calculate its eye diagram, using I/O buffer information specification (IBIS) models. Data standards specify allowable eye opening values for channels to ensure SI performance, and the components need to remain above those values. Optimizing the via has increased both the eye height and width and offers more leeway to add additional components to the channel (see ***Figure 6***).



▲ *Fig. 8 Eye diagram for a channel including a PCI Express socket and two vias. The eye opening is now 73.12 ps wide and 278 mV high.*



▲ *Fig. 9 PCB simulation model showing several PCI Express traces (highlighted).*

BUILDING THE CHANNEL

With the traces laid out, the next step is to build the rest of the channel. Where a channel crosses from one board to another, there needs to be a connector or socket. In this case, a PCI Express socket (see ***Figure 7***) is used to connect the riser card to a motherboard. In some cases, a 3D model or an S-parameter model of a component is available from the manufacturer and can be implemented in the design directly. In other cases, the component might need to be modeled within the simulation software or characterized through measurements. In this case, the PCI Express connector is modeled while the motherboard is represented by a length of stripline. These were linked together using the circuit simulation solver in CST STUDIO SUITE®, which allows 3D models and analytical circuit elements to be combined. Adding the socket and the motherboard reduces the eye height to 278.0 mV, which is a significant drop compared to that seen when the stripline was kept to a single board (see ***Figure 8***).

In a real PCB, the exact route of the traces is also important, especially when taking crosstalk into account. The spectrum of high speed signals extends to very high frequencies — the fifth harmonic of an 8 Gbps signal is at 20 GHz. At these frequencies, the return currents in the reference planes have a severe impact on the signal integrity; even individual pads can cause unexpected resonances. Only full wave 3D solvers model these effects rigorously. In this particular case, a channel which includes a riser board (with a stripline trace and the vias), a socket and a motherboard are considered, with several transitions that can affect the signal. Taking the 3D structure of the PCB (see ***Figure 9***) into account reveals that there is a noticeable effect on the eye diagram — the eye width is reduced again to 72.5 ps and the eye height to 252.8 mV. This would not have been detectable using a simplistic analytic trace model.

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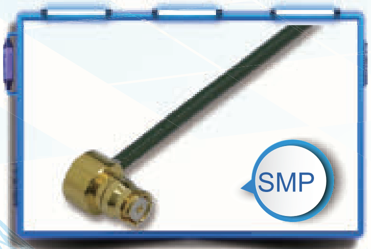
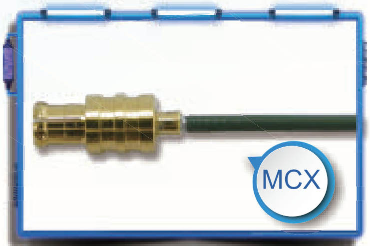
C25 Series Ultra Flexible .047 Cable Assemblies with Excellent Phase Stability over Flexure





C25 series is super flexible for durable cable assemblies of superior mechanical and electrical performance, well suited for applications requiring extremely limited installation space. C25 series can be built with a wide range of connectors, such as SMA, MCX, SMP and 2.92mm. These assemblies provide consistent performance with repeated bending and handling.

Advantages and Features:

- Ideal for applications requiring extremely limited installation spaces
- High strength braid with high retension
- Small bend radius of 5mm (0.2")
- Frequency up to 40GHz
- Excellent attenuation & phase stability over flexure
- Outstanding return loss performance
- High shielding effectiveness ＞100dB
- Direct replacement of .047 semi-rigid cable

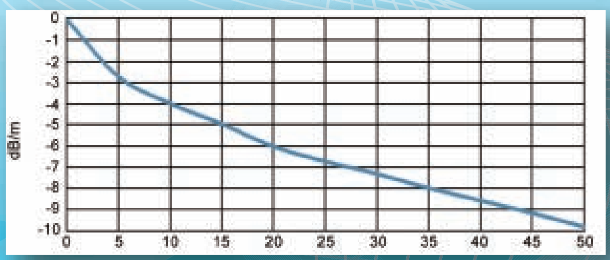
Optional Connetors			
Connector Code	Description	Frequency GHz	VSWR for Assembly (same connectors at both end)
01	SMA Straight Male	26.5	＜1.25
27	MCX Straight Male	12	＜1.25
37	SMP Straight Female	40	＜1.45
38	SMP Right Angle Female	26.5	＜1.40
40	2.92mm Straight Male	40	＜1.35
46	2.92mm Straight Female	40	＜1.40

Custom-assemblies with different connectors and length are available!

Part Numbering Code C25-01-37-16

- Length(default is inch)
- Connector code of end B
- Connector code of end A
- Cable Code

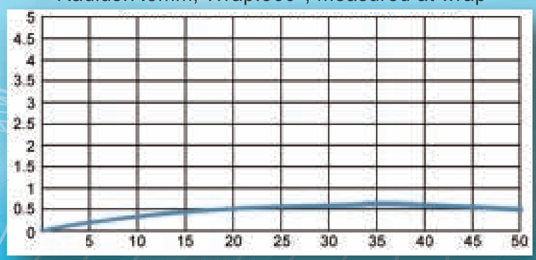
Attenuation



Frequency (GHz)

Phase Change vs. Flexure

Radius:7.5mm, Wrap:360°, measured at wrap



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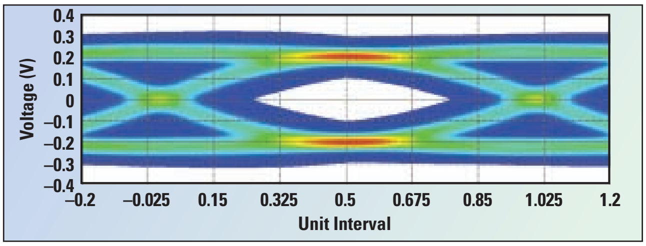

Fig. 10 Eye diagram for the full channel including crosstalk. The eye opening is now 65 ps wide and 206.9 mV high.

In this case, there are additional differential pairs on either side of the channel, driven by the same devices and acting as aggressors. Taking these into account is a matter of adding additional ports to the simulation. 3D simulation is critical here, as the exact separation between the traces across their entire length and especially near discontinuities will have a massive impact on the crosstalk. When the simulation is repeated with the aggressor channels included, it was found that the eye has closed even further (see ***Figure 10***). The width of the eye is now 65 ps, with an eye height of 206.9 mV. Compared to the bare stripline, the introduction of transitions, the consideration of the realistic 3D traces and the inclusion of crosstalk effects has revealed that the actual SI performance of the channel is significantly different.

With the full channel modeled, one more important figure of merit can be calculated. This is the timing bathtub, which shows the expected bit error rate (BER) at different sampling times (see ***Figure 11***). The eye width determines the width of the bathtub. In this case, the channel still meets PCI Gen 3 specifications, but in other cases the channel will need to be rerouted or otherwise modified to improve its transmission characteristics and reduce crosstalk.

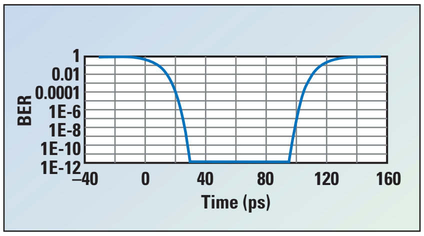

Fig. 11 Bathtub curve for the full channel, including crosstalk.

CONCLUSION

The performance of a high speed digital SerDes channel is dependent on the performance of every part of it, from the traces and the connectors to the transmitters and receivers. Identifying and mitigating potential SI problems early in the design process can save time and money later on, but these SI problems can depend on complex couplings that can only be identified by full 3D electromagnetic simulation. These include the back drilling of vias, the quality of the connectors, the routing of the traces and the chips that drive the channel. All of these can be considered by simulation, allowing the performance of the entire system to be analyzed. ■

INVITED PAPER

DPI With Integrated Current and Voltage Measurement

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Special test procedures are needed to determine the immunity of integrated circuits (IC) to RF interference. Defined RF disturbances must be injected into the IC via defined networks for this purpose. The electromagnetic compatibility (EMC) standard for ICs (IEC 62132) provides three methods for such characterization: the direct power injection (DPI) method, the transverse electromagnetic (TEM) cell method and the use of an IC stripline. The DPI method is based on the conducted injection of disturbance power into the IC. The TEM cell method and the IC stripline are characterized with an electromagnetic field that propagates within a defined cell and acts directly on the IC surface.

