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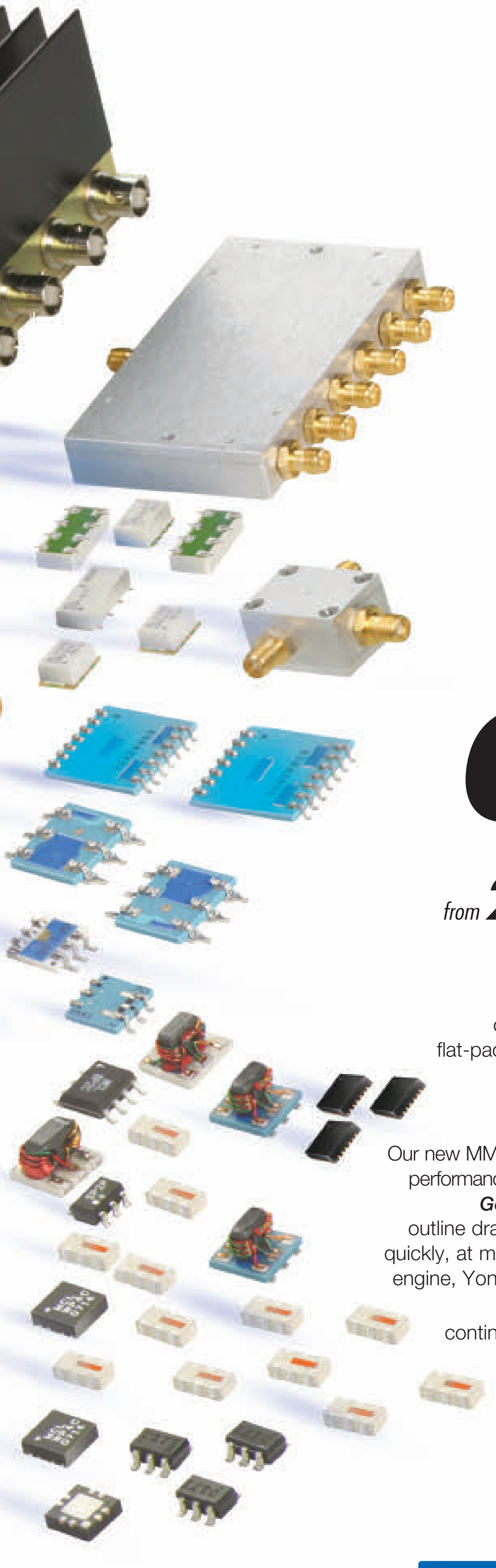

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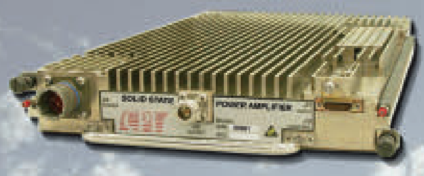

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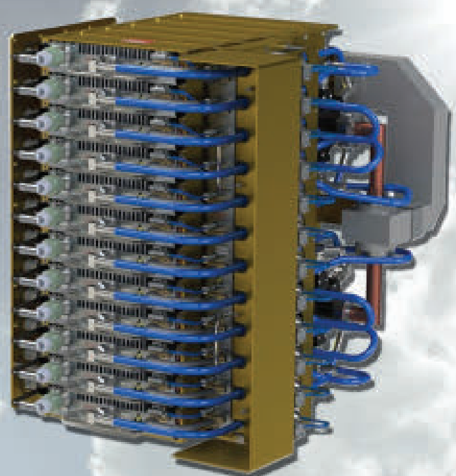

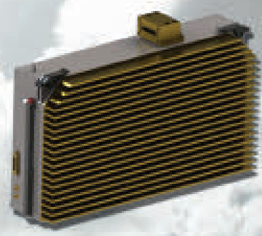

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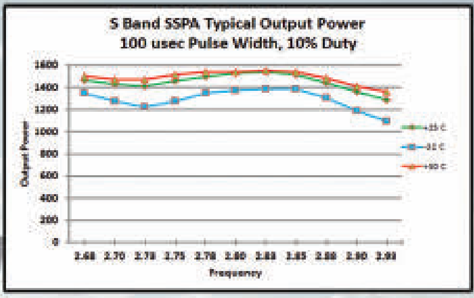

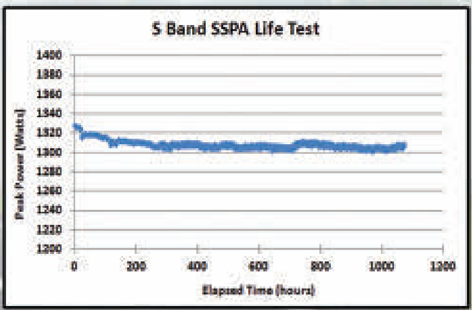

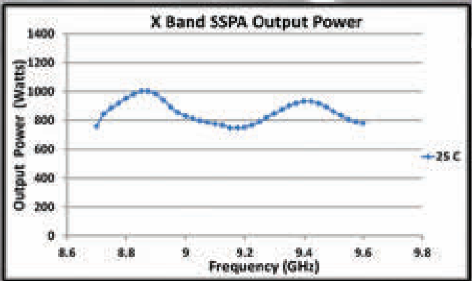

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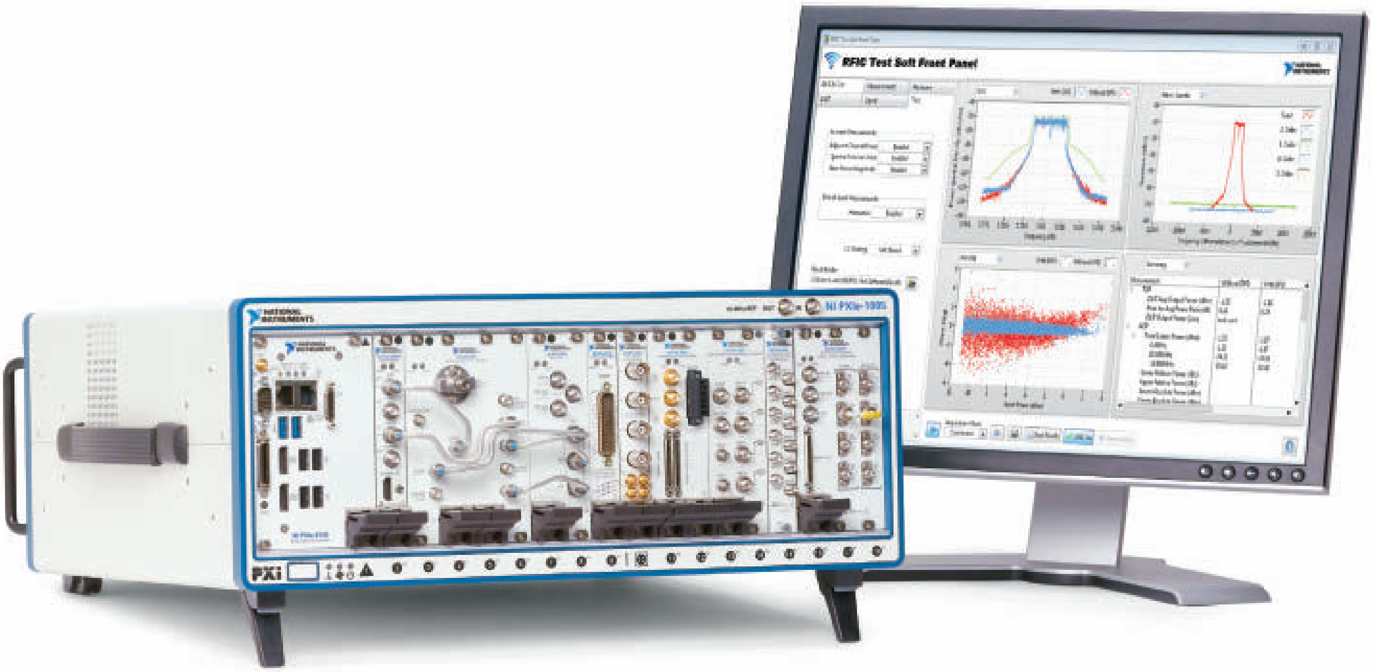

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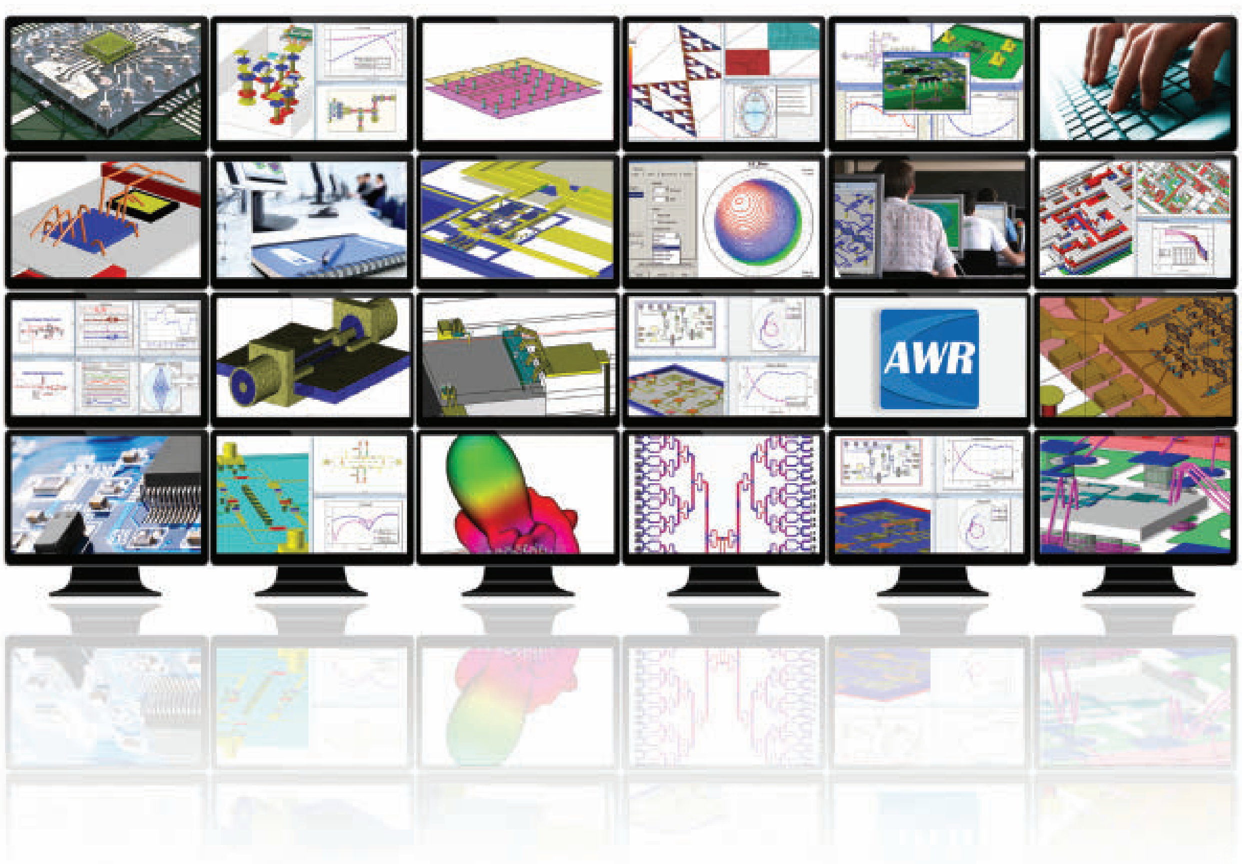
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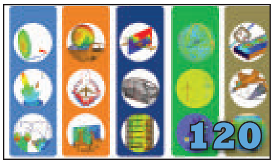

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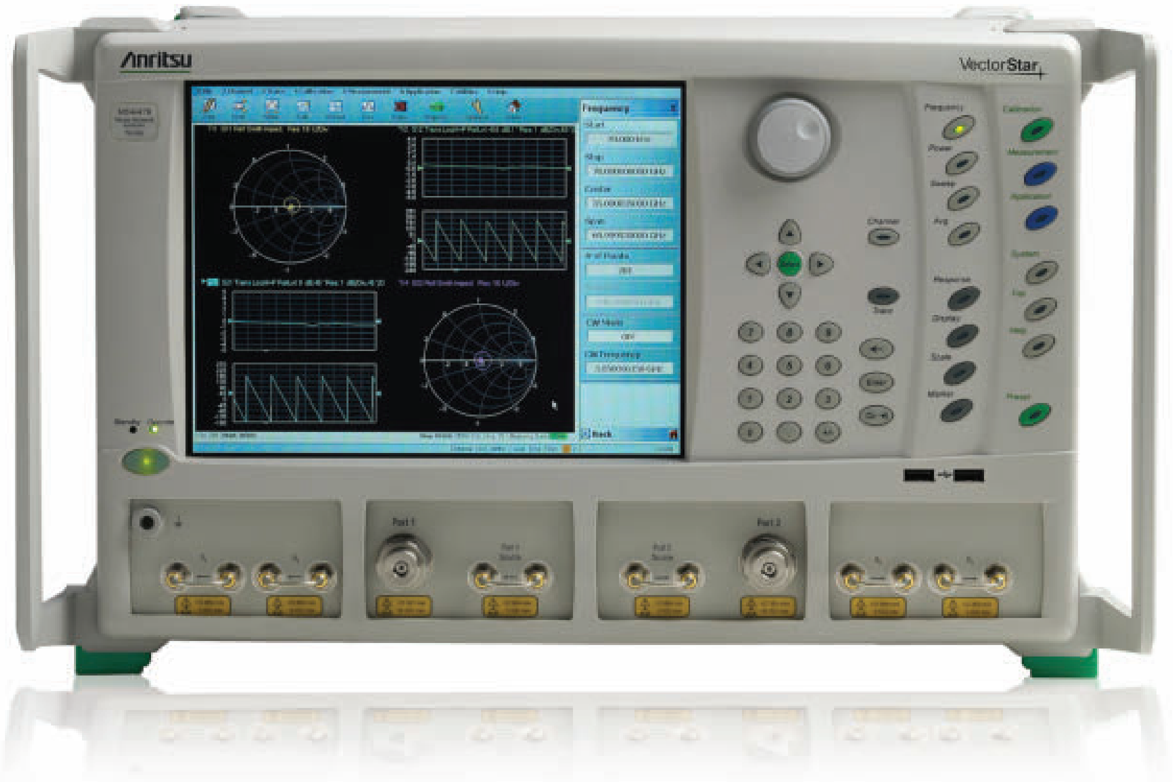

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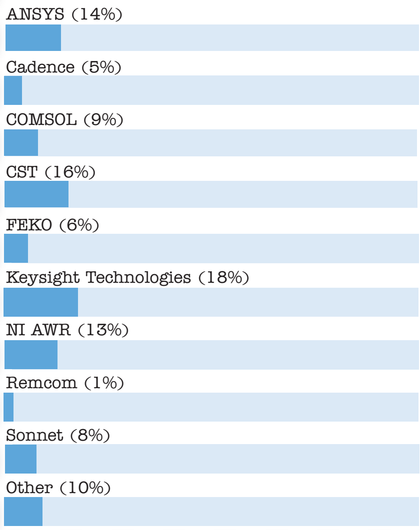

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Lorne Graves, chief technologist at **Mercury Systems**, discusses the changing threat environment, how EW strategy is responding and how Mercury Systems is addressing these changing requirements.

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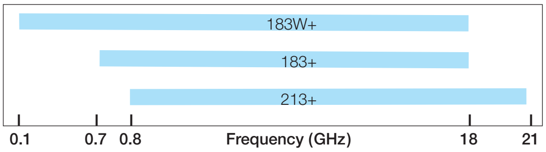

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Utilizing Commercial Best Practices for Success in NewSpace

Gregg Peters
Keysight Technologies Inc.
Formerly Agilent Technologies electronic measurement business
Santa Rosa, Calif.

The space industry is in the midst of an exciting and dramatic change. NewSpace is a term that's been coined to describe that change. According to NewSpace Global (www.newspaceglobal.com), it defines an emerging global industry of private companies and entrepreneurs who primarily target commercial customers, are backed by risk capital seeking a return and profit from innovative products or services developed in or for space. While NewSpace signifies an exciting time for the space industry, it's also driving disruption — the likes of which haven't been seen since the original space race in the 1960s. These disruptions include the challenges for electronic design and test strategies and processes that NewSpace's new business models create. Overcoming these challenges is critical to enabling the higher volume, lower cost and high quality products that NewSpace demands. Let's take a closer look.

NEWSPACE 101

Today a huge number of companies are entering the space business. When NewSpace Global started in 2011, it was tracking about 125 companies. NewSpace Global now tracks well over 800 companies, about 700 of which are privately held. Most people have seen the press coverage of SpaceX, OneWeb, Google and Facebook and their change the world scale plans for space. These companies will certainly drive disruptive change on a massive scale, but they are far from the only ones. Hundreds of other companies are getting into space with an amazingly wide variety of business models and mission types, from communications, earth imaging and weather forecasting to mining asteroids and interplanetary human existence. The NewSpace movement is not limited to new entrants. Many traditional space companies and organizations are adapting and working to understand how best they can take advantage of the opportunities that NewSpace presents. Alliances have been and continue to be formed between new entrants and established space players.

All of this has significant implications for electronic design and test. To better understand these implications, it's important to highlight the characteristics that distinguish NewSpace from traditional space. Unlike traditional space companies, NewSpace companies primarily target commercial enterprise, and that means commercial business principles apply. Accordingly, most NewSpace endeavors construct business models based on a level of investment, ongoing cost structure and revenue stream that results in a profitable outcome. Funding in NewSpace endeavors comes from sources not historically associated with the space industry (e.g., venture capital, crowd funding and angels). One of the most telling attributes of NewSpace is risk tolerance. With traditional space ventures, risk is viewed as bad, and tremendous amounts of time, effort and expense are employed to eliminate it. NewSpace companies, on the other hand, understand that risk is something to be considered,

TABLE 1

SMALL SATELLITE SUB-CLASSIFICATIONS

Sub-Classification	Mass Range (kg)
MiniSat	100 to 500
MicroSat	10 to 100
NanoSat	1 to 10
PicoSat	0.1 to 1
FemtoSat	<0.1

assessed and managed, rather than be eliminated at all cost.

One key trend enabling NewSpace is lower launch cost. Some of the methods that have emerged to enable that are ride-sharing, use of reusable boosters and development of small launch vehicles designed to deliver smaller payloads at a lower price and with higher launch frequency. The rapid growth of relatively low cost small satellites (SmallSats) is another driving force in the NewSpace movement. SmallSats range in size from extremely small (e.g., PocketQube at 150 g) to 500 kg and are categorized according to the sub-classifications shown in ***Table 1***. Business models vary significantly across these classes. Also, the number of satellites associated with many NewSpace business models/missions is much larger than traditional space norms. In fact, many SmallSat businesses are planning to deploy large constellations — tens, hundreds even thousands of satellites — the majority of which will be in low earth orbit (LEO). Intended mission lifetimes are much shorter, two to five years or less, rather than the 15 years which is common for most traditional satellites. The large number of companies deploying constellations, the size of the constellations and the relatively short orbital lifetimes are combining to drive dramatic volume growth in SmallSat production, with some estimates predicting 2500 to 4000 new SmallSats in orbit by the end of the decade.

With less stringent design requirements, many SmallSat designs are relying heavily on commercial off-the-shelf (COTS) parts. Intended for terrestrial industries, these parts are far less expensive, more available and typically further advanced in performance than space-qualified parts. While their use does introduce risk, NewSpace developers generally perform some level of qualification of COTS parts that is consistent with their mission, risk profile and business model to make them "somewhat space qualified." Automotive and industrial parts, which are subject to a more rigorous qualification process than consumer electronics, are also widely used and are still far less expensive than space-qualified. Unlike traditional space development, a number of NewSpace companies are also employing agile methods for developing spacecraft in months rather than years. Several companies have even extended agile methods into orbit by launching a prototype capability, learning from it on-orbit and then feeding those learnings back into the next revision.

WARNING: CHALLENGES AHEAD

While the NewSpace movement provides great opportunity, some significant business challenges face the industry. For example, with risk tolerance comes the requirement for an effective approach to dealing with risk, one that includes both mitigation and contingency plans. NewSpace companies also face pressure to deploy satellites sooner. In some cases, that schedule pressure is driven by the market and competition, but it may also be driven by a specific launch window or the need to get satellites in orbit quickly to replace those approaching end-of-life, without disrupting the revenue stream. Another challenge is being able to scale to the volumes required for NewSpace while maintaining product quality. In order for the NewSpace business model to work, cost targets must be achieved. This is driving the need to control development, product and deployment costs across the enterprise. Finally, to sustain a strong business model and remain competitive, NewSpace companies must continuously innovate, while controlling cost and maintaining schedule. Given that space is hard, this is a fundamentally difficult task. Overcoming these challenges and delivering continuous innovation requires a lot of high quality technical talent, and this makes attracting and keeping experienced technical professionals and new graduates a top priority.

Electronic design and test are integral to any spacecraft development and deployment. As NewSpace

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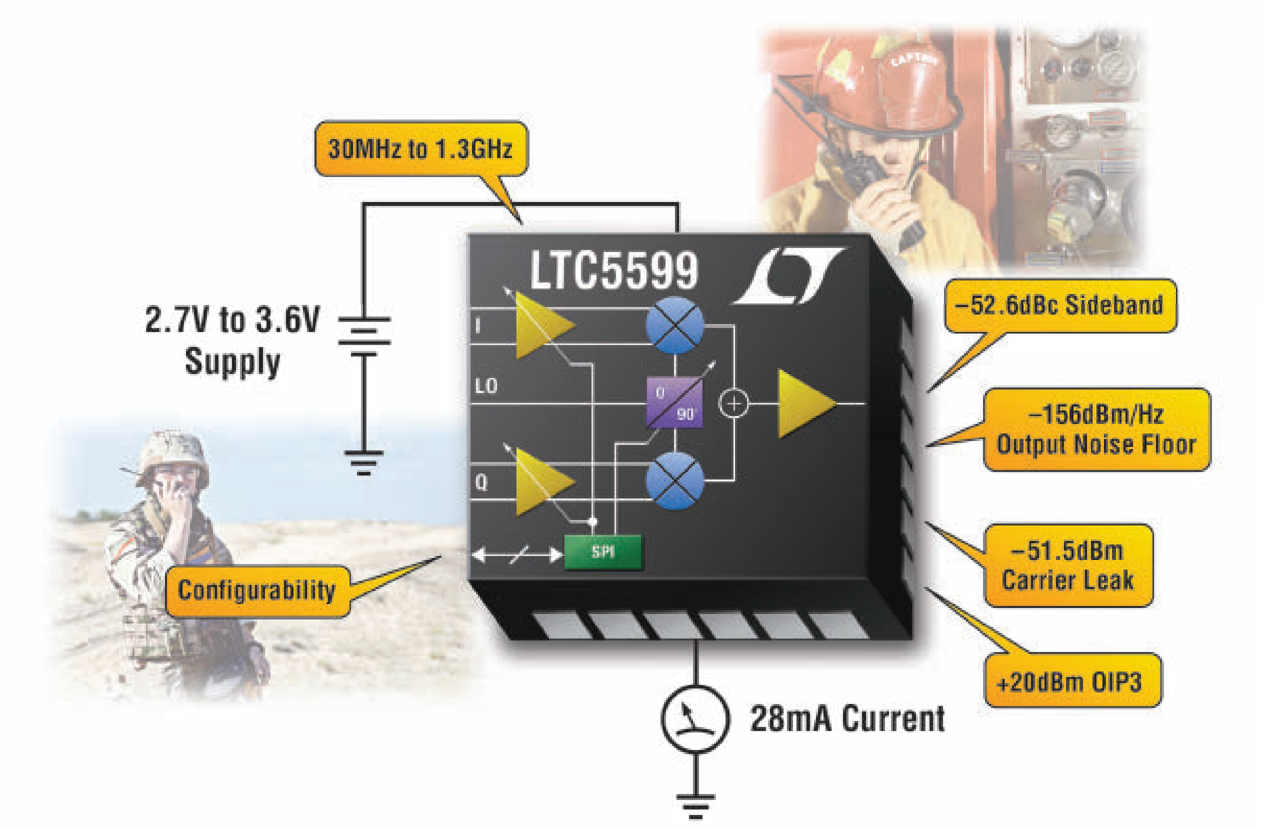

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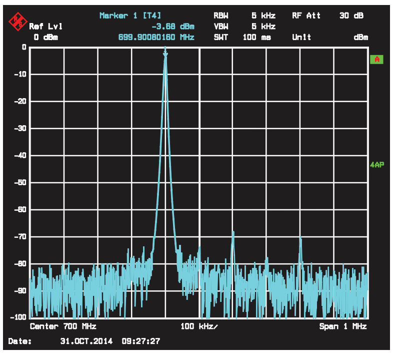

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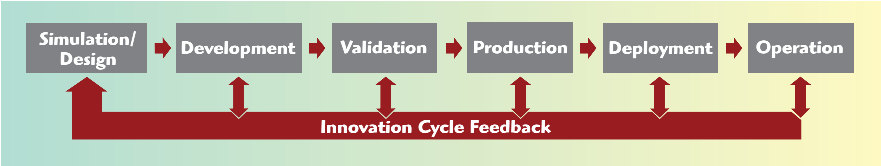


Fig. 1 Typical electronic product development cycle.

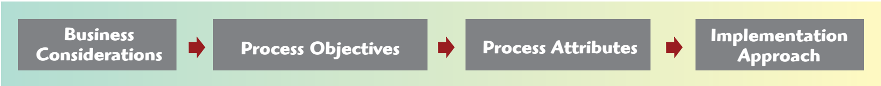


Fig. 2 Design and test process definition flow.

drives change with its volume, cost and schedule challenges, the philosophies, strategies, processes and requirements associated with electronic design, development, production, test and measurement must change as well. Utilization of best practices from the commercial electronics sector, efficiently aligned with the unique needs of space, offers one way to ensure a successful and sustainable NewSpace business model. The basic construct of the electronic product development cycle, as shown in ***Figure 1***, is common across industries. Key elements that distinguish different industries are the definition of each stage, the criteria for moving between them and the rigor with which the process is followed. In very low volume conditions like traditional space, the lines between development, validation and production are often blurred. With the volumes of many NewSpace businesses, however, the lines must be well defined in order to scale volume efficiently. As volumes increase, it's particularly important to clearly define criteria for the release to production. Debugging design problems in production impacts cost and schedule and slows down the primary function of production, which is to ship products. Additionally, different industries and companies have different approaches to how much they utilize innovation cycle feedback. This loop is integral to meeting the business challenge of continuous innovation. Simulation and measurement tools that support this feedback mechanism are also key.

BEST PRACTICES FOR SUCCESS

Achieving business success in NewSpace, requires defined electronic design and test strategies and processes that are consistent with your business model and business realities. Business considerations drive design and test objectives, which dictate the attributes of the design and test process required to meet those objectives and, ultimately, drive a specific implementation approach (see ***Figure 2***). Some of the key considerations relevant to the design and test strategy are:

- functional, performance and physical requirements
- timeline and market window
- cost requirements
- volume and throughput requirements
- risk profile
- future plans
- core versus context.

