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August 2016

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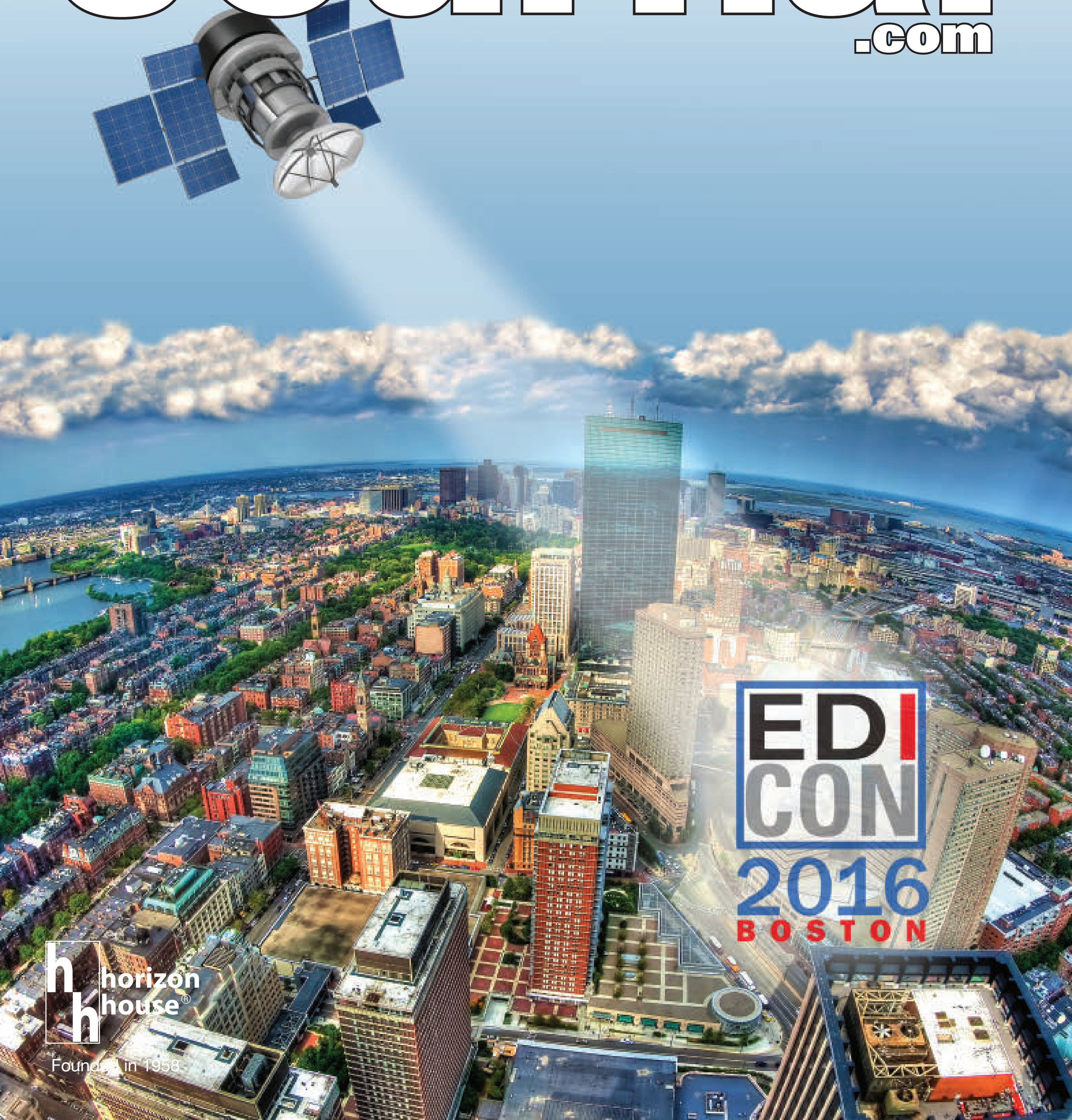

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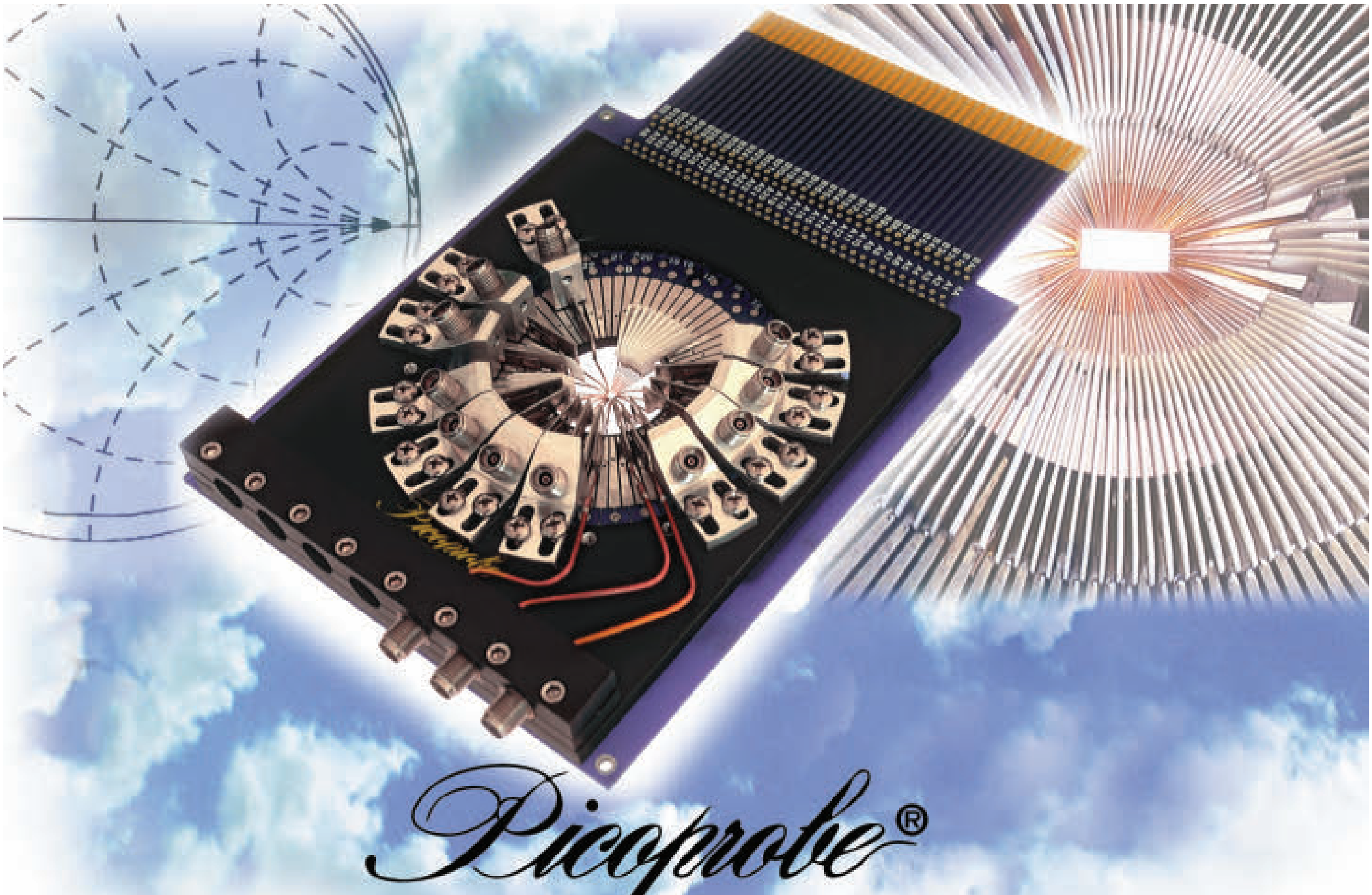

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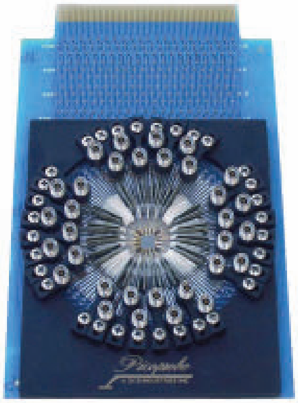

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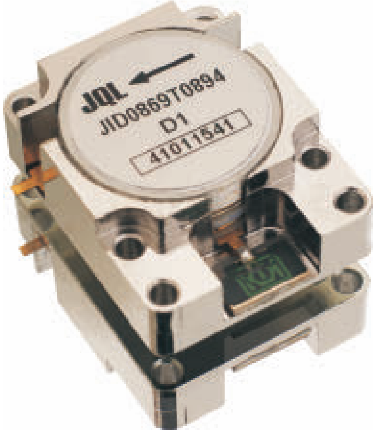

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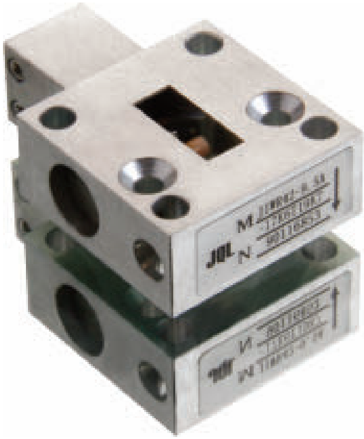

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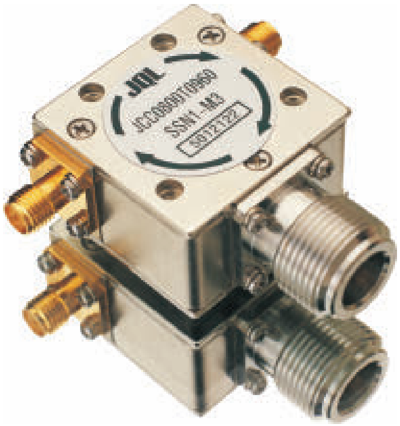

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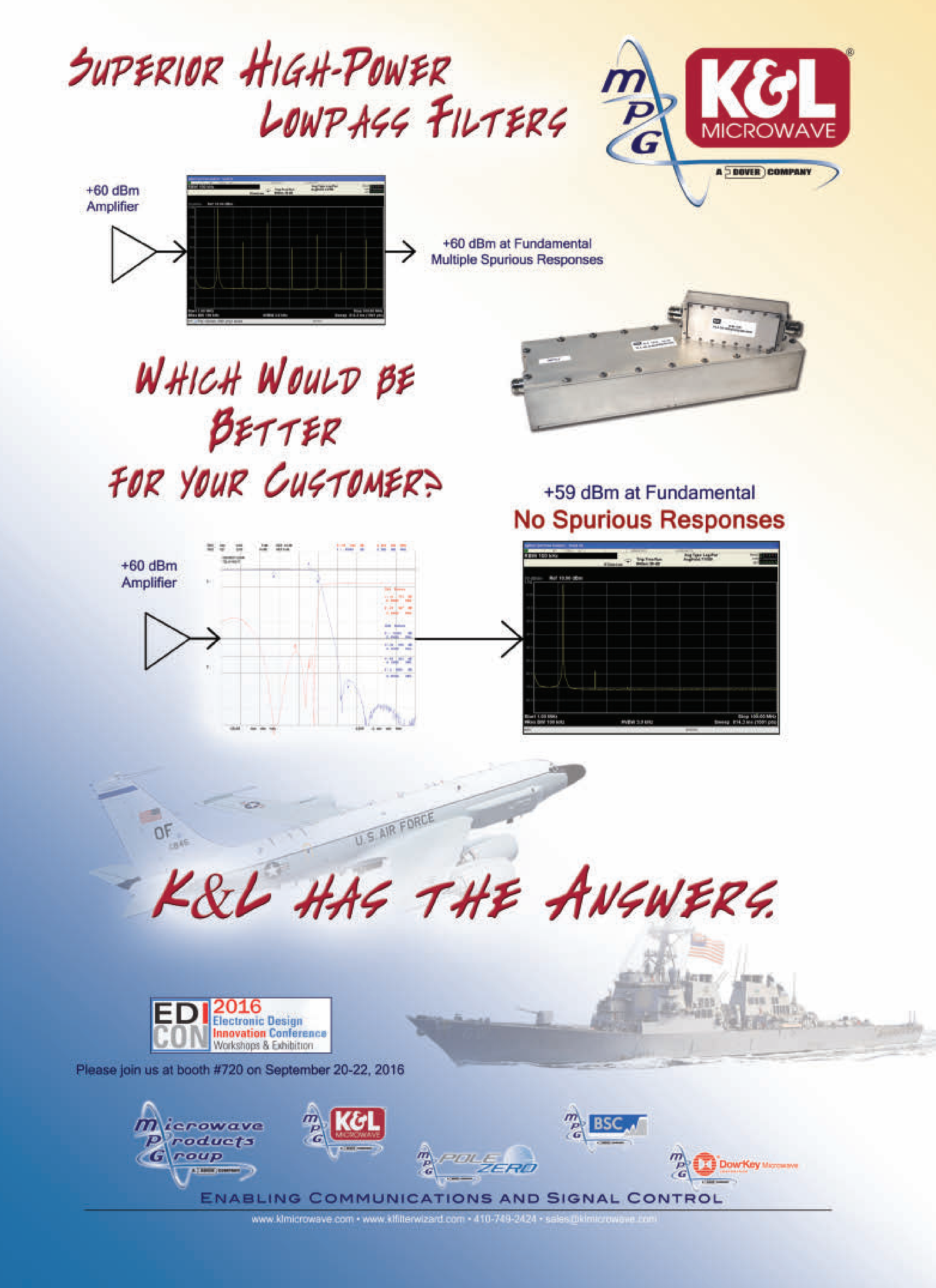
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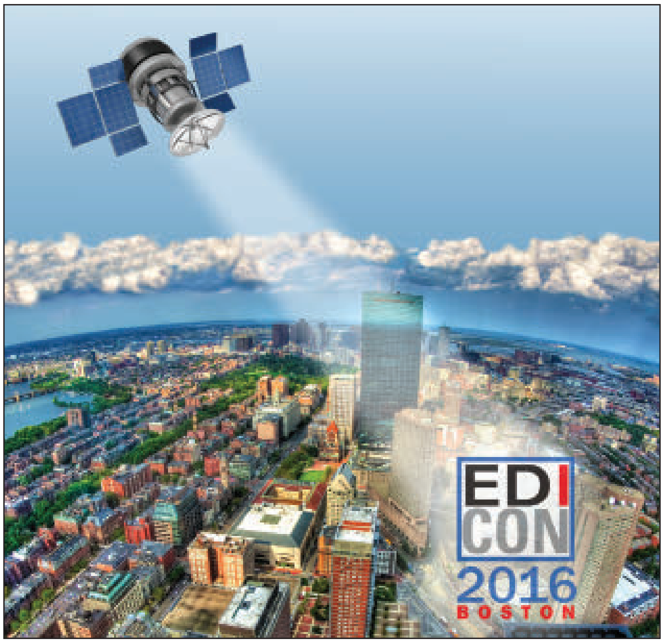

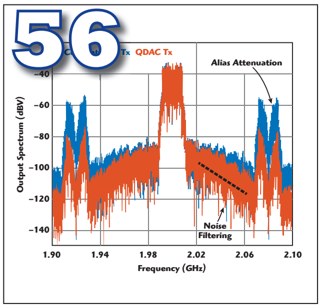

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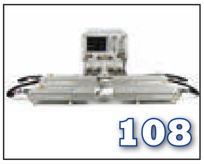

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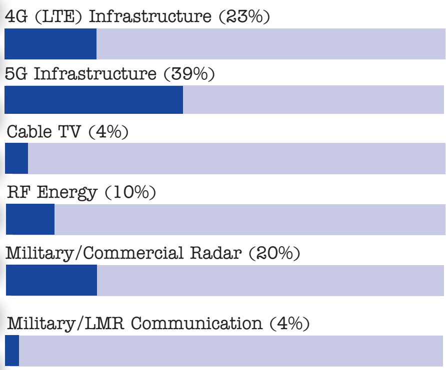

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Yuenie Lau, president and CEO of **OML**, discusses the company's 25-year legacy supporting millimeter wave applications, the increasing demand for millimeter wave spectrum and how OML is addressing this trend.

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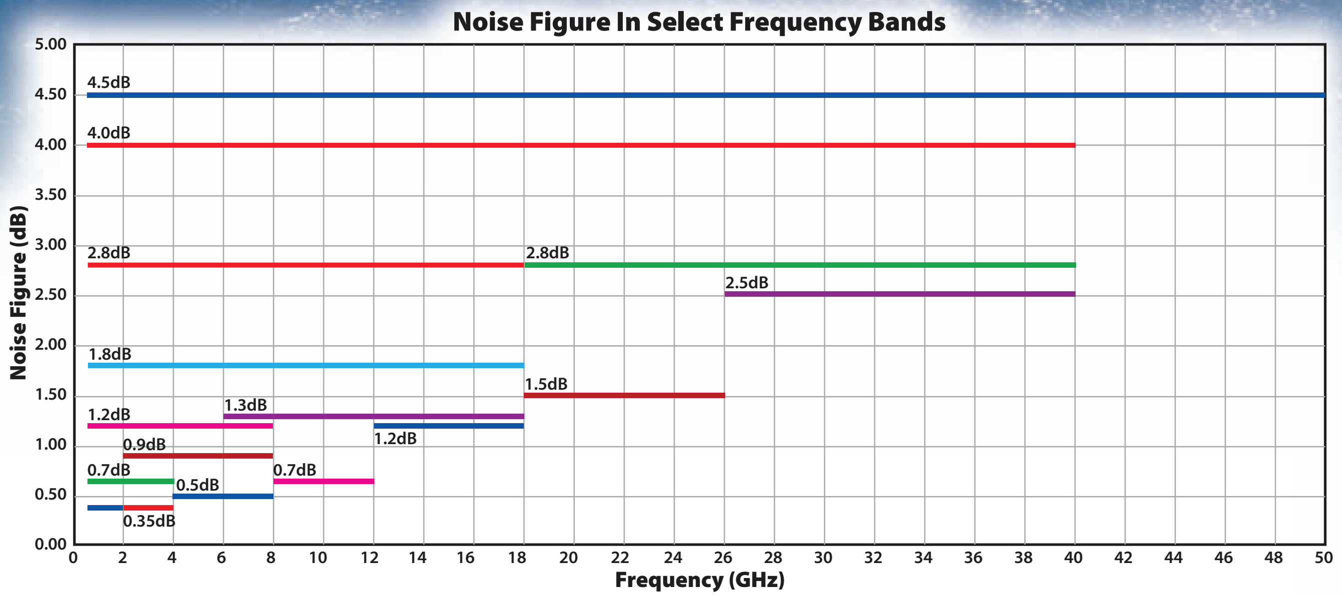

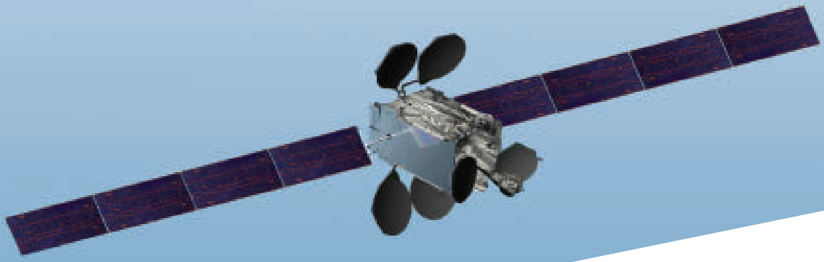

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Satellites Remain Key Link in Evolving Hybrid Network Chain

Thierry Guillemin
Intelsat, Luxembourg District, Luxembourg

Editor's Note: The global demand for bandwidth, which shows no sign of plateauing, has service providers and internet companies scrambling to add capacity, whether by evolving existing network technologies (e.g., hybrid fiber coax) or developing greenfield approaches (e.g., high altitude balloons). Among the mix, existing satellite players and new entrants are developing the next generation of satellites to blanket the globe with 10s of Gbps of capacity. **Microwave Journal** ***asked Intelsat, the company that launched Intelsat 1 in 1965 and now operates the world's largest satellite services business, to describe their strategy for high bandwidth satellites.***

For a typical mobile network operator (MNO), increasing demand for connectivity around the globe offers an enormous opportunity. Operators are racing to deploy more capable networks and expand their geographic reach to capture new subscribers and grow revenues. The challenge these operators face remains finding a fast, cost-efficient means to evolve their networks in a financial environment that limits available resources.

A typical network today consists of cell sites connected to the network using microwave links developed to support voice traffic. Yet the demands of the end user are shifting away from voice, toward high volumes of data traffic, as well as taking networks further from metro areas. Expanding via the build-out of conventional towers can mean fixed capital expenditures (capex), heavy equipment and limited options once the new node is in place. New solutions are emerging with potentially more attractive economics for MNOs: high throughput satellite (HTS) technology is entering the marketplace and will quickly dispel those constraints and see satellites serving as an integral part of the hybrid wireless networks of the future.

HTS THE TIPPING POINT

If done correctly, HTS technology delivers major breakthroughs in performance, economics and access, and this will impact multiple sectors. These new satellites will have the throughput, quality, flexibility, security, adaptability and scalability needed to deliver broadband everywhere. They will be a significant enabler in changing the way MNOs approach their networks.

For example, the Intelsat Epic^{NG} platform will deliver 25 to 60 Gbps per satellite, 10× the throughput of traditional satellites, and operate at C-, Ku- and Ka-Bands. This cost-effective, readily available infrastructure will enable network operators to upgrade and expand without huge capex investments. To accomplish this, Intelsat developed a platform based on an open architecture and backward compatibility, so network operators can upgrade their infrastructures using existing hardware investments. Intelsat Epic^{NG} is fully integrated with Intelsat's globalized network, which combines the world's largest satellite backbone with terrestrial infrastructure, managed services and an open, interoperable architecture. All of these efforts help operators improve the performance and reach of their networks in the most costs-efficient manner. By reducing the amount of capex often required with network upgrades, customers can focus on expanding into new regions and identifying new applications to drive growth.

The heart of the Intelsat Epic^{NG} platform — one of many design features that provide the performance needed to take advantage of future opportunities — is the digital payload (see ***Figure 1***). This technology allows for connectivity in any bandwidth increment and from any beam to any beam. For customers integrating high throughput capacity into their operations, uplinks and downlinks can be connected regardless of location within the footprint. The combination of these capabilities provides the coverage of a large hemi-style beam with the power of high performance Ku-Band. This eliminates the need for a network to have multiple hubs and allows customers to configure their network topologies to leverage existing ground hardware and operate using multiple spectrum bands. For example:

- A communications provider with an established, successful C-Band business can integrate high power Ku-Band spot beams from the existing C-Band hub to maintain promised service quality for customers in areas of high demand.
- A wireless carrier operating a network in a heavy rain region can use a mix of C- and Ku-Band connectivity running off a single hub, which will keep operational costs down, expand capabilities and provide quicker service recovery in the event of weather-related interruptions.

▲ *Fig. 1 Digital payload of the Intelsat Epic^{NG} satellite.*

Intelsat has introduced the IntelsatOne Flex service, a global managed service designed to deliver an enterprise grade, wholesale Mbps service with tiered committed information rate (CIR) plans. This simplifies the aggregation of HTS and traditional wide beam capacity into a single product and optimizes bandwidth allocations. Surges and geographic shifts in demand can be addressed to ensure the delivery of bandwidth where and when it is needed. IntelsatOne Flex is scalable, making it easier for customers

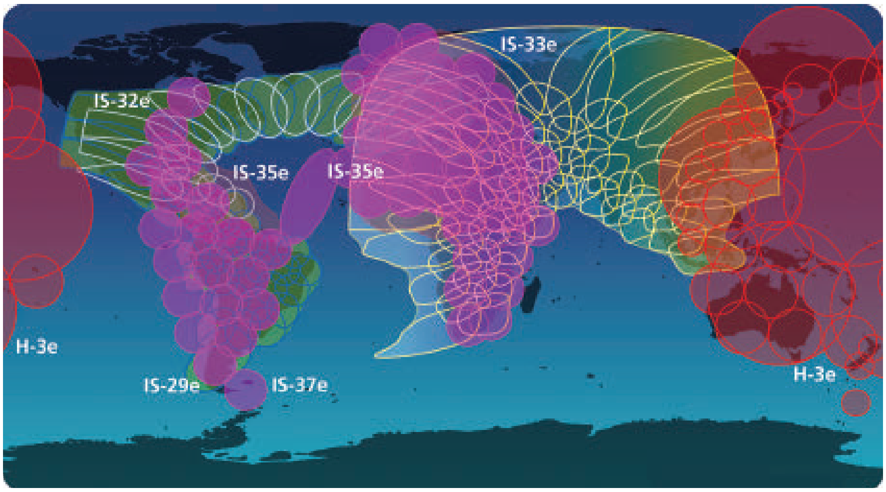
▲ *Fig. 2 Intelsat 29e HTS prior to launch. The satellite is now providing service over the Americas, Caribbean and the North Atlantic.*

to meet growing broadband requirements and stay competitive over the long term.

The first Intelsat Epic^{NG} satellite, Intelsat 29e (see ***Figure 2***), was launched into geostationary orbit in January 2016 and has started service over the Americas, Caribbean and North Atlantic route. Intelsat 33e (see ***Figure 3***) is on track for launch in the third quarter of 2016 and will provide services in Africa, Asia-Pacific and Europe. The launch of Horizons 3e, scheduled for the second half of 2018, will complete the global footprint with coverage of the Pacific Ocean region. By 2020, seven Intelsat Epic^{NG} satellites will be in geostationary orbit, ensuring enough capacity to serve regions of high demand around the globe (see ***Figure 4***).

▲ *Fig. 3 Intelsat 33e, scheduled for launch in August 2016, will provide service over Africa, Asia-Pacific and Europe.*

Each new Intelsat Epic^{NG} satellite will introduce more innovations, evolving the technology with new flexibility



▲ *Fig. 4 Planned coverage of the Intelsat Epic^{NG} fleet.*

that will take this new generation of HTS towards fully software-defined satellite missions. Every characteristic of spacecraft performance will be adaptable and can be modified by simple commands sent from the ground. Customers will have the most powerful and consistent space infrastructure built, with the ability to adapt, modify and improve the infrastructure as the market demands.

ACCESSIBLE FOR NETWORK EXPANSION

While Intelsat has made tremendous strides in satellite performance, the story is more than building high throughput, high performance satellites. The in-orbit advancements have been paired with parallel efforts to innovate throughout the satellite ecosystem and make it easier for network operators to integrate satellite solutions into their networks and tap into the power that HTS delivers. For example, one of the biggest hurdles to expanding the reach of wireless networks to rural and remote populations is the investment required to build and maintain base stations on the edge. The receiving equipment is costly to transport and install, the installation of the satellite dish often requires a specially trained technician and site power requirements may be dramatically out of sync with the local environment.

To fully optimize the performance of the Intelsat Epic^{NG} fleet and simplify access to the technology, Intelsat has made strategic investments in antenna technology with two providers, Kymeta and Phasor, to develop antennas and terminal products optimized for Intelsat Epic^{NG}. Initially, both of these developments will result in thin, light and low cost Ku-Band satellite tracking antennas for the mobility sector. In the future, they will benefit the wireless sector, specifically improving capabilities for rural network operations. As these technologies mature into second- and third-generation designs and production volumes rise, this small, electronically steerable antenna technology can aid MNOs that are expanding operations along the network edge. With smaller equipment, base stations can be set up more quickly and easily and, by cutting the amount of power required for operations, maintenance cost will be reduced — possibly nearly eliminated through the use of solar power. The smaller size also enables the equipment to be relocated to a more opportunistic site without a major reinvestment of labor, if the base station is not meeting expected revenue.

Future generations of the technology have the potential for customers to offer new services and address new market demands, such as satellite-connected

- Picocells: a small cellular base station that adds network capacity in areas with high bandwidth requirements, such as stadiums and high traffic suburban areas
- Femtocells: a small, low power station that extends services inside homes and small businesses.

Although Intelsat has an extensive fleet of geostationary satellites that covers the globe several times and reaches fixed and mobile users in most regions of the world, the company invested in

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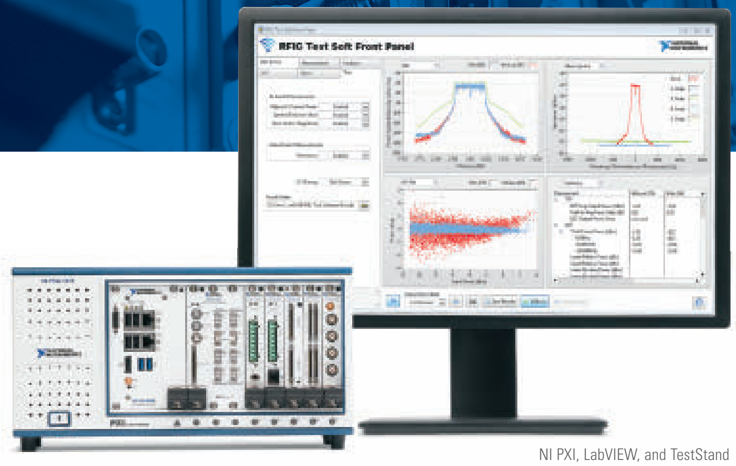

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OneWeb Chooses LEO

Commercial communications satellites have historically been placed into geostationary equatorial orbit (GEO), where they remain "stationary" over a given portion of the Earth – key to maintaining links with the fixed antennas on the ground. More accurately, a GEO satellite orbits the Earth at the same rate as the Earth rotates, which requires that the satellite orbit 26,199 miles from the Earth's center or 22,236 miles above mean sea level. In addition to the advantage of being stationary, only three GEO satellites are needed to cover the globe, a modest investment in expensive satellites. The disadvantage of the GEO satellite is the latency or transit time from Earth to satellite and back: a minimum of approximately 240 ms for links at the equator. For many applications this is not a disadvantage; however, for voice communications and internet applications, the latency is noticeable and may limit the services that can be provided (e.g., achieving the proposed 5G latency targets).

Seeing an opportunity to provide global, low latency, internet access and communications, Greg Wyler founded OneWeb in 2012. OneWeb proposes to launch a LEO constellation of 648 "micro" satellites, weighing some 300 lb each, that will orbit at 1,200 km. The OneWeb network design supports a total latency of 30 ms, with each satellite having a capacity of 50 Mbps. The satellites will use the Ku-Band spectrum previously allocated for Skybridge, a satellite constellation proposed in the 1990s but never launched. Small and low cost ground terminals – some solar powered – will link to the OneWeb satellites at Ku-Band and convert the data to standard cellular and Wi-Fi frequencies. The ground terminal will act as a base station or access point, so users won't need special equipment.

OneWeb's business model is to extend the communications network of existing operators, rather than competing with them. Use cases include cellular and internet access for developing and rural regions, emergency communications following natural disasters and in-flight connectivity for airlines, business and military aviation. In June 2015, OneWeb raised $500 million from strategic investors, including Intelsat, and plans to launch satellites beginning in 2018, completing by the end of 2019. OneWeb's board includes Paul Jacobs, executive chairman of Qualcomm, Richard Branson, founder of Virgin Group, and Thomas Enders, CEO of Airbus Group.

the OneWeb low Earth orbit (LEO) satellite constellation in June 2015 (see ***OneWeb Chooses LEO*** highlight above). Intelsat's agreement with OneWeb calls for OneWeb to be interoperable with Intelsat's network, including Intelsat Epic^{NG}. This investment reflects Intelsat's strategy to enable innovation that complements and expands the company's space infrastructure, adding polar region access for the international routes of Intelsat's mobility customers and providing higher elevation angles in urban areas.

COST-EFFICIENT OPTIONS FOR MNOs

Given the enormous demand for connectivity, no single technology will provide all the answers for network operators. Intelsat believes operators will benefit from the combination of the bandwidth advantages of microwave and the ubiquity and reach of satellites. By making it simpler and more cost-effective to integrate satellite services, network operators can balance the demands of voice and data traffic in a cost-efficient manner. They can combine delivery methods to better serve subscribers on the metro edge and in suburban areas, where traffic demand may not be sufficient to support the cost of full time, fixed bandwidth. Satellites can add capacity in times of high demand and to meet burst requirements that are driven by data and video traffic.

Throughout its history, the satellite sector has played a valuable role in the delivery of entertainment, services and critical communications around the globe. Intelsat's work in the past few years shows the exciting potential to expand the role of satellite as the world becomes more connected. With innovation in space, matched by new developments on the ground, the satellite sector, working closely with the vast array of communications technologies available today, can solve the challenges facing network operators and deliver the benefits of connectivity to a broader audience.■

photo courtesy of the
U.S. Military & NASA

3 x 3 x 1.14 mm

Simulating the Satellite in Mobile Satcom Systems

AtlanTecRF
Braintree, Essex, UK

Geoff Burling, CEO, AtlanTecRF explains how his career and his company have taken off since working on Concorde and highlights his approach to design, manufacturing and market development.
Visit www.mwjournal.com to read this in-depth interview.

Of high importance among the many considerations that need to be taken into account when designing new products in an evolving market is the intended user. Improvements in performance alone will not impress and significant attention must be paid to the practical issues, including convenience and the time consumed in set up and operation.

In the world of satellite communications, the traditional equipment supplied for facilitating off-line tests and providing continuous quality monitoring in a ground station installation is the Loop Test Translator (LTT). Input to the LTT is provided by tapping into a transmission path and translating the sampled signal back to the receive path but, with today's compact mobile systems, often capable of high data rates, in-system connectivity may not be available and another test method has to be found.

If a hard-wired solution is not viable, an alternative is to make tests using RF and, in this case, the very RF signal with which the mobile station communicates with the satellite is utilized. This is how AtlanTecRF's newly introduced LSS Satellite Simulators operate. ***Figure 1*** shows the front of the unit complete with antennas.

▲ *Fig. 1 LSS Satellite Simulator with antennas on the front.*

So, how does it work? Imagine the Ka-Band system buried deep within the airframe of a commercial airliner, military transport or executive jet whose only visible presence is the antenna blister on top of the fuselage. The system provides internet and data services to crew and passengers at bandwidths normally only achievable at home or in the office. To test the transmission path, the LSS is placed on the platform of a 'cherry picker' – a standard piece of aircraft maintenance equipment. So, while the aircraft is in its hangar, the live test can be carried out.

The LSS is powered by an internal rechargeable battery, with 24 hour duration, thereby ensuring its total autonomy in the loopback test function, where it becomes a simulated satellite. Reception from the system under test (SuT) and transmission back to it is achieved by a pair of horn antennas. The receiving antenna terminates in WR42 for the SuT 30 GHz uplink band and the transmitting antenna terminates in WR28 for the SuT 20 GHz downlink band.

In each case, the transmissions between LSS and the SuT can take place in both left hand and right hand circular polarizations simultaneously, thereby further establishing the similarity between the test condition

and an actual operating situation, live on the satellite.

While it would be possible to control the instrument remotely during tests, avoidance of Wi-Fi or other unnecessary radiations is achieved using purely manual controls (see ***Figure 2***) which, once initially set for the range involved, should not require further adjustment.

For each polarization there is a signal path attenuator which can be set and locked and, while the translation paths within the instrument remain independent, each is served by a common local oscillator (LO) at either 9.8 GHz or 10.3 GHz, depending on the actual Ka-Band frequencies of the SuT.

The style of the instrument case used for the LSS is such that the carry handle can be folded back and used to point the antennas at the SuT on the aircraft but the individual horn designs are of a type where a degree of misalignment in both the vertical and horizontal planes, up to 10 degrees, can be tolerated without loss of performance in the

▲ *Fig. 2 Once the manual controls on the back of the unit are initially set for the range involved, they should not require further adjustment.*

loop test. The size of the LSS is just 260 mm × 150 mm × 420 mm (10.3" × 5.9" × 16.5") making it very easy to maneuver into position and align with the system being tested.

Frequency stability is provided by a high quality internal OCXO, again for autonomy, and LO phase noise, while not needing to be to transmission standards for the tests, is nonetheless good at -100 dBc/Hz at 10 kHz offset.

The attenuator in each polarization path is continually variable over a 30 dB range and can be set to mimic typical atmospheric conditions even though the tests would normally take place in a sheltered environment and over a SuT to LSS distance of around 30 m. Variants with amplification are also offered where the test range distance is considerably greater, in which case the nominal -35 dB conversion gain of the LSS can be increased up to +30 dB with close to 1 W of available output power in the downlink band.

Although just one typical application for the satellite simulator is described here, namely airborne systems, the same principle and the same product can be employed for vehicular, railway and marine systems as well as portable flyaway and manpack products.

Equally, there is a Ku-Band version, for a similar range of applications, which will loop back the common uplink frequencies to the multiple downlink frequencies, albeit with larger antennas in a slightly increased instrument size.

Throughout the product development from concept through to delivered hardware, ease of set up and application has been a dominant consideration, thereby saving considerable elapsed test time with greater speed into service for the system under test. Where airline service is concerned, this is a very significant factor.

VENDORVIEW

AtlanTecRF
Braintree, Essex, UK
www.atlantecrf.com

DDG 1000 Destroyer Completes Trials

VIEW VIDEO

Key ship capabilities were rigorously tested in recently completed Builder's and Acceptance Trials, including the Raytheon-developed comprehensive Total Ship Computing Environment integrated mission system. All systems performed well throughout both periods at sea, culminating with the recommendation for ship acceptance by the Navy's Board of Inspection and Survey. While underway on Builder's Trial, the Raytheon team onboard also conducted 20 hours of hands-on training with several members of the pre-commissioning crew.

Building on the successes of Alpha Trials, completed in early December, the Total Ship Computing Environment again operated well for the duration and achieved the demonstration goals for acceptance. Similarly, DDG 1000's engineering control systems, integrated bridge, navigation and electro-optic surveillance systems performed well throughout both trials.

With official verification of fully-capable Hull Machinery and Electrical systems, DDG 1000 transferred to the Navy from the shipyard. Soon, the ship will sail to Baltimore for its October commissioning, and then transit to its homeport in San Diego for the commencement of mission systems activation.

Raytheon provides electronic and combat systems for the three-ship class, contributing some of the most advanced systems in the Navy. These technologies will benefit these ships and the Navy for years to come. At the core is the Total Ship Computing Environment. It provides all shipboard computing applications, including the combat management system; command, control, communications, computers and intelligence elements; ship and machinery control systems; damage control; and support system. From networks, navigation and communications, to sensors, weapons and a high degree of automation, the DDG 1000 class features innovations from stem to stern that enhance operations onboard and deliver advanced, multi-mission capabilities.

The DDG 1000 class, the Navy's next-generation of multi-mission surface combatants, is tailored for sustained operations in the littorals and land attack, and will provide independent forward presence and deterrence, support special operations forces, and operate as an integral part of joint and combined expeditionary forces.

U.S. Navy/Released

Q-53 Radar Demos Counter-UAS Capability

The Lockheed Martin AN/TPQ-53 counterfire radar recently demonstrated its ability to identify and track unmanned aerial systems and pass that information to a command and control node, a key capability as the battlespace rapidly becomes more crowded with emerging air threats.

"The demonstration showed that the Q-53 radar can provide soldiers in combat real time awareness of air threats," said Rick Herodes, Q-53 program director, Lockheed Martin. "The inherent flexibility of the Q-53's active electronically scanned array (AESA) hardware architecture allows us to constantly evolve the Q-53's software to deal with emerging threats. This demonstration provided further verification that the Q-53 enables the warfighter to stay ahead of changing global threats."

The demonstration was part of the U.S. Army's Maneuver and Fires Integration Experiment (MFIX) at Fort Sill, Ok. The annual MFIX exercise brings together military, industry and academia to assess solutions to future warfighting needs in a live environment.

In the demonstration, the Q-53 radar showed it can be readily adapted to provide both air surveillance and counter fire target acquisition in one tactical sensor. The radar identified and tracked several unmanned aerial systems and provided data to Forward Area Air Defense Command and Control. Simultaneously, the Q-53 radar performed its original mission by providing accurate targeting data on rockets, artillery and mortars, providing a multi-mission radar (MMR) capability.

The solid-state phased array radar system detects, classifies, tracks and determines the location of enemy indirect fire in either 360° or 90° modes.

U.S. Army Photo

Finessing Miniaturized Magnetics into the Microelectronics Mix

A newly announced DARPA program is betting that unprecedented on-chip integration of workhorse electronic components, such as transistors and capacitors, with less-familiar magnetic components with names like circulators and isolators, will open an expansive

For More Information Visit mwjournal.com for more defense news pathway to more capable electromagnetic systems. The Magnetic, Miniaturized and Monolithically Integrated Components (M3IC), program will orchestrate research into miniaturized magnetic components with a goal of catalyzing chip-based innovations in radar and other radio frequency (RF) systems—and satisfying growing military and civilian demands for new ways to maneuver within the increasingly crowded electromagnetic spectrum.

"Magnetic materials let us access unique physics and functionality that we cannot duplicate with electronic components," said Dev Palmer, program manager for M3IC (pronounced "M-Cubic"), which is slated for a five-year run with total funding up to $26 million. "M3IC could change the way we design RF circuits and systems."

The physics and functionality Palmer refers to reside in the principles of electromagnetism, which govern RF signals. It is has been far easier for engineers to design, deploy, and miniaturize RF signal processing in electronics than with magnetic devices, yet some signal processing functions are more effectively achieved by manipulating magnetic fields. One reason for the slow adoption of magnetic components has been the difficulties inherent in miniaturizing and integrating such components directly on chips, alongside electronic circuitry. Among other issues, the magnetic fields that accompany these components can interfere with electronic behavior on chips in unpredictable and undesirable ways. This is why designers of radio, radar, and other RF systems typically segregate the magnetic functions they need off-chip, a limitation that results in bulkier, heavier and more power-hungry systems compared to the ones that the M3IC program are anticipated to enable.

> Chip-friendly magnetic materials combined with microelectronics could provide a portal to a new generation of magnetics-boosted circuits.

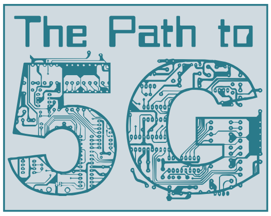
"M3IC is about distributing the magnetic functionality throughout the circuit instead of pushing it out to the edges," said Palmer. "It's about designing and fabricating circuits holistically, so the designer can supercharge state-of-the-art RF electronic circuits with magnetic functionality wherever it is needed, and only where it is needed, in one monolithic chip."

In particular, Palmer said, seamless co-design and integration of magnetic materials and semiconductors should lead to new generations of more compact microwave monolithically integrated circuits, or MMICs—a class of chips for RF technology developers that offer wider frequency ranges (bandwidth), better stability, and lower power needs than conventional chips.

5G Manifesto for Deployment of 5G in Europe

The 5G Manifesto for timely deployment of 5G in Europe has been produced by key players in telecoms and in sectors in which 5G technologies will help build innovative products and services. The 5G Manifesto outlines the main opportunities and challenges linked to the deployment of 5G infrastructure in Europe.

In particular, it provides recommendations for a common vision and a calendar for deployment of investments, standards and the synchronised introduction of services in Europe. It underlines the need for spectrum and improved regulatory conditions in terms of local installation of cells, open internet rules which promote innovation, data protection and fair use.



In the 5G Manifesto, the telecom companies propose a challenging calendar for the introduction of 5G networks across Europe. They commit to starting large-scale demonstrations by 2018 and launching 5G commercially in at least one city in each of the 28 Member States by 2020. This responds to a call made by European Commissioner Günther H. Oettinger at the 2016 Mobile World Congress to raise ambitions to make Europe a leader in 5G deployment.

Key recommendations of the manifesto include that the Commission and Member States should promote the benefits of 5G networks to meet connectivity needs of vertical industries and public institutions. It also states that industry is committed to pan-European 5G trials in areas such as connective automotive; connected eHealth, transport and logistics, Public Safety, smart grids, smart cities, media and entertainment. In 2017, it will deliver a roadmap for trials and demonstrators to start in 2018.

Economically, industry calls on the Commission to use existing instruments such as EFSI and structural funds to create a €1 billion 5G venture fund to take equity stakes in European innovative start-ups aiming at developing 5G technologies and applications across verticals. Technologically, the manifesto calls for timely identification and granting of spectrum for 5G including 700 MHz, 3.4 to 3.8 GHz and higher frequency bands (for 24 GHz and beyond) by 2020.

CHROMED Telemedicine Project

The EU-funded CHROMED project has been researching telemedicine care models for chronic diseases, offering the benefits of early diagnosis and treatment alongside a reduction in the socioeconomic burden. The project was set up to assess the benefits for elderly patients of adopting a health and lifestyle self-monitoring system at home. These patients were suffering from a combination of Chronic Obstructive Pulmonary Disease (COPD) and comorbidities, such as Chronic Heart Failure and Sleep Disordered Breathing (SDB), severely compromising their quality of life.

CHROMED was conducted as an international, multicentric, randomised control trial (RCT) over a nine month period. It involved 312 patients across five European countries: the United Kingdom, Sweden, Estonia, Spain and Slovenia. The participating care organisations of these countries all had pre-existing systems in place for age-related disease management.

> ...benefits of early diagnosis and treatment...

The project comprised principally of three elements. Firstly, the Home Patient Monitor (HPM) was a touch screen device which collected the data. It shared 3G connectivity with additional devices and by functioning as a gateway for these devices, patients were reminded of monitoring activities and care givers were able to give remote patient support. At the end of daily monitoring, data was sent to a central server and automatically analysed against clinical algorithms to determine any necessary courses of action.

Overall, CHROMED demonstrated proof of concept for getting unsupervised lung function measurements outside of laboratories. The study concludes that applying CHROMED solutions across EU healthcare systems would result in significant cost savings with an optimisation of resources and improved quality of life for patients. The study recommends clinical practices looking specifically at rolling out the system to high-risk patients with a history of hospitalisations.

Vodafone and Ericsson Demonstrate 5G Proof of Concept

Ericsson and Vodafone have demonstrated a new 5G Proof of Concept. The two companies created a 5G Smart Network Edge prototype including a 5G ready core and demonstrated the benefits of network slicing and distributed cloud technology using the example of a Machine Vision application.

In a live demo shown during the Innovation Days at Ericsson's R&D Centre in Aachen, Germany, both companies showed how the 5G Smart Network Edge enables much greater efficiency for industry: due to reduced network latencies the recognition rate of a cloud-based face detection application was increased; significantly less video traffic had to be sent over the Wide Area Network and sensitive data was kept locally and was therefore better protected against unauthorized access.

Sonja Graf, head of Vodafone Innovation Park, Vodafone Germany, said, "Within only three months we created a 5G Smart Network Edge prototype by connecting our labs. The Face Recognition use case is just one example

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demonstrating how 5G will meet the diverse needs of a wide range of industries."

Valter D'Avino, head of Ericsson Western and Central Europe, said, "We are delighted that the Ericsson and Vodafone labs have come together to innovate and this first use case shows an excellent example of how 5G can enable industries to become more efficient as well as more secure and cost effective."

NXP Supports China's Intelligent Transportation System

NXP Semiconductors and Tongji University announced their support for the launch and implementation of China's first ever large-scale road test initiative for intelligent connected vehicles through the NXP-Tongji University Joint Lab. As part of the Shanghai Intelligent and Connected Vehicle Demonstration Program, the road testing initiative will serve as a foundation for China's development of smart transportation and vehicle-to-vehicle communications standards.

> "...the creation of world-class intelligent transportation systems in China..."

NXP and its partner Cohda Wireless will provide secure vehicle-to-vehicle and vehicle-to-infrastructure (V2X) communications technology for cars and roadside infrastructure. Road testing will collect V2X communications data in real time from multiple test scenarios, including measures of active safety, traffic management and information services.

The launch of road testing represents a significant milestone for the Shanghai Intelligent and Connected Vehicle Demonstration Program. Launched in October 2015, the first phase involves approximately 200 vehicles from the Shanghai Automotive Industry Corporation (SAIC), one of China's largest domestic auto manufacturers, as well as from other participating automakers. As additional carmakers join the program, the aim is to have 1,000 intelligent and connected vehicles by 2017, 5,000 vehicles by the end of 2019, and 10,000 vehicles by 2020.

"We are pleased to partner with SAIC and Tongji University to further advance the Shanghai Intelligent and Connected Vehicle Demonstration Program," said Li Zheng, President of NXP Greater China. "Developing intelligent transportation systems is vital for building sustainable cities. As a global leader in secure connected vehicle solutions and autonomous driving platforms, NXP is truly honoured to offer the proven reliability of RoadLINK technology and our deep automotive expertise for the creation of world-class intelligent transportation systems in China."

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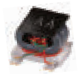

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Cliff Drubin, Associate Technical Editor

New 3GPP IoT Standards to Boost Global Cellular IoT Shipments

VIEW VIDEO

NB-IoT will consume more than 70 percent of Release 13 shipments and more than one third of all cellular IoT shipments—a value which is greater than legacy M2M or the current Cat-1 standard.

"While some in the industry view the new 3GPP standards as competitors to the current non-3GPP LPWA technologies and predict their demise, we believe that NB-IoT will complement LPWA," says Nick Marshall, research director at ABI Research. "But it is true that out of the 15 LPWA technologies we profiled, some were designed for use cases that are unsuitable for NB-IoT, such as where downlink data is not required."

The 3GPP Release recently finalized three, new cellular LTE-based IoT standards—Cat-M1, NB-IoT and EC-GSM—that offer a cellular alternative to proprietary unlicensed low-power wide-area network (LPWA) technologies like Ingenu, LoRa and SIGFOX. The standards make it easy to configure an LTE network through a simple software upgrade to the existing LTE radio interface, which is why ABI Research expects rapid growth and worldwide deployment of NB-IoT to start in 2017.

Pre-standard NB-IoT pilots and trials are already taking place, or are about to, with operators such as AT&T, China Mobile, China Unicom, Deutsche Telekom, Orange, Telefonica and Vodafone working with equipment from vendors including Ericsson, Huawei, Intel, Nokia and Qualcomm.

> "NB-IoT stands ready to unlock the full potential of IoT..."

"Ultimately, the choice of IoT radio link involves trade-offs between conflicting features, which often involve capacity, licensed versus unlicensed operation, range, reliability, battery life, cost and proprietary versus standards-based schemes," concludes Marshall. "NB-IoT stands ready to unlock the full potential of IoT thanks to its high link budget for maximum coverage extension, low cost, and ability to reuse existing LTE networks with carrier grade reliability and security."

GPS Industry Shifts from Traditional Markets, Embraces Indoor Location Technology

GPS personal tracking device shipments will more than double by 2021 with a 21 percent CAGR as the industry shifts away from traditional markets, such as family and pet locator devices. ABI Research predicts that non-traditional markets including elderly/health, corporate and personal asset tracking will embrace ubiquitous indoor and outdoor location technology.

"Traditional markets still attract attention, given the huge total available market, but they remain too fragmented, with no obvious sales and distribution channels," says Patrick Connolly, principal analyst at ABI Research. "As a result, a number of established companies in this space are being forced to consider new areas to find future growth."

> "...we see stronger device shipments in corporate, industrial and personal asset tracking..."

New healthcare applications in elderly, dementia and remote patient monitoring, for instance, have great potential. ABI Research anticipates location-enabled health devices to break two million shipments by 2021. "When you consider the fact that average healthcare spending is increasing at a time when approximately 30 percent of U.S. hospitals are losing money, there is an immediate need for technology to remove the inefficiencies of the current market," continues Connolly.

Meanwhile, the lone worker market shows significant acquisition activity, which is leading to an increase in pricing pressures as companies look to buy market share. This is a dangerous strategy in a market that will not scale rapidly.

But indoor location will open up new applications and services. "We see stronger device shipments in corporate, industrial and personal asset tracking, with a combined total exceeding 25 million by 2021," concludes Connolly. "BLE beacons will open up these markets, but we also see a host of other technologies emerging, such as UWB, sensor fusion, magnet field, proprietary Wi-Fi and LPWAN. We believe this will spark demand for 'outdoor' technologies like GPS."

Smart City Solutions Push for Connectivity Coordination

As LTE and other wireless technologies advance smart city solutions, it is crucial that solutions providers liaise with city planners to take a coordinated approach on connectivity selection. This includes analyzing the physical and cybersecurity benefits and limitations. Smart city solutions' importance is increasing as nearly 70 percent of the global population will live in an urban environment by 2050.

"Solutions providers should take this time to bring down the cost of deployment and management, as well as analyze the ROI scenarios for city planners," says Jake Saunders, managing director and vice president at ABI Research. "And city planners need to understand and embrace the benefits connectivity technologies will bring as a platform to these solutions."

The benefits to smart city solutions are substantial.

For More Information

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> Smart city solutions' importance is increasing as nearly 70 percent of the global population will live in an urban environment by 2050.

Smart meters can efficiently manage and control demand as cities face increasing strain on resources and distribution infrastructures due to rapid urbanization. They also cut operational costs by reducing the required number of on-site meter readings. Smart street lighting allows operators to dim them when appropriate, extending their usage and reducing operating expenses. And smart bins help trash collectors optimize their routes and keep cities clean.