This article examines the DPI test method and explains limitations that are used as a starting point to extend this method. The parameters obtained with the extended method describe the IC's immunity for its future practical use. The IC user can use these immunity parameters as a basis for selecting the appropriate IC for a specific electronic system and as a basis for EMC design in printed circuit board (PCB) development. Furthermore, the IC manufacturer can use this information to narrow and eliminate weak points in the chip. The article also presents a practical example of a local interconnect network (LIN) transceiver that is examined using an extended DPI test method.

The DPI method according to IEC 62132-4 (see ***Figure 1***) has proven successful in evaluating the EMC immunity of ICs. RF is injected into an individual IC pin by conductive coupling. The RF current flows from a power amplifier to the respective pin via a 50 Ω line and a coupling capacitor. The intensity of the RF disturbance is determined by the forward power that is measured with directional couplers. The power is the correct physical evaluation parameter if an RF-induced rise in temperature in the IC results in its malfunctioning.

Other RF interference events may, however, be independent of the power that is fed in. The oscillator may stop or demodulation may occur in an operational amplifier, a transistor or diode, for example. These interference mechanisms depend only to a small degree on the power converted in the IC; rather, they are triggered directly by basic physical parameters such as the RF current and voltage (e.g., demodulation of the RF current). The disturbance voltage or current is also the parameter responsible for driving the respective interference event in the device under test (DUT) in other fields of EMC testing, such as burst or ESD tests. A high current or a high voltage is not necessarily accompanied by high power.

When testing semiconductors, matching depends on the switching state. In addition, the switching edge has to be taken into account with its own mismatch characteristics. The average $P_{forward}$, P_{back} power measurement does not provide relevant system information in terms of the u(t) and i(t) parameters. The variation of the RF current and voltage over time, however, is crucial for gaining new insights, such as the identification of weak points in the IC and for organizing countermeasures in IC and PCB development.

MEASURING INTERFERENCE WITH AN AMMETER AND VOLTMETER

The ohmic resistance of a microcontroller power supply pin is usually small, in the range of a milliohm to an ohm. A capacitance of several nF may be integrated into the IC, which also presents impedances on the order of an ohm at frequencies of 100 MHz or higher. IC line inductances produce similar values. Hence, the IC's internal resistance is very low and may be considerably smaller than the 50 Ω source of the power amplifier. This means that the power amplifier operates under short-circuit conditions, supplying its maximum current. The fed-in current interferes with the IC function, but a power meter shows only a few mW. Consequently, the IC is evaluated as much too weak and is misclassified based on the power evaluation.

The impedances of other IC pins may be between a milliohm and a kilohm. The system approaches short-circuit conditions for IC impedances less than 50 Ω and open-circuit conditions for impedances greater than 50 Ω. Immunity tests at a quasi open-circuit voltage, as are common practice in high voltage technology, are not possible with RF injection into an IC. The current and voltage conditions are system dependent and must be measured directly on the pin (see ***Figure 2***). This electrically short measurement setup avoids metrological difficulties caused by standing waves that may be generated on the line to the power amplifier.

Figures 3 and ***4*** show the P500 probe measurement system. RF disturbances flow from the power amplifier into the IC pin to be evaluated via the connected P500 probe. An ammeter and voltmeter are integrated into the probe so that the current, voltage and phase angle can be measured directly with an oscilloscope. Power, impedance and other

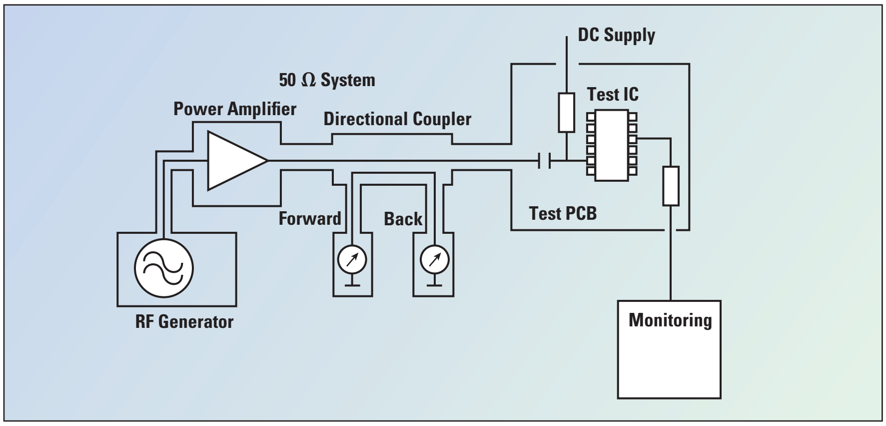

Fig. 1 DPI method according to IEC 62132-4.

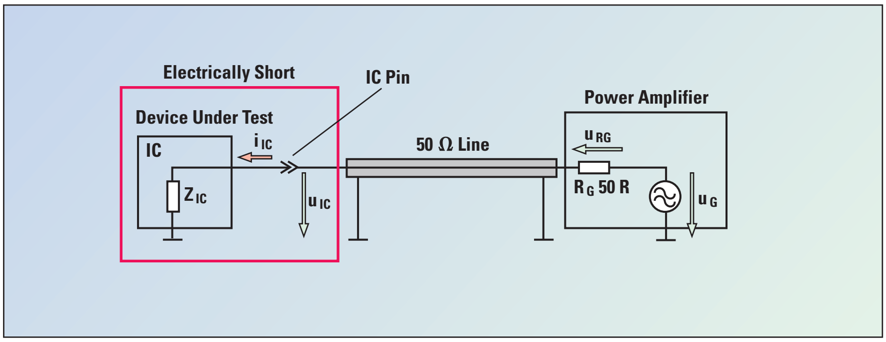

Fig. 2 Setup to measure current and voltage on the pin.

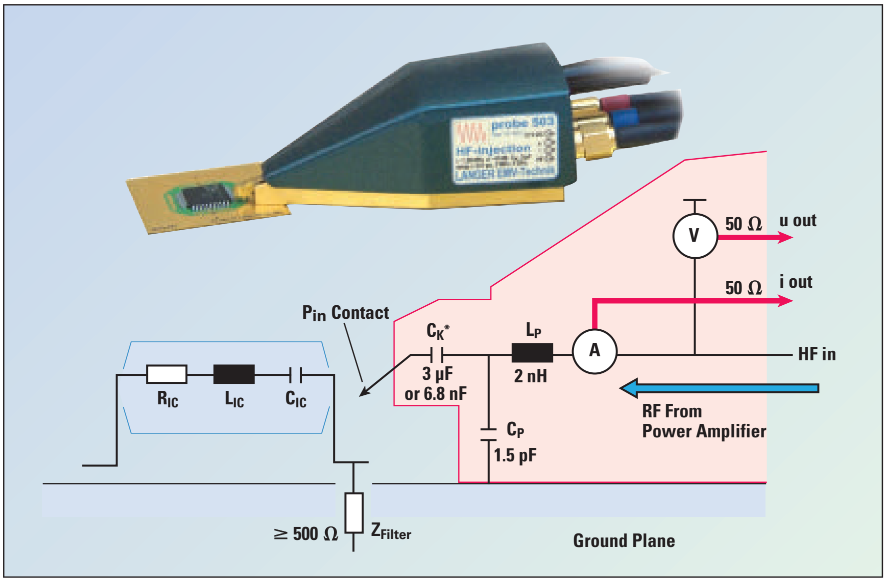

Fig. 3 P503 probe.

parameters of the device under test are calculated from the measured values. These parameters allow engineers to draw more detailed conclusions about an IC's EMC within the respective electronic system. Malfunctions that occur at high current intensities, for example, are often due to magnetic coupling, while those that occur at high voltages are due to capacitive coupling. This new RF injection method using integrated current and voltage measurement is beneficial for IC development. It enables the measurement of reactive currents that remain undetected with usual power measurements and provides detailed physical insights that are not otherwise attainable.