While many of these may seem obvious, others are not as clear or often get overlooked in a challenging schedule and cost-constrained environment. Documenting and tracking requirements, which can get pushed aside in very schedule-driven developments, is a perfect example. When this happens, confusion between the designers and test developers often results in schedule slippage.

A critical part of achieving business success is having a design and test process that aligns with your risk profile. Historically, the design, validation and test approach employed in the space industry has differed greatly from that of the commercial electronics industry. The highest priority of the process in traditional space was to eliminate risk, often at the expense of schedule and cost — test everything and test it a lot. NewSpace, however, is willing to accept some level of risk. Consequently, a key element of its test strategy is to define what risks are and are not acceptable, i.e., establish and document a risk profile. Suppose, for example, that you are willing to accept a 5 percent failure rate over a two year period and plan to mitigate this risk in your system design. A detailed assessment of risk will help drive the test strategy and process. A test process targeted at a 5 percent

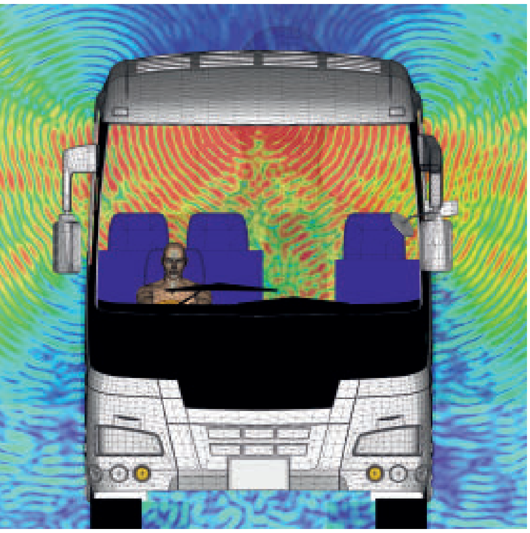


TABLE 2
PRIMARY OBJECTIVES, ATTRIBUTES AND IMPLEMENTATION ELEMENTS

Objectives	*Attributes*	*Implementation Elements*
Predictable performance from proposal through operation	Effective modeling of product and system performance	Model and measure early to understand weak points
Identify and eliminate problems as early in process as possible	Design for manufacturability, test and cost (DFx)	Start testing early – breadboards and early prototypes
Identify and understand weak or potential points of failure early	Consistent, common and repeatable measurement science throughout the process	Detailed and inclusive DFx reviews
Sustainable quality	Data consistency to support trending and prediction	Utilize methods for accelerated testing to ferret out weak points quickly and effectively
Continuous process improvement	Clear criteria for "production ready"	Focus test resource on areas of greatest concern
Minimize test system setup time	Robust validation testing	Test enough – don't test too much
Maximize yield	Efficient production testing	Eliminate rework in the forward flow
Maximize uptime	Minimize use of hand-crafted products	Failed units move immediately to reverse flow
Ensure throughput targets	Clear delineation between forward and reverse flow	Automation
	Minimize probabilty of operator error	Parallel test
		Outsourcing

failure rate is quite different from one that targets 1 or 20 percent. One that targets 1 percent would achieve the 5 percent target but may exceed cost and schedule targets.

It's also important to consider your future plans as part of the process definition. Assess short, medium and long-term goals. Do you plan to grow in volume, expand your product portfolio or increase complexity? If your need will change in the future, you should make choices now that will allow you to adapt and upgrade over time. Often overlooked in the process definition is the concept of core versus context. Core refers to content an organization is uniquely capable of executing better, faster or cheaper than an outside source. Context is everything else that is necessary for business success but is not part of the core. The more you focus on your core by outsourcing context items, the higher the likelihood of a successful and sustainable process. Of course, what's defined as core or context may change over time, so it's important to review it regularly; this will help you maintain focus on key differentiators as business conditions change.

Given these considerations, there are a number of ways NewSpace companies can achieve much higher volume with much lower cost while maintaining high product quality. These include:

Process Objectives, Attributes and Implementation: The objectives, attributes and specific implementation approach of a design and test process (see ***Table 2***) are very tightly linked and often get blurred. It's critical that the attributes align with the objectives, and the implementation aligns with the attributes and achieves the objectives. No single implementation approach will fit every NewSpace business model. However, focusing on the items discussed here will provide the context to make the best implementation choices for a given business model. While all of the items in Table 2 have some level of impact across the business model, each also has a primary impact in one of three broad categories: design robustness, volume enablement and cost management.

Design Robustness: Effective and accurate modeling increases confidence that a given product or system concept will meet requirements and align with the business model. Simulation tools used should support margin analysis and the ability to incorporate measured data. Improperly managed margins can add significant cost and risk to a program. If margins are too tight, unnecessary costs are

pushed down to subsystems and components. If margins are too loose, they could stack up unfavorably, leading to poor system performance or failure. Simulation and models help properly manage margins for optimum performance and cost tradeoffs. Simulation and test data consistency throughout the process also enables trending and improved prediction over time. It's key that the measurement science employed at each stage is repeatable and consistent with other stages. Modeling also provides early insight into the problem areas and potential weak points in the design. Problems caught early in the process are far less costly, in terms of money and schedule, than problems found late in the process; start testing early. Build breadboards and early prototype assemblies and rigorously test them. Hardware-in-the-loop should be integrated with your simulation software and models to increase the fidelity of your system simulations. Doing so will help ensure the system's proper operation at its first turn on.

Highly accelerated life testing (HALT) or highly accelerated stress testing (HAST) are also effective approaches for early detection of design problems and infant mortality. The level and formality of HALT/HAST used should be consistent with the product and business model. For example, to test the lifetime quality of electrical connections, a combined thermal and vibration environmental test can be done to add additional stresses. This may lead to the detection of fatigue or a fracture that would normally take years to manifest itself as a failure. By doing a rapid test that might constitute some percentage of the lifetime number of cycles expected, issues can be caught without the need for extremely long test cycles.

Volume Enablement: Design-for-manufacturability, design-for-integration, design-for-test, design-for-quality and design-for-cost are essential for a profitable business model. These DFx techniques are tightly related and, therefore, must be considered and reviewed early in the process. The reviews should include all of the key stakeholders (R&D, test engineering, production and quality). Early feedback on DFx issues pays off in production with improved throughput and yield. It is also crucial to have clear and aligned criteria for "production ready." Rigorous and broad testing and debugging of the design should be focused on the development and validation phases.

As you move into production, focus on the areas of greatest concern. Consider not testing or only sample testing the areas that have little cause for concern, and test at a level that's consistent with the risk profile and potential failure modes. In the production test process, it's critical to have clear distinction between forward flow and reverse flow to achieve throughput objectives. If a unit fails in forward flow, it must be removed and transferred into reverse flow. When failed units remain in forward flow for debugging, they create a bottleneck that slows, or even stops, product shipments.

Process automation is a powerful tool in a volume test process, bringing significant advantages like reduced test system setup and measurement time, reduced risk of test operator

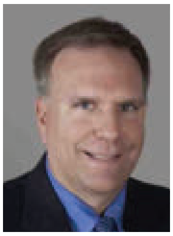
error and maximized usage of capital equipment. It also improves yield and reduces rework and re-test as well as human attended test time. However, automation typically incurs additional up-front expense and initial setup time. The level of automation that is sensible will be dictated by several factors. Assess and determine what level of automation best delivers the target metrics defined above. Parallel testing can take several forms, such as multiple channels, multiple measurement types and multiple units under test (UUT). The primary objective is to ensure that throughput and asset utilization objectives are achieved.

Cost Management: Outsourcing is widely used in the commercial electronics industry. For those areas deemed context rather than core, outsourcing may be a viable alternative, providing advantages in process efficiency and overall cost. Outsourcing also helps address the challenge of attracting technical talent, as contract resources may be available where permanent hires are not. While outsourcing is certainly not something to be taken lightly, it should be considered as part of an effective business model.

When aligning the design and test process with the business model, one of the primary factors to understand is how it impacts cost. Primary contributors to cost include yield, test time and throughput, utilization and equipment cost. When computing the equipment cost, it's essential to take a total cost of ownership (TCO) view of the process and the associated value delivered. TCO is defined as the total cost to own and operate a piece of equipment over its useful life. Often, the equipment cost is viewed only in terms of the initial purchase. TCO is key to understanding the real cost and associated impact on the business model.

CONCLUSION

NewSpace is creating tremendous excitement in the space industry. New companies are entering the industry and traditional companies are adapting. Many completely new business models are emerging, which challenge existing electronic design and test strategies and processes. Fortunately, there are now some approaches that can be used to help overcome these challenges; however, ensuring product quality while dramatically increasing volume and reducing cost continues to be difficult. To fully realize the promise of NewSpace, it will be critical to strike a strong balance between commercial electronics and traditional space industries and couple this with completely new discoveries. Likewise, realizing the promise of NewSpace business models will require bringing together the best of commercial and aerospace electronic design and test. ■



Gregg Peters *is vice president and general manager of Keysight's Component Test Division, where he manages a global team of engineers, architects, product line managers, technical marketing engineers and business development managers. He joined Hewlett-Packard (HP) in 1984 and has held a variety of positions within HP, Agilent and Keysight Technologies. Gregg holds a bachelor's degree in electronics engineering from Iowa State University and an MBA from the University of Colorado.*

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First 50 GHz Handheld Analyzer Speeds Field Work

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

The engineers and technicians who install, maintain and troubleshoot radar and satellite systems face difficult challenges and compromises. The challenges are usually logistical and often environmental, as they work in remote locations, perhaps aboard a ship or aircraft, and deal with potentially harsh weather conditions. Many of the compromises involve the equipment they carry into the field. Getting sufficient accuracy often means using benchtop-caliber tools, and making the full range of necessary measurements means transporting more than one bulky instrument.

Today's alternative is Keysight's family of FieldFox handheld analyzers. This month, the company released six millimeter wave models. Among these, the flagship is the industry's first 50 GHz handheld microwave (combination) analyzer. The new models expand a lineup that already included RF units and microwave models, introduced in 2008 and 2012, respectively. The new models provide laboratory-grade spectrum analysis, vector network analysis and cable and antenna test (CAT) in a rugged, portable unit that weighs 7.1 lbs, including the internal battery. With these capabilities, FieldFox can replace three or four single-function instruments — benchtop or handheld — that are typically used for maintenance and troubleshooting of systems that operate at or above Ka-Band. It provides unprecedented functionality and convenience at about half the cost of each equivalent benchtop instrument.

FieldFox analyzers are optimized for field testing. With its fully sealed enclosure — no fans or vents — FieldFox is compliant with US MIL-PRF-28800F Class 2 standards and also type tested meeting MIL-STD-810G requirements for operation in explosive environments (Method 511.5, Procedure I). The analyzers are also type tested to meet IEC/EN 60529 IP53 requirements for protection from dust and water.

The new models include three combination analyzers that cover 32, 44 or 50 GHz. The other three are spectrum analyzer models that cover the same frequency range. In all six new analyzers, spectrum measurements are up to eight times faster than those made with comparable units. Displayed average noise level (DANL) is -135 dBm/Hz at 50 GHz, and amplitude accuracy is ±0.6 dB from 9 kHz to 50 GHz. In vector network analysis mode, dynamic range is 90 dB, and trace noise is ±0.008 dB, both at 50 GHz.

The FieldFox handhelds offer a range of functionality that is software upgradeable, letting users choose the capabilities they need initially and add others later. Examples include vector voltmeter, TDR cable measurements, built-in power meter, pulse measurements, spectrum analyzer time gating, interference analyzer (with spectrogram) and GPS receiver.

SNAPSHOT: RADAR APPLICATIONS

Radar is used in applications as diverse as traffic enforcement, weather prediction, civilian air traffic control and military air defense. To enhance system uptime and ensure favorable outcomes, routine maintenance, impromptu troubleshooting and occasional repairs are essential. When working on radar components and systems in the field, it is often necessary to measure time and frequency domain performance over a range of test conditions. Given the complexity of today's systems, maintainers must also coordinate and compare waveforms in both domains. They may even need to test and tune the various functional blocks or line-replaceable units (LRU) within the radar system.

Covering all of the necessary measurements often requires three or four separate instruments. For example, a peak power meter is used to measure the absolute amplitude of a transmitter as a function of time, and a spectrum analyzer is needed to measure absolute amplitude as a function of frequency. When performing relative measurements, the peak power meter can measure the relative time and amplitude of a waveform, but a vector network analyzer (VNA) or vector voltmeter is needed to measure amplitude and phase as a function of frequency. FieldFox combination analyzers provide the same measurement capabilities of the four instruments described above. With the addition of a peak power sensor, FieldFox provides a solution that can easily be carried to a test site for measurements of the time and frequency performance of a radar system. A combination analyzer also has the functionality needed to test to the LRU level. Supported measurements include full pulse analysis capability to 40 GHz with a USB peak power sensor and relative timing measurements of the transmitter main versus auxiliary pulses. FieldFox analyzers also support stable local oscillator (STALO) phase alignment through the vector voltmeter mode.

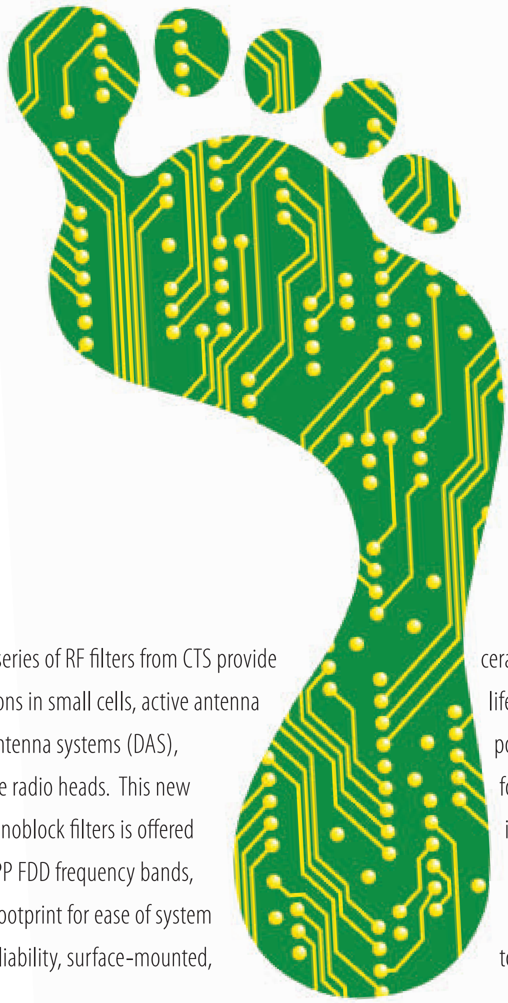
Fast, accurate characterization of cables, waveguides and components helps increase system uptime and reduce mission risk. The ability to use a single instrument improves personnel efficiency and reduces the cost of ownership with just one instrument to purchase, learn and maintain.

SNAPSHOT: SATELLITE APPLICATIONS

Satellite systems are used for broadcast, bi-directional data, navigation, remote sensing and mobile communications. Every system has space and ground segments. A typical ground segment has at least three sub-segments: satellite control system, gateways and hubs and user terminals. The control system provides tracking, telemetry and command (TT&C). Communications, including voice, video and data are carried between the gateways, hubs and user terminals.

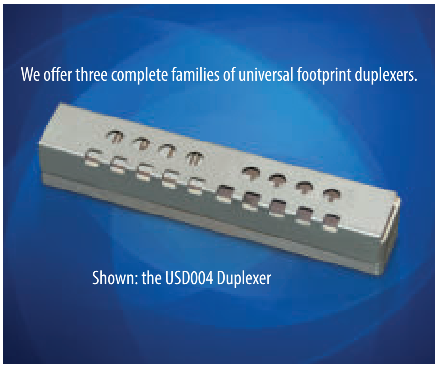
Effective maintenance and troubleshooting of satellite earth stations requires testing of key elements — antenna, transmission lines, transmitter and receiver — as well as the overall system. The required measurements include the

Universal Footprint RF Duplexers



Universal-footprint series of RF filters from CTS provide better communications in small cells, active antenna arrays, distributed antenna systems (DAS), repeaters and remote radio heads. This new breed of ceramic monoblock filters is offered for all the major 3GPP FDD frequency bands, sharing a common footprint for ease of system design. Our high-reliability, surface-mounted, ceramic filters support 20-year operating lifetimes and as much as 200 W peak input power handling capability. Universal footprint filters provide industry-leading insertion loss and rejection. For more information on our ceramic universal duplexers and bandpass filters go to www.ctscorp.com.

Filters with Industry-leading insertion loss and rejection.



Shown: the USD004 Duplexer

	UMB/UMD Pair of Bandpass Filters For Metro Cell	USD DUPLEXER For Small Cell	UPD DUPLEXER For Pico Cell
Input Power Rating	20W Avg 200W Pk	6W Avg 60W Pk	1.5W Avg 15W Pk
Insertion Loss (5MHz AVG)	2.2dB	2.6dB	3.0dB
Rx Band Isolation*	80dB	72dB	63dB
Tx Band Isolation	74dB	66dB	57dB
Universal Footprint Size (mm)	62 x 44	63 x 18	44 x 18
Operating Temp Range	-40 to +85°C	-40 to +85°C	-40 to +85°C

* Note: "Difficult" bands may have 2dB lower worst case Rx band isolation.

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return loss of the antenna, fault location in transmission lines, the high power amplifier (HPA) performance in the transmitter, low noise amplifier (LNA) performance in the receiver and system carrier-to-noise measurements. Completing these measurements requires another extensive roster of equipment: power meter, spectrum analyzer, vector network analyzer, line sweeper, RF and DC sources. A FieldFox combination analyzer can be configured to provide all of this capability in a single unit. A single analyzer makes it possible to validate system performance with fast, detailed analysis of uplink and downlink signals (see ***Figure 1***). Its calibrated VNA and CAT measurements help maintenance personnel maintain cable, waveguide and antenna systems consistently and efficiently. The combination of network analysis, spectrum analysis, power measurements and more enables faster fault diagnoses.

Fig. 1 FieldFox handheld analyzers enable field personnel to fully characterize complex satellite earth stations with a single instrument. Photo courtesy of INTELSAT.

SNAPSHOT: R&D COMPANION TOOL

The highest performance benchtop VNAs and signal analyzers tend to have high-end prices. An R&D lab may only have one or two of each, and these will be shared by engineering staff. Limited access can mean delays in characterization, debug and troubleshooting of new designs or the latest board turns. FieldFox makes it possible to affordably equip engineers to make a variety of must-have measurements up to 50 GHz. This helps designers and developers stay productive when someone else is using the shared high performance benchtop instruments. Users can measure with confidence, because FieldFox measurement results agree with those from trusted Keysight, Agilent and HP instruments. Also helpful, an engineer can easily carry the analyzer to a unique or stationary device to be tested, thanks to its portable form factor and battery operation.

In radar and satellite applications, FieldFox provides laboratory-grade measurements while eliminating the need to transport multiple benchtop instruments to remote sites with harsh environments. With frequency coverage to 50 GHz, FieldFox can provide spectrum analysis, vector network analysis and additional measurements of K- and Q-Band systems.

VENDORVIEW

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DefenseNews
Cliff Drubin, Associate Technical Editor

Future Army Nanosatellites to Empower Soldiers

The U.S. Army Space and Missile Defense Command/ Army Forces Strategic Command's Nanosatellite Program, or SNaP, will be a small satellite communications, or SATCOM, constellation allowing communication across great distances using existing UHF tactical radios. "SNaP is a technology demonstration with the goal of showing the military utility nanosatellites can provide to the disadvantaged user," said Thomas E. Webber, director, SMDC Technical Center Space and Strategic Systems Directorate. "The primary uses are beyond line of sight communications and data exfiltration. SNaP is a natural fit for the command since we are the Army proponent for space and also the SATCOM provider."

In many remote areas where Soldiers operate, service members radio over-the-horizon communication from the field to higher headquarters, like the brigade, is nonexistent. Army scientists and researchers built the SMDC-ONE nanosatellite as an innovative technology solution. The ONE stands for Orbital Nanosatellite Effect. SMDC-ONE was a technology demonstration, which

Source: U.S. Army

showed nanosatellites in low Earth orbit could be used for beyond-line-of-sight communications and data exfiltration. Three next-generation SNaP nanosatellites are scheduled to launch this year and an undetermined number could go up afterward.

SNaP is a 5-kilogram mass cube satellite, or CubeSat, which costs about $500,000 and is about the size of a loaf of bread. It provides data and over-the-horizon communications capabilities. It has multi-functional relay capability with five times the data rate of SMDC-ONE and uses deployable solar arrays versus fixed arrays to increase power generation over SMDC-ONE. SNaP also has a propulsion capability for station keeping to maintain constellation spacing.

"Nanosatellites in low-Earth orbit are traveling approximately 17,000 mph and are about the size of a football, which makes them very survivable," Webber said. "Providing the ability for our warfighter to communicate in an environment where traditional SATCOM is unavailable can literally be the difference between life and death." Designed for UHF communication with existing Army and some coalition radios," Webber said. "The advantage low-Earth orbit provides is the fact that satellites are so much closer to the Earth, which allows much lower signal levels to be received and processed."

SMDC plans for future constellations of relatively low-cost nanosatellites deployed in mission-specific, low-Earth orbits to provide cost effective, beyond-line-of-sight data communications capabilities. "SNaP will provide resiliency to the warfighter communication capability by providing beyond-line-of-site communications when no satellite communication is available due to line-of-site issues or a denied or degraded environment," Webber said.

Raytheon Installs First GPS OCX Hardware

VIEW VIDEO

Raytheon has installed the first operational hardware for the Global Positioning System's Next Generation Operational Control System, known as GPS OCX. The new ground command and control system will significantly modernize U.S. GPS capabilities and manage the next generation of GPS satellites. Installation of the Launch and Checkout System (LCS) hardware was completed in early July at Schriever Air Force Base in Colorado, the eventual home for the new GPS OCX Master Control Station.

GPS OCX will deliver a host of new capabilities, including automation for operational efficiencies, improved accuracy, interoperability with geo-positioning and navigation systems of other nations for better global coverage, and a cybersecurity architecture that provides unprecedented levels of protection. The Launch and Checkout System delivers a large subset of the full OCX ground system capabilities, and establishes the OCX cyber-hardened infrastructure for additional mission applications that will be added to complete the Block 1 capability.

> **The new ground command and control system will significantly modernize U.S. GPS capabilities and manage the next generation of GPS satellites.**

U.S. warfighters use GPS services to support air, land, sea and space missions. GPS is also used by millions of people to enhance daily life activities, including personal navigation. It's also required for industry and businesses and is essential to support safety-of-life missions for air traffic controllers and emergency responders. The modernized ground system will bring new capabilities and precision to the GPS enterprise.

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DoD Officials Observe Counter-Drone Demo

Small, unmanned aircraft systems, or drones, are easy to obtain and launch and they're hard to detect on radar, making them of particular concern to the Department of Defense, according to officials who took part in Black Dart 2015 recently at Point Mugu, Calif.

Black Dart 2015 was the DoD's largest live-fly, live-fire joint counter-UAS technology demonstration bringing together some 1,000 people, including industry personnel, observers from allied nations, and participants from four military branches.

According to Navy Cmdr. David Zook, chief of the Capabilities Assessment Division with the Joint Integrated Air and Missile Defense Organization (JIAMDO), small drones can be launched from virtually anywhere and fly a significant radius. "Small manned and unmanned aircraft have always been hard to find," he said. "It's hard to tell the difference in the radar cross section from that and other small airborne vehicles or even birds."

Black Dart 2015 provided "a unique and very valuable window for us to come together for two weeks here and practice in a littoral environment, a land-based environment and a deep-sea environment in many different scenarios," Zook said. The demonstration featured cooperation and interoperability among military services in air and missile defense, while also assessing the anti-UAS capabilities of DoD, its agency partners and industry.

Staying One Step Ahead

"One only needs to look at recent news reports to see incidents involving members of the public using drones, including a quadcopter that landed at the White House," said Air Force Maj. Scott Gregg, Black Dart's project officer. "Drones can easily be purchased over the Internet or at a hobby shop. Defense officials are focused on staying ahead of the threat."

The smaller class of drones was an "emphasis item" this year at Black Dart, in response to concerns from combatant commanders and interagency partners, including law enforcement agencies. "It's a problem for everyone," said Gregg.

"More than 70 countries are using UASs, either in government or military application." Gregg also pointed out that radio-controlled model aircraft have similar performance and capabilities to some of the UASs that are considered to be threats. "It's a burgeoning market. The threat is expanding rapidly, proliferation is expanding rapidly and it's not just a military threat; our allies are using them, our coalition partners are using them, but our adversaries are using them too."

ITU Regulatory Report Reveals Fast-Evolving ICT Landscape

The latest edition of the International Telecommunication Union's (ITU) comprehensive report on global Information and Communications Technology (ICT) regulatory developments, *Trends in Telecommunication Reform 2015*, reveals a fast-evolving ICT landscape, as devices and services proliferate, broadband connectivity becomes increasingly pervasive, and the hyper-connected world of the 'Internet of Everything' starts to become a reality.

Characterized by greater complexity and cross-sectoral implications, fourth-generation regulation attempts to come to grips with the enormous social and economic disruption ICTs are bringing in their wake. The report recommends flexible, light-touch regulation and recognition of the rights of both businesses and consumers in defining new frameworks for an emerging global digital environment.

Trends in Telecommunication Reform 2015 confirms that future network traffic will increasingly be driven by machine-to-machine (M2M) traffic generated by billions of connected devices, products and sensors, with M2M communications over mobile cellular networks already emerging as the fastest-growing ICT service in terms of traffic.

In total, one billion different kinds of wireless IoT devices are expected to be shipped in 2015, up 60 percent from 2014, reaching a predicted installed base of 2.8 billion connected devices by the end of 2015. Wearable devices are estimated to have reached 109 million by the beginning of 2015.

> ...broadband connectivity becomes increasingly pervasive...

As many as 25 billion networked devices are predicted to be connected by 2020, driven largely by consumer-connected entities and followed by manufacturing, utilities and transportation. In terms of revenues, the market for IoT is expected to grow to $1.7 trillion by 2019 to become the largest device market worldwide.

E3NETWORK Initiative Utilizes ST's BiCMOS-Based RF Transceiver

The European Energy efficient E-Band transceiver for backhaul of the future networks (E3NETWORK) R&D initiative for developing energy-efficient, high capacity transmission systems in next-generation mobile networks has selected STMicroelectronics' advanced BiCMOS55 SiGe technology.

Skyrocketing mobile-data usage requires networks to support greater capacity and higher data rates. This places new challenges on the backhaul infrastructure, accelerating the transition to advanced network architectures, such as Heterogeneous Network and Cloud Radio Access Network (RAN) and higher frequency bands (such as E-Band), where more spectrum is available to support faster data-rate channels.

To build these super-efficient mobile networks, equipment manufacturers need high performance electronic components that combine large-scale chip integration, reduced power consumption, and optimized cost. The E3NETWORK project leverages the integration and power advantages of ST's BiCMOS55 SiGe technology delivering heterojunction bipolar transistors (HBT) with Ft up to 320 GHz in 55 nm lithography. This technology allows the integration of a high frequency analogue section with high performance, dense digital blocks such as logic, AD/DA converters and memories.