ABI Research forecasts global smart meter revenue will top $13 billion in 2021. The number of smart bins will increase from roughly 70,000 in 2015 to almost one million in 2021. And while smart street lighting solutions barely scratched their market potential, they will grow to reach 78 million shipments by 2021.

Wireless connectivity will capture the lion's share of new smart street lighting deployments, but power line communication (PLC) solutions are unlikely to disappear in the foreseeable future.

Carrier Wi-Fi Investment Shifts to LTE-U and LWA

Mobile Experts LLC released a report providing detailed analysis of the Carrier Wi-Fi market, predicting a decisive transition from 'pure Wi-Fi' to unlicensed services tied to LTE in various ways. The report provides detailed information about License Assisted Access (LAA), LTE Wi-Fi Aggregation (LWA), and LTE WLAN Radio Level Integration with IPSec Tunnel (LWIP), as well as LTE in Unlicensed bands (LTE-U).

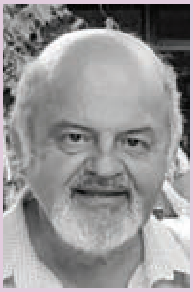
"In the past, mobile operators have invested in significant Wi-Fi networks," explained Kyung Mun, senior analyst at Mobile Experts. "In the future, we expect even more investment in the unlicensed bands, but it will be redirected toward LAA, LWA and LWIP. The competition for unlicensed spectrum use via Wi-Fi or LTE-U is a reflection of the competitive dynamics of the different types of operators."

"This research expands on our comprehensive study of small cells, DAS and enterprise mobile infrastructure so that we can provide a 360 degree view of the in-building wireless market. We are watching the investments growing in small cells with LAA and LWA capability integrated into the mix, as well as new investments in stand-alone unlicensed LTE services by completely new players."

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

IN MEMORIAM



▲ *Costas D. Varmazis*

Costas D. Varmazis, of Chelmsford, Mass., died on June 2, 2016. Highlights of his career include being a founding faculty member and tenured Professor of Physics at the University of Crete in Iraklion, Greece; and a more than 25-year career in semiconductor engineering at MACOM and Tyco Electronics, in Lowell, Mass., where he was senior principal engineer and distinguished fellow of technology. He was awarded numerous patents, and in 2007 was a recipient of the Tyco Electronics Impact Innovation Award and Lifetime Achievement Award. He is survived by his wife, Catherine (Katina) Galatsianos Varmazis; son, Dimitri; daughter, Maria and son-in-law, Eric Bergeron; and his siblings, Nikos Varmazis, Ioannis Varmazis, Maria Karabidi, Eleni Varmazi and Agathi Modiati, all of Greece.

MERGERS & ACQUISITIONS

Carlisle Companies Inc. announced the acquisition of **Micro-Coax Inc.**, a global supplier of high-performance, high frequency coaxial wire and cable, and cable assemblies for mission-critical RF/microwave applications for defense, satellite, test and measurement, and other industrial customers. With annual sales of approximately $45 million and 235 employees, Micro-Coax has manufacturing facilities in Pottstown, Pa. and a joint venture operation in Blackburn, UK. The company has been in business for over 50 years and is a supplier to the world's leading defense, aerospace and electronics companies. Micro-Coax designs, manufactures and sells customized, high-reliability wire and cable for signal transmission on defense, space and satellite platforms and in high-end industrial equipment.

Genstar Capital, a middle-market private equity firm focused on investments in targeted segments of the industrial technology, software, healthcare and financial services industries, announced the acquisition of **Infinite RF Holdings Inc.** (IRF), a supplier of engineering grade RF technology components. Infinite RF offers a broad range of connectivity components and assemblies serving the aerospace and defense, industrial, government, consumer electronics, instrumentation, education/medical, and telecommunications markets. Operating under the Pasternack and Fairview brand names, IRF serves a global engineering customer base with deep technical expertise and one of the broadest inventories of RF products available for immediate shipment.

Samtec Inc., a provider of high bandwidth and micro-pitch interconnect systems, announced the acquisition of **nMode Solutions**, of Oro Valley, Ariz. The acquisitions of nMode Solutions and their subsidiary, Triton Microtechnologies will allow Samtec to invest in advanced technology to enable next generation systems.

COLLABORATIONS

Anritsu and **Keycom** have signed a collaboration agreement based on which Anritsu becomes the exclusive distributor in EMEA of the Keycom Radar Test System developed for verification. In the future, it is expected that autonomous self-driving vehicles will require high performance radar systems for collision avoidance, and this is an expanding area of technology for sensor and image fusion for autonomous driving. Radar technology has been added to mid-range and standard model vehicles in recent years, as it becomes an affordable technology. It was first introduced into high end luxury models for adaptive cruise control, but now performs an important safety role for many types of vehicles.

Mitsubishi Electric US and **NextGen RF Design** have joined forces to offer RF design engineers a 7 W, UHF Band amplifier evaluation kit and associated reference design package (RD07 reference design kit) to help accelerate design cycle times. NextGen RF Design developed and customized the RD07 reference design kit specifically for Mitsubishi Electric's RD07MUS2B silicon RF (SiRF) transistor (RD07). This kit is a RoHS-compliant 7 W MOSFET, which can be used as the final output stage prior to the antenna or, in higher power applications, as a high-efficiency driver. It serves as the transmitter backbone for a variety of mobile and portable communication devices.

NEW STARTS

Massachusetts Bay Technologies Inc. (MBT), an RF/microwave semiconductor diode and passive component manufacturer has launched a new website. The new site, www.massbaytech.com, includes extensive product information to help customers understand MBT's complete product portfolio. Whether you are looking for a high-rel diode, standard diode(s),or custom chip capacitors, the new website provides a detailed overview of MBT's capabilities.

International Manufacturing Services (IMS) is inviting users to explore their newly redesigned website launched earlier this year. The new website provides a supreme user-friendly experience with simple navigation allowing customers to access detailed product information. The new website has a clean uncluttered design, improved functionality and content that focuses on the company's mission to provide the electronics manufacturing industries with the highest quality devices and components. Visitors can stay informed with the latest news, request a quote or sample

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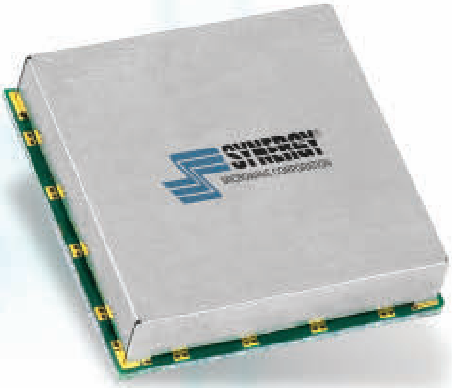

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HFSO745R84-5	745.84	0.5 - 12	+5 VDC @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 VDC @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 VDC @ 20 mA	-146
HFSO800-5H	800	0.5 - 12	+5 VDC @ 20 mA	-144
HFSO800-5L	800	0.5 - 12	+5 VDC @ 20 mA	-142
HFSO914R8-5	914.8	0.5 - 12	+5 VDC @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 VDC @ 35 mA	-141
HFSO1000-5L	1000	0.5 - 12	+5 VDC @ 35 mA	-138
HFSO1600-5	1600	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO1600-5L	1600	0.5 - 12	+5 VDC @ 100 mA	-133
HFSO2000-5	2000	0.5 - 12	+5 VDC @ 100 mA	-137

** Package dimension varies by model (0.5" x 0.5" or 0.75" x 0.75").*

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ACHIEVEMENTS

ASELSAN, with its 40 years of expertise in defense electronics, has been designing and developing the 94 GHz, phased array and scalable SiGe integrated circuits for use as transmitter (TX) and receiver (RX) modules for potential civil radar systems. RX ICs will be ready as of mid-2016 and TX ICs are also coming soon. These integrated circuits will allow ASELSAN to develop cost effective and high performance civil radar applications, such as border security, airport foreign object debris detection, collision avoidance, autonomous landing, meteorology, etc. This will enable ASELSAN to expand its defense oriented product range to cover a broader spectrum including civilian applications.

ZTE Corp. announced that they have completed verification and performance tests for the 5G high-frequency communication and massive MIMO technologies in Shanghai and Shenzhen respectively. The tests were organized by the Chinese IMT-2020 (5G) Promotion Group, and fully implemented in both Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) scenarios. ZTE is now one of IMT-2020 (5G) Promotion's first suppliers that has completed the high-frequency communication and uplink massive MIMO tests.

Advantech Wireless has been recognized as winner of two awards, one for innovation and the second for International Market Development, both in the large companies categories at the Mercuriades Awards during the 36th edition of the business competition organized by the Federation of Chambers of Commerce of Québec (FCCQ). The winners of Les Mercuriades 2016 were announced on May 16th at the Grand Gala evening held at the Palais des Congrès de Montréal. This is Advantech Wireless' third time winning the Les Mercuriades prize for Innovation in R&D.

Akoustis Technologies, a manufacturer of innovative BulkONE™ bulk acoustic wave (BAW) high band RF filters for mobile wireless, has been awarded multiple foundational patents related to its single crystal piezoelectric materials, novel BAW resonators, wide bandwidth RF filters and their application in mobile devices. The U.S. Patent and Trademark Office (USPTO) has issued U.S. Patent No. 9,362,887. Further, the China Patent Office (SIPO) has issued China Patent Nos. ZL 201520549840.3, ZL 201520566852.7 and ZL 201520652061.6.

CONTRACTS

Jacobs Engineering Group Inc. announced it received a contract to provide the **U.S. Naval Air Warfare Center Weapons Division** (NAWCWD) with test and evaluation/training threat/target systems (T4S) for warfighter training and debriefing systems. Under the terms of the contract, Jacobs is expected to assist NAWCWD in its efforts to research, develop, deliver, sustain and upgrade its threat systems; range instrumentation equipment; range command

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Around the **Circuit**

and control equipment; data routing, storage and display equipment, as well as to provide software for pre-deployment aircrew warfighter training and weapons systems test and evaluation. The contract is valued at $427 million over five years.

The U.S. Marine Corps Logistics Command has awarded **Raytheon Co.** up to $249 million with options over five years for work on the Secondary Reparable, or SECREP program, rebuilding vehicle parts such as engines, transmissions and electronics. The Marine Corps takes delivery of the items at approximately half the price of buying new. The savings can be reinvested into Marine Corps logistics, helping to ensure the readiness of Raytheon has helped the Marine Corps realize millions in cost underruns through sustainment programs, which were made available for reinvestment. Raytheon's 98 percent on-time delivery of these mission critical components has resulted in significant cost efficiencies.

CACI International Inc. announced it has been awarded a $40 million single-award, indefinite delivery/indefinite quantity contract (IDIQ) from the **Defense Logistics Agency** (DLA) to provide development and sustainment support for the Department of Defense (DoD) Wide Area Workflow (WAWF) and Electronic Document Access (EDA) systems. This three-year contract continues CACI's business in its business systems market area. Designed to eliminate paper from the receipt/acceptance and invoice/payments process of the contracting lifecycle, the CACI-supported WAWF has saved DoD approximately $250 million a year in invoice processing.

Cobham recently received a series of orders from a leading defense firm for RF microelectronics and antenna assemblies that support an airborne electronic warfare (EW) program valued at approximately $18 million. The work will be performed by the Lansdale, Pa., San Jose and San Diego, Calif. locations of the Cobham Advanced Electronics Solutions sector. Cobham Advanced Electronic Solutions provides Electronic Attack (EA), Electronic Protection (EP), and Electronic Warfare Support (EP) capabilities specifically designed and built for air, land and maritime operations. EW related products include microelectronic components, integrated assemblies modules and subsystems, antenna and jammer solutions, as well as positioner and gimbal solutions.

Teledyne Defence, a business unit of Teledyne Microwave Solutions, announced that it has been chosen by **OneWeb Satellite** for the supply contract to produce hundreds of space-qualified 'flexible channelisers' for its global satellite constellation deployment. Two flexible channelisers, also known as 'converters', will be required for each of the 900 small satellites that will be produced in the next few years by OneWeb. The low Earth orbit satellites require flexible channelisers that can support constantly changing frequencies to successfully deliver OneWeb's broadband internet access services. An additional contract option will follow this development stage for the production of the remaining flexible channelisers needed for all 900 OneWeb satellites.


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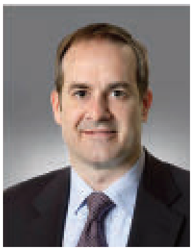
▲ *Mark J. Murphy*

Qorvo®, a provider of innovative RF solutions that connect the world, announced the appointment of **Mark J. Murphy**, 48, as chief financial officer, effective June 6, 2016. Murphy will report to Bob Bruggeworth, president and chief executive officer of Qorvo, and will succeed Steven J. Buhaly, who previously announced his intention to retire from the company in 2016. Buhaly will remain in an advisory capacity until July 31, 2016 and will work closely with Murphy to ensure a seamless transition.


▲ *Andy Crawford*

Andy Crawford has been promoted to the newly created position of head of After Sales and Support Worldwide at **TMD Technologies Ltd.** In his new role Crawford reports directly to TMD's new Sales and Business Development director, Jane McAlister, and will be focusing on all aspects of further improving and enhancing TMD's post order customer service. Crawford has gained a wealth of experience in his 12 years at TMD, in a variety of senior roles – starting as ATC product specialist and latterly as territory manager for all TMD's products in North America, Canada and the Middle East.


▲ *Bob Adams*

Analog Devices Fellow **Bob Adams** was awarded the 2016 Industrial Pioneer Award from the IEEE (Institute of Electrical and Electronics Engineers) Circuits and Systems Society for his groundbreaking work on commercial delta-sigma converters. He is one of only 16 people to receive this prestigious honor. Adams is an Analog Devices Fellow, which is a distinguished technical position awarded to engineers who contribute significantly to the company's business success through exceptional innovation, leadership, entrepreneurship and an unparalleled ability to bridge organizations and mentor other Analog Devices employees.

PLACES

Anritsu Corp., a provider of innovative test and measurement solutions for wireless, optical, RF/microwave and digital instruments, announced that it has opened a new office in Ireland. The office is located in Dublin, a location chosen to best serve key customers in the region. The Irish office will be headed by Steve Wilding, sales director Western Region, who brings 20 years of experience in test and measurement. He will be coordinating the regional sales and business development efforts for the Irish marketplace. The account team for Ireland includes Sophie Barc, Fiona Booker and Raffaella Ricci.

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INVITED PAPER

Compact SAW-less Transmitter for 3G, 4G and Beyond

Pedro Emiliano Paro Filho[1,2], Mark Ingels[1], Piet Wambacq[1,2], Jan Craninckx[1]
Imec[1], Leuven, Belgium; Vrije Universiteit Brussel[2], Ixelles, Belgium

The point where wireless communication and ubiquitous connectivity became an essential part of our lives has already passed. Generation after generation, communication speed is being taken to unprecedented levels, requiring both state-of-the-art hardware and software to handle a huge volume of data, delivered to an increasing number of users in an overcrowded spectrum. As tough as it sounds, to our delight the challenges are always plentiful.

With respect to the radio front-end, providing extremely low noise emission with improved signal integrity are key requirements to supporting high-order modulation schemes (e.g., 64 QAM) in situations where anyone's transmitter can be interfering with a neighboring user or its own receiver in frequency-division full duplex. On the transmit side, linearity requirements are commonly translated into ACLR and EVM parameters, whereas out-of-band noise is typically defined by the maximum power spectral density allowed in the receive band. Increasing power consumption or area are not options. On the contrary, for an improved user experience, the battery should last longer, and the price per component should always go down so that more and more features can be added to the mobile device. Thus, making a better performing radio front-end that consumes even less power and is smaller is a hot research topic, especially the transmitter and power amplifier (PA) designs — considered by many the "battery killers" on most mobile devices.

ANALOG VS. DIGITAL-INTENSIVE

A quick analysis of literature shows that the state-of-the-art for transmitter implementations is divided into analog and digital-intensive architectures. In terms of out-of-band noise, analog intensive architectures are undoubtedly the best performing implementations.[1–5] However, their improved noise performance is typically achieved through extensive lowpass filtering along the entire signal path, which has a significant impact in area consumption. To filter out quantization noise and the sampling aliases from the digital-to-analog conversion, bulky reconstruction filters (which can use up to 1.37 mm^2) are commonly used.[3] The implementation of such analog blocks is becoming more and more difficult using digital-driven, highly-scaled CMOS technologies. The reduced supply voltage, limited transistor gain and increased leakage are a few of the issues aggravated with every new technology node.

Digital-intensive implementations, on the other hand, are by far the most portable, area efficient and scaling friendly.[6–9] However, the lack of filtering for both noise and aliases makes it very challenging to meet the stringent out-of-band noise requirements with a SAW-less design. The direct digital-to-RF conversion leaves no analog path for a reconstruction filter to be introduced, so both quantization noise and sampling aliases are up-converted to RF frequencies without any attenuation. In these architectures, the quantization noise is addressed by either increasing the number of bits in the digital-to-analog converter (DAC), $\Sigma\Delta$ modulation or filters notching at specific parts of the spectrum (e.g., the receive band in frequency division duplex (FDD) systems). The aliases, in turn, are often attenuated by the sinc transfer function, using large sampling frequencies. Nevertheless, depending on the overhead circuitry and speed, some of these

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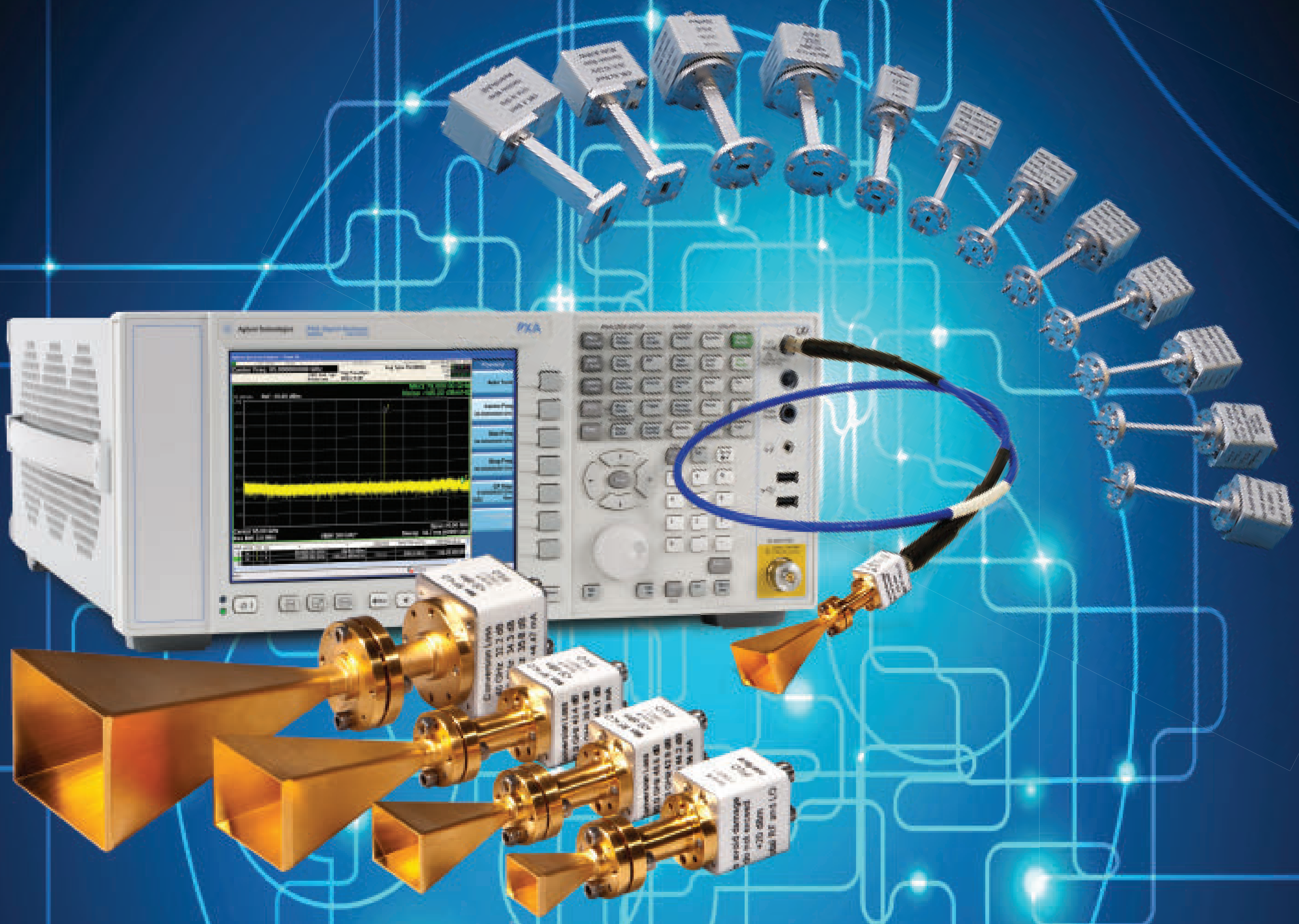

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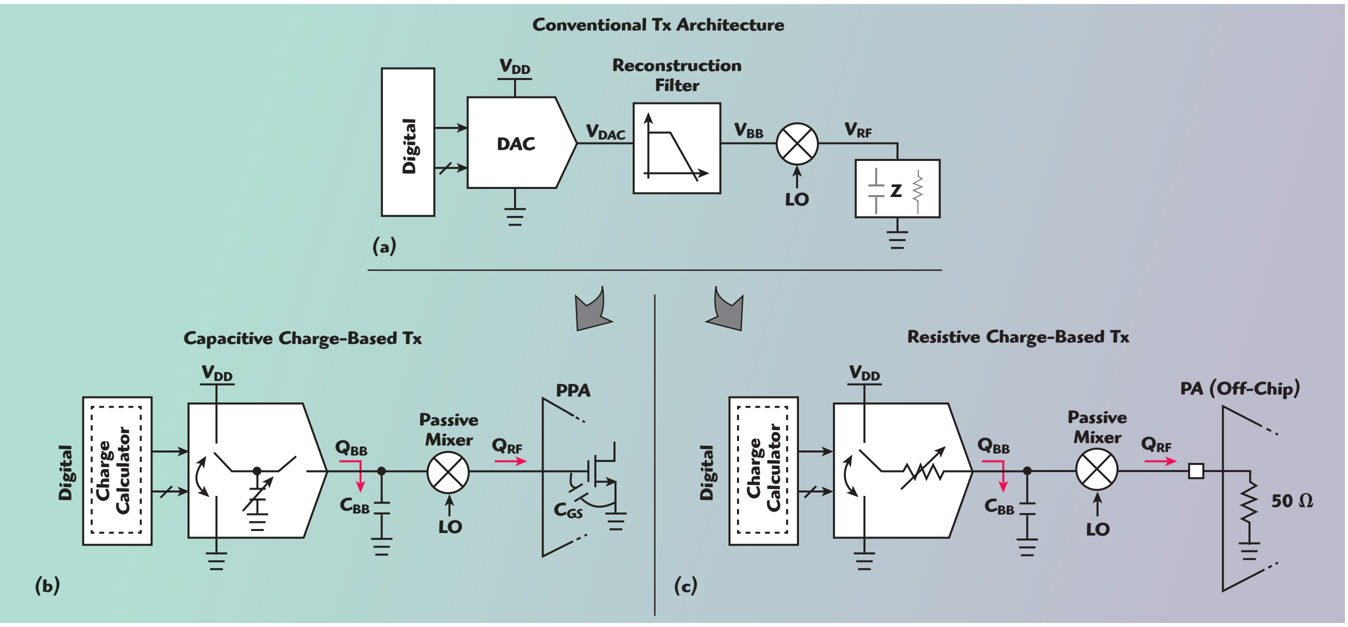


▲ *Fig. 1 Conventional Tx architecture (a) with capacitive[10] (b) and resistive[11] (c) charge-based realizations.*

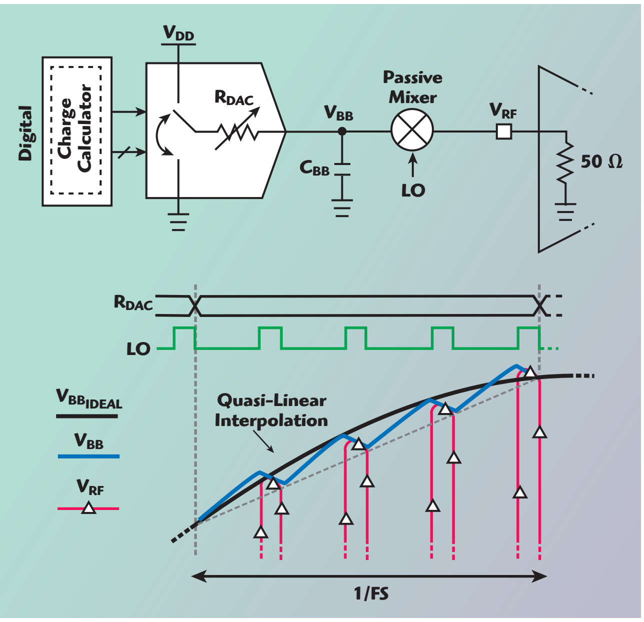
solutions conflict with the intended reduction in power consumption and area.

INCREMENTAL CHARGE-BASED OPERATION

A novel, digital-intensive transmitter architecture that can relax this trade-off was first presented at ISSCC 2015.[10] Through the combination of charge-domain operation with incremental signaling, this architecture gives the best of both worlds, providing the reduced area and high portability of digital-intensive architectures and the improved out-of-band noise performance from intrinsic noise filtering capabilities.

The simple observation of a conventional transmitter implementation leads to the conclusion that the modulator is always driving a capacitive load, either an active mixer input transistor or the pre-power amplifier (PPA) input capacitance driven through a passive mixer. In either case, providing the required speed and linearity demands low output impedance circuitry that typically increases power consumption significantly, especially when the signal swing is increased to improve the signal-to-noise ratio (SNR). Driving capacitance can be much more efficient if operated incrementally, in the charge domain. When all capacitances across the signal path are known, changing their voltages can be done by simply adding or subtracting charge. If no biasing is required, the only charge taken from the supply corresponds to the increment — hence, the minimum charge needed to provide the desired voltage swings. The same reasoning applies even when the RF load is not capacitive.[11]

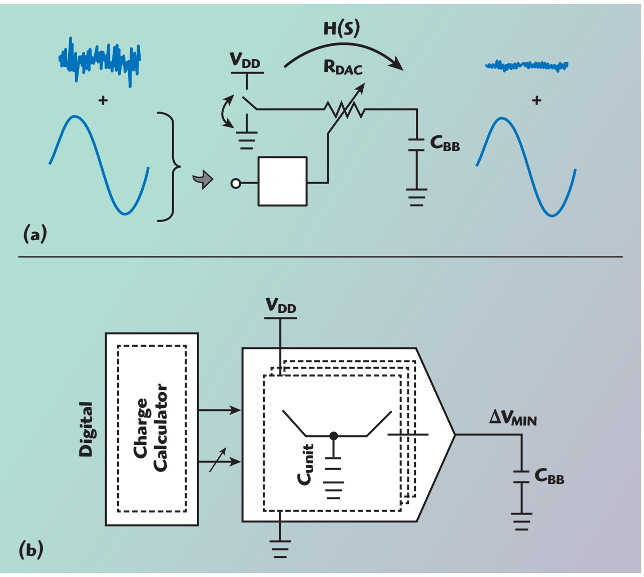
The operation of this architecture is based on two charge components, baseband (Q_{BB}) and RF (Q_{RF}). The baseband component represents the amount of charge required to drive a baseband capacitance C_{BB}, moving the baseband voltage up and down as defined by the digital input signal. The RF charge, on the other hand, is the amount subtracted from C_{BB} to drive the RF load every time the mixer switch is closed. As expected, the exact Q_{RF} depends on the nature of the RF load, whether resistive or capacitive (see ***Figure 1***).[10–11] Whenever a new baseband data sample arrives, a charge calculation block in the baseband processor determines how much extra charge should be accumulated on each one of the baseband capacitors and subsequently transferred to the RF output, so that every node follows its expected voltage excursion. The total amount of charge given by the sum of Q_{BB} and Q_{RF} ($Q_{TOTAL}=Q_{BB}+ Q_{RF}$) is then delivered from the supply to the baseband capacitors (and vice versa) by the so-called charge-based DACs (QDAC).



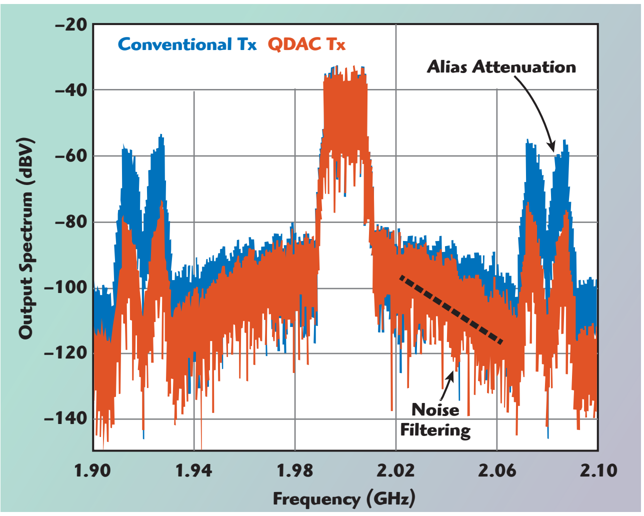
▲ *Fig. 2 Quasi-linear interpolation improves alias attenuation.*

Two implementations of the incremental charge-based transmitter have been demonstrated since last year.[10–11] They differ on how the QDAC is implemented and the RF load being driven. In the first, the RF load is the input capacitance of a PPA stage, and the QDAC is implemented with a

controllable capacitance that is first pre-charged and then connected to C_{BB}. Fractions of the total charge (Q_{TOTAL}) required per sampling period are conveyed at LO speed in discrete packets, sized by adjusting the DAC capacitance accordingly. In the second implementation, the ability of the charge-based architecture to deliver more power was investigated. Based on the observation that the first IC's power consumption is highly impacted by the PPA bias current, a direct launch implementation was evaluated, where the PA is driven directly from the QDAC. In this case, the benefits include removing a power-hungry block from the signal path (i.e., the PPA) and increasing the effectiveness of pre-distortion by directly controlling the PA input — represented by a 50 Ω load in this implementation. In the direct launch case, the QDAC was implemented using a 12-bit conductance array, which proved to be the most area-efficient way of increasing the charge capac-



▲ *Fig. 3 Noise filtering mechanisms: the signal-dependent RC filter attenuates uncorrelated noise (a) and the charge-based architecture reduces quantization noise (b).*



▲ *Fig. 4 Output spectrum showing both noise and alias reduction provided by the charge-based architecture.*

ity of the QDAC. Instead of delivering packets of charge at the LO rate, as in the first implementation, the required total charge is transferred to the baseband node by charging and discharging C_{BB} in continuous time. Since the DAC switches are operated at baseband speed (and not LO), further improvements in power consumption can also be achieved compared to the first implementation.

IMPROVED NOISE PERFORMANCE

Recapitulating, an important drawback of the RF DAC's output spectrum is that baseband noise sources and spurs (including thermal noise, quantization noise and sampling aliases) are up-converted to RF without any filtering. However, the charge-based architecture can provide sensitive improvements in noise performance.

In transmitter architectures applying conventional DACs, the transmit signal is reconstructed from digital to analog at the baseband sampling rate. The resulting aliases are hence shaped by a sin(x)/x or sinc transfer function, inherent with zero-order hold systems. On the other hand, with the two charge-based architectures, without oversampling the digital input signal or increasing the interface speed of the QDAC, the continuous charge and discharge of C_{BB} provides an inherent quasi-linear interpolation between the consecutive baseband samples (see ***Figure 2***). The output spectrum in this case is shaped by a sinc^2 transfer function that significantly attenuates the sampling aliases. For example, more than 20 dB of alias attenuation is inherently provided when a 20 MHz bandwidth signal is sampled at 500 MSPS.

The intrinsic noise filtering capability of the architecture is another key enabler to improving the out-of-band noise performance. Clearly seen with the resistive QDAC implementation, the combination of the baseband capacitor C_{BB} and the resistive QDAC array yields an inherent single-order lowpass filter in the signal path. However, since the resistive component is constantly changing over time, in order to adjust the amount of charge transferred to C_{BB}, the cutoff frequency is not fixed. The equivalent RC time constant, which defines the filter cutoff frequency, is signal dependent, and automatically adjusted to provide the required instantaneous swing at the baseband node. As a result, the wanted signal is properly built at the baseband node without any attenuation. On the other hand, uncorrelated signals — not part of the digital input and which do not affect the charge calculations — do not have the same "on demand" bandwidth adjustment. Because of the architecture, they are filtered, with an equivalent cutoff frequency numerically approximated by the average QDAC conductance over time (see ***Figure 3a***):[12]

$$f_{-3dB}(\text{NOISE}) = \frac{\text{RMS}\left(1/R_{DAC}\right)}{2\pi C_{BB}} \quad (1)$$

This noise cutoff frequency, which applies to any noise contributor coupled to the baseband (including quantization), is a major advantage of the

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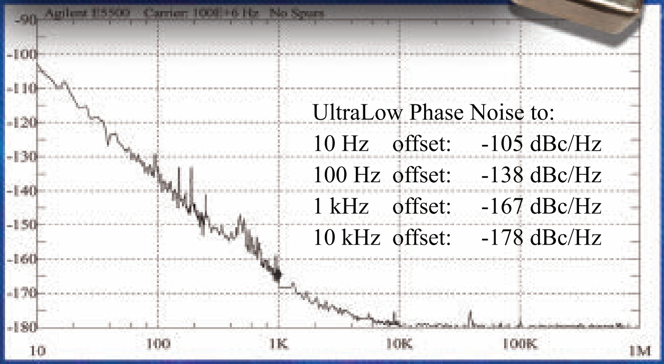

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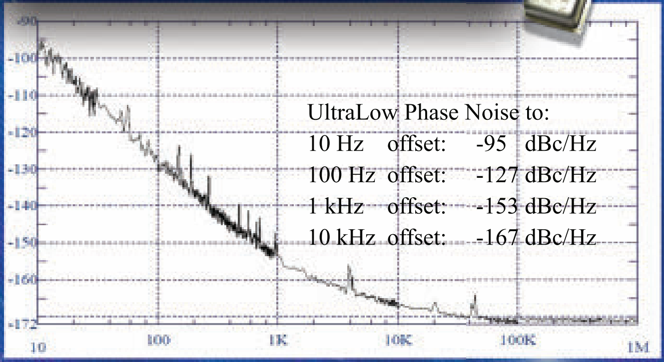

MV341

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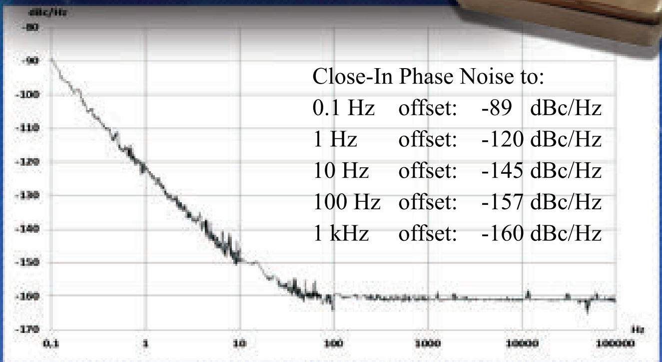

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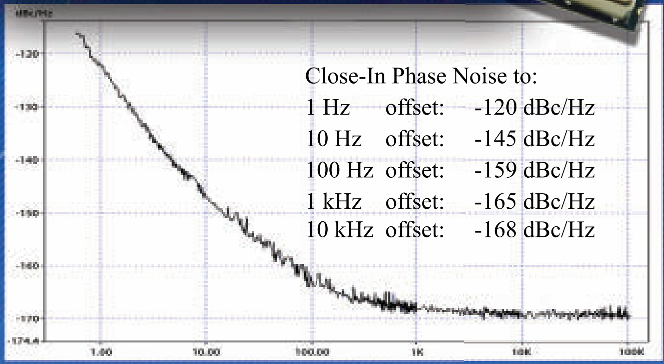

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incremental charge-based transmitter.

In addition to noise filtering, quantization noise is inherently improved by the charge-based architecture. Introduced whenever an infinite resolution analog signal is represented by its discretized digital counterpart, quantization noise for a given DAC is bounded by the minimum voltage or current step that can be created at its output. In a conventional architecture, it corresponds to the least significant bit (LSB), which is the full output scale divided by the total number of steps enabled by the number of bits. In a charge-based DAC, however, the minimum voltage step that can be resolved at the output is given by (see ***Figure 3b***):

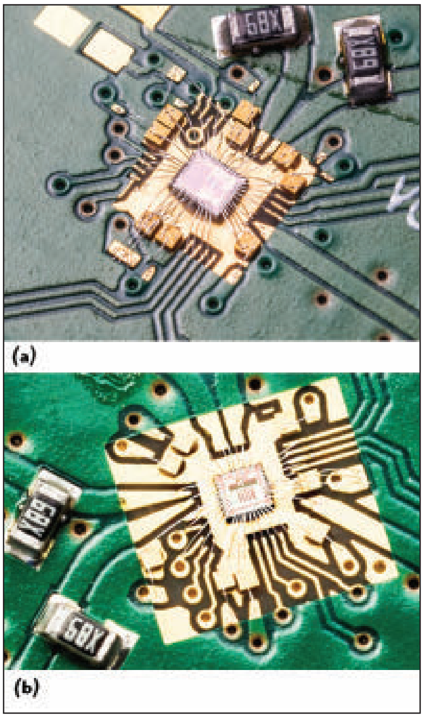
$$\Delta V_{MIN} = \frac{C_{unit}}{C_{unit} + C_{BB}}\left(V_{REF} - V_{BB}\right) \quad (2)$$

where V_{REF} can be either V_{DD} or ground (0 V), if the net charge in the system is being increased or decreased, respectively.

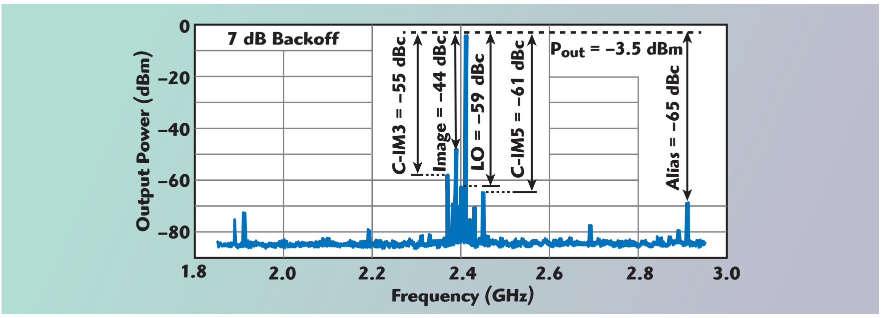
The ΔV_{MIN} at the QDAC output is fundamentally determined by the ratio between C_{unit} and C_{BB} and, as a result, the quantization noise on this charge-based transmitter can be decreased by simply choosing a small enough unit capacitance with respect to C_{BB}, another remarkable feature of the proposed architecture. With a fixed 45 pF baseband capacitor, for example, a quantization noise SNR of 86 dB can be achieved with a 2 fF unit capacitance — roughly a 14-bit effective number of bits (ENOB). Both noise filtering and alias attenuation are obvious in ***Figure 4***, which shows the simulated output spectrum of a 20 MHz baseband signal transmitted at 2 GHz.

MEASURED RESULTS

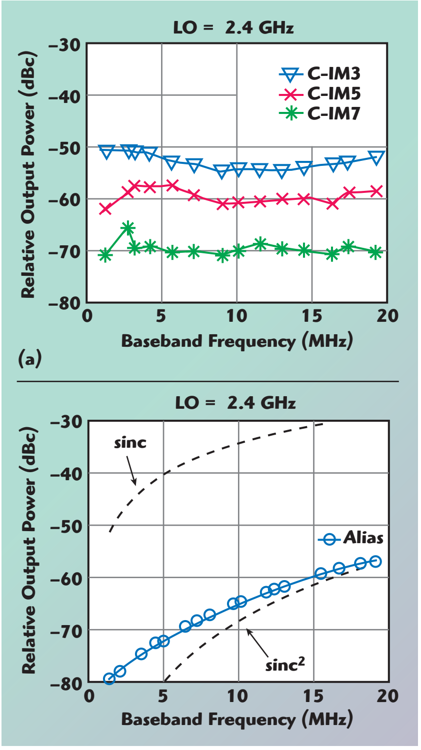
Both charge-based transmitter implementations were prototyped using 28 nm, 0.9 V CMOS technology (see ***Figure 5***). The first charge-based transmitter consisted of a capacitive QDAC driving the PPA input through a 45 pF baseband capacitance. With a 10-bit DAC running at 128 MSPS, it demonstrates all the noise filtering ca-



▲ *Fig. 5 Capacitive (a) and resistive (b) charge-based Tx prototypes. With the resistive prototype, an out-of-band noise spectral density of –159 dBc/Hz was achieved at 45 MHz offset, using an area of only 0.22 mm².*



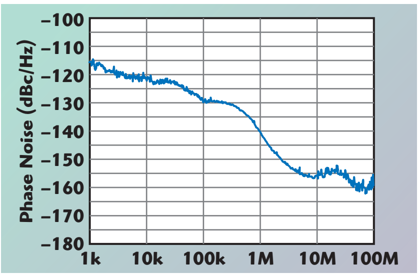
▲ *Fig. 6 Measured output spectrum of resistive charge-based Tx, with 10 MHz single tone sampled at 500 MSPS.*



▲ *Fig. 7 Carrier to intermodulation power ratio (a) and relative alias power (b) vs. baseband frequency, with a 2.4 GHz LO.*

pabilities of charge-based operation, notably a noise floor 15 dB lower than a transmitter using a conventional DAC with the same number of bits and operating at the same sampling frequency. At 45 MHz offset from a 1 GHz modulated carrier, it provides an out-of-band noise spectral density of -155 dBc/Hz and ACLR 1 and 2 of -42 dB and -47 dB, respectively.

The same improved noise performance was achieved in the second implementation, where the PPA was removed from the signal path. In this case, the charge-based architecture demonstrated the ability to deliver considerable power by directly driving a 50 Ω load that represents the PA input. Two different external baluns were used to validate transmitter performance at both 900 MHz and 2.4 GHz. Achieving a peak power of 3.5 dBm with a 0.9 V supply, measurements with baseband frequencies ranging from 1 to 20 MHz show a maximum LO feedthrough and image of -55 dBc and -44 dBc, respectively. The charge-based architecture spectrum is clean (see ***Figure 6***), especially the alias. At 7 dB backoff, C-IM3 at



▲ *Fig. 8 Noise spectral density of a 2.4 GHz modulated carrier (10 MHz single tone sampled at 500 MSPS, with the baseband harmonics removed for clarity).*

any baseband frequency is always below -50 dBc at both 900 MHz and 2.4 GHz. As with the previous implementation, the sampling aliases are shaped by a sinc^2 transfer function, which corresponds to at least 20 dB of additional attenuation compared to a conventional architecture (see ***Figure 7***). ACLR 1 and 2 for a 20 MHz signal are -47 dB and -59 dB, respectively, and the measured EVM is 1.6 percent. At 45 MHz offset, a modulated noise power density of -159 dBc/Hz was measured at both LO frequencies (see ***Figure 8***). What is unique is that even in backoff conditions, the noise performance is not degraded significantly, thanks to the intrinsic noise filtering capabilities of the charge-based architecture.

With the achieved out-of-band noise performance and a core area of only 0.22 mm^2, the charge-based architecture achieves — to the author's knowledge — the best out-of-band noise performance vs. area compared to other designs. ACLR and EVM performance are also among the best. ■

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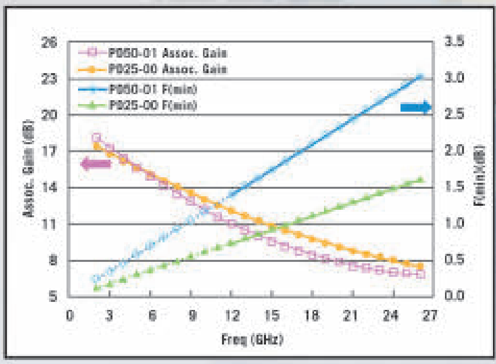

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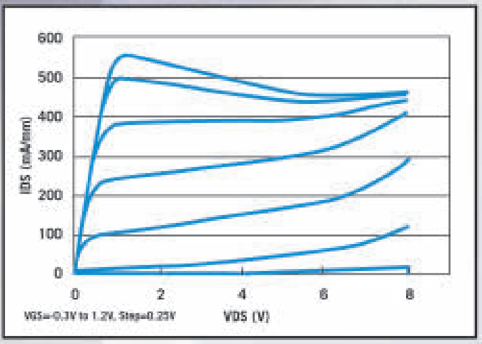
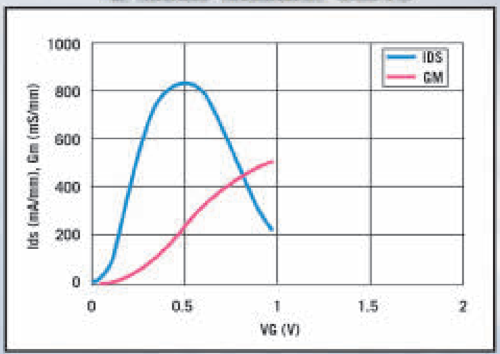


E-mode Transfer Curve



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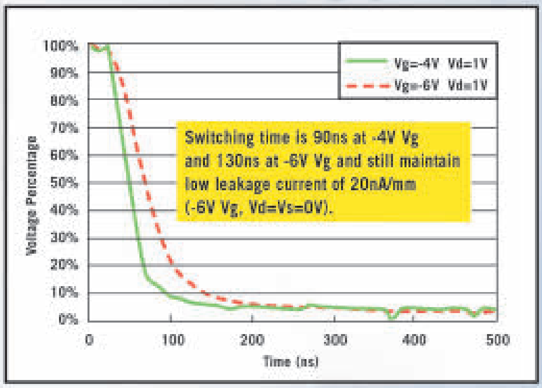

D-mode Device Performance

	PD50-01		PD25-00	
	Single	Triple	Single	Triple
Ron (ohm.mm)	1.9	3.7	1.3	2.2
Coff (fF/mm)	168	83	163	92
RonxCoff(ohm.fF)	316	310	209	198

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INVITED PAPER

Smart Antennas for 5G

David Freeborough
Cambridge Consultants, Cambridge, U.K.

Smart antenna technology is a strong candidate for fifth generation (5G) wireless communications standards, but validation of system performance may prove to be an impossible task. This article will use a multi-disciplinary approach to look at the challenges of implementing a smart antenna system, in order to form an assessment of the key technical risks for developers.

Smart antennas are essentially arrays of transceivers that form radio signals into narrow beams. The trade-off is to use complex signal processing and extended physical size to improve focus. The main benefit of a smart antenna is that the focused beam can be used to reduce interference and amplify the wanted signal. In dense urban deployments, there is likely to be no direct line-of-sight path for radio communications. Multipath reflections cause complex, rapidly changing scattering patterns that a smart antenna can resolve constructively to form a spot of good coverage around a user.

When used on a High Altitude Platform (HAP), such as a satellite or aircraft, the radio signal follows a clear line-of-sight and so the objective is to form smart antenna beams that are highly directional in order to improve the link margin and reduce interference from the many other users that occupy the same extended cell.

Both small cell and HAP deployments rely on the fundamental physics of an antenna array and beam forming to improve system performance. So far, so good, but there are some challenges. To make it easier to follow the analysis, this article groups these items into the broad categories of radio, antenna and physical layers, finishing with a look at system issues. However, as you will see, smart antenna systems defy the conventional approach of breaking down an engineering design into single-disciplinary layers of functionality.

BASICS OF THE APPROACH

Future generations of cellular networks will make greater use of beamforming in their RF front-ends, regardless of the frequencies at which they operate. LTE Release 9 includes a provision for MIMO beam forming and future releases allow for increasingly advanced techniques to improve link budgets, especially at cell edges. Normally, LTE systems are uplink limited due to interference and propagation losses. One of the major advantages in using beam forming is that it increases rejection of noise and interference coming from other directions and maximizes gain in the direction of the user equipment (UE). UE uplink margin is limited by RF power available at the transmitter; however, the receiver compensates with downlink antenna gain. The result is greater coverage that is less constrained by interference and uplink range. Network operators are also able to run their base stations with higher downlink EIRP, providing greater SNR at the UE receiver and enabling the link to operate at a higher data rate. The benefit of reducing gain imbalances is an increase in overall cell capacity.

Beam forming at the antenna for cellular frequencies below 6 GHz can be achieved with antenna arrays. For signals with a bandwidth that is a small fraction of the operating frequency, beam squint is normally obtained by feeding each element of the array with a phased shifted analog copy of the original signal, as shown in ***Figure 1***.

If new generations of networks are designed for operation in the 28 GHz region, as seems likely, propagation losses and building attenuation will be greater than that experienced at lower frequencies by current cellular networks. Maximizing antenna gain through the use of beam forming techniques will be important; it is quite likely that massive beam forming will be a key factor in the deployment of this technology.

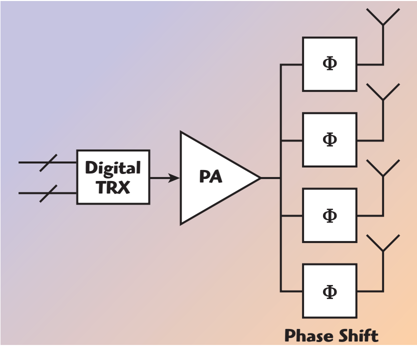


Fig. 1 *Classic topology for beam steering.*

RADIO

Phase Shifting Architecture

Constant phase shifts across wide bandwidths can be difficult to achieve using analog techniques. Fortunately, integrated RF transceiver chips are now available with standard digital interfaces (digital TRX), which make it easier to create phase-shifted copies in the digital domain and have architectures that present multiple signals at the antenna that are independently generated by multiple DACs and up-converters in parallel paths (see ***Figure 2***). True broadband phase shifting can be achieved in the digital signal processor (DSP), and because phase shift is performed in the digital domain, the antenna beam can be rapidly switched from one beam position to another.

Each individual PA can have lower RF output power, as the required field strength in the desired direction is achieved over the air by combining the emitted fields of the different antennas. Lower power PAs can more easily support multiband operation and can be considerably cheaper as lower cost process technologies are used. Reducing PA output power also reduces the associated costs for items such as power supplies and heat sinks.

The phased array architecture, however, requires that parallel paths be well matched as, for example, the gain and phase responses of the power amplifiers change over temperature and particularly with antenna matching. To address these issues, new systems will require sophisticated means of calibration and continuous adaptation, which should be readily achievable in the digital domain.

Multi-Band RF

Multi-band base station solutions are of interest in practical systems

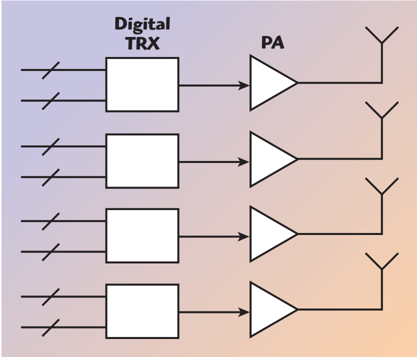


Fig. 2 *Modern topology for beam forming.*

that must cover a range of installation requirements. While a reduced individual PA output power requirement helps enable a broadband front end, the distributed approach still needs to meet regulatory requirements to avoid interference with other users of the radio spectrum. Transmitter spectral mask and out-of-band noise and harmonic specifications are always challenging to meet and are very often achieved only on powerful base stations through the use of large and expensive bandpass filters.

ANTENNA

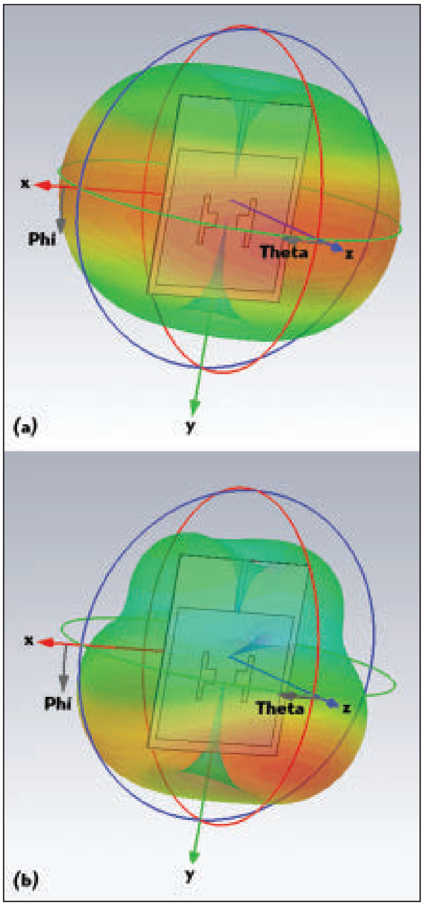
Antenna Element Design

The first challenge is to maintain antenna pattern stability across a wide range of operating frequencies. This is illustrated with simulations showing the propagation patterns for a single element antenna covering multiple bands (see ***Figure 3***). In a phased array, this could be the building block of a multi-band beam forming solution. What often happens in multi-octave antennas is that, although matching can be achieved at the desired frequencies, the antenna propagation pattern varies with frequency, making it difficult to calibrate the phase response.