INVESTIGATING A LIN TRANSCEIVER

An RF equivalent circuit can be derived for each IC pin from the results obtained with the P500 probe measurement system. The impedance of the pin depends not only on the switching state of the signal but also on the RF generator voltage. The P500 probe is used to inject a small RF level into the pin. These disturbances must be low enough to prevent protection diodes from opening and additional current paths and elements from becoming effective. On the basis of the u, i and φ values measured with the oscilloscope, the IC's resistance and reactance is determined as a function of frequency. If there is no dominant capacitive or inductive component, the reactance can be split into X_C and X_L by calculation. This requires measurements at different frequencies. Weak points can be found in the IC through a high frequency and low frequency current and voltage analysis on the IC pin. The high frequency voltage may cause diode paths to open, for example, resulting in an impedance change.

The measurement system can be used for a variety of practical analyses. For example, it allows the visualization of time-varying, non-sinusoidal high frequency current and voltage waveforms (see ***Figure 5***). Additional current paths will open as soon as the forward voltage of internal diodes is reached. The impedance of the IC drops, the current increases, and the voltage may be limited (feedback to supply network). When a diode opens, new coupling paths become effective; the current that flows through the diode enters other network sections as rectified current. These currents or voltages are superimposed onto useful signals such as trigger or control signals on the LIN driver and cause the FET to go into a blocked, open or undefined state. Further internal IC mechanisms may be clarified by analyzing current and voltage as a function of time. Manufacturers can launch a targeted IC improvement and users can derive EMC countermeasures addressing the IC's practical use.

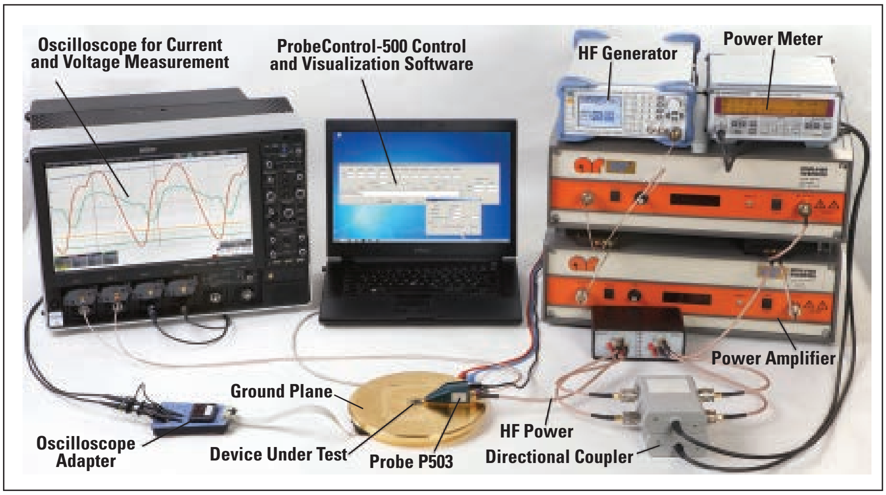

Fig. 4 Measurement setup with a P503 probe.

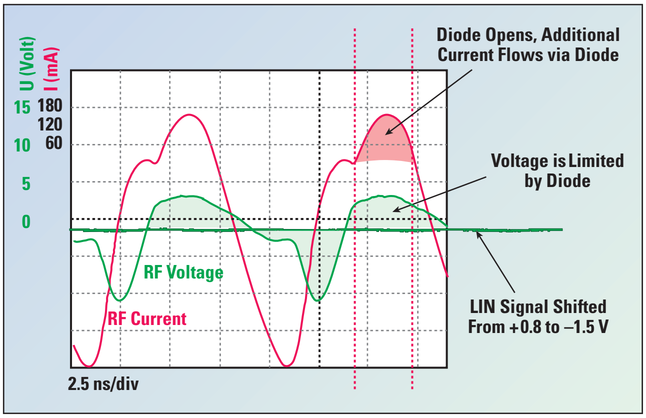

Fig. 5 Time-varying, non-sinusoidal, high frequency current and voltage waveforms measured with the probe.

USE WITH MODULE DEVELOPMENT

A sensitive IC can fall victim to interference if an RF current couples to susceptible pins via internal coupling paths in the layout. RF current may flow from a vehicle board network plug to the V_{bat} pin of the LIN transceiver via corresponding line connections. The RF current may also reach the ground pin via the ground system, particularly in the segmented ground of a two-layer PCB. This coupling path can be blocked by an all-over contact ground system. In addition, the blocking capacitors have to be adequately dimensioned on V_{bat}. A filter structure that comprises an inductor and two filter capacitors in a pi network is recommended. The filter prevents RF current from reaching the sensitive pin. This measure can be taken with due care at the beginning of development if the V_{bat} pin is known to be sensitive.

Interference suppression on a module that comprises LIN transceivers is difficult in practice, as the respective pins responsible for IC interference must be identified. The situation becomes unclear if the IC has several sensitive pins that all contribute to its malfunction. The effectiveness of individual measures is concealed due to coupling to other pins. If the IC's sensitive pins are known, reliable countermeasures may be taken in the right places even before beginning the actual EMC work. EMC problems of ICs can thus be controlled more quickly and easily. ■

INVITED PAPER

Appropriate Data Line Common Mode Choke Selection

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Würth Elektronik eiSos GmbH & Co. KG

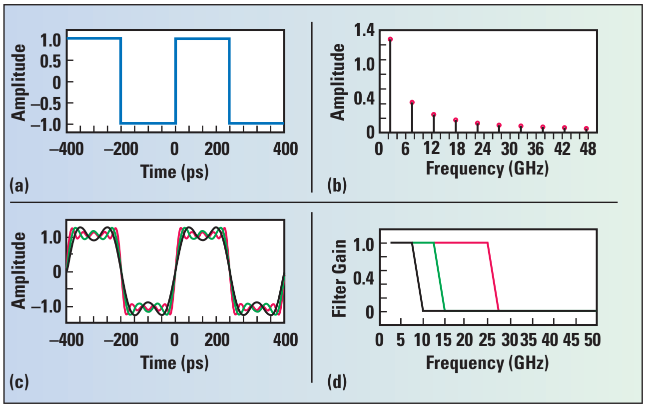
Selecting a common mode choke usually comes with more issues than might be expected. The selection process involves evaluating a range of different filter characteristics and aligning them with the desired system specifications. The aim of this application note is to help the design engineer to choose the right filter for the application and explain some concepts that are important when choosing a suitable filter for the requirements of a given system. These include matching impedances as well as considering the adequate cutoff frequency, and differential and common mode attenuation.

A number of 'eye diagrams' are referred to, which are composed of an overlay of several data frames to give an indication of how a component or transmission line changes the waveform of a transmitted signal. Statistical data frame overlays are used, which reveal reflections on the line, phase shifting as well as added signal noise.

Most digital signal standards such as USB or HDMI define a mask to fit into the free area of the eye diagram, thereby establishing limits for the minimal eye opening or signal shape. This translates into both the minimal voltage level needed to avoid signal decoding errors and the minimum signal width or time period for the digital symbol to be maintained to avoid signal decoding errors. Both parameters are important indicators for the integrity of a given signal. The eye diagrams shown were measured on a network analyzer with Time Domain Reflectometry (TDR).

CUTOFF FREQUENCY

A low pass filter's cutoff frequency (f_c) is defined as the frequency at which the filter attenuates the amplitude of the signal by 3 dB. A 3 dB attenuation reduces the power of the input signal to half of its original value. This frequency is also known as f_{3dB}. ***Figure 1*** demonstrates the effect of a series of low pass filters with different cutoff frequencies under ideal conditions. ***Figure 1a*** shows the input signal and ***Figure 1b*** the signal's harmonics. ***Figure 1c*** shows the signal's output shape after the filters — the color of each of the lines corresponds to the filter — the frequency response of which can be seen in ***Figure 1d***. This graph also reveals which of the input signal's harmon-



▲ *Fig. 1 Effect of different filters on a digital signal under idealized conditions.*

ics are being filtered by the individual filters. Their f_{3dB} values are 9, 14 and 26 GHz, respectively.