> ...more spectrum is available to support faster data-rate channels.

E3NETWORK is designing an integrated E-Band transceiver using ST's BiCMOS55 technology for fronthaul and backhaul infrastructure, which enables digital multi-level modulations, highly focused 'pencil-beam' transmissions, and data rates above 10 Gbps. The pencil-beam property facilitates a high degree of frequency reuse in the deployment of backhaul and fronthaul links, while preserving the spectrum efficiency over the millimeter wave interval.

GSA Confirms 422 LTE Networks Launched

In its latest update of the Evolution to LTE Report the Global mobile Suppliers Association (GSA) revealed that 422 operators have commercially launched LTE in 143 countries, with 106 operators having commercially launched LTE service in the past year. 677 operators are investing in LTE across 181 countries. This comprises 638 firm network deployment commitments in 176 countries (of which 422 networks have launched), and 39 pre-commitment trials in a further five countries.

LTE-Advanced deployments have taken hold in all markets around the world. Now over 30 percent of operators are investing in LTE-Advanced system deployments, with the commercialization of carrier aggregation the first feature to be exploited. 88 operators, i.e., over 20 percent of all LTE operators, have commercially launched LTE-Advanced service in 45 countries. 15 LTE-Advanced networks support Category 4 devices (above 100 Mbps up to 150 Mbps peak downlink speed) while 73 networks support Category 6 devices (above 150 Mbps up to 300 Mbps). Several operators are trialing LTE-Advanced technology capable of supporting Category 9 devices (above 300 Mbps up to 450 Mbps) and beyond.

The most widely used spectrum for LTE network deployments continues to be 1800 MHz (3GPP Band 3).

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LTE1800 is now used in 187 commercially launched networks in 89 countries representing over 44 percent of LTE network deployments. The next most popular contiguous band for LTE systems is 2.6 GHz (Band 7) being deployed in 100 networks. 800 MHz (Band 20) is by far the next most popular spectrum choice, used by 91 i.e., more than one in five LTE operators.

While most operators (90 percent) deployed LTE networks in paired spectrum using the FDD mode, the LTE TDD mode (TD-LTE) for operators with unpaired spectrum continues to develop in all regions. Currently 59 operators, which is almost one in seven of all LTE operators, have commercially launched LTE service using the TDD mode in 35 countries. Band 40 (2.3 GHz) is the most widely deployed spectrum. 17 operators have deployed both FDD and TDD modes in their networks. Converged FDD and TDD LTE networks are gaining traction amongst many operators.

Ericsson and SK Telecom to Collaborate on 5G Network Slicing

Ericsson and SK Telecom have signed a Letter of Intent (LoI) to collaborate on the development of a 5G core network that deploys network slicing technology. Under the terms of the agreement, the two companies will develop and deploy network slicing technology optimized for 5G services. They will also continue their existing partnership to build a joint 5G test bed, which is starting this year, with the ambition to provide the world's most advanced end-to-end 5G pilot services.

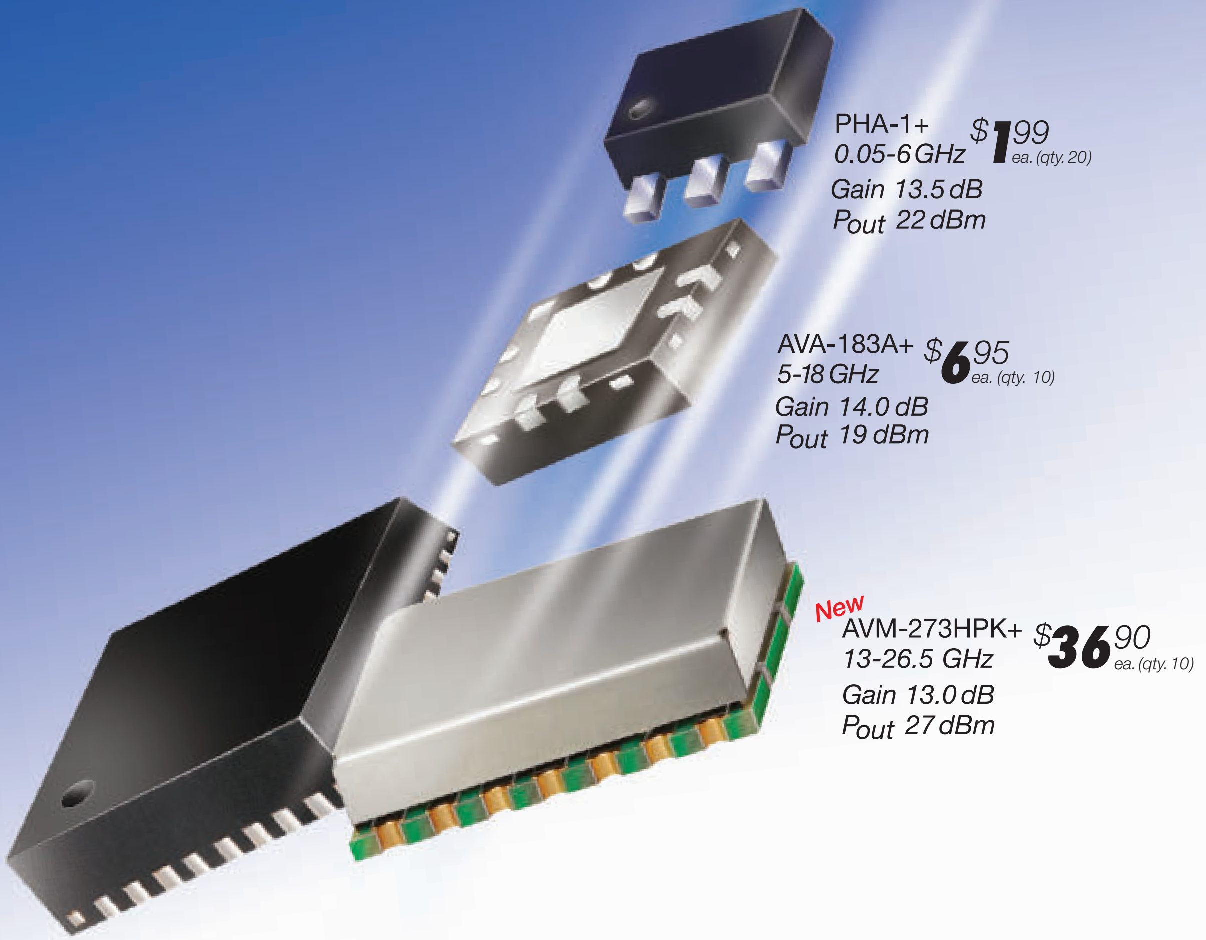
Projected 5G use cases such as remote machinery, intelligent transportation and virtual reality will place new performance and security demands on networks. To meet these requirements, 5G networks will be built with network slicing technologies that use logical instead of physical resources, and which enable operators to provide networks on an as-a-service basis. The instantiation of the network slicing will use the Ericsson Virtual Evolved Packet Core solution.

"Virtual network architecture, including network slicing, is critical to supporting new services in the era of 5G. We will build an optimal network for a wide array of services from the overall end-to-end standpoint, and pioneer the evolution of innovative networks," said Alex Jinsung Choi, chief technology officer at SK Telecom.

The collaboration will leverage the capabilities of Ericsson's Regional Cloud Lab, which is distributed across four sites in North East Asia including Anyang in South Korea, Beijing and Shanghai in China, and Tokyo in Japan. Fully operational since 2014, the Lab supports operators with the development and verification of cloud, Network Functions Virtualization and software-defined networking technologies.

50 MHz to 26.5 GHz

MICROWAVE MMIC AMPLIFIERS



Mini-Circuits' New AVM-273HPK+ wideband microwave MMIC amplifier supports applications from 13 to 26.5 GHz with up to 0.5W output power, 13 dB gain, ±1 dB gain flatness and 58 dB isolation. The amplifier comes supplied with a voltage sequencing and DC control module providing reverse voltage protection in one tiny package to simplify your circuit design. This model is an ideal buffer amplifier for P2P radios, military EW and radar, DBS, VSAT and more!

The AVA-183A+ delivers 14 dB Gain with excellent gain flatness (±1.0 dB) from 5 to 18 GHz, 38 dB isolation, and 19 dBm power handling. It is unconditionally stable and an ideal LO driver amplifier. Internal DC blocks, bias tee, and microwave coupling capacitor simplify external circuits, minimizing your design time.

The PHA-1+ + uses E-PHEMT technology to offer ultra-high dynamic range, low noise, and excellent IP3 performance, making it ideal for LTE and TD-SCDMA. Good input and output return loss across almost 7 octaves extend its use to CATV, wireless LANs, and base station infrastructure.

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BLE Beacon Shipments to Break 400 Million in 2020

VIEW VIDEO

ABI Research's report, "BLE Tags: The Location of Things (LOT)" reveals that total BLE Beacon shipments will comfortably exceed 400 million units in 2020. Principal Analyst Patrick Connolly comments, "BLE Beacons are cropping up everywhere, with particularly strong growth coming in Enterprise/Industrial, IoT and connected home, as well as more established markets like retail and personal asset tracking. The arrival of Eddystone is a huge driver here, particularly in non-retail markets, where new signals and features are particularly beneficial. However, this year there have been significant advances around network management, meshing, technology hybridization and software-based beacon upgrades. All of these advances are creating confidence with huge shipments into unexpected areas like asset tracking and industrial."

> Pure Beacon shipment revenues are expected to break $1 billion but the real opportunity is in network management and analytics.

Pure Beacon shipment revenues are expected to break $1 billion but the real opportunity is in network management and analytics. Although there are exceptions like Radius Networks and Perples, retail will be a tough business for Beacon start-ups, especially when the majority of future revenues are in advertising. Instead, many are starting to focus on specific non-retail verticals, where individual contracts are much larger with a higher RoI on services like analytics.

"Three very interesting verticals are asset tracking, vending machines and dedicated BLE Beacon advertising networks, where OEMs like Gimbal, Sensoro, Kontakt.io, and Bluvision are having initial success. BLE Beacons can completely revolutionize these markets and ABI Research expects early adopters will gain a huge advantage."

Combo ICs to Take 12 Percent of 802.15.4 Market by 2019; IP-Enabled Solutions Set to Continue

VIEW VIDEO

The 802.15.4 wireless connectivity market is set to continue its transition towards IP-enabled solutions, increasing from 6 percent of the market in 2015 to over 30 percent by 2019, finds ABI Research. Alongside this, the market share of combo ICs from the total shipments of 802.15.4 chips is set to grow from 1 percent to over 12 percent.

Emerging IP-enabled networking technologies such as Thread are expected to take a significant proportion of the 802.15.4 market, most notably in the smart home, while the recent collaboration to enable the ZigBee Cluster Library to run over Thread networks will bring about a more rapid development process and provide a boost to 802.15.4 chipset shipments as a whole.

With significant market opportunities for both ZigBee and Thread, there is a growing incentive for suppliers to provide a futureproof multi-protocol solution able to support the varied IoT device types down the line. "It is becoming increasingly clear that the market for the connected home and other low-power wireless networking environments will continue to adopt multiple connectivity solutions based on different needs and priorities. Although there is a clear trend towards IPv6 solutions, not every end device will need to support IP, and there will be room for both IP and non-IP solutions across the various IoT markets," comments Malik Saadi, VP, Strategic Technology.

> In order to drive demand, reduce costs, and improve time to market, suppliers need to have a connectivity portfolio large enough to allow customers to support numerous protocols.

In order to drive demand, reduce costs and improve time to market, suppliers need to have a connectivity portfolio large enough to allow customers to support numerous protocols. "In the past, the majority of key Wi-Fi and Bluetooth IC suppliers have not provided an 802.15.4 solution, while 802.15.4 suppliers have not been aggressively pursuing Wi-Fi or Bluetooth," Saadi adds. Vendors such as TI, Silicon Labs, STM, Freescale, Nordic, Marvell and Microchip – with diversified connectivity portfolios encompassing Wi-Fi, Bluetooth, 802.15.4 and other low-power wireless solutions – will be able to take advantage of these opportunities. These combo solutions will become vital in providing the scalability and flexibility needed to drive the smart home and other IoT vertical markets in the near future.

Markets for Compound Semiconductor MMICs Forecast to Grow Through 2020

Compound semiconductor substrates are maintaining their importance for the fabrication of various types of monolithic microwave integrated circuits (MMIC). Although silicon technology (notably CMOS) is steadily advancing into some of the territory previously occupied by compound semiconductors there are many microwave systems for which the required performance levels can only be met by compound semiconductor MMICs.

Engalco's CS MMICs update report provides market data on microwave (0.5 to 30 GHz) MMICs fabricated using GaAs, GaN, InP, InGaP and SiGe into the following systems applications: defense (AESAs, EW); industrial, sci-

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> Global markets of about $730 million in 2014 are forecast to increase to $851 million in 2020.

entific and medical (ISM); Ka-Band VSATs, Ku-Band VSATs and microwave radio. Power amplifier MMICs and "non-power" MMICs are considered separately for all the market segments researched. Annual total market data are indicated for base year 2014 and for each forecast year to 2020. Geographic regions covered are Europe, North America and "rest of the world". According to Terry Edwards, senior analyst and executive director at Engalco, total global markets were about $730 million in 2014 increasing to $851 million in 2020.

Markets for GaAs-based MMICs remain strong, albeit increasingly impacted by competition from GaN mainly on the power amplifier side and SiGe BiCMOS for signal processing – notably for medium-to-high market volumes. The markets for most types of CS MMICs are well entrenched in AESAs, SATCOM (VSAT) and microwave radios. Most markets grow at least moderately, although the market for MMICs in microwave radios declines somewhat owing to the increasing impact of fiber optics for cellular network backhaul – to the detriment of microwave in this particular application.

Prominent among 50 players identified are Analog Devices (acquired Hittite Microwave in 2014), Custom MMIC, MACOM, METDA, Qorvo (RFMD/TriQuint merger), TowerJazz and UMS. These players serve major portions of the total market.

LiDAR Market Worth $1B by 2020

According to a new market research report, "LiDAR Market by Product (Airborne, Ground-Based), Component (Laser Scanner, GPS, IMU, Others), Application (Corridor Mapping, Engineering, Environment, ADAS, Urban Planning, Exploration, Meteorology, and Others), & Geography - Global Forecast to 2020," the LiDAR market is expected to rise to more than $1 billion by 2020, growing at a CAGR of 16.32 percent between 2014 and 2020.

The LiDAR market is expected to witness a high-growth phase from its traditional applications like corridor mapping and cartography as well as emerging applications like urban planning and advanced driver assistance systems (ADAS). Aerial surveying is set to receive a boost with the development of the Geiger-mode LiDAR technology which enables high-resolution data collection even from higher elevations. At the same time, mobile LiDAR systems are becoming more compact and affordable, especially in the automotive sector, with the introduction of Velodyne LiDAR's "puck" device. These recent breakthroughs are expected to not only drive the LiDAR market in the coming years but also lead to new market segments.

Around the Circuit

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

M/A-COM Technology Solutions Holdings Inc. announced that it has entered into a definitive agreement to sell its automotive business to **Autoliv ASP Inc.** The automotive business represented approximately 18 percent of MACOM's consolidated revenue in its second fiscal quarter, which ended April 3, 2015. The agreed consideration to MACOM for the automotive business is to be $100 million in cash, subject to customary working capital and other adjustments, plus the opportunity to receive up to an additional $30 million in cash based on achievement of revenue-based earn-out targets through 2019.

Lockheed Martin has entered into a definitive agreement to acquire **Sikorsky Aircraft**, a world leader in military and commercial rotary-wing aircraft, for $9 billion. The price is effectively reduced to approximately $7.1 billion, after taking into account tax benefits resulting from the transaction. The acquisition is subject to customary conditions, including securing regulatory approvals, and is expected to close by late fourth quarter 2015 or early first quarter 2016. The transaction will have no impact on the company's previously stated commitments to return cash to shareholders through dividends and to reduce outstanding share count to below 300 million shares by the end of 2017.

GeoTraq Inc., a development stage company focused on developing next-generation wireless location technology, announced it intends to acquire **OmniM2M**, a technology company focused on IoT and Ci2i, a technology consulting company focused on analytics. Under the terms of the Letter of Intent, GeoTraq will issue to the shareholders of OmniM2M and Ci2i a total of 120 million common shares. Both OmniM2M and Ci2i had combined gross revenues of over $1 million in 2014. The acquisition will create immediate additional revenues to GeoTraq from existing OmniM2M and Ci2i contracts, and significantly increase the company's bottom line and overall shareholder value.

ams AG, a provider of high performance sensors and analog ICs, announced that the company has acquired the CMOS Sensor Business from **NXP Semiconductors**. The acquisition expands ams' environmental sensor portfolio with advanced monolithic and integrated CMOS sensors that measure several environmental variables such as relative humidity, pressure and temperature in one sensor device. The newly enlarged line of ams environmental sensors is anticipated to drive high-value growth opportunities for smartphones, wearables and other mobile devices as well as for smart buildings and the industrial, medical and automotive markets.

COLLABORATIONS

Novatel Wireless Inc., a provider of wireless solutions for the Internet of Things, delivers comprehensive managed services for new telematics offering to surveillance specialist **QVIS Monitoring Ltd.** in the United Kingdom. Under the partnership, Novatel Wireless is supplying QVIS with a feature-rich out of the box-ready telematics solution which includes the MiFi® Drive model MT 3060, events reporting software and airtime.

RFaxis and **Silicon Labs** will be collaborating on chipset reference designs to address the high growth Internet of Things (IoT) and smart home markets. Specifically, RFaxis has developed RF front-end reference designs that extend the reach and capabilities of Silicon Labs' ZigBee® and Thread EM35x mesh networking products. Silicon Labs is a founding member of the Thread Group that is helping product developers and consumers easily and securely connect more than 250 devices into a low power, wireless mesh network that supports seamless Internet and cloud access.

NEW STARTS

The High Performance Foams Division of **Rogers Corp.** has officially changed its name to **Elastomeric Material Solutions** to better reflect the growing range of products and capabilities available to meet customer needs. Elastomeric materials are, by definition, any resilient material composed of chainlike molecules, or polymers, that recover their original shape after being stretched. Rogers Elastomeric Material Solutions produces a variety of elastomeric products such as PORON® foams, BISCO® silicones, XRD® extreme impact protection materials, and the recently acquired ARLON® silicones.

ACHIEVEMENTS

▲ *Ulrich Rohde*

Oradea University has issued a special citation of thanks to **Prof. Dr.-Ing habil Dr. h. c. mult. Ulrich Rohde** for more than 20 years of collaboration and thanks for accepting the honorary distinction of Doctor Honoris Causa. Oradea University is located in Oradea in north western Romania and has cooperated on many projects with Rohde over the years to further research in the RF and microwave field.

M2 Global Technology Ltd., a designer and manufacturer of precision electronic components and subassemblies, was awarded Platinum Premier Supplier status by **Rockwell Collins**. Rockwell Collins, a developer and provider of communication and aviation electronics solutions for commercial and government applications, awarded M2 Global Technology Ltd. the highest level in its Trusted Supplier Program. This program recognizes M2 Global for meeting the highest level of quality, delivery and business alignment in its supply of RF passive components.

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POWER DIVIDERS RoHS

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

~ With matched operating conditions

HYBRIDS RoHS

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

◊ In excess of theoretical coupling loss of 3.0 dB

COUPLERS RoHS

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

* Add suffix - LF to the part number for RoHS compliant version.
~ With matched operating conditions

Unless noted, products are RoHS compliant.

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Around the **Circuit**

CONTRACTS

NASA's Goddard Space Flight Center has awarded **Raytheon Co.** a five year contract valued at up to $240 million to continue its support of the Earth Observing Systems Data and Information System (EOSDIS). This system ingests, archives and makes earth science data available to the scientific community worldwide. The latest EOSDIS Evolution and Development (EED-2) contract is the third competitively awarded contract Raytheon has received to maintain, operate and develop improvements for data access and system performance. The initial contract award was in 1992.

Harris Corp. has been awarded an IDIQ contract with a ceiling value of $228 million to support the **U.S. Navy's** maritime mine countermeasures (MCM) efforts. The five-year contract includes a three-year base and two one-year options. The Space and Naval Warfare (SPAWAR) Systems Center Pacific in San Diego, Calif., awarded Harris the contract to provide surface and subsurface unmanned maritime systems solutions. Harris will provide solutions to support current systems and future technologies in MCM, anti-submarine warfare, intelligence, surveillance and reconnaissance, and force protection.

The Radant Technologies Division of **Communications & Power Industries LLC** (CPI) has received multi-year orders totaling $7.6 million for the provision of radomes and related services to support an airborne electronic warfare system for the **U.S. Navy.** CPI Radant Technologies Division has provided radomes for this electronic warfare system for several years, and the most recent contract extends its participation in this system until 2020. The contract was awarded by the U.S. military's Defense Logistics Agency (DLA) Aviation in Philadelphia. Work on this contract will be performed in Stow, Mass.

Mercury Systems Inc. announced it received $5.2 million in orders from a leading defense prime contractor to provide radar subsystems and related digital processing technologies for a missile defense application. The orders were booked in the company's fiscal 2015 fourth quarter and are expected to be shipped over the next several quarters.

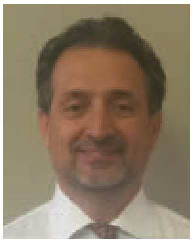
Comtech Telecommunications Corp. announced that its New York-based subsidiary, **Comtech PST Corp.**, received a $1.3 million order for solid-state, high-power RF switches from a major domestic prime contractor. These switches provide for very broad frequency coverage and are key components in an integrated electronic countermeasures system used by the U.S. Military. Comtech PST Corp. is an independent supplier of broadband, high power, high performance RF microwave amplifiers for use in a broad spectrum of applications.

PEOPLE

Custom MMIC announced that **John Greichen** has joined its leadership team as vice president of sales and marketing. He will be responsible for all aspects of sales and marketing for Custom MMIC, as the company continues to rapidly grow its standard product and design services offerings. Greichen has over 30 years of broad technology and business experience. Most recently, he was general manager of the RF and microwave business unit at Analog Devices Inc., where he started a group in 1997, which grew into a substantial, highly profitable business for the company.

▲ *John Greichen*

Santier, a custom thermal management solutions provider with a full range of heat sinks for electronic packaging, announced the addition of **Mansoor Mosallaie** as vice president of operations. Mosallaie has 25 years of experience in manufacturing and operations, most recently as Hermetic Division Manager at Hi Rel Connectors. Prior to that, Mosallaie was general manager at Ametek HCC Industries, where he worked for over 20 years, and where he had direct profit and loss responsibility for two divisions and over 500 employees.



▲ *Mansoor Mosallaie*

Anaren Inc. has named **Diane E. Moore** as the company's new vice president of human resources. Moore has over 20 years of human resource management experience. Most recently, she was vice president of human resources for New York Air Brake, where she headed the HR function for six locations and was a member of its strategic leadership committee. Prior to that, Moore worked at Carthage Area Hospital, King & King Architects and Blue Cross/Blue Shield of Utica/Water.

▲ *Diane E. Moore*

3D Glass Solutions announced the newly elected chairman of its board of directors, **Stuart Schoenmann**. Schoenmann joins the 3D Glass Solutions Board with more than 30 years of expertise in the applied technology and high tech manufacturing industry, along with 12 years of CEO and COO experience. His experience also includes implementing aggressive growth strategies and leading companies from $10 million to $200 million in sales.

▲ *Stuart Schoenmann*

Norsat International Inc., a provider of innovative communication solutions that enable the transmission of data, audio and video for remote and challenging applications, announced it has appointed **Peter Ciceri** to the board of directors. Shannon Susko, who had served the board since 2014, has stepped down to focus on a new venture. A successful CEO, corporate director and international executive, Peter Ciceri is currently Chairman of Archipelago Marine Services and a corporate director of Terapeak Data Inc.

REP APPOINTMENTS

Custom MMIC announced the appointment of **Seaport Technical Sales Inc.** as its new technical representative covering the Pacific Northwestern territory, including Idaho, Montana, Washington, Oregon and British Columbia.

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Waveguide Band (GHz)	**WR15** 50-75	**WR12** 60-90	**WR10** 75-110	**WR6.5** 110-170
Dynamic Range (BW=10Hz, dB, typ)	120	120	120	120
(BW=10Hz, dB, min)	100	100	100	90
Magnitude Stability (±dB)	0.15	0.15	0.15	0.25
Phase Stability (±deg)	2	2	2	4
Test Port Power (dBm)	6	6	6	0

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Around the **Circuit**

Remcom announced a partnership with **Moasoft Corp.**, a provider of software and consulting services in South Korea. The partnership will expand Remcom's presence in the Korean market and enable customers there to more easily access its Electromagnetic Simulation Software, services and support.

RFMW Ltd. and **ParkerVision Inc.** have announced a worldwide distribution agreement for ParkerVision products and services. Under the agreement, RFMW will support sales and distribution logistics of ParkerVision's high performance modulators and demodulators, operational amplifiers, low noise amplifiers and power management ICs. In addition, RFMW will provide access to ParkerVision's engineering services and ASIC design services.

Richardson Electronics Ltd. announced a new global distribution agreement with **Ohmite Manufacturing Co.**, a Chicago-based provider of resistive products for high-current, high-voltage and high-energy applications. The agreement supports Ohmite's efforts to expand sales and technical support of its high performance resistor technology.

DiTom Microwave, an AS9100 Rev C. certified U.S. manufacturing company located in Fresno, Calif. with over 28 years of experience engineering, designing and manufacturing high quality ferrite isolators and circulators for the space and defense markets, announced the appointment of **IMC. Ltd.** as the company's new exclusive representative for Japan. Their office is located at Nittochinishishinjuku Bldg. 8F, 6-10-1 Nishishinjuku, Shinjuku-ku, Tokyo, Japan.

PLACES

Vaunix Technology Corp., a manufacturer of USB controlled and powered test equipment, recently moved its head office to Newburyport, Mass. This move will help accommodate future growth and allow for advances in the engineering and manufacturing of their products. Additionally, Newburyport offers a greater variety of business opportunities and development which will be beneficial to moving the company forward. The address of the new location is 7 New Pasture Road, Newburyport, Mass. 01950. All other contact information, including phone numbers, remain the same.

Cobham Communications and Connectivity has opened a new facility in Singapore, to drive further growth of its business activities across the Asia Pacific market. This new office brings together the Cobham Group's Antenna Systems, AvComm, SATCOM, Tactical Communications & Surveillance (TCS) and Wireless business units. The region contributes significant revenues annually, making Asia Pacific one of Cobham's most important and rapidly expanding markets.

S-Band Omnidirectional Antenna System for Nano/ Micro Student Satellites

V. Sambasiva Rao
PES University, Bangalore, India
M.C. Basava Raj and L. Nicholas
Formerly With Kavveri Telecom Products Ltd., Bangalore, India

This antenna system provides omnidirectional coverage of telemetry, tracking and command (TT&C) communication links for a student satellite. The compact, lightweight antenna is designed for dual circular polarization in S-Band (2.0 to 2.3 GHz), covering both the transmit and receive TT&C frequency bands. Two cross polarized antennas mounted on opposite sides of a nano or micro satellite assure 100 percent coverage with acceptable gain at both transmit and receive frequencies.