In Figure 3, the propagation pattern of a multi-band patch antenna shifts as the operating frequency changes. ***Figure 3a*** shows a 900 MHz pattern, with 2 dBi peak gain along the z-axis (shown horizontally). ***Figure 3b*** shows a pattern at 2.4 GHz, with 3.5 dBi peak gain angled down significantly from the z-axis. In a typical system design, this makes the selection of the antenna tilt angle more challenging.

Antenna Spacing

Because operating bands are often spaced more than one octave apart, it is difficult is to determine the op-



▲ *Fig. 3 Propagation patterns of a single element, multi-band patch antenna at 900 MHz (a) and 2.4 GHz (b).*

timum separation between elements. The ideal element spacing is λ/2; however, this is not possible to achieve at all frequencies in a wideband system unless multiple redundant elements are used. Consequently, element spacing is always a compromise. The element pattern and the spacing selected for the array influences its behavior over frequency, compromising gain and side lobes. This is illustrated in ***Figure 4***.

Figure 4a shows a neatly defined 900 MHz directional antenna radiation pattern. The eight antenna elements are spaced 16 cm apart, which is λ/2 at that frequency. ***Figure 4b*** shows what happens when the frequency is increased to 2.4 GHz with the element spacing unchanged. While both antennas achieve 12 dBi gain, the radiation pattern at 2.4 GHz becomes much less directional and is correspondingly less useful as part of a smart antenna system.

In a second pair of simulations (see ***Figure 5***) the spacing of the eight antenna elements is decreased to 6.25 cm, which is λ/2 at 2.4 GHz. As expected, the 2.4 GHz pattern in ***Figure 5b*** shows good directional behavior with 13 dBi output, whereas the result in ***Figure 5a*** shows only 8 dBi at 900 MHz, along with degraded directional performance.

So what is the answer? Higher frequencies permit antenna arrays with more elements within the same area although the total number of transceivers that feed each of the elements grows correspondingly. A disruptive solution is in emerging technologies like metamaterials, which are demonstrating their effectiveness in producing very compact steerable antennas with high gain.

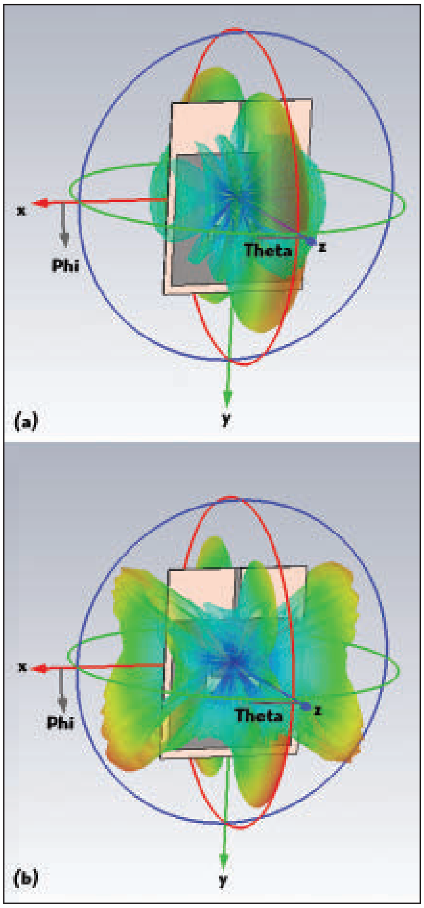
Measurements and Calibration

With a beam forming approach, the precise location of each antenna must be known, and antenna-radio chains must be synchronized, with any path length differences calibrated and adjusted. For a spot forming design, knowledge of the position of the antennas is not so important but tight synchronization is required; and, calibration of the differences between transmit and receive chains is absolutely fundamental. Spot forming systems also require accurate measurements of the dynamically changing radio environment.

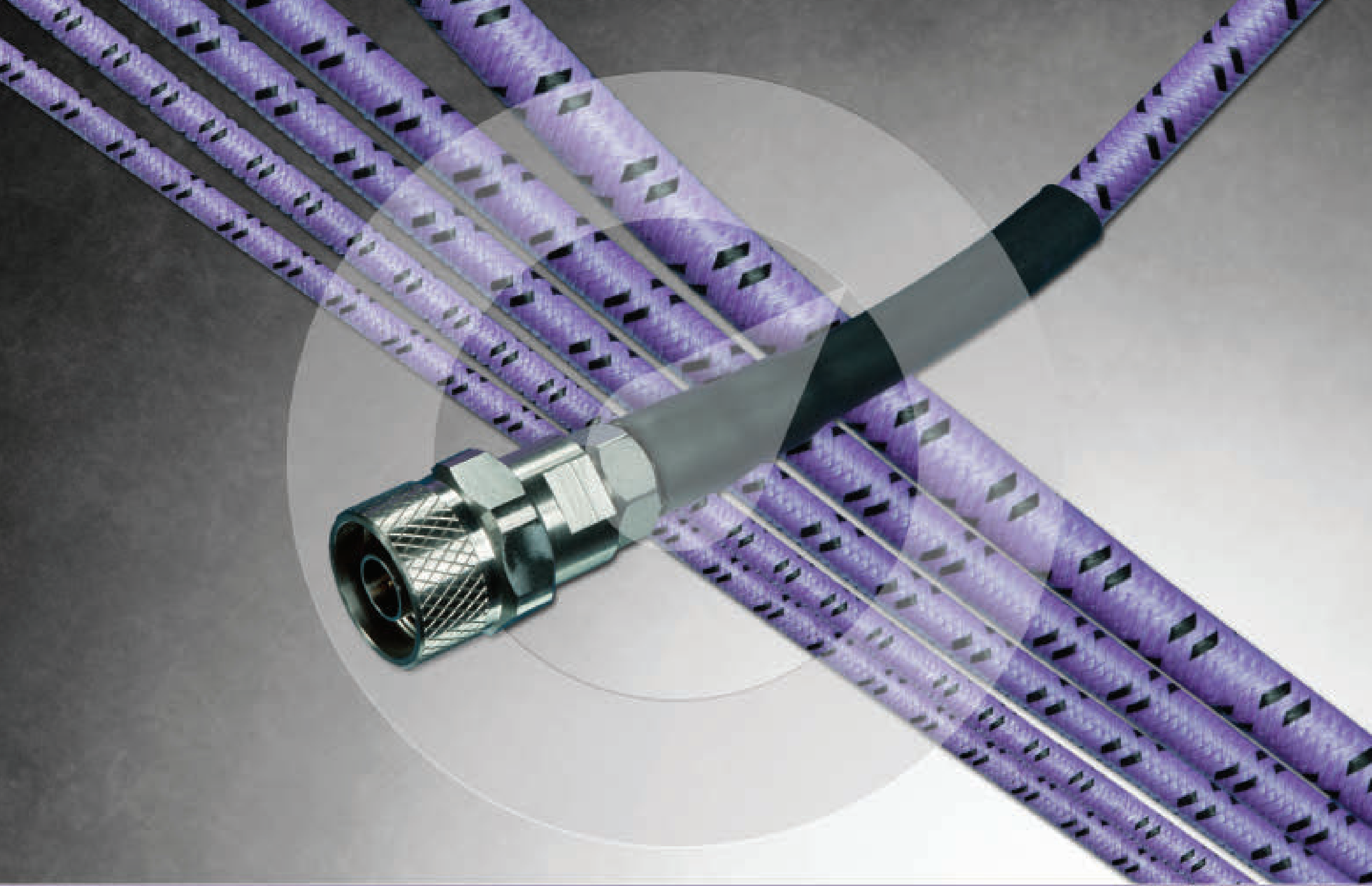
PHYSICAL LAYER

Computational Complexity

The obvious challenge associated with physical layer of a smart antenna system is the increase in computational complexity. When compared to a single omni-directional antenna, the next generation, line-of-sight smart antenna is estimated to be on the order of 100x more complex. In a non-line-of-sight, multi-path scenario, there is even a greater increase in complexity required to form a "spot" of coverage – approximately 100,000x. These numbers may seem problematic, but in the long term Moore's law to is expected to make



▲ *Fig. 4 Propagation patterns at 900 MHz (a) and 2.4 GHz (b) with 16 cm element spacing.*



them increasingly achievable.

Power Consumption

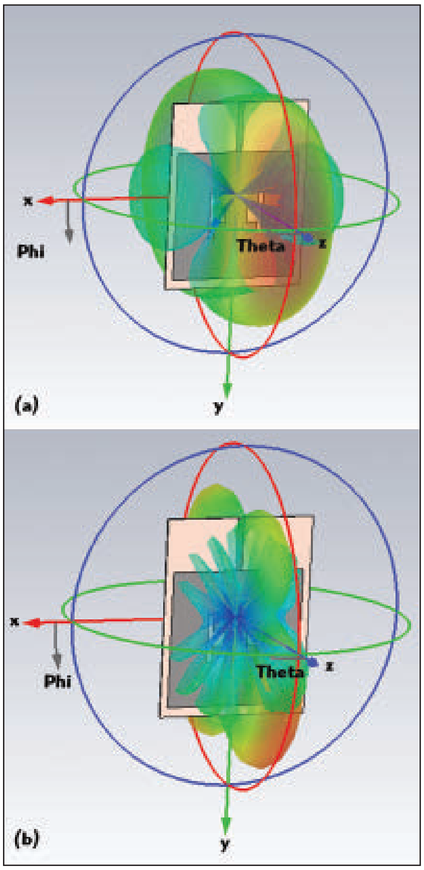
The difficulty in optimizing smart antenna systems is that no single part of the system works in isolation. In a conventional system with a small number of antennas, power consumption is dominated by power amplifier transmit power requirements. When scaled up to hundreds or even thousands of antenna elements, the total RF output power is the same, and the total PA power doesn't change significantly. The power consumed by the remaining analog and digital circuitry, however, increases linearly with the number of elements, which could be 100x to 1000x.

This is particularly challenging for HAPs, as a key design parameter is to optimize for a limited power budget. It is also a challenge for small urban cells and 5G, since mobile operators are looking to decrease operational expenditure (OPEX). The optimization of power consumption becomes a multi dimensional problem with PA power, antenna count, DSP calculation complexity and media access control (MAC) scheduling all affecting performance.

Coordination is Not Just Within the Physical Layer

Obviously, signals from each antenna element must be combined with those from all of the other elements to produce the desired beam shape, which requires data to be copied accurately within the physical layer. However, there is a challenge to coordinate this operation across a number of separate logic devices, causing the implementation to break out of a neatly layered approach. For example, when physical layer operation is extended across many devices to provide coordinated multipoint behavior, there is an associated cost for the additional data transfer and accurate synchronization between devices.

A further complication occurs in the scheduling of packets for trans-



▲ *Fig. 5 Propagation patterns at 900 MHz (a) and 2.4 GHz (b) with 6 cm element spacing.*

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Insertion Loss	13 dB Max - Measured 8.2 dB
VSWR	1.75:1 Typ - Measured 1.65:1
Phase Shift	360°
Accuracy	±5° Max - Measured +3.4°/ -2.6°
Control	10-Bit TTL Compatible: 15 Pin Sub-D (Male)
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mission. Because the shape of the cell has been deliberately skewed, there is a timing-varying problem with cells potentially causing brief but intense periods of interference for neighboring cells. The best way to mitigate this problem effectively is for schedulers within peer MAC layers to communicate and coordinate their actions. We should expect packet routing to become more predictive and for applications to become more aware of the smart behavior. The overall effect is that management of the radio resources is rapidly becoming a task that is distributed throughout the layers of the architecture. This presents two problems: first, the architecture breaks the simple layered approach to module design and becomes multi-disciplinary; and second, there is communications overhead to maintain coordinated operation between separate peer entities.

SYSTEM

A challenge that may not be solvable in a practical product is system validation.

System validation is needed early in the design cycle to prove that proposed system gains live up to the promises of the theoretical analysis. No one can afford to deploy a smart antenna system and hope to resolve complex, interdependant issues in the field.

Validation is especially tough for the most difficult use cases, which show up only when large numbers of users are accessing the network. The problem is how to scale up existing test strategies to reproduce networks with multiple base stations and thousands of transceivers, all cooperating closely in real time. The test network must operate in real time, in an automated and repeatable way that allows different system configurations and optimizations to be accurately measured and benchmarked across a range of conditions.

CONCLUSION

Smart antennas are an exciting new technology, but system design challenges must be overcome. To avoid unacceptable increases in overall solution size and current consumption, a real world solution needs to balance antenna performance enhancements against the complexity of the radio and physical layer.

It is unlikely that a 100× to 1000× increase in either size or power consumption will be acceptable; therefore, workable solutions are likely to leverage Moore's Law by maximizing the level of digital integration and miniaturizing analog elements by incorporating them in a module that integrates all duplicated components when an antenna element is added. At 5 GHz and above, it becomes practical to implement a reasonably efficient antenna radiating element on a chip scale module. An attractive system solution, at these frequencies, might be a single ASIC incorporating all physical layer functions up to the RF digital interface and an array of front-end modules each incorporating a radio, a power amplifier and an antenna radiating element. The challenge then becomes: how do you validate the real world performance of such a system? ■

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Using a Passive Vector Modulator to Realize a Super Linearity High Power Feedforward Amplifier

Lamin Zhan, Kun Li and Guoan Wu
Huazhong University of Science and Technology
Wuhan, China

A super linearity high power amplifier uses the feedforward technique. A key element of this technique, an adjustable vector modulator, is made of passive devices. The advantage of passive devices, compared with active devices, is that they do not distort high power signals. In order to improve cancellation of intermodulation products, this adjustable vector modulator has high resolution as well. A 50.4 dBm output power amplifier with -62 dBc third-order intermodulation distortion is demonstrated.

The VHF power amplifier is widely used in wireless applications and is a critical transmitter component. Its purpose is to produce a high signal output for proper transmitter operation. This may be achieved, however, at the expense of linearity. Normally, the third-order intermodulation distortion of a Class A amplifier at 1 dB compression is no better than -20 dBc. This is far above the requirement of many systems, where third-order intermodulation distortion must be -50 dBc with greater than 50 dBm output power.

There are three main methods to linearize an amplifier: feedback, predistortion and feedforward.[1] The feedforward technique is widely used because it can achieve the best linearization performance,[1-3] but low efficiency is a major drawback. Appropriate power-retreat has often been used to provide suitable third-order intermodulation distortion before linearization is employed. In our system, the main power amplifier is retreated to a third-order intermodulation distortion of -39 dBc with 52.5 dBm output power. This is good performance, but is still not sufficient. The adaptive feedforward technique can be used to meet today's system requirements in the presence of environmental variations,[4] but it is rarely used in high power systems because it uses an electronically adjustable vector modulator employing active devices. When RF power is high, active devices introduce distortion. In our approach, however, an adjustable vector modulator composed of passive devices provides high resolution to realize excellent cancellation of third-order intermodulation products. With the exception of the main amplifier and the error amplifier, the devices in this system are passive. Experimen-


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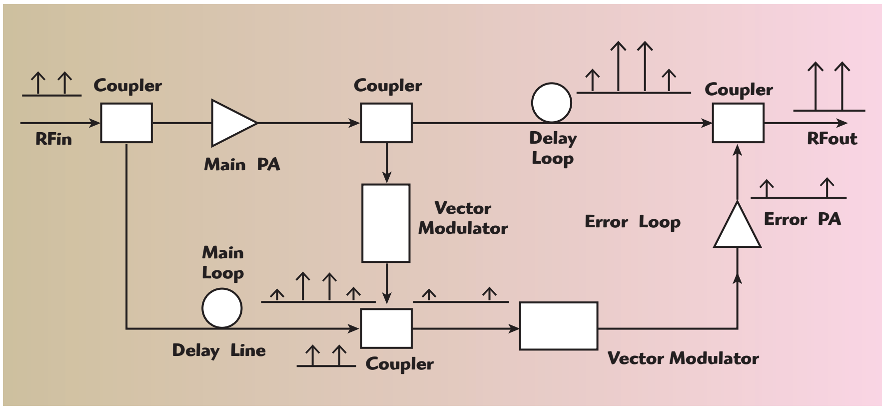


▲ *Fig. 1 Feedforward system block diagram.*

tal results show that third-order intermodulation distortion is reduced from -39 dBc for original amplifier with an output power of 52.5 dBm to -62 dBc for the linearized amplifier with an output power of 50.4 dBm.

CANCELLATION PERFORMANCE OF SIGNALS

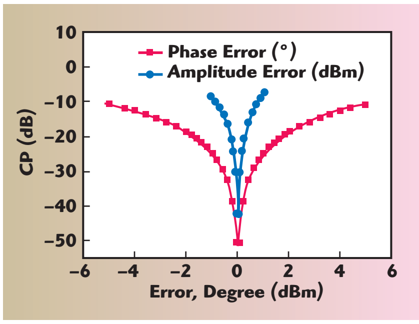
Since the feedforward linearizer is designed to eliminate third-order intermodulation distortion through cancellation, the cancellation of two signals is analyzed (see ***Figure 1***). Assuming that the two signals are sinusoidal, the greatest cancellation occurs when their amplitudes are equal and their phases are opposite. The relationship between cancellation performance versus amplitude and phase error is[5]

$$\mathrm{CP(dB)} = 10\log\left[1+\alpha^2-2\alpha\cos\left(\theta_{err}\right)\right] \qquad (1)$$

$$\alpha = \frac{V_{err}}{V_m}$$

where CP is the cancellation performance, V_{err} is the voltage amplitude error, V_m is the voltage amplitude of the signals and θ_{err} is the phase error. It is apparent that CP is more sensitive to amplitude error and decreases with the rise of signal power.

Simulation (see ***Figure 2***) shows the effects of amplitude and phase mismatch on the CP of two signals. The power of each signal is 10 dBm with a phase difference of 180 degrees in order to simulate the third-order intermodulation distortion of the main amplifier. The intermodulation signals can be suppressed by more than 30 dB only when the phase error is less than 0.5 degrees and the amplitude error is less than 0.08 dBm. This is hard to achieve in practice. To ensure



▲ *Fig. 2 Cancellation of two equal-amplitude, anti-phase signals as a function of phase or amplitude error.*

that the CP is small, high resolution of the vector modulator is necessary.

For a dual-tone signal, CP is also affected by the group delay of each delay line, as shown in Equation 2.[5]

$$\mathrm{CP(dB)} = 10\log\left[1+\alpha^2-2\alpha\cos\left(2\pi\left(\frac{L_{err}}{\lambda_0}\right)\left(1-\frac{f}{f_0}\right)\pm\theta_{err}\right)\right] \qquad (2)$$

where f_0 is the center frequency, λ_0 is the wavelength at the center frequency and L_{err} is the length difference between the delay lines. CP is less sensitive to L_{err} as compared with α and θ_{err}. L_{err} can be decreased by adjusting the lengths of the delay lines.

FEEDFORWARD SYSTEM DESIGN

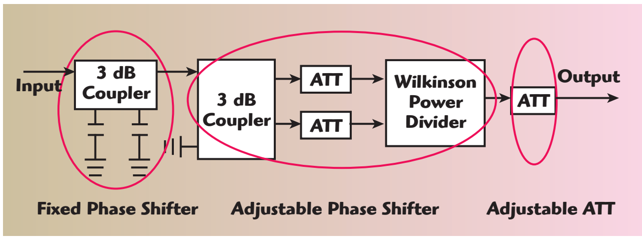
As shown in Figure 1, this feedforward system is composed of a main loop and error loop. The main loop includes the main amplifier, couplers, delay line and vector modulator. The function of main loop is to suppress the signal in order to extract the third-order intermodulation distortion for input to the error loop. The error loop is composed of the error amplifier, couplers, delay line and vector modulator. Its function is to eliminate third-order intermodulation distortion of

the main amplifier output using the output of main loop. To realize a super linearity, both loops must have excellent cancellation performance.

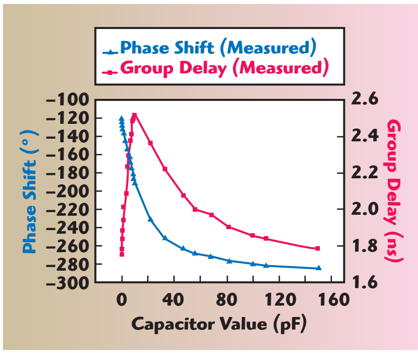
In order to minimize insertion loss and preserve overall efficiency, the main path consists only of couplers, the main amplifier and delay line. Efficiency can be expressed as

$$\eta' = \frac{OP_m 10^{\frac{TL_m}{10}} + OP_e 10^{\frac{P_{back}}{10}}}{OP_m + OP_e}\eta \qquad (3)$$

where η' is the overall system efficiency, η is the overall efficiency of the main and error amplifiers, OP_m and OP_e are the amplifier output powers, TL_m is the transmission loss of main path and P_{back} is the retreated power of the error amplifier. Because OP_m is much larger than OP_e, η' is more sensitive to TL_m. This implies that TL_m must be minimized.



▲ *Fig. 3 Vector modulator block diagram.*



▲ *Fig. 4 Vector modulator phase shift and group delay as a function of capacitor value.*

Figure 3 is a block diagram of the vector modulator. It consists of a fixed phase shifter, an adjustable phase shifter and an adjustable attenuator. The fixed phase shifter is composed of a 3 dB quadrature coupler and two equivalent capacitors. ***Figure 4*** shows test results for the fixed phase shifter. Capacitor values can be adjusted to change the phase shift and group delay. The adjustable phase shifter is composed of a 3 dB quadrature coupler, two adjustable attenuators and a Wilkinson power divider. The principle is illustrated by

$$\frac{V}{\alpha_1}\sin(\omega t+\theta)+\frac{V}{\alpha_2}\sin\left(\omega t+\theta+90^\circ\right)=$$

$$\frac{V}{\alpha_1\alpha_2}\sqrt{\alpha_1^2+\alpha_2^2}\,\sin(\omega t+\theta+\varphi) \qquad (4)$$

where $\varphi = \arctan\frac{\alpha_1}{\alpha_2}$

α_1, α_2 are the voltage attenuation values of the two paths and φ is the phase shift of the vector modulator.

The input is divided into two equal amplitude signals with 90 degree phase difference by the 3 dB quadrature coupler. The two signals pass through attenuators and are combined in the Wilkinson power divider. The phase shift is determined by α_1 and α_2 controlled by the attenuators. The ideal phase shift of the vector modulator is 90 degrees. Over the range of attenuation, the vector modulator can achieve only about 75 degrees phase shift, however; so a fixed phase shifter is added in front of the vector modulator to provide a suitable phase shift and group delay. Furthermore, the vector modulator produces some degree of attenuation determined by α_1 and α_2. An adjustable attenuator is added at the output to control overall attenuation. Adjusting the length of delay lines and the capacitor values equalizes the group delays. The phase shift at the center frequency is adjusted by the attenuation in each path. To provide equal dual-tone signal amplitudes, an LC network is placed before main amplifier to compensate for an uneven gain curve.

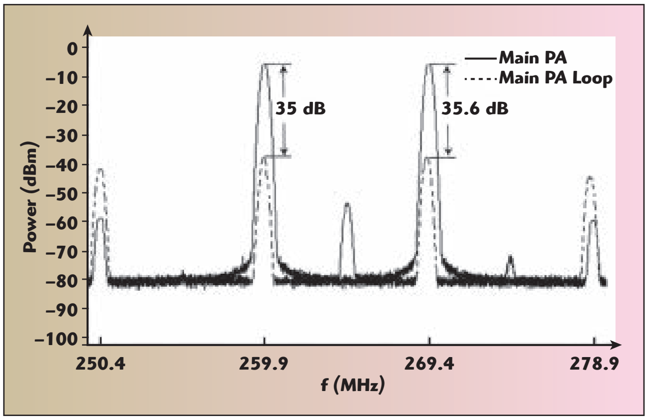
Amplitude and phase resolution of the vector modulator is determined by the adjustable attenuator at the output. In this system, when the CP is about -30 dB, less than a 0.01 dB change in amplitude and a 0.06 degree change in phase, respectively, will lead to a 1 dB change of CP. The adjustable attenuator used is manually adjustable and its resolution is as high as 0.01 dB, corresponding to a phase resolution for the vector modulator of less than 0.06 degree.

TEST RESULTS

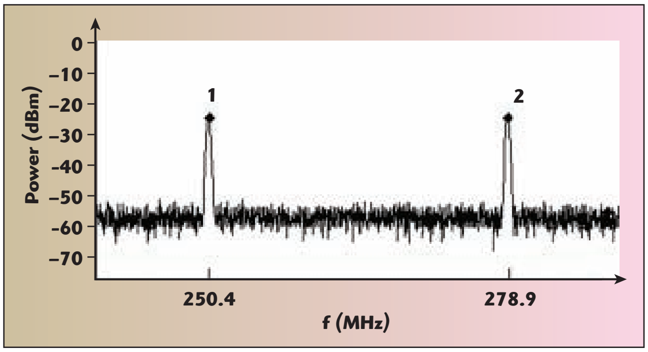
Analysis shows that, to meet system requirements, the output power of error amplifier should be about 30 dBm. A power amplifier with a 1 dB compression point of about 47 dBm and gain greater than 65 dB is chosen to provide adequate linearity. At an output power of 30 dBm, third-order intermodulation distortion is less than -45 dBc. The main amplifier center frequency is 264.6 MHz with 10 MHz bandwidth. The power gain is about 50 dB with 1 dB gain flatness. The input is a dual-tone signal at 259.9 MHz and 269.4 MHz, respectively, each at 3 dBm.

Figure 5 shows the output spectrum of the main amplifier versus the output power of the main loop, indicating that cancellation may be as high as 35 dB. Cancellation of feedforward system, however, is determined by the error loop, which is tested individually.

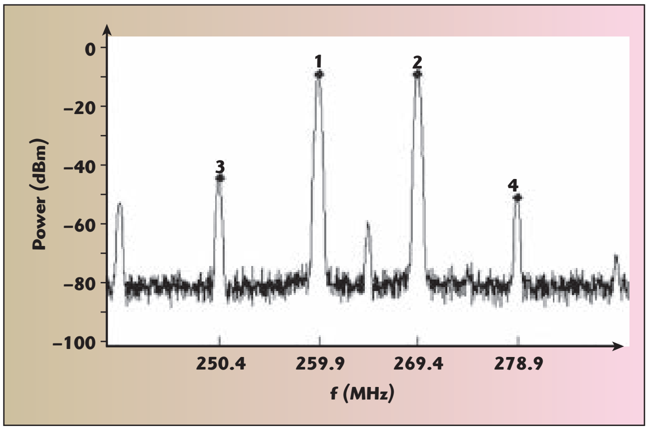
The dual-toned test signal for the error loop is 10 dBm (each tone) at 250.4 MHz and 278.9 MHz, respectively. ***Figure 6*** is the output spectrum of the error loop. Values at the marker points are -22.68 dBm (MKR1) and -22.59 dBm (MKR2), indicating that the input signal can be



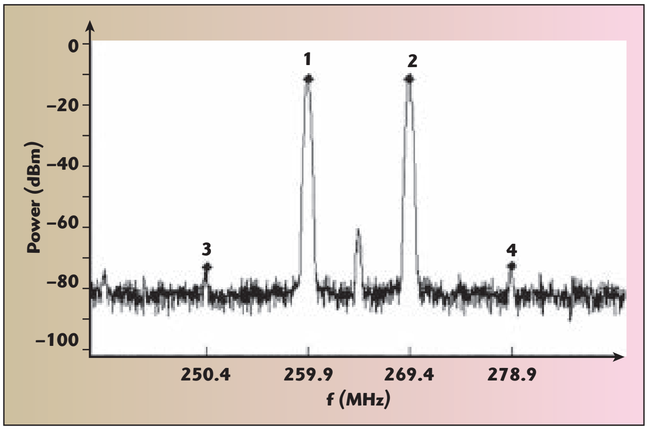
▲ *Fig. 5 Output spectrum of the main amplifier vs. output power of the main loop.*



▲ *Fig. 6 Output spectrum of the error loop.*



▲ *Fig. 7 System output spectrum with the error amplifier disconnected.*



▲ *Fig. 8 System output spectrum with the error amplifier connected.*

suppressed more than 32 dB in error loop.

Finally, the entire feedforward system is tested, with a 58 dB attenuator at the output to protect the spectrum analyzer. ***Figure 7*** is the output spectrum of the entire system with the error amplifier disconnected. The four markers are at -10.28 dBm (MKR1), -10.14 dBm (MKR2), -45.31 dBm (MKR3) and -51.75 dBm (MKR4). The main amplifier is driven to an output power of 52.5 dBm and the left and right third-order intermodulation products are -38.7 dBc and -41.1 dBc respectively. The transmission loss of the path between the main amplifier output and the system output connector is approximately 2 dB, including delay line and coupler losses.

Figure 8 is the output spectrum of system with the error amplifier connected. The markers are at -10.65 dBm (MKR1), -10.59 dBm (MKR2), -72.53 dBm (MKR3) and -72.36 dBm (MKR4). It shows the third-order intermodulation distortion of main amplifier suppressed from -48 dBm to -72.3 dBm. Fifth-order intermodulation distortion is also suppressed to the background noise. Third-order intermodulation distortion of the system is approximately -62 dBc. The cancellation is 24 dB on the left and 21 dB on the right. From Figures 7 and 8, the main signals are suppressed about 0.4 dB due to residual signals from the main loop.

CONCLUSION

A super linearity high power feedforward amplifier is realized based on the feedforward technique. A key element of feedforward system, a high resolution adjustable passive vector modulator is designed in order to fully suppress third-order intermodulation products. Third-order intermodulation distortion of the linearized amplifier is -62 dBc at an output power of 50.4 dBm. High output power with low third-order intermodulation distortion makes the system attractive in transmitters for today's wireless applications. Moreover, the adjustability of the vector modulator makes the system useful for other frequency bands and bandwidths. ■

ACKNOWLEDGMENT

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A Hyperbolic Compact Generalized Smith Chart

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The Smith chart was introduced by Philip Hagar Smith in 1939 and then refined and extended several years before becoming an icon of microwave engineering. To have a finite and practical size, the classical 2D Smith Chart is constrained to the unit circle. Hence, loads with reflection coefficient magnitude greater than one cannot be plotted. In 2011, the 3D Smith chart was published by A.A. Muller, P. Soto, D. Dascalu, D. Neculoiu and V. E. Boria. The 3D Smith chart unifies the design of active and passive circuits with any magnitude of the voltage reflection coefficient on the sphere by keeping all the circle forms of the classical Smith chart unchanged, but its handling requires a spherical surface and thus a CAD tool (www.3dsmithchart.com) was developed in order to utilize it.

The creators of the 3D Smith chart have now extended the tool by using a hyperbolic Smith chart suitable for representing both circuits with negative and positive resistance with the magnitude of the voltage reflection coefficient ρ of any possible value ($0<\rho<\infty$) in a compact manner in the unit disc. This is done by the means of single equation given by the Poincare disc model of hyperbolic geometry. Circuits exhibiting negative resistance have the magnitude of the voltage reflection coefficient bigger than unity and thus are mapped into the exterior of the classical Smith chart. In order to overcome the visual problems generated by this issue, two solutions were previously successfully proposed: the 3D Smith chart which implies the usage of sphere and the negative Smith chart, however both having their inconveniences; the 3D Smith chart, because it cannot be completely exploited without the means of a software tool while the negative Smith chart because it cannot be used at the same time as the regular Smith chart the scales used for one are meaningless for the other.

HYPERBOLIC SMITH CHART CONSTRUCTION

The infinite generalized 2D Smith chart is regarded in the 3D Euclidean plane as lying on a plane and is mapped onto the superior part of two sheet hyperboloid using an immersion (vertical pull) onto the infinite surface of the hyperboloid. Then a stereographic projection form the point (0, 0, -1) from the two sheet hyperboloid onto the unit disc (used in the Poincare unit disc model of hyperbolic geometry), is then used to compact the entire surface of the superior part of the two sheet hyperboloid onto the unit disc.

A sequence of vertical pulling/stereographical projection, as shown in ***Figure 1***, is applied (inspired by Beltrami-Klein model of non Euclidean geometry while using Poincare hyperboloid model).

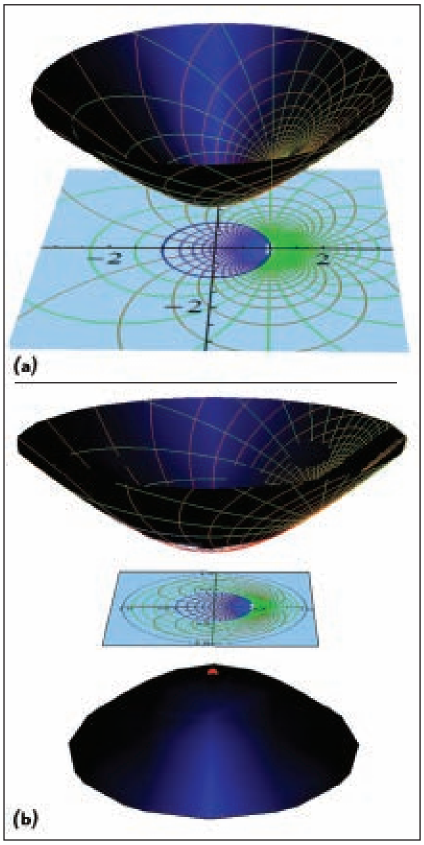
The hyperbolic Smith chart maps the circuits with positive reactance above the hori-

zontal (real line) of the ρ^h plane and the circuits with negative reactance below the real line of the hyperbolic reflection coefficients plane – as in the Smith chart. The constant reflection coefficients circles (0<|ρ|<1) of the classical Smith chart are completely mapped into circles with $0<|\rho^h|<0.414$ (in the hyperbolic reflection coefficients plane while the (1<|ρ|<∞) constant circles (which are outside of the classical Smith chart- South hemisphere on the 3D Smith chart) are mapped all together in the unit disc of the hyperbolic reflection coefficients plane with $0.414<|\rho^h|<1$.

APPLICATION EXAMPLE

To obtain an oscillator at a specified frequency, the microwave active circuit must be designed to provide an infinite reflection coefficient at such a frequency. This requires moving to infinity in the reflection plane, thus a planar Smith chart not very useful (see ***Figure 2***). In the hyperbolic reflection plane, infinity is represented by the unit circle (the way in which this approached proving an inductive or capacitive behavior). One may think in the hyperbolic reflections plane that as a reflection coefficient one moves towards the unit circle, its energy becomes lower and thus its movements become slower thus reaching it becomes impossible since it means infinity. The hyperbolic Smith chart allows solving this type of problem in the plane graphically using a unique visual representation (as shown in ***Figure 3***), since the infinite mismatch point is placed in a bounded and finite position on the unit circle.

To the best of our knowledge, the first complete generalized hyperbolic Smith chart in the unit disc of the complex plane by mapping the entire reflection coefficients plane 0<|ρ|<∞into the unit disc of the hyperbolic reflection coefficients plane has been developed here. Circuits



▲ *Fig. 1 Preliminary construction: Generalized Smith chart mapped on the upper part of the two sheet hyperboloid (the upper sheet extends to infinity) (a) and stereographical mapping of the hyperboloid Smith chart in the unit disc from the red point (b).*

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with negative resistance or with the magnitude of reflection coefficient $|\rho|>1$ which occur in oscillator, amplifier and other designs can be successfully plotted together with other circuits which can be visualized on the Smith chart. The hyperbolic Smith chart is governed by a single equation and can be easily drawn on any CAD tool using the Poincare disc model. If the reflection coefficient is tending towards infinity $|\rho|=\infty$, then it will tend towards the unit circle of the hyperbolic Smith chart. The Smith chart mapped all the circuits with positive resistance in the unit circle of the reflection coefficients plane, while the hyperbolic Smith chart maps all circuits (exhibiting positive and negative resistance) in the unit hyperbolic reflection coefficients plane. ■

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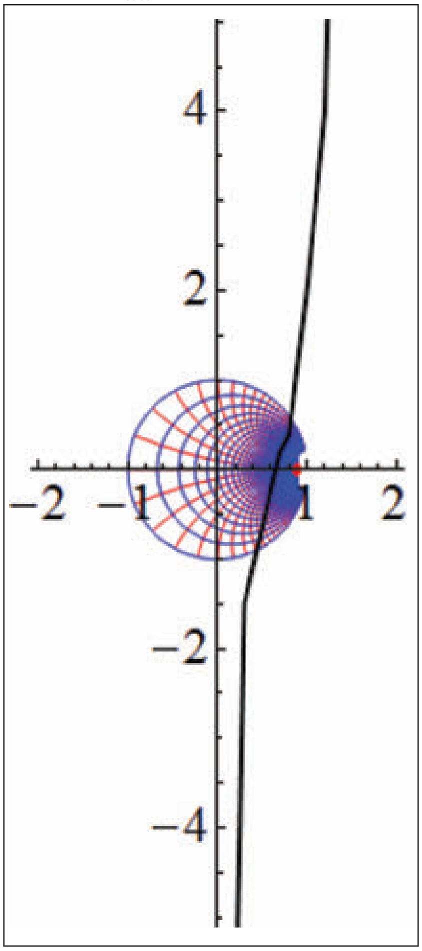
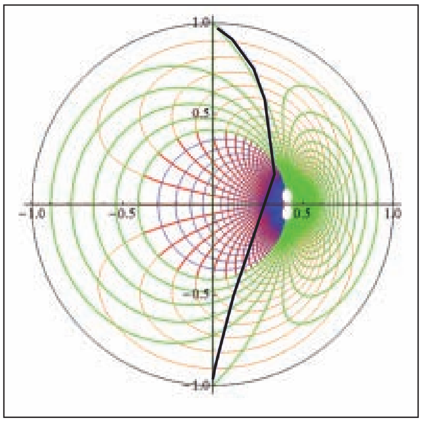


▲ *Fig. 2 Input impedance (in black) of a microwave oscillator based on an Infineon bipolar transistor on the traditional Smith chart, the input impedance at the oscillation frequency is thrown towards infinity.*



▲ *Fig. 3 Input impedance (in black) of a microwave oscillator based on an Infineon bipolar transistor is tending towards infinity (unit circle)$|\rho|=\infty \leftrightarrow |\rho^h|=1$ on the hyperbolic Smith chart.*

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Dynamic Range (BW=10Hz, dB, typ)	120	100	120	120	120	120	115
(BW=10Hz, dB, min)	100	120	100	100	100	100	100
Magnitude Stability (±dB)	0.15	0.15	0.15	0.15	0.25	0.25	0.3
Phase Stability (±deg)	2	2	2	2	4	4	6
Test Port Power (dBm)	6	6	6	0	0	-4	-9

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INVITED PAPER

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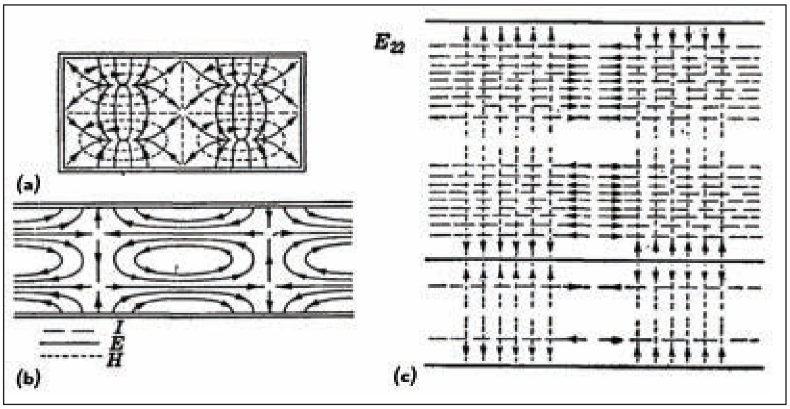
RF Waveguide Tips and Facts You Can't Learn in School

Pasternack
Irvine, Calif.

For many microwave and millimeter wave applications, RF waveguides are the guided transmission technology of choice. Typically, waveguide interconnects and devices provide lower insertion loss and better VSWR than coaxial or microstrip transmission lines. Also, the high power handling capability, solid construction and high heat handling make waveguides particularly attractive to aerospace, military and scientific applications that require high power and performance. There are many nuances and easily forgotten factors to ensure waveguide assemblies and interconnects operate at maximum performance. It takes a good deal of knowledge to enter the waveguide game and, as many technologies rely on waveguides — especially millimeter wave — a lot of time and money can be saved with expertise.



▲ *Fig. 1 E_{22} mode field distribution in a rectangular waveguide: cross-sectional (a) longitudinal (b) and surface (c) views.*[1]

TYPES, MODES AND FREQUENCY BEHAVIOR

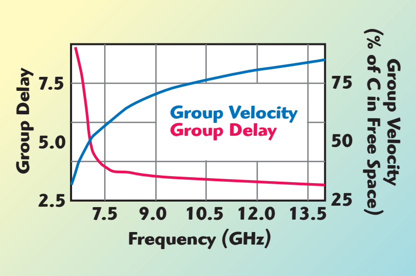
The conductive walls of a closed circular, elliptical or rectangular waveguides facilitate the propagation of guided mode electromagnetic (EM) waves. There are several different modes for each type of waveguide (see ***Figure 1***), and the equations that determine the frequency behavior of the modes are dif-

TABLE 1

CUTOFF FREQUENCIES FOR X-BAND RECTANGULAR WAVEGUIDES (22.86 × 10.16 mm)

m	n	F (GHz)
TEmn Mode Cutoff Frequency		
m	n	F (GHz)
1	0	6.562
2	0	13.123
0	1	14.764
1	1	16.156
TMmn Mode Cutoff Frequency		
m	n	F (GHz)
1	1	16.156
1	2	30.248
2	1	19.753

ferent for each type. For rectangular waveguides, the TE_{10} mode is the most commonly used, as it has the lowest attenuation. Rectangular waveguides also tend to be the most common type for components and assemblies. However, for routing purposes, circular or elliptical waveguide interconnects are commonly used for long runs. Waveguides are capable of



▲ *Fig. 2 WR90 group delay and group velocity vs. frequency.*

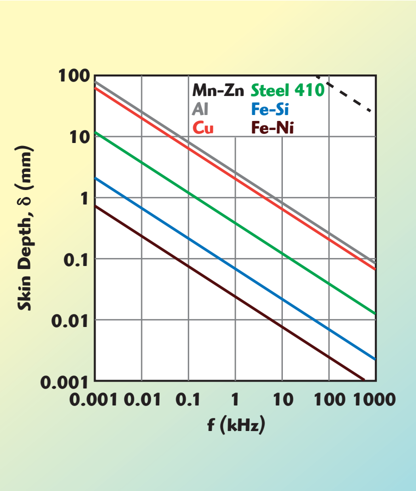
multi-mode operation, but this may not be ideal since the interaction between the modes can degrade signal integrity for any single mode — when evanescent wave coupling occurs with higher modes, for example.

The lower frequency limit of a waveguide is a hard cutoff where the attenuation exponentially increases as the frequency lowers, disabling transmission (see ***Table 1***). Most rectangular waveguides are specified with a 2:1 width to height ratio to achieve a maximum bandwidth ratio of 2:1, i.e., the ratio between the maximum frequency and minimum cutoff frequency. This way, maximum power is carried by the waveguide before microwave breakdown, dielectric breakdown or multipaction can occur. This differs from a circular waveguide since it can only propagate a maximum bandwidth ratio of 1.3601:1, which is the maximum single mode frequency to minimum cutoff frequency. The recommended frequencies of operation for a rectangular waveguide are 30 percent higher than the cutoff frequency and 5 percent below the cutoff frequency of the next higher mode. These recommendations prevent dispersion at the lower frequencies and multimode operation at higher frequencies.

Even if a waveguide is operated within the recommended frequency range, the group delay and phase delay over its entire bandwidth is a significant percentage of the speed of light (see ***Figure 2***). This is unlike TEM mode transmission lines, such as coaxial transmission lines, which have a relatively flat group delay over their operational frequencies. Nonlinear phase or wide variations in group delay can cause fidelity errors in wide bandwidth radar systems and even intersymbol interference in wide bandwidth digital communication systems. Devices such as phase shifters are used to correct the phase delay from the waveguide response, component delays and unequal length routing.

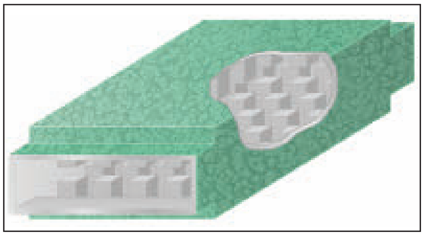
With a short length of waveguide interconnect, it may be difficult to measure the insertion loss, phase delay or VSWR. The extremely low insertion loss and other performance factors over a short length may be below the measurement capabilities of all but the highest performance vector network analyzers (VNA). The insertion loss may only be a small fraction of a dB, and the dynamic range of the VNA may not be adequate to differentiate the insertion loss from noise.

Though waveguides are generally very high performing, routing with coaxial cables is occasionally preferable, such as when several mating/demating transitions occur, the routing is very tight and complex or to reduce cost. For systems with a low noise amplifier (LNA), a waveguide segment may be used to route RF energy from the antenna to the LNA input, with the output of the LNA connected to a coaxial segment, as the biggest impact to the signal-to-noise ratio (SNR) and dynamic range



▲ *Fig. 3 Materials with greater skin depth have less loss at high frequencies.*[2]

(DNR) is loss before the input of the LNA. High power systems may also use waveguides to route high power signals at the input and output. Systems can convert from waveguide to coaxial, to take advantage of the lower cost coaxial routing, where higher insertion loss and poorer VSWR have less impact.



▲ *Fig. 4 In complex waveguide components, calculating the necessary spacing at various power levels requires predicting material properties.*[4]

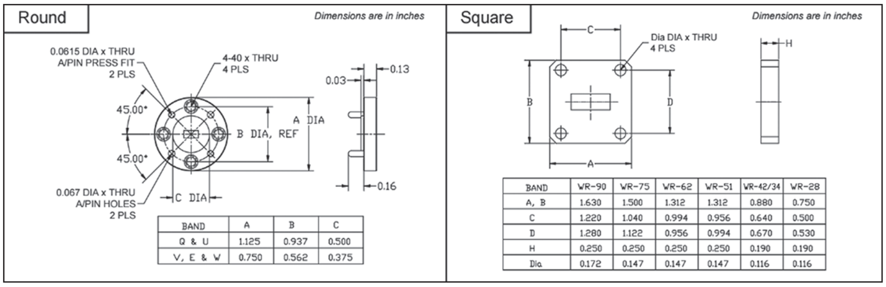
EM PHENOMENON, SKIN EFFECT AND MICROWAVE BREAKDOWN

At certain frequencies and power levels, the electrical and material properties of conductors and dielectrics can change and produce unexpected effects. At higher microwave frequencies, the electrons in a conductor migrate toward the surface, a phenomenon known as skin effect (see ***Figure 3***). Also, if power levels are too high, the dielectric material between two conductors ionizes and becomes conductive, resulting in microwave dielectric breakdown. With skin effect, as the frequency of the EM energy in a waveguide increases, more of the traveling electrons migrate toward the surface of the inside walls of the waveguide. The inside walls are more significant to wave propagation than the outside surface of the waveguide, since the conductor's high frequency conductivity is less in the bulk of the material than near the surface — a significant reason why high frequency losses in a conductor are much higher than low frequency losses.

For non-ferromagnetic conductors, the DC resistance is many times higher than at RF and microwave frequencies. Still, for ferromagnetic materials such as nickel, iron and steel, the AC resistance has a more significant increase with the greater magnetic permeability. For these reasons, very high conductivity metallization, such as silver and gold, are often used to plate the inside walls of a waveguide, especially for higher microwave and millimeter wave and power applications. At only 1 GHz, 98 percent of the electrons in a copper sheet are traveling within several micrometers of the copper sheet surface. At high microwave and millimeter wave frequencies, the region in which the majority of electrons travel is much smaller, making the surface conditions of the conductor extremely important. This means that the final plating material on the inside walls of a waveguide is often the only conductive material that has an impact on the EM propagation. Hence, surface conformity and smoothness are critical to reduce RF losses throughout the waveguide.

Another phenomenon that impacts high frequency and high power systems is the EM energy induced dielectric breakdown between the conductive walls of a waveguide that can cause high energy arcing. The arcing that occurs within a waveguide at high power can cause standing waves at extreme power levels and induce potentially damaging heat or even deplating the surface metals of the waveguide material. The power threshold where microwave breakdown occurs depends upon the dielectric properties, temperature, distance between conductors, frequency and pressure of the gaseous dielectric inside the waveguide. For high power waveguide filters, the spacing of the filter cavities with the surrounding metal is also important to prevent multipaction[3] (see ***Figure 4***).

Fig. 5 Minor contamination on plating can induce failures. Poorly plated silver led to the failure of a waveguide transfer switch array in NASA's Mars Reconnaissance Orbiter (MRO).[5]



BAND	A	B	C
Q & U	1.125	0.937	0.500
V, E & W	0.750	0.562	0.375

BAND	WR-90	WR-75	WR-62	WR-51	WR-42/34	WR-28
A, B	1.630	1.500	1.312	1.312	0.880	0.750
C	1.220	1.040	0.994	0.956	0.640	0.500
D	1.280	1.122	0.956	0.994	0.670	0.530
H	0.250	0.250	0.250	0.250	0.190	0.190
Dia	0.172	0.147	0.147	0.147	0.116	0.116

Fig. 6 MIL-DTL-3922 defines the dimensions of waveguide flanges.[6]

Gases with higher breakdown properties can be injected into a waveguide system to increase the power threshold before microwave breakdown occurs. After assembly, waveguide systems are sometimes purged of humid air with dry gases to prevent condensation and humidity that will reduce the microwave breakdown threshold. Specially made flanges with gas inlet and outlet valves are used for this.

QUALITY COUNTS

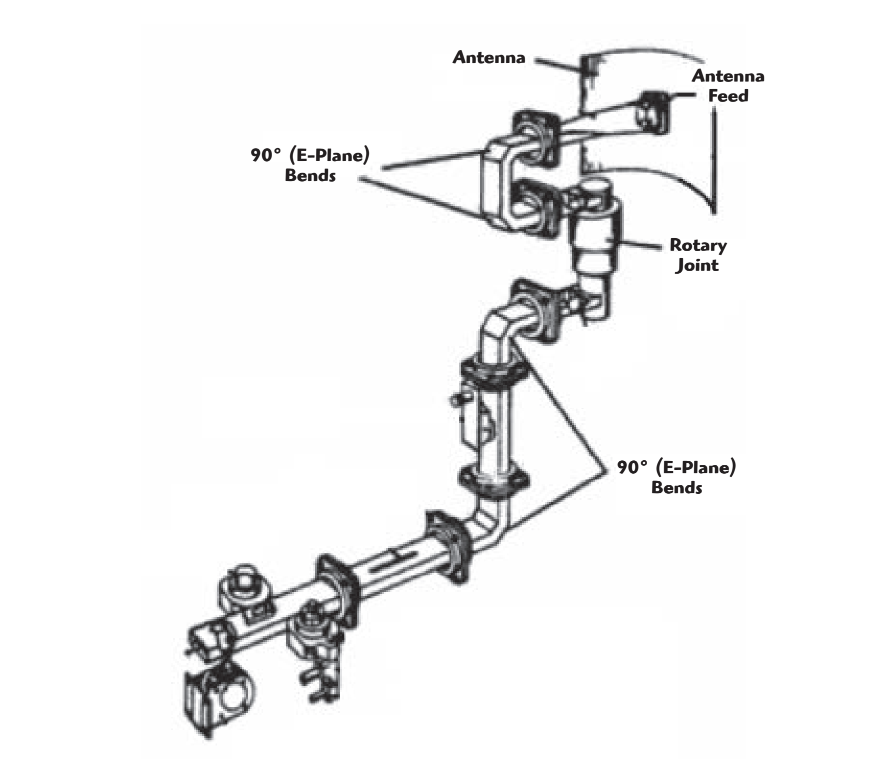
The quality of construction and materials can have a large impact on the performance of a waveguide system, especially at microwave frequencies and when carrying high power. Such waveguide can become difficult to manufacture and evaluate, as the tolerances are extremely small at microwave and millimeter wave frequencies. To achieve the necessary millimeter wave component and interconnect quality, soldering must be performed with a detailed visual inspection to ensure that no pits or holes exist in the solder. In space applications, even minute holes or pits can allow flux to leak from the material, increasing losses and degrading performance (see ***Figure 5***). Machining tolerances for waveguides can be very tight, not only to ensure mechanical stability and strength but also because RF performance depends upon the precise relationship between the geometries, the plating and the smoothness of the inside waveguide walls and flanges. Any tooling marks or imperfections in the material can cause losses, reduced VSWR as well as misalignment when connecting with other waveguide components.