In order to retain the integrity of a signal, it is recommended not to filter its first four harmonics. In keeping with this, the cutoff frequency should be greater than the fourth harmonic frequency of the signal. For a square wave, this is four times its base frequency.

TRANSMISSION PARAMETERS

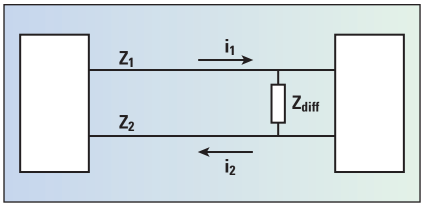
The next step would be to put all this together and look into a typical product catalogue to identify a filter that is the best fit for the application. However, this might not be quite as easy as expected: Some parameters — notably the cutoff frequency — do not appear in many of these compilations. Instead of the attenuation in differential and common mode, impedance values in both modes are given, so finding the right common mode choke might be a bit of a challenge. However, the specifications do include graphs and these will help find the right filter if used in the right way.

The graphs included in such a catalogue tend to be closely related, meaning that when the attenuation of a component increases the impedance will also increase. However, a closer look into the specification details can reveal other ways to retrieve the desired attenuation values.

The main way to derive a filter's attenuation is by means of its scattering parameters, which provide transmitted and reflected signal ratios. There are two ways of representing these parameters; as scattering parameters or as mixed mode scattering parameters.

The single ended scattering parameters represent the relationship between input and output levels using different test configurations for the common and differential modes. These test configurations or test fixtures deliver good approximations of the attenuation of a filter up to a few gigahertz but for frequencies beyond 3 GHz these approximations may not be valid.

Mixed mode S-parameters are four wire type measurements. With reliable measurement in the high frequency components, there is no need for extra approximation to be done. It is possible to send a differential signal through the coaxial cables and see the effect of the circuit on this signal. Furthermore, it is possible to measure the attenuation of a common mode signal or the conversion between common and differential modes. This measurement method yields the mixed mode scattering parameters, SDD for the differential mode and SCC for the common mode, while the general S-parameters do not differentiate between differential or common mode unless certain other SMD test fixtures or approximations are used.



▲ *Fig. 2 Trace configuration.*

TRANSMISSION LINE IMPEDANCES

When considering the requirements for a differential data line there are certain terms used such as characteristic impedance, differential mode impedance, or common mode impedance. The characteristic impedance of a line is the relationship between the amplitudes of oscillating voltages and currents travelling through the line. This value is calculated in a line without reflections, so the length of the line has no influence on it.

The common mode and the differential mode impedances depend on the characteristic impedance (Z_o) and the coupling factor between traces (k). To clarify the meaning of these two impedance values, this note will explain the meaning of the terms odd mode impedance (Z_{odd}) and the even mode impedance (Z_{even}).

Figure 2 shows a trace configuration in a differential transmission line. From this configuration, the applied voltage in each trace can be calculated as:

$$V_1 = Z_1 i_1 + Z_1 k i_2$$
$$V_2 = Z_2 i_2 + Z_2 k i_1$$

If the transmission is balanced and the traces are designed carefully

$$i_1 = -i_2 \text{ and } Z_1 = Z_2 = Z_0$$

Under these assumptions, the first two equations can then be rewritten as:

$$V_1 = Z_0 i_1 - Z_0 k i_1 = i_1(1 - k)Z_0$$
$$V_2 = Z_0 i_2 - Z_0 k i_2 = i_2(1 - k)Z_0$$

Rewriting the equation to show Z_{odd} results in:

$$Z_{odd} = (1 - k)Z_0$$

In unbalanced transmission mode the following applies:

$$i_1 = i_2$$
$$Z_1 = Z_2 = Z_0$$

So the applied voltages in the traces can be rewritten as:

$$V_1 = Z_0 i_1 + Z_0 k i_1 = i_1(1 + k)Z_0$$
$$V_2 = Z_0 i_2 + Z_0 k i_2 = i_2(1 + k)Z_0$$

This results in Z_{even} as:

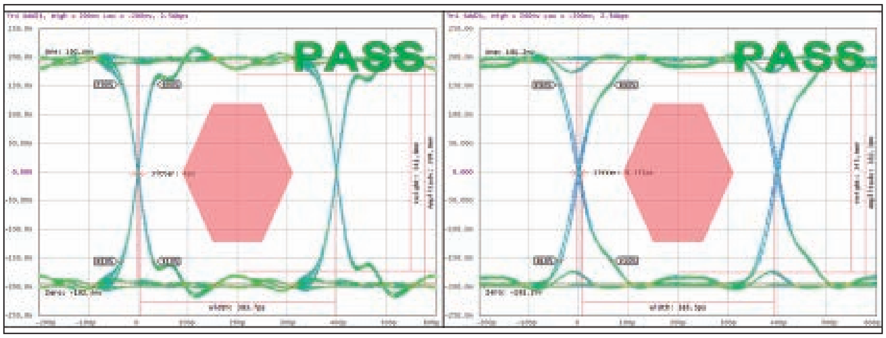
$$Z_{even} = (1 + k)Z_0$$

Once Z_{even} and Z_{odd} have been calculated it is easier to define the differential and common mode impedances. It is assumed that both lines are connected to ground at the end. In differential mode, the fact that $i_1 = -i_2$ is made use of, which means there is no current flowing to ground. This leaves the impedance between the two lines equal to the Z_{odd} values of each trace connected in serial:

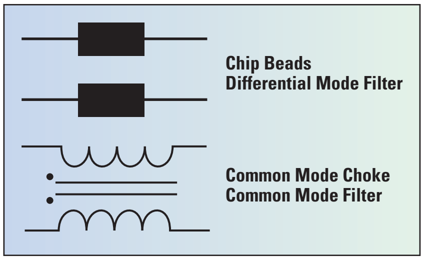
$$Z_{diff} = 2Z_{odd} = 2\,(1 - k)Z_0$$

This explains why the impedance in differential mode can be much higher than the characteristic impedance.

Now, making the same assumption for the common mode and taking into



▲ *Fig. 3 Reflection effect of common mode chokes in differential mode visualized with eye diagrams.*



▲ *Fig. 4 Filter setup.*

account that $i_1 = i_2$, meaning that all current will flow through ground, establishes the common mode impedance as equal to the Z_{even} values of each line connected in parallel:

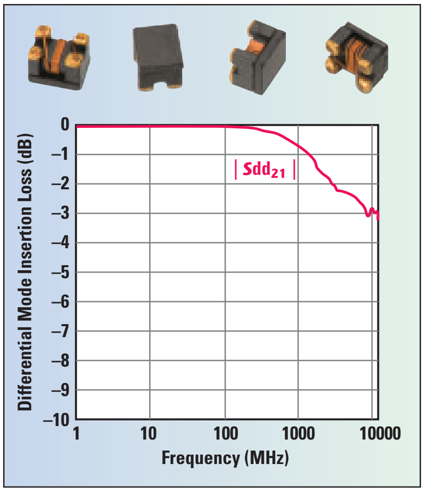
$$Z_{comm} = 2\,Z_{even} = (1+k)Z_0/2$$

IMPEDANCE MATCHING

In order to reach the maximum power transfer the impedances involved should be considered. When designing a circuit the aim should be to match the source impedance with the load impedance as a necessary condition to avoid reflections that might disturb the signal.

However, when a new component is added the impedance of the system will change and there may be undesirable reflections. The best filter to insert into the system would be one with no differential mode impedance at the operating frequency but this is impossible in practice. Because of this, a filter is required with as low a differential mode impedance in the desired frequency range as possible.