Conventional methods of mounting two antennas of the same polarization on opposite sides of a satellite cannot provide full omnidirectional coverage because considerable interference in the overlapping coverage areas creates deep radiation pattern nulls. This typically provides about 85 percent coverage with considerable zones having gain as low as -10 dBi.[1] A configuration for obtaining nearly full coverage with acceptable null depths is discussed in this article. Two antennas with hemispherical coverage of opposite polarization, left hand circular (LHC) and right hand circular (RHC), when mounted on opposite sides of a satellite, provide omnidirectional coverage in two polarizations.

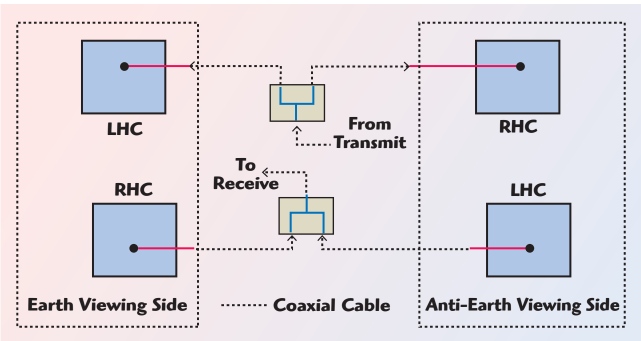

Fig. 1 Basic configuration of the omnidirectional antenna system.

Variants of a helical antenna are conventionally used onboard low earth orbit (LEO) satellites for obtaining circular polarization with wide bandwidth. The size of these antennas, however, restricts their use on-board micro/nano satellites. Microstrip patch antennas, by virtue of their low profile, light weight and small size are preferred for satellite applications, but conventional microstrip antennas[2] cannot support the total TT&C frequency band of a satellite and also provide good axial ratio. To overcome this problem, separate antennas for receive and transmit are considered. ***Figure 1*** shows a typical antenna system for achieving omnidirectional coverage with acceptable gain; this configuration uses four antennas.

Antenna cross polarization isolation through the use of receive and transmit antennas of opposite polarization also reduces bandpass filter isolation requirements. The ground station will have the provision to receive signals in dual polarization and apply diversity combining for optimum performance. The transmit signal can be sent in either polarization based on the received signal strength. Alternatively, transmission in linear polarization will simplify ground station transmission, albeit with 3 dB degradation in the uplink; it is straightforward to transmit 3 dB higher power from the ground station to overcome polarization loss.

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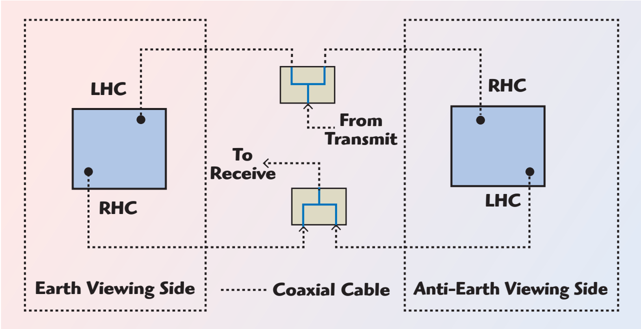


Fig. 2 Omnidirectional antenna system with dual polarized antennas.

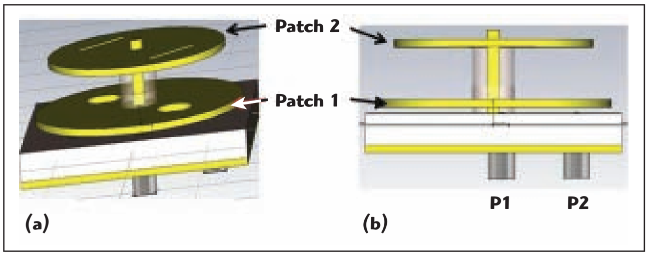


Fig. 3 Isotropic (a) and side (b) views of the antenna configuration.

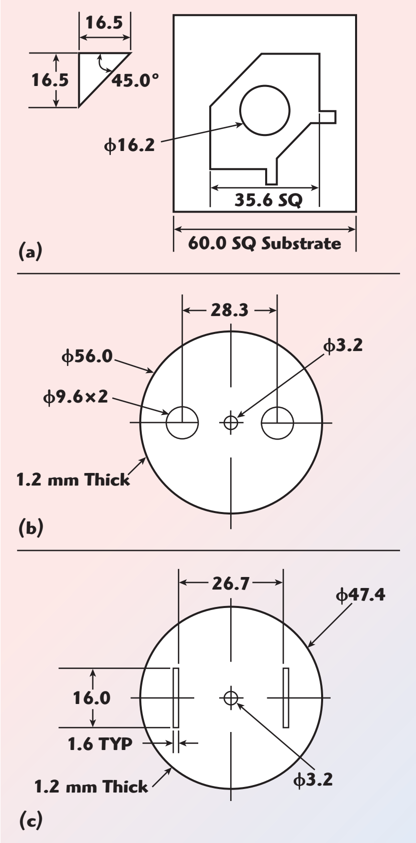
DUAL POLARIZED WIDE BANDWIDTH ANTENNA

A wideband antenna with dual polarization capability can reduce the number of antennas (see ***Figure 2***). To achieve this, a dual circularly polarized microstrip antenna coupled with two circular shaped parasitic patches is designed and developed. Broad bandwidth, compact size, light weight, good port-to-port isolation and dual circular polarization with good axial ratio are the main features of the design. The antenna consists of two electromagnetically coupled circular parasite patches aligned over a microstrip radiating patch fabricated on a low loss substrate.[3] The three patches are separated by air layers (see ***Figure 3***).

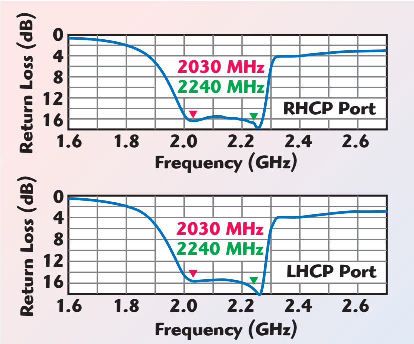
The basic microstrip patch is printed on a 4.75 mm thick dielectric substrate having an ε_r of 3.0. The antenna is fed by two coaxial probes (P_1 and P_2), placed orthogonally to obtain LHC and RHC polarizations. To enhance the bandwidth, two circular passive patches with a pair of holes and slits are stacked over the substrate with spacing optimized for performance. Holes are made on the immediate circular parasitic patch, and slits are cut on the second parasitic circular patch. These patches are aligned over the diagonal of the basic microstrip patch. The antenna dimensions are shown in ***Figure 4***. Opposite corners of the square patch are truncated, as illustrated in ***Figure 4a***, in order to excite two orthogonal modes. Pairs of holes and slits are located diagonally on the circular parasitic patches 1 and 2, respectively (see ***Figure 4b*** and ***4c***), to achieve a good axial ratio and good impedance matching over the required frequency band of operation. The dimensions and positions of the holes and slots are adjusted through a number of iterations to broaden the beamwidth and optimize the axial ratio. A 1 mm spacing between the truncated radiating patch and circular parasite patch 1 and an 8 mm spacing between circular parasite patch 1 and circular parasite patch 2 are found to provide the required performance.

Simulation and optimization were performed using the transient solver in CST Microwave Studio®. Simulated return loss for both LHCP and RHCP ports over the fre-

quency band of interest are plotted in ***Figure 5***. Radiation patterns and axial ratio for both ports at 2030 and 2240 MHz are shown in ***Figure 6***.



▲ *Fig. 4 Dimensions (mm) of the corner truncated patch on TLC-30 substrate (a) circular parasitic patch 1 (b) circular parasitic patch 2 (c).*



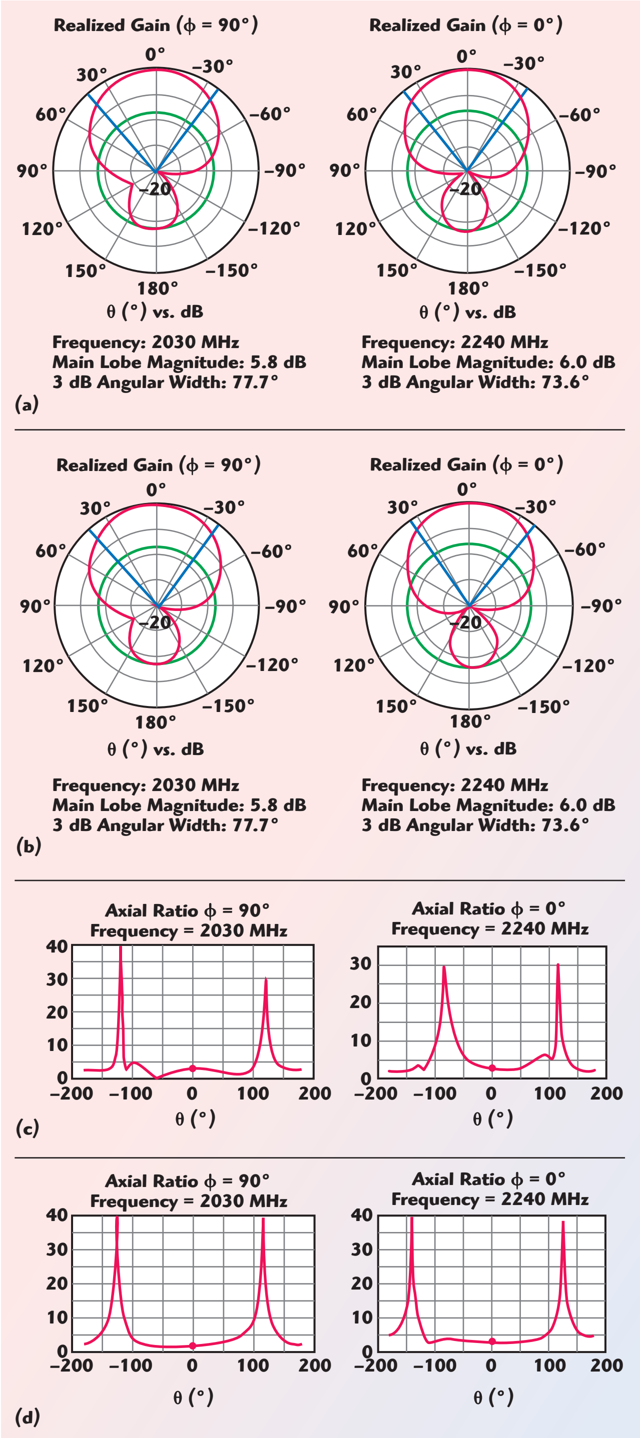
▲ *Fig. 5 Simulated return loss at the LHCP and RHCP ports.*

▲ *Fig. 7 Dual circularly polarized antenna prototype.*

TEST RESULTS

Figure 7 is a photograph of the prototype dual circularly polarized antenna. Radiation patterns at the center frequency (2130 MHz) for the LHC (Port 1) and RHC (Port 2) polarizations are shown in ***Figure 8***. An axial ratio of less than 3 dB is achieved over the full frequency band. Port-to-port isolation measures 14 dB at 2030 MHz, improving to 19 dB at 2240 MHz. VSWR is less than 1.4:1 across the band.

Two antennas have been mounted on opposite sides of a student nano satellite (PISat) being developed at the PES Institute of Technology in Bangalore, India. The satellite is 254 × 226 × 180 mm in size. The receive and transmit ports of the antennas are connected as shown in Figure 2. ***Figure 9*** shows the combined radiation patterns measured in an anechoic chamber at the receive (2030 MHz) and transmit (2240 MHz) frequencies. The total variation in the measured combined radiation pattern is 10 dB, with a minimum antenna system gain of -7 dBi and a peak gain of about +3 dBi. The patterns show that 100 percent coverage can be obtained with a minimum gain of -7 dBi.



▲ *Fig. 6 Simulated radiation patterns at 2230 and 2240 MHz of LHCP port 1 (a) and RHCP port 2 (b). Simulated axial ratio at 2230 and 2240 MHz of LHCP port 1 (c) and RHCP port 2 (d).*

CONCLUSION

A simple configuration for achieving omnidirectional coverage on-board a satellite, using dual circularly polarized microstrip patch antennas, has been presented. A wide bandwidth, dual circularly polarized truncated corner microstrip antenna coupled with two parasitic patches was designed, simulated and optimized. Diagonally embedded holes and slots on the parasitic patches significantly improve cross polarization bandwidth. The antennas were mounted on a nano satellite and tested

in an anechoic chamber. Complete coverage was obtained with a minimum of -7 dBi antenna gain. The model may be easily scaled to any other frequency band. ■

ACKNOWLEDGMENTS

The authors wish to acknowledge the support extended by Kavveri Telecom Products Ltd., Bangalore, for simulation, fabrication and testing and would like to thank Dr. TS Chandar, HOD, Dept. of ECE; Dr. V.K. Agrawal, Director, CORI; and Dr. K.N.B. Murhty, Vice Chancellor, PES University for their encouragement.

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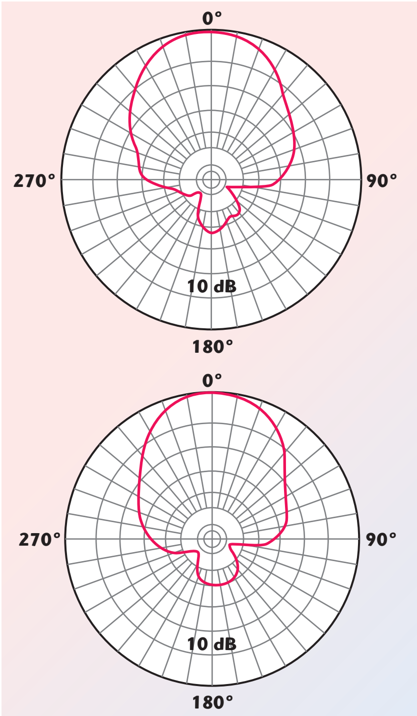
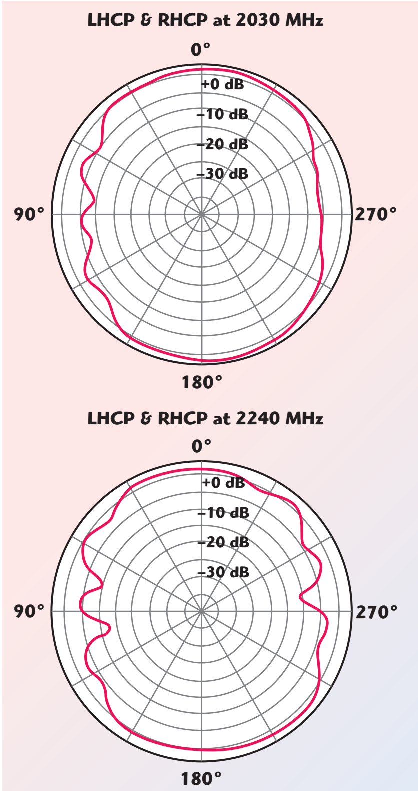


▲ *Fig. 8 Measured RHC and LHC radiation patterns at 2130 MHz.*



▲ *Fig. 9 Measured combined radiation patterns at 2030 MHz and 2240 MHz.*

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INVITED PAPER

GaAs MMIC Diode Technology Enables High Linearity and Low Power

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In this article, we discuss MMIC mixers designed using high performance GaAs Schottky diodes. Compared to fixed Schottky diode options already on the market, we describe, for the first time, GaAs diodes with forward voltages ranging from 0.29 to 0.9 V. These diodes enable new circuit capabilities previously not possible in GaAs diode circuits. A state-of-the-art MMIC mixer has been developed and new performance characteristics demonstrated, including low LO drive for power sensitive applications and high LO drive for high linearity applications.

The "fabless" model is pervasive in the semiconductor integrated circuit (IC) industry. In this model, IC designers rely on the expertise of external foundries to support ongoing production as well as next generation device and process development. In this partnership, the fabless company is free to develop new designs efficiently while the foundry is able to amortize the costs of running the factory over numerous fabless or "fab-lite" customers and achieve better economies of scale. As it is well known in the industry, a foundry must achieve high wafer run rates in order to maintain high yields and high profitability. Most of the nimble, aggressive and smaller IC design firms cannot afford to run an internal fab, so they instead invest in the modeling, simulation, packaging and testing of the devices. This often implies that the fabless company understands the fine intricacies of a foundry process as well, or potentially better, than the foundry itself. Moreover, the foundry can often provide superior technical solutions to what is considered standard, but they may not develop these solutions without sufficient persuasion (i.e., economic, technical, etc.). By communicating the relative strengths and weaknesses of a given process openly, technical breakthroughs are achieved that benefit both firms. To use an analogy, the foundry builds racecars and the fabless designers are the drivers. The driver has no expertise to build the car, but he or she is well qualified to critique the performance and suggest improvements.

In the spirit of this synergistic designer-foundry relationship, Marki Microwave and GCS have recently collaborated to solve the major technical challenge of offering high quality GaAs Schottky diodes in a commercial foundry setting, with diode forward voltages (V_f) from 0.29 to 0.9 V. As we will describe, this new foundry process overcomes a previous technological boundary, where GaAs Schottky diodes were only offered with 0.7 V turn-on voltage. By engineering the diode processing and epitaxial layer design, GCS achieves variations in the V_f that were traditionally only possible in Si Schottky diodes. With this new type of device, Marki Microwave designers achieve a variety of previously impossible performance metrics in a GaAs MMIC platform. We focus on double balanced mixer designs because they benchmark well with classical Si-based designs. This GaAs process can be applied to any circuit that typically uses Schottky devices from DC through millimeter wave.

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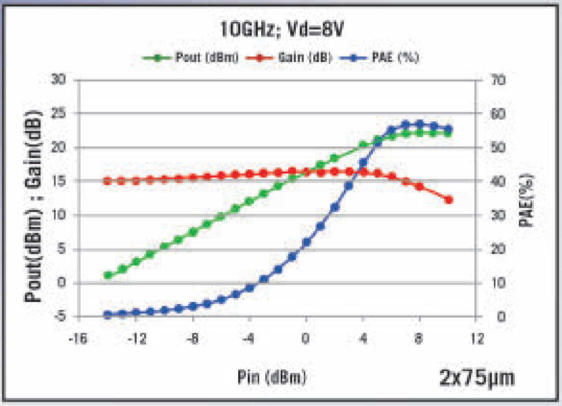

Gain (dB)	P1dB (dBm)	P1dB (mW/mm)	Psat (dBm)	Psat (mW/mm)	PAE Max(%)
15.0	22.1	1086	22.2	1114	56.8

2x75µm device @8V, 10GHz, 150 mA/mm

Summary of WIN mmWave pHEMT portfolio

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Gate length	0.25 µm	0.15 µm	0.15 µm	0.1 µm
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Vto	-1.15 V	-1.3 V	-0.7 V	-0.95 V
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f_{max}	190 GHz	185 GHz	150 GHz	180 GHz
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SCHOTTKY DIODES IN MIXERS

Historically, mixers based on diode technology have split into two camps: hybrid mixers using discrete diodes and MMIC mixers using integrated diodes. Generally, hybrid mixers are thought of as higher performance, broader band and more flexible in being optimized for specific performance specifications. MMIC mixers, on the other hand, overcome the limited flexibility by offering much smaller form factors at significantly lower cost. Generally, hybrid and MMIC mixers are so different in performance that suitable applications for the two technologies are distinct and non-overlapping. In other words, if highest performance and/or tunability is needed, hybrid mixers must be used; if cost and size are most important, MMIC mixers must be used. With few exceptions, these truisms have existed for at least two decades.

The "hybrid/MMIC divide" is explained by many physical differences:

- Hybrid mixers use suspended substrate balun structures on low dielectric material
- MMIC mixers are most commonly built on GaAs, which is a grounded substrate with high dielectric constant
- Hybrid mixers use discrete diodes that are hand assembled, limiting size reduction
- Hybrid mixers can be designed on almost any material platform, giving the designer many options to modify performance characteristics
- MMIC mixers have strict design rules for the stack-up, which limits design flexibility
- Hybrid mixers can use any kind of diode (e.g., low barrier Si, GaAs, beam lead, flip chip) while MMIC mixers must use the diode device offered by the process.

This final point regarding diode options is essential to understanding why hybrid mixers have survived and prospered in the marketplace for over a half century, despite higher cost and larger size. GaAs devices have been restricted to applications where a barrier potential of 0.7 V is acceptable, while hybrid mixers (mostly based on Si Schottky diodes ranging from 0.25 to 0.9 V) offer performance tailored advantages for applications where very low or high V_f is necessary.

THE SCHOTTKY DIODE PROCESS

While it is true that MMIC mixers can be fabricated using familiar GaAs PHEMT and MESFET processes, these technologies are generally not ideal for achieving high quality Schottky diodes. For example, mixers fabricated using PHEMT processes demonstrate worse performance because of the inferior I-V characteristics and device options of drain-to-source shorted PHEMT diodes. A cursory market survey of commercially available MMIC mixers reveals that mixers made in PHEMT and MESFET processes regularly have inferior conversion loss characteristics compared to hybrid diode mixers. It is normal to expect 10 dB conversion loss in mixers fabricated in PHEMT, where bona fide Schottky-based mixers regularly achieve 6 dB conversion loss. The poor performance of PHEMT diodes is because PHEMT devices are primarily intended for use in amplifiers, and PHEMT processes are designed to optimize the transistor ft and fmax – albeit to the detriment of the diode characteristics.

In 2010, GCS recognized this limitation in PHEMT solutions and released a new GaAs process optimized for Schottky diode-based ICs. The diodes produced by the optimized epi-layer and junction design offer significantly better I-V characteristics than PHEMT diodes, with RC time constants measured in THz. The process includes Schottky diode and passive components (thin film resistors, MIM capacitors, inductors and transmission lines) that can be integrated on a single chip.

Until now, all commercial GaAs processes (PHEMT, Schottky, etc.) have featured Schottky diodes with turn-on voltages near 0.7 V. This has been attributed throughout the literature to the pinning of the Fermi level to a fixed energy at the metal-semiconductor interface in III-V materials.[1] It has been shown repeatedly that the GaAs Schottky forward voltage is essentially independent of the metal work function. Si Schottky diodes, by contrast, do not experience this Fermi level pinning phenomenon to the same extent and can more easily be engineered to a variety of barrier heights. Hence, one finds Si diodes from many suppliers with V_f below 0.2 to greater than 1 V. GaAs diodes lack this variety.

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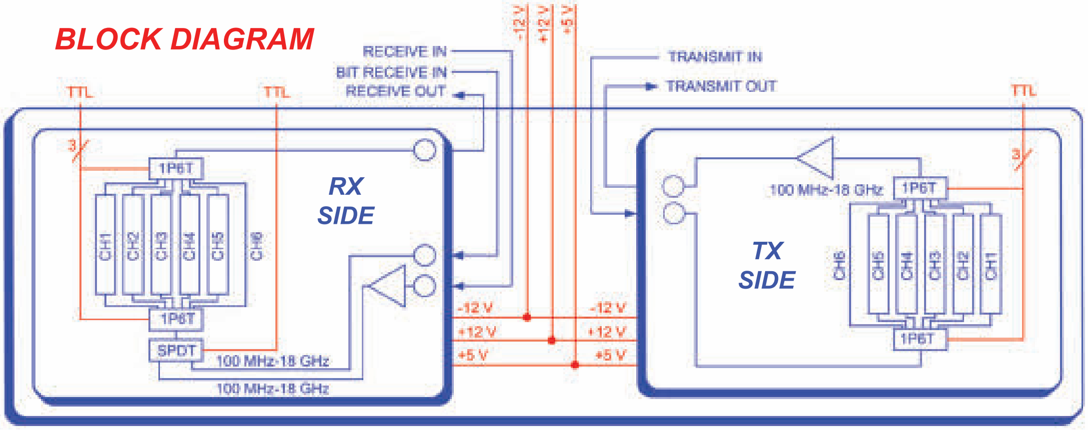
BLOCK DIAGRAM



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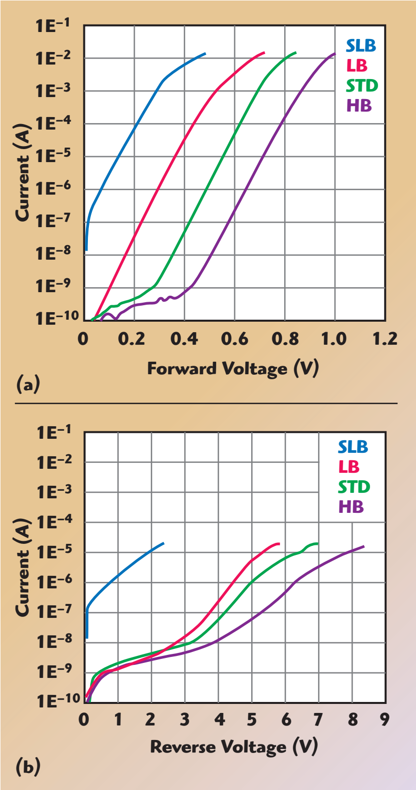
Recently, GCS succeeded in developing a modification to its traditional 0.7 V Schottky process to enable alternative diode levels in GaAs. This breakthrough was achieved by careful engineering of the epi layer and Schottky contact on the GaAs substrate. The resultant diodes exhibit nearly identical RC properties to the standard 0.7 V diodes and with the added benefit of altered junction potential. The diode forward and reverse I-V characteristics are shown in ***Figure 1***, and the DC parameters of a 1.6 × 8 μm² Schottky diode are summarized in ***Table 1***. All diodes offer impressive performance characteristics, including an ideality factor (n) of approximately 1.1 with THz bandwidth capability (as calculated by the RC time constant). By engineering the epi-layer and fabrication processes, forward voltages range from about 0.29 to 0.9 V (@ 1 mA). In principle, other diode characteristics can also be achieved.

The goal is to offer a high quality GaAs diode that compare favorably with existing Si diodes in terms of V_f, C and R. Owing to the obvious speed advantages of GaAs versus Si, if GaAs diodes can be made with virtually the same V_f as Si, the GaAs alternative can offer significantly superior RC characteristics. For example, a low barrier Si diode (~ 0.3 V_f) for high frequency use might have C = 100 fF and R = 15 ohms. A comparable GaAs diode would have C = 30 fF and R = 3 ohms. This RC improvement directly impacts circuits like mixers, multipliers and detectors since, generally speaking, diode resistive losses are unwanted and high frequencies are limited by diode capacitance. In Si Schottky diodes, diode resistance and reverse breakdown voltage are often traded to realize low capacitance. By comparison, GaAs diodes have an outstanding reverse breakdown of ~10× the V_f and a resistance ~2.5 to 3 ohms.