Though there are many reputable and high quality waveguide suppliers, some — particularly offshore — may streamline machining techniques to reduce manufacturing time and cost. These shortcuts can dramatically degrade waveguide component and system performance. Any misalignments or machined geometries beyond specified levels can increase the VSWR and allow RF leakage between the flanges, leading to increased maintenance and service costs. One example is the drilling of fastening holes in a waveguide flange. To achieve high precision alignment, the waveguide flange needs to be attached to the waveguide prior to drilling. However, some machining houses will drill the waveguide flanges prior to attachment. This results in xy and rotational displacement between the waveguide flange holes and the specified locations for the waveguide size and flange type. The errors may be so slight that they aren't visually discernable or measurable with a pair of calipers. However, highly precise xy-coordinate machines are available to measure hole dimensions and can be used to evaluate incoming parts. Some high microwave and millimeter wave waveguides use guide pins, with detailed specifications provided in MIL-DTL-3922 (see ***Figure 6***). At higher frequencies, these pins are specified to be 0615; however, some companies will use 0612 pins, as they are a standard stock pin. Although the differences in pin sizes are not discernible to the eye, the wrong guide pin can lead to misalignments.

MECHANICAL AND MACHINING CONSIDERATIONS

Waveguides are predominantly constructed entirely with conductive metals, with the exception of pressure windows, some gaskets and jacketing materials. Generally, this means that waveguides are constructed in machining facilities by technicians knowledgeable in waveguide construction. Some of this knowledge is based on physics, such as the proper bend radius and lengths of bends; some depends upon experience gained through trial, error and troubleshooting. For instance, generic flexible waveguides tend to have poorer RF performance, i.e., insertion loss and VSWR, even though they may solve routing, misalignment and vibration challenges. Nonetheless, if a flexible waveguide is made with the appropriate sized sections for a specific frequency, the insertion loss and VSWR can nearly match a solid waveguide over a very narrow bandwidth. Additionally, some suppliers will perform a fully assembled flexible waveguide to reduce the occurrence of mechanical stress on a flexible waveguide segment that often causes the decoupling of the flex segments.

For waveguide twists and bends, there are very simple physics-based rules to follow to ensure that RF performance is optimized (see ***Figure 7***). With rectangular waveguide, bends can be in the width for distorting the electric field, known as an E-bend, or the bend can be in the height wall for distorting the magnetic field, known as an H-bend. The radius required to have an optimal performing bend is greater than two wavelengths at the lowest frequency of interest. For a 45 degree twist, or sharp bend, the simple rule is that the outer wall length should be one quarter of the wavelength of interest. With sharp bends, the phase of the output signal will be inverted compared to the input, and the bandwidth will be limited compared to other routing options. With twists, a 90 degree bend requires at least two wavelengths, where a 180 degree twist requires four wavelengths for a full inversion. The polarization of the RF energy is changed during a twist



▲ *Fig. 7 A properly designed waveguide bend will not cause additional loss or reflection, critical in long waveguide runs.*[7]

and may need to be corrected, depending upon the system.

Another area of concern for many waveguide purchasers is cost, due to the amount of gold plating on many waveguide products. For higher frequency microwave and millimeter wave applications, precious metal plating is necessary to minimize losses in the waveguide but is only needed on the inside surface of the waveguide and flanges. The plating on the outside surface of the waveguide, or plating on waveguides used at lower frequencies, is purely cosmetic or used to reduce corrosion. In this case, a much lower cost passivation layer may suffice.

ASSEMBLING: TROUBLESHOOTING AND HANDLING

Though waveguide components and interconnects tend to be formed of relatively sturdy metals, some aluminum and copper waveguides for higher frequency and aerospace applications can easily be dinged and dented. While these dings and dents are sometimes a useful tuning technique, they can dramatically change the performance of a waveguide or waveguide component. Ensuring proper packaging and shipping can prevent untimely surprises upon arrival. As shock and vibration during shipping can misalign the fittings, some suppliers will ship a waveguide assembly attached to a keeper plate to mitigate shipping and storing issues.

After receiving, the assembly and care of the waveguide component and interconnect can impact performance. One frequent issue is the attachment of the waveguide flanges. If no gasket is used, the surface of each flange needs to be clean and flat. Any marring, dust or peeling plating can lead to RF leakage and reduced performance from misalignment. Waveguide bends and twists may also form stress cracks from thermal cycling and mechanical stress. The higher the frequency of the waveguide, the more sensitive the system performance is to proper assembly and care. With flange attachments, a consistent and specified amount of torque should be applied at each corner (see ***Table 2***). If one corner of a waveguide is torqued more or

TABLE 2
WAVEGUIDE FLANGE RECOMMENDED TORQUE AND TENSION[8]

Screw Size	Threads Per Inch	Torque (inch-lb)	Tension (lb)
4	40/80	4.5/ 5.5	235/280
6	32/40	8.5/10	360/410
8	32/36	18/20	625/685
10	24/32	23/32	705/940
1/4"	20/28	80/100	1800/2200
5/16"	18/24	140/150	2540/2620
3/8"	16/24	250/275	3740/3950
7/16"	14/20	400/425	4675/4700
1/2"	13/20	550/575	6110/6140

less than the others, a small gap will form and degrade VSWR and insertion loss. RF leakage can occur. This can also happen as a gasket degrades with age or heating/cooling cycles. Threaded screws can back up under vibration and heavy loading. Methods that ensure stable fastening should be used, as long as they do not impact RF performance and even clamping of the flanges.

If higher than expected loss or VSWR occurs, the next step is to track down the area of leakage. Rather than pulling the system apart and testing each connection, a detector probe can be used to scan an assembly for leakage points while running a test. Keeping a reasonable distance by using probes that prevent human contact with the waveguide assembly is recommended to avoid arcing, as RF leaks can lead to high voltage occurrences.

CONCLUSION

The low insertion loss, incredible VSWR and high frequency and power handling capabilities of waveguides comes at a price: a large learning curve and careful design and assembly. Some of the physics-based knowledge of waveguides can be found in a good book. However, there is a large amount of practical knowledge about construction and system design that is rarely available outside an experienced waveguide manufacturer and system design team.■

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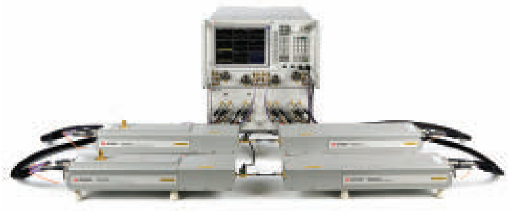
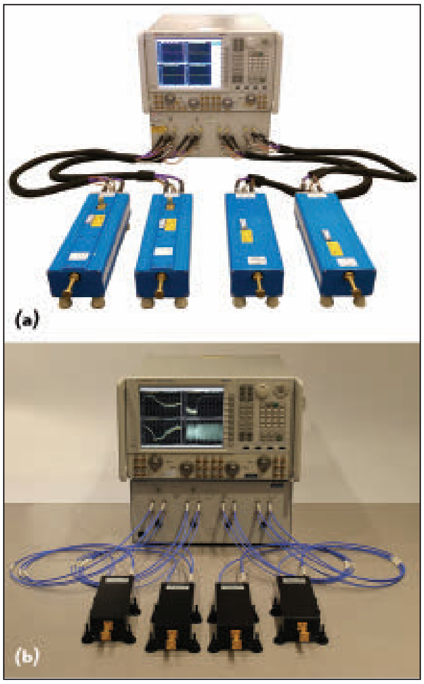


THz Spectrum Analysis With A Vector Network Analyzer

Keysight Technologies
Santa Rosa, Calif.

Device characterization can be challenging and complicated when venturing into the terahertz frequency range. To further complicate the situation, achieving an insightful understanding of component performance and behavior often requires two instruments: a vector network analyzer (VNA) and a spectrum analyzer (SA). During a typical measurement session, the need to frequently connect, disconnect and reconnect the device under test (DUT) is both inconvenient and time-consuming. It can also introduce measurement errors, extend measurement time, and damage the probes, the test cables and even the DUT.



▲ *Fig. 1 The addition of solution-partner frequency extenders to the PNA enables a banded terahertz solution. With OML (a) and Virginia Diodes (b) extenders.*

One solution is to incorporate VNA and SA capabilities into a single instrument. Recently, faster digitizers, digital signal processors (DSP) and central processing units (CPU) have enabled Keysight to implement an SA capability that is fast enough to accelerate crucial — and often tedious — measurements, such as the search for spurious signals. In the analog portion of the block diagram, the next step is extending SA capabilities into the terahertz region while retaining the expected functionality, performance and accuracy of VNA and SA measurements.

REACHING THz

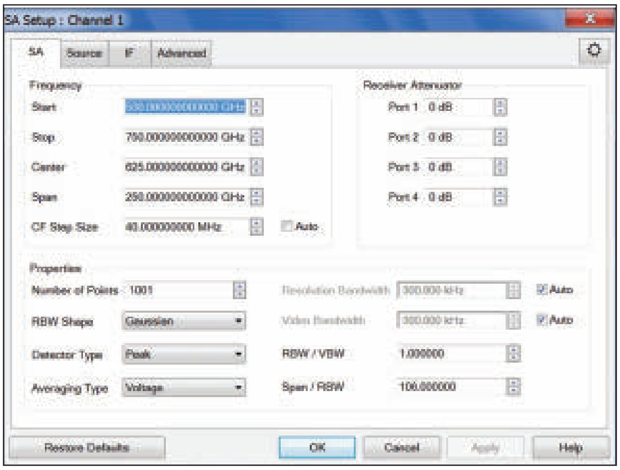
VNA test solutions that measure below 67 GHz are usually implemented as a single, integrated instrument. Extending VNA capabilities to higher frequencies is typically achieved by using what is called a distributed architecture. This requires the use of frequency extenders that up-convert stimulus signals and down-convert response signals to support DUTs that operate into the terahertz range. A mmWave VNA can be implemented as a preconfigured solution or as a user-integrated system built around an existing VNA.

For example, Keysight offers an integrated system under a single model number, the N5251A mmWave network analyzer. This configuration covers 10 MHz to 110 GHz and currently offers extensions to 1.1 THz. The core instrument is a Keysight PNA microwave network analyzer. These solutions can be configured in two ways: one supports single sweep measurements through 1.0 mm coaxial connections; the other supports a variety of banded measurements via waveguide. The single sweep configuration is based on a 67 GHz PNA and includes a pair of companion mmWave controllers that support two- or four-port measurements (Keysight N5261A or N5262A, respectively). These connect to broadband frequency extenders, providing the interface between the mmWave test-head modules and the network analyzer. The extenders provide a 1.0 mm coaxial interface to the DUT up to 110 GHz, as shown in the product photo, and waveguide is used above 110 GHz.

The banded configuration supports a variety of frequency extenders from OML and Virginia Diodes (VDI). These use waveguide for frequencies above 110 GHz and in some frequency bands between 67 and 110 GHz (see ***Figure 1***). The latest version of Keysight's optional "SA on VNA" capability now supports all of these configurations, enabling integrated spectrum analysis into the terahertz range on the PNA and PNA-X network analyzers.

BUILT IN SA

The optional spectrum analyzer mode includes a user interface that presents the typical array of setup parameters: center frequency and span, start and stop frequencies, step size, resolution bandwidth (RBW), detector shape, averaging and receiver attenuation (see ***Figure 2***). One important note about using SA in the distributed configuration: because the internal receiver attenuators are bypassed, external attenuators may be required when testing high power DUTs.



▲ *Fig. 2 The popup window for SA setup enables selection of key parameters for multiple measurement channels.*

The integration of SA capabilities enables quick handoffs from the VNA mode without changing the physical test setup. For example, if an anomaly crops up in a VNA trace, the user can place a marker at that point and press "Marker to SA" to initiate a spectrum measurement. The measurement appears in a new window, enabling further observation and analysis of spectral content and behavior. The PNA and PNA-X also include a calibrated stimulus that can be directed to any and all DUT ports. Through tight control of frequency, amplitude and DC offset, this provides a very accurate test solution for the characterization of harmonics and intermodulation products. In addition, internal pulse generators and modulators enable characterization of DUTs with pulsed RF stimuli. The net result is the ability to evaluate DUT behavior under a wide operating range and in a variety of operating conditions.

The Keysight implementation of spectrum analysis is built on its existing VNA architecture. A typical spectrum analyzer includes a microwave pre-selector (i.e., a filter) that blocks high level signals while measuring low level signals as well as unwanted mixing products; this removes receiver harmonics and image responses. The SA-on-VNA design relies on custom hardware and software to provide spectrum analyzer performance. The PNA series uses custom RFICs designed in proprietary processes, coupled with software algorithms, to eliminate images. The hardware design also compensates for remote up- and down-converter topologies and nonlinearity.

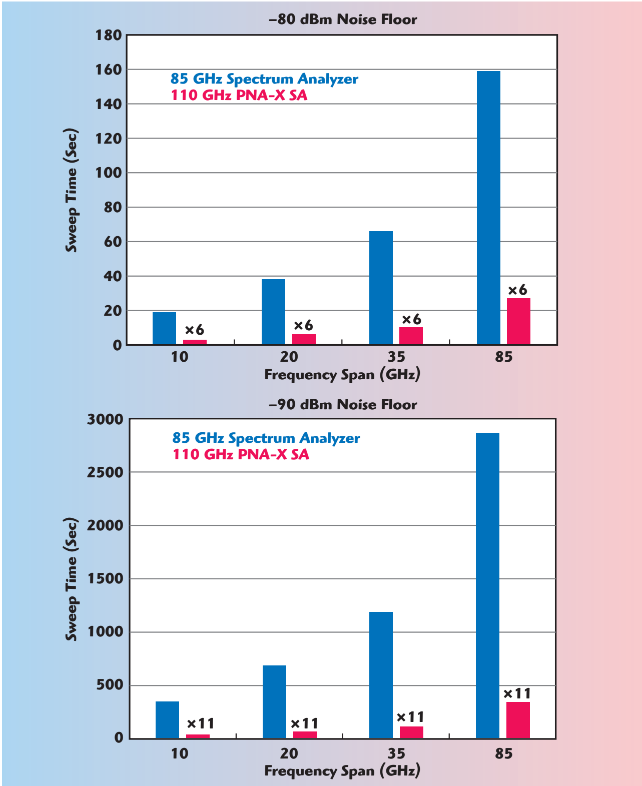
The same techniques can be utilized in the distributed architecture VNA configuration used for mmWave measurements. The only additional consideration is a special calibration of the SA receivers to ensure accurate measurements. This calibration must include the frequency extender heads as well as all associated hardware, ca-

bling and fixturing. Because the user may change one or more of these elements to suit a specific frequency range or setup, two types of calibrations must be performed any time the test configuration changes: power level and IF receiver. To simplify these situations, the new high frequency SA options include functionality that automates the calibration processes and guides the user.

THE ADVANTAGES

The integration of SA capabilities into a VNA offers two key advantages over the multi-instrument approach: multiple

▲ *Fig. 3 The single connection, multi-channel SA capability provides accurate, simultaneous measurements on all DUT ports.*



▲ *Fig. 4 As span increases (lower noise floor), the integrated SA capability provides a significant speed advantage over stand-alone spectrum or signal analyzers.*

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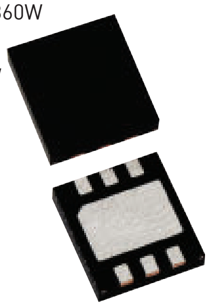

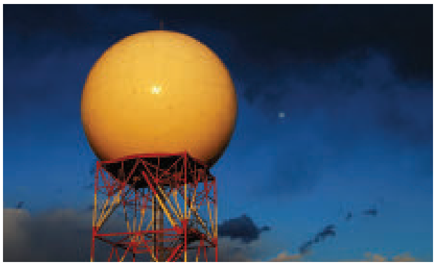

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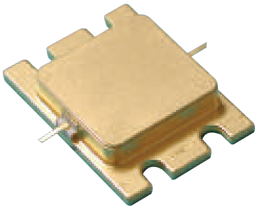

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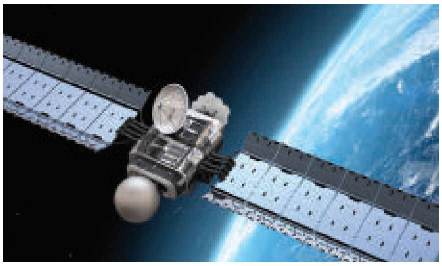

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simultaneous measurements and calibrated accuracy. Through its multiple test ports, a VNA enables multi-channel spectrum analysis that is synchronized with the internal swept signal generators. A PNA or PNA-X, through a single connection, provides simultaneous measurements on all DUT ports. The range of possible measurements includes input spectra, output spectra, channel power, gain compression, feedthrough, reflections, conversion gain, harmonics and intermodulation (see ***Figure 3***). This simplifies characterization of devices such as mixers, frequency converters, amplifiers, high frequency modules and subsystems. VNA calibration and de-embedding techniques are essential to the accuracy of in-fixture and on-wafer measurements. The process corrects for the instrument's systematic errors, and it removes cable and fixture effects. It can be used with frequency extenders, and it is also applicable to the SA-on-VNA capability. In addition, the power compensation features can be used to deliver a stimulus of known power to the DUT, compensating for known loss in the fixture or probes. The resulting improvement in measurement accuracy enables a deeper understanding of a DUT's true performance.

Spurious are unwanted signals — harmonic or non-harmonic — that may cause interference from transmitters, false responses in radar systems or reduced dynamic range in communications receivers. Spurs must be identified and measured before a designer can reduce them to sufficiently low levels, as defined by a system or device specification. The search for spurs presents two challenges: time and complexity. The process of checking spurious performance is time-consuming, especially when searching for low level signals over a broad frequency range. Characterizing spurs over the operating range of typical mixers and frequency conversion devices tends to be tedious and complicated, and it often requires external control software. With the integrated high performance SA capability, a PNA or PNA-X can perform fast spurious searches across a broad frequency band, improving test time compared to a stand-alone signal analyzer. Speed does not degrade accuracy: measurements results are comparable to those obtained with today's most sophisticated spectrum or signal analyzers (see ***Figure 4***).

CONCLUSION

Working at mmWave and sub-mmWave frequencies can be challenging. As implemented in the Keysight PNA and PNA-X microwave network analyzers, the optional addition of integrated SA capabilities to a distributed VNA architecture makes it possible to characterize component performance and behavior into the terahertz range with a single test setup. The integrated stimulus, with the ability to perform spectrum analyzer measurements on multiple channels simultaneously, offers research and design engineers new insights in much less time and with excellent accuracy.

VENDORVIEW

Keysight Technologies
Santa Rosa, Calif.
www.keysight.com/find/thz

Low Noise, Low SWaP Synthesizers

Pronghorn Solutions
Denver, Colo.

RF/microwave synthesizers are ubiquitous in today's world — practically in every wireless device, from the smallest handheld to the largest communication towers, in every electronic countermeasure (ECM) and electronic warfare (EW) system, in medical and plasma research, in radio astronomy, in instrumentation and test, in laboratory and production environments.

Pronghorn Solutions has developed a new family of synthesizers, covering 10 MHz to above 24 GHz and offering industry-leading phase noise, frequency resolution of 0.01 Hz, fast switching of less than 100 µs in list mode, low spurious, small size and low power consumption. The products in the PHS8500 family are available in modular (PHS8500M), handheld (PHS8500H) and benchtop (PHS8500B) formats. The benchtop model allows multiple synthesizers in one box, all controlled by a single reference source, with options for multiple tone testing and phase continuous, multiple frequency operation. The handheld and modular systems weigh under 1 lb and consume less than 8 W, with a power saver option for lowering power consumption in airborne units. The handheld unit offers battery operation as an option. The modular version is quite small: 3.5" × 5.5" × 1". With these three configurations, the PHS8500 family is suited for production and operational test, laboratory test and field applications.

INSIDE THE BOX

Phase-lock loop (PLL) synthesizers have been the workhorse in telecommunications, EW, ECM and test and instrument systems for well over 50 years. During this time, PLLs have evolved from complex, typically narrow band designs that were limited to below L-Band frequencies to integrated, multi-octave and multidecade ICs. Digital processing speeds have also been increasing, enabling direct digital synthesizers (DDS) to reach well over 4 Giga symbols per second (GSPS). Direct analog synthesizers (DAS), which derive the desired frequency by combinations of multiplying and mixing a reference signal, have become smaller and achieve wider bandwidth, using ever-shrinking IC designs. The patented PHS8500 family uses a combination of the best characteristics of PLL, DDS and DAS technologies to create superior performance in a low power consumption, flexible package — a specific goal of the design team.

The PHS8500 operates from an internal 100 MHz temperature-compensated crystal oscillator (TCXO). It can also use an external 10, 100 or optional 1000 MHz reference. The

phase noise close to the carrier (< 300 kHz) and stability of the synthesizer are directly related to the reference noise (see ***Figure 1***).

In the PHS8500 synthesizer, the DDS is operated in a region that eliminates any spurious using special filtering and wave-forming circuits, to assure optimum performance. The DDS allows modulation (an option), a limited range of continuous sweep, phase coherent small-step switching and other characteristics that make the PHS8500 a very flexible synthesizer. The DAS is used to achieve excellent close-to-carrier phase noise at all frequencies. Combining the three, the PLL assures broadband, quick switching; DAS assures close-to-carrier phase noise that is essentially at the level of the reference source; and DDS provides extremely small frequency step sizes, excellent modulation capabilities and phase-coherent frequency changes.

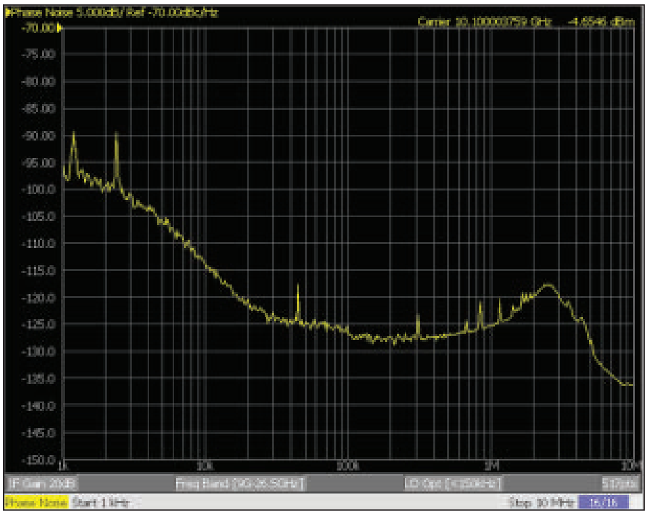

Fig. 1 PHS8500 phase noise measured at 10 GHz output.

The PHS8500 family enables a product or system design that starts in a laboratory to be transitioned to the field or the production floor seamlessly, with very low capital cost. The primary software interfaces to the instrument, via SCPI-compliant USB or SPI drivers, are identical in all three models. The benchtop, handheld and modular units all come with a flexible and industry standard SCPI-compatible interface. These include USB port and SPI ports. The benchtop model adds a built-in LAN interface, so that the instrument can be wirelessly controlled as part of an Internet of Things (IoT) network. An external LAN interface is also available as an option for the modular version. The handheld unit has the standard SCPI-compatible USB interface. All PHS8500 models come with a Visual Studio instrument graphical user interface (GUI), which can be used as a front panel control with a PC. The benchtop and handheld models have a convenient 4 × 4 keypad, allowing most of the synthesizer's functions to be entered and displayed on a backlit LCD display.

The PHS8500 family was designed for low power consumption. Operating from a single positive 8 V DC power supply, total current draw of the modular unit is less than 1.0 A, giving a total power consumption less than 8 W. If additional power conservation is needed — during non-operational states of the synthesizer, for example — an option allows the total power consumption to be reduced to under 1 W with a simple command. The external 120/240 V AC power cord in the benchtop and handheld models externally converts the line voltage to an 8.4 V DC output that plugs into the instrument. The handheld unit has an optional, externally rechargeable battery pack that can be used for field operations.

The PHS8500 family excels in all applications: production testing, laboratory product development, field testing and alignment and other embedded applications. For those who want to embed the synthesizer in a custom system — within a PXI, other module or special purpose instrument — the PHS8500X is offered as a customer-specific, board-level synthesizer that can plug in to many systems. Pronghorn plans to add models to the family, which will offer lower phase noise and other performance enhancements.

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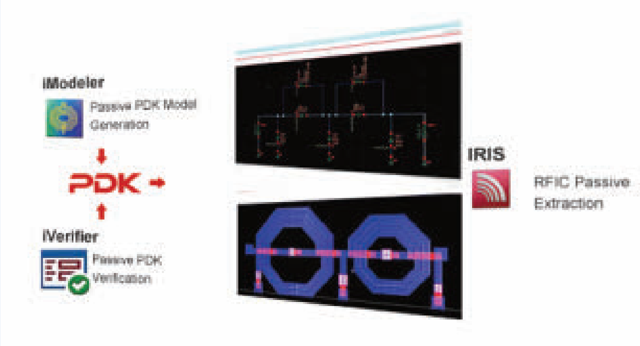

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With the rapid growth of wireless and mobile communications, the demands on RF connectivity ICs are ever increasing. While the semiconductor process moves to advanced node technologies at 28 nm and below, traditional quasi-static extraction is not able to accurately model passives and interconnects. On the other hand, the 3D full-wave solvers in traditional RF/microwave design tools lack speed and usability in the IC design flow. RFIC designers need a 3D full-wave EM simulation that combines both. IRIS is such a tool, providing 3D full-wave accuracy, allowing designers to quickly perform EM simulation without leaving the layout environment.

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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

80905 Munich, Germany

P.O. Box 450533

Telephone: +49-89-3548-040

Facsimile: +49-89-3548-0490

WWW.SPECTRUM-ET.COM

Email: sales@spectrum-et.com

Ultra-Narrowband Cavity Filters to Ku-Band

MCV Microwave offers high performance ultra-narrowband cavity filters and duplexers covering frequencies up to 13 GHz. Typically, cavity filters are known for low insertion loss, tight frequency selectivity and broad spectrum rejection. MCV Microwave's dielectric loaded, cavity bandpass filters and duplexers — BCCD and DCCD series, respectively — bring these desirable performance characteristics to a new height for the microwave engineering community.

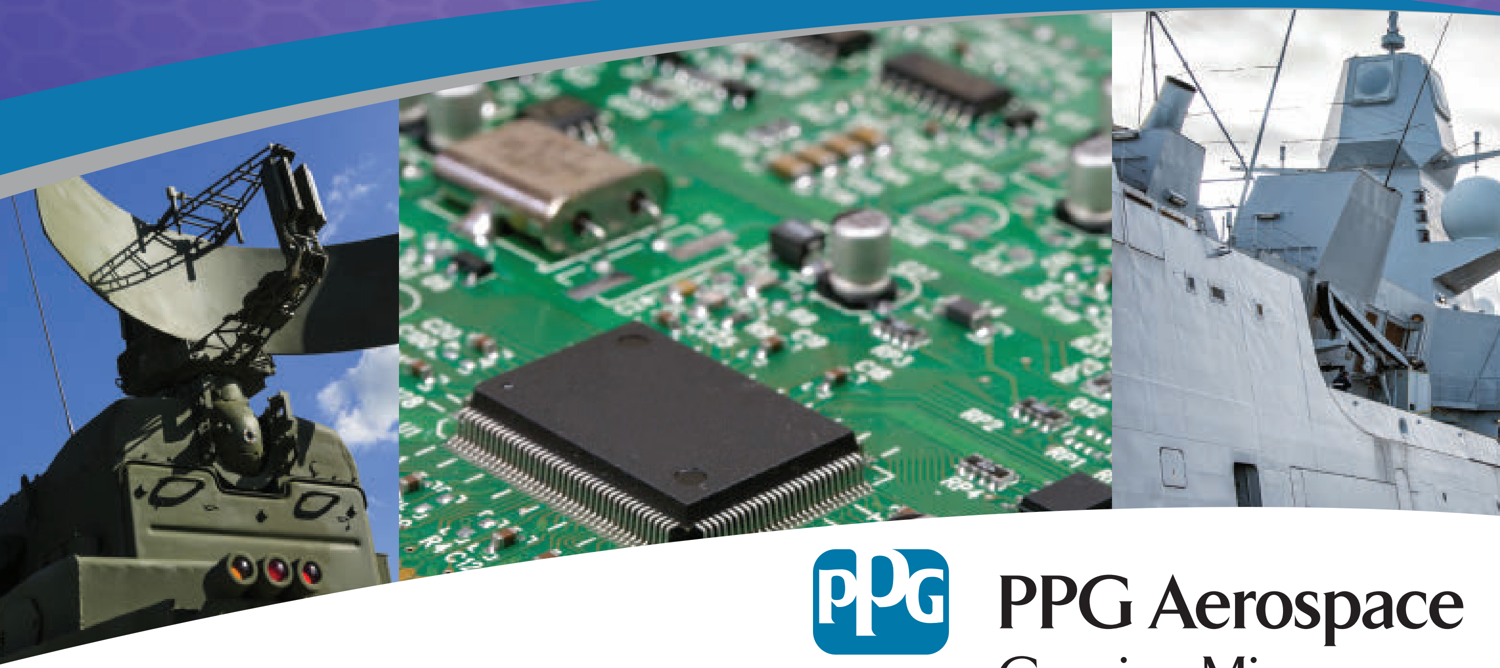
One example of the BCCD series is a 7.8 GHz cavity bandpass filter with only a 2 MHz 3 dB bandwidth (0.03% Fc) and 30 dB rejection 10 MHz from the center frequency on both sides. An example of a DCCD series is a 2 GHz with a 6 MHz split cavity duplexer that has a 3 MHz 3 dB bandwidth (0.1% Fc) with 60 dB rejection 1.5 MHz away from either band edge between the two passbands and 40 dB rejection 5.5 MHz away from the lower and higher band edges. These are offered in very compact packages: 2" × 1" × 0.5" for the BCCD cavity bandpass filter and 12" × 10" × 1.5" for the DCCD cavity duplexer.

In addition to cavity filters and duplexers, MCV offers dielectric resonators (DR) and DR loaded cavity filters for high power LTE and public safety base stations.

Vertically integrated, with in-house proprietary ultra-high Q dielectric resonators and 3D electromagnetic (EM) modeling, MCV Microwave designs and manufactures their ultra-narrowband filters and duplexers with precision and practicality. High Q and tight tolerance in both dielectric constant, ε_r, and temperature coefficient, T_f, are important characteristics in achieving RF/microwave system performance goals and maintaining stability over the operating temperature range.

VENDORVIEW

MCV Microwave
San Diego, Calif.
www.mcv-microwave.com



EDI CON USA Promises a Technical Program That Tackles Real-World Challenges

EDI CON 2016

Janine Love, Microwave Journal *Contributing Editor*

With a proven record of success in China, EDI CON will launch its first EDI CON USA conference in the U.S., September 20-22 at the Hynes Convention Center in Boston, Mass. This conference is a unique one in the U.S., as it brings together RF/microwave, EMC/EMI and high-speed digital designers in one location for educational training, product information and networking opportunities.

What does it mean for conference attendees? Peer reviewed presentations across nine tracks, workshops and trainings directly from the experts, short courses designed to delve deep into topics critical to today's RF/microwave and high-speed system designers, panels on topics such as 5G and connected automobiles, a plenary session and featured keynotes designed to bring you the latest technical information. In addition, attendees can visit with 130+ vendors on the exhibition floor, participate in speed trainings, see demonstrations and ask questions of their peers during the poster session.

CONFERENCE PROGRAM

EDI CON USA features a robust technical program, packed with 60 30-minute technical sessions featuring peer reviewed presentations, 27 workshops, 10 sponsored talks, 4 short courses, featured keynotes, panels, a plenary session and an all-day "RF Back to Basics" seminar. The technical program is designed to give conference attendees an opportunity to hear from and interact with experts in their fields, addressing immediate design concerns with technologies that are available now.

The technical program sessions cover the following tracks: Radar/Defense, 5G Advanced Communications, Signal Integrity/Power Integrity, RF/MW Design, Systems, Measurement, Modeling, IoT, and RF/MW: Amplifiers. Highlights from the technical program include "Simulation of Beamforming by Massive MIMO Antennas in Dense Urban Environments," presented by Greg Skidmore, director of Propagation Software & Government Services at Remcom, which promises to present a new predicative capability for simulating massive MIMO antennas and beam forming in dense urban propagation environments. Dan Orban of Orban Microwave Systems will give an "Introduction to Patch Antennas," where he aims to provide attendees with the knowledge and tools to confidently discuss antenna design requirements as well as attempt basic designs themselves.

See the online technical program for a full listing of presentations

The program also includes two featured keynote speakers. Dr. James Komiak, BAE Systems Global Engineering/Scientific Fellow at Electronic Systems in Nashua, N.H., will lead off the RF/MW Amplifiers Track with a talk on "Microwave and Millimeter Wave Power Amplifiers: Technology, Applications, Benchmarks and Future Trends," where he plans to cover principles of operation, structures, characteristics, classes of operation and device state-of-the-art benchmarks. In another featured keynote, "Invisibility Cloaks and Deflector Shields: Disappearing at Microwave's Frontiers," Dr. Nathan Cohen will provide an introduction to a fractal-based approach, showcasing a microwave demonstration which he hopes will provide motivation for attendees to learn more about this exciting technology.


PIVOTONE
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On Thursday afternoon, conference attendees can select among four short courses presented by acknowledged leaders in their respective fields. Dan Swanson of SW Filter Design, will present "Intuitive Microwave Filter Design with EM Simulation"; Eli Brookner, formerly of Raytheon, will present "Basics, Advances, & Breakthroughs in Phased-Arrays, Radar and MIMO"; Ken Wyatt of Wyatt Technical Services LLC, will present "Radiated Emissions - Product Evaluation and Pre-Compliance Testing"; while Steve Sandler of Picotest and Heidi Barnes of Keysight will present "Fundamentals of Power Integrity." These courses are designed to delve deep into the current technical understanding behind these four topics, providing attendees with techniques and insights that they can immediately apply after leaving the course.

EXHIBIT HALL

The exhibit hall opens on Tuesday at noon, and will be home to more than 130 exhibitors from the RF, microwave and high-speed digital markets. Conference pass holders as well as free expo pass holders can see the latest products, demonstrations and booth presentations on the show floor, as well as take in the presentations in the Frequency Matters Theater (mentioned below), visit with authors and network with peers during the poster session held on Tuesday from 2-4 p.m. The show floor is also home to a demonstration area, which will showcase unique, live demonstrations of some of the latest electronic technologies. And, it will also host the new Signal Integrity Zone, a place for high-speed digital designers to meet, network, and see some of the latest demonstrations from vendors working in signal integrity and power integrity. The exhibit hall will also be home to numerous networking coffee breaks, lunch concessions plus a happy hour on Wednesday.

SHOW FLOOR TRAINING

Attendees who choose to only take a free Expo pass will also benefit from some technical program content, as EDI CON will include programs and presentations during the exhibition in the Frequency Matters Theater. Confirmed programming on Tuesday, September 20 includes: "Forensic Analysis of Closed Eyes," presented by Dr. Eric Bogatin, renowned signal integrity expert, and "Best Practices for Signal Integrity during PAM4 Functional Test," by Gordon Vinther, CTO and founder of Ardent Concepts.

On Wednesday, attendees can spend a few hours learning the basic theory behind modern digital radio and RF circuits by participating in Dr. David Ricketts' "From Bits to Waves: Building a Modern Digital Radio in 1 Day" hands-on training which begins in the Frequency Matters Theater and then expands onto the show floor. Later that day, Joe Mazzochette of Eastern OptX will present on the development of the NASA Airborne and Satellite-based Snowpack Measurement (ASSM) capability, which makes use of radar test systems.

On Thursday, Frequency Matters Theater goers can see a presentation on "Ham Radio – the Original Social Network," by long-time HAM and former ADI employee Doug Grant as well as a look at landmine detection applications using "Vivaldi Antennas for Ground Penetrating Radar," by Skander Chaouch-Bouraoui. Fans of Pat Hindle and Gary Lerude's "Frequency Matters" program can get a chance to see the stars live as they present episodes from the Frequency Matters Theater on both Wednesday and Thursday.

Exhibition Hours

Tuesday, September 20:
12:00 p.m. - 6:00 p.m.
Wednesday, September 21:
10:00 a.m. - 5:00 p.m.
Thursday, September 22:
10:00 a.m. - 3:00 p.m.

PLENARY SESSION

On Tuesday, September 20 at 4:30 p.m., EDI CON USA will hold its plenary session, which will include introductory remarks by the EDI CON USA 2016 Honorary Chair, Dr. Eli Brookner, and include a talk by Tom Sikina, Raytheon IDS Electrical Design Directorate, staff principal engineering fellow, that traces "Innovation in Phased Arrays: Past, Present and Future."

Sikina will be joined on the plenary stage by Todd Cutler, vice president and general manager of Keysight Design & Test Software, who will address both the high-frequency and high-speed digital designers at EDI CON USA, offering insight into how emerging trends in high-frequency and high-speed design are driving a revolution in the design and measurement industry. Rohde & Schwarz's Faride Akretch will discuss how to "Continue the Innovation Towards Next-Generation Technologies," and National Instruments Jin Bains, VP of RF R&D, will reflect on "Tomorrow's Wireless: How 5G, 802.11ad, and the IoT is Shaping the Future of Wireless Technology." Be sure to join us at 4:30 p.m. for this plenary session, and then conference pass holders can head over to the welcome reception at Fenway Park (badge and ticket required; tickets will be given to conference pass holders that check in on Monday or Tuesday).

The EDI CON USA technical program team and Technical Advisory Committee aimed to create a program that speaks to the practical needs of engineers working on high-speed and/or high-frequency designs. We hope you will join us in Boston September 20-22, 2016. Come, share your insights with your peers, and plan to leave enriched with new ideas, skills and tools for success. See you in September!


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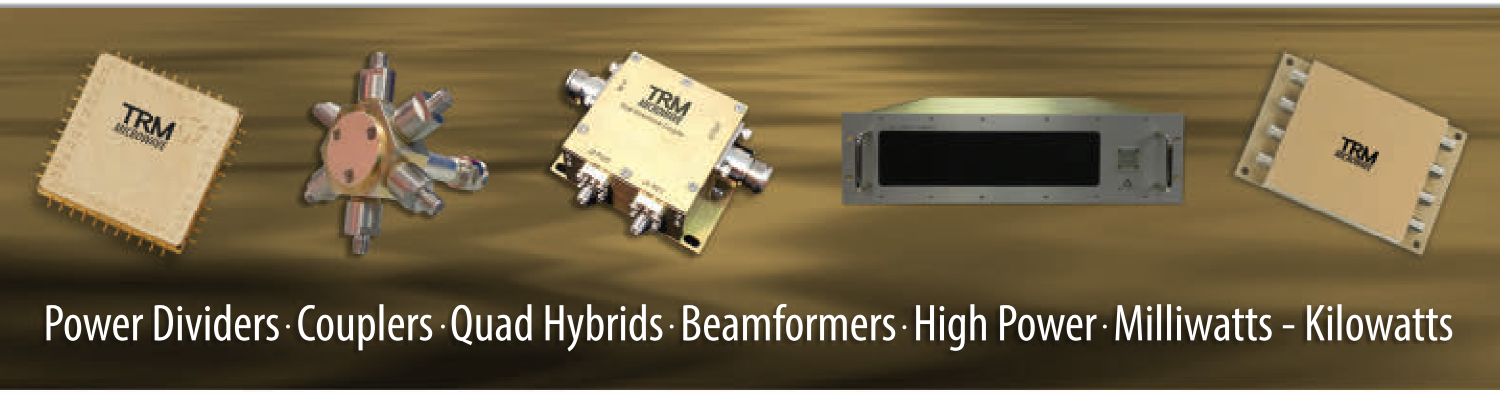
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EDI CON 2016

Tuesday, September 20, 2016

Room	201	202	203	207	208	209		
8:00 - 5:00	On-Site Registration							
	General Technical Sessions							
	Signal Integrity/ Power Integrity Track	Modeling Track	RF/MW: Amplifiers Track	Measurement Track	5G/Advanced Communications Track	RF/Microwave Design Track		
9:30 - 10:00	TU_101: Signal Integrity Characterization of 40 GHz Bulk Cable Clamp Test Fixtures (16) M. Witte, Harting KGaA	TU_102: Which Model is Best? Comparing DPD Models for Mobile Handset PA Linearization (96) B. Glass, NI	FEATURED KEYNOTE: Microwave and Millimeter Wave Power Amplifiers: Technology, Applications, Benchmarks and Future Trends (31) James Komiak, BAE Systems	TU_104: Testing Global Navigation Satellite Systems (GNSS) Devices (59) L. Wilson, R&S	TU_105: 5G Modulation Scheme Candidates - Spectrum and Modulation Measurements (47) K. Sander, R&S	TU_106: Optimizing the Analog Interface for Multi-GSPS ADC System (22) B. Sam, ADI		
10:10 - 10:40	TU_201: Practical Model of Conductor Surface Roughness Using Cubic Close-Packing of Equal Spheres (64) B. Simonovich, Lamsim Enterprises Inc.	TU_202: Conductor Profile Structure Effects on Propagation in Transmission Lines on Extremely Low Loss Circuit Laminates (82) A. Horn, Rogers Corp.	TU_203: A 1-Kilowatt Power Amplifier for SAR Remote Sensing in P-Band (68) J. Walker, Integra Technologies Inc.	TU_204: Calibration and Measurement of Terahertz Applications up to 500 GHz (53) V. Herrmann, R&S	TU_205: Simulation of Beamforming by Massive MIMO Antennas in Dense Urban Environments (90) G. Skidmore, Remcom	TU_206: Multimode Extractor and Converter for Monopulse Tracking System for mmWave Satellite Tracking (73) A. Pandey, Keysight Technologies		
10:50 - 11:20	TU_301: Building an Algorithm in FPGA to Detect Abnormal Events in Electrical Signals (32) R. Azevedo, NI	TU_302: High-Speed and Wideband On-Wafer Load Pull for Model Extraction, Validation and Design (70) G. Simpson, Maury Microwave Corp.	TU_303: 50 nm MHEMT Technology for Ultra-Sensitive Low Noise Amplifiers (102) P. Smith, BAE Systems	TU_304 Atomic Microwave Receiver (79) D. Stack, MITRE	TU_305: Co-Designed CMOS Based Antenna Modules for 5G Radio Nodes (55) C. Scholz, R&S	TU_306: An Introduction to Patch Antennas (39) D. Orban, Orban Microwave		
11:30 - 12:00	TU_401: A Novel Approach for Modeling and Co-Simulation of FPGA Base Package and Board (86) S. Surender, Cadence	TU_402: Easy and Effective Methods to Generate Substrate Stack-Up Files for Accurate EM Simulation (103) C. Kalluru, Keysight Technologies	TU_403: Amplifier Measurements Using Non-CW Stimulus (62) F. Ramian, R&S	TU_404: Broadband Sensing and Measurement of RF Power (23) E. Nash, ADI	TU_405: Overview of 5G: Addressing the Requirements of Next Generation Wireless Communications Systems (85) D. Hall, NI	TU_406: AlGaAs mmW PIN Diode Switch: A New Benchmark for Power Handling (15) T. Boles, MACOM		
12:00 - 2:30	Lunch Break & Dedicated Exhibit Time - Exhibition Floor							
		Workshops and Panels				Sponsored Talks		
1:30 - 2:10			WS_TU103: GaN Power Amplifiers in Mobile Communication Systems (117) ADI	WS_TU104: Spectrally Agile RF Subsystems: Utilizing OpenRFM, a Scalable, Modular, and Interoperable Open RF Architecture (138) Mercury Systems	WS_TU105: 5G Vision and Enabling Technologies (7) Keysight Technologies	CT_TU106 (2 papers): Three Technologies That Can Make or Break Your Spectrum Monitoring System (145), NI & Designing of Wideband High-Efficiency PAs Through Advanced Load-Pull Simulation (42), NI	Exhibit Hall open 12 - 6 p.m.	
2:20 - 3:00		WS_TU202: 3D Electromagnetics and the Validation Continuum (109) Mentor Graphics	WS_TU203: Techniques and Challenges in Designing Wideband Power Amplifiers Using GaN vs. LDMOS (122) NXP	WS_TU204: Fundamentals of Wideband Signal Generation: Going Beyond the Banner Specs (133) R&S	WS_TU205: Massive MIMO Technology Insights and Challenges (8) Keysight Technologies	CT_TU206 (2 papers): Advances in RF Design Enablement for Wireless and Wireline ICs (40), Tower Jazz & RF Technical Innovations that Improve System Signal to Noise Ratio and Reduce Intermodulation Distortion (105), IDT		
3:00 - 3:30		Coffee Break: Exhibition Floor						
3:40 - 4:20			WS_TU202: Hybrid Beamforming for Wireless Communication Systems (129) Mathworks	WS_TU304: PCB Material Design Choices and Their Impact on Thermal Management (140) Rogers Corp.	PA_TU305: PANEL: Designing and Testing 5G Components/Systems Today	CT_TU306 (2 papers): Get Ready for mmWave in Production Test (89), NI & Techniques for Extending Microwave Frequency Instruments for mmWave Measurements (136), NI		Poster Session: Exhibition Floor 3 - 4 p.m.
4:30 - 6:00		Plenary Session: Room 302/304						
7:00 - 10:00		Welcome Reception for Conference Attendees (Badge & Ticket Required)						

EDI CON 2016

Wednesday, September 21, 2016

Room	201	202	203	207	208	209	
8:00 - 5:00	On-Site Registration						
	General Technical Sessions						
	IoT Track	Signal Integrity/ Power Integrity Track	RF/MW Design Track	Modeling Track	Systems Track	Measurement Track	
9:00 - 9:30	WE_101: Maximizing Wireless Communications Energy Efficiency (45) E. McCune, Eridan Communications	WE_102: High-Speed Signal Integrity Measurements (52) V. Herrmann, R&S	WE_103: State-of-the-Art RF Design Technique for RF Switches to Maintain Near Constant Impedance When Switching RF Ports (101) M. Schrepferman, IDT	WE_104: In-Situ Antenna/ Circuit Simulation for Scanned Antenna Arrays (41) J. Dunn, NI	WE_105: Planar Active Antennas: Approaches to Scaling to Higher Frequency (88) D. Carlson, MACOM	WE_106: Amplifier Testing with Envelope Tracking Technology (60) L. Wilson, R&S	
9:40 - 10:10	WE_201: The IoT for Connected Soldiers & Battlefield Security (38) L. Salman, ANSYS	WE_202: DDR4 and LPDDR4 Bus Level Signal Integrity Insight (24) J. Grosslight, Keysight Technologies	WE_203: The MATRICs RF-FPGA in 180nm SiGe-on-SOI BiCMOS (97) G. Flwelling, BAE Systems	WE_204: Hierarchical Chip/ System/Board Modeling With Circuit/EM Co-Simulation (43) J. Dunn, NI	TU_205: Design & Implementation of Visible Light Wireless Communication System for Audio Applications (1) A. Abousaada, Suk Ajoumaa Higher Institute	WE_206: Wideband Satellite Component Test Challenges (21) K. Cassacia, Keysight Technologies	
10:20 - 10:50	Coffee Break - Exhibition Floor						
	IoT Track	Signal Integrity/ Power Integrity Track	RF/MW Design Track	RF/MW: Amplifiers Track	Systems & SI Tracks	Measurement Track	
10:50 - 11:20	WE_301: Coexistence Testing in the World of IoT (57) L. Wilson, R&S	WE_302: Chip, Package and PCB Co-Design (111) R. Myers, Mentor Graphics	WE_303: Time Domain Gating of Microwave Component Responses Using Analog Techniques (77) T. Reeves, MathWorks	WE_304: 12 W, 2 to 18 GHz GaN on Diamond, MMIC with Embedded Cooling (99) C. Creamer, BAE Systems	WE_305: Evaluating Waveform Coexistence for 5G, Wireless and Radar Applications (11) G. Jue, Keysight Technologies	WE_306: Phase-Coherent Vector Signal Analyzer Systems for MIMO Applications (81) V. Fernandez, NI	
11:30 - 12:00	WE_401: Multi Physics Simulations of an Energy Efficient IOT-Based Smart Home (37) C. Blair, ANSYS	WE_402: Leveraging SerDes Design Flows for AMI Model Development (114) T. Westerhoff, SiSoft	WE_403: Characterization and Modeling of High Q Dielectric Resonator Loaded Cavity Design for RF/Microwave Oscillators (107) E. Liang, MCV Microwave	WE_404: Designing for Maximum PA Efficiency Using CAD Transistor Waveform Optimization (118) R. Pengelly, Prism Consulting NC	WE_405: Probe Loading Effects on Common High Speed Signals (63) J. Bartlett, Tektronix		
11:30 - 1:00	Lunch Break & Dedicated Exhibit Time - Exhibition Floor						
		Workshops and Panels				Sponsored Talks	Exhibition 10:00 a.m. - 5:00 p.m.
1:00 - 1:40			WS_WE103: Practical Antenna Design for Advanced Wireless Products (44) NI	FEATURED KEYNOTE: Invisibility Cloaks and Deflector Shields: Disappearing at Microwave's Frontiers (135) Nathan Cohen, Fractal Antenna	WS_WE105: The Communication System Architect's Guide to 5G Physical Layer Modeling (9) Keysight Technologies	CT_WE106 (2 papers): Next Generation Interconnect Cabling (95), Southwest Microwave & Simulation Apps Provide Unlimited Ways to Optimize Numerical Models (139), COMSOL	
1:50 - 2:30		WS_WE202: Overcoming the Evolving Test and Measurement Requirements of IoT Devices (143) Copper Mountain	WS_WE203: Fundamentals of Vector Network Analyzers (126) R&S	WS_WE204: From Wave-Based Load-Pull to Behavioral Nonlinear Models (123) ElectroRent	WS_WE205: A Flexible Testbed for 5G Waveform Generation & Analysis (10) Keysight Technologies	CT_WE206 (2 papers): A Programmable Delay Line? What's That? (127), Colby Instruments & Non-Linear and Noise Modeling of a 0.15um GaN Die Family (20) Modelithics Inc.	
2:40 - 3:20		WS_WE302: Test Soutions (141) Mini Circuits	WS_WE303: Minimizing Uncertainty in Noise Figure Measurements (80) NI	PA_WE103: Panel: Not Your Father's Oldsmobile: The Connected Car (144)	WS_WE305: 5G mmWave MIMO Channel Sounding (12) Keysight Technologies	CT_WE306 (2 papers): Crest Factor as a Figure of Merit for Communication Amplifiers (150) M. Diessner, Wireless Telecom Group and Additive Manufacturing Techniques for the Production of RF Components (151) Microwave Development Labs	
3:30 - 4:10	Dedicated Exhibition Time						
4:00 - 5:00	Happy Hour - Exhibition floor						
5:00 - 8:00	Geek A Palooza Reception (separate registration required) www.ediconusa.com/registration.asp						

EDI CON 2016

Thursday, September 22, 2016

Room	200	202	203	207	208	
8:00 - 3:00	On-Site Registration					
	All Day Seminar	RF/Microwave Design Track	Measurement Track	Radar/Defense Track	Signal Integrity/Power Integrity Track	
9:00 - 9:30	RF BACK TO BASICS Seminar, Keysight Technologies (Separate Registration Required)	TH_102: Reaching New Heights in Mixer Linearity with GaN MMIC Technology (115) C. Trantanella, Custom MMIC	TH_103: Impact of Test Equipment Calibration on Power Amplifier Characterization (34) M. Manaloto, Keysight Technologies	TH_104: Advances in Kilowatt UHF Radar Power Amplifiers With RF GaN Transistors Operating at 150 V (17) J. Walker, Integra Technologies	TH_105: How to Evaluate the Signal Integrity Performance for Your High Bandwidth Real-Time Oscilloscopes (30) M. Chong, Keysight Technologies	
9:40 - 10:10		TH_202: Software Controlled Narrowband Tunable Bandpass Filters for UHF Receivers (74) Y. Yigit, ASELSAN Inc.	TH_203: Simplifying Phase Coherent Signal Generation (58) L. Wilson, R&S	TH_204: 24 GHz Radar Technology Enable Next Generation Sensors (18) P. Walsh, ADI	TH_205: Using VNAs as a Tool for Signal Integrity in High Speed Digital Systems (35) T. McCaig, Anritsu	Exhibition 10:00 a.m. - 3:00 p.m.
10:20 - 10:50		Coffee Break - Exhibition Floor				
11:00 - 11:30			TH-303: Considerations for ADC Testing (61) L. Wilson, R&S	TH_304: Automotive Radar Systems - Radio Testing in the E-Band (50) K. Sander, R&S	TH_305: Modeling Ferromagnetic Components in Voltage Regulation Modules (VRM) (3) C. Warwick, Keysight Technologies	
11:30 - 1:00	Lunch Break & Dedicated Exhibition time - Exhibition Floor					
		Workshops & Short Courses				
1:00 - 1:40	RF BACK TO BASICS Seminar, Keysight Technologies (Separate Registration Required)	WS_TH102: Introduction to 802.11ax: High Efficiency Wi-Fi (83) NI	WS_TH403: A Single EM Simulation Tool for Integrating the Many Aspects of New Electronics Product Design (125) CST	WS_TH404: Highly Integrated Antenna Front-End Design for Radar, SATCOM and 5G (116) ElectroRent		
1:50 - 2:30 / 2:40 - 3:20		WS_TH202: From VHF to Ka-Band: LTCC, A Suitable Yet Challenging Technology for Both Passive and Active Components (142) Mini-Circuits	WS_TH503: Electromagnetic System Modeling - Concept and Reality (66) ANSYS	WS_TH204: Analyzing Wideband Signals in mmWave Bands (134) R&S		
3:20 - 5:00		SC_TH-602: Intuitive Microwave Filter Design With EM Simulation (36) D. Swanson	SC_TH603: Radiated Emissions - Product Evaluation and Pre-Compliance Testing (67) K. Wyatt	SC_TH604: Basics, Advances & Breakthroughs in Phased-Arrays, Radar and MIMO (121) E. Brookner	SC_TH605: Fundamentals of Power Integrity (106) S. Sandler & H. Barnes	

Details in this conference matrix were correct at the time of going to press. They are subject to change. For up-to-date information visit www.ediconusa.com.