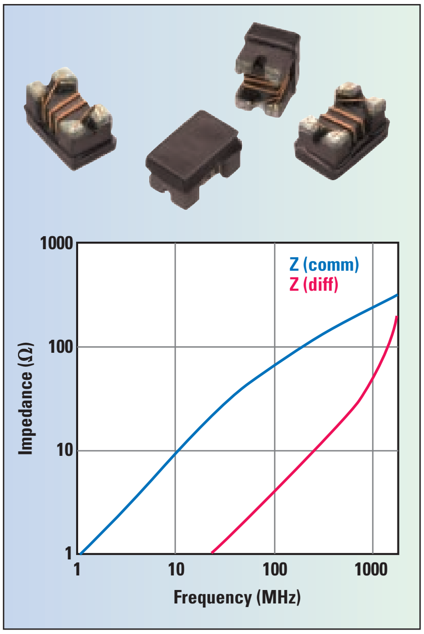
The target for the common mode choke is to balance the differential signal, which means that the signal power levels in both lines should be the same but with opposite signs. To reach this goal the common mode interference portion must be removed without affecting the integrity of the differential signal. This is why it is essential to look for a common mode choke that offers higher common mode impedance and lower differential mode impedance in the desired frequency range.



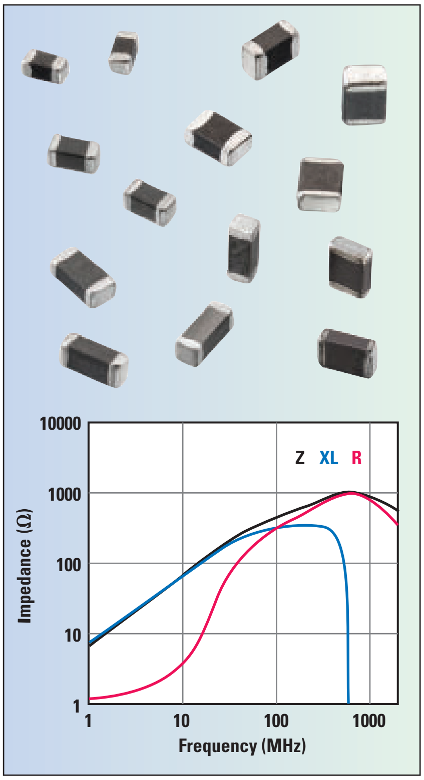
▲ *Fig. 5 First Filter: WE-CNSW HF 0504 (7442335900) characterized by the mixed scattering parameters.*

Figure 3 illustrates the effect of a common mode choke on a digital signal at 5 Gbps with Non Return Zero (NRZ) modulation. Some reflections still appear when the filter is inserted because of a small impedance mismatch on the transmission line. However, this mismatch does not dramatically affect the shape of the signal, allowing the eye diagram to pass a suitability test with a mask as required. It is important, however, to keep in mind that the negative effect will increase with frequency and component impedance.

The higher the operating frequency and the impedance of the filter, the greater the effect on the signal eventually resulting in total information loss due to reflections and attenuations occurring in the line due to an unsuitable filter. Common and differential mode impedances are related to each other and are governed by the component's physical properties and geometry. For any one choke series with a specific core size, higher common mode attenuation will come with higher differential mode attenuation.



▲ *Fig. 6 Second Filter: WE-CNSW 0805 with impedance curve of 744231091.*



▲ *Fig. 7 Third Filter: WE-CBF HF with impedance curve of the 74286314.*

The following key principle applies: The lower a choke's differential mode impedance, the smaller the effect on the signal but it will never disappear completely. There are no perfect or ideal filters but a good component selection will help avoid surprises.

FILTER ANALYSIS

To see how the differential mode attenuation affects the signal shape consider three filters, each using a different type of component. The filters are inserted into a differential line with 50 Ω characteristic impedance and 90 Ω differential impedance. The

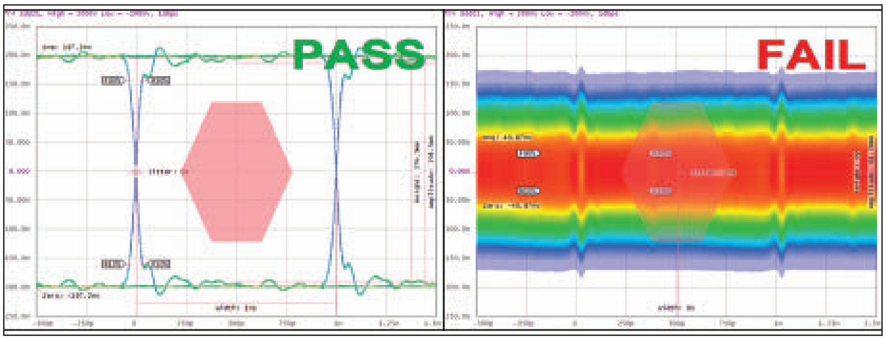


Fig. 8 Comparison between the line without filter (left) and the line with WE-CBF HF filter (right).

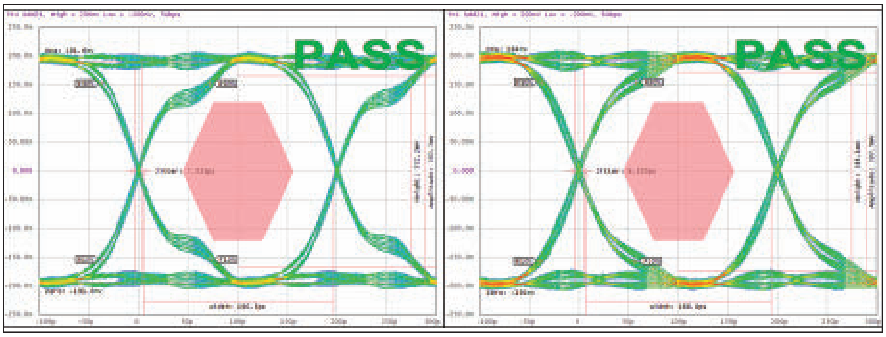


Fig. 9 Eye diagram with the standard filter (left) and the high frequency filter (right) at 5 Gbps.

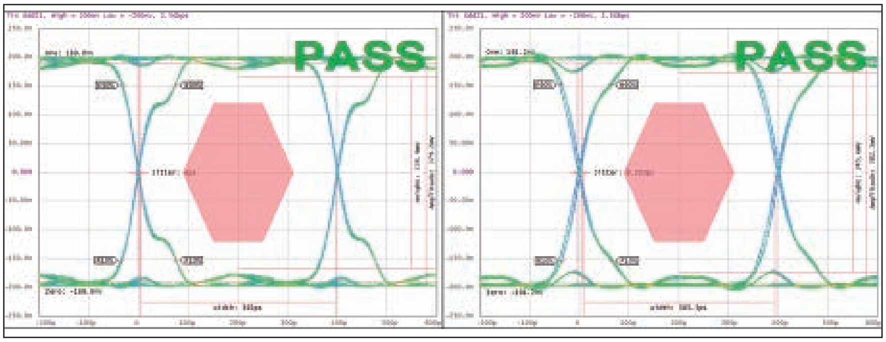


Fig. 10 Eye diagram with the standard type choke (left) and the high frequency type choke (right) at 2.5 Gbps.

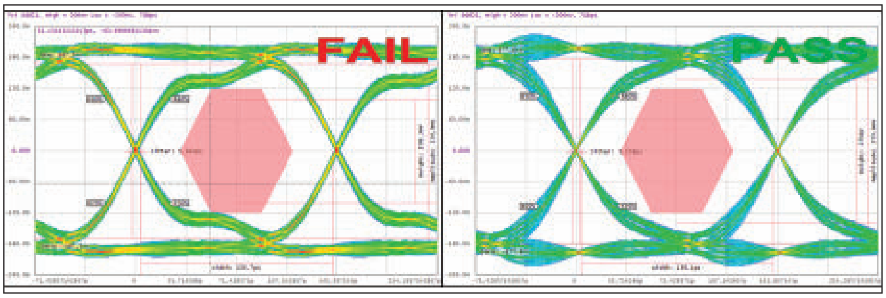


Fig. 11 Eye diagram with the standard type choke (left) and the high frequency type choke (right) at 7 Gbps.