▲ *Fig. 1 Forward (a) and reverse (b) I-V characteristics for a 1.6 × 8 μm² diode.*

7 TO 26.5 GHz MMIC MIXER

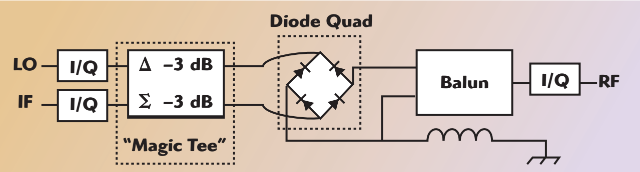
A common band for diode mixers is 7 to 26.5 GHz. Below 6 GHz, many solutions exist for frequency conversion, including hybrid mixers, Si IC mixers (CMOS and SiGe) and FET mixers. Moreover, analog-to-digital (ADC) and digital-to-analog (DAC) converters and digital processing are becoming sufficiently fast so that many of the lower frequency mixer "slots" are being replaced by digital solutions. Generally, digital solutions are preferred over analog if the dynamic range and DC power dissipation requirements can be met. This trend will continue.

Above 6 GHz, fewer options exist. Si IC solutions generally require high volume applications, so microwave solutions are not usually cost

TABLE 1

SUMMARY OF DC PARAMETERS OF A 1.6 X 8 μm² SCHOTTKY DIODE

Parameter	*Unit*	*SLB*	*LB*	*STD*	*HB*
Ideality Factor		1.17	1.16	1.17	1.23
V_f (Forward Turn-On Voltage @ 1 mA)	V	0.29	0.51	0.69	0.86
V_{rb} (Reverse Breakdown @ 10 μA)	V	1.95	5.1	6.4	8.0
R_s (Forward Bias Series Resistance)	Ω	2.97	2.85	2.57	2.69

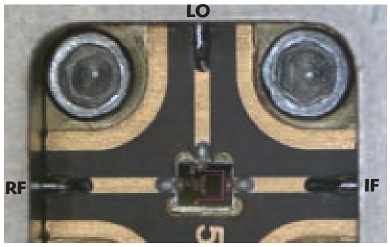


▲ *Fig. 2 Double balanced mixer circuit schematic for a "horseshoe" configuration.*

effective. Second, ADCs and DACs do not offer sufficient dynamic range, so analog mixing with diodes is usually necessary. Therefore, a 7 to 26.5 GHz mixer with a DC to 10 GHz IF response has been designed on the GCS diode process. (The mixer actually performs well to 38 GHz; the performance data was truncated by the 26.5 GHz bandwidth of the test setup). The mixer is based on the standard double balanced architecture, colloquially referred to as the "horseshoe" topology (see ***Figure 2***). The mixer was designed using HFSS™ (for the FEM analysis of the balun structures) and the Microwave Office™ harmonic balance engine, using a previously published design flow.[2] The authors have demonstrated that if the diode models are accurately generated, near perfect agreement with measurement and simulation can be achieved. Although the simulations are not shown in this article, excellent agreement was obtained. This confirms that the diode models supplied in the process design kit (PDK) from GCS are very accurate and suitable for computer-aided design, optimization and tape-out of the masks.

The ICs were mounted into a test fixture with SMA connectors and wire bonded on all input and output ports (see ***Figure 3***). The measured linear performance is shown in ***Figure 4***. All the mixers exhibited nearly identical isolation and VSWR on all ports, regardless of the forward voltage. This is expected because the diode level does not impact the linear performance of a double balanced mixer if the LO drive signal is sufficiently large to switch the diodes. Figure 4a shows that 6 dB conversion loss is measured for all the diode types, the only differences due to the higher LO drive on the higher V_f ICs.

Where high linearity mixing is required, higher barrier diodes are used. When the diode V_f is higher, incoming small-signal RF tones are less likely to intermodulate the I-V characteristics of the diodes, limiting unwanted higher-order spurious tones. When the V_f is low, the incoming RF voltage more easily perturbs the I-V characteristics, leading to lower P1dB, lower IP3 and higher spurious content. These trends



▲ *Fig. 3 Mixer MMIC mounted in a connectorized fixture with gold wire bonding. The chip size is 1.4 × 1.1 mm.*

are confirmed by the measured data in ***Figure 5*** and ***Table 2***. The downconversion spurious values are averaged over the entire 7 to 26.5 GHz RF range, with a fixed IF of less than 100 MHz. The variation in spurious levels is typically ± 5 dB. Measuring spur levels better than 100 dBc are limited by the dynamic range of the measurement equipment. Using the same mask set and different processing to change V_f, Figure 5 shows how the nonlinear performance varies with V_f. As expected, the low barrier diodes yield the worst nonlinear performance, and the high barrier diodes yield the best performance, albeit at the expense of high LO drive power.

25 TO 67 GHz MMIC MIXER

A second mixer design was fabricated to highlight the high frequency capability of the process. Here, the lowest barrier process was combined with the low capacitance (~15 fF) diode design to create an extremely broadband and high frequency mixer that covers 25 to 67 GHz, with an IF response of DC to 30 GHz.

With prior GaAs MMIC mixers, the normal diode V_f of 0.7 V requires an LO drive level greater than +15 dBm. With increasing frequency, circuit losses increase, requiring higher LO drive – possibly up to +20 dBm. Therefore, using a fundamental mixer at millimeter wave frequencies requires high LO drive, with few options to generate such power over a broad bandwidth.

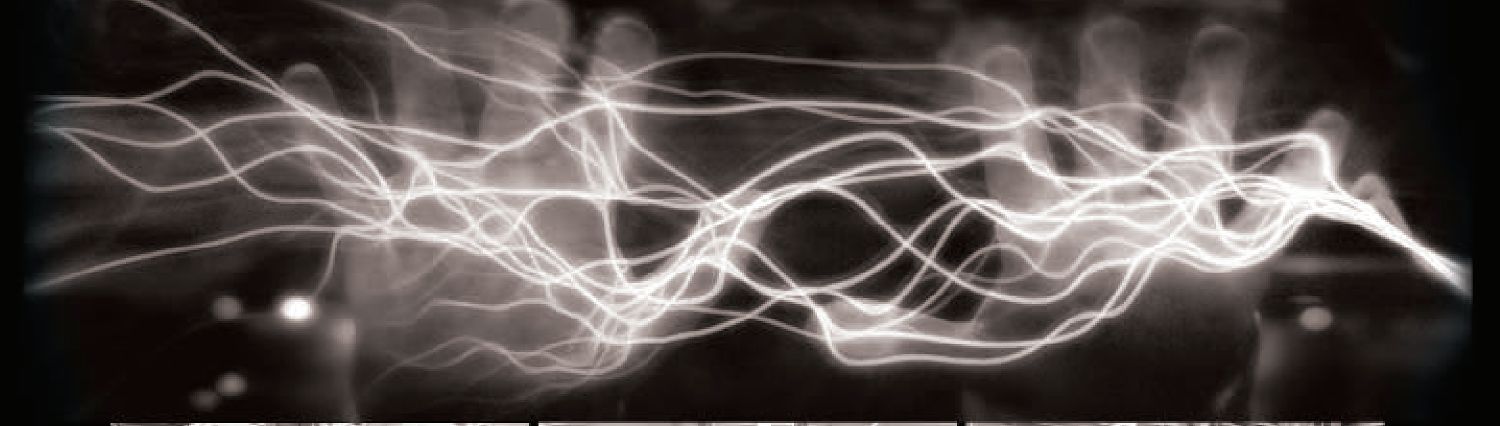
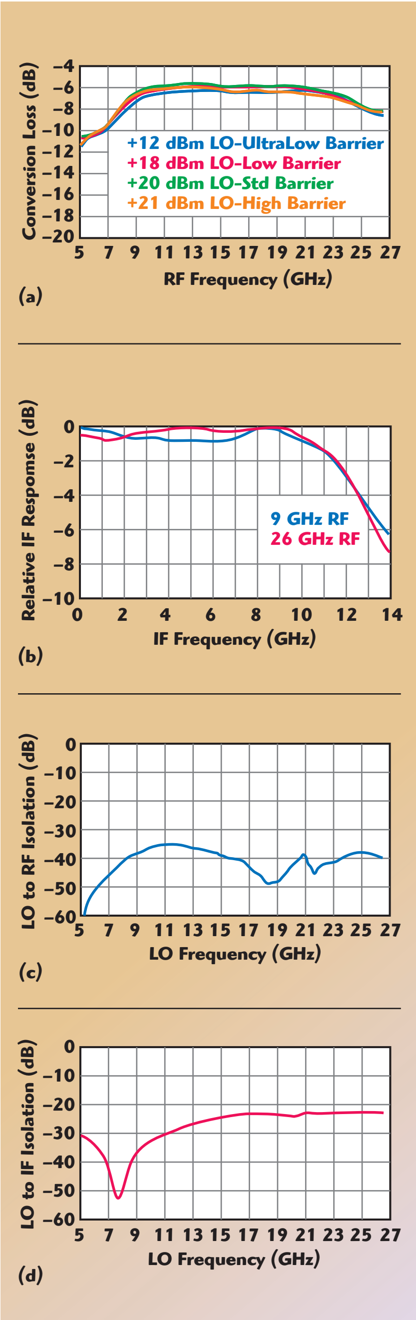


TABLE 2

**NONLINEAR PERFORMANCE OF THE 7 TO 26.5 GHz MIXER
NORMAL DOWN-CONVERSION ULTRA-LOW/LOW/STANDARD/HIGH**

-10 dBm RF Input	0 x LO	1 x LO	2 x LO	3 x LO	4 x LO	5 x LO
1 × RF	16/15/16/15	Reference	17/16/16/15	10/10/10/10	19/17/17/18	21/23/23/22
2 × RF	63/68/68/70	47/58/58/61	48/57/59/61	46/55/56/58	51/58/61/64	47/52/53/58
3 × RF	79/90/91/92	50/63/66/74	54/68/71/77	55/69/71/76	53/67/70/78	58/65/68/71
4 × RF	112/114/117/111	80/85/90/101	79/93/99/103	80/95/100/106	78/95/100/107	82/95/101/108
5 × RF	122/124/124/124	90/105/114/121	86/106/112/118	88/111/117/120	88/109/116/120	92/112/118/125



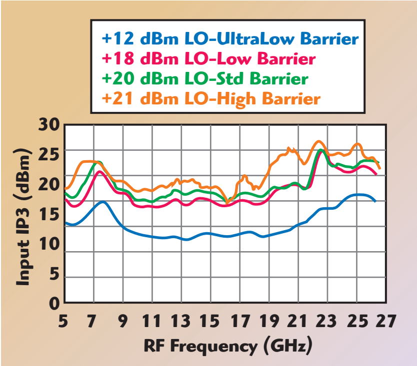
▲ *Fig. 4 Linear performance of the 7 to 26.5 GHz mixer: conversion loss (a) relative IF response (b) LO to RF isolation (c) and LO to IF isolation (d).*


38GHz
60GHz
24GHz
79GHz

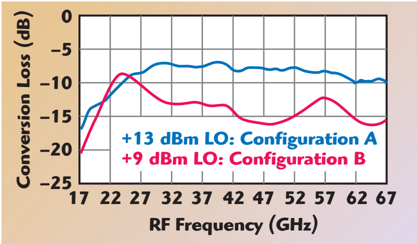
However, it is possible to design a power efficient millimeter wave mixer with the low barrier process that only requires a modest +10 to +15 dBm LO drive. The conversion loss for such a design is shown in ***Figure 6***. If conversion loss is not critical, the mixer can be operated "backwards" (i.e., driving the LO into the RF port, rather than the LO port) to make use of the higher efficiency RF balun. In this power efficient but lossy mode (Configuration B in Figure 6), the mixer can reliably be operated with only +9 dBm at 67 GHz. Additional measurements show excellent operation in configuration B with the LO as low as +6 dBm for lower frequency designs. Because this mixer design uses the horseshoe topology, the IF response is flat within 2 to 3 dB from DC to 30 GHz.

CONCLUSION

For over half a century, mixer designers exploited the broad range of



▲ *Fig. 5 Nonlinear performance of the 7 to 26.5 GHz mixer.*



▲ *Fig. 6 Conversion loss of the 25 to 67 GHz mixer with the IF fixed at 91 MHz. The high frequency performance is limited by the PNA test equipment; the high frequency roll-off is simulated to be 80 GHz.*

Si diode V_f to penetrate many different applications. For the first time this flexibility is available in a commercial GaAs IC process. The RC advantages of GaAs make this process especially compelling for Schottky circuits where either higher linearity or lower power are required. Conveniently, designs with different diode levels do not require separate mask sets – the biggest cost driver for IC development – merely a change in the starting wafer at the beginning of fabrication. Various applications can be served as long as the mixer passive circuitry (i.e., the balun and magic tee) is designed properly. The circuit results described in this article were obtained with only one mask set.

Marki Microwave has recently released a broad range of catalog GaAs MMIC mixers ranging from 3 to 67 GHz. GCS is offering access to the process through their foundry service. ■

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Challenges Making Millimeter Wave IMD Measurements

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Higher power millimeter wave (mm-wave) devices and more demanding applications are increasing the need for accurate mm-wave intermodulation distortion (IMD) measurements. While a variety of expressions are still needed, as at microwave frequencies – intercept points, relative product levels, intermodulation distortion (IMD) product asymmetry – the challenges can be intensified in terms of absolute power accuracy, measurement receiver linearity effects, combiner behavior and other areas. Typical measurement behaviors in these categories will be explored in a vector network analyzer (VNA) context, along with some approaches that can help to optimize accuracy.

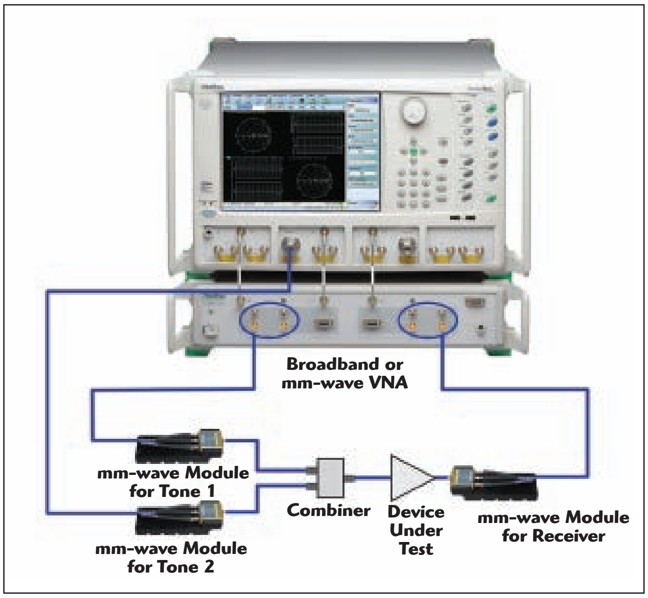
While IMD measurements have been very popular at RF and microwave frequencies for decades, the progress in mm-wave technologies of late has enabled higher power devices in the higher frequency ranges, making those same measurements also of interest in the mm-wave domain. Whether it is GaN-enabled, watt-class power amplifiers at W-Band or combined structures enabling high linearity at E-Band or higher, the IMD measurement is a potentially important part of the qualification and specification process. The basic concept of two tones generating in-band (and out-of-band) mixing products in the device is no different, but some of the measurement challenges can be heightened. While the basics can be found elsewhere,[1,2,3] this article will focus on some of the measurement details for this higher frequency class of devices.

It is useful to reintroduce some of the common IMD metrics that are used in all frequency ranges as well as abbreviations used in this article. Here they are all generalized to n^{th} order products, although third order is the most common, meaning where the products land one tone delta away on either side of the main tones (delta refers to the spacing between the two stimulus tones):

- IPn – n^{th} order intercept point
- IMn – n^{th} order intermodulation product relative to either one or an average of the main tones
- PWRn – Absolute power of the n^{th} order intermodulation product
- ASYMn – n^{th} order product asymmetry, i.e., the difference between the upper and lower product levels

The intercept point is an often quoted metric, although it does have its weaknesses. It is

an ideal projection of the power level (input or output referred) where the main tone power and the product power would be equal based on one measurement. The issue with this approach is that the calculated projection is normally a strong function of power, so the result based on a measurement at a single power may be an anomaly rather than typical. Asymmetry, the imbalance of the products, is becoming an increasingly important metric, as it can reveal memory effects that might be generated by thermal or bias system time constants, which can affect modulated distortion, particularly relatively close to the carrier.[4]



▲ *Fig. 1 VNA-based setup for measuring the IMD of a mm-wave circuit.*

A VNA-based measurement setup using mm-wave modules (usually broadband, but they can be narrower band) is shown in ***Figure 1***. While many different configurations are possible, often the highest frequency signals are generated and down-converted (on the receive side) in modules close to the device under test (DUT), to minimize cable loss. Other instruments could certainly be used, but the integrated calibration capabilities (in terms of signal power and receiver calibration at any reference plane) and ability to perform other measurements on the DUT can make a VNA platform attractive.

MEASUREMENT CHALLENGES

In terms of measuring IMD quantities at mm-wave frequencies, a number of aspects become more challenging.

Power Accuracy: If one is concerned with a relative metric like IMn, one may think absolute power accuracy is less important, but the operating point of the DUT is often a critical part of the measurement setup. The DUT IM level will usually change by multiple dB for a 1 dB change in drive power. Power calibration and measurement are somewhat more challenging at mm-wave frequencies, as basic power meter accuracy can degrade and often the return loss in the test setup (and the DUT) is not as high. As return loss is a dominant power measurement accuracy term, this can be quite important. In a common W-Band power measurement configuration, sensor linearity may limit accuracy to 2 percent, basic power sensor calibration factor uncertainty may be 3 percent, but mismatch (with a 14 dB return loss port) may contribute 4 percent. The net uncertainty can be on the order of 0.5 dB in many cases.

Short of a higher level of traceable power sensor calibration, perhaps the one way to improve these uncertainties is to optimize match in the test setup. Correction for mismatch at the DUT ports can be helpful, particularly for absolute measurements, but this does not address the operating point concern. In all cases, the DUT return loss can be a larger issue for larger deltas, as the product and main tones may see different mismatch levels.

Receiver Calibration: On the stimulus side, a local power calibration can take care of test setup losses on the input but output-side network losses can be quite important at higher frequencies, particularly for the absolute metrics (and for relative metrics if the delta is large). A power-referred receiver calibration at the DUT output reference plane helps to minimize these issues and, if delta is

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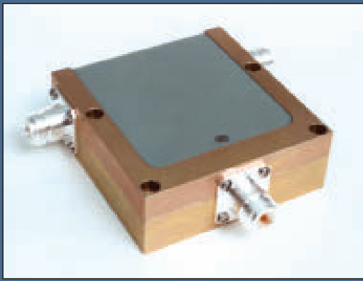

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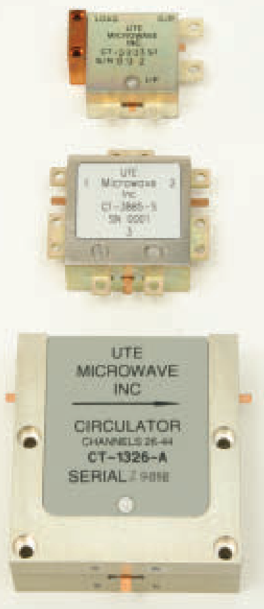

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Contact us for more information on our extensive product line and current catalog. We accept Visa, MC, Amex large, is aided by a sufficiently dense frequency list. The latter can come about since the network losses may vary significantly over the scale of tens or hundreds of MHz, depending on the structure. As an example, ***Figure 2*** shows the net receiver calibration error when a full frequency list is used (the "dense" trace) compared to a calibration at only the main tone frequencies (the "sparse" trace). The test system was designed for E-Band but included some substantial cable runs to allow other measurements. The resulting error is mainly connector/cable repeatability; at non-calibrated frequencies, it could exceed 0.5 dB with a reasonably well-matched setup (i.e., 15 dB return loss). Using the dense frequency list and calibrating at product as well as main tone frequencies helps significantly.

Receiver Linearity: In terms of the measurement, receiver linearity can be a limiting factor for more linear DUTs. Many mm-wave receivers are harmonic converters; their linearity can degrade depending on the structure, LO drive, or other factors.[5] Broadband receivers exist with effective IP3 levels in the range of 25 to 35 dBm. With receivers around 35 dBm, inherent third-order product levels are better than -90 dBm for tone levels of -10 dBm at the test port, which can be useful for all but the most linear DUTs. ***Figure 3*** compares the third-order intercept point of two different receivers. One is a standard two diode, harmonic mixer being driven by a sinusoid and using the 12th harmonic. The other is a converter based on a nonlinear transmission line (NLTL) using a limited LO waveform with a high breakdown voltage sampler, operating on the 11th and 13th harmonics. The latter achieves better linearity and enables the measurement of more linear devices than the first converter.

Stimulus Issues: Source contamination can also play a role. Since many millimeter wave stimulus signals are multiplied, spurs are somewhat more of a concern than at lower frequencies. Because one knows the desired product locations, some clever frequency plan manipulation can avoid most problems. Multiplied phase noise is also a potential issue, particularly for smaller deltas. While a clean starting synthesizer is helpful, additional levels of correlation between stimulus and receiver synthesizers can improve the net measurement noise at small deltas.[6]

Leveling systems in the stimulus signal source sometimes create mysterious issues. Since combiner isolation is not perfect, particularly in broadband setups, the signal from one tone can leak over to the other tone's sourcing path, enter its leveling detection system and mix with the other tone (see ***Figure 4***). The resulting difference frequency (equal to delta) can be within the leveling loop's bandwidth and remodulate as a sideband on the

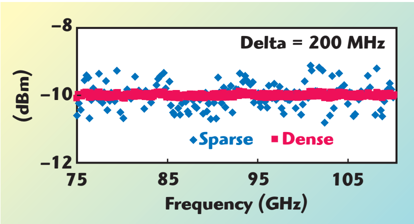


Fig. 2 The effect of the calibration frequency list on the residual accuracy of a receiver calibration.

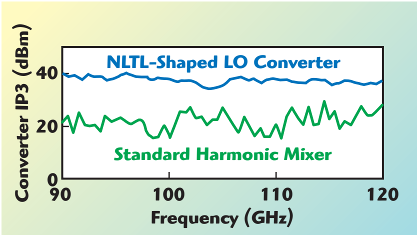


Fig. 3 The structure and LO drive behavior of the receiver can have a significant impact on the net receiver linearity, setting the maximum IPn that can be measured.

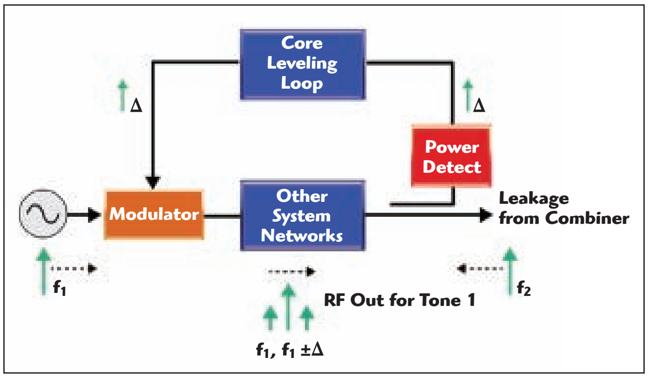


Fig. 4 A simplified diagram of the signal generation for IM, including the leveling circuitry.

tone. Unfortunately, this sideband is in exactly the same location as a third-order product, leading to an IMD measurement error. Using a higher isolation combiner – or attenuators, if the measurement power requirements permit – can help. A system with a dynamic leveling loop bandwidth[5] will also help minimize these effects, by not allowing the mixing product of the two tones to remodulate on the stimulus. In millimeter wave systems, the location of the leveling detection system varies greatly, and this can also play a role. More isolated detection paths augment combiner isolation and can minimize stimulus issues.

To illustrate these effects, consider an amplifier that has a known bias system resonance near 15 kHz. This resonance could cause issues with close-in modulated performance, and it would be useful to identify it with an IMD measurement. The IMD measurement needs sufficient dynamic range at deltas on the order of the resonant frequency. Using a system with adequate leveling bandwidth control, phase noise and a high isolation combiner, the measured signature of the third-order product is shown by the blue diamonds in ***Figure 5***. The DUT bias resonance is apparent. Using a different system with a lower isolation combiner (6 dB from a splitter), without leveling bandwidth control and with somewhat degraded phase noise, the data represented with triangles was measured. Noise was elevated at very low deltas, the measurement system signature was unintentionally obtained and the DUT response of interest was missed.

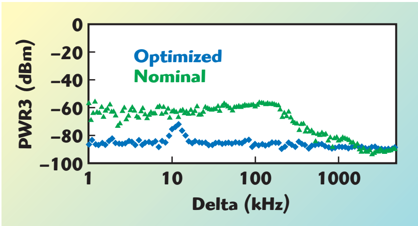
NET UNCERTAINTIES

The uncertainties discussed to this point can be combined with mismatch and repeatability to give some general estimates. The mitigation techniques discussed were employed, including a reasonably well-matched test system with ~15 dB return loss, full frequency list receiver calibrations, a high linearity receiver in the VNA and an improved stimulus system. The resulting uncertainty in product power at 100 GHz and DUT output tones of -10 dBm are shown in ***Figure 6***. At higher product levels, the uncertainty is mainly a function of power accuracy. There is some delta dependency from multiplied synthesizer phase noise and a product level dependency from the signal-to-noise ratio.

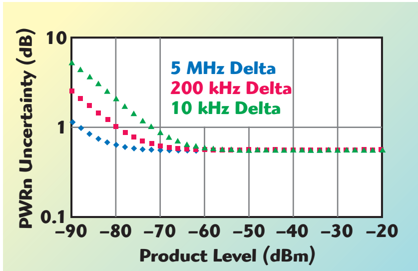
The uncertainties in the other IMD metrics follow from the basic intermodulation product power measurement uncertainty (see Figure 6). The relative product measurement (IMn) and asymmetry measurement (ASYMn) are both the combination of two power measurements. One often assumes that these uncertainties will add on a root-sum-of-squares basis, although other methods are possible since correlations between the two measurements can vary.[7] An intercept point (IPn) calculation is also basically the combination of two power measurements in a more complex form:

$$\mathrm{IPn(dBm)} = \mathrm{Pwr_{main}(dBm)} + \frac{\mathrm{Pwr_{main}(dBm)} - \mathrm{Pwr_n(dBm)}}{n-1}$$

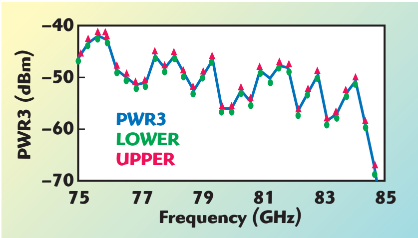
Again, one approach is to use a root-sum-of-squares basis but with



▲ *Fig. 5 An improved leveling system and combiner allow a 15 kHz bias resonance to be identified with the PWR3 measurement.*



▲ *Fig. 6 PWRn uncertainty for a 100 GHz, –10 dBm tone with deltas of 10 and 200 kHz and 5 MHz.*



▲ *Fig. 7 Amplifier third-order product measurement with 3 MHz delta, showing inferred uncertainty bounds.*

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CTE Z-axis (50 to 260°C)	2.90%	2.80%	2.80%	2.90%	2.90%
T-260 & T-288	>60	>60	>60	>60	>60
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the weighting factors implied in the equation. This is normally done in a linear form, rather than in dBm; if the uncertainties are small enough, the results will be numerically similar.