EDI CON 2016

EXHIBITOR LIST

These booth numbers are complete as of July 7, 2016. Exhibitors in red have an ad in this issue.

A.J. Tuck Company 705
Accel-RF Instruments 428
Accurate Circuit Engineering 221
Ad Tech Ceramics 326
AEM 113
Agile Microwave Technology Inc. 210
Altair Engineering 111
Amplical Corp. 612
AmpliTech Inc. 710
Analog Devices 409
Anokiwave 208
Anritsu 121
Anritsu-SI ZONE SI8
ANSYS 408
Applied Thin-Film Products 328
AR RF/Microwave Instrumentation 606
ARC Technologies 613
Ardent Concepts 229
Artech House 302
AWR 313
B & Z Technologies 621
Barry Industries Inc. 610
Berkeley Nucleonics 622
Boonton 712
BSC Filters 720
CapeSym 109
Centerline Technologies 708
Colby Instruments SI7
COMSOL Inc. 510
Copper Mountain Technologies ... 715
CST-Computer Simulation Technology AG 515
dBm Corp Inc 713
Dow-Key Microwave 720
Dynamic Engineers Inc. 216
Dynawave Inc. 607
Electro Rent Corp. 615
EMSCAN 320
Essco Calibration Laboratory 228
Evans Capacitor Co. 115
Focus Microwaves 312
Fractal Antenna Systems 812
GEIB Refining Corp 214
GigaTest Labs 427
Gowanda Electronics 704
High Frequency Electronics 209
Holzworth Instrumentation 504
Instec 704
Integra Technologies 711
Integrated Device Technology (IDT) 213
International Manufacturing Services Inc. 223
Ion Beam Milling 620
IW Microwave Product Division .. 224
JFW Industries Inc. 509
K&L Microwave 720
Keysight EEsof EDA SI2
Keysight Technologies 321
L3 Narda - MITEQ 218
Lake Shore Cryotronics 327
Laser Services Inc 107
Lighthouse Technical Sales 816
LPKF Laser and Electronics 511
MACOM 309
Marki Microwave 305
Marvin Test Solutions 808
Massachusetts Bay Technologies. 105
Mathworks 810
Maury Microwave 521
Mentor Graphics Corp 527
Mercury Systems 826
Mician Inc 725
MicroFab 709
Microlab 712
Microtech 117
Microwave Communications Laboratories, MCLI 626
Microwave Development Labortories 329
Microwave Journal 201
Microwave Product Digest 225
Microwave Products Group 720
Millitech 721
Mini-Circuits 215
Mitsubishi Electric US 206
Modular Components National ... 605
MOSIS 429
National Instruments 313
NexTek 129
Noise XT 727
Noisecom 712
Noisewave 612
Nuhertz Technologies LLC 706
NXP Semiconductors 714
Ophir RF Inc. 529
Orban Microwave 820
Passive Plus Inc. 814
Pickering Interfaces 822
Pico Technology 729
Piconics Inc. 211
Planar Monolithics Industries Inc 804
Polar Instruments 127
Pole/Zero 720
PPG Aerospace-Cuming Microwave 624
Presto Engineering 324
Queen Screw & Mfg. Inc. 307
Reactel Inc. 404
Response Microwave Inc. 604
Richardson RFPD 806
Rogers Corp. 405
Rohde & Schwarz 413
Semiconductor Enclosures Inc. 610
SemiGen Inc. 505
Signal Integrity Journal 201
Signal Integrity Software Inc (SiSoft) SI1
SignalCore Inc 707
Smith's Microwave Subsystems .. 721
Sonnet Software 628
Southwest Microwave Inc. 212
SV Microwave 308
SW Filter Design 226
Synergy Microwave Corporation 306
Taconic 611
TDK- LAMBDA Americas HP Division 525
TechPlus Microwave Inc. 513
Tech-X Corp. 125
TECOM Industries 721
Tektronix Inc 506
Times Microwave Systems .... 204 & 207
TowerJazz 523
TRAK Microwave 721
Transline Technology Inc. 304
TTE Filters LLC 704
T-Tech Inc. 322
UltraSource Inc 824
UMASS Lowell ....
Weinschel Associates 205
Wenzel Assoc. 528
Werlatone Inc. 508
Wireless Telecom Group 712
X-Microwave 426
Yuetsu Seiki Co. Ltd. 227
Zentech Manufacturing 406

EDI CON 2016 FLOORPLAN

Hynes Convention Center, Boston, MA — Level 2

These booth numbers are complete as of July 11, 2016.

EDI CON 2016
Electronic Design Innovation Conference
Workshops & Exhibition

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The Global Specialty Foundry Leader

Media Partners:

interference technology

HIGH FREQUENCY ELECTRONICS

MICROWAVE ENGINEERING EUROPE

MPD MICROWAVE PRODUCT DIGEST

Wireless Design & Development

Organized by:

horizon house

Official Publications:

Microwave Journal

Signal Integrity Journal
Signal Integrity · Power Integrity · EMC/EMI

EDI CON 2016

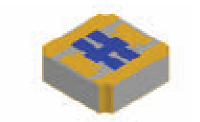
PRODUCTSHOWCASE

AISLES 100-200

The following booth numbers are complete as of July 6, 2016.

Massachusetts Bay Technologies — Booth 105

Attenuator Chips



Massachusetts Bay Technologies' aluminum nitride fixed attenuator chips are fabricated using its state-of-the-art thin film process and advanced photolithography technology. All devices are available in chip form with a metalized ground connection on the back. This ground is wrapped around on the four corners of the chip so additional ground bonding ribbon is not required. The chips may be attached using conductive epoxy or solder preform. Gold contacts on the input and output pads make assembly, using standard bonding equipment, fast and reliable. Custom values available on request.

www.massbaytech.com

CapeSym Inc. — Booth 109

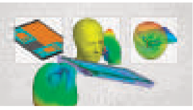
SYMMIC

Still waiting to learn how hot your newest design is? Stop waiting. Thermal analysis with SYMMIC frees you from dealing with complex geometric modeling, meshing and analysis packages. Easily assemble integrated circuits from pre-optimized analysis templates for the foundry process. Assemble MMICs into transmit/receive modules, and modules into subsystems. Analysis at any stage yields boundary conditions for earlier stages to accurately calculate FET junction temperatures. SYMMIC facilitates both steady-state and transient analysis inside your existing RF design tools.

www.capesym.com

Altair Engineering — Booth 111

FEKO Software Tool



FEKO, part of the Altair HyperWorks® suite, is a state-of-the-art computational electromagnetic simulation software tool that enables users to solve a wide range of electromagnetic problems. Typical applications include analyses of horns, radiation patterns and hazard zones, wire, reflector, conformal, and broadband antennas, microstrip patches, arrays, antenna placement and design. Analyses related to EMC (including shielding & cable coupling), RCS (scattering problems), waveguide structures (RF components), SAR extraction (bio-electromagnetics), and multiple dielectric layers (radomes) are also covered.

www.altair.com

AEM Inc. — Booth 113

Tin Whisker Mitigation Process

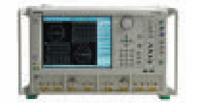
AEM's Tin Whisker Mitigation process utilizing tin-lead conversion with fusion processing ensures system reliability for mission critical programs. AEM's process is suitable for surface-mount chips, surface-mount molded body packages as well as other unique package styles. Components post tin-lead conversion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

www.aem-usa.com

Anritsu — Booth 121, SI8

VectorStar VNAs

VENDORVIEW



For applications ranging from microwave component testing to on-wafer device characterization, the VectorStar™ vector network analyzer family uses nonlinear transmission line (NLTL) technology to provide best-in-class performance — and it's only from Anritsu. Get the confidence you need in every VNA measurement. Visit Anritsu's Booth 121 and additional Booth SI8 in the Signal Integrity Zone at EDI CON USA.

www.anritsu.com/VectorStar

Tech-X Corp. — Booth 125

VSim

VSim is a high performance code using the FDTD method. VSim excels at solving large electromagnetic problems with complex materials. Also, VSim offers particle solutions for performing multipacting analysis and the solution of vacuum electron amplifiers such as klystrons and gyrotrons. In addition, VSim enables you to switch easily between 1, 2, or 3 dimensions to save time in performing your quick analysis.

www.txcorp.com/vsim

NexTek — Booth 129

Wideband Lightning and Surge Protection

NexTek is a leading manufacturer of coaxial RF surge arrestors for protection against lightning, HEMP/NEMP and ESD energy. One of NexTek's wideband solutions is the QWSNF-NF0600 device, an always-on quarter wavelength shorted stub design which provides unmatched surge performance and toughness along with an ultra-wide RF passband. NexTek, experts in coaxial RF surge protection, designs and builds everything it sells in the U.S. and provides a 10-year warranty. Contact NexTek directly for selection help or samples.

www.nextek.com

Mitsubishi Electric Corp — Booth 206

Transistor Modules

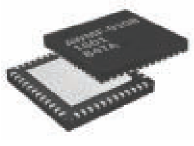
Mitsubishi Electric Corp. commercially launched new silicon RF high-output metal-oxide-semiconductor field-effect transistor (MOSFET) modules capable of automatic mounting on printed circuit boards of professional radio equipment. High-power amps for professional radio equipment commonly are mounted on their cabinets with screws. Product features include first automatic-mounting MOSFET module in the 60 W output class, optimized circuit design reduces size, weight and power consumption, and two module types available as a pair for professional radio equipment transmitters.

www.mitsubishielectric-usa.com

Anokiwave — Booth 208

Silicon Core ICs

VENDORVIEW



Anokiwave offers a family of silicon quad core AESA ICs at X- and K/Ka-Bands for 5G, commercial RADAR, SATCOM and A&D markets. Anokiwave's product portfolio of Si Core ICs and System-in-Package solutions allows its customers the fastest-time-to-market possible, with expert systems engineering and optimal technology solutions.

www.anokiwave.com

Agile Microwave Technology Inc. — Booth 210

Broadband 15 W Power Amplifier

Agile MwT's new broadband 15 W power amplifier operating from 2 to 18 GHz is offered in a bench top box or in a compact module configuration. AMT-A0350 provides Psat of 15 W with flat small signal gain of 43 dB typical, ±1 dB typical gain flatness with VSWR of 1.8:1 typical. The family of these PAs are competitively priced and ship from stock or short lead time. Agile MwT offers great value with some of the most innovative designs in the industry.

www.agilemwt.com

Southwest Microwave Inc. — Booth 212

SSBP High-Performance Multi-Port Cable Harnesses

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

www.southwestmicrowave.com

Integrated Device Technology (IDT) — Booth 213

RapidIO Switches

Need to connect clusters of embedded processors in a peer-to-peer network? IDT's portfolio of RapidIO switches delivers the ultra-low latency and scalability for speeding the movement and processing of data, meeting the needs of demanding applications like mobile edge computing, high-performance computing and data analytics. The company recently introduced its new 5G-ready RXS family of switches, with switching performance of up to 600 Gbps in a single switch or 4.8 Tbps at rack scale.

www.idt.com/go/srio

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from $68.95 ea. (qty.1-9)

Why do 10,000 customers trust Mini-Circuits test cables? Because they simply don't fail! Our test cables have been performance qualified to 20,000 flexures* and come backed by our 6-month product guarantee**, so you can be confident you're getting rugged construction, reliability, and repeatable performance you can depend on. Whether you're performing production test, burn-in, over-temperature testing, hi-rel testing – you name it – chances are there's a Mini-Circuits test cable for your application in stock, ready for immediate shipment. Order some for your test setup at minicircuits.com today, and you'll quickly find that consistent long-term performance, less retesting and fewer false rejects really add up to bottom-line savings, test after test!

	Model Family	Capabilities	Freq. (GHz)	Connectors†
	KBL	Precision measurement, including phase, through 40 GHz	DC-40	2.92mm
	CBL- 75+	Precision 75Ω measurement for CATV and DOCSIS® 3.1	DC-18	N, F
	CBL	All-purpose workhorse cables for highly-reliable, precision 50Ω measurement through 18 GHz	DC-18	SMA, N
	APC	Crush resistant armored cable for production floors where heavy machinery is used	DC-18	N
	ULC	Ultra-flexible construction, highly popular for lab and production test where tight bends are needed	DC-18	SMA
	FLC	Flexible construction and wideband coverage for point to point radios, SatCom Systems through K-Band, and more!	DC-26	SMA
NEW!	VNAC	Precision VNA cables for test and measurement equipment through 40 GHz	DC-40	2.92mm (M to F)

* All models except VNAC-2R1-K+

** Mini-Circuits will repair or replace your test cable at its option if the connector attachment fails within six months of shipment. This guarantee excludes cable or connector interface damage from misuse or abuse.

† Various connector options available upon request.

Contact apps@minicircuits.com to discuss your special requirements.

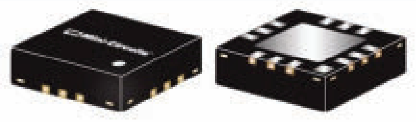
Mini-Circuits®

www.minicircuits.com P.O. Box 350166, Brooklyn, NY 11235-0003 (718) 934-4500 sales@minicircuits.com

EDI CON 2016

Mini-Circuits Booth 215

Wideband MMIC Balun Covers 2000 to 7000 MHz in 3 x 3 mm QFN



Mini-Circuits' MTX2-73+ is a wideband MMIC balun transformer with an impedance ratio of 2:1 covering a wide range of applications from 2000 to 7000 MHz. Fabricated using IPD process technology, this model provides outstanding repeatability with 0.6 dB insertion loss, 0.8 dB amplitude unbalance, 4° phase unbalance, and RF power handling up to +34 dBm (2.5 W). The unit comes housed in a 3 × 3 × 0.8 mm QFN package.

75 Ω MMIC Amplifier Supports DOCSIS® 3.1 Bandwidth Requirements

Mini-Circuits' PGA-122-75+ is a 75 Ω MMIC amplifier with a 40 to 1500 MHz frequency range, supporting a wide range of applications including DOCSIS 3.1 systems and equipment. This model provides 15.5 dB gain with ±0.1 dB flatness, +43 dBm IP3, +54 dBm IP2, 21 dB reverse isolation and 2.9 dB noise figure. It operates on a single 9 V supply and comes housed in a tiny SOT-89 package.

USB/Ethernet Controlled High-Sensitivity Power Sensors, 50 to 6000 MHz, -45 to +10 dBm

Mini-Circuits' PWR-6LRMS-RC is a USB/Ethernet controlled power sensor for high-sensitivity measurement of CW, multi-tone and modulated signals over frequencies from 50 to 6000 MHz with dynamic range from -45 to +10 dBm. The power sensor is provided with Mini-Circuits' user-friendly GUI control software which provides measurement averaging, time-scheduled measurements, and multi-sensor support (up to 24), as well as DLLs for 32- and 64-bit Windows® systems.

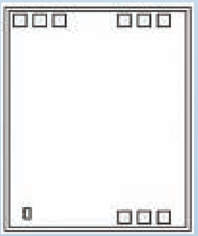
2-Way, 0° MMIC Splitter/Combiner Covers 0.5 to 9.5 GHz in 5 × 5 mm Package

Mini-Circuits' new EP2W1+ MMIC 2-way, 0° splitter/combiner offers an industry-leading combination of bandwidth and tiny size, covering applications from 0.5 to 9.5 GHz in a 5 × 5 mm QFN. The splitter/combiner provides low insertion loss (1 to 3.4 dB), 19 dB isolation, 0.1 dB amplitude unbalance and 3° phase unbalance. It handles up to 2.5 W RF input power as a splitter and has an ESD rating of HBM Class 2.

Wideband Surface-Mount Limiter, 30 to 3000 MHz, +17 to +30 dBm

Mini-Circuits' RLM-33H+ is a surface-mount limiter ideal for protecting sensitive receiver circuitry from unwanted high-power signals. This model has a frequency range from 30 to 3000 MHz and input power range from +17 to +30 dBm. It provides low output power of +18 dBm, 0.2 dB Δ output/1 dB Δ input, 16 ns recovery time, 0.23 dB insertion loss and 1.05:1 VSWR. The unit measures 0.25" × 0.31" × 0.16".

Wideband Double Balanced MMIC Mixer Die, Level 15, 2200 to 7000 MHz



Mini-Circuits' MDB-73H-D+ is a wideband double-balanced level 15 MMIC mixer die with an IF bandwidth from DC to 1600 MHz and LO/RF bandwidth from 2200 to 7000 MHz. This model provides 9 dB conversion loss, 46 dB L-I isolation, 35 dB L-R isolation and good input/output return loss over its full frequency range without the need for external matching components. Available in gel-paks, partial and full production wafers.

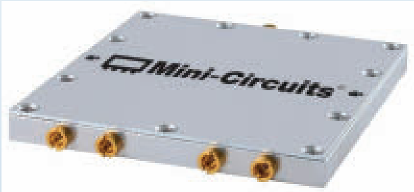
Connectorized High-Pass Filter Provides Passband from 3800 to 6000 MHz

Mini-Circuits' ZFHP-3800+ is a connectorized high-pass filter with a passband from 3800 to 6000 MHz supporting a variety of transmitter/receiver applications. This model provides low passband insertion loss of 1 dB, high stopband rejection of 27.3 dB, and RF input power handling of 2 W. The filter comes housed in a compact aluminum alloy case (1.25" × 1.25" × 0.75") with SMA connectors.

Coaxial Triplexer Separates C-Band and L-Band Input Signals

Mini-Circuits' ZTPL-4620+ is a coaxial (SMA) triplexer with a lowpass channel-1 from 9.8 to 10.2 MHz, bandpass channel-2 from 852 to 1872 MHz, and highpass channel-3 from 3300 to 4620 MHz. This model is ideal for separating C-Band and L-Band signals on the common port and routing them non-interactively to separate output ports. It also routes a 10 MHz reference signal on the fourth port to the common port.

Ultra-Thin, 4-Way, 0° Splitter/Combiner Accommodates Tight Layouts, 500 to 3000 MHz



Mini-Circuits' ZN4PD-33SMP+ is a 4-way 0° splitter/combiner covering the 500 to 3000 MHz band with 0.9 dB insertion loss, 22 dB isolation, 0.2 dB amplitude unbalance and 3° phase unbalance. It handles up to 10 W RF input power as a splitter and 1.0A DC current (250 mA each port). The splitter comes in an ultra-thin aluminum alloy case measuring 3.10" × 3.28" × 0.30" with blind mate SMP snap-on connectors.

X4 Surface-Mount Multiplier Produces Output Signals from 3600 to 4400 MHz

Mini-Circuits' RKK-4-442+ ×4 frequency multiplier converts input frequencies from 900 to 1100 MHz into output frequencies from 3600 to 4400 MHz. This model achieves low conversion loss of 24.5 dB with high rejection of unwanted harmonics (F3, 23 dBc; F5, 31 dBc). It provides RF input power range from +19 to +23 dBc, and comes housed in a miniature shielded surface-mount package (0.50" × 0.50" × 0.18").

VENDORVIEW
www.minicircuits.com

EDI CON 2016

PRODUCT SHOWCASE AISLES 200-300

Dynamic Engineers Inc. — Booth 216

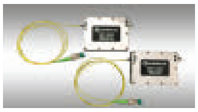
Low Power, High Stability OCXO

Dynamic Engineers is now offering a new line of ultra low power, low noise, and highly stable OCXOs from Magic Xtal. The M037/14L, MX037/14 and MX037/8 series feature a height profile as low as 8 mm with a frequency range of 8 to 300 MHz. Typical warm-up time is 30 s and power consumption is less than 180 mW. Stability over temperature can attain less than 1 ppb over -40°C to +85°C, and daily aging can reach less than 0.1 ppb per day.

www.dynamiceng.com

L3 Narda-MITEQ — Booth 218

Low Cost, Low Noise Fiber-Optic Link



L-3 Narda-MITEQ announced a new low noise fiber-optic link product, the SBL-3000. The SBL fiber-optic transmitter and receiver was designed for customers looking for low cost, high performance fiber-optic links for analog and digital applications such as antenna remoting and interfacility data links. The SBL-3000 components are plug and play with a frequency range of 10 to 3000 MHz and 110 dB/Hz2/3 SFDR.

www.nardamiteq.com

Accurate Circuit Engineering — Booth 221

3D PCB

Accurate Circuit Engineering is proud to announce the first 3D PCB. Most printed circuit boards are 2D and flat with a milled area or cavity. ACE using it's unique routing, milling and beveling Technology has successfully produced a circuit board that actually has a 3D topography. There is nothing mounted or attached to the PCB shown here it is all machined and plated at ACE. See this unique and exciting PCB technology at Booth 221.

www.ace-pcb.com

International Manufacturing Services Inc. — Booth 223

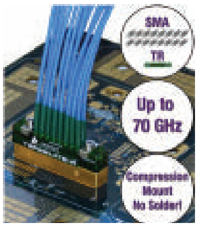
Partial Wrap Resistors

IMS' partial wrap resistors are industry leaders in high frequency performance. However, they were only available in low power versions – until now. Announcing the new IMS partial wrap resistors on aluminum nitride (AlN). These new AlN partial wraps offer the same excellent high frequency performance as their alumina counterparts combined with the superior thermal performance of AlN. Instead of trading-off high frequency performance for power handling, or vice versa, you can now have both. No frequency trade-off. No power trade-off. Request your sample today.

www.ims-resistors.com

Ardent Concepts — Booth 229

TR Multicoax Series

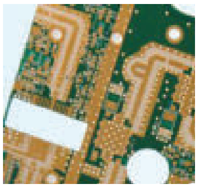


TR Multicoax series delivers superior signal integrity from multiple GHz channels. With a choice of 20 GHz, 40 GHz or 70 GHz configurations, all using the same footprint, users can upgrade their connectors as data rate requirements of their applications increase. TR is the highest-density high speed multicoax connector on the market. The interface is compression-mount and can be reused across programs which drives lower total cost of testing by avoiding costly solder-down components, like SMAs, that cannot be recovered.

www.ardentconcepts.com

Transline Technology Inc. — Booth 304

RF/Microwave, Hybrid and Standard Printed Circuit Boards

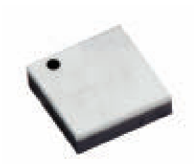


Transline serves the RF, microwave, aerospace, defense, medical and satellite industries among others, to create solutions for ever-advancing concepts and designs. Features and services include RF and microwave applications, hybrid and exotic materials, oversized (large) PCBs, FEP bonding and fusion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

www.translinetech.com

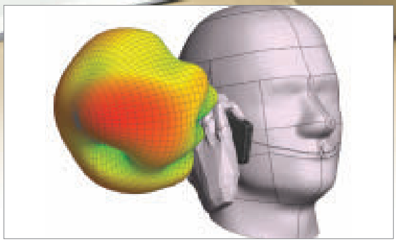
Marki Microwave — Booth 305

T3 MMICs

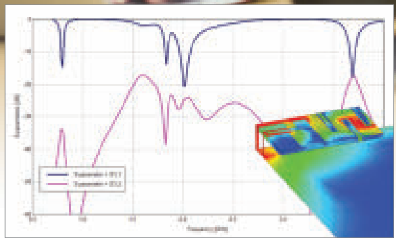


Since 2013 Marki Microwave has offered small form factor chip style double balanced mixers such as the Microlithic® and MMIC lines of mixers that cover from 1 GHz to 67 GHz. Now Marki is proud to introduce the new MT3 line of small form factor, high linearity mixers. These integrated mixers offer the high linearity (IP3, P1dB, spurious suppression) and low conversion loss of the T3, but with the size and production scaling benefits of a MMIC.

www.markimicrowave.com



Radiation pattern optimization



Multiport antenna matching

SAR & OTA compliance verification

Synergy Microwave Corp. — Booth 306

Phase Locked Ultra Low Noise Signal Sources

Synergy Microwave Corp. introduces a series of ultra-low phase noise, fixed-frequency, phase-locked DRO oscillators (PLDRO). The KSFLOD1280-12-1280 is a 12.8 GHz fixed frequency, source which, when locked to a low noise reference at 1200 MHz, will deliver exceptional phase noise of -96 dBc/Hz at 100 Hz offset and -158 dBc/Hz at 10 MHz offset. This source is packaged in a 2.25" × 2.25" module housing and includes lock alarm. Options are available to 15 GHz and extendable to 30 GHz.

www.synergymwave.com

SV Microwave — Booth 308

High Density, High Performance Precision Connections

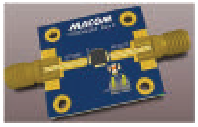
Looking for subminiature high density, high performance solutions? Check out SV Microwave's complete line of SMP, SMPM and SMPS products. Features include Blindmate design for quick installation, COTS versions readily available, cable connectors for 0.047, 0.065, 0.085, conforms to MIL-STD-348, board mounts, edge launch, adapters, VITA 67, tape and reel packaging availablability, and DC to 40 GHz (SMP), DC to 67 GHz (SMPM), DC to 100 GHz (SMPS).

www.svmicrowave.com/products/search

MACOM — Booth 309

Octave Tuning VCO

VENDORVIEW



MACOM introduces new 10 to 20 GHz octave tuning voltage controlled oscillator for the test and instrumentation market space. The MAOC-415000 offers excellent phase noise performance, typically -100 dBc/Hz at 100 kHz offset. The part draws 70 mA total current from a 5 V supply, and operates over the tune voltage range 0 to 20 V. Output power is 3 dBm with excellent pushing and pulling performance. The MAOC-415000 is available in a 4×4 mm package and operates over the -40° to +85 C° temperature range.

www.macom.com

Focus Microwaves — Booth 312

RAPID Digital Tuner

The RAPID digital tuner is the heart of a precision, high-speed, load-pull device characterization system. It has been developed by Focus' UK subsidiary MESURO and is suitable for every phase of the design and production test cycle. This series of new digital tuner products provide performance, reliability and cutting edge features. The RAPID can be used as a stand-alone impedance synthesis and measurement system, or combined into a hybrid solution when paired with Focus' MPT series harmonic tuners.

www.focus-microwaves.com

National Instruments — Booth 313

Second-Generation Vector Signal Transceiver

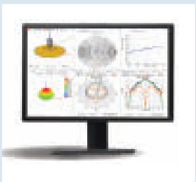
VENDORVIEW

NI's recently released second-generation VST combines a 6.5 GHz RF vector signal generator, 6.5 GHz vector signal analyzer, high-performance user-programmable FPGA and high-speed serial and parallel digital interfaces into a single 2-slot PXI Express module. With 1 GHz of bandwidth, the latest release of the VST is ideally suited for a wide range of applications including 802.11ac/ax device testing, mobile/Internet of Things device testing, 5G design and testing, RFIC testing, radar prototyping and more.

www.ni.com

NI AWR — Booth 313

AntSyn™



AntSyn™ is an evolution in antenna design. A cloud-based, SaaS automated antenna design, synthesis, and optimization tool, AntSyn operates on a "what you want is what you get" principle. The user inputs the antenna requirements rather than a (parameterized) physical design and the software produces antenna designs as outputs. AntSyn was designed by antenna engineers to be used by all levels of experience, from experts to those who are relatively new to antenna design.

www.ni.com/awr

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EDI CON 2016 PRODUCT SHOWCASE AISLES 300-400

EMSCAN — Booth 320
ERX+

EMSCAN's ERX+ enables the PCB and design engineers to diagnose EMC/EMI problems between 150 kHz and 8 GHz. ERX+ provides 7 levels of resolution (110 microns to 7.5 mm). Level 1 resolution (7.5 mm) allows the engineers to visualize the hot spots, current loops or intermittent problems) in real-time. After locating the unintended radiators, engineers can select the resolution level based on the density of their board design. The built-in spectrum analyzer turns ERX+ into a plug-and-play test system.

www.emscan.com

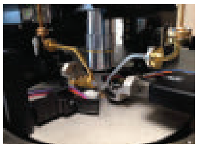
Keysight Technologies Inc. — Booth 321
5G Waveform Generation and Analysis

VENDORVIEW

Keysight's 5G waveform generation and analysis testbed reference solution combines hardware, software and measurement expertise providing the essential components of a flexible 5G waveform generation and analysis test platform. Its flexibility allows broad "what if?" analysis to evaluate proposed waveforms with prototype algorithms and hardware. It can easily create waveforms at RF, microwave and mmWave frequencies with modulation bandwidths of up to 2 GHz, allowing engineers to evaluate early concepts that use a variety of modulation schemes at different frequencies and bandwidths.

www.keysight.com/find/solution-5Gtestbed

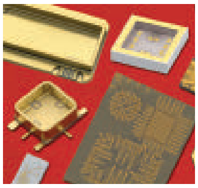
Presto Engineering — Booth 324
Wafer Level RF Test Services



Presto Engineering's services cover all aspects of test—test plan development to hardware and software development, to validation, correlation, ramp and production. Their application coverage extends from DC to microwave and millimeter wave, up to 100 GHz.Capabilities include all major ATE brands, digital, analog, RF and advanced RF, E, V, Ka/Ku-Band, frequency domain, time domain (Bert), CMOS and SiGe, GaAs, InP and GaN.

www.presto-eng.com

AdTech Ceramics — Booth 326



AdTech Ceramics offers custom HTCC microwave packages and hermetic feedthroughs for high-reliability applications including microwave spectrometry, high power and high frequency applications up to 95 GHz. Capabilities include electromagnetic and thermal modeling and simulation for microwave packages in the X- through W-Band frequency ranges. AdTech's manufacturing facility has a 45+ year history of designing, tooling and manufacturing multilayer ceramic packages and feedthroughs and includes a custom design center. The U.S. based company is AS9100C and ISO 9001:2008 certified.

www.adtechceramics.com

Lake Shore Cryotronics — Booth 327
Cryogenic Probe Stations

Lake Shore Cryotronics' industry-leading cryogenic probe stations enable DC, RF or microwave measurements at temperatures as low as 1.6 K and in fields to over 2 T for early-stage device research. Plus, Lake Shore is now offering on a pre-order basis, a new, unique THz probe arm option. Designed for precise on-wafer probing of millimeter wave devices at 75 to 110 GHz and 140 to 220 GHz frequencies, it allows calibrated S-parameter and other high-frequency measurements to be performed in a cryogenic environment.

www.lakeshore.com

Applied Thin-Film Products — Booth 328
Microstrip Transmission Lines Engineering Kits

Applied Thin-Film Products (ATP) is pleased to offer new microstrip transmission lines engineering kits to help your bread-boarding needs with a cost effective solution. Engineering kits are readily available on .005" (0.127 mm), .010" (0.254 mm), .015" (0.381 mm), .020" (0.508 mm), .025" (0.635 mm) thick ss-fired alumina. Each engineering kit contains a variety of single transmission lines with or without tuning pads, in lengths of 0.50" (1.270 mm), .075" (1.905 mm), .100" (2.540 mm), .125" (3.175 mm), .150" (3.810 mm), .200" (5.080 mm), .250" (6.350 mm) and .500" (12.700 mm).

www.thinfilm.com

Reactel Inc. — Booth 404
RF & Microwave Filter, Multiplexer and Multifunction Assembly

VENDORVIEW

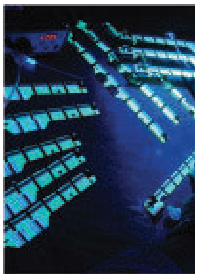
Visit Reactel in Booth 404 to see their latest RF and microwave filter, multiplexer and multifunction assembly offerings. Their booth will feature high performance notch filters which are perfect for co-location interference issues. While speaking to Reactel's engineers, be sure to inquire about their entire line of application specific surface mount, connectorized and high power filters covering up to 50 GHz.

www.reactel.com

EDI CON 2016

Zentech Manufacturing — Booth 406

RF Manufacturing Process

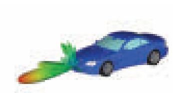


Zentech's senior management team has broad experience in the RF, defense, medical and telecom industries. Providing RF product realization services from concept through full life cycle management, Zentech has a proven track record of successful RF programs in a variety of disciplines. Zentech operates out of an ITAR registered, ISO compliant, 42,000 sq. ft. facility in Baltimore, Md. Zentech is an engineering-driven, agile facility equally experienced in new product introduction (NPI) and program level manufacture of RF assemblies.

www.zentech.com

ANSYS — Booth 408

ANSYS HFSS



ANSYS HFSS, the industry standard 3D full wave electromagnetic field simulation software, includes advancements that will allow you to dominate your wireless communication competitors. New features include antenna synthesis, design and processing; encrypted 3D components with patent-pending hidden and encrypted design; and new high frequency solvers for antenna placement and radio frequency interference (RFI) diagnosis. See why this highly automated and collaborative wireless design flow is ideal for designing IoT devices, wearable electronics, 5G, UAV and automotive radar and more.

www.ansys.com

Analog Devices Inc. — Booth 409

AD9162 D/A Converter

VENDORVIEW

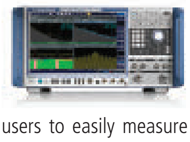
The new AD9162 D/A converter provides broadband and wireless service operators with the industry's highest bandwidth and dynamic range to satisfy rising consumer demand for higher quality, always-on data and video streaming without requiring expensive, large-scale architecture or converter design changes. Also, the new AD9164 D/A converter allows designers of military and commercial radar and precision instrumentation equipment to lower system cost and complexity by eliminating FPGAs and other digital circuitry and software previously required to rapidly switch across multiple frequency channels.

www.analog.com

Rohde & Schwarz — Booth 413

Phase Noise Analyzer

VENDORVIEW



The R&S FSWP phase noise analyzer and VCO tester enables ultra sensitive and ultra-fast phase noise measurements. It allows users to easily measure pulsed sources and additive phase noise of RF components and signal sources such as generators, synthesizers and oscillators more quickly than with any other solution. With up to 50 GHz, the extremely low phase noise of its local oscillator and cross-correlation the FSWP performs complex measurements that in the past required complex test setups with just a push of a button.

www.rohde-schwarz.com

X-Microwave LLC — Booth 426

Online Nonlinear System Simulator

X-Microwave offers an online nonlinear system simulator that is powered by Keysight's Genesys Spectrasys. Simulate with hundreds of models of real system components using the intuitive user interface. X-parameter or S-parameter models are extracted from X-Microwave 's drop-in components (X-MWblocks) using Keysight's PNA-X analyzer. An X-parameter model of an amplifier serves as a live data sheet to determine the P1dB or IP3 at a given operating point of interest.

www.xmicrowave.com

Gigatest Labs — Booth 427

GTL-5050 Probing Platform

Gigatest Labs designs and manufactures precision probing systems and microwave probes for signal integrity applications. The GTL-5050 probing platform allows for testing a wide range of structures from flex-circuits to multi-ple-board-interconnects, BGAs, test sockets, PCBs and back-planes. The 5050 system's remote-positioner control and HDMI video, offers a superior level of precision in the placement of test probes on the test structure, and improving accuracy in the measuement process. Visit Booths 427 and 526 to discuss your SI requirements

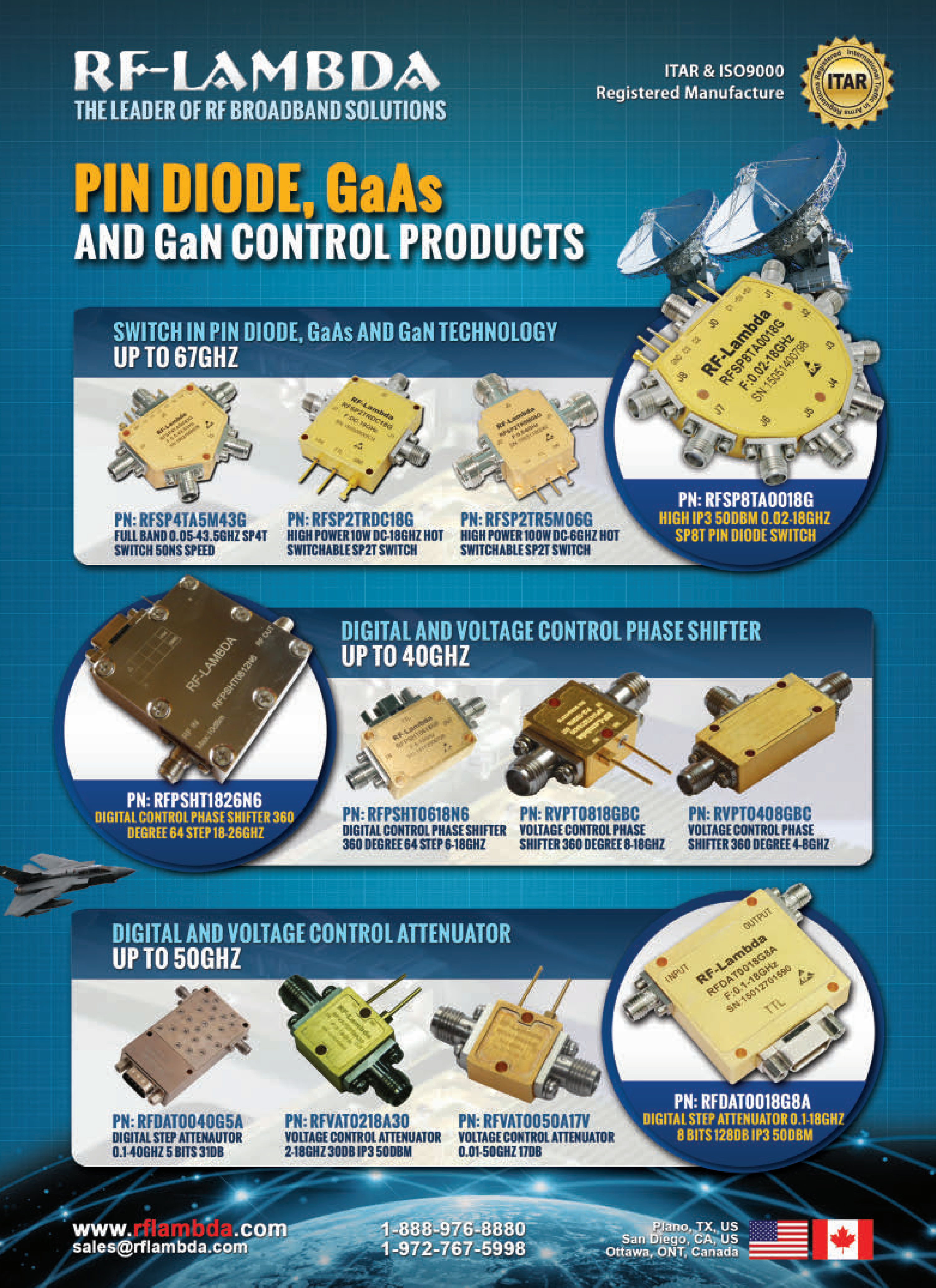
www.gigatest.com

Accel-RF Instruments — Booth 428

Automated Accelerated Reliability Test Systems

Accel-RF offers the world's only line of fully integrated, modular platform, plug-and-play, completely automated accelerated life test systems. These systems deliver an unbeatable combination of capabilities needed for accelerated-aging and parametric testing of RF semiconductor devices. The company's millimeter wave Automated Accelerated Reliability Test Systems (AARTS) and fixture solutions are available in standard frequency ranges from 26.5 to 67 GHz. Accel-RF's customers receive maximum return-on-investment (ROI) through reduced product development time, demonstrated reliability, and increased "permission-to-play" market opportunities.

www.accelrf.com



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

EDI CON 2016

MOSIS — Booth 429

Prototype and Volume-Production

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

www.mosis.com

Holzworth — Booth 504

HSX Series RF Synthesizers

Holzworth's new 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), spectral purity of better than -85 dBc (spurious), and output power dynamic range of +20 dBm to -110 dBm (0.01 dB of resolution). User defined configurations from 1 to 4 independently tunable RF outputs provide the best performance-to-price ratios in industry. 6 GHz models are currently available with 12 GHz and 20 GHz models available by late 2016.

www.holzworth.com

SemiGen Inc. — Booth 505

Semiconductor Diodes and Passive Products

VENDORVIEW

SemiGen introduces a new line of semiconductor diodes and passive products. Their PIN, limiter, beam lead PIN, Schottky, step recovery and point contact diodes along with their capacitor, attenuator and additional passive thin-film products will be released in a new product catalog available in September 2016. The catalog will cover data and available designs of the company's semiconductor products as well as their assembly and testing services.

www.semigen.net

Tektronix Inc. — Booth 506

Mixed Domain Oscilloscope

Tektronix will be showcasing the MDO4000C mixed domain oscilloscope that includes up to six built-in instruments, each with exceptional performance to address tough challenges. Every MDO4000C features powerful triggering, search and analysis, and these are the only scopes to offer synchronized analog, digital and RF signal analysis at the same time — ideal for wireless communications in IoT and EMI troubleshooting. The MDO4000C is completely customizable and fully upgradable to enable engineers to add the instruments as needed.

www.tektronix.com

Werlatone Inc. — Booth 508

SMT RF Components

Werlatone® has recently expanded its line of surface mount and drop-in directional couplers, in-phase combiners, and hybrid combiners. Concentrating on wider bandwidths at higher power levels, Werlatone's designs are compact, low loss, and offer conservative power ratings. Their newest 90° quadrature design, model QH10541, covers the full 700 to 6000 MHz band; rated at 100 W CW. Measuring just 0.66" × 0.86" × 0.09", the QH10541 operates with excellent amplitude balance and less than 0.5 dB of insertion loss.

www.werlatone.com

JFW Industries Inc. — Booth 509

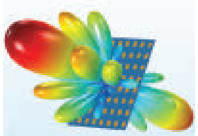
Rotary Attenuators

Introducing JFW's newest family of manual, rotary attenuators, now offering more attenuation than ever before at 3 GHz and beyond. The single-rotor, 50R-397 is DC to 3 GHz with 0 to 70dB in 10 dB steps; while their benchtop assembly, the 50BR-147 allows for up to 110 dB in 1 dB increments. This family also includes two versions of JFW's versatile dual-rotary attenuators, which can be easily integrated into RF systems for OEM or test applications.

www.jfwindustries.com

COMSOL Inc. — Booth 510

The RF Module



The RF Module, an add-on product to COMSOL Multiphysics® software, is used by designers of RF and microwave devices to model antennas, waveguides, filters, circuits, cavities and metamaterials. By simulating electromagnetic wave propagation and resonant behavior, engineers are able to compute electromagnetic field distributions, impedance, S-parameters, far field radiation pattern and power dissipation. With COMSOL Multiphysics® engineers are able to extend their model to include multiple physics effects such as temperature rise, structural deformations and fluid flow.

www.comsol.com/rf-module

LPKF Laser & Electronics — Booth 511

ProtoLaser S4 Laser System

The LPKF ProtoLaser S4 laser system uses a green laser wavelength and can laser etch PCBs in minutes on a wide range of laminated substrates, FR4 and PTFE or woven PCB materials. Prototypes and small production batches can also be produced on short notice if required The LPKF ProtoLaser S4 is even more precise than the mechanical systems and is therefore ideal for HF and microwave circuits, as well as digital and analog circuits.

www.lpkf.com

TechPlus Microwave Inc. Booth 513

1U High VHF Duplexer

The TM1003 is a 1U High VHF duplexer operating between 135 to 172 MHz. TechPlus Microwave Inc. is a state-of-the-art, innovative, RF/microwave filter supplier specializing in economical, high quality microwave filters and assemblies. Their capabilities include small and large production runs utilizing state-of-the-art test equipment. TechPlus manufactures filters, duplexers and multiplexers for all of the wireless protocols, as well as spread spectrum for point-to-point, point-to-multipoint to 40 GHz.

www.techplusmicrowave.com

CST-Computer Simulation Technology AG Booth 515

CST STUDIO SUITE®

VENDORVIEW

The electromagnetic simulation software CST STUDIO SUITE® is the culmination of many years of research and development into the most accurate and efficient computational solutions for electromagnetic designs. It comprises CST's tools for the design and optimization of devices operating in a wide range of frequencies—static to optical. Analyses may include thermal and mechanical effects, as well as circuit simulation.

www.cst.com

Maury Microwave Booth 521

Measurement and Modeling Device Characterization Solutions

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

www.maurymw.com

TowerJazz Booth 523

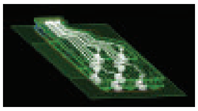
Integrated Circuits

TowerJazz's industry leading RF SOI technology, coupled with its advanced design enablement tools that include modeling of the substrate, are ideally suited for designing low insertion loss and highly linear multi-throw switches, and LNAs with very low noise figures and high linearity. TowerJazz also offers a new integrated SiGe-based "FEM-on-a-Chip" RF BiCMOS platform tailored to meet the challenges of IoT and other wireless applications by enabling PAs, LNAs and switches on a single chip.

www.towerjazz.com

Mentor Graphics Booth 527

HyperLynx® Full-Wave Solver



Mentor Graphics' HyperLynx® full-wave solver delivers unprecedented speed and capacity, through accelerated boundary element technology, while preserving gold-standard Maxwell accuracy. Achieve greater accuracy and fewer re-spins, even on the most complex structures.

www.mentor.com/pcb

Wenzel Associates Inc. Booth 528

Multiplied Crystal Oscillator

The typical multiplied crystal oscillator (MXO) is comprised of Wenzel's industry-leading VHF ultra low noise OCXO integrated with several low noise multiplier stages. Options such as phase locking (PLL) can also be specified on some models to phase lock to an external reference. The golden multiplied crystal oscillator series (GMXO) offers the same options as the MXO series oscillators, but provides superior phase noise performance. Wenzel's latest ultra-low noise oscillator technology and special multiplier stages are combined in the golden series products to allow a phase noise floor improvement of up to 10 dB.

www.wenzel.com

Ophir RF Inc. Booth 529

RFPA System

Using the latest in GaN technology, Ophir RF introduces model 5294 (700 to 6000 MHz, 100 W). This RFPA system achieves very high linearity, and delivers full power even into poor load conditions. As with all Ophir RF amplifier systems, model 5294 comes with a standard three year warranty.

www.ophirrf.com

AR RF/Microwave Instrumentation — Booth 606

Solid-State Pulsed Amplifiers

VENDORVIEW

For automotive and military EMC radiated immunity susceptibility testing, as well as radar and communication applications, there is now a very attractive alternative to traveling wave tube amplifiers (TWTAs). AR's new offerings include various frequency ranges and output power levels to meet several standards, or designs can be tailored to suit your specific application. These amplifiers feature a touchscreen control panel, GPIB interface, TTL gating, fault monitoring and forced air cooling.

www.arworld.us

Dynawave — Booth 607

ArcTite™ Assemblies

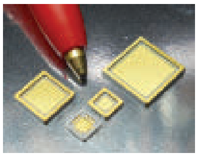
Dynawave's new ArcTite™ series cable assemblies provide tight bend radius capability without the need for added strain relief shrink boots. ArcTite™ assemblies can provide less than a 0.54" (13.7 mm) height from connector reference plane to the top of the bent cable. Ideal for high density packaging, these assemblies are available with SMA straight plugs or SMA bulkhead jacks connectors in both 0.086 and 0.141 cable sizes. ArcTite™ assemblies have consistent (-100 dB) shielding and low VSWR through 26.5 GHz.

www.dynawave.com

Barry Industries Inc. — Booth 610

HTCC Air-Cavity Quad-Flat-No-Lead (QFN) Packages

VENDORVIEW



Barry Industries introduces their line of hermetically sealable HTCC Quad-Flat-No-Lead (QFN) packages with air cavity for high frequency applications. These QFN packages are available in six sizes from 3 mm to 8 mm with standard JEDEC MO-220 footprints. They feature broadband low-loss transitions for superior performance over frequency. Maximum insertion loss is 0.5 dB from DC to 18 GHz, 1.5 dB from 18 to 35 GHz and 4 dB from 35 to 40 GHz. HTCC construction provides for enhanced mechanical strength and higher thermal conductivity compared with LTCC packages.

www.barryind.com

Amplical Corp. — Booth 612

PIN Diode Switches

Amplical Corp.'s family of broadband coaxial PIN diode switches feature low insertion loss, low VSWR high isolation, and fast switching speed. Standard configurations range from single-pole, single-throw (SPST) through single-pole, 12-throw (SP12T). All switches are available with either absorptive or reflective inputs operating over ultra-broad bandwidths up to 20 GHz. Amplical offers complete electrical and mechanical customization for all standard models as well as your application-specific requirement up to 40 GHz, including unlimited number of throws, high power, hermetic seal and MIL/hi-rel screening.

www.amplical.com

NoiseWave — Booth 612

Amplified Noise Source

NoiseWave announces the immediate availability of the NW3G-M amplified noise source. The NoiseWave NW3G-M features broadband frequency coverage from 10 MHz to 3 GHz. The NW3G-M offers 0 dBm output power with spectral flatness of ± 2.0 dB. The unit is internally regulated and operates from +15 Vdc and typically draws less than 120 mA. The NoiseWave NW3G-M comes standard with an sma output connector and is in a small low profile housing 4" × 1"× 0.5".

www.noisewave.com

ARC Technologies Inc. — Booth 613

Engineer's Survival Kit

ARC Technologies is the leading supplier of RF and EMI absorbing materials. Whether you are facing problems at 10 MHz or 110 GHz, near field or far field, narrowband or broadband, ARC Technologies has the right solution, offering a variety of standard and custom products. Their FREE Engineer's Survival Kit (ESK) offers samples of several popular products that no RF or electrical engineer should be without.

www.arc-tech.com/engineers-survival-kit/

Electro Rent Corp. — Booth 615

Design Software

When you need test equipment you need to decide "what" but also "justify" that new expense. Electro Rent's product showcase focuses on solving real-world testing problems both technically and financially. Design software new to Electro Rent: IMST, Germany, offer unique software design tools, specializing in radio technologies and microelectronics. Digital Testing: as RF signals get faster and more complex, new digital testing techniques are necessary. Electro Rent offers the most RF/microwave instruments in inventory.