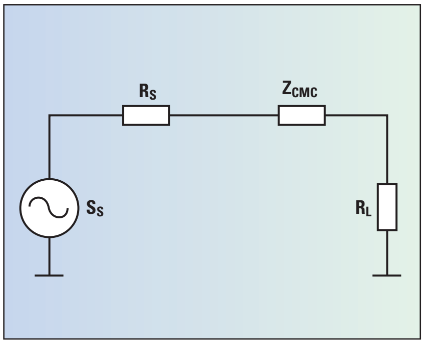
architecture setup is shown in ***Figure 4***. The components used to build the filters and the characterizations of graphics are shown in ***Figures 5***, ***6*** and ***7***.

Eye diagrams obtained for different data rates are compared in figures 8 to 11. The signals are NRZ coded and the data rates are 1, 2.5, 5 and 7 Gbps. ***Figure 8*** shows the effect obtained with a filter using ferrite beads as shown in Figure 7. Such a filter will deform the signal dramatically. The 'eye' is completely closed and the test fails. The ferrite beads do not distinguish between the differential and the common mode signals so the carrier signal disappears along with the noise. These ferrite beads have a really good performance when used for a lower data rate as a differential mode filter, but if they are not designed for this function they will not give as good a performance as a common mode choke.

Focusing the attention on the comparison between the WE CNSW (standard type), and the WE CNSW HF (high frequency type) it is easy to see how the cutoff frequency affects the signal with the effects on the standard type (left side) and the high frequency type (right side) shown. Both components have almost the same impedance in common mode. The main difference is in the differential mode impedance. Comparing the effect at 5 Gbps in ***Figure 9***, it is possible to see that the standard type has a lower cutoff frequency than the high frequency type.

At 2.5 Gbps the difference is smaller as can be seen in ***Figure 10***. The signal's critical harmonics are filtered by neither the high frequency component nor the standard component. In both cases the signal is not strongly affected by the component because both filters are designed to have low differential impedance. But increasing the data rate of the signal will also increase the harmonics and the number that are being filtered. The cutoff frequency of the standard type is about 2 GHz, whereas with the high frequency type the cutoff frequency is at least doubled, conserving the impedance value in common mode.

In ***Figure 11*** the different eye diagrams at 7 Gbps for both filters are shown. In case of the standard type the base frequency of the signal is also affected and attenuated. However, with the high frequency type, only the high frequency harmonics are attenuated, resulting in good results for the eye diagram test.



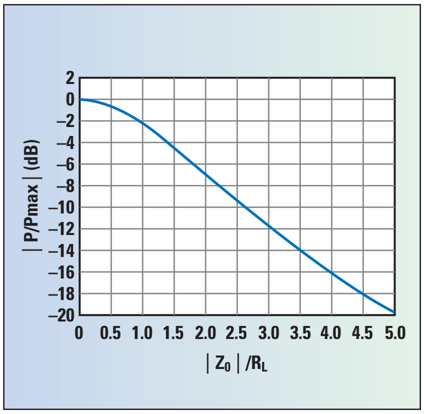
▲ *Fig. 12 The circuit used to show the relationship between the choke's impedance and the resulting attenuation.*

There are several important factors to take into account when building a filter. However, not all of them can be derived from the impedance curve alone. Depending on the underlying measurement method, data sheets will show the impedance curve, the attenuation curve, or the scattering parameters curve. There is, however, always the possibility to extract the information needed to choose the right common mode choke for the desired filter application, even if this information is not shown explicitly in the datasheet.

Figure 12 shows the equivalent circuit of the system in differential mode. The source (RS), the load (R_L) and the choke (Z_{CMC}) impedances are present in the equivalent circuit. For a perfect match the load impedance should be the conjugate of the source impedance (same real part, opposite imaginary part) and the choke impedance should be zero. This last requirement is not possible with real components. Keeping the source and load impedances constant it is possible to calculate the attenuation added by the component:

$$Z_{comm}=2Z_{even}=(1+k)Z_0/2$$

To simplify the calculation and proceed directly to the important point the choke impedance is considered to be imaginary. This approximation will give the ratio in the worst case. ***Figure 13*** shows the effect of the relationship between the choke's and the load's impedance on the attenuation.



▲ *Fig. 13 Effect of the choke impedance on the attenuation.*

By designing circuit with a common mode choke in mind it is possible to adapt the impedances to reduce the attenuation of the filter. The complexity of the matching circuit will increase, but the effect of the filter on the differential signal will be reduced.

CONCLUSION

This note affirms that a high frequency choke will be always more appropriated for high frequency applications and it should be used for circuits with a differential mode line with a high speed data rate. The size, attenuation or impedance depend on the application. And once the relationship between the different parameters is known, it should be possible to estimate the effect of the choke on the differential data line, irrespective of the way this information is shown.

In a first approximation to choose the appropriate choke, the application must be located in a frequency range. Once the cutoff frequency is decided, the choke family that will be chosen depends on the important parameters for the design. For example, if the application has a signal with harmonics in frequencies higher than 1 GHz a high frequency choke should be used, offering good attenuation at the high frequencies, with a broad transmission bandwidth, which means, the impedance in differential mode is negligible up to 8 to 10 GHz. Once the match code has been decided, the next step is to decide on the size, which depends on the rated current, DC and AC impedance, etc.■

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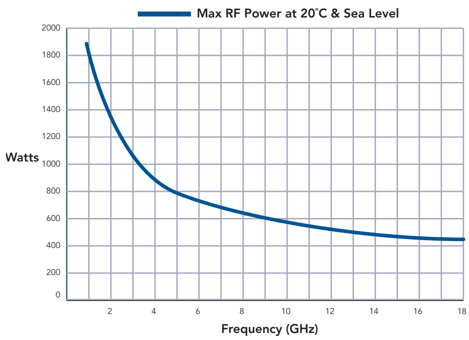
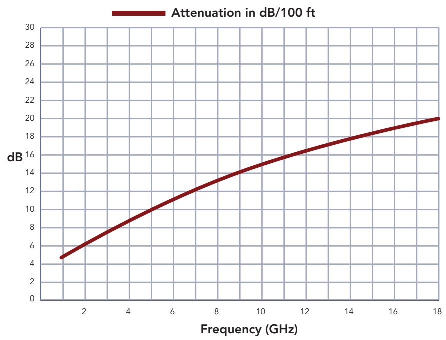


Attenuation in dB/100 ft



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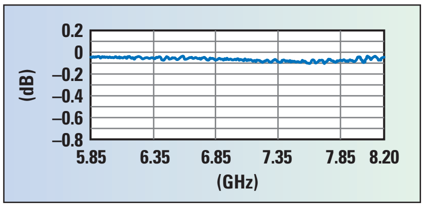
Flexible Waveguide Eases Interconnect Alignment

Pasternack
Irvine, Calif.

In many applications — radar, microwave communications, military, aerospace — and during the prototyping and testing phases of development, complex waveguide arrangements are commonly encountered by system designers. Unfortunately, these alignment issues are not foreseen until deadlines are approaching and critical systems must be deployed or tested. To respond to these needs, Pasternack Enterprises is offering 36 high quality, flexible waveguide twist sections, in stock and ready for same-day shipping. Pasternack's neoprene sleeve "flexguides" cover the waveguide frequency bands from 5.85 to 40 GHz – WR137 to WR28 – in 12", 24" and 36" sections, solving an expanse of waveguide alignment and displacement challenges.

In many installations and test bench scenarios, a precisely designed, rigid waveguide structure with the proper flanges and orientation is not readily available. Lead times of several weeks to months are common to receive the correct part. This is not always convenient in a design, repair or replacement situation. Flexible waveguides at various lengths allow twisting and flexing over a considerable range, which solves many installation problems caused by misalignment. Microwave antenna or parabolic reflector positioning is another example which may require physical adjustment many times to ensure proper alignment. In these applications, flexible waveguides allow a much wider range of alignment possibilities without the cost or lead time for customized parts.