The third-order power product of a millimeter wave amplifier was measured across 75 to 85 GHz, with a 3 MHz delta (see ***Figure 7***). The implied uncertainties in the measurement are also shown. These bounds are in line with those shown in Figure 6, with some expansion at the higher frequencies where the absolute product level is dropping.

CONCLUSION

mm-wave IMD measurements have been explored from the viewpoint of potential measurement challenges that are exacerbated at the higher frequencies. Techniques exist, both procedural and with the equipment, to help improve the results and achieve uncertainties under 1 dB for modest product levels and deltas. ■

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A Wideband Chaotic Colpitts Oscillator With Negative Resistance Enhancement for UWB Applications

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A wideband cascode chaotic Colpitts oscillator with enhanced negative resistance is demonstrated. The circuit is implemented with InGaP/GaAs HBT technology. The measured fundamental frequency is 2.7 GHz, and the output power spectrum covers the 3.1 to 5.8 and 6.1 to 9 GHz ultra-wideband (UWB) bands. Negative resistance degradation caused by the Miller capacitance is compensated with an optimized base inductor. The fundamental frequency and bandwidth of chaotic oscillation is improved versus a normal common-base oscillator by increasing the voltage swing between the junctions as well as the transconductance of the transistor. This design also reduces power consumption in the oscillation loop.

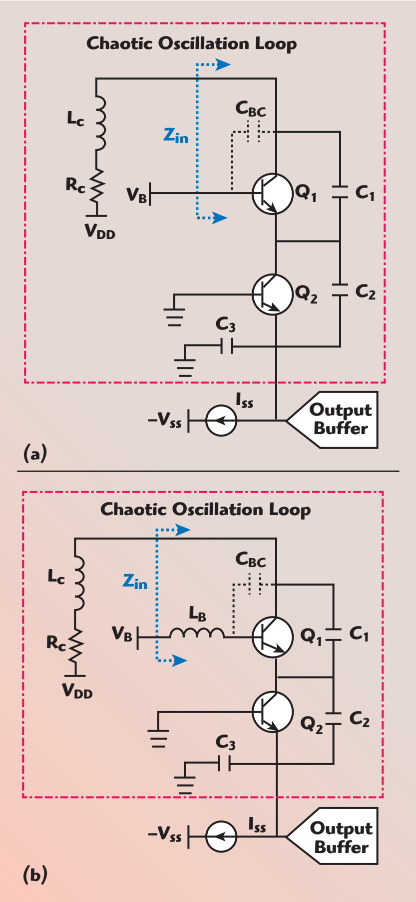
Chaotic signals are wideband, deterministic, non-periodic and random-like signals derived from nonlinear dynamic systems. They offer a number of attractive features, particularly for UWB applications.[1, 2] Several chaotic signal generator design technologies have been proposed to meet bandwidth demands at microwave frequencies. One proposed technology is based on the chaotic Colpitts oscillator.[3]

Colpitts-based chaotic oscillators have received significant attention in the past decade,[4,5,6,7,8] but the performance of a typical chaotic Colpitts oscillator is constrained by the influence of transistor parasitics that limit its fundamental frequency f_0.[5] To mitigate the influence of parasitics and to increase f_0, various design techniques have been proposed including the use of parasitics as parts of the oscillation loop,[5] an addition of a series L and diode load to redistribute the effects of base-collector parasitic capacitance C_{BC},[6] and a cascode structure to reduce the Miller effect at C_{BC}.[7,8]

Improved chaotic Colpitts oscillators have had limited success, however, in increasing f_0 and bandwidth, while lowering power consumption. To gain an in-depth understanding of the performance issues and to explore the use of advances in normal oscillator design techniques for chaotic circuits, it is essential to recognize the commonality as well as differences in normal and chaotic oscillator designs.

A non-chaotic Colpitts oscillator exhibits a sharp decrease in negative resistance at high frequencies due to the Miller effect at C_{BC}, limiting its maximum oscillation frequency.[9] The effect appears in chaotic Colpitts oscillators as well. Unlike a normal narrowband os-

cillator, however, a serial resistor is often included in the oscillation loop of a chaotic Colpitts to satisfy the requirement for broadband chaotic oscillation. This leads to a low Q and high power losses in the loop. The broadband oscillation requirement in a chaotic circuit imposes the need for a higher negative resistance than in a normal oscillator. Thus, the challenge in a chaotic circuit design is to determine a proper and sufficient negative resistance for overcoming resonator losses in order to reach a start-up chaotic oscillation and optimize f_0.



▲ *Fig. 1 Normal common-base version of the cascode chaotic Colpitts oscillator without base inductor L_B (a) and new version with base inductor L_B (b).*

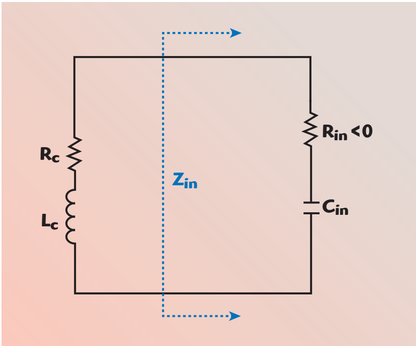
A cascode chaotic Colpitts oscillator design is introduced with two separated inductors connected at the base and collector nodes respectively. Tuning of these two inductors enhances negative resistance to compensate for its degradation from the decrease of transistor transconductance (g_m) at high frequencies and maximizes the fundamental frequency f_0. The enhancement of g_m with base inductance reduces the need for a higher bias voltage and current, thus lowering resonator power consumption. Measurement results demonstrate operation from 1.3 to 9 GHz, covering the 3.1 to 5.8 and 6.1 to 9 GHz UWB bands.

CIRCUIT DESIGN

Figure 1a represents a normal chaotic Colpitts oscillator design,[7,8] while ***Figure 1b*** shows the new cascode chaotic Colpitts oscillator design. The chaotic circuit of Figure 1b evolves from a traditional normal common-base cascode Colpitts oscillator by including an additional inductor L_B at the base node. The bias current I_{SS} is controlled by tuning the voltage source V_{SS}. In contrast to a standard common-base chaotic Colpitts design,[4,6,7,8] this circuit has two important design features. First, the parallel equivalent inductance of L_C-R_C and L_B-C_{BC} is smaller than that of L_C and L_B. Without significantly impacting the fundamental frequency f_0, the g_m of the transistor can be enhanced by increasing L_B. Consequently, the negative resistance is enhanced by increasing the voltage swing between the junctions as well as the g_m of the transistor. Second, the enhancement of g_m with L_B reduces the demand for higher V_{DD} and I_{SS}, thus lowering power consumption of the oscillation loop.

NEGATIVE RESISTANCE ANALYSIS

Figure 2 shows the equivalent circuit of the chaotic oscillation loop in Figure 1b. The input impedance Z_{in} between base and collector nodes can



▲ *Fig. 2 Equivalent circuit of the chaotic oscillation loop.*

be viewed as an equivalent circuit of a negative resistance R_{in} in series with a capacitance C_{in}.

$$Z_{in} = R_{in} + \frac{1}{j\omega C_{in}} \tag{1}$$

R_{in} of the normal common-based circuit in Figure 1a can be expressed as:

$$R_{in}^{a} = -\frac{g_m}{\omega^2 (C_1 + C_{BE}) C_e} \cdot \frac{1}{\left(1 + \frac{C_{BC}}{C_1 + C_{BE}} + \frac{C_{BC}}{C_e}\right)^2 + \left[\frac{g_m}{\omega (C_1 + C_{BE})} \cdot \frac{C_{BC}}{C_e}\right]^2} \tag{2}$$

R_{in} of the circuit in Figure 1b can be expressed as:

$$R_{in}^{b} = -\frac{g_m}{\omega^2 C_1 C_e} \cdot \frac{\frac{1+k}{1-k}}{\left[1 + \frac{1}{1-k}\left(\frac{C_{BC}}{C_1} + \frac{C_{BC}}{C_e}\right)\right]^2 + \left[\frac{g_m}{\omega C_1}\left(\frac{C_{BC}}{C_e} \cdot \frac{1}{1-k} - \frac{k}{1-k}\right)\right]^2} \tag{3}$$

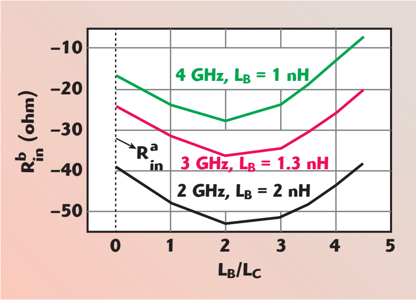
$$C_e = \frac{C_2 (C_3 + C_{BE})}{C_2 + (C_3 + C_{BE})} + C_{BC}, k = \omega^2 L_B C_{BC}, \omega = 2\pi f \tag{4}$$

where C_{BE} and C_{BC} are base-emitter and base-collector parasitic capacitance respectively, f is the oscillation frequency of the loop; Q1 and Q2 are the same transistors.

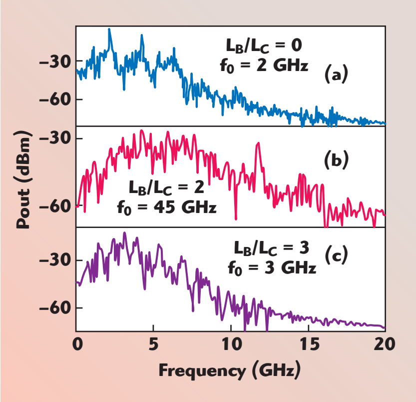
When L_B = 0 nH,

$$R_{in}^{a} = R_{in}^{b} \tag{5}$$

Equation 5 shows that the equivalent circuits of the two chaotic oscillators in Figure 1 are the same without considering L_B. From Equations 2, 3 and 4, we can calculate the negative resistance R_{in} (2 μm InGaP/GaAs HBTs with f_T=29.5 GHz, C_{BE}=0.49 pF and C_{BC}=0.28 pF are used in calculation). ***Figure 3*** shows the negative resistance R_{in}^{b} dependence on the ratio of L_B/L_C. Each curve is generated by fixing the value of L_C and the oscillation frequency. R_{in}^{a} is a constant value with fixed oscillation frequency. When the L_B/L_C ratio equals zero, R_{in}^{b} and R_{in}^{a} are the same as shown in Equation 5. The equivalent circuit of L_B-C_{BC} is capacitive and its impedance is inversely proportional to L_B. When L_B is small, -R_{in}^{b} increases with L_B because the impedance of L_B-C_{BC} is much larger than -R_{in}^{b} and its decrease in value can be neglected. Thus, -R_{in} is mainly dominated by the transistor g_m, which is directly proportional to L_B and the voltage, current swing in the circuit. However, when L_B is large, -R_{in}^{b} decreases as L_B increases, because the impedance of L_B-C_{BC} is too low to be neglected and the voltage and current swing and g_m enhancements become saturated. -R_{in}^{b} is mainly determined by the impedance of L_B-C_{BC}, decreasing with increasing L_B. An optimum L_B/L_C ratio is observed for the maximum



▲ *Fig. 3 Calculated negative resistance vs. L_B/L_C.*



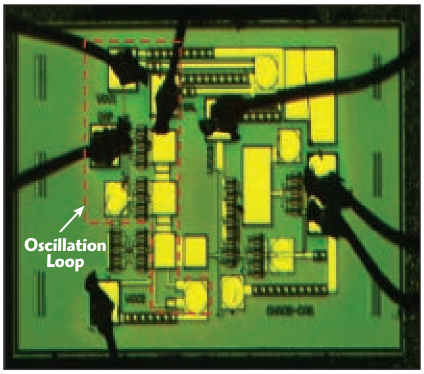
▲ *Fig. 4 Simulated output power spectrum vs. L_B/L_C.*

negative resistance. When L_B is 2 to 3 times L_C, $-R_{in}^b$ is improved by almost 50 percent over $-R_{in}^a$. Therefore, with an optimum L_B/L_C ratio, L_C, C_1, C_2 and C_3 are reduced to increase the chaotic oscillation frequency.

Figure 4 shows the simulated output power spectrum of the circuit. Transistors used in this simulation are the same as aforementioned InGaP/GaAs HBTs. When L_B/L_C=0, the highest fundamental frequency f_0 for chaotic oscillation is only 2 GHz. When L_B/L_C=2, f_0 increases to 4.5 GHz. When L_B/L_C = 3, f_0 decreases to 3 GHz. From these simulation results, an optimum L_B/L_C ratio is observed for the maximum fundamental frequency f_0, which is consistent with calculated results in Figure 3.

MEASUREMENT RESULTS

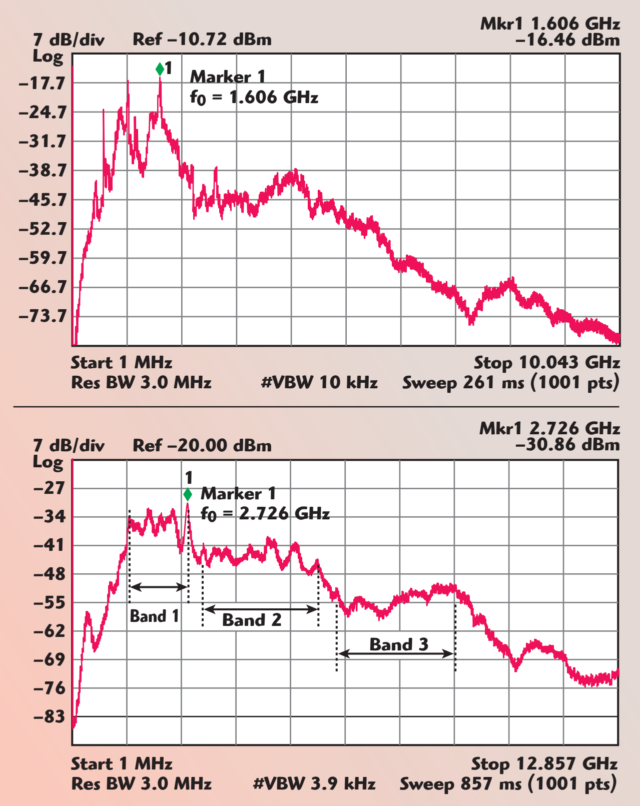
The proposed cascode (with L_B) and the normal common-base (without L_B) chaotic Colpitts circuits are implemented with 2 µm InGaP/GaAs HBT technology. ***Figure 5*** is a photograph of the fabricated 0.6 × 0.6 mm chip. As chaotic circuits are extremely sensitive to circuit elements, L_B, L_C and R_C in Figure 1 are not designed into this chip, enabling adjustment of L_B, L_C and R_C values on the PCB to fit chaotic oscillation start-up conditions.



▲ *Fig. 5 Photograph of the fabricated 0.6 × 0.6 mm circuit.*

To optimize the fundamental frequency, f_0, the values of the loop inductances L_C, L_B, capacitances C_1, C_2, C_3 and the loss resistance R_C are chosen based on the concept previously outlined. Note that the effect of parasitic base-emitter capacitance C_{BE} has been considered in choosing capacitance. V_{DD} is fixed and V_{SS} is adjusted to achieve the desired output chaotic signals. ***Figures 6a*** and ***6b*** show the measured output power spectrum of the normal cascode circuit without L_B and the proposed circuit with optimized L_B, respectively. In Figure 6a, L_B = 0 nH, L_C = 5 nH, R_C = 25 Ω, C_1 = 3 pF, C_2 = 3 pF, C_3 = 3 pF, V_{DD} = 10 V, I_{SS} = 16 mA and f_0 = 1.6 GHz. In Figure 6b, L_B = 2.7 nH, LC = 1.3 nH, R_C = 22 Ω, C_1 = 2 pF, C_2 = 2 pF, C_3 = 2 pF, V_{DD} = 7 V, I_{SS} = 12 mA and f_0 = 2.7 GHz.

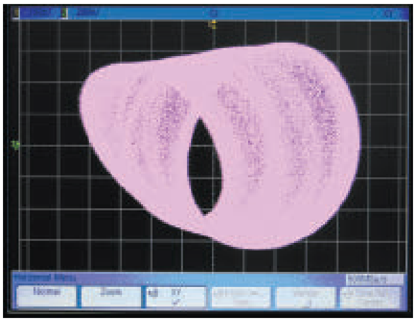
The optimum L_B of 2.1 times L_C is consistent with calculated results



▲ *Fig. 6 Measured output power spectrum of the normal cascode circuit without L_B (a) and with the optimized L_B (b).*

in Figure 3 and simulation results in Figure 4. The fundamental frequency f_0 is 1.6 GHz and 2.7 GHz for circuits without L_B and with optimum L_B, respectively, illustrating an increase in f_0 of 69 percent. Using the chaotic bandwidth (BW) definitions in Mykolaitis et al.,[4] and Bumelienė et al.,[8] frequency bands of the output power spectra are: Band 1: 1.3 to 2.7 GHz, Band 2: 2.9 to 5.8 GHz and Band 3: 6.1 to 9 GHz as shown in Figure 6b. Band 2 and Band 3 cover the 3.1 to 5.8 GHz and 6.1 to 9 GHz UWB bands respectively. Wire inductance and parasitic resistance on the circuit board may be causes for a lower measured f_0 than simulated.

Figure 7 shows the double scroll attractor of the proposed circuit measured with an oscilloscope. Circuit elements are the same as in Figure 6b. The horizontal axis (200 mV/div) represents the collector voltage of Q1 and



▲ *Fig. 7 Measured double scroll attractor (horizontal axis = 200 mV/div, vertical axis = 100 mV/div).*

the vertical axis (100 mV/div) is the base voltage of Q1. The double scroll attractor confirms that the oscillation is chaotic.

Table 1 compares the performance of this design with recently published microwave chaotic Colpitts oscillators.[4,6,8,10] The fundamental frequency f_0 for this design is much higher. Excluding power consumption of the current source and output buffer, the loop power consumption (LPC) is estimated by $(V_{DD}+0.8\ V) \times I_{SS}$ in a Colpitts circuit using BJTs and by $(V_{DD}+1.6) \times I_{SS}$ in a Colpitts circuit using HBTs. LPC in this design is much lower compared to the others represented in the table.[4,6,10] This power reduction is attributed to an increased g_m with an optimum base inductor alleviating a sharp decrease at reduced bias voltage V_{DD} and current I_{SS}.

CONCLUSION

A cascode Colpitts oscillator with enhanced negative resistance is designed for the chaotic oscillator. Theoretical calculation shows that the negative resistance degradation at high frequencies is compensated by increasing the voltage and current swing in the circuit and the transconductance of the transistor via an optimum base inductor. With enhanced negative resistance, the fundamental frequency f_0 is increased to 2.7 GHz. The circuit operates from 1.3 to 9 GHz, covering the 3.1 to 5.8 and 6.1 to 9 GHz UWB frequency bands. This design also reduces power consumption in the oscillation loop. ■

ACKNOWLEDGMENTS

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TABLE 1
CHAOTIC COLPITTS OSCILLATOR PERFORMANCE

References	4	6	8	10	Normal Design (Fig. 1a)	New Design (Fig. 1b)
Transistor	BJT	BJT	BJT	BJT	HBT	HBT
Structure	Single-Ended	Single-Ended	Cascode	Single-Ended	Cascode	Cascode
f_0 (GHz)	1.06	1.1	1.1	1.61	1.6	2.7
V_{DD} (V)	8.7	12	6.3	5	10	7
I_{ss} (mA)	21	17	–	20	16	12
LPC (mW)	200	218	–	116	186	103

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A Computer Centric Pulse Creation and Measurement Method for Characterizing High Power RF Devices

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Philips Research China; Philips (China) Investment Co. Ltd., Shanghai, China

An integrated and highly-automated method of pulsed-RF signal measurement employs a computer as the central controller and user console to perform both scalar and vector measurements of RF signals. It also uses peripheral RF instruments, such as a vector network analyzer, signal generator and spectrum analyzer as building blocks. Matlab® codes are developed for instrument control, measurement execution and data visualization. A graphical user interface (GUI) facilitates the monitoring and control of measurement processes as well as the display of test results.

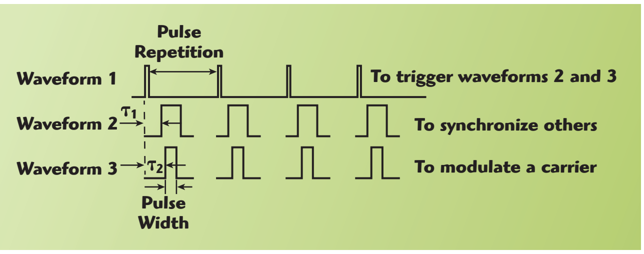
A pulsed-RF signal is often employed in a radar or communication system with a time division multiple access (TDMA) or time-division duplexing (TDD) protocol. Typically the input and output signal to a high-power RF device is not designed to work in a continuous wave (CW) mode, so its characteristics must be measured while operating in a pulsed mode. This requires an attenuator to reduce a large signal to an acceptable level for laboratory instruments and a means for creating and capturing the RF pulses. A synchronized trigger is also needed to control the pulses. The trigger signal enables and disables a device under test (DUT) and allows a receiver to synchronously capture the incoming pulsed waveform.

Along with auxiliary power suppliers, several instruments must work together to provide the proper signal environment. This is typically built around a central instrument, often a vector network analyzer (VNA)[1] or a nonlinear vector network analyzer (NVNA).[2] For this type of system each instrument is set with the precise state and working mode to function properly as a whole for a dedicated measurement.

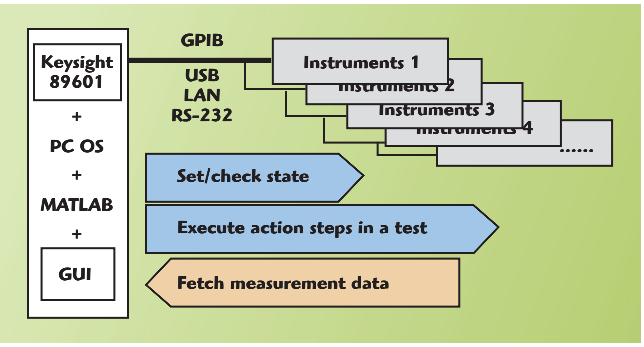
This article describes a more flexible approach in which a computer acts as the central coordinator with the test scheme, instrument state setting, test execution, measurement retrieval, data processing and visualization of results planned in a test script. The test script, employing several reusable routines, is stored in the computer and executed through a graphical user interface (GUI). Execution of the test script calls the right routines in the proper order.

This computer centric method retains the original functionality of the measurement system while adding some new features. First, the states of all instruments are recorded and set by the software, instead of through manual operations. This greatly reduces human error. Second, integration and programming offers the flexibility to readily perform multiple

test tasks. Selected instruments from the system can be easily grouped and programmed to perform specific measurements in a reliable and traceable way. Third, the measurement data is seamlessly managed by the computer. Routine tasks such as data storage and management, data processing and visualization and report generation are performed instantly once the measurement is complete. Data review and measurement re-examination are straightforward. Moreover, the GUI interface provides ease of use for operators, while providing instrument setting transparency.



▲ *Fig. 1 Timing diagram of signals in RF pulse creation.*



▲ *Fig. 2 Architecture of the test platform.*

OPERATION

Pulse Creation

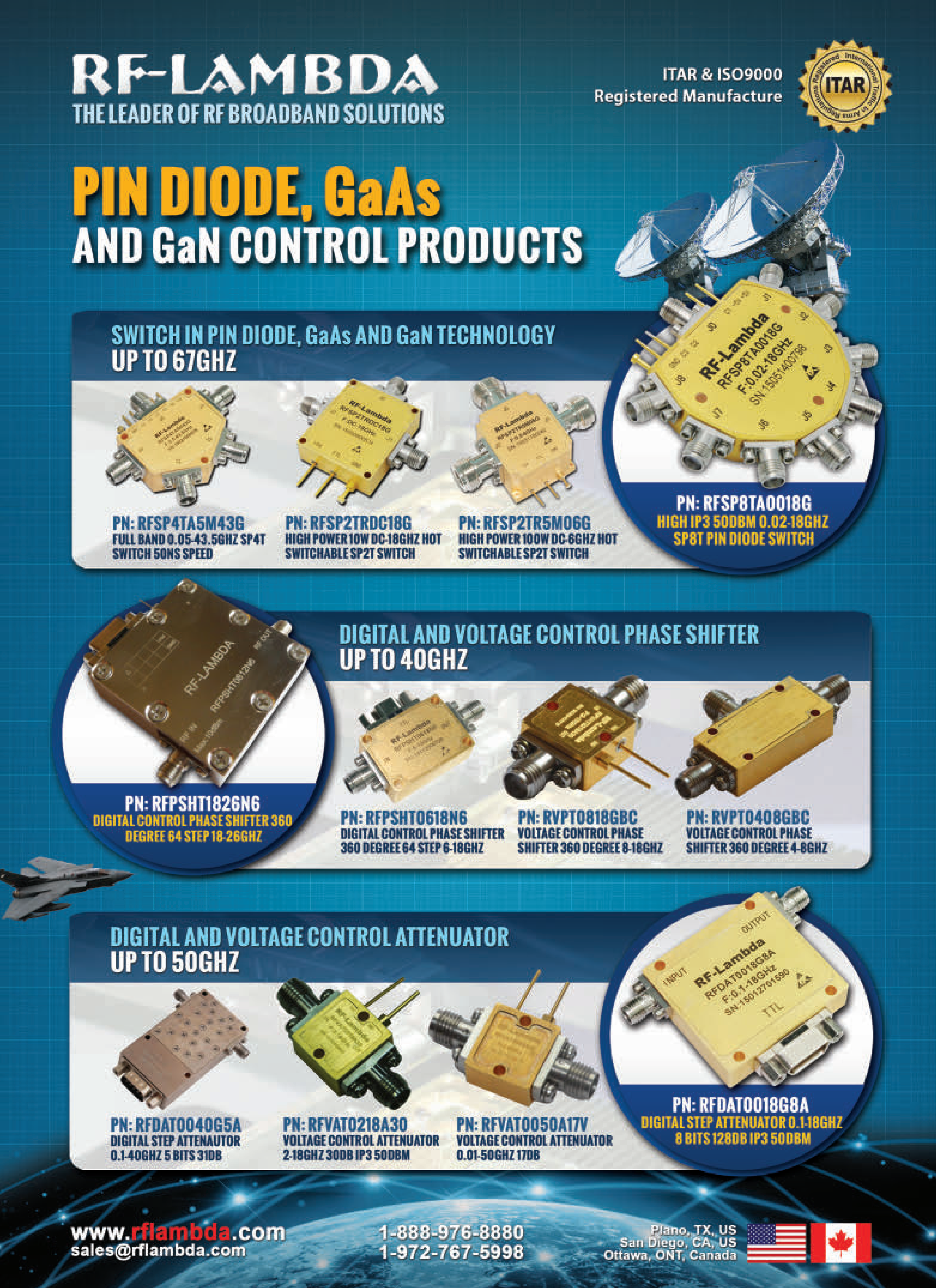
The pulsed RF signal and trigger signal are created with three waveform generators in most scenarios (see ***Figure 1***). Keysight Technologies' 33250A and 33220A arbitrary waveform generators are often employed. The first waveform, the pilot signal for the rest, is a continuous stream of rectangular pulses with a pulse repetition time (PRT) equal to that of the pulsed RF signal. The pilot signal triggers two other waveform generators, each of them producing one rectangular pulse for every trigger but with an added delay, τ_1 or τ_2. Waveform 2 triggers a receiver or enables the DUT. Waveform 3 modulates an RF carrier to produce the desired pulsed RF signal. Precise control of τ_1 and τ_2 locks the pulses to each other in time.