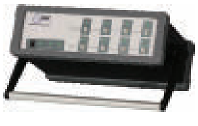
www.electrorent.com

EDI CON 2016 PRODUCT SHOWCASE AISLES 600-700

Berkeley Nucleonics Corp. — Booth 622

Signal Generator

VENDORVIEW



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

www.berkeleynucleonics.com

PPG Aerospace-Cuming Microwave — Booth 624

Microwave Absorbers

PPG Aerospace-Cuming Microwave is a manufacturer of microwave absorbers for cavity suppression and free space applications. Its featured product is C-RAM™ RGD-S, an iron filled silicone rubber microwave absorber with a high magnetic loss. It is available in three grades: -117, -124 and -192. C-RAM™ RGD-S can be used for lowering the Q of cavities and eliminating unwanted resonances. Other products include: C-RAM™ Lossy Foams and Elastomeric Flat Sheet Absorbers, C-RAM™ Anechoic & Free-Space Materials, C-RAM™ Turnkey Anechoic & EMC Chamber Design and Installation, and C-STOCK™ Low Loss Dielectric Materials. Custom formulations and fabrications are available. Email cmc-sales@ppg.com or call (508) 521-6700.

www.cumingmicrowave.com

Sonnet Software — Booth 628

Sonnet Suites Release 16

Sonnet Software maintains a single, dedicated focus on providing the industry's most accurate and reliable high frequency electromagnetic (EM) software. Sonnet recently premiered Sonnet Suites Release 16, featuring speed increases in larger projects, new integration with the Modelithics® CLR Library for Sonnet, and additional new features that give users more control and automation. Sonnet Suites targets today's demanding design challenges involving predominantly planar (3D planar) circuits and antennas, including spiral inductors, filters, microstrip, stripline, co-planar waveguide, and both PCB and integrated circuits incorporating layers of stratified dielectric material.

www.sonnetsoftware.com

Gowanda Electronics — Booth 704

Broadband Conicals to 5A DC

Gowanda Electronics will feature new component designs including the C550FL series of high-current, thru-hole, wirewound broadband conical inductors providing a current rating to 5A DC. As with Gowanda's other conicals, the new series provides predictable frequency response and repeatable performance from 40 MHz to 40 GHz and is specifically designed for high frequency applications where ultra-low insertion loss is a design requirement. Gowanda Electronics' conicals and RF & power inductors, Communication Coil's custom magnetics, TTE's RF & microwave filters and Instec's EMI/RFI filters will all be on display; all are affiliates of Gowanda Holdings.

www.gowanda.com

TTE Filters — Booth 704

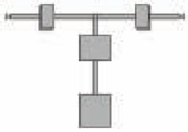
Bias Tees to 40 GHz

TTE's bias tees are now available for frequencies from 10 MHz to 40 GHz and current handling to 7A DC. They offer superior broadband performance, low insertion loss, minimal return loss, desirable VSWR characteristics, extremely flat gain response and RoHS-compliant options. TTE's RF & microwave filters are available to 26 GHz, featuring built-to-order lead times as short as 3 to 5 days. TTE's filters, Gowanda Electronics' conicals and RF & power inductors, Communication Coil's custom magnetics and Instec's EMI/RFI filters will all be on display; all are affiliates of Gowanda Holdings.

www.tte.com

Nuhertz Technologies LLC — Booth 706

FilterSolutions®



Nuhertz Technologies introduces a version of FilterSolutions.® Version 14.4.1 features the design of inverted microstrip filters in suspended substrate, with overlay capacitors utilizing interlaced resonators to achieve coupling. The approach removes the need for vias. The sample filter shown is a nine-pole interlaced high-pass Chebyshev. The design is shown after synthesis by FilterSolutions, without post-processing or optimization. Rapid Sonnet or Axiem port-tuning is supported. Nuhertz will present this version at Booth 706.

www.nuhertz.com

SignalCore Inc. — Booth 707

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 10kHz 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. Full implementation instructions and GUI included. Available in USB, SPI, RS-232, and PXIe.

www.signalcore.com

Centerline Technologies — Booth 708

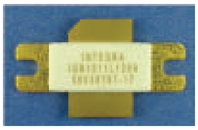
Glass and Ceramic Materials

Centerline Technologies will be showcasing beveled, grooved, slotted and diced glass, fused silica and ceramic materials. Centerline's recently expanded diamond sawing capabilities provide superior edge quality using optical alignment and provides tighter tolerances (accuracy ±.0003" repeatability within .0001"). Centerline subdivides fully patterned substrates with computer programmed auto recognition software. Other services on display will include lapping, polishing, laser machining, diamond sawing, back-lapping, and filled via planarity process. Centerline is dedicated to providing the highest quality services at the greatest value possible.

www.centerlinetech-usa.com

Integra Technologies Inc. — Booth 711

1200W GaN Transistor

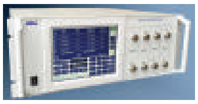


Integra Technologies Inc. (ITI), a designer and manufacturer of high-power RF transistors, pallets and amplifiers, announced the release of a 1200 W GaN transistor, IGN1011L1200, for IFF avionics applications. The IGN1011L1200 operates over the instantaneous bandwidth of 1.03 to 1.09 GHz. Under ELM Mode S (48 × (32µs on, 18µs off), 6.4%) pulsing conditions, it supplies a minimum of 1200 W of peak output power with typically >17dB gain and 75% efficiency from a 50 V supply voltage. The IGN1011L1200 transistor is available immediately for sampling.

www.integratech.com

dBm Corp Inc. — Booth 713

Advanced Channel Emulator



dBmCorp Inc. will release its Advanced Channel Emulator (ACE), an ultra-high bandwidth (600 MHz) high fidelity test platform for radio/satellite link, multipath fading and payload emulation. The ACE can emulate changing delays, carrier/signal Doppler, phase shift, link attenuation and sophisticated multipath (up to 12 paths at 600 MHz bandwidth per channel) for emulating all types of wireless and COM links. Programmable group delay, phase offset, AM/AM & AM/PM nonlinearity and amplifier gain compression/distortion may be emulated in real-time.

www.dbmcorp.com

NXP Semiconductors — Booth 714

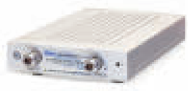
GaN Power Transistor

NXP introduces the high performance A2G26H281-04S in-package asymmetric Doherty GaN RF power transistor for 2496-2690 MHz targeting current and next-generation cellular base stations. This product enables NXP customers with an average RF output power of 50 W (288 W peak), gain of 15.3 dB and drain efficiency of 57% configured in a NI-780S-4L air-cavity ceramic package. The A2G26H281-04S GaN device offers superior performance at higher frequencies which is key to the expanding 4G LTE deployments and emerging 5G marketplace.

www.nxp.com/RFgan

Copper Mountain Technologies — Booth 715

Vector Network Analyzer



Copper Mountain Technologies' S5065 is a highly compact lab-quality USB vector network analyzer for S-parameter measurements from 9 kHz to 6.5 GHz. It is capable of >138 dB dynamic range typ. (1 Hz IF) and measurement time per point of 60 µs, min typ. Thanks to its unmatched portability, S5065 can be shared easily within a team or brought to test sites.

www.coppermountaintech.com

Dow-Key Microwave — Booth 720

Standard Matrix Summary

Designed for microwave, RF and audio test applications in the DC to 18 GHz frequency range, Dow-Key's standard matrix product line includes standard configurations ranging from 1 × 100 to 12 × 12. Packaged in a self-contained 19" rack-mountable enclosure and provided with remote interfaces such as RS232, RS-422, GPIB, USB and Ethernet along with a touchscreen LCD front panel display or keypad for manual override. Dow-Key uses its own line of coaxial switches for these matrices, providing low loss and excellent isolation.

www.dowkey.com

K&L Microwave — Booth 720

Ultra-miniature Lumped Element Filters

Ultra-miniature lumped element filters provide reduced size and weight while affording ultimate flexibility. Bandpass, lowpass, highpass and notch filters, including elliptic and pole placed designs are available in very small surface mount packages. Integrated covers assure performance in sizes typically less than 0.2" wide by 0.15" tall. Join K&L at Booth 720 to discuss your custom requirements.

www.klmicrowave.com

Pole/Zero Corp. — Booth 720

Extended Range Filters

Pole/Zero is showcasing the production release of its new NANO-ERF® series of extended range filters that covers the entire 30 to 520 MHz tuning range in a single 28 × 28 × 0.216 mm surface-mount package. Tuning speeds are 25 μsec typical, 35 μsec max with inband RF power handlings of +6 dBm. Pole/Zero's complete product line includes tunable filters, integrated cosite equipment and low noise and cosite power amplifiers.

www.dovermpg.com/polezero

Millitech — Booth 721

E-Band Linear-Circular Polarizer

Millitech's E-Band linear-circular polarizer boasts a low axial ratio of < 0.6 dB, low insertion loss of < 0.5 dB, and can be optimized for any frequency you require from 18 to 110+ GHz. With over two times the bandwidth of similar products and an industry leading axial ratio performance, this polarizer is a first of its kind.

www.millitech.com

Planar Monolithics Industries Inc. — Booth 804

PMI A Series Amplifiers

VENDORVIEW

PMI's A-Series amplifiers are available low noise, medium power and lost cost designs and operate over the 10 MHz to 40 GHz frequency range. These new models feature form fit & function design, low noise figure, operating temp: -54° to +85°C, unconditionally stable over temperature, excellent group delay and phase linearity, field replaceable SMA connectors, internal DC regulated voltage and internal reverse polarity protection available options temperature compensation, phase & amplitude matching, phase and amplitude tracking, gain /frequency slope and input limiter protection. Custom designs welcome.

www.pmi-rf.com/Products/amplifiers/PMI-A-Series-Amplifiers.htm

Richardson RFPD — Booth 806

Specialized Electronic Component Distribution

VENDORVIEW

Richardson RFPD, an Arrow Electronics company, is a specialized electronic component distributor providing technical expertise and global design support for the latest products from leading suppliers of RF, wireless, energy and power technologies. Richardson RFPD offers the newest products from leading suppliers of RF and wireless technologies to more than 10,000 customers, through their sales team of engineering experts. The company supports the design efforts of RF engineers in markets such as A&D, cellular infrastructure, ISM, CATV, T&M and IoT/M2M.

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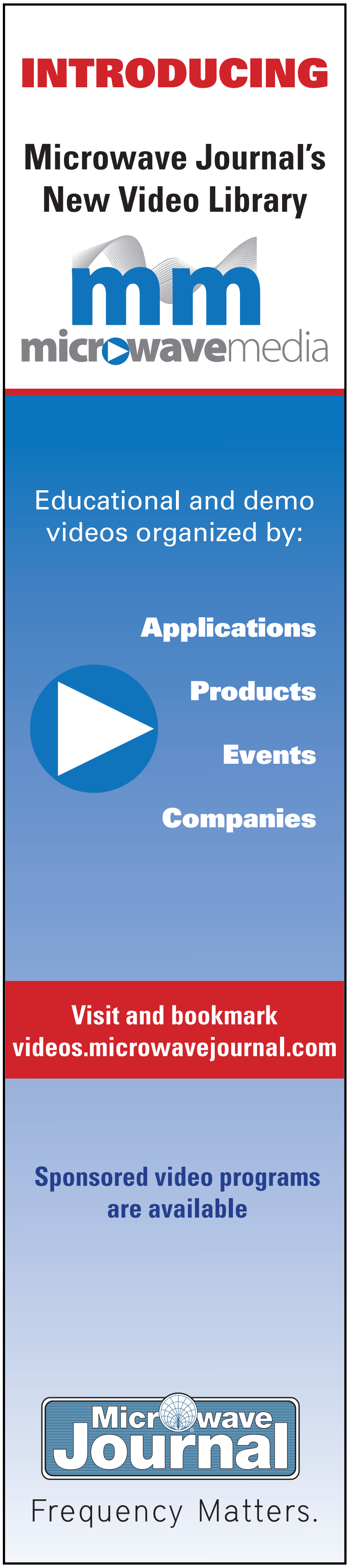


Marvin Test Solutions — Booth 808

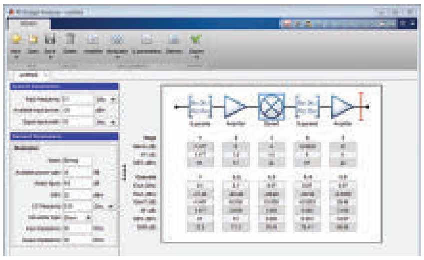
TS-960 Semiconductor Test System

The TS-960 semiconductor test system from Marvin Test Solutions is an integrated test platform that takes full advantage of the PXI architecture to provide capabilities comparable to proprietary ATE systems in a compact footprint. The TS-960 is available in benchtop and integrated manipulator configurations for both package and wafer test. Offering 20 PXI slots and a receiver that supports digital and RF resources, the TS-960 can support a wide range of digital and RF capabilities.

www.marvintest.com

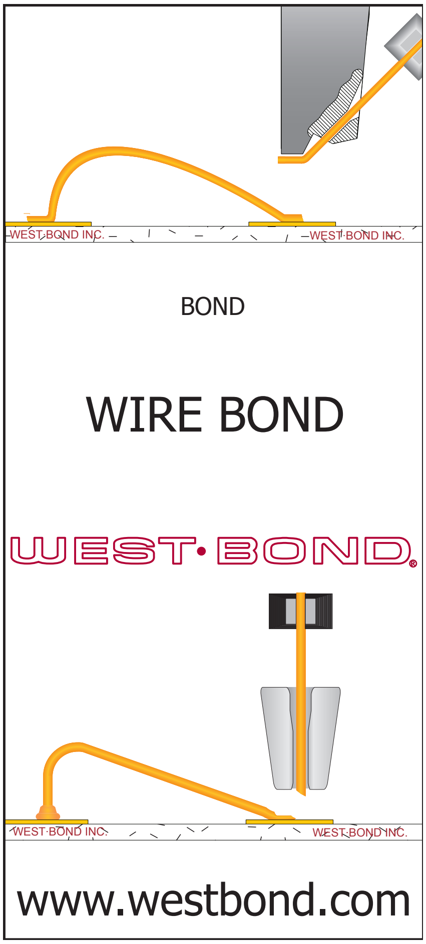
MathWorks — Booth 810

RF Budget Analyzer



The RF Budget Analyzer in RF Toolbox helps engineers design RF front-ends and get started with RF modeling and simulation. This helps teams efficiently iterate between system-level specifications and implementation of architectural designs, and reduces time spent in debugging validation test benches. Engineers can rapidly build executable specifications of the RF front-end and integrate the results into a system-level simulation. This allows for help with validation of behavior and, by facilitating sharing, supports collaboration with colleagues, suppliers and customers.

www.mathworks.com



Passive Plus Inc. — Booth 814

RF/Microwave Passive Components

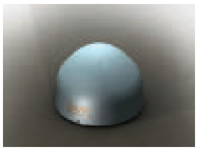
VENDORVIEW

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

www.passiveplus.com

Orban Microwave — Booth 820

Antennas



Orban Microwave designs and manufactures a wide range of antennas for various applications such as GPS, avionics, medical and satcom covering VHF to Ka-Band. One of our strengths regarding GPS antennas is our wide variety of existing designs like choke ring antennas, rover antennas and passive and active antennas that can be integrated in GPS receivers. Orban Microwave offers the latest in technology, custom built to your specifications.

www.orbanmicrowave.com

Pickering Interfaces — Booth 822

PXI Microwave Multiplexer Modules

VENDORVIEW

Pickering's multiplexers have a characteristic impedance of 50 Ω and are capable of switching signals up to 40 GHz. Available in single, dual or triple, SP6T or SP4T formats, they are suitable for constructing complex microwave switching networks. These multiplexers are compatible with any PXI chassis and can be used in Pickering's LXI Modular Chassis for users preferring control via an Ethernet port. Connection is by a high performance front panel mounted SMA or SMA-2.9 connectors.

www.pickeringtest.com

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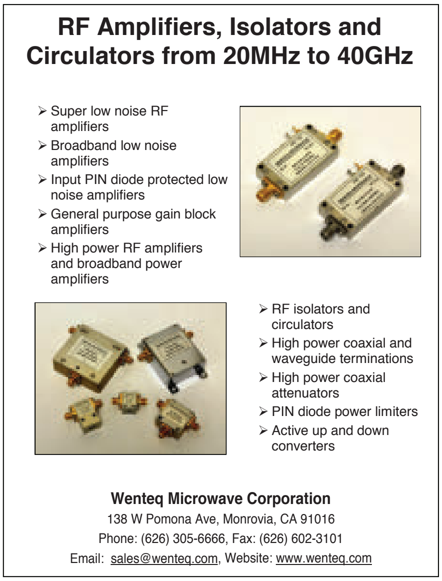

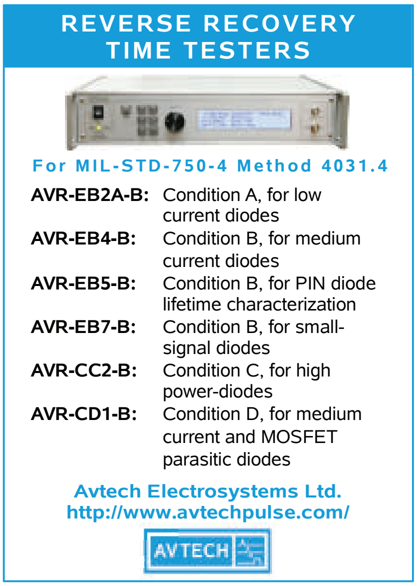

Mercury Systems — Booth 826

OpenRFM™ Rapid Development Capability

OpenRFM™ is a modular open systems architecture approach that standardizes the electromechanical, software, control plane, and thermal interfaces. Based on the OpenRFM™ architecture, Mercury and X-Microwave have created an ecosystem of hundreds of pre-engineered RF/microwave elements that facilitate the rapid development and prototyping of complex designs. Elements are laid out creating the RF design which can then be simulated, prototyped and verified. It is then packaged in an OpenRFM™ pre-engineered brick. Workshop at EDICON USA September 20 at 1:30 p.m.

www.mrcy.com

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The IEEE Microwave Theory and Techniques Society's 2017 International Microwave Symposium (IMS2017) will be held 4 - 9 June 2017 at the Hawai'i Convention Center in Honolulu, Hawai'i as the centerpiece of Microwave Week 2017. IMS2017 offers technical sessions, interactive forums, plenary and panel sessions, workshops, short courses, industrial exhibits, application seminars, historical exhibits, and a wide variety of other technical and social activities including a guest program. As usual, the Microwave Week 2017 technical program also comprises the RFIC Symposium (**www.rfic-ieee.org**) and the ARFTG Conference (**www.arftg.org**).

With over 8000 participants and 500 industrial exhibits of state-of-the-art microwave products, Microwave Week is the world's largest gathering of radio-frequency (RF) and microwave professionals and the most important forum for the latest research advances and practices in the field. IMS2017 offers something for everyone:

- The first-ever IMS Hackathon and IMS 3-Minute Presentation Competitions
- A 5G Summit showcasing next-generation wireless technologies
- An Executive Forum to discuss the latest in 5G and Internet of Things (IoT)
- RF Boot Camp – a three-quarter day course on RF/microwave basics
- The first-ever IMS Exhibitor Workshops for exhibitors to present the technology behind their products
- Networking events for Young Professionals and Women in Microwaves
- Student Design, Student Paper, Best Industry Paper, and Best Advanced Practice Paper Competitions
- Project Connect for under-represented minority engineering students, and the PhD Student Initiative for new PhD students
- *Teaching that inspires...students that aspire* – an exciting STEM program exposing middle school and select high school students, as well as their teachers, to RF/microwave technology

IMS2017 will include a comprehensive portfolio of events featuring recent 5G developments, including a plenary session, focus session, workshops, panel session, and a technology-development pavilion.

Paper Submission: Authors are invited to submit technical papers describing original work and/or advanced practices on RF, microwave, millimeter-wave, and terahertz (THz) theory and techniques. The deadline for submission is 5 December 2016. A double-blind review process will be used to ensure anonymity for both authors and reviewers. Detailed instructions on submitting a double-blind compliant paper can be found at **www.ims2017.org**. Papers will be evaluated on the basis of originality, content, clarity, and relevance to IMS.

Emerging Technical Areas: IMS2017 enthusiastically invites submission of papers that report state-of-the-art progress in technical areas that are outside the scope of those specifically listed in this Call for Papers, or that may be new to IMS, but are of interest to our attendees.

Workshops, Short Courses, Focus and Special Sessions, Panel and Rump Sessions: Topics being considered for these areas include Next-Generation Wireless Systems (5G and beyond), Internet of Space, Latest Technologies for RF/Microwave Measurements, and Advances in RFIC Technology. Please consult **www.ims2017.org** for a more detailed list of topics and instructions on how to prepare a proposal. Proposals must be received by 6 September 2016.

MicroApps and Exhibitor Workshops: The Microwave Application Seminars (MicroApps) serve as a forum for IMS exhibitors to present technology behind their commercial products and special capabilities. New for IMS2017 are Exhibitor Workshops, which offer IMS exhibitors a chance to present in-depth technical topics, via two-hour sessions, in a meeting room off the exhibit floor. Both presentation formats are open to all conference and exhibit attendees – MicroApps are free of charge and Exhibitor Workshops require a nominal fee. Please visit **www.ims2017.org** for details on submitting MicroApps and Exhibitor Workshop presentation ideas.

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5G Spectrum and Standards

Geoff Varrall

This book is a miracle. As author Geoff Varrall recounts, unlike each of the previous cellular generations, which took five years to develop, 5G's gestation is being compressed into two years so that it can be proudly demonstrated at the 2018 Winter Olympics in South Korea. Jumping into this frenzy, Varrall seeks to tell the story of 5G spectrum and standards — before they are fully defined. So he presents the options and considerations, and he does an amazing job, given the compressed writing and publishing schedule. Among the topics addressed: the physical layer candidates (modulation, coding and multiplexing), the frequency bands allocated for 4G and possible bands for 5G, the process for allocating spectrum and coexistence issues.

Counter to how we typically think about spectrum, Varrall argues that 5G ought to be considered by wavelength, not frequency, since wavelength "determines the form factor and functional performance of RF devices." Using this taxonomy, he groups the physical layer options into three categories: the meter band (300 MHz to 3 GHz), the centimeter band (3 to 30 GHz) and the millimeter wave band (30 to 300 GHz). For each, he discusses services using the same bands and the RF considerations for 5G radio links. The chapter on the millimeter wave band, for example, spans from smart adaptive arrays and beam forming to RF power amplifier transistors, filters and substrate materials.

It's not all about RF, though. Throughout its history, cellular has stood on the shoulders of digital signal processing. Varrall devotes a chapter to how Moore's and Gene's Laws have enabled the industry and the relationship between increasing channel bandwidth and the current performance of analog-to-digital converters and digital signal processors.

You would think that covering 5G is enough. Yet the final chapter teases that it is not the final frontier, that future generations will expand to 3D radio access networks (adding satellites) and use terahertz and optical signals. To learn about these, you'll have to wait for Varrall's next book — hopefully published at least a few years after the 2018 Winter Olympics.

To order this book, contact:

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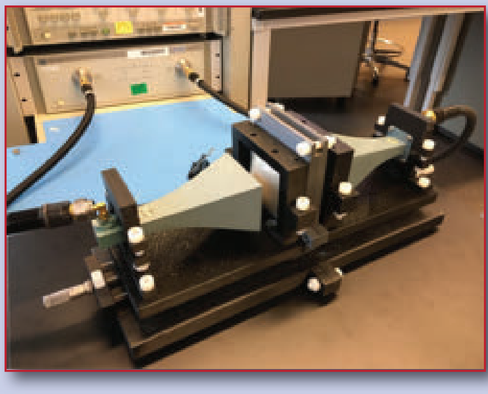
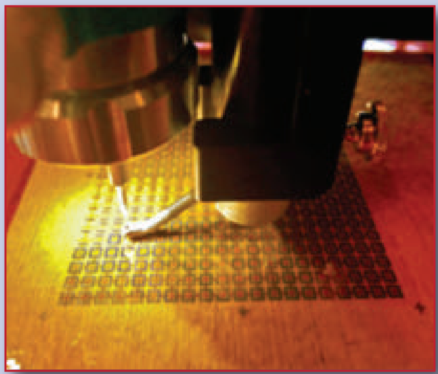
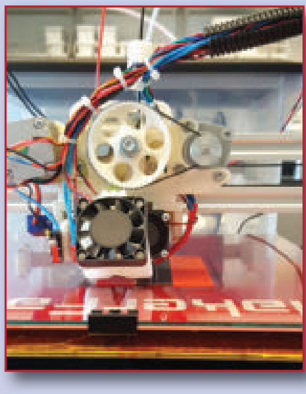
UMass Lowell Sees the Future – Printed Electronics







As Dustin Hoffman's character in "The Graduate" was famously told, "I just want to say one word to you. Just one word. Plastics." But in this case, it's actually three words — 3D printed plastics.

The Printed Electronics Research Collaborative (PERC) at the University of Massachusetts in Lowell has established a world-class Additive Manufacturing and Printed Electronics research center rooted in real-world applications. PERC is developing innovative circuits such as frequency selective surfaces, antennas, phased arrays and tunable devices printed on plastic materials, with a focus on RF and microwave applications. The center is a strategic partnership between industry, university and government. It includes companies of all sizes, public and private universities, as well as DoD and New England partners who will help strengthen and expand the region's capabilities in printed and flexible electronics.

Raytheon Co. is the leading sponsor and recently dedicated the Raytheon-UMass Lowell Research Institute (RURI), a joint research facility focused on the advancement of innovative technologies including flexible and printed electronics. RURI serves as a launch pad for collaboration and learning among UMass Lowell faculty, students and Raytheon employees (some are right on site). PERC has eight corporate sponsors: Raytheon, Rogers Corp., BAE, Micro Chem, FLEXcon, Creative Materials, SI2 Technologies and TSI. These projects leverage various academic departments (electrical engineering, plastic engineering, mechanical engineering) and other research centers (e.g., nanomanufacturing) for a truly interdisciplinary effort.

The lab is set up to design, fabricate and characterize materials and prototype devices quickly. If a design does not work, the CAD model is easily modified and the next device can be made in hours. This completely changes the paradigm in electronics prototyping compared to developing an expensive mask set and waiting months to get a wafer lot run processed in a fab. A major objective of PERC is to develop a future supply chain for printed electronics.

The facility is made up of five labs occupying 8,000 square feet of space, including modeling, printing, microwave test, antenna characterization, and packaging and subsystem integration labs. The modeling lab primarily uses the ANSYS suite of software tools and commonly simulates across many tools such as EM, and mechanical and thermal solvers. The work is very hands-on, with much of the action in the printing lab, where various 2D and 3D printers are buzzing, including a custom 3D printer designed and built by students. One student explained how commercial 3D printers do not work well with unusual plastic filaments — particularly the electrically conductive filaments — because they are more thermally conductive than standard plastic filaments, which tend to gum up the extruders in commercial 3D printers. So he built a 3D printer from scratch, creating the parts he needed using another 3D printer. He replaced the brass nozzles with stainless steel and redesigned some other parts like the feeding mechanism. The students also built their own anechoic chamber.

PERC uses commercially available conductive plastics as a seed material for electroplating, selectively plating areas on complicated geometries by printing the conductive plastic only on the areas to be plated and using normal non-conductive plastics for the other areas. The most important material that PERC has developed is a ferroelectric ink that enables varactors to be printed onto their circuits for tunable applications such as tunable FSS and phased arrays. No other organization has this material. They have also printed coplanar waveguide structures and 3D antennas, plus developed a process for printing flat structures onto 3D objects, which would enable circuits or antennas to be printed onto objects. PERC is an innovative cooperative doing leading edge development in additive manufacturing and printed electronics. Look for more innovation to come.

https://www.uml.edu/Research/PERC

2016

Military Microwaves

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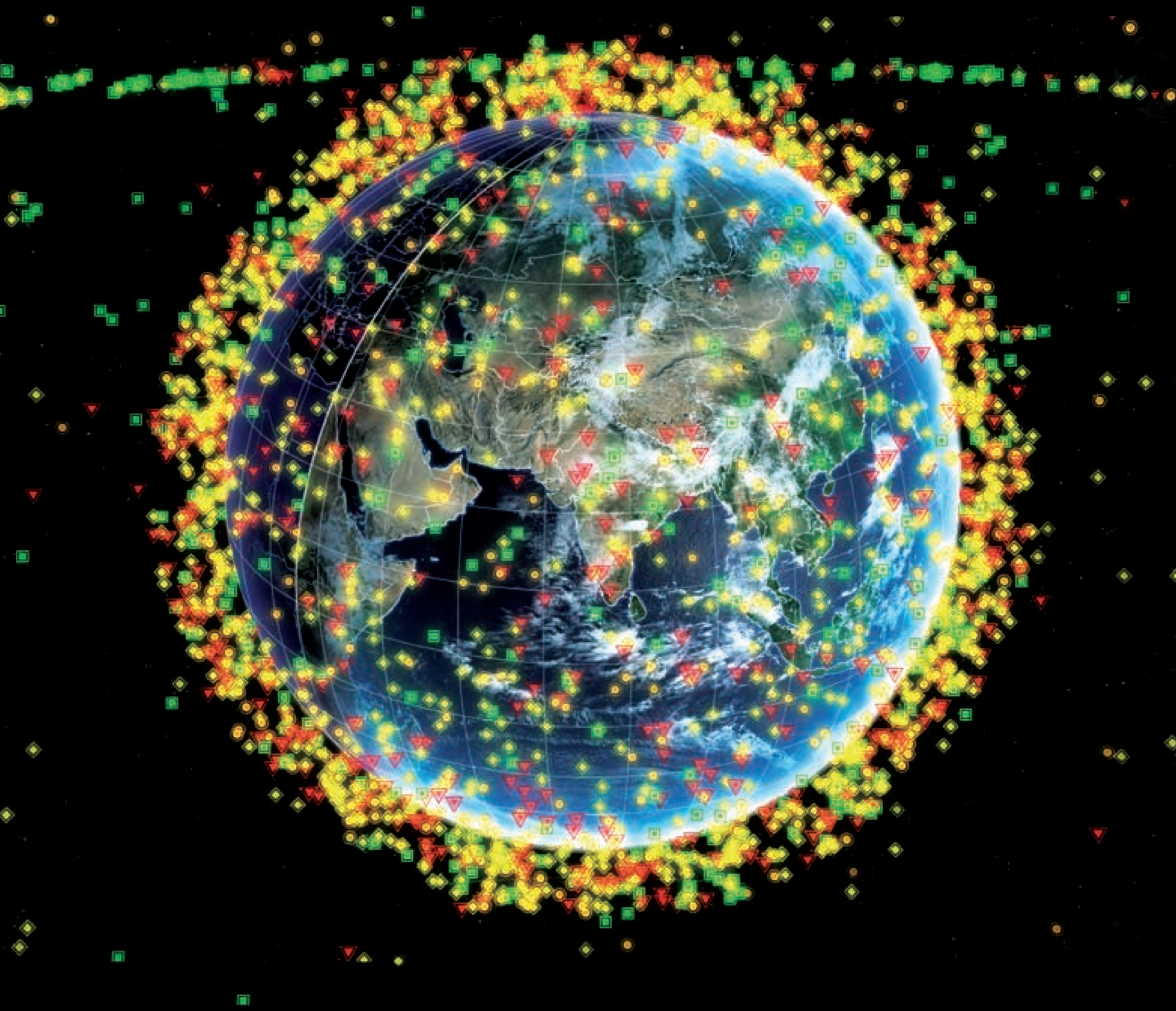

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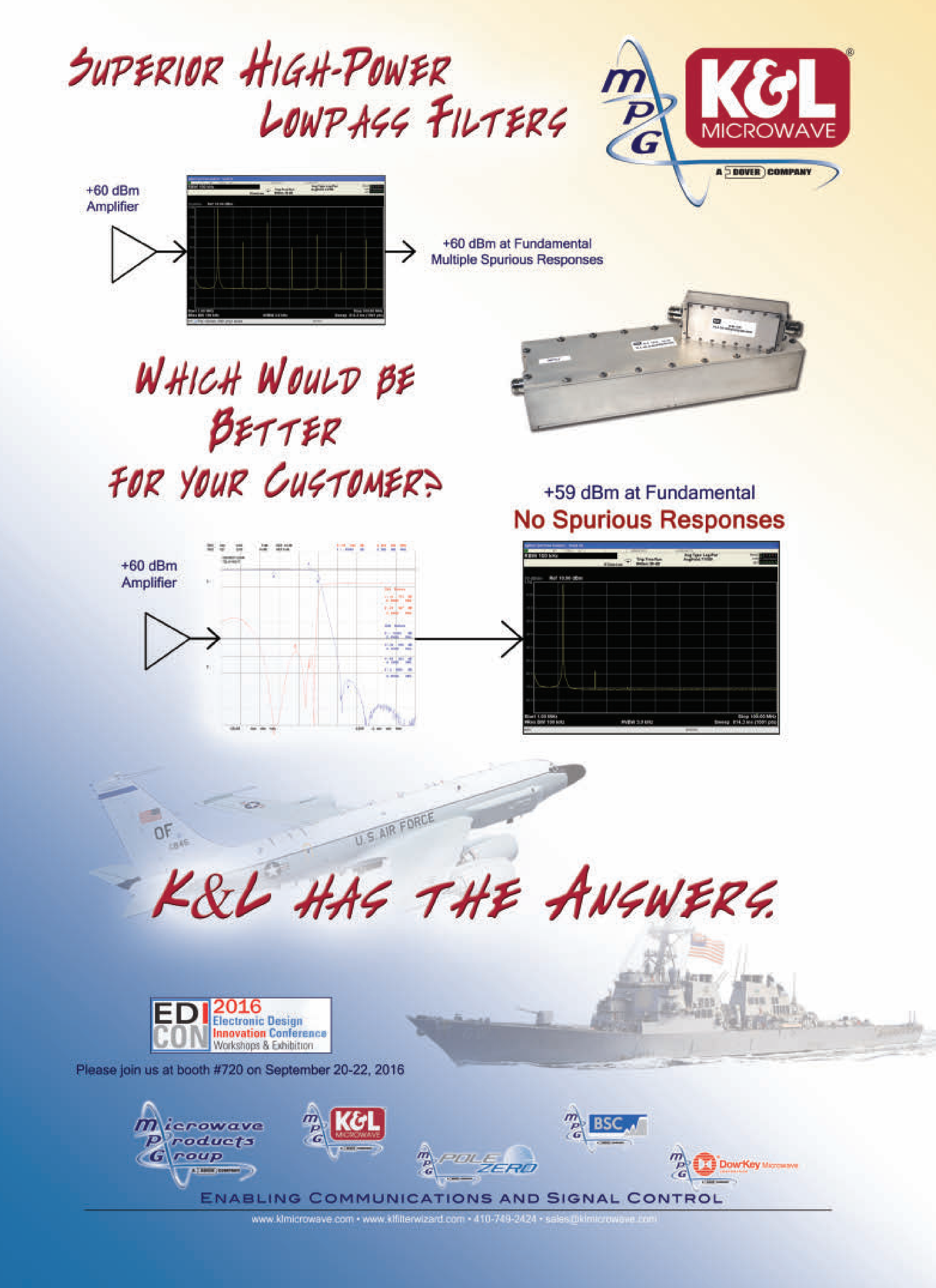
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Editor's Note: Because of its high power density, GaN is widely recognized as providing a step-function increase in the capability of solid-state power amplifiers. Arguably not as well known is the impact GaN is having at the system level, particularly military systems. While logical to assume GaN enables evolutionary improvements, in some cases the system would not be possible without GaN. The Space Fence radar is one example, described in this article by Lockheed Martin.

GaN 101

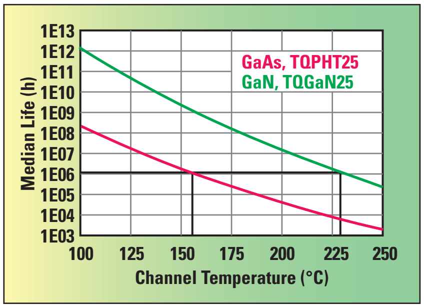
GaN is a compound semiconductor using III/V group elements that represents a leap ahead of existing GaAs technologies for many RF applications. GaN high electron mobility transistors (HEMT) are constructed using very similar fabrication techniques as GaAs RF devices but provide significant advantages.

The reason for the leap in technology GaN has over GaAs results from significantly higher operating RF power density and higher reliability. The secondary benefits built on these first two are: smaller chips for a given output power; smaller modules; higher overall efficiency due to lower combining losses; lower module assembly cost; higher power handling survivability and higher impedance for large devices, making for easier impedance matching.

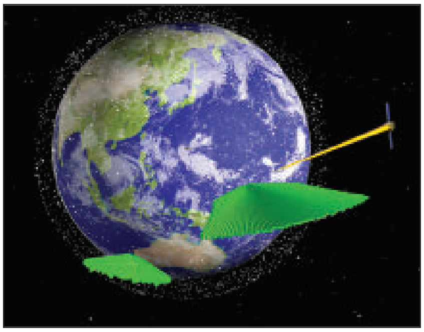
The inherent advantage of GaN over GaAs is due to basic physics of the devices and materials. GaN is referred to as a wide bandgap semiconductor because of the wider energy gap between the valence and conduction bands, compared to conventional semiconductors. The wider energy gap (3.4 eV for GaN compared to 1.42 eV for GaAs) allows higher electric field strengths and higher breakdown fields, which translate into higher operating voltages.[1]

Another advantageous characteristic of GaN is electron drift velocity, which in GaN increases with higher field strength, while it decreases with higher field strength in GaAs. Another way of describing it is that the low field drift velocity of GaAs is superior to GaN, but the high field drift velocity of GaN is far superior to GaAs. The peak in this characteristic (electron drift velocity vs. field strength) is the saturation velocity. In GaN it is 2.46×10^7 cm/s, while GaAs is 1.8×10^7. However, at high fields where GaN is 2.46×10^7, GaAs electron drift velocity is under 1×10^7.[1] Since electron drift velocity is related to current density, it basically means that at high voltage, GaN is also capable of high current, whereas GaAs is not. Also, since power is a function of voltage and current, the wide energy gap and high drift velocity make for ideal high power devices. For these reasons, GaAs will never outperform GaN for high power applications; however GaAs should retain its applicability in low voltage and low power applications.

A third important aspect of GaN technology, especially for power devices, is the substrate material. Since GaN substrates were not very advanced and were thermally inferior, silicon carbide (SiC) emerged as the best substrate material for GaN RF power devices. The thermal conductivity of SiC is superior to other



▲ *Fig. 1 Reliability comparison of Qorvo GaN and GaAs PHEMT processes.*



▲ *Fig. 2 Space Fence comprises two radars, one located near the equator at Kwajalein Atoll and an optional second site in Western Australia.*

substrates, such as silicon or sapphire, and allows the high power potential of GaN to be realized. The thermal conductivity of SiC is approximately 10× better than GaAs. These advantages allow operation of systems and sensors that would not have been possible with GaAs semiconductors. For example, new systems have steep requirements for both performance and operational availability. GaN enables sensors to operate with longer reliability and be driven harder (i.e., longer pulse width per duty cycle), based on the inherent higher power density properties.

Assessing reliability, GaN devices can operate at a much higher channel temperature than GaAs for equivalent reliability; at equivalent channel temperatures, GaN achieves much higher reliability. Comparing the reliability of Qorvo's GaN and GaAs technologies (see ***Figure 1***), at T_c = 150°C the median life of GaN is 1×10^9 hours vs. 1×10^6 hours for GaAs. At 1×10^6 hour median life, GaN can operate 75°C hotter than GaAs (i.e., 225°C for GaN vs. 150°C for GaAs).[2]

Overall, GaN can lead to smaller, cheaper, more efficient and higher power RF modules. For example, a single GaN MMIC high power amplifier (HPA) can replace a pair of GaAs HPAs which need a power combiner/divider, extra supporting components and additional assembly. Efficiency is gained not only at the MMIC level, where on-chip combining losses are reduced, but also at the module level, where combining losses are eliminated when two or more GaAs HPAs need to be combined.

Use of GaN HPAs in solid-state phased array radar provide numerous benefits. As described, GaN supports higher output power, higher transmit duty factor and longer pulse lengths than previous technologies, such as GaAs and Si BJT. These allow smaller aperture sizes and reduce overall system acquisition costs. Since GaN operates at higher efficiency, operational costs are also reduced, as less prime power is consumed and less heat is dissipated, reducing the need for active cooling. An example of this would be an existing radar which utilizes a solid-state semiconductor such as GaAs. An equally sized radar employing GaN would benefit from a significant increase in radar range with a slight increase in prime power. Conversely, for the same prime power, the power density of GaN could significantly reduce the radar aperture. This has first order effects of reducing acquisition costs, including both front-end and back-end electronics. Lastly, GaN has higher reliability than previous technologies. Higher reliability reduces operational costs through reduced maintenance and spare parts.

SPACE FENCE RADAR

Space Fence is a ground-based system of S-Band radars designed to greatly enhance the U.S. Air Force Space Surveillance Network. Space Fence provides unprecedented sensitivity, coverage and tracking accuracy and contributes to key space mission threads, with the ability to detect, track and catalog small objects in low Earth orbit (LEO), medium Earth orbit (MEO) and geosynchronous orbit (GEO). Space Fence's capabilities of detecting, tracking and cataloging hundreds of thousands of satellites and debris in orbit around the earth will revolutionize space situational awareness.[3]

Space Fence includes up to two minimally manned radar sites (see ***Figure 2***). The first radar site is under construction on Kwajalein Atoll in the Pacific Ocean near the equator and is expected to become operational in late 2018. The second site, currently an unfunded contract option, is located in Western Australia. The sensor sites provide assured coverage for objects in LEO and are integrated through an operations center located in Huntsville, Ala.

The initial Kwajalein radar will provide a persistent surveillance "fence" comprised of thousands of radar beams covering LEO altitudes. As the Earth rotates, this fence sweeps the space around the Earth, providing assured coverage to detect satellites and orbital debris. To form high quality orbital estimates, objects that cross the fence are tracked over long arcs with dedicated beams. Space Fence can also be tasked to search for higher altitude objects in MEO and GEO. The optional second site will complement the first site's LEO coverage and also provide tasking capability to MEO and GEO.[3]

As shown in ***Figure 3a***, each radar site features a design with closely spaced but separate transmit and receive phased array antennas, prime power and liquid cooling. The transmit array building houses a 36,000 element transmit phased array antenna beneath an air supported low loss Kevlar environmental radome. The receive building supports an 86,000 element array, also under a low loss Kevlar radome. Both arrays are provided power and cooling through the common services building. Radar data processing and control of the apertures is performed off-array in commercial off-the-shelf (COTS) processing equipment located within the operations building. Both transmit and receive arrays are automatically calibrated with horns that are mounted on calibration towers and can transmit or receive test signals. The extremely large phased arrays are optimized for high availability and low lifetime support costs and use GaN HPAs for transmit amplification, providing unprecedented sensitivity to detect small objects. On receive, digital beam forming (DBF) at the element level permits thousands of simultaneous beams instantaneously in any direction. This enables the system to provide persistent LEO surveillance coverage while simultaneously track-

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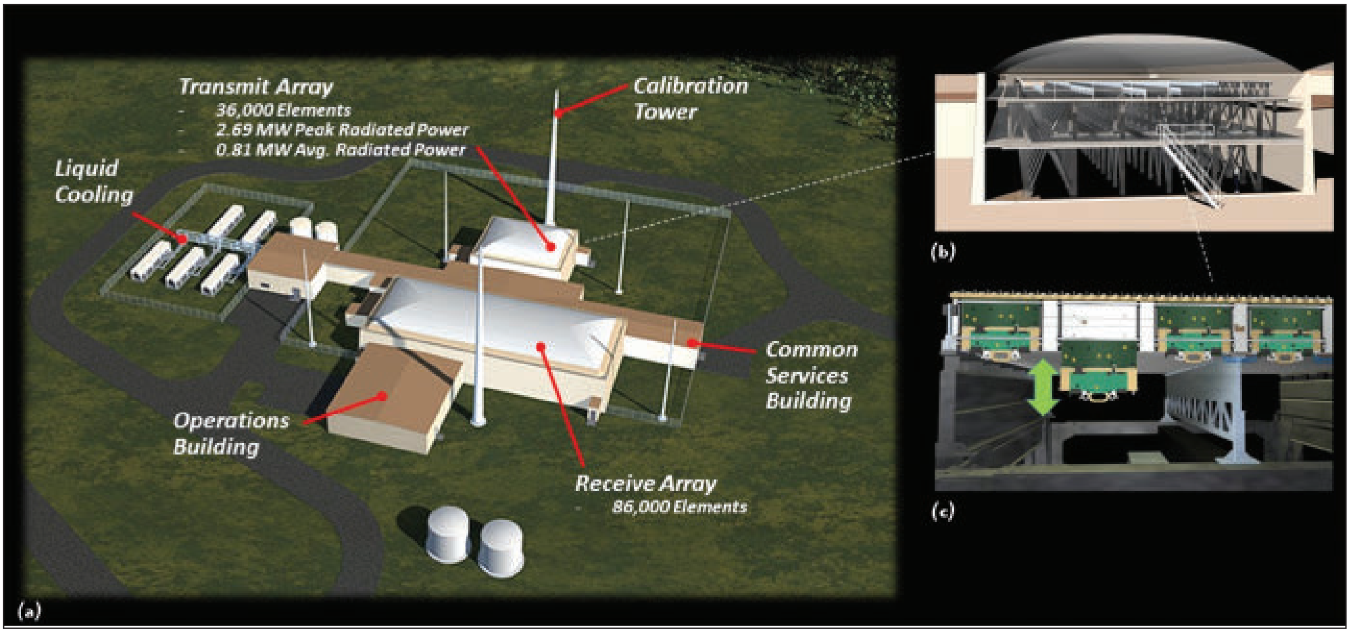

Fig. 3 Space Fence radar site (a) cutaway of the transmit array (b) and cross-section of the "radar-on-a-board" transmit LRUs (c).

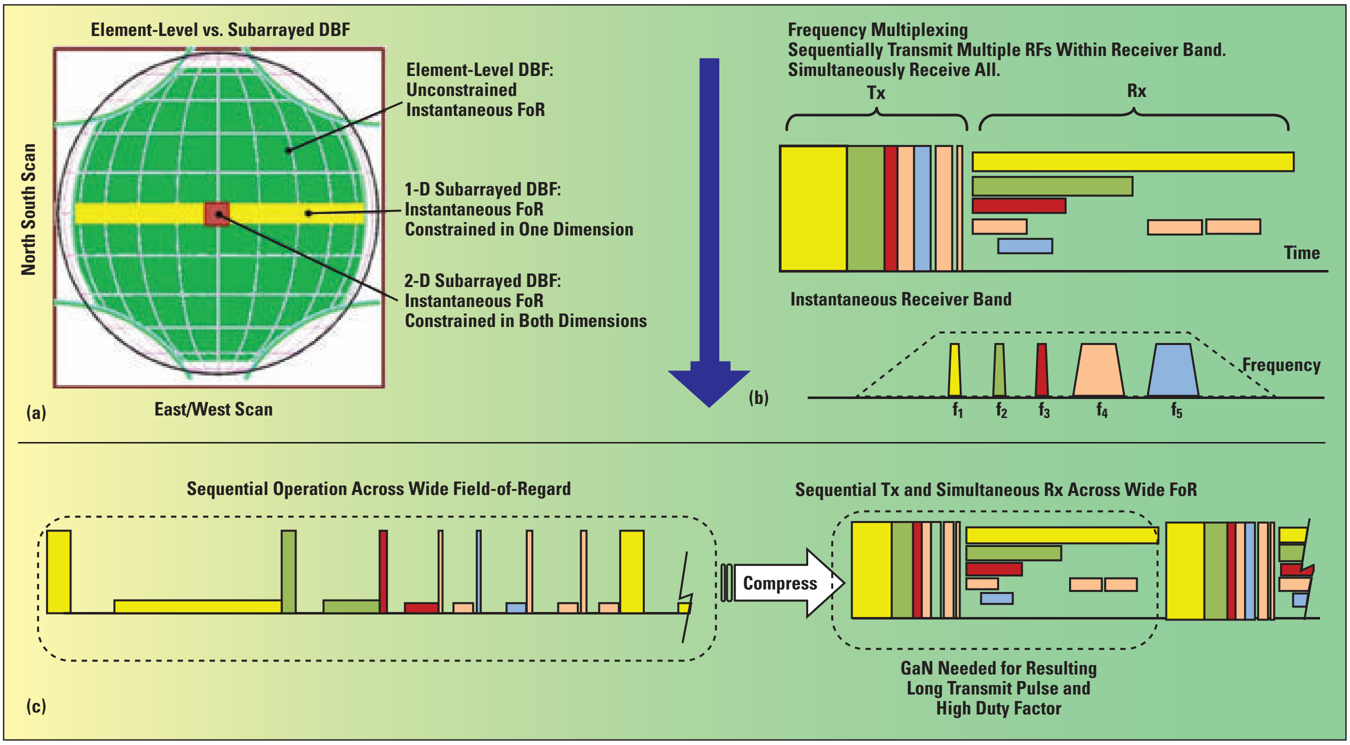

Fig. 4 Digitizing at the element, instead of combining multiple elements into subarrayed receivers, enables beams to be formed anywhere in the array FoR (a). Multiple frequency channels, each for a different radar function, can be received at the same time by beams on the receive array, allowing many functions to be performed simultaneously (b). GaN is the only technology that supports the "machine gun" transmit sequence, with long pulses and high duty factor (c).

ing hundreds of objects, performing cued search tasks in other surveillance regimes (including MEO and GEO) and supporting user-defined flexible surveillance volumes. Transmit and receive arrays are oriented to face straight up and are designed integrally with the building (see the transmit array cutaway in ***Figure 3b***). A scalable facility structure supports liquid cooled cold plates, which house the radar electronics. Radiator tiles are mounted on the top of the cold plates while "radar-on-a-board" digital transmit and receive line replaceable units (LRU) are mounted on the sides (see ***Figure 3c***). Each transmit LRU incorporates digital waveform generation, up-conversion to S-Band and high power GaN amplification for eight transmit radiating elements. Mounting the LRUs on the sides of the cold plates provides the GaN HPAs with a direct and efficient thermal path. To provide high system availability, the LRUs are serviceable from beneath the array and can be re-

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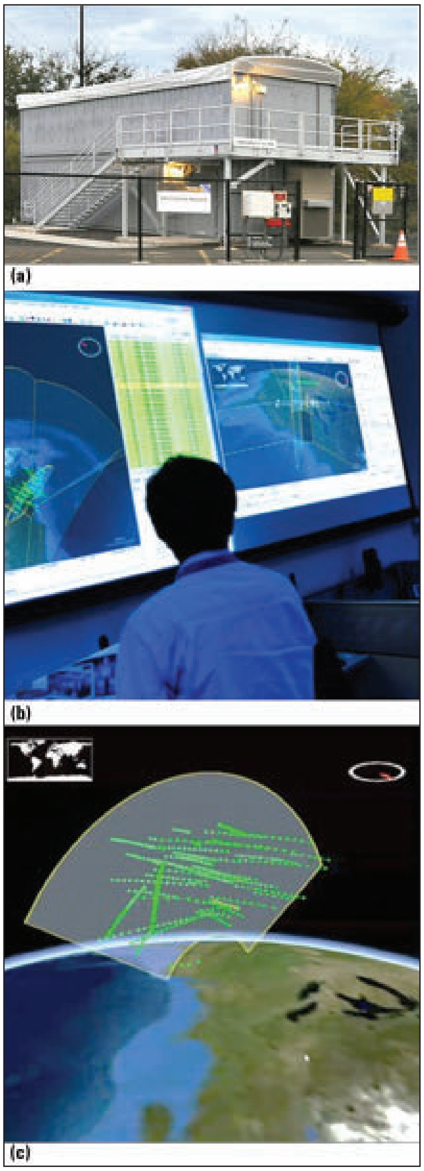
GaN high power amplification was one of the critical enabling technologies for the Space Fence solution. Relative to other technologies, the high output power of GaN reduces the number of transmit elements to achieve the required sensitivity for the target size, which reduces overall acquisition cost. GaN's high efficiency also reduces power consumption and heat dissipated, which reduces operational costs for the sensor site. In order to effectively support the LEO orbital regime (and tasking up to GEO) and get sufficient energy back for detection, transmit pulse lengths need to be long. Previous technologies, such as GaAs or Si BJT didn't support these pulse lengths at the required output power.

The long pulse capability of GaN in the transmit array also enables extremely efficient timeline utilization of the radar when combined with element level DBF in the receive array. Space Fence has a receiver connected to each array element within the receive array to digitize the returned signals. Unlike subarrayed antennas, which combine multiple elements in microwave electronics prior to digitizing to reduce the number of receivers, the beams in an element level DBF system can be simultaneously placed anywhere in the field-of-regard (FoR) of the array. Subarrayed approaches limit the digitally formed beams to constrained volumes and require changing analog phase shifters to move the volume from one radar event to the next (see ***Figure 4a***). Space Fence is able to use its flexibility along with frequency multiplexed functions within the receiver band to form thousands of beams simultaneously (see ***Figure 4b***). This allows many functions that would have been performed sequentially to be performed simultaneously, reducing the Space Fence array sizes along with the associated acquisition cost and operating costs. Use of GaN HPAs are needed to support the resulting concatenated "machine gun" like transmit sequence, which is longer and transmit higher duty factor than supported by other technologies (see ***Figure 4c***).

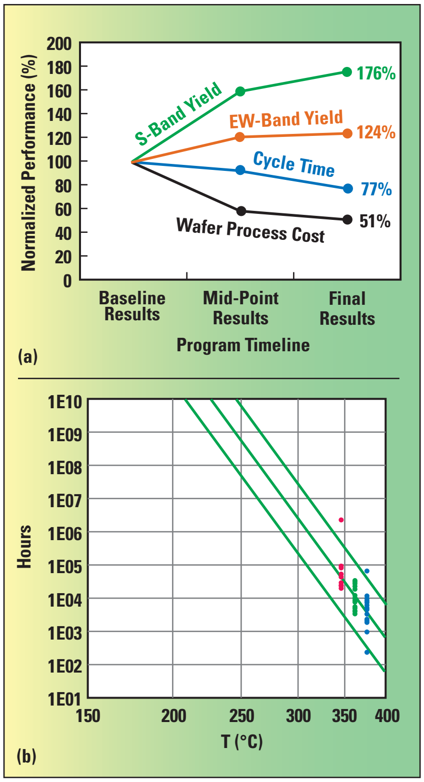
At the start of concept development for Space Fence in 2007, Lockheed Martin leveraged an existing Independent Research and Development (IRAD) project that was maturing GaN for use in radar applications. Over the course of the Space Fence development, GaN was optimized to the Space Fence application for additional efficiency and reduced operational costs. Lockheed Martin also embraced an open foundry concept and worked with two suppliers to develop GaN for Space Fence. Space Fence transmit LRUs have been successfully tested with GaN modules from both of these companies. Use of multiple suppliers reduced program risk and provided competition to reduce acquisition costs.