▲ *Fig. 1 Typical insertion loss of 12", WR137 flexible waveguide interconnect.*

Even rigid waveguide may not provide the necessary features for some installations. For applications that produce vibration, shock or creep, a flexible waveguide may be preferred over a rigid waveguide, as the flexibility can provide isolation to more sensitive waveguide parts. Additionally, where applications have high temperature variability, thermal expansion and contraction can damage even mechanically robust interconnect structures. Flexguide is able to contract and expand slightly to accommodate thermal variations. In situations with extreme thermal expansion and contraction, an additional bend loop can be incorporated to enable greater displacement.

SUPERIOR ELECTRICAL PERFORMANCE

The flexguide models cover the 5.85 to 40 GHz waveguide bands and have WR137 to WR28 flanges. The typical VSWR for the lowest frequency flexguide is 1.05, and the highest frequency model achieves a low VSWR of 1.3. The quality of the waveguide structure results in little change in VSWR over the 12", 24" or 36" lengths. The lowest frequency, 12" waveguide provides 0.07 dB insertion loss (see ***Figure 1***); the same length at the highest frequency achieves 0.6 dB loss. Insertion loss tends to increase linearly with length. Though

VSWR and insertion loss may change slightly under different flex and twist configurations, the high quality flexguide construction reduces variation from manipulation.

The malleable conduit structure of the flexguide is superior to many prior implementations of flexible waveguide. The flexguides can bend in both the H- and E-plane, with the higher frequency models able to bend with an E-plane radius as tight as 1" and an H-plane minimum bend radius of 2". The flexguide can twist in both directions, up to 180 degrees for the higher frequency models. The lowest frequency model is capable of a one-time minimum bend radius in the E-plane of 4" and 8" for the H-plane. The maximum twisting capability of the lowest frequency model is a one-time offset rotation of 64 degrees. The maximum operating pressure for the flexguides ranges from 30 to 45 psig. The physical structure that enables this high performance, even under high flex and twisting, is the specialized helically-wound, silver coated brass strip construction. The precision wound strips are then coated in a highly flexible and durable neoprene sleeve. With this construction, the flexguides resist thermal variations in length and size, and they are capable of attenuating vibrational energy without sustaining damage.

Pasternack's flexguide sections are available in a wide range of rectangular and circular flanges, which are made of solid brass. Several models in the range from 5.85 to 40 GHz are offered with military standard MIL-DTL-3922 (UG) features for flange waveguide interconnect. For the models that cover 5.85 to 12.4 GHz, commercial connector pressurized rectangular (CPR) flanges are available. For pressurized waveguide systems, a flexguide component can reduce stresses on the more rigid pressurized sections, potentially lengthening lifetime and reducing maintenance and service requirements. The complete set ranges from WR137 to WR28, with square cover flanges available for the frequencies from 10 to 22 GHz.

The neoprene rubber material used as the sleeve for the flexguides provides a much more flexible and environmentally resilient sleeve than rubber and PVC sleeve technologies. Even thin neoprene coatings are capable of preventing moisture, acids, corrosives and gas exchange between the membrane and outside environment. Neoprene coatings can withstand many bends, flexures and minor physical abrasions without further splitting and cracking, while flexible waveguide without neoprene can crack and expose the highly corrodible metals of a waveguide body to damaging environmental conditions. Neoprene coatings are stable over time and degrade more slowly than other materials, offering longer waveguide lifetimes in harsh environments.

VENDORVIEW

Pasternack
Irvine, Calif.
+1 866-PASTERNACK
www.pasternack.com

Flexible Low PIM Test Lead

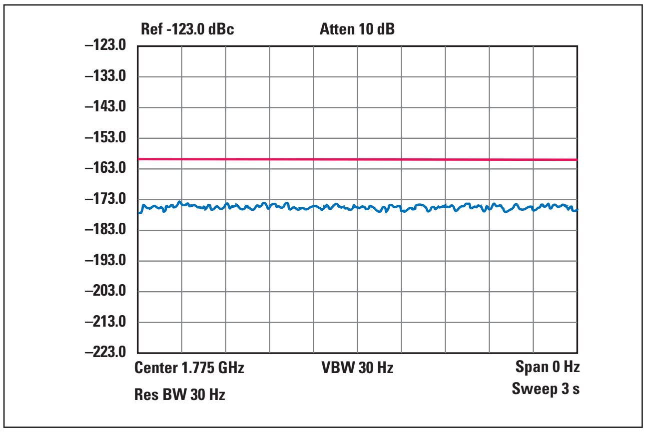
HUBER+SUHNER
Herisau, Switzerland

The measurement of passive intermodulation (PIM) has always been tricky with regards to getting the right technological balance between offering flexibility while achieving low intermodulation. In the past it was possible to achieve the PIM requirement but offering real flexibility has been an issue. Until recently, the traditional offering has been rather stiff corrugated cable construction with welded copper tube outer conductors. The bending moment and the spring back effect of these heavy products have not allowed true flexibility.

▲ *Fig. 1 The TL-P offers a flexible, reliable and lightweight option for field testing. (Image source: Anritsu)*

Taking advantage of its expertise in coaxial cable, connector and assembly design under one roof, HUBER+SUHNER has designed what it says is the first truly flexible low PIM test lead, known as the Test Lead – PIM (TL-P). Its ductility, weight and handling are believed to put it on par with state-of-the-art network analyzer test leads. TL-P is based on a flexible cable which is optimized up to 4 GHz. The assembly offers a dynamic flex life of greater than 10,000 cycles (with a 110 mm bend radius) and is designed with steel spring armoring that protects against kinking and assures a long lifetime. The robust design is completed with molded protection between connector and cable. This comes with a guaranteed PIM performance of -160 dBc and connectors that can handle more than 2,000 mating cycles.

The TL-P product line has been developed for outdoor and indoor applications where passive intermodulation and return loss have to be tested. It combines user friendly handling, durability and reliable PIM results in one product, making it an investment that can benefit the total cost of ownership.



▲ *Fig. 2 Each assembly comes with a PIM test report.*

OUTDOOR AND INDOOR

With its light weight and smooth physical characteristics, TL-P is an asset for field test applications. Users of portable PIM test devices will appreciate the portability of a much less bulky test cable, as shown in ***Figure 1***, with a very high degree of reliability that makes repeated rebuilding and reterminating unnecessary and reduces overall work time and cost. Field use requires flexible and rugged test equipment. Offering longer life, with the capability of withstanding rough conditions (IP67), the TL-P product line is specifically designed for harsh environments.

Offering excellent return loss performance, the TL-P product line is suitable for benchtop PIM analyzers in indoor lab or factory testing, such as antenna components. Designed for high mating cycles, these factory-made cable assemblies are produced under stringent manufacturing and quality standards. They are 100 percent tested for PIM, return loss and attenuation, and each assembly comes with a PIM test report (see ***Figure 2***) and protection caps on the connectors.

Whether used for outdoor or indoor applications, the outstanding PIM and return loss performance make the assembly suitable for any relevant test and measurement application. Its highly flexible, rugged and reliable construction offers high resistance to wear and high mechanical endurance. The TL-P product line is available with straight male 7/16, N and 4.3-10 connectors in standard lengths of 1,500 mm and 3,000 mm, while other interfaces and assembly lengths are available on request.

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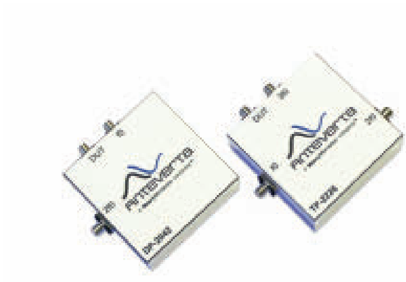
HUBER+SUHNER
Herisau, Switzerland
www.hubersuhner.com



Low Loss Diplexers and Triplexers for Wireless Test and Measurement

Maury's line of diplexers (DP-series) and triplexers (TP-series) are designed for applications which require combining or splitting signals at or around harmonic frequencies (nf_0) and are connectorized (SMA) for design-in and test and measurement applications. With a concentration in wireless communications, Maury multiplexers are available in bands between 600 MHz and 6 GHz and associated second and/or third harmonic frequencies.