Infrastructure and Connections

In addition to the signal source and receiver, a PC or laptop acts as the central controller, user's console and data station. All surrounding instruments and peripheral devices, such as RF switches, are connected to the computer via general-purpose interface bus (GPIB), USB, LAN or RS-232 cables. Often a USB-GPIB adaptor or a PCI-GPIB adaptor is required to enable GPIB communication. Communication between the computer and instruments is bidirectional, which is based upon the Standard Commands for Programmable Instruments (SCPI) language. The development environment is Matlab® through its Instrument Control Toolbox™.

Figure 2 shows the system architecture. The operating system (OS), the Matlab environment with GPIB drivers and the computer-to-instrument interfaces constitute the software infrastructure of the measurement platform. The computer also contains measurement software for Keysight's 89601 vector signal analyzer (VSA). The computer checks the instrument states and sets working modes. These are programmed in the test script beforehand to accomplish a specific measurement objective. Measurement is initiated by a user's click of a GUI button. The ordered SCPI instructions are sent to related instruments and raw data is automatically sent back to the computer. A graphic representation of the final test result is then displayed.

A Keysight E4438C signal generator and E4440A spectrum analyzer are the source and the receiver in a scalar configuration (see ***Figure 3***). With the addition of a Keysight 89601 VSA, a quasi-vector measurement may be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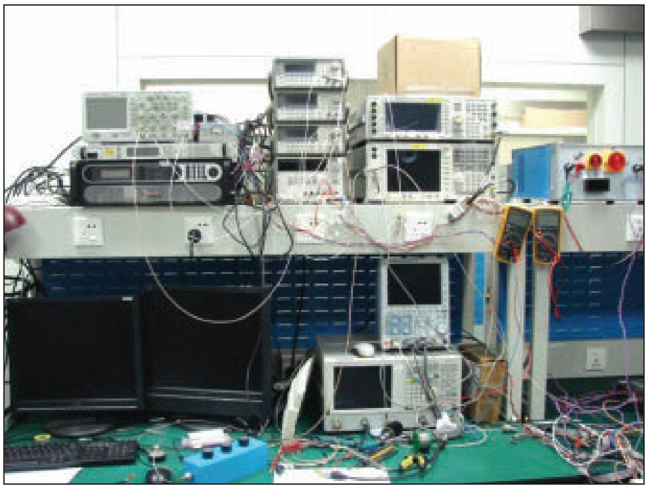
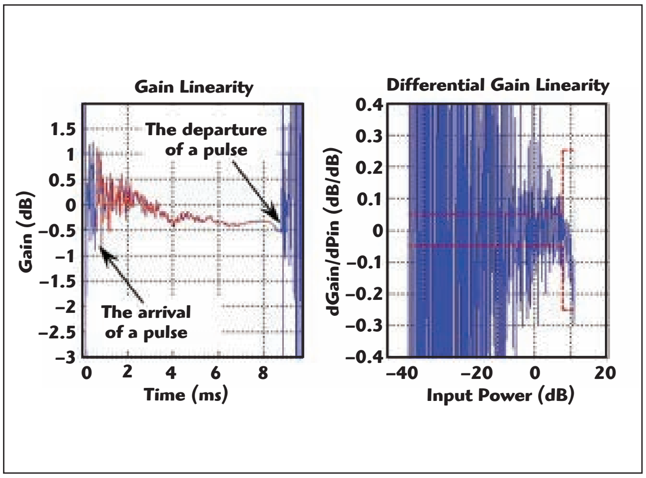


▲ *Fig. 3 Pulsed RF test platform in the lab.*



▲ *Fig. 4 Gain linearity and differential gain linearity.*

performed. Other instruments include a Keysight E8357A vector network analyzer to measure scattering parameters in pulsed mode, several Keysight 33250A and 33220A arbitrary waveform generators to provide the pulse modulation and triggering signals, and GUI controllable power supplies.

FEATURE ILLUSTRATIONS

The use of a computer as a central coordinator brings new features to the measurement system and gives users more freedom to design a custom measurement capability. The following are a few examples:

Real-Time Measurement of Linearity

Differential linearity is a measure of gain variation as a function of input signal. It is defined by two measures: the change in the magnitude of gain with respect to input power, i.e., $\partial G/\partial P_{in}$, and its change in phase with respect to input power, i.e., $\partial \phi/\partial P_{in}$. These differential quantities, though not normally available in the set of an instrument's standard test features, are important for troubleshooting a high power pulsed RF amplifier. The computer-driven method offers the capability to measure and display the differential gain linearity and the differential phase linearity in real time (see ***Figures 4*** and ***5***). The corresponding gain linearity and phase linearity are also displayed.

$\partial G/\partial P_{in}$ and $\partial \phi/\partial P_{in}$ are calculated from two data sources. One is the presumably stable input signal measured beforehand by the signal generator directly. The other is the output of DUT, measured by the VSA for every pulse. Each time a pulse is captured, the displays shown in Figures 4 and 5 are refreshed with the latest data.

The specific requirement on $\partial G/\partial P_{in}$ and $\partial \phi/\partial P_{in}$ are displayed as red dashed lines. Thus, a user has real-time feedback while fine tuning. The traces of $\partial G/\partial P_{in}$ and $\partial \phi/\partial P_{in}$ are calculated directly from measurement and therefore contain considerable noise. A moving average with a reasonable window size will improve the display.

On the Spot Self-Calibration

An aged signal generator is often nonlinear at the lower power levels of its arbitrary waveform output. This can be observed using a receiver, such as the E4440A. The waveform of the signal generator is measured using the receiver and compared with its IQ template. The error in-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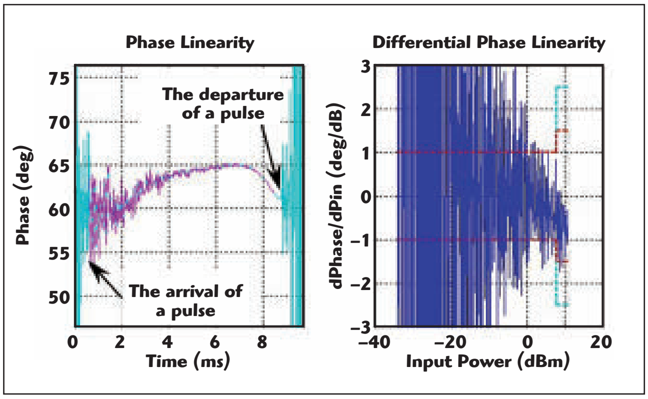


▲ *Fig. 5 Phase linearity and differential phase linearity.*

formation is used to create a modified IQ template used to generate a new, linearized, arbitrary waveform. All steps are carried out in a rapid, straightforward manner through the GUI (see ***Figure 6***).

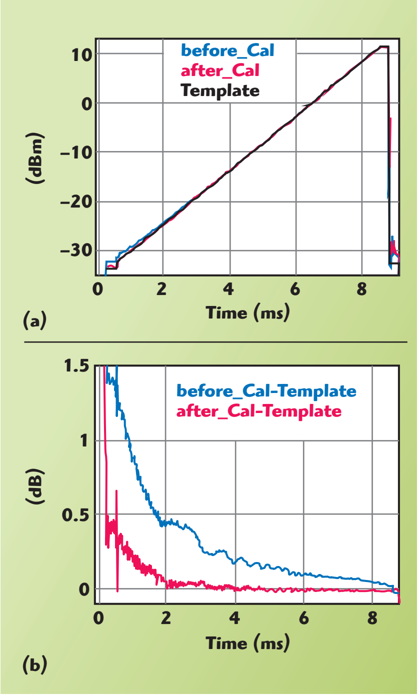
Figure 6a displays one pulse in a chain of sawtooth pulses created by the desired template and one by the modified template. Deviation is apparent at lowest power level. ***Figure 6b*** displays the error in dB of these two pulses relative to the original sawtooth template. The modified (predistorted) template reduces the error to less than 0.1 dB over a larger dynamic range of approximately 37 dB.

Automatic Harmonic Scan

Traditionally, there are two ways to measure the harmonic products of a distorted carrier signal. One is to display the signal spectrum over a wide frequency span, wide enough to show all harmonic products of interest. However, the spectrum resolution and sweep time cannot be optimized simultaneously for a pulsed measurement using this method. The second method employs a built-in spectrum analyzer application controlled by the computer.[3]

The spectrum analyzer first scans a relatively narrow frequency range centered at the fundamental, which is captured and stored by the computer. Then, it acquires the second order harmonic, which is similarly captured and stored. The spectra at higher order harmonics are successively scanned and stored in the same manner until the highest order harmonic of interest is measured.

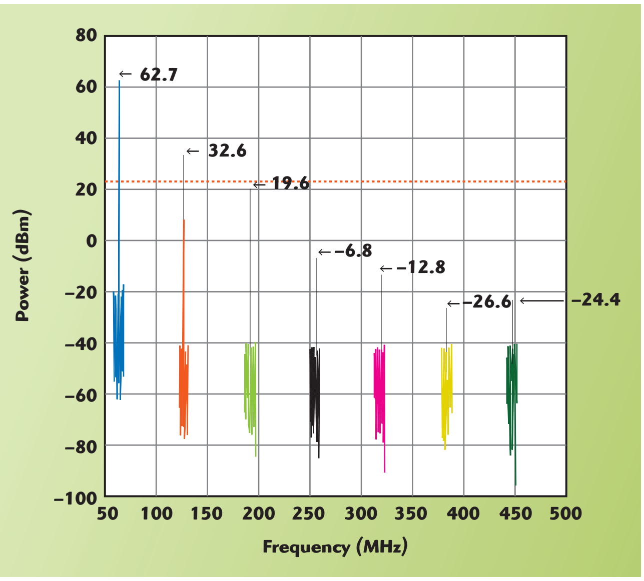
Figure 7 displays the harmonic products, up to the seventh order, in the output signal of an amplifier. Each color represents a segment of the spectrum, centered at each harmonic, measured over the span of 10 MHz. Since only 1/40 of the entire spectrum from the fundamental up to the seventh harmonic is scanned, considerable time is saved; this would be impossible if pulses with short duration were measured over a long sweep time. This type of harmonic measurement can also be conducted in the time domain. ***Figure 8*** demonstrates the harmonic measurement with the frequency span of the spectrum analyzer set to zero.



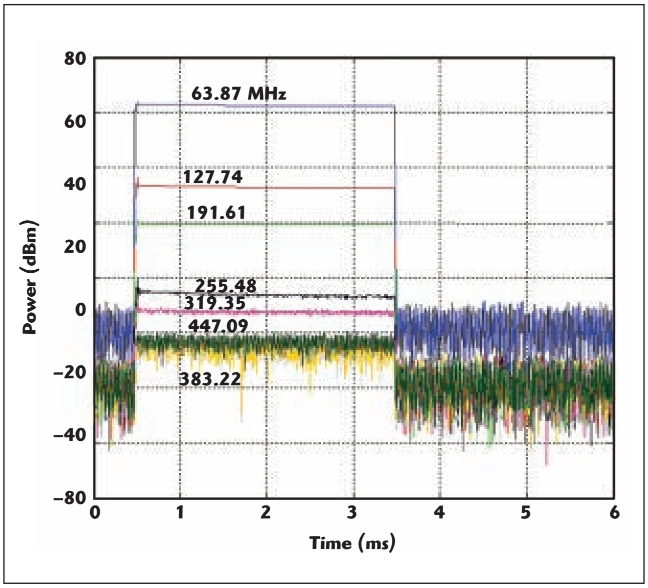
▲ *Fig. 6 Linearity correction on an arbitrary waveform; waveform before and after calibration (a) error relative to the original waveform template (b).*

PULSED S-PARAMETER MEASUREMENT WITH AN ORDINARY VNA

A dedicated NVNA is normally required for this task,[2] because the available E8357A VNA does not have an internal pulse generator. The pulsed



▲ *Fig. 7 Amplifier harmonic products. The fundamental frequency is 63.87 MHz.*

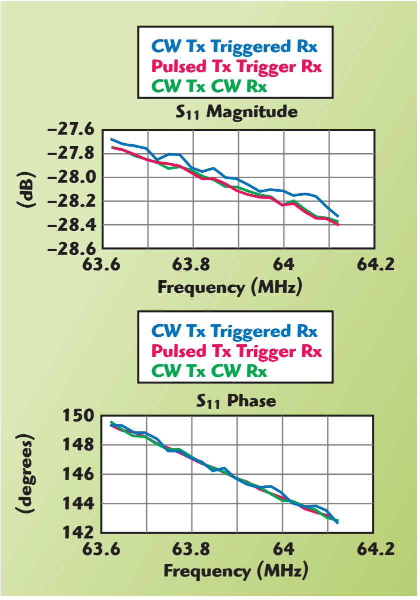


▲ *Fig. 8 Amplifier harmonic products displayed in the time domain.*

mode of this VNA, however, can be still be used with computer control. Waveform 3 in Figure 1 modulates the VNA's internal source through the AM port on its rear panel, while Waveform 2 triggers the VNA's internal receiver, but with a narrow pulse width. The modulation signal (Waveform 3) may be omitted if the DUT can tolerate a continuous wave input.

If the frequency span is set to zero on the VNA, the arrival of the receive trigger signal (Waveform 2) is ahead of the transmit modulation signal (Waveform 3), and the sweep time of the VNA is set to be longer than the pulse width, then the VNA will scan the S-parameter over the entire pulse duration and display it in the time domain. Strong noise is usually found in the S-parameter measurement before the arrival of a pulse and after the fall of a pulse. This is also called a "pulse profile" measurement.[4]

If the VNA is set to measure one point for each trigger and the receive trigger arrives when the RF pulse is on, the VNA will scan the S-parameter while hopping from one frequency point to another. This VNA mode brings the measured S-parameter into the fre-



▲ *Fig. 9 S_{11} measurement of one device with several signal formats.*

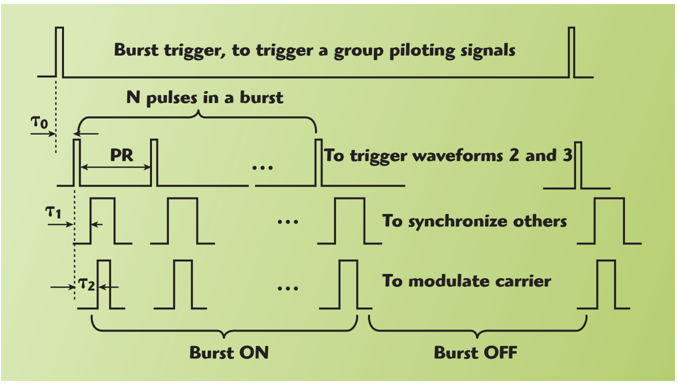


Fig. 10 Timing diagram for pulse burst creation.

quency domain. This is also described as the "point-in-pulse" measurement.[4] In order to implement this mode, pulse delay τ_1 or τ_2 must be adjusted to locate the narrow width of Waveform 2 within the pulse width of Waveform 3.

Figure 9 shows the measurement of S_{11} (magnitude and phase) in the frequency domain at the input port of a broadband CW amplifier with three signal formats. One format is the conventional CW signal. Another one is the "point-in-pulse" measurement with a pulsed RF transmit signal and triggered measurement. The last one is a CW RF transmit signal and triggered measurement. The difference in S_{11} due to having different signal formats is small.

Continuous Capture and Stability Measurement

An RF pulsed waveform is usually transmitted as a sequence of bursts with every burst containing a few pulses. Using the computer controlled measurement method, the sequence of bursts is created by adding one more waveform generator to the architecture of Figure 1 (see ***Figure 10***). The added waveform generator creates a pulse sequence called a burst trigger. The original pulse pilot signal of Figure 1 is now triggered by the burst trigger and a limited number of pilot signals, N, are generated after each burst trigger. The instrument diagram for this measurement is shown in ***Figure 11***. The E8357A VNA measures S_{21} in time domain and sends the data back through the GPIB continuously, under control of the central computer. Note that transmitter modulation is not used in the diagram of Figure 11.

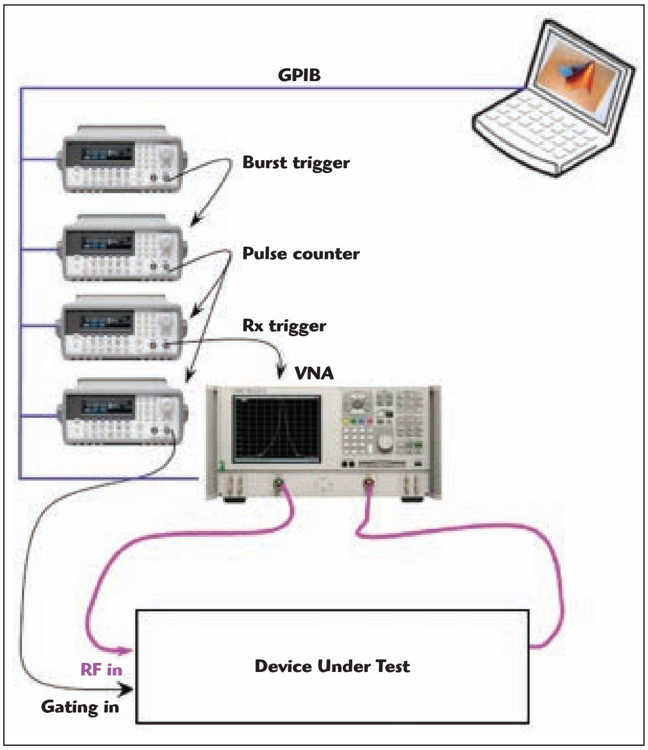
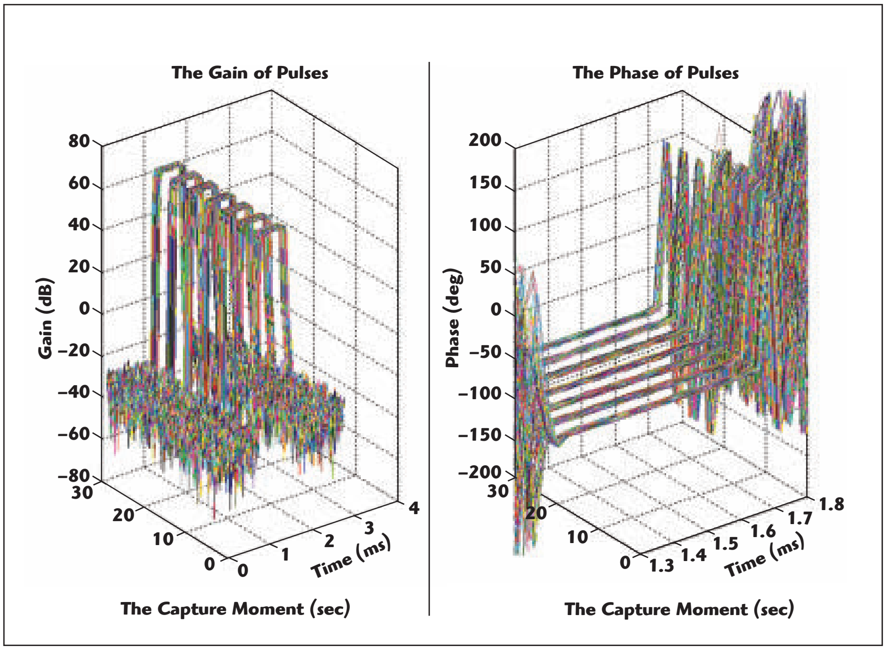


Fig. 11 Instrument diagram of a vector measurement with pulse bursts.

When pulse capture is complete, a data processing routine compares and analyzes all the pulses and displays the results as desired. ***Figure 12*** provides a 3D view of the S_{21} measurement on the pulse bursts. The pulses in different bursts are aligned to have the same start time in different frames. Both the magnitude and phase of S_{21} are displayed in the left and right frames, respectively. Each colored trace represents a captured pulse. Noise appears when a pulse is off.



▲ *Fig. 12 Measurement of S_{21} on bursts of pulses.*

CONCLUSION

The computer centric measurement brings many advantages to the characterization of pulsed high power RF devices. First, it minimizes operator dependent measurement errors. The combination of appropriate instrument states and working modes of selected instruments are saved and recalled by the computer precisely and in an orderly manner for each specific measurement. Second, the programming and execution mechanism makes the measurement system flexible for multi-purpose tests with a subgroup of instruments. Third, the GUI hides the complex programming and instrument interrelationships while providing the user with the convenience of a reliable one-click operation. For the measurement designer, on the other hand, the test script is transparent and readily accessible. The potential conflict of GUI operation is avoided by software interlock. Last, but not at least, it offers the freedom to perform data processing on a measurement. The codes for data visualization are separate from the raw data obtained from instruments. A user has the flexibility to revisit the data and express the results from various perspectives. The powerful data visualization codes can provide new measurement features, even beyond those of existing instruments. ■

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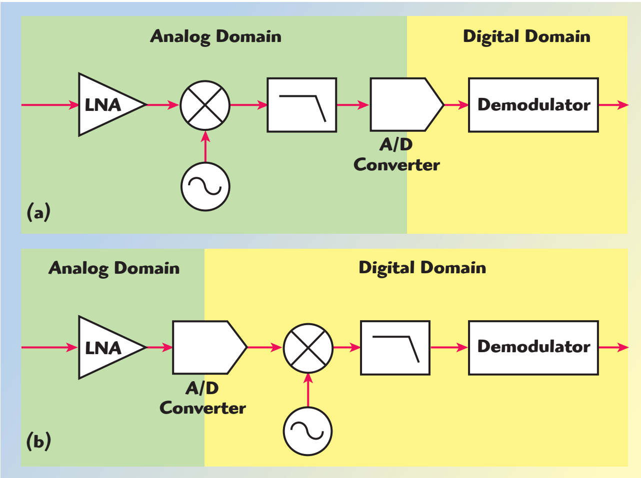
INVITED PAPER

A New Method for Testing Satellite TV Tuners and LNBs

Ed Petruzzelli
EchoStar, Englewood, Colo.
Peter Lampel
Rohde & Schwarz, Munich, Germany

Gain, noise factor, intermodulation suppression testing of satellite tuners and low noise block converters (LNB) has always been a job for classic RF test and measurement equipment. But even here, digital technology is increasingly replacing analog circuitry. Instead of conventional tuners, next-generation devices use broadband analog-to-digital (A/D) converter front-ends for reception in L-Band. Due to this technology shift, new test strategies are needed. U.S. based satellite operator EchoStar plans to use load profiles to test set-top boxes and LNBs and considers digital multichannel signal generators as an efficient solution.

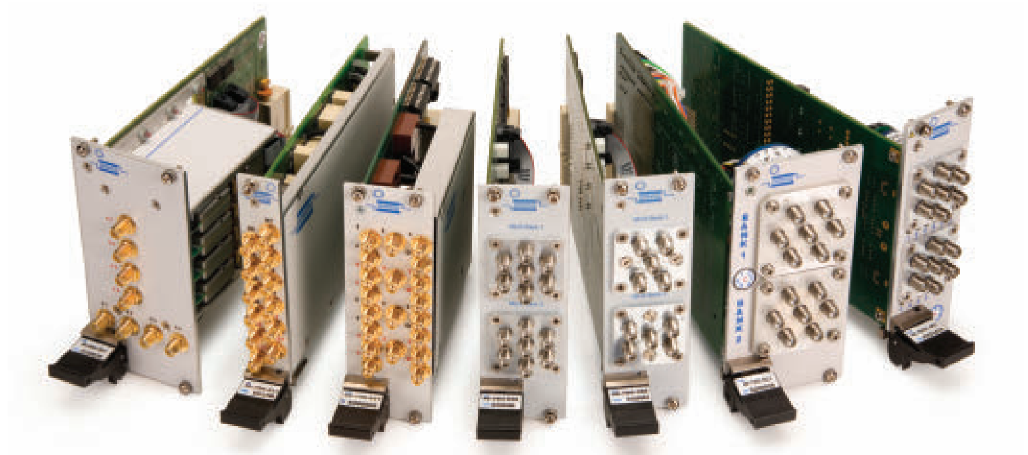
For as long as satellite TV has existed, LNBs and satellite tuners have been designed as superheterodyne receivers. The LNB converts the downlink signal from Ku-Band to L-Band. The satellite tuner in the TV or set-top box then converts the L-Band signal to a lower intermediate frequency where the desired channel is selected and decoded. Testing of such receivers has worked perfectly well with standard RF measuring instruments: a network analyzer to measure the gain and matching, a spectrum analyzer to test the image frequency rejection and third-order intercept and to detect spurious responses and a noise source to measure the noise factor. CW carriers were used as test signals, and a modulated carrier from a signal generator was required only to test the decoder. It was considered that simulation of a fully loaded band was not practical due to cost constraints, since a separate modulator with L-Band up-converter would have been required for each channel.

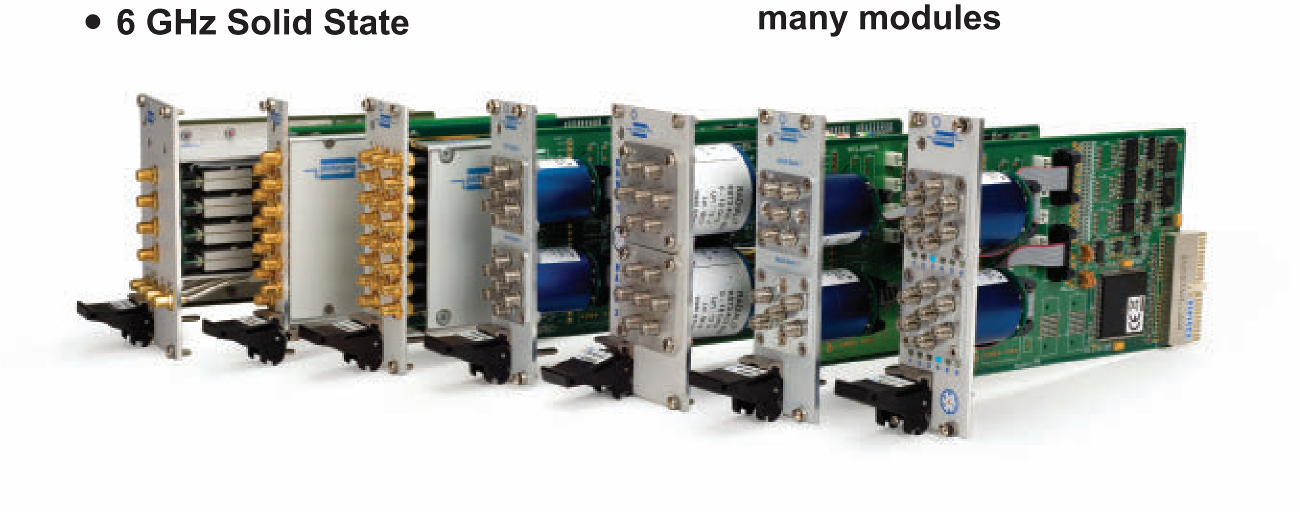


▲ *Fig. 1 Conventional satellite tuner with a superhet receiver (a) compared with a next-generation satellite tuner with full-band capture (b).*

FAST A/D CONVERTER REPLACES ANALOG TUNER

Now, however, the situation is changing in a fundamental way. In next-generation set-top boxes and outdoor units (ODU), the superhet front-end is replaced by an A/D converter for direct sampling of the satellite IF signal, which is normally in the 950 to 2150 MHz range (L-Band). However, there are cases where the signal can begin at 250 MHz and extend all the way to 3 GHz. The new receivers digitize a wide sub-range that can span 1000 MHz, for example. This is known as full-band capture technology (see ***Figure 1***). The channel to be decoded is selected based on digital signal processing. The advantages of such an architecture are obvious: less analog circuit technology means fewer tolerances, less alignment and less space needed on the printed board. Since fast A/D converters are commercially available, this





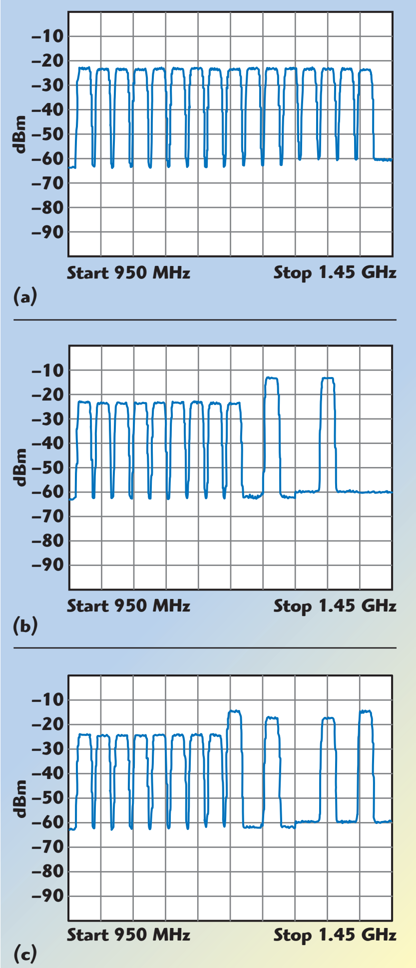
approach is also more cost-effective.

However, these new direct-sampling receivers require a different test and measurement approach. Since analog test equipment can no longer access the IF signal processing chain, parameters such as gain may have to be derived from other measurements. Measurements with a single CW signal or a carrier that has a narrowband profile compared to the receive bandwidth are not adequate. Instead, the receiver must be tested with full transponder load in order to simulate the real world satellite signal as closely as possible. Previous methods utilizing a single carrier at a simulated total aggregate power will yield different or undesired results in the A/D section. For an A/D converter, it is crucial to optimize the functionality over the entire expected dynamic range of the input signal.

TESTING WITH TRANSPONDER LOADS

Network operators use a large number of different transponder loads, as shown in ***Figure 2***. Due to spot beams, these can have a wide dynamic range. To test LNBs and set-top boxes, EchoStar has developed a new test strategy based on simulated transponder loads. The tests are executed with a series of load profiles in order to simulate the different transponder loads in a real world satellite TV network. Load profiles are chosen that will stress the A/D converter in various ways to ensure that the LNBs and set-top boxes do not degrade the received signal under real conditions, guaranteeing best modulation error ratio (MER) and a low bit error rate (BER). The satellite operator is adopting this test strategy for the latest generation of LNBs and set-top boxes for the first time. It is expected that manufacturers will increasingly test with load profiles in the future.

For the test and measurement equipment, the greatest challenge associated with this test strategy is generating a sufficient number of modulated transponder signals. Until now, two different approaches were available, each with specific technical or economic drawbacks. One approach involves using a number of satellite TV modulators as they are typically used in the uplink and aggregating their output signals. Such a setup is complicated to configure and calibrate and requires a great deal of space and power. It is also relatively costly due to the large number of modulators. Alternatively, an arbitrary waveform generator with sufficient bandwidth can be used, although it is not easy to generate a suitable I/Q waveform file for multiple satellite TV transponders. Even minor changes to the configuration require the creation of a new waveform file, which makes this approach rather inflexible. Using a multichannel satellite load generator (SLG) greatly simplifies this job by simultaneously generating up to 32 satellite transponder signals. The symbol rate, forward error correction (FEC), frequency and level can be indi-



▲ *Fig. 2 Load profile with 16 CONUS transponders (a) nine CONUS transponders and two spot beams (b) and eight CONUS transponders and two higher level spot beams for the target region (c). The two lower level spot beams between the two higher level carriers in (c) are from an adjacent target region.*

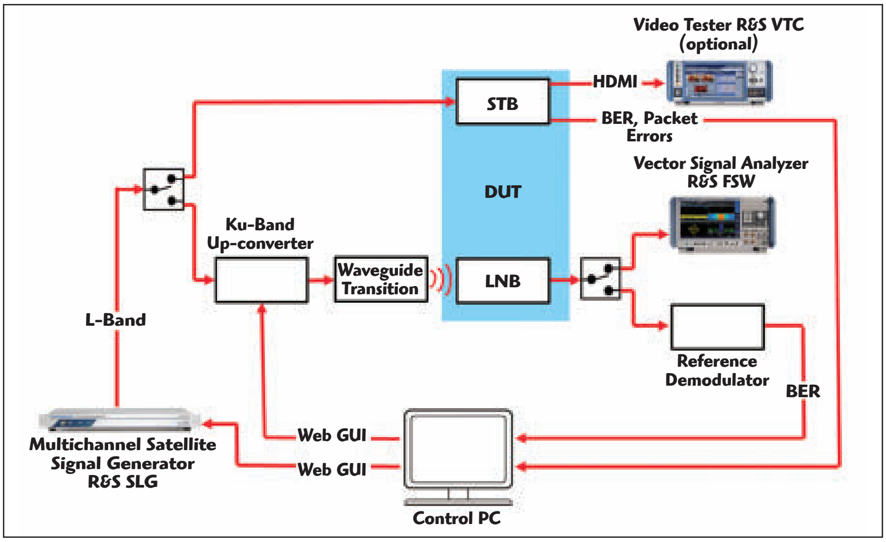


Fig. 3 System for testing set-top boxes or LNBs with load profiles.

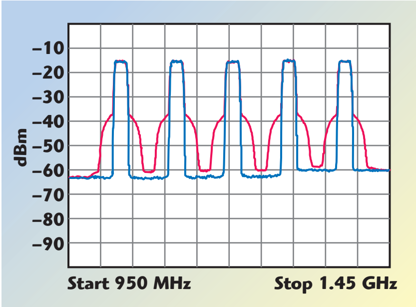


Fig. 4 Selective degradation of the signal quality in a transponder using phase noise.

vidually set for each transponder. Up to 16 transponders can transmit live video signals.

Figure 3 illustrates the test system used at EchoStar. A multichannel SLG produces the modulated signals in the frequency range from 250 to 3000 MHz. The different load profiles are stored on the instrument as configurations and then called up in sequence. When testing a set-top box, the generator's output signal is fed directly to the input of the device under test (DUT). The instrument basically simulates the output of an LNB. The set-top box supplies the bit error ratio or the number of uncorrected FEC packets per time unit. Alternatively, the picture quality of the HDMI™ output signal from the set-top box can be analyzed, with a video tester for example. To test an LNB, the SLG load profile is first converted with an up-converter to Ku-Band and then passed to the DUT input. The DUT supplies a satellite IF signal that is either measured with a vector signal analyzer or decoded with a reference receiver. The reference receiver outputs the BER along with a number of other parameters for the demodulated signal. A PC controls the different instruments and stores the results.

The multichannel signal generator is a very useful signal source for this test system because it requires much less space and power and generates less heat and noise than 16 individual modulators. It is controlled over an Ethernet interface for ease of local or remote control. Stored load profiles can be easily recalled for subsequent usage, and the signal can be selectively degraded with additive white Gaussian noise (AWGN) and phase noise (see ***Figure 4***). The phase noise generator is especially attractive to EchoStar as it will enable deeper insights into the performance limits of the new direct-sampling tuners. The company had previously found it nearly impossible to develop and verify a specification for phase noise.

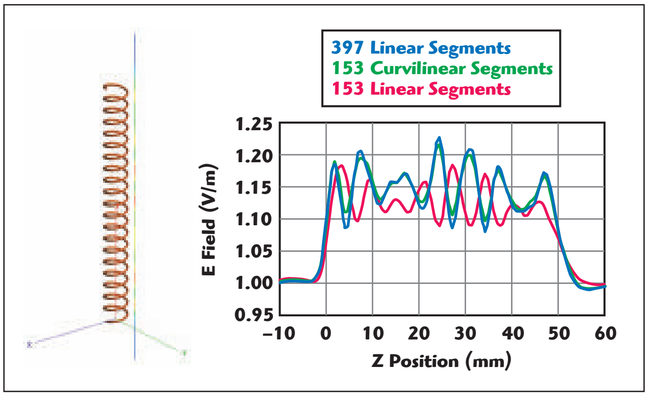
CONCLUSION

The next generation of direct-sampling front-ends is revolutionizing the design of satellite receivers. Digital multichannel signal generators allow users to keep pace with this technological advance and test the new receivers as thoroughly as classic superhet receivers were tested in the past. ■

FEKO Integrated in HyperWorks 14.0

Altair Engineering Inc.
Troy, Mich.

Altair's computer-aided engineering (CAE) simulation software platform for simulation-driven innovation is HyperWorks, which includes modeling, visualization, analysis and optimization technologies and solutions for structural, impact, electromagnetics, thermal, fluid, systems and manufacturing applications. The electromagnetics solver suite in HyperWorks is FEKO, a comprehensive electromagnetic analysis software used to solve a broad range of electromagnetic problems. It includes a set of hybridized solvers, giving the possibility to combine methods to solve complex and electrically large problems, with all solvers included in the same package.

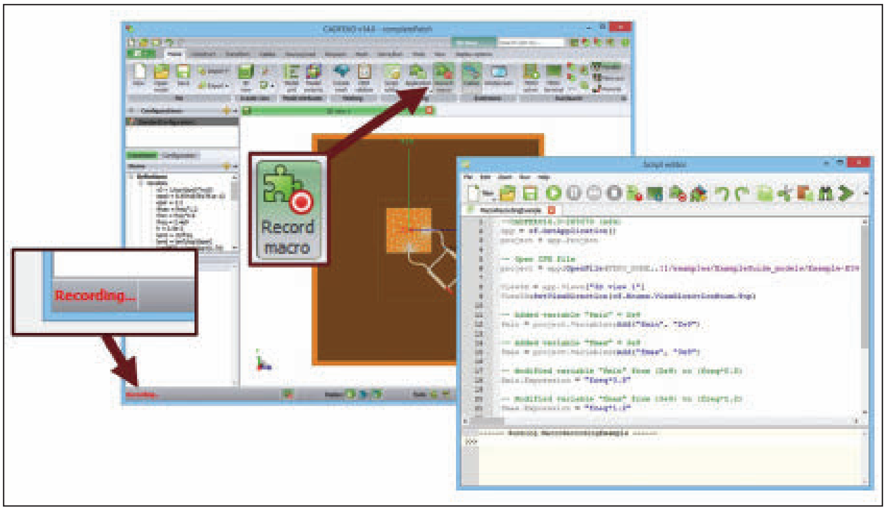


▲ *Fig. 1 Electric near fields computed at 5 mm from the axis of a 20 turn helix (with radius 2.5 mm, height 50 mm and wire radius 0.2 mm) illuminated by a plane wave at 7.4 GHz. Comparison using linear and curvilinear segments.*

EMSS-S.A., the developer of FEKO, was acquired by Altair in June 2014. Since early 2015, FEKO has been available under Altair's patented on-demand software licensing system. Users can run multiple HyperWorks applications, including FEKO, and other Altair products for a flat rate, rather than paying for each license in use. As part of Altair's portfolio, the FEKO version number will jump from FEKO Suite 7.0 to FEKO 14.0 to align with HyperWorks 14.0, the next version of HyperWorks.

FEATURES OF FEKO 14.0

Curvilinear meshes for triangles have been supported in FEKO from Suite 6.3, since they reduce computational requirements significantly by using larger mesh elements without sacrificing accuracy. In this new release, the software will support curvilinear meshes of segments for the method of moments (MoM) and for the multilevel fast multipole method



▲ *Fig. 2 New script recording feature in CADFEKO to perform repetitive actions (record script once and then repeat the set of actions just using the script) and for advanced and customized actions (record and extend the script).*

(MLFMM). This extension reduces computational requirements and achieves the same accuracy with fewer segments compared to linear segments. This feature benefits users interested in modeling wires, including helix structures or medical leads. ***Figure 1*** shows that to get the same accuracy with linear segments, 397 segments are needed instead of 153 segments when using curvilinear wires.

High order basis functions (HOBF) allow the user to mesh geometry with larger triangles and obtain the same solution accuracy. FEKO has supported HOBF for MoM and MLFMM since Suite 6.2. Now, in version 14.0, users will be able to use HOBF for the MoM region when hybridized with uniform theory of diffraction (UTD) or ray launching – geometrical optics (RL-GO) to analyze electrically large problems more efficiently. Depending upon the case, this new feature can reduce the required number of triangles of the mesh for the MoM region by a factor of 70 or more.

FEKO's finite difference time domain (FDTD) solver was added in Suite 7.0 to solve highly inhomogeneous materials and wideband problems, including the effects of electromagnetic pulses radiation. In this new release, features like using multiple configurations in a single model, perfect magnetic conductor (PMC) boundaries, OpenMP parallelization for multicore machines and others have been added.

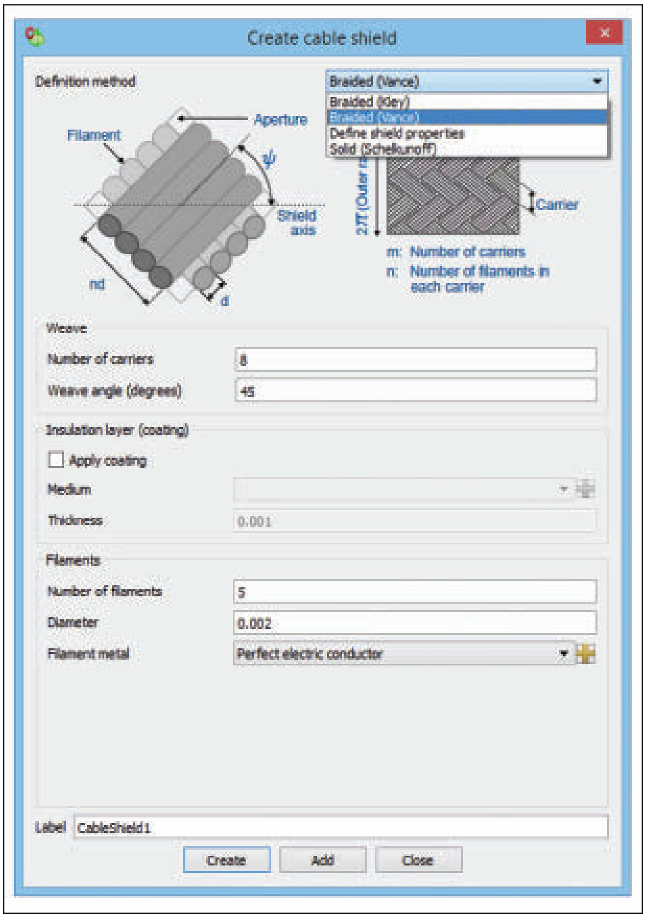
APPLICATION AUTOMATION AND LUA SCRIPTING

In FEKO 14.0 the application automation in CADFEKO is complete, and any action performed manually in CADFEKO can be done via scripting. It also supports script recording. The workflow for this process is simple: start recording, perform actions and stop recording. Once recorded, the user can re-run the script to avoid performing repetitive actions or modify a script for advanced or customized actions (see ***Figure 2***).

Users often have specific requirements for model setup or visualization that are not included in the FEKO user interface. For such cases, Lua scripting is used to implement these solutions. In version 14.0 the parameter sweep script has been improved to investigate the effect of changing variables. The plug-in to interface FEKO with Optenni Lab, for automatic matching circuit generation, has been upgraded to include a new workflow option and more advanced automation integration. A new script has also been created and is available to users to perform co-site interference analysis in platforms using multiple transmitters and receivers.

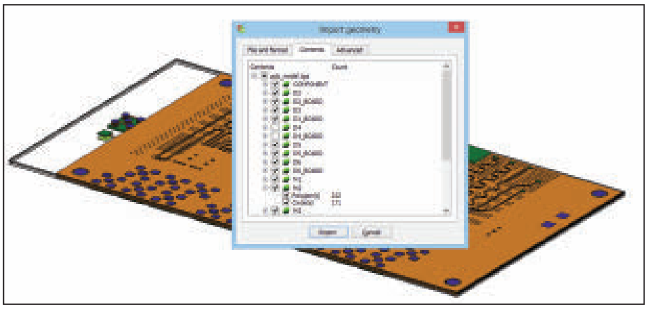
EMC, PCB MODELING AND RCS

Electromagnetic compatibility (EMC) is one of the key applications



▲ *Fig. 3 Create cable shield dialog in CADFEKO including the Vance braided shield type, added via the dropdown menu.*

where FEKO is used extensively. In the new release, the comprehensive cable modeling tool adds the Vance braided shield type (see ***Figure 3***). Due to the increasing interest of users in PCB modeling, new features have been added; for instance, layers can be selected or deselected in Gerber, ODB++, 3Di or AutoCAD files (see ***Figure 4***).



▲ *Fig. 4 Import geometry dialog in CADFEKO where the layers and elements of the Gerber, ODB++, 3Di or AutoCAD files can be selected to import.*

Active RCS calculations in a model with sources other than plane waves are now supported.

FEKO 14.0 includes other features and improvements, some related to CAD handling and visualization.

The HyperWorks Student Edition, supporting much larger models, is replacing FEKO LITE.

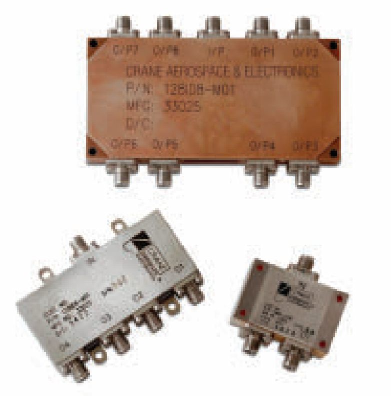
FEKO'S INTEGRATION INTO HYPERWORKS

FEKO 14.0 includes an integration between FEKO and HyperStudy, the multi-disciplinary design exploration, optimization and stochastic analysis tool. Meshes from Altair's HyperMesh, the high-performance finite element pre-processor, can also be imported.

FEKO also works with PBS Works from Altair, workload management software, which includes Compute Manager, a web-based application to submit, manage and monitor jobs on HPC environments. It can now be used with Altair's cloud solutions, including HyperWorks Unlimited Physical Appliance, a private cloud solution with fully configured hardware and unlimited use of all Altair software within the appliance.

VENDORVIEW

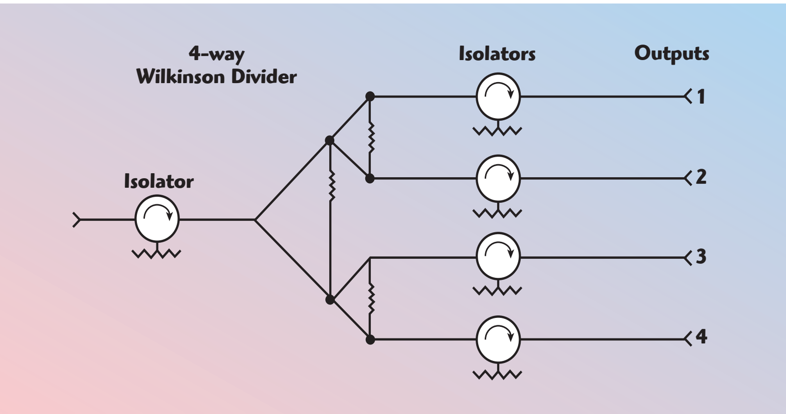
Altair Engineering Inc.
Troy, Mich.
www.altairhyperworks.com/FEKO



New Iso-Dividers Improve Performance for Satellite Applications

Crane Aerospace & Electronics
West Caldwell, N.J.

Have you ever been in a design discussion with a customer about the product they intend to purchase and you find that you may be able to solve their problem by creating a new product? That is exactly what happened with Crane Aerospace & Electronics, which led to the introduction of a new product family: Ku-Band Iso-Dividers. The Crane microwave team was meeting with a satellite customer who was planning to procure separate power dividers and isolators. They were seeking a convenient method to connect the power divider with the isolators, optimizing connector positioning to allow the power divider to be directly connected with the isolators and minimize or eliminate cables. Understanding the needs of the customer and the technology available across Crane's organization, Crane engineers went a step further and offered an integrated solution – both parts in a single package, which gave birth to a new product family of Iso-Dividers (and Iso-Combiners). These products combine Wilkinson power dividers with ferrite isolators. The functional block diagram of a four-way Iso-Divider is shown in ***Figure 1***.



▲ *Fig. 1 Functional block diagram of a 4-way Iso-Divider.*

DESIGN APPROACH

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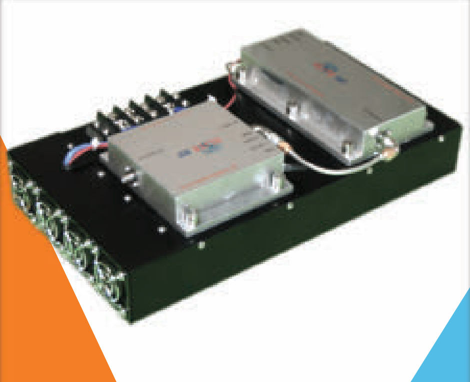
RF Amplifier Module

Model	Freq. - min	Freq. - max	Power	Gain	Supply
(Part Number)	(MHz)	(MHz)	(Watts)	(dB)	(dc)
M10207B3	500	2500	50	50	48
M10212B3Q2	800	1000	200	40	28
M10024B	100	1000	80	40	28
M10213B4	850	2100	150	50	48
M10004A2	20	1000	10	45	28
M10046B4	2000	18000	5	40	28
M10028B4	1000	6000	5	40	28



RF Amplifier Sub Assembly

Model	Freq. - min	Freq. - max	Power	Gain	Supply
(Part Number)	(MHz)	(MHz)	(Watts)	(dB)	(dc)
A10200A3Q2	500	2500	50	50	48
A10024B3Q2	100	1000	150	50	28
A10027B3	30	512	150	40	28
A10031B3	2000	6000	5	40	28
A10017B3Q2	200	2200	100	50	48
A10056B4	1000	1600	500 PK	40	48
A10067B4	6000	10000	25	40	48

19 " Rack Mount RF Amplifier

Model	Freq. - min	Freq. - max	Power	Gain	Supply
(Part Number)	(MHz)	(MHz)	(Watts)	(dB)	(ac)
R10204B4Q4	700	1000	350	50	120/240
R10205B4Q4	1700	2700	250	50	120/240
R10202B4Q8	400	1000	1000 PK	50	120/240
R10202A4	7000	10000	5	50	120/240
R10207B5Q8	20	500	1000	60	120/240
R10201A2	2000	18000	5	40	120/240
R10244B	8000	10000	25	45	120/240

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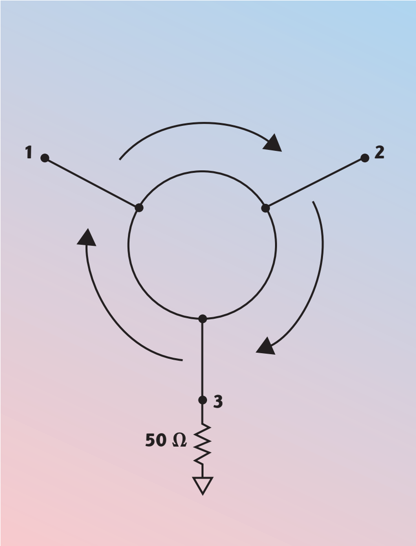


▲ *Fig. 2 Signal flow in a ferrite circulator.*

dancy and antenna sharing. Wilkinson dividers provide low insertion loss and good isolation between the unit's outputs. However, they require a good impedance match to each input and output. If a device attached to a divider port fails, the divider will likely see a mismatch, causing performance issues such as higher insertion loss, VSWR and poor isolation. Inserting ferrite isolators is one way to make the Wilkinson divider immune to a failure presented at one of its output ports.

Isolators are three-port devices with the third port having a well-matched termination. As shown in ***Figure 2***, RF energy incident at the input port (Port 1) is passed on to the output port (Port 2). Conversely, energy presented to the output port (Port 2) is directed to the termination (Port 3). In this way, the isolator functions as a one-way "check valve." If the device connected to the output port (Port 2) does not present a perfect load to the circuit (a 1.0 VSWR), some energy will be reflected back; without the isolator present, it would be reflected to the source. The isolator absorbs the reflected energy in the termination, making up for any issues in the load circuit. This property is a major benefit if the character of the load changes during operation, such as a part failure or stray signals being presented from the load. The isolator provides protection to the circuitry.

The traditional method of providing this function in a system has been to purchase a stand-alone power divider and add separate isolators. Using the example of a four-way power divider; the bill of material (BOM) would be:

- One four-way power divider
- Five isolators
- Five semi-rigid cables with SMA to SMA connectors.

Assembling the components inside this functional block requires 10 SMA connections. Each component in the assembly must be mounted with a minimum of two screws per part, at least 12 screws total.

INTEGRATED ISO-DIVIDER BENEFITS

Procuring an integrated solution lowers cost by reducing the BOM to a single device and simplifying management to a single supplier, rather than several. Reliability is also improved with the integrated implementation. Separately connected components reduce the MTBF, given the additional potential for failure at each interconnection. The performance of the single unit is better, with lower insertion loss and VSWR degradation than if the components were connected with cables and connector interfaces. Insertion loss is 1.2 dB for an integrated four-way divider, versus 2.2 dB for the discrete implementation. For Crane to achieve this improved electrical performance, matching between the divider circuit and the isolator must be optimized. With control of all elements of the circuitry, adjustments can be made to the characteristics of both the power divider and isolators to ensure good matching between them. This tailoring improves loss, ripple and phase linearity across the operating band, which would not be possible with individually purchased components.

Combining all parts into a single package allows the integrated unit to be smaller than the individual components with separate cables – a 60 percent reduction in volume with Crane's solution. Along with size, weight is reduced, since extra cables and connectors are no longer required. When satellites become smaller and the industry moving to deploy large constellations of micro-satellites, "space in space" is a premium. Satellite and payload manufacturers must fit more functionality into a smaller volume.

TABLE 1

ISO-DIVIDER FAMILY PERFORMANCE

Performance	2-way	4-way	8-way
Frequency Range	10.7 to 14.8 GHz	10.7 to 14.8 GHz	10.7 to 14.8 GHz
Return Loss (Input & Output)	20 dB min	20 dB min	20 dB min
Isolation Between Outputs	36 dB min	38 dB min	38 dB min
Insertion Loss (Above 3 dB Theoretical)	1.8 dB max	1.2 dB max	2.2 dB max
Phase Balance