With the large Space Fence arrays and number of GaN devices, high reliability is necessary to keep maintenance costs down. To ensure mature technology, Lockheed Martin tested the Space Fence GaN amplifiers at the module, at the transmit LRU and at the array. After years of extensive testing (more than 5,000 hours of life testing, including accelerated life testing), the technology has proven to be extremely robust, showing a high reliability confidence level which supports the rigorous operational availability of the mission.

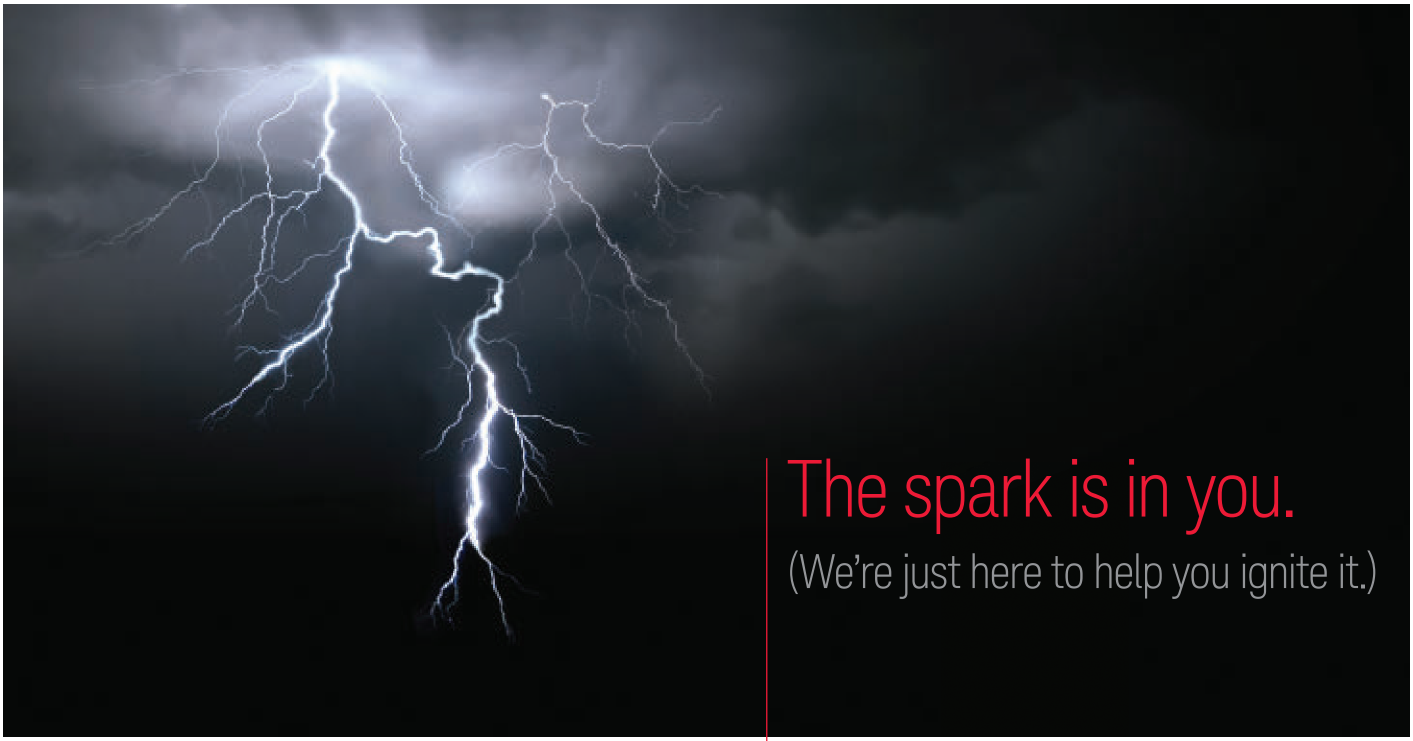
Since 2011, Lockheed Martin has had an operational end-to-end system prototype employing all its critical technologies, including GaN and element level DBF, in scaled-down arrays (see ***Figure 5***). Prototype system data was used by the U.S. Air Force in a technology readiness assessment in 2015, resulting in a Technology Readiness Level (TRL) 7 and Manufacturing Readiness Level (MRL) 7. In January 2016, an Integration Test Bed (ITB) using final production hardware was commissioned in Moorestown, N. J. The ITB supports hardware/software integration, maintenance training and verification testing; it will provide remote support to the integration of Sensor Site 1 on Kwajalein Atoll.



▲ *Fig. 5 Space Fence prototype: antenna building (a) mission operations center (b) and critical design review (CDR) demonstration.*



▲ *Fig. 6 Wolfspeed DPA Title III performance improvement (a) and reliability (b).*



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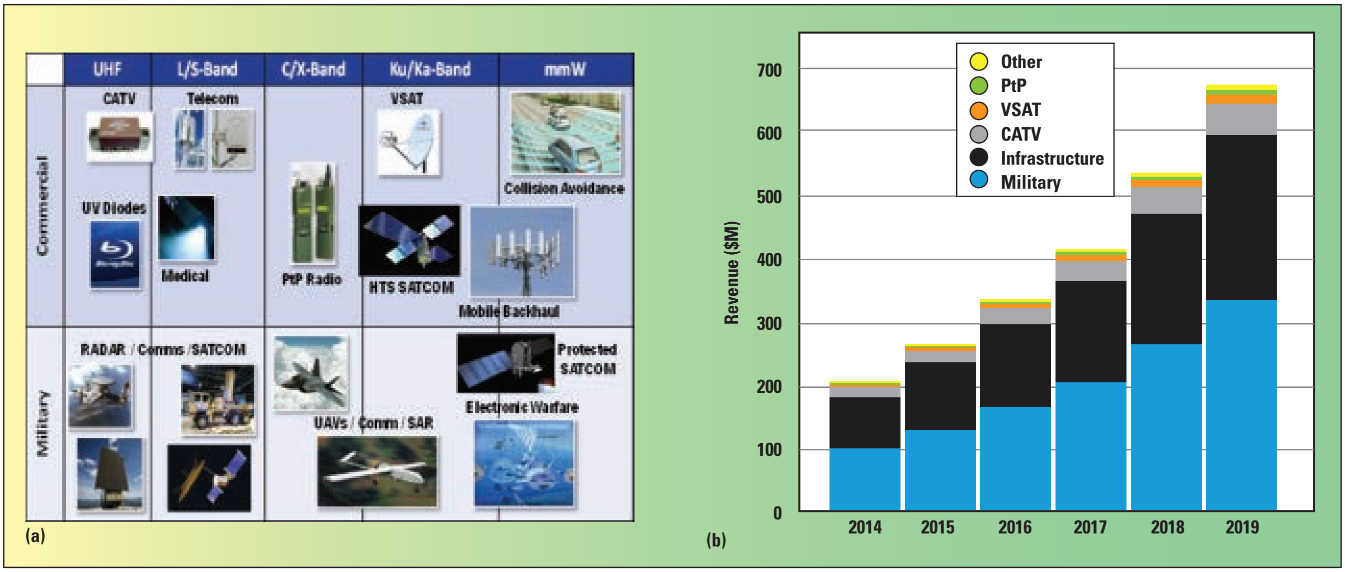

Fig. 7 Commercial and military products using GaN (a) and projected GaN market growth (b). Commercial pull for GaN will be more than 2x military applications by 2019.[6]

OPEN FOUNDRY MODEL

The development of GaN with ever increasing government funding has been occurring since the 1970s.[4] Since the early 2000s, both the Department of Defense and commercial foundries have considerably increased this funding. One example is the DARPA Wide Bandgap program which funded various semiconductor foundries to mature the technology, investing approximately $150 million. This program followed the successful initiatives of the 1980s and 1990s to fund GaAs, such as DARPA's MIMIC and MAFET programs. Among the key parameters and facets of the technology development were the physics of the devices, to understand and unleash the potential of the superior physical properties of the semiconductors, and the development of accurate models.

The completion of the DARPA Wide Bandgap program in 2011 led to an additional program funded through the Defense Production Act (DPA) Title III program office. The mission of the DPA Title III program is to "create assured, affordable and commercially viable production capabilities and capacities for items essential for national defense." The main focus of the GaN Title III program was to improve the manufacturability of GaN, essentially to increase the MRL to level 8. The program was structured as three phases: 1) baseline manufacturing readiness, 2) improvement and refinement of processes and 3) final manufacturing readiness assessment.

Wolfspeed was able to substantially increase their yield over the three phases, while simultaneously reducing cycle time and wafer processing costs (see ***Figure 6***).[5] Over the three phases, yield increased 76 percent for S-Band devices, cycle time reduced 23 percent and wafer costs decreased 49 percent. Reliability of 1×10^7 hours was demonstrated at a channel temperature of approximately 275°C. Through manufacturing process refinement and building significant robust wafer lots, Wolfspeed reached MRL 8 in 2014, i.e., demonstrated pilot line capability and ready to be-

gin low rate initial production (LRIP). One of the other major commercial foundries, Qorvo (formerly TriQuint) was the only funded foundry that achieved MRL 9 in 2014, i.e., demonstrated LRIP and capability in place to begin full rate production (FRP).

GaN has been inserted into several Lockheed Martin and other DoD contractor systems and has achieved TRLs through level 9. Space Fence has achieved TRL 7. Since the completion of both the DARPA Wide Bandgap and DPA Title III programs, GaN has been following a Si CMOS trajectory, in terms of applications and utilization in commercial markets.[6] GaN has found its way into base stations, medical equipment and even residential/commercial lighting available at local hardware stores (see ***Figure 7***).

Lockheed Martin employs an open foundry model (LM OpenGaN), which leverages the commercial market for the best technology at the most competitive cost. The cost of owning and running a foundry year after year can be significant. Given the growth projections for semiconductors, in general, it makes more sense to allow high commercial volumes to mature the technology process and drive costs down.[7] A study conducted by Strategy Analytics[6] (see ***Table 1***), identified Qorvo and Wolfspeed as GaN leaders, with no other domestic suppliers close to providing equivalent volume. In the semiconductor industry, volume production lends itself to higher maturity, stable processes and lower costs.

Lockheed Martin adopted an open foundry model to address the Department of Defense's official memorandum on Better Buying Power 3.0 and the "3rd Offset," with the goal of increasing the capability and rapid technology development required by the warfighter.[8] It is not economical to have any particular foundry develop various semiconductor processes, not just III/IV (i.e., GaAs, GaN, InP) but also SiGe and CMOS.

GaN has had significant investment over the past 10 years and is proven to be field ready, reliable and cost competitive with existing technologies (e.g., GaAs). The system benefits enable enhanced capabilities for backfit military systems and are required for the performance of future systems. The Space Fence program would not have been possible without GaN nor as successful without the affordability enabled by the LM Open GaN foundry model.

THE FUTURE

The next generation of GaN development is focused around increasing capability by pushing into higher oper-

TABLE 1

GaN MARKET SHARE
STRATEGY ANALYTICS, JANUARY 2015

	Military Segment	Total Worldwide
Wolfspeed	19%	25%
Qorvo	24%	22%
Sumitomo	17%	22%
Raytheon	13%	7%
Northrop Grumman	11%	6%
UMS	6%	6%
Others	10%	12%

ating frequencies, improving thermal performance and enabling chip-scale integration of GaN with other IC technologies. Developments of 150 nm and 90 nm process nodes will extend f_t to 60 and 100 GHz, respectively.

While DBF systems such as Space Fence represent a significant capability upgrade, the challenges from the increased IC design complexity in the areas of size, weight and power (SWAP), bandwidth and latency performance must be overcome. To address this, programs such as DARPA's Diverse Accessible Heterogeneous Integration (DAHI) program are focused on developing chip-scale integration of GaN with high density Si CMOS, as well as other technologies such as InP and MEMS. These resulting capabilities will enable the wider proliferation of the high performance mixed-signal integration solutions required to develop the capabilities to further advance state-of-the-art sensor systems.

While GaN is capable of generating extremely high RF power densities, thermal management remains a significant challenge, especially at higher frequencies where thermal density is most extreme. On the DARPA IceCool program, Lockheed Martin has made tremendous gains in unlocking the ultimate potential of millimeter wave GaN by developing a micro-fluidically cooled HPA with a 3× reduction in thermal resistance compared to conventional thermal management solutions. This IceCool solution enables an 8.3 dB increase in output power for the same device, while simultaneously reducing operating temperature by increasing power-added efficiency between 2.5× and 3.5×.[9] Overall, these advancements will further extend the true potential of GaN and its ability to realize tremendous capability upgrades for a wide variety of systems. ■

ACKNOWLEDGMENT

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MWJ REVIEW BOARD APPROVED

Characterization of Single-Shot Large-Signal Phenomena Using High-Speed Oscilloscopes

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Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany
S. Kühn
Phasor Instruments

The use of fast real-time oscilloscopes allows the recording of single transient events at GHz frequencies in the large signal operation of electronic components. With sampling rates over 100 GS/s, such equipment can be used to detect and store high frequency signals over a wide frequency spectrum. Sampling oscilloscopes that have been used for many years are restricted to periodic signals, e.g., with active harmonic pull. This article describes how real-time oscilloscopes can be used to capture single transient events that occur during device failure.

Standard measurement equipment such as network analyzers and spectrum analyzers are unable to record single transients. This limitation does not apply to the approach described here, making it particularly suitable for measuring non-periodic events. Not only RF behavior, but bias parameters as well, are recorded simultaneously. This places strict requirements on calibration of both the RF and bias circuits. Because there is no second source at the output, only the input reflection coefficient (S_{11}) and forward gain (S_{21}) are determined.

Most related measurement approaches determine breakdown under dc and pulsed dc conditions.[1-4] Other measurement setups use load line analysis.[5,6] All use sequential sampling techniques and thus require periodic signals. In this article, however, real-time sampling is used, allowing one-shot measurements essential for studying irreversible effects.

MEASUREMENT SETUP

The measurement setup resembles a classic load-pull system (see ***Figure 1***). A generator and power amplifier provide the necessary RF-input power. A test fixture with input and output boards allows easy assembly and pre-matching of the device under test (DUT) while tuners provide matching to the 50 Ω environ-

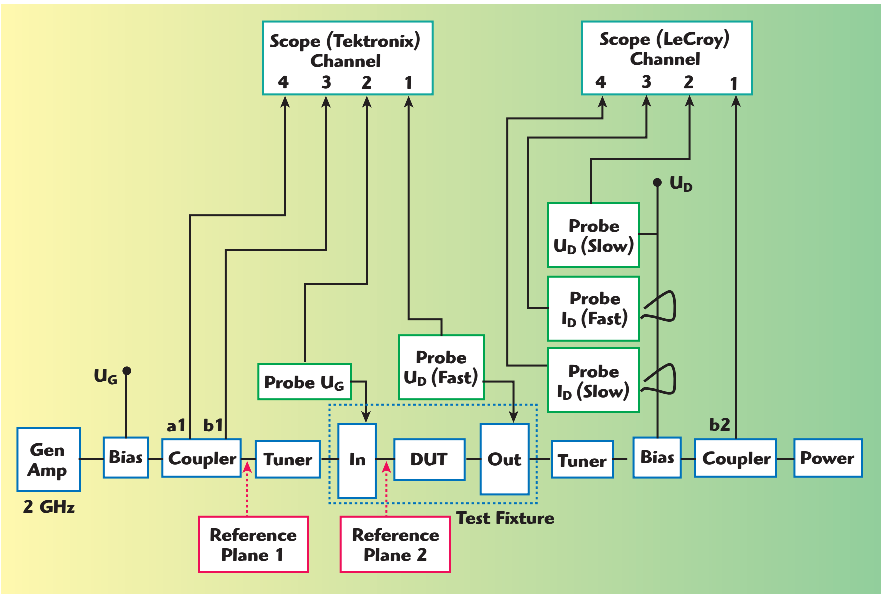


Fig. 1 Measurement setup.

TABLE 1

PROBE CHARACTERISTICS

Probes	Resistance (Ω)	Attenuation/ Sensitivity	Lower Bandwidth	Upper Bandwidth/τ
U_G	500	-20 dB	DC	6 GHz/60 ps
U_D (fast)	1 k	-37 dB	1.5 kHz	6 GHz /60 ps
U_D (slow)	10 M	-20 dB	DC	500 MHz/700 ps
I_D (fast)		200 mA/V	250 kHz	3 GHz/200 ps
I_D (slow)		1 A/10 mV	DC	50 MHz/7 ns
a1	50	ca. -40 dB	1 GHz	13 GHz
b1	50	ca. -40 dB	1 GHz	13 GHz
b2	50	ca. -40 dB	1 GHz	3.5 GHz

ment. In this case the transformer pre-matches 22.5 to 50 Ω. The 22.5 Ω characteristic impedance is related to the transmission-line structure formed by the leads of the transistor package. DC power is provided through bias-tees. The scattering parameters are determined by means of directional couplers.

The load-pull setup is extended by real-time oscilloscopes with several measurement channels. A TDS 6124C by Tektronix and a WP 735Zi by LeCroy provide 8 measurement channels with 20 GS/s each for data recording. The analogue bandwidths are 12 GHz (Tektronix) and 3.5 GHz (LeCroy), respectively. Maximum memory depths of 8 M points/Channel allows a recording time of 400 μs in 50 ps steps. This makes the digital recording of the incident (a_1), reflected (b_1) and transmitted (b_2) waves from the directional couplers possible. Relevant bias current and voltages are recorded as a function of time via the other oscilloscope measurement channels.

Voltage probes at the input and output boards measure gate and drain voltages while output drain current is measured with current probes. Because the fast drain voltage and current probes have lower cut-off frequencies, they are augmented with slower DC-coupled probes to record DC levels. The fast probes are bandwidth limited on the high end as well. A step of the drain voltage detected through the fast probe yields a signal at the oscilloscope that rises with a time constant at the upper bandwidth limit and then falls with the much slower time constant of the lower bandwidth limit. ***Table 1*** shows the bandwidth limits of the relevant probes.

With regard to the transition ranges, input voltage and output currents and voltages may be measured over a wide time interval, ranging from picoseconds to seconds — enabled by the instruments' large memory depths. Numerous trigger options allow triggering of many events. In this case, the trigger is activated by the lack of an output signal, i.e., the malfunction of the device under test. Using special features in the oscilloscopes, even events before the trigger are recorded and stored. Hence, it is also possible to look at the time prior to the malfunction; then, the trigger event simply ends permanent signal recording. The trigger-out signal of the faster Tektronix oscilloscope is connected with the trigger-in of the second oscilloscope. This is triggered after a very short, precisely-defined time delay.

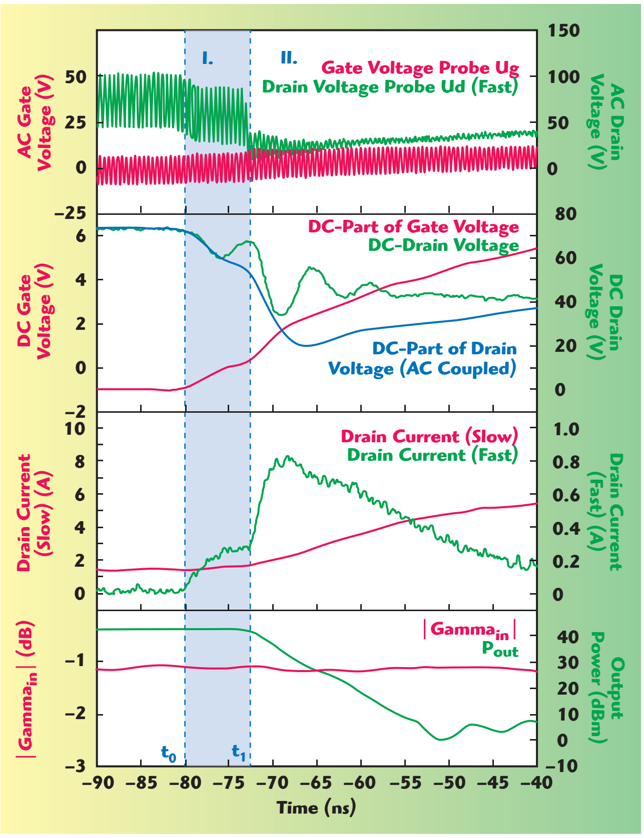
CALIBRATION

In order to allocate the data to a timeline, it is necessary to first calibrate each system (load-pull as well as probes) individually. Then, both systems are adjusted to each other.

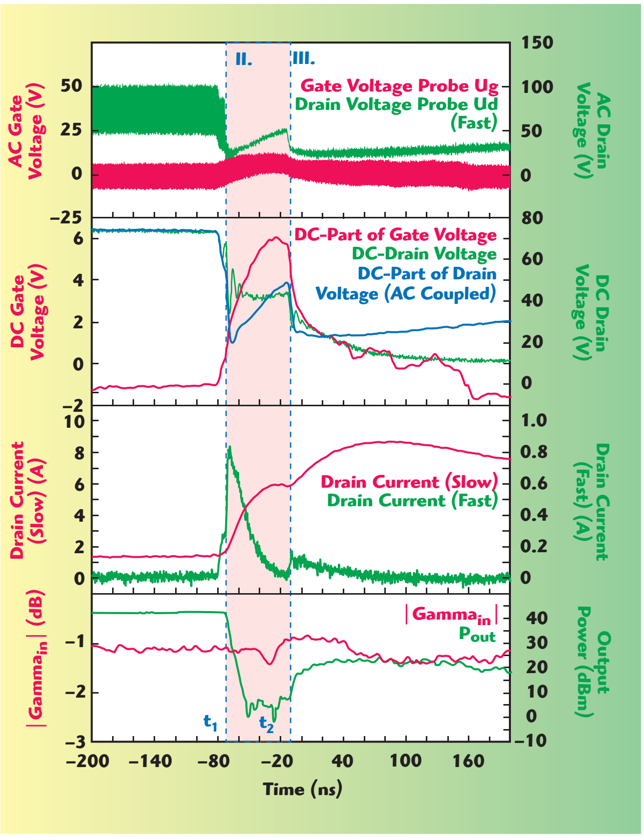
For this purpose, voltage probes on the input and output boards are placed directly at the location of the device under test (i.e., Reference Plane 2 in Figure 1) and a signal with a fast slope (e.g., a step function) is applied at Reference Plane 1. Channels 1 and 2 (voltage probe input and output) are calibrated for 0 ps delay to the leading transient of the input signal by adjusting the skew for each channel individually. Probe attenuation factors are determined separately using a calibrated signal generator output with a matched 50 Ω line.

Loading of the DUT by the probes must also be considered. The power transistors used here have low input and output impedances. Hence, the loading by the (nominal) real parts of the voltage probes of 500 Ω or 1 kΩ, respectively, is marginal. The capacitive part of the voltage probe input impedance, however, must be taken into account when setting up the matching boards and performing through-calibration of the load-pull system. Hence, the capacitive part is considered when determining the optimal source and load impedances through load-pull.

To determine the complex Gamma, a calibration at Reference Plane 1 with open, short and load is performed. With known S-parameters of the tuners and test fixture boards



▲ *Fig. 2 High time resolution measurements.*



▲ *Fig. 3 Medium time resolution measurements.*

one can transform the reflection coefficient from Reference Plane 1, in the direction of the DUT, to Reference Plane 2.

TRANSISTOR MEASUREMENT

To demonstrate the performance and capabilities of the system, single-shot measurements of a gallium nitride (GaN) transistor with 10 mm gate width are conducted at a fundamental frequency of 2 GHz. The purpose of these measurements is to examine the behavior of the transistor during failure, when the drain bias voltage is increased step-by-step while keeping RF power constant.

The transistor is biased with a DC-power supply via bias tees. The DC bias point is set at a relatively low drain voltage (i.e., 28 V). Considering the influence of the probes, the optimum source and load impedances are determined by load-pull measurements. Load-pull tuning is conducted only at 28 V in order to avoid the risk of transistor failure, because the tun-

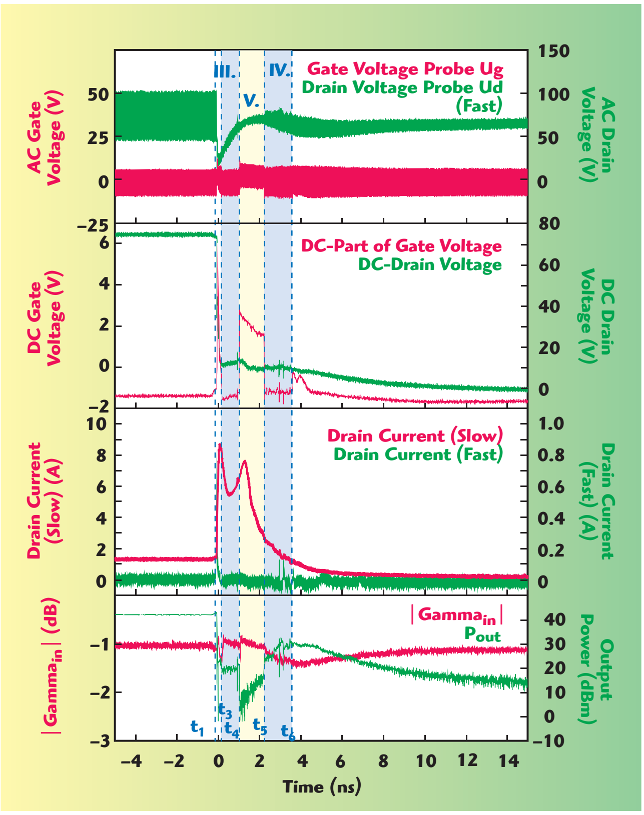


Fig. 4 Low time resolution measurements.

ing procedure takes it outside its safe operating area at higher drain voltages.

The transistor is then driven to its P_{1dB} point by applying the relevant source and load impedances derived under 28 V bias. Next, the drain voltage is increased step-by-step, while keeping all other conditions including the RF input power unchanged. At a certain drain voltage, the transistor will fail. The Tektronix oscilloscope triggers the failure of the RF-voltage and stops all other measurements.[7] This is independent of the reason for failure, which may be high drain voltage, high drain current or high dissipated power. With data stored for the time prior to malfunction, the failure mechanism can be investigated in detail.

MEASUREMENT RESULTS

Using the calibration routine described earlier, the measurement data stored in the memories of each channel is allocated to a timeline. The high memory depth of the oscilloscopes in single shot mode allows a good overview as well as the possibility to examine all details within the maximum sample rate of 20 GS/s. ***Figures 2*** through ***4*** show the transistor parameters obtained in this way for different time scales. Analyzing this data one finds that the breakdown process occurs in four phases:

Phase I: The first changes appear at point t_0 = -80 ns (trigger offset). The drain voltage decreases while drain current and gate voltage increase. The output power still remains constant. It is probable that a drain-gate breakdown has occurred. The leakage current from drain to gate shifts the bias point (see ***Figure 5a***).

Phase II: At time t_1 a further drain-gate breakdown takes place forming a low-impedance connection between the drain and gate. The gate voltage becomes significantly positive and the drain current increases rapidly. Now, the output power and drain voltage drop continuously. There is an overshoot at the slow drain voltage probe due to the probe inductance. The RF output power reaches its minimum.

The end of Phase II is denoted by t_2 when the gate voltage reaches a maximum at +6 V. The drain current reaches a temporary maximum as well at t_2. This may be the point when the air bridge at the drain of the respective finger bends because of the high current density there (see ***Figure 5b***). Note that air bridges are more vulnerable to high current densities

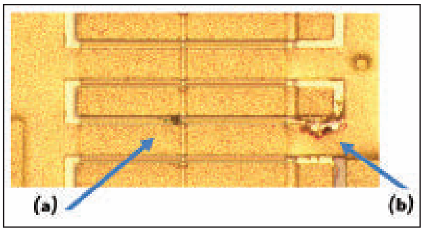


Fig. 5 Photograph of the damaged transistor, showing damage in the gate area (a) and at the drain air bridge (b).

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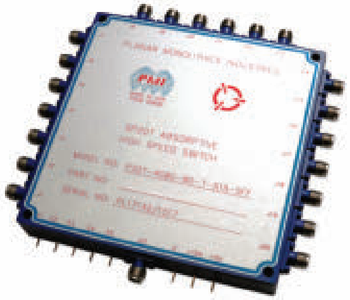
Insertion Loss	4.0 dB Max - Measured 3.95 dB
VSWR In/Out	2.0:1 Max, 1.8:1 Typ
Input Power	100 mW Max CW (Hot Switchable)



- Package Size: 4.0" sq x 0.63"
- DC Voltage: +5 VDC @ 144 mA, +15 VDC @ 160 mA
- Switching Speed: 100 ns Measured

Model P32T-0R5G18G-60-T-SFF
Absorptive, SP32T PIN Diode Switch

Frequency	0.5 to 18.0 GHz
Isolation	60 dB Min (0.5 - 2.0 GHz) 70 dB Min (2.0 - 18.0 GHz) - Measured 77.3 dB
Insertion Loss	9.5 dB Max - Measured 8.66 dB
VSWR In/Out	2.0:1 Max
Input Power	20 dBm CW Max (Operating)

- Package Size: 8.0" x 3.5" x 1.0"
- DC Voltage: +5 VDC @ 1470 mA, -5 VDC @ 100 mA
- Switching Speed: 85 ns Measured

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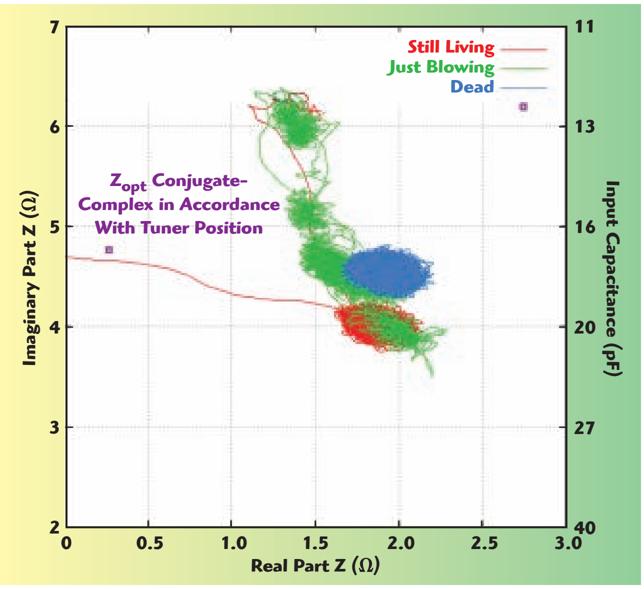
since they are missing the heat sinking through the substrate. This bending brings the air bridge in close proximity to the metallization below and thus initiates a local breakdown.

The resulting high current causes a protection fuse to switch off the drain power supply. Now, the remaining current results from discharging of capacitance in the drain bias circuit.

Phase III: Due to the short circuit at the drain, the drain current increases, the drain voltage drops and the gate voltage returns to its default value because no current flows from drain to gate. As a consequence, the air bridge cools down and reopens the drain-source contact.



▲ *Fig. 6 Trend of the complex input impedance during transistor failure.*

Phase IV: Since the drain contact is open, the gate voltage increases rapidly again, but not to the high values at the beginning because the power supply is switched off and the drain voltage relates to the remaining charge in the bias capacitors. The effect is not seen at the drain probe because of probe inductances.

This repeats for some time until the bias circuit capacitors are empty of charge. At the end, the air bridge melts and there is a permanent short at the drain air bridge and a short between gate and drain (and source) as a result of the breakdown. During the entire time after the failure, change of the input reflection coefficient is monitored. It is assumed to be caused mainly by variations of the other operational parameters during the failure process.

Figure 6 shows the trend of the complex input impedance during transistor failure within a Cartesian coordinate system. The change of the reactive part from 4 to 4.5 Ω with 6 Ω in the interim is particularly remarkable. Clearly, the impedance changes in discrete steps. Presumably some parts of the gate fail which leads to a gradual decrease of the input capacitance. Note that the input capacitance of a working transistor is higher because of the Miller capacitance and it decreases when gain is reduced. Thus, the input capacitance of the damaged transistor is lower than before. After the damage, small parts of the gate structure are no longer operational and short circuit the entire transistor.

Measurements and photographs reveal the following picture for the possible course of destruction of the transistor: Due to high field strength and overheating, a drain-gate breakdown occurs starting from t_0 onwards. The high current flow in turn causes a high current density within the corresponding drain air bridge. These air bridges are not sufficiently cooled by the substrate, become overloaded by the current, bend and in turn cause a short circuit. This short circuit reopens if temperature decreases and so an oscillation of drain shorting may occur. It is presumably the combination of the overheating of the transistor and the high drain field strength that leads, finally, to transistor destruction.

CONCLUSION

The measurement setup described allows characterization of linear and non-linear DUTs with periodic and single transient events, up to a fundamental frequency range of 4 GHz. Its special feature is the detection of single transient events, also irreversible ones as encountered, for example, dur-

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ing device failure. The system collects time-dependent data of bias as well as RF quantities, including S-parameters.

Its potential is demonstrated by investigating the failure mechanisms in a high-power GaN microwave transistor. In this way, conclusions regarding possible failure mechanisms can be drawn to assist in optimizing the devices and improving reliability. For example, it is found that care must be taken in designing the periphery such that all air bridges have a sufficient heat sinking to avoid thermal overload under all operating conditions.

One should note that the approach presented is not limited to the 4 GHz range used in our experiments. Oscilloscopes with bandwidths of up to 60 GHz and sample rates of up to 160 GS/s are state of the art. With the newest equipment, the approach described above could be extended to cover the 10 to 20 GHz range. Moreover, ongoing developments in the field of real-time oscilloscopes will enable further improvements in capability using this technique. ■

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INVITED PAPER

Device and PA Circuit Level Validations of a High Power GaN Model Library

Larry Dunleavy and Hugo Morales
Modelithics Inc.
Charles Suckling and Kim Tran
Qorvo Inc.

Modelithics and Qorvo are collaborating to provide designers with free access to state-of-the-art high accuracy models for a growing number of power GaN transistors. The available and developing GaN model library supports simulation-based design flows for GaN power amplifiers (PA) with output power requirements from 5 W to over 500 W. This article summarizes the library content, features and devices as well as circuit level "closed loop" PA validations of the new models.

Microwave power amplifier design has been a hot research and development topic for several years now. What keeps the topic interesting and advancing is the interesting mix of new applications with challenging requirements, combined with ever changing technologies that have gone from Silicon to GaAs to GaN (and for a few applications back to Silicon) over the years. GaN has emerged as the clear technology winner for high power/high frequency applications and there are significant investments and rapidly evolving product advances in the worldwide GaN device and GaN power amplifier market.

Traditionally, microwave power amplifier design has been accomplished with a lot of know-how and very little if any computer simulation. For many the simple, but extremely practical "Cripp's Technique"[1] of load-line based analysis suffices to produce a simple starting point design that is built then taken to the lab where skilled technicians and engineers use their know-how to tune and tweak at the board level until desired specs are met.

Others rely strictly on load-pull data to define their design criteria for achieving power amplifier output matching goals that achieve some desired compromise between output power, efficiency and linearity. A limitation is that load-pull data is expensive to acquire at each frequency and may not always be available at desired frequencies for new designs. Usually, bench tuning is still needed to achieve the desired performance goals.

The classroom of "old school" PA design is clearly the power test bench, producing "graduates" who are experts in knowing how to move capacitors and foil around on a breadboard circuit to achieve desired goals. A very worthwhile skill indeed, and many PA gurus out there really know how to make these approaches work to produce excellent power amplifier products; however, this build-test-tune approach is not always the most efficient.

The availability of accurate nonlinear models,[2,3] combined with powerful EDA tools such as Keysight Technologies' Advanced Design System and similar tools, has changed the para-

digm of power amplifier design so that less time is spent on bench tuning. Instead, more and more PA designers start with model-enabled nonlinear simulation design flows, which increasingly can lead to design goals being met on the "first-pass" of fabrication and test, with little or no tuning. The availability of complete model-enabled PA circuit simulations allows for optimization of nonlinear circuit performance for complex sets of PA goals over either narrow or wide bandwidths. Nonlinear models provide significant benefits to designers who want quick turnaround designs, but may not have measured load-pull data at target frequencies.

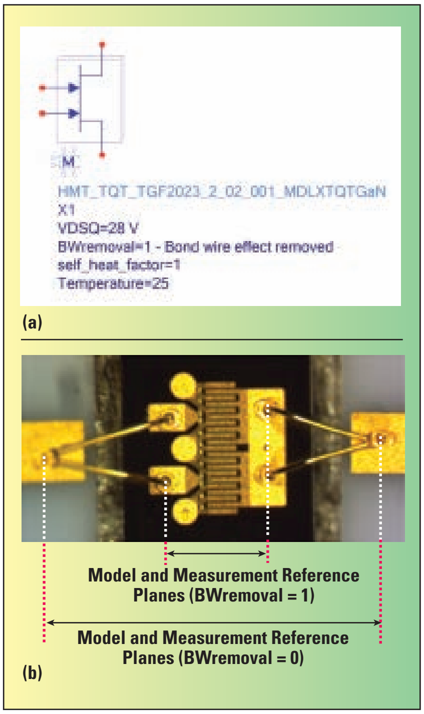


Fig. 1 Die model schematic (a) and die with reference planes (b).

Such simulation capability can also be very useful in guiding post-fabrication adjustments, if needed, to improve or fine tune bench performance. As a result, many modern designers will not even consider using a new PA transistor if a model is not available. Another trend for many designers that want to use "waveform engineering"[4] for optimizing high efficiency PA operating modes such as class B, AB, class F, and class J, among others, is the demand for access to intrinsic voltage and current ports.

The Modelithics®-Qorvo GaN Library was created to meet the increasing demand in accurate nonlinear models for GaN devices by PA designers. This article describes the content, advantages and novel features of this growing library, and presents examples of validations being done to validate the quality and accuracy of the models at the device and circuit level. The library is currently available for use in Keysight Advanced Design System (ADS) and NI-AWR Design Environment. The library, model features and validations will be demostrated using Keysight ADS EDA software.

GaN LIBRARY DESCRIPTION

The current version (1.7) of the library includes models for 17 die and 35 packaged devices, with many more models in development. The model library is set up to maximize designer convenience with a simple "click through" installation process and detailed model information data sheets accessible within the simulator. For example, in Keysight ADS, this is done simply by clicking the "Help" button on the model parameter pop-up window. The GaN Library is being distributed and supported by Modelithics for free, with sponsorship provided by Qorvo. Among the advantages of this arrangement is professionally managed software support, version control and frequent updates. With each update, additional models and model updates are provided and all models are kept up to date and operational with the latest EDA software revisions.

The GaN models themselves are currently based on a customized version of the Chalmers Angelov model.[5] Advanced custom features of the models that benefit the designers include the following:

- Scaling of operating voltage ($V_{ds}Q$)
- Ambient temperature and partial or full ON/OFF self-heating affects
- Intrinsic voltage/current node access for waveform optimization
- Switch to turn on/off bond wires for die models, as applicable.

Figure 1 shows a typical die model ADS symbol showing the user inputs for the model. $V_{ds}Q$ for this particular model can be scaled from 12 to 28 V, while other models in this library can have values as high as 50 V depending on the device nominal operating bias condition. This can be thought of as a "scalable" sweet spot for the model. This is in contrast to typical nonlinear models; although they are inherently bias scalable, they are generally tuned for best performance around a particular operating voltage. This bias scalability feature improves accuracy for variable bias conditions and, for example, takes into account the fact that the Pulsed I-V data used to build the model is different when pulsed from different $V_{ds}Q$ values as shown in the model results of ***Figure 2a***.

The models allow the designer to take ambient and self-heating effects into account as well. ***Figure 2b*** shows simulation of I-V data with the "self heat factor" of Figure 1 set to 0 (no self-heating) and 1 (full self-heating, used for static bias/CW conditions). As another advanced custom feature, intermediate values between 0 and 1 can be used to estimate approximate partial self-heating effects of pulsed signals by setting the self heat factor equal to the duty cycle. Ambient temperature variation is provided by the "temperature" input to the model, which for this particular model is fit to temperature varied data over a range of 25° to 85°C. This range may vary as documented in the model information data sheet provided for each model.

The bond wire removal feature is provided for die models developed using fixtures with bond wires present. It allows users to conveniently either recreate the same simulation validations shown in the model information data sheet provided with bond-wires included, or remove the bondwires for embedding the model within their own unique circuit environments. This feature is not present in packaged devices, for models of die that can be directly wafer probed and for die models developed as scaled versions of measurement-based models from smaller die sizes.

Based on designer feedback, all models in the library provide for access to intrinsic voltage and current nodes for use in waveform analysis and optimization. ***Figure 3*** illustrates the concept. The goal is to provide designers access to the voltage/current nodes at the model's drain-to-source current generator plane while removing all parasitic effects. As seen in ***Figure 3b***, the reactance of the parasitics causes the simulated dynamic load line to swing outside the constraints of the I-V plane, even to negative currents; properly extracted intrinsic waveforms do not. ***Figure 4*** shows simulated intrinsic voltage and current waveforms. It is reassuring to see that the class A, B and AB currents are behaving as classically we would expect, with a full-wave current for Class A, half-wave rectified for Class B, and a similar, but reduced "conduction angle"[6] waveform for the Class AB current.

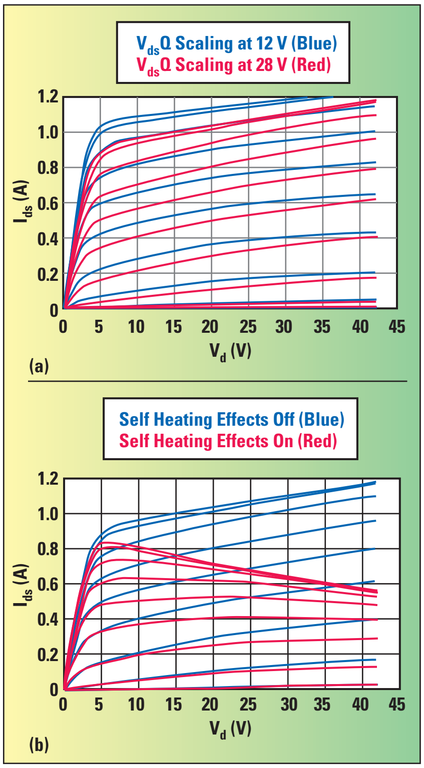
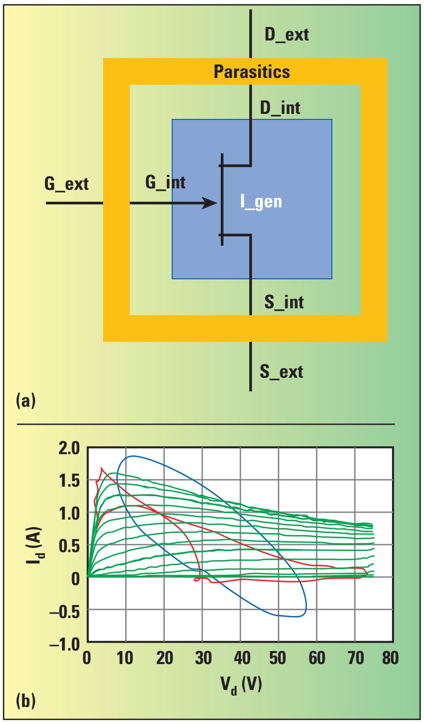


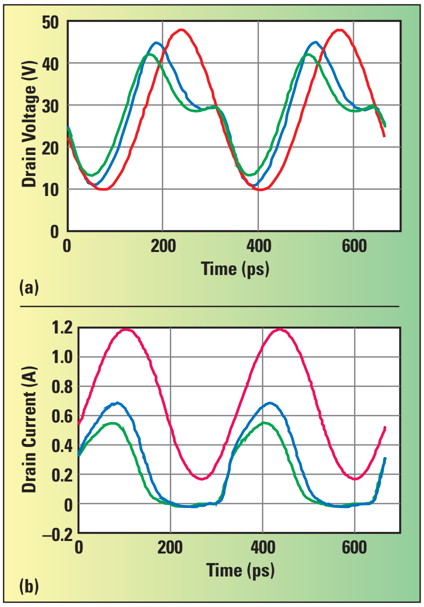
Fig. 2 Quiescent bias voltage ($V_{ds}Q$) scaling (a) and self heating effects (b) for the model of Fig. 1. Vgs range is -4 V to +1 V with a 0.5 V step.

DEVICE LEVEL VALIDATIONS

The model information data sheet mentioned earlier is the key to understanding the details of each model contained within the library. These details include a model features block, detailed device level validations, and in some cases PA circuit level validations employing a reference design. Typical data sheets contain 15 to 20 pages (or more) of information. Example device validations include simulated model agreement to applicable measurements of current-voltage (I-V) characteristics, multi-bias S-parameters, load-pull data and Pout/PAE/Gt power swept data. Some device models also include fitting against noise parameter data.

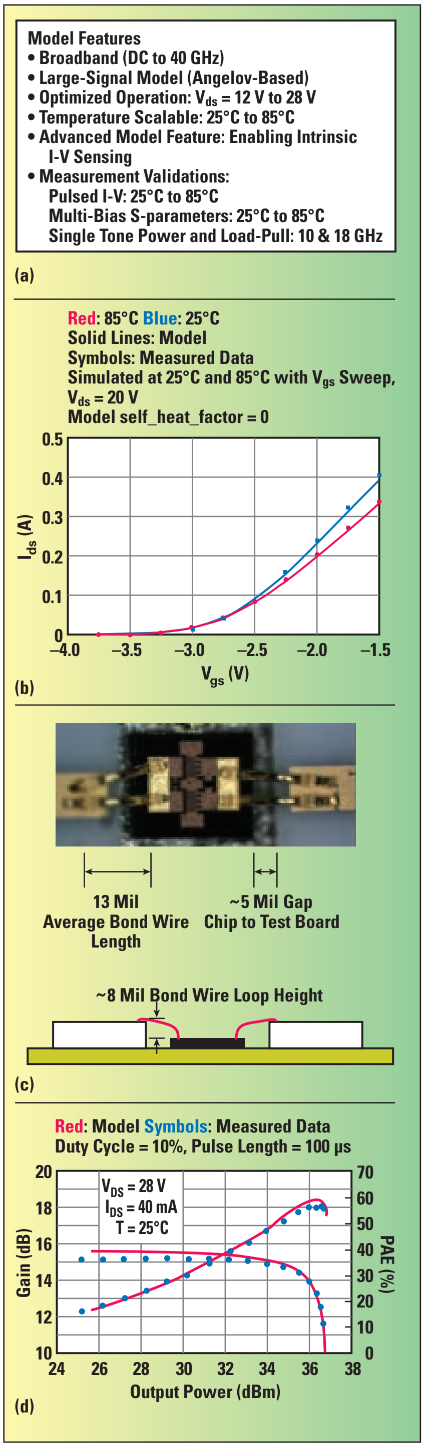


▲ *Fig. 3 Intrinsic waveform sensing concept (a) and simulated dynamic load-line results for a packaged transistor at the extrinsic (blue) and intrinsic (red) nodes (b).*



▲ *Fig. 4 Intrinsic voltage (a) and current (b) waveforms for a TGF2023-2-01 transistor die at intrinsic reference planes for class A (red), class AB (blue) and class B (green) biasing, at backed-off power.*

Figure 5 contains a few snapshots of the type of information contained in the data sheets for one of the most recently added GaN die devices based on a 0.15 um technology process. As summarized in the model features block (see **Figure 5a**), this particular model for the Qorvo TGF2935 device was validated to 40 GHz for S-parameters and at 10 and 18 GHz for high power performance on a large-signal load-pull bench. A snapshot of simulated and measured I-V performance is shown at two temperatures (see **Figure 5b**). An assembly diagram clarifies reference planes and bond-wire details (see **Figure 5c**). A plot of swept transducer gain (Gt) and efficiency versus output power validates the model's high power behavior against measured data (see **Figure 5d**). Large-signal and small-signal models are also available for the 0.15 um technology die devices that accurately predict noise parameters up to 26 GHz.



▲ *Fig. 5 Model data sheet information for the large-signal version of the TGF2935 die model: features block (a) I-V model vs. measurement (b) fixture assembly (c) 10 GHz single tone power sweep, power matched (d).*

Similar information is provided for packaged device models as suggested by **Figure 6**, which includes selected information from the model data sheet for the 285 W Qorvo T1G2028536-FL-001 device. The model features block (see **Figure 6a**) shows that this model is validated to 3 GHz for S-parameters, is temperature scalable and is validated against high power data at 1 and 1.5 GHz. Also shown are plots of simulation versus measurement for load-pull and power drive up data.

PA CIRCUIT VALIDATIONS

In addition to the device level model validations discussed above, validations are also performed at the power amplifier circuit level. This section, discusses four examples of simulation-based PA reference designs that have been used for additional model validations of packaged device models from the GaN library. These PA designs range from medium to high power using several unique device models in this library, with each model displaying its value in achieving successful first-time designs. All of the designs presented are as measured after first assembly with no board tuning or bias adjustment.

For 'closing-the-loop' on initial measurements and simulations for

these types of amplifier examples, detailed attention to the modeling of the passive matching and bias circuits is often found to be as important as the nonlinear model in terms of predicting the frequency dependent behavior of these amplifiers. Some board-dependent discrepancies are also significant to address along with the use of accurate parasitic models for all surface mount passive components, when used. These were modeled with Modelithics CLR Library™ models.[7]

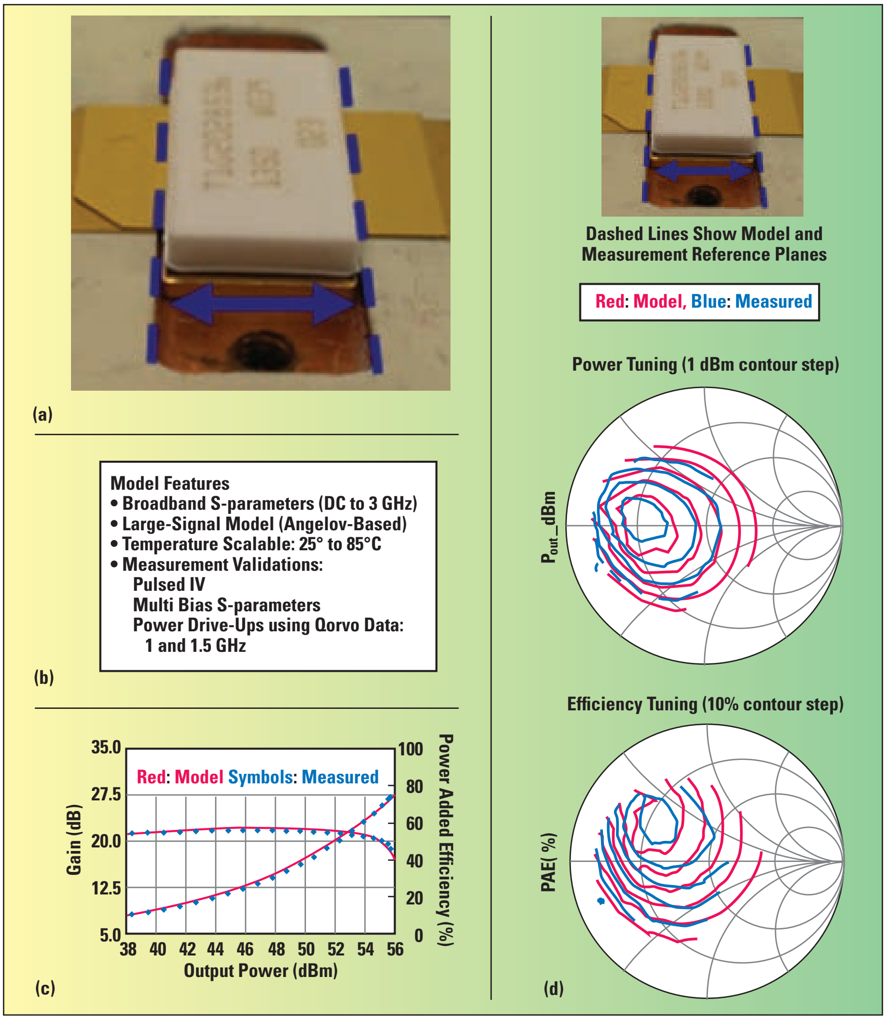
Table 1 summarizes the goals and results for the first PA design example used to validate the Modelithics model of Qorvo's TGF2819-FL discrete packaged GaN product. The assembled PA and simulation-to-measurement comparison are shown in ***Figure 7***. The use of the model enables a 'quick-turn' L-Band reference design of a high power, high efficiency PA, with greater than 150 W power and over 60 percent efficiency.