Tailored for low, medium and high power applications such as amplifier R&D, Maury multiplexers are designed to handle 100 W average power. Unlike traditional wideband combiners/splitters, which can suffer from high combining and resistive losses, the DP- and TP-series multiplexers have typical insertion losses better than 0.5 dB between fundamental frequency and common (combined) ports.

The DP- and TP-series multiplexers have been optimized for passive, active and hybrid-active multi-harmonic load-pull systems.

Maury Microwave Corp.
Ontario, Calif.
www.maurymw.com

High Power PSMP Provides Board-to-Board Solution

The PSMP connector series from Amphenol RF provides a solution for blind-mate applications requiring high power. PSMP connectors have the same PCB footprint as the SMP connector and are designed to handle up to 200 W at 2.2 GHz and operate to 10 GHz.

Developed for board-to-board applications, the compact three-piece design supports a minimum board spacing of 12.6 mm, which allows maximum flexibility for high density board spacing and blind-mating situations. The PSMP interconnects are flexible, tolerating misalignment of 1 mm axial and 4 degrees radial. They are available in smooth bore, limited detent and full detent configurations.

With the same PCB footprint as the SMP connector, the PSMP can easily replace the SMP in applications that require higher power handling. PSMP interconnects are suitable for a wide range of board-to-board applications, including base stations, filter units, amplifiers and handheld radios.

The PSMP connector series complements Amphenol RF's other standard and custom engineered products, which include RF connectors, coaxial adapters, RF cable assemblies, multi-port ganged interconnects, blind-mate and hybrid mixed-signal solutions.

Amphenol RF
Danbury, Conn.
www.amphenolrf.com

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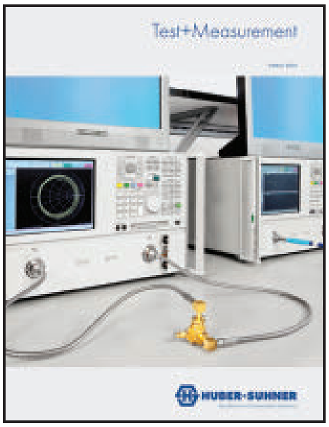

Test & Measurement Product Catalogue

VENDORVIEW

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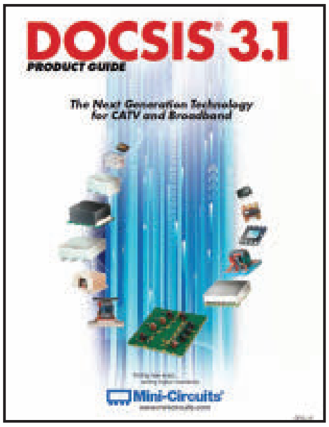

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Mini-Circuits' Test Solutions Product Guide is an 88-page, full color publication that features detailed information about the company's innovative line of RF test and measurement solutions including custom rack-mounted systems, user-defined modular racks and portable test devices. The guide showcases the many capabilities these products offer and applications they support. Comprising functionality ranging from signal source to amplification, routing, attenuation, distribution and power measurement, Mini-Circuits' test solutions have significantly lowered costs and improved test efficiency for customers. For more information contact testsolutions@minicircuits.com.

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The Cable Creator

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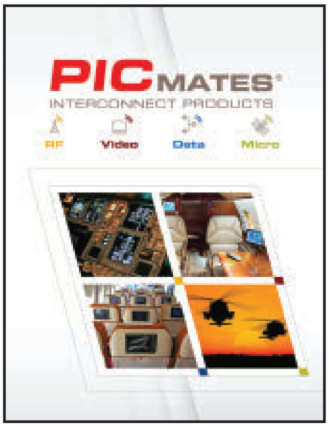

PICMATES Interconnect Products

The PICMATES family of cables and connectors offers solutions for high frequency/microwave applications plus network/communications, data transfer and entertainment demands. The company's brochure highlights their broad selection of specialized coaxial, triaxial, high speed data and custom cable options. In particular, MicroMATES are designed to advance interconnect technology for Ku- and X-Band assemblies supporting satellite communications and onboard connectivity in aircraft. Visit www.picwire.com for more information.

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Spectrum Elektrotechnik GmbH

www.spectrum-et.com

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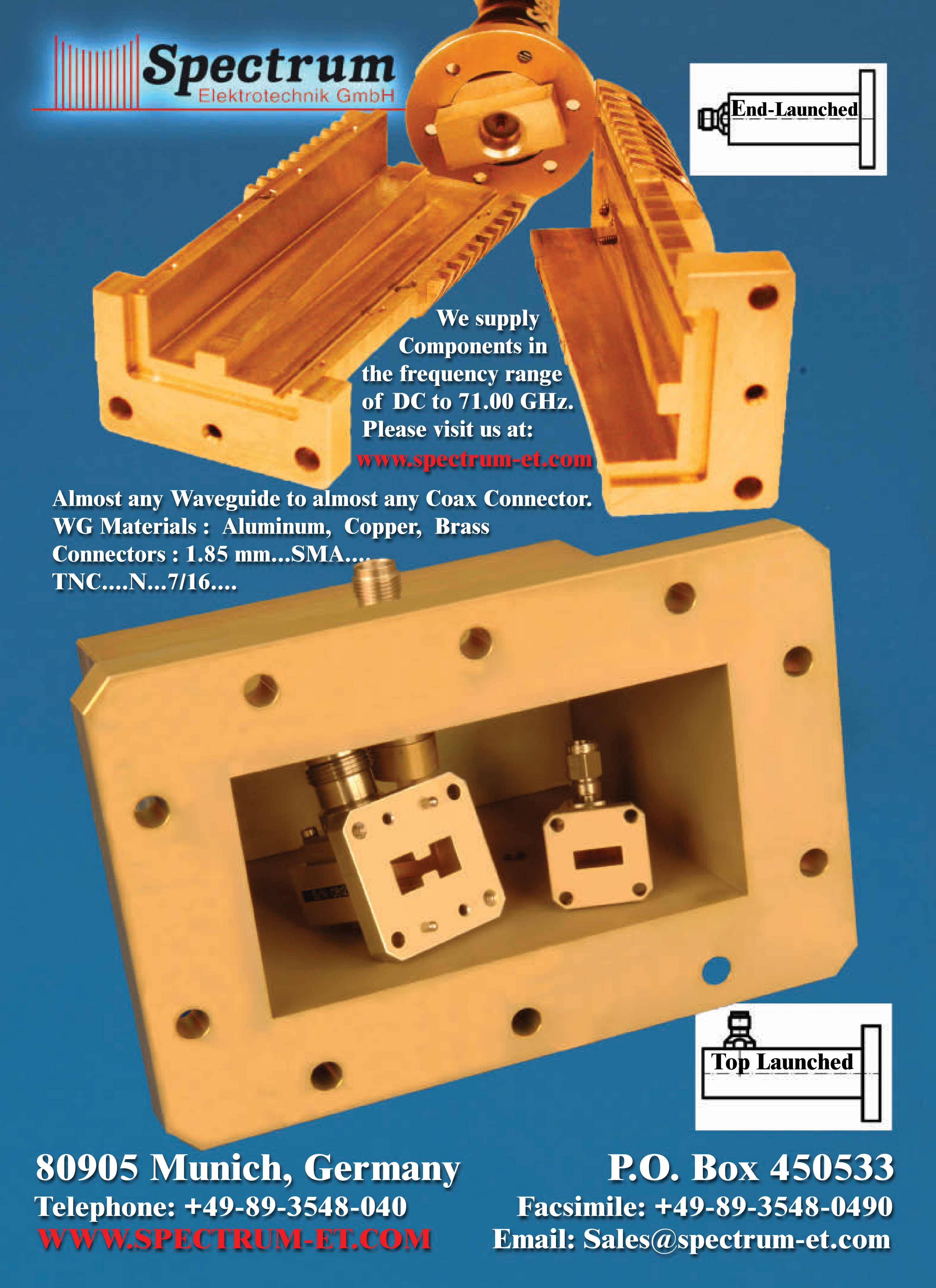

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