A second PA validation circuit is summarized in ***Table 2***, with details shown in ***Figure 8***, for validation of the Qorvo T2G6000528-Q3 GaN product. This is a 10 W design with

TABLE 1

SUMMARY OF 1.35 TO 1.75 GHz VALIDATION CIRCUIT FOR QORVO TGF2819-FL DEVICE MODEL

Design Specification	*Goal*	*Simulation*	*Measurement/Goal Met*
Device TGF2819-FL	Capable of 150 W	Operation: Class AB	Q Bias: 50 V at 250 mA
Gain (Linear)	17 dB ±1 at 1.55 GHz	17 dB ±1 at 1.55 GHz	✓
Power	>150 W, L-Band	>150 W	✓
Power-Added Efficiency	50%, L-Band	>60%	✓

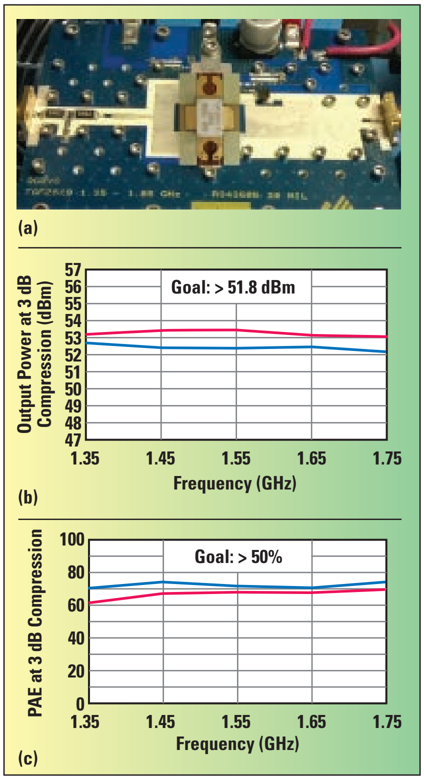


▲ *Fig. 6 Load-pull and power drive up validations for Qorvo's T1G2028536-FL-001 device (a) model features block (b) power swept validation at 1 GHz with power-tuned load (c), load-pull at 1 GHz on a 5 Ω Smith Chart and +35 dBm input power (d).*

TABLE 2

SUMMARY OF 5 TO 6 GHz VALIDATION CIRCUIT FOR QORVO T2G6000528-Q3 DEVICE MODEL

Design Specification	*Goal*	*Simulation*	*Measurement/ Goal Met*
Device T2G6000528-Q3	Good PAE at P_{3dB} > 40 dBm From 5 to 6 GHz	Operation: Class AB	Q Bias: 32 V at 50 mA
Gain (Linear)	13 dB	✓	✓
Power	10 W	✓	✓
Power-Added Efficiency	55%	✓	✓



▲ *Fig. 7 Assembled TGF2819-FL PA (a) with simulated vs. measured output power (b) and power-added efficiency (c). Red = simulation; blue = measurement average for five device samples mounted on one evaluation board.*

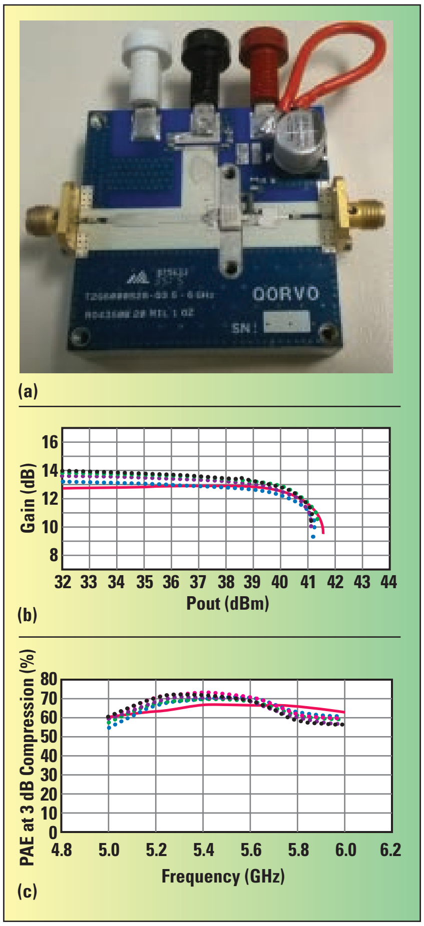
good measured to model agreement for a design operating from 5 to 6 GHz. The design has 55 percent efficiency and 13 dB gain. Furthermore, this example demonstrates the added value of the Modelithics large-signal model use for "design for production" by predicting the performance of a typical unit from Qorvo. The five units used in each amplifier have a two year data code gap which indicates good production consistency. The simulation is able to predict the average performance of the multiple amplifier units using the large-signal model.

Table 3 and ***Figure 9*** outline a third example, a 2 to 2.7 GHz design built by Qorvo producing 10 W, 50 percent efficiency and 20 dB gain with same device from the second PA example. ***Table 4*** and ***Figure 10*** show the details of the fourth PA validation circuit example using a model for the Qorvo T2G6003028-FS packaged product. This is a narrowband design centered at 5.8 GHz with 30 W of output power, while achieving 50 percent power-added efficiency and 14 dB gain. There is good agreement between simulation and measurement, except for a slight shift down in center frequency from the design target. A recent application note discusses the circuit level modeling process for this circuit in some detail, performed using Keysight ADS.[8]

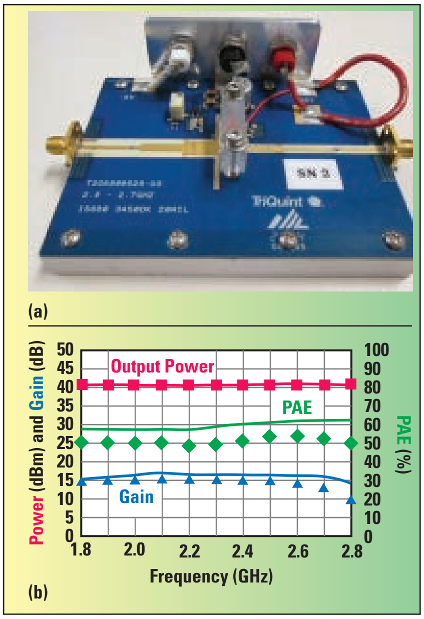
For all four of these designs, first pass design success was achieved thanks to the accuracy of the models used along with ADS simulations and optimizations of the circuits and element values prior to fabrication.

CONCLUSION

A productive collaboration between Qorvo and Modelithics has led to the advancement of an extensive library of GaN models for discrete die and packaged transistors. Each model



▲ *Fig. 8 10 W, 5 to 6 GHz PA reference design (a) with simulated vs. measured output power at 5.4 GHz (b) and power-added efficiency vs. frequency (c). Solid lines = simulation, dashed lines = measurement of five PAs.*



▲ *Fig. 9 10 W, 2 to 2.7 GHz PA (a) with simulated vs. measured performance at 3 dB compression (b). Solid lines = simulation, symbols = measurement.*

is very well documented with extensive device level validations outlined in a model information datasheet. A series of power amplifier reference designs have been used to validate the utility and accuracy of the models for practical PA design. This work has demonstrated that the new paradigm in PA design is to start with sound device models and solid modeling of all passive networks with the goal of replacing "old school" bench tuning with simulation and optimization to enable a one-pass 'simulate-build-test-done' PA design process.■

ACKNOWLEDGMENTS

The authors would like to thank the Modelithics engineering team for their hard work in developing and maintaining the Modelithics-Qorvo GaN library and the associated validations discussed in this application note. Thanks also to Richard Martin and Neil Craig of Qorvo for their enabling coordination of the collaboration leading to the described model library as part of the Modelithics Vendor Partner program.

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TABLE 3

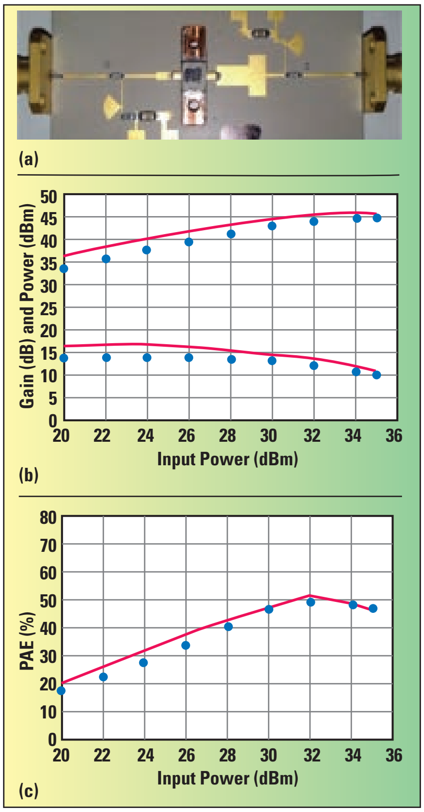
SUMMARY OF 2 TO 2.7 GHz VALIDATION CIRCUIT FOR QORVO T2G6000528-Q3 DEVICE MODEL

Design Specification	*Goal*	*Simulation*	*Measurement/Goal Met*
Device T2G6000528-Q3	Capable of 10 W	Operation: Class AB	Q Bias: 28 V at 50 mA
Gain (Linear)	20 dB ±1 at 2.4 GHz	20 dB ±1 at 2.4 GHz	✓
Power	10 W	10 W	✓
Power-Added Efficiency	50%	50%	✓

TABLE 4

SUMMARY OF 5.8 GHz VALIDATION CIRCUIT FOR QORVO T2G6003028-FS DEVICE MODEL

Design Specification	*Goal*	*Simulation*	*Measurement/Goal Met*
Device T2G6003028-FS	Capable of 30 W	Operation: Class AB	Q. Bias: 28 V/200 mA
Gain (Linear)	14 dB ±1 at 5.8 GHz	14 dB ±1 at 6 GHz	✓
Power	30 W	30 W	✓
Power-Added Efficiency	50%	50%	✓



▲ *Fig. 10 30 W, 5.8 GHz PA (a)[8] with simulated vs. measured gain and output power (b) and power-added efficiency (c). Solid lines = simulation, symbols = measurement.*

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CONTACT INFORMATION

For information on accessing the Modelithics-Qorvo GaN Model Library visit www.modelithics.com/mvp/qorvo (free to Qorvo approved designers). Contact support@modelithics.com in case of any difficulties or questions about Library or PA validation circuits. For information about Modelithics CLR Library or Modelithics COMPLETE Library, contact Modelithics at sales@modelithics.com or visit www.modelithics.com.

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ZVM-273HP+	13000-26500	14.5	0.5	0.5	2195
ZVE-3W-83+	2000-8000	35	2	3	1295
ZVE-3W-183+	5900-18000	35	2	3	1295
ZHL-4W-422+	500-4200	25	3	4	1160
ZHL-5W-422+	500-4200	25	3	5	1670
ZHL-5W-2G+	800-2000	45	5	5	995
ZHL-10W-2G+	800-2000	43	10	12	1295
• ZHL-16W-43+	1800-4000	45	12	16	1595
• ZHL-20W-13+	20-1000	50	13	20	1395
• ZHL-20W-13SW+	20-1000	50	13	20	1445
LZY-22+	0.1-200	43	16	30	1495
ZHL-30W-262+	2300-2550	50	20	32	1995
ZHL-30W-252+	700-2500	50	25	40	2995
LZY-2+	500-1000	47	32	38	2195
LZY-1+	20-512	42	50	50	1995
• ZHL-50W-52+	50-500	50	63	63	1395
• ZHL-100W-52+	50-500	50	63	79	1995
• ZHL-100W-GAN+	20-500	42	79	100	2395
ZHL-100W-13+	800-1000	50	79	100	2195
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ZHL-100W-43+	3500-4000	50	100	100	3595

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Rotary Joints for Transmitting HD-SDI Signals Through a Blocked Central Axis

SPINNER GmbH
Munich, Germany

Transitioning from analog to digital video, and especially to HD-SDI 292M or 424M, is not a simple matter. Normal coaxial cables work with non-rotating applications, but if the system is turning the digital signal has to pass through the rotary joint. For transmitting slower signals, the conventional approaches include the use of gold-on-gold, silver-graphite-on-brass or silver-plated slip rings. The diameter of the overall system is the constraining factor here. They can work at frequencies up to 250 MHz with very small diameters and at up to 100 MHz with larger diameters.

However, a different transmission technology is needed for 1.5 Gbit/s and faster signals. Contactless technology is the best solution for blocked central axes but when the axis is open, the best approach is a fiber-optic link. For cases in which the central axis is blocked (because it contains a mechanical interface, RF components, etc.), no acceptable solution was available for transmitting a test signal which contains a pathological pattern until recently. To address this, SPINNER has modified its standard capacitive coupling device to meet the specification, resulting in a perfect eye diagram.

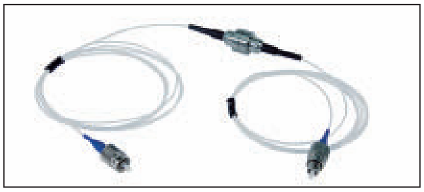


Fig. 1 The single-channel FORJ 1.14.

For HD-SDI (SMPTE 292M) signals, the company has adapted a number of hybrid rotary joint units involving signal multiplexers for RS422, RS232, CAN bus, I/O lines and 1000BaseT Ethernet. One example is a very complex installation with three HD-SDI cameras and around 150 RS422 lines. For this a fiber-optic rotary joint that is half the size of a conventional slip ring unit and has an MTBF of at least 300,000 hours was developed. This is a 1000 percent improvement.

The other benefits of a solution like this include less weight, smaller interfaces, lower prices, and an end to issues with terminations and end-to-end resistances.

Currently there are uses for HD-SDI contactless rotary joints in tracking radar systems, gun systems and naval optronic systems. They are available with clear internal diameters of up to 300 mm and more. If the central axis is free, fiber-optic rotary joints can be used.

FIBER OPTIC ROTARY JOINTS

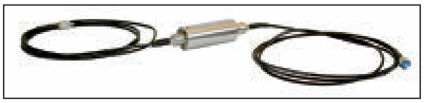
SPINNER has developed a series of Fiber Optic Rotary Joints (FORJ). Single-mode and multimode FORJs are used in land-based, naval, and airborne applications, either by themselves or integrated in a slip ring.

The new FORJ 1.14 (see ***Figure 1***) family of single-channel products is claimed to exhibit

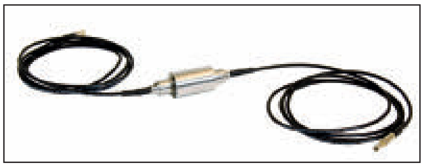
outstanding performance despite its very compact dimensions. Its design reduces the typical insertion losses to less than 1 dB with single-mode fibers. Its small size, combined with a light weight of only 18 g, permits it to spin at speeds of 10,000 rpm or more. Also, the company's FLEXIFLANGE makes it easy to adapt this rotary joint to specific applications.

The FORJ 1.17 (see ***Figure 2***) is engineered for harsh environments, being able to withstand intense vibrations, strong jolts, high humidity and saltwater. It was originally designed to meet the needs of offshore and underwater vessels and has an IP 68 protection rating. The single-channel rotary joint FORJ 1.17pc version is supplied with integrated pressure compensation for deep-sea applications down to depths of 4500 m.

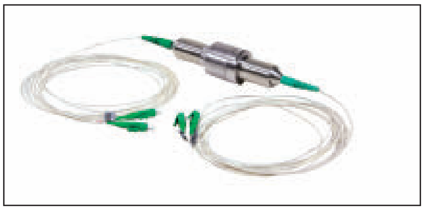
For harsh industrial environments the FORJ 1.22 (see ***Figure 3***) is rated



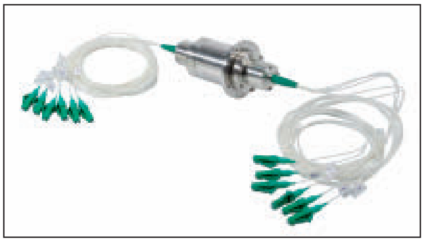
▲ *Fig. 2 The FORJ 1.17 is engineered for harsh environments.*



▲ *Fig. 3 The FORJ 1.22 is rated at IP 65.*



▲ *Fig. 4 The FORJ 2.28 fills the need for a basic two-channel, single-mode rotary joint.*



▲ *Fig. 5 The FORJ x.40 has an outer housing diameter of only 39.5 mm.*

at IP 65 for protection from dust and humidity. It includes protective tubing for the fibers to prevent them from breaking or otherwise being damaged during or after installation.

The dual-channel FORJ 2.28 (see ***Figure 4***) fills the need for a basic two-channel, single-mode rotary joint. Its patented mechanical system makes it very compact with a total length of just under 90 mm and an outer diameter of only 28 mm. It is offered in versions that include multimode only or a combination of single-mode and multimode fibers.

Finally, the FORJ x.40 (see ***Figure 5***), with an outer housing diameter of only 39.5 mm, is claimed to deliver market-leading compactness for multi-channel solutions involving up to six channels. It is available in single-mode, multimode and mixed fiber configurations.

VENDORVIEW

SPINNER GmbH
Munich, Germany
www.spinner-group.com

V-, E- and W-Band, Full S-parameter VNA Extenders

SAGE Millimeter Inc.
Torrance, Calif.

The millimeter wave industry is experiencing enormous growth from an increasing and diversified customer base, created by new consumer demand and continuing defense requirements. There is an undeniable call for new technologies in both connectivity and radar applications. With the current amount of research and development invested in new systems at multi-gigabit rates (e.g., WiGig, 802.11ad, 5G, last mile connectivity, small cells, cube satellite networks, driver assisted automotive systems and the IoT), low cost instrumentation and measurement solutions are greatly needed at millimeter wave frequencies.

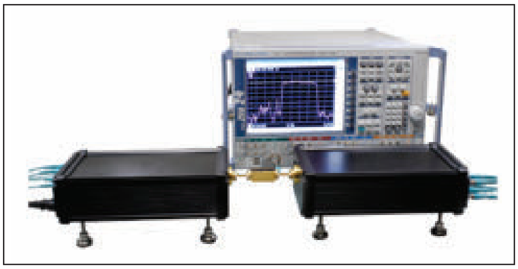


Fig. 1 VNA extender with an OEM's low frequency VNA.

Responding to these marketplace demands, SAGE Millimeter called upon its millimeter wave expertise to extend its reach into test and instrumentation. Known for high performance millimeter wave components, the company drew from its broad product offering to develop three new VNA extenders, which were introduced at IMS2016. SAGE Millimeter's vertical approach is what provides RF engineers with a cost-effective solution for their test environments.

Models STO-15-S1, STO-12-S1 and STO-10-S1 are millimeter wave, full waveguide band vector network analyzer (VNA) extenders that enable a standard 20 GHz VNA to cover the frequency range from 50 to 110 GHz. The extenders are offered in three waveguide bands: V-, E- and W-Band and are designed to work with multiple VNA systems (see ***Figure 1***). The extenders function seamlessly with Rohde & Schwarz, Keysight Technologies and Anritsu's VNA systems that have direct receiver access, preserving the full functionality offered by the original VNAs. The extended VNAs in the millimeter wave bands are capable of performing full S-parameter measurements as well as the other functions of the standard 20

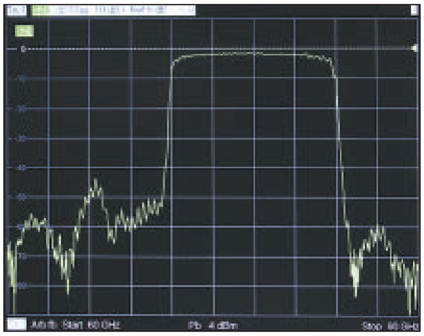


Fig. 2 Measured insertion loss of a 73 to 83 GHz bandpass filter using the E-Band VNA extender.

GHz VNA, such as gain compression, IMD, etc. ***Figure 2*** shows the measured insertion loss of a 73 to 83 GHz bandpass filter measured using the E-Band extenders.

The VNA extenders include two identical transmitter/receiver boxes (see ***Figure 3***), with a simple interconnection and setup process. The test ports of the VNA extenders are standard waveguide. The interconnections between the extenders and OEM low frequency VNA are made through four, 3" long, high performance, phase stable cables with SMA male connectors at both ends. The extenders are powered by the standard wall outlet, with a voltage range from 100 to 240 VAC. To ensure full product integrity and control, all the VNA extender models are built with SAGE Millimeter's in-house components, which include amplifiers, harmonic mixers, isolators, multipliers and filters. The specifications of the standard V-, E- and W-Band VNA extenders are shown in ***Table 1***. The designs can be customized to specific customer requirements, leveraging SAGE Millimeter's extensive component capabilities.

A full line of waveguide calibration kits has also been developed to complement the VNA extenders. These kits allow for full two port calibration of the extended VNA in their respective millimeter wave bands.

VENDORVIEW

SAGE Millimeter Inc.
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info@sagemillimeter.com
www.sagemillimeter.com

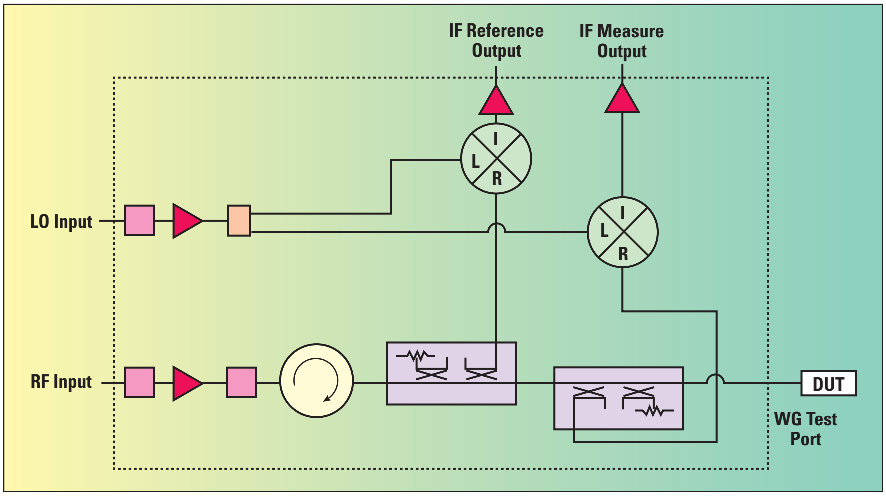

Fig. 3 Transmitter/receiver box block diagram.

TABLE 1

SPECIFICATIONS OF MILLIMETER WAVE EXTENDERS

Extender Model Number	STO-15-S1	STO-12-S1	STO-10-S1
Operating Frequency	50 to 75 GHz	60 to 90 GHz	75 to 110 GHz
RF Output Power	+1 dBm	0 dBm	-1 dBm
System Dynamic Range	90 dB	90 dB	90 dB
Directivity	40 dB	40 dB	40 dB
LO Path Multiplication Factor	×6	×6	×6
LO Path Input Frequency	8.33 to 12.5 GHz	10 to 15 GHz	12.5 to 18.33 GHz
LO Path Input Power	0 to +6 dBm	0 to +6 dBm	0 to +6 dBm
RF Path Multiplication Factor	×4	×8	×8
RF Path Input Frequency	12.5 to 18.75 GHz	7.5 to 11.25 GHz	9.375 to 13.75 GHz
RF Path Input Power	+3 to +10 dBm	+3 to +10 dBm	+3 to +10 dBm
IF Output Frequency	10 to 1000 MHz	10 to 1000 MHz	10 to 1000 MHz
IF Output Connectors	SMA (F)	SMA (F)	SMA (F)
RF Path Input Connector	SMA (F)	SMA (F)	SMA (F)
LO Path Input Connector	SMA (F)	SMA (F)	SMA (F)
Test Port Interface	WR-15 UG385/U Flange	WR-12 UG387/U Flange	WR-10 UG387/U-M Flange
Extender Size	11.11" (L) × 6.15" (W) × 4.56" (H)		
Extender Weight (oz)	8 lbs Each		
Extender Finishing	Black Anodized		
Outline	TN-VV	TN-EV	TN-WV


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Two- and Four-Way Power Combiners Handle Up To 800 W

Fairview Microwave
Allen, Texas

With the growth in wireless communications, the mobile infrastructure is handling higher data rates and tasked to have lower noise and greater power efficiency. Many of these systems combine power amplifiers with high power density over wide bandwidths, and the power combining must be packaged to withstand rugged environments. Similarly, many defense systems – from radar to electronic warfare – are combining power amplifiers to meet higher power mission requirements. The power combining requirements are similar, with stringent demands for ruggedness and reliability.

Designed to address these needs, Fairview Microwave's family of high power RF combiners offers power handling up to 800 W, covering various frequency bands to 6 GHz with low insertion loss, low VSWR and high isolation. The combiners are excellent for amplifier power combining, as their low insertion loss minimizes power loss to deliver a higher power combined signal at the output. The combiners have high reliability to meet the requirements for defense and infrastructure applications.

In addition to high power handling, Fairview Microwave's power combiners are designed to maintain very low insertion loss and high isolation over a wide bandwidth, up to 5 GHz. Competitive power combiners typically have a maximum input power handling of 100 W and cover less bandwidth. All the power combiners in the Fairview Microwave family use a reactive design, which yields low insertion loss, excellent amplitude and phase balance, high port-to-port isolation, high power handling and compact size. Package sizes range from 1.4" × 2" × 0.73" to 5.1" × 4.72" × 1.54". The combiners have a standard impedance of 50 Ω and operate from -55° to +85°C. The family includes both Type N and SMA connector options, with the Type N combiners able to handle higher input power.

ARRAY OF OPTIONS

With 17 high power combiners to choose from, the product family offers an array of options: 2- and 4-way, input power handling and frequency. The part numbering system denotes the frequency range, maximum input power and whether 2- or 4-way (see ***Figure 1***). All combiners are in stock and ready for immediate shipment.

20 MHz to 1 GHz Combiners

The MPP0201K0100-2, MPP0201K0500-2, MPP0201K0200-4 and MPP0201K0300-4 all operate from 20 MHz to 1 GHz. The 2-way combiners, MPP0201K0100-2 and MPP0201K0500-2, handle a maximum input power of 100 and 500 W, respectively. The MPP0201K0200-4 and MPP0201K0300-4 are 4-way combiners with maximum input power handling of 200 and 300 W, respectively. The 4-way combiners have a maximum insertion loss of 0.75 dB and a minimum isolation of 12 dB. The 2-way, 100 W combiner has an insertion

loss of 0.6 dB with an isolation of 15 dB (see ***Figure 2***), and the 500 W combiner insertion loss is a maximum of 0.8 dB, with an isolation of 10 dB.

500 MHz to 2.5 GHz and 800 MHz to 2.5 GHz Combiners

The MPP8002K5600-2, MPP8002K5800-2, MPP8002K5200-4 and MPP8002K5600-4 all cover 800 MHz to 2.5 GHz, and the MPP5002K5200-2 spans 500 MHz to 2.5 GHz. The three 2-way combiners have maximum input power of 200, 600 and 800 W — 800 W being the highest power offered in the family. The maximum insertion loss for all of these combiners ranges from 0.4 to 0.8 dB, with isolation as high as 13 dB.

800 MHz to 4.2 GHz Combiners

The MPP8004K2200-2 and MPP8004K2200-4 cover the 800 MHz to 4.2 GHz frequency range. Both have a maximum input power of 200 W.

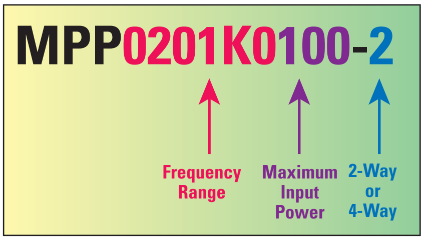


Fig. 1 The part number denotes the frequency range, maximum input power and whether the product is 2- or 4-way.

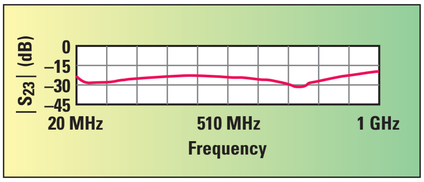


Fig. 2 Isolation vs. frequency of the 2-way, 100 W, 20 MHz to 1 GHz combiner (MPP0201K0100-2).

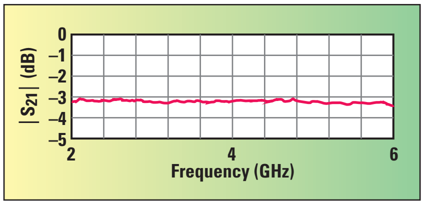


Fig. 3 Insertion loss vs. frequency of the 2-way, 100 W, 2 to 6 GHz combiner (MPP2K06K0100-2).

2 to 6 GHz Combiners

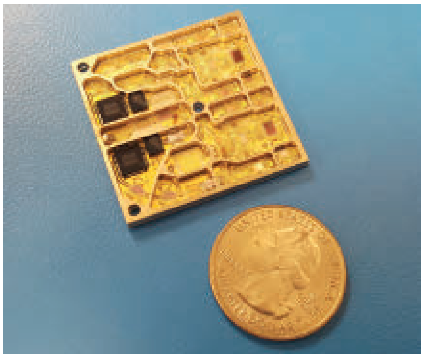
The MPP2K06K0100-2, MPP2K06K0100-4 and MPP2K06K0400-4 cover 2 to 6 GHz. The 2-way MPP2K06K0100-2 and 4-way MPP2K06K0100-4 handle a maximum input power of 100 W, while the 4-way combiner MPP2K06K0400-4 handles 400 W. The maximum insertion loss of the 4-way power combiners is 0.8 dB, and the 2-way combiner's insertion loss is only 0.35 dB (see ***Figure 3***).

1 to 6 GHz Combiners

The MPP1K06K0100-4 is the broadest bandwidth combiner offered in the series, with an input power of 100 W, an insertion loss of 0.85 dB and a minimum isolation of 6 dB.

Combiner pricing ranges from $727 to $2,166, depending on the input power handling and whether 2- or 4-way.

Fairview Microwave
Allen, Texas
www.fairviewmicrowave.com



2 to 18 GHz Receiver in a BGA Package

For critical applications where size, weight and power are as important as performance, Mercury Systems developed the MSC0218L4444, a 2 to 18 GHz receiver integrated in a 1.4" × 1.4" × 0.125" surface-mount module. The input signal passes thru a limiter, to prevent receiver damage, and is then filtered into four 4 GHz-wide channels. The two higher frequency channels are down-converted prior to detection and digitization, and the two lower frequency channels are detected and digitized. The input signal amplitude is represented by a 14-bit digital word. The power-limited output of each channel is presented through the BGA for further detection and processing. The analog-to-digital converters and down-converting mixers are integrated in the module with the 9.15 GHz VCO used for the down-conversion supplied from an external source.

The receiver has a maximum noise figure of 6.5 dB. Gain can be controlled through internal analog attenuators with a 32 dB range, set with a +2.5 V control signal. The input 1 dB compression point is –2 dBm from 2 to 10 GHz and –8 dBm from 10 to 18 GHz, with an input IP3 of +7 and –2 dBm from 2 to 10 GHz and 10 to 18 GHz, respectively. Integrated, tunable bandstop filters, with a maximum rejection of 25 dB, help suppress interfering signals; tuning is set with a +14 V tuning voltage. The receiver dissipates approximately 9.4 W, biased with +9 V at 0.52 A, +5 V at 0.94 A and –5 V at 10 mA. The operating temperature range is –50°C to +85°C.

The MSC0218L4444 is packaged in a ball grid array (BGA) with 12 mil diameter, Sn 63 balls to connect the output, LO, tuning, attenuation and bias. The RF input signal uses an SMPS full detent connector mounted on the side of the module. The unit is environmentally sealed and has three 0-80 thru holes for mounting.

Mercury Systems
Chelmsford, Mass.
mrcy.com/sip

Real-Time Cross Correlation Phase Noise Analyzer

The HA7062C tunable phase noise analyzer responds to industry demand for an easy to use phase noise measurement system that is highly reliable and intuitive while offering real-time measurement speeds for optimal manufacturing test throughput. The HA7062C operates from 10 MHz to 6 GHz with an option to 20 GHz. It is a cost effective solution for R&D, offering measurement floors below -190 dBc/Hz and ANSI Z540 calibrated accuracy.

The core engine combines the best of traditional analog phase noise measurement front-ends (virtually spur free) with the latest technology in cross correlation analysis. The digital analysis system leverages a proprietary DSP with a powerful cross correlation engine. Holzworth's fully shielded, fanless 1U chassis eliminates ground loops and troublesome microphonics for uncompromising performance when compared to traditional "rack and stack" style systems.

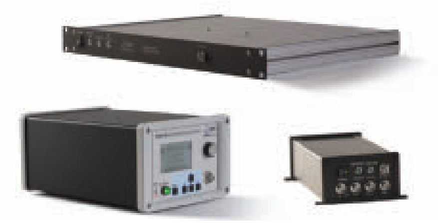
The HA7062C is outfitted with a pair of Holzworth HSX Series RF synthesizers which are utilized as the built-in tunable LO sources for measurements made in internal LO mode. The HSX Series phase noise performance enables the HA7062C to quickly measure the phase noise of extremely stable signal sources.

In addition, the HA7062C offers External LO Bypass Mode, which allows users to connect and calibrate two external LOs with similar performance to the DUT. This enables accurate measurements of extremely high performance oscillators within seconds.

All data processing is performed internally. Settings can be changed using serial commands. Results can also be read from the instrument directly without requiring a specific operating system. The hardware includes a MATLAB™ Runtime based GUI. To backup the reliability, a three-year product warranty covers 100% of any potential manufacturing defects.

VENDORVIEW

Holzworth Instrumentation
Boulder, Colo.
(303) 325-3473, option 1
Email: sales@holzworth.com
www.holzworth.com



Low Phase Noise, Micro-Hz Resolution Signal Generators to 26.5 GHz

Berkeley Nucleonics' 845 series RF/microwave signal generators cover 9 kHz to 12, 20 or 26 GHz with exceptional phase noise: –115 dBc/Hz at 1 kHz offset with a 4 GHz signal, for example. Advanced frequency synthesis with a fractional-N divider provides the low phase noise as well as micro-Hz resolution. The series has full analog modulation capabilities, i.e., frequency, phase, power, pulse and chirp; the signal generator can also be provided without modulation capability (LO option) for a lower price.

The 845 RF/microwave signal generators are available in formats and packages that make them versatile for any application, from lab to remote field use: a small module based synthesizer, a 1U 19" rack-mount enclosure, and a compact benchtop unit with internal rechargeable battery option and carrying case for field use. The adjustable output power can be increased from the standard +15 dBm to +26 dBm (option HP).

With the fast switching option (FS), the 845 provides extremely fast sweeps that, combined with the trigger system, generates accurate and rapid frequency and power ramps down to 10 µs. Compared to traditional analog sweeps, fast digital sweeps can be synchronized at any time during the sweep and yield precise frequencies throughout the sweep. The signal generator can be programmed to execute sweeps with either the free BNC graphical user interface (GUI) or by SCPI commands via USB, LAN or GPIB. The sources may also be accurately synchronized to external equipment using input and output triggering.

The 845 series is a proven alternative to large, complex and expensive instruments — for a fraction of the cost.

VENDORVIEW

Berkeley Nucleonics Corp.
San Rafael, Calif.
www.berkeleynucleonics.com

Company Showcase

Connectorized Modules

VENDORVIEW

Leveraging the industry's broadest device portfolio, including many recent releases, together with advanced mechanical and thermal design expertise, Analog Devices has created a wide range of connectorized modules, from 40 GHz switches to 8 kW power amplifiers. These easy-to-use, high RF performance and hermetically sealed modules offer not only fast development times and high-reliability, but also enable complete signal chain solutions for aerospace and defense, instrumentation and communications applications. Visit www.analog.com/conmodules to see the module solutions brochure, and www.analog.com/subsystemchallenges for an article on mastering defense subsystems thermal challenges.

Analog Devices
www.analogdevices.com

Solid-State Power Amplifier

VENDORVIEW

CPI Beverly Microwave Division's VSC3645 is a C-Band 4 kW modular GaN, high power, solid-state power amplifier, operating from 5.2 to 5.9 GHz at 10 percent duty. Designed to be modular, this amplifier consists of four, blind mated, ruggedized, SSPAs and is designed around GaN semiconductors from Wolfspeed. Benefits include: BIT and controls via EIA-422 remote connection, blind mated DC and control connectors, high gain, excellent pulse fidelity and outstanding spectral performance. For use in maritime, defense radar and weather radar applications.

CPI Beverly Microwave Division
www.cpii.com/bmd

Solid-State Amplifier Solutions

CTT announced a new 48-page product catalog: Solid-State Amplifier Solutions for Military and Commercial Applications. The new catalog features over 830 amplifier products, of which over 365 are all new. Product offerings include new GaN power amplifier technology for narrowband, wideband and ultra-wideband applications. Many new GaAs-based power and low-noise amplifier designs are also listed, including new Ka-Band, low-noise amplifiers. The catalog also includes application information and case outline drawings. Visit CTT's website for a free download.

CTT Inc.
www.cttinc.com

Programmable Attenuators

Fairview Microwave Inc. released a new family of digitally controlled programmable attenuators with performance up to 40 GHz and up to 60 dB attenuation range with 0.03 dB minimum step size. In-stock and available to ship today, these programmable attenuators are commonly used in electronic warfare, military and space communication systems, radar, and test and measurement applications. Fairview's digitally controlled attenuators perform the important function of adjusting the amplitude of signal levels in RF, microwave and millimeter wave systems.

Fairview Microwave Inc.
www.fairviewmicrowave.com

Reliable, High Performance Solutions

VENDORVIEW

The first part of HUBER+SUHNER's new Defense Catalogue shows connectivity solutions for different applications, such as airborne, radar, naval, command & control, vehicles and tactical equipment. The second part is a mirror of the growing product portfolio of defense specific products for data, signal and energy transmission such as: SUCOFLEX 200, SUCOFLEX 300, Eacon, Self-Locking connectors, VITA 67, Minibend CTR, RF-over-Fiber series, SENCITY Shield and GPS Antennas. Available for download online or contact your sales representative for the printed version.

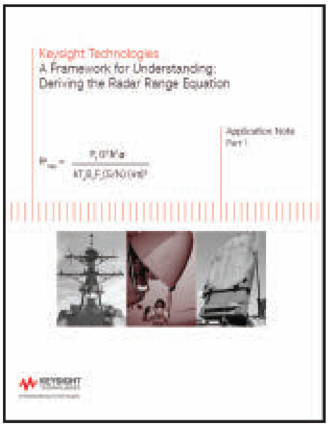
HUBER+SUHNER
http://Aerospacedefense.hubersuhner.com/downloads

Broadband Switch

HXI's HSWM22801-309 SPDT broadband switch covers a wide range of applications in the 26 to 40 GHz band. The switch uses a low loss microstrip structure and a GaAs MMIC which also offers high RF power handling. Superior performance in a compact size is featured in this design. Applications include transmit/receive switching, receiver protection, integrated subsystems and general RF switching. Renaissance Electronics & Communications LLC and its wholly owned subsidiary HXI LLC, provide RF, microwave and millimeter wave solutions for military and commercial applications.

HXI LLC
www.hxi.com

Company Showcase



Radar System Fundamentals

VENDORVIEW

Keysight Technologies' new application note, "A Framework for Understanding: Deriving the Radar Range Equation," covers the fundamentals of the radar range equation, which captures essential variables that define maximum distance at which a given radar system can detect objects of interest. This mathematical foundation provides a powerful framework for understanding, characterizing and verifying the actual performance of any radar system. Subsequent application notes in this series will focus on four sections of the block diagram: transmitter, receiver, duplexer and antenna.

Keysight Technologies Inc.

www.keysight.com/find/radar

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

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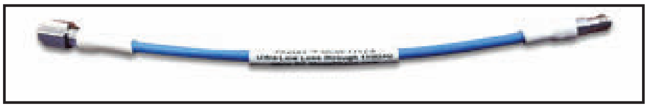
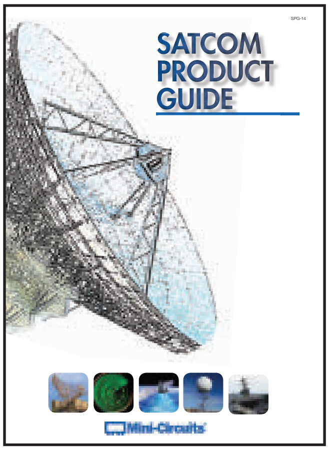


110 GHz Cable Assemblies

MegaPhase offers its Mega110 products with 1.0 mm connectors in both semi-rigid and flexible cable assemblies. Their lightweight 110 GHz cable assemblies are specifically designed for the demands of high-bandwidth applications such as automotive radar, probe stations and mobile backhaul. Visit http://www.megaphase.com/rf/110 and http://megaphase.com/rf/ to review and download the product datasheets. Contact MegaPhase for a quote: Solutions@MegaPhase.com or (877) MEGAPHASE.

MegaPhase LLC

www.megaphase.com



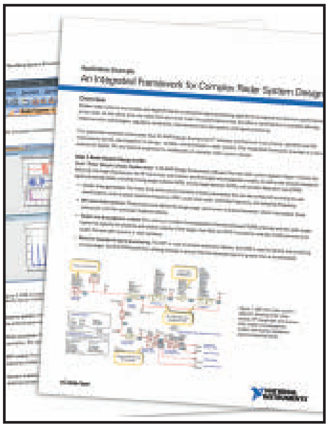
SATCOM Product Guide

VENDORVIEW

Mini-Circuits' SATCOM Product Guide features a full survey of components and assemblies for satellite and Earth station systems. With selected models from over 20 different product types to 40 GHz, this guide provides key performance parameters for each product and serves as a handy reference for engineers in the satellite communications field evaluating parts for their design needs. The SATCOM Product Guide also features several integrated modules showcasing some of their custom design capabilities supporting satellite IF band applications.

Mini-Circuits

www.minicircuits.com



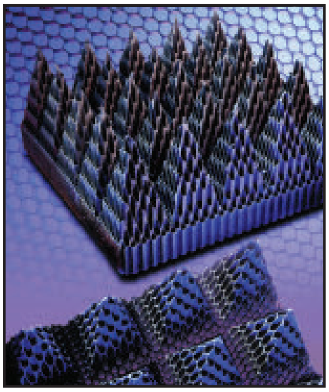
Complex Radar System Design

VENDORVIEW

Modern radar systems are complex and rely heavily on advanced signal processing algorithms. The radio front-end must meet specifications, often a combination of available devices, implementation technologies and regulatory constraints. This new application note showcases how NI AWR Design Environment, LabVIEW and PXI instruments work together to design, validate and prototype a radar system, providing a unique avenue for digital, RF and system engineers to collaborate on complex radar system design. Visit www.awrcorp.com/sites/default/files/AN-RDR-EMP-2015.6.23.pdf.

National Instruments

www.awrcorp.com

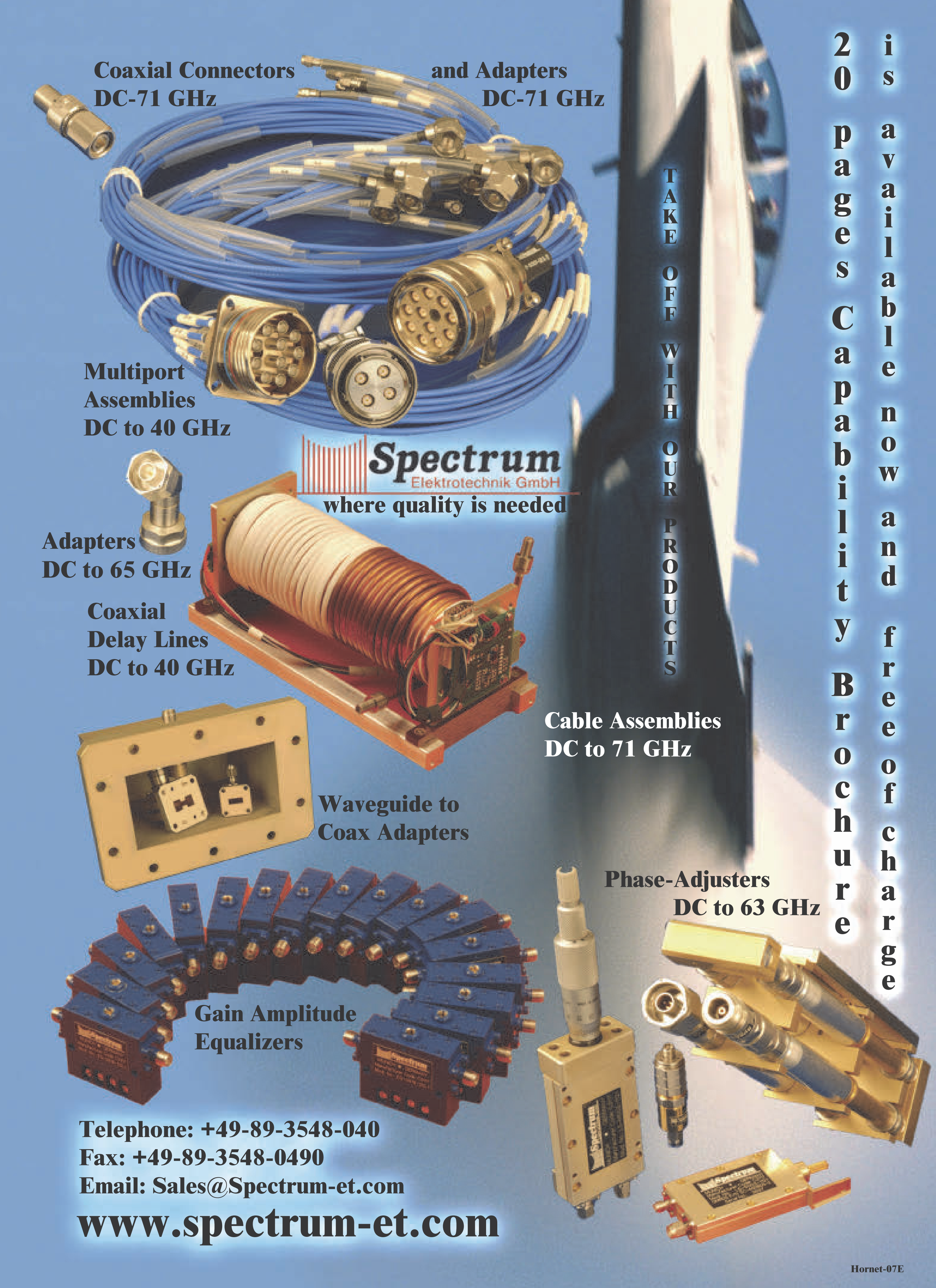


Microwave Absorbers

PPG Aerospace-Cuming Microwave is a manufacturer of microwave absorbers for cavity suppression and free space applications. Their featured product is the C-RAM™ SFC-HC high-power, broadband pyramidal honeycomb RF absorber, a phenolic-coated honeycomb able to handle up to 10 W/in^2 of power with no forced air. Other products include: C-RAM™ Lossy Foams and Elastomeric Flat Sheet Absorbers, C-RAM Anechoic & Free-Space Materials, C-RAM Turnkey Anechoic & EMC Chamber Design and Installation, and C-STOCK™ Low Loss Dielectric Materials. Custom formulations and fabrications available. Email cmcsales@ppg.com or call (508) 521-6700.

PPG Aerospace-Cuming Microwave

www.cumingmicrowave.com



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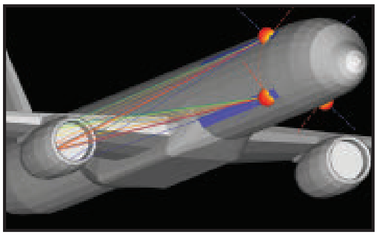
Company Showcase

Filters, Multiplexers and Multi-Function Assemblies

VENDORVIEW

When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. You can count on Reactel to satisfy the most demanding requirements for units used in extremely harsh environments. The full-line catalog features RF and microwave filters, multiplexers and multi-function assemblies for the military, industrial and commercial industries. To request a copy visit the company's website or e-mail reactel@reactel.com.

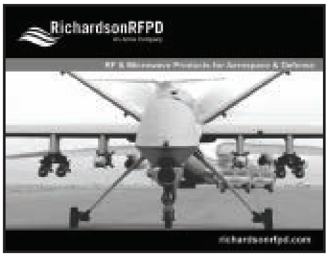
Reactel Inc.
www.reactel.com



EM Analysis for Electrically-Large Platforms

Remcom's XGtd is a general purpose ray-based electromagnetic analysis tool for assessing the effects of a vehicle or vessel on antenna radiation, estimating radar cross section (RCS), and predicting coupling between antennas. It is ideally suited for applications with higher frequencies or very large platforms where the requirements of a full physics method may exceed available computational resources. Learn more at www.remcom.com/xgtd.

Remcom
www.remcom.com/xgtd



Aerospace & Defense Selector Guide

VENDORVIEW

Richardson RFPD is an AS9120-certified, global component distributor specializing in advanced connectivity solutions, and A&D is their largest market. The company's GaN technology portfolio and wide range of MMICs, RF transistors, PAs and diodes from leading brands like ADI, MACOM, Microsemi, NXP and Qorvo serve a range of A&D applications, including radar, avionics, EW and communications. Among the latest additions to their A&D line are New Edge products and the Metelics diodes now offered by MACOM.

Richardson RFPD
www.richardsonrfpd.com

Expanded Website

RLC Electronics has expanded its "New Products" feature on their website, adding press releases, photos, electrical information and outline drawings where available. Some of the latest releases include high-power 18 GHz SPDT switches with N connectors, 30 GHz surface mount cavity filters, Ka-Band connectorized cavity filters, miniature SP2T switches with MS connectors and phase trimmers, as well as integrated assemblies such as switched filters. RLC will continue to publish new products in this section moving forward on a bi-monthly basis.

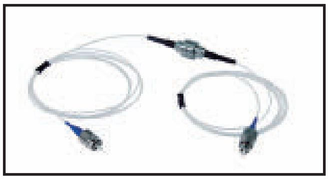
RLC Electronics Inc.
www.rlcelectronics.com

True Swept Connectors

VENDORVIEW

In order to achieve outstanding performance of a connector, air as dielectric and a narrow bead for captivation is needed. Spectrum offers the right angle airline connectors of series 1.85 mm, 2.4 mm, 2.92 mm and 3.5 mm; N and TNC with PTFE dielectric. The VSWR is almost identical to straight units, operating to 18, 26, 40, 50 and 63 GHz. From the outside the units look like mitered, but internally they are true swepts. The units are available for operation temperature to +80°C and to +150°C as well.

Spectrum Elektrotechnik GmbH
www.spectrum-et.com



Fiber Optic Rotary Joints

VENDORVIEW

The SPINNER FORJ 1.14 is designed with a low profile and minimal weight for use in rough environments characterized by strong vibrations and jolts. It is typically integrated in the airborne targeting systems of UAVs, aircrafts or helicopters. In ground-based and mobile military radar systems, the SPINNER FORJ enables transmission of the massive amounts of data passing between the rotating antenna and the processing unit inside the shelter or vehicle. For these applications, SPINNER has equipped a multi-channel FORJ with RF rotary joints, slip rings, and media joints for supplying power and coolant to the antenna.

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www.spinner-group.com

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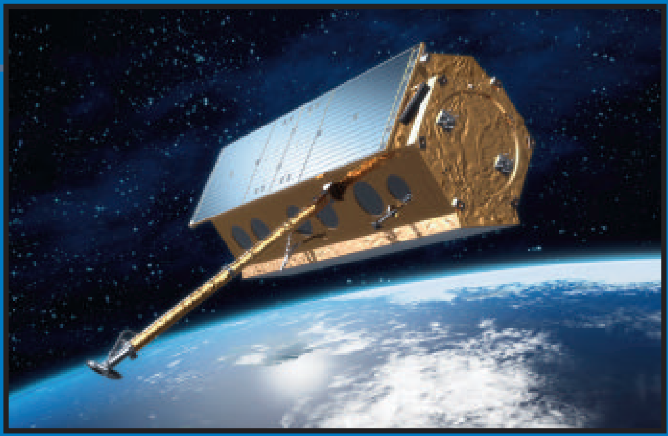
Instantly Improve the Performance of Your Phased Array Radar!



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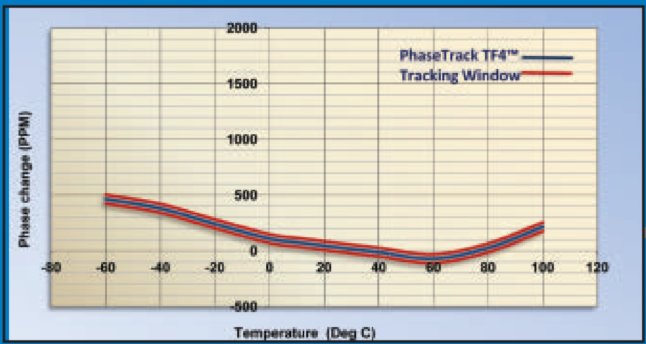
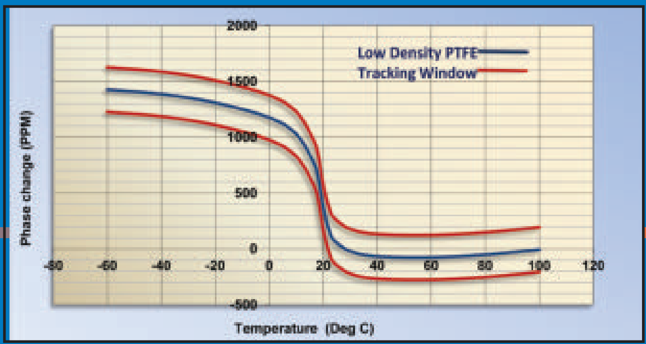


Typical Low Density PTFE Performance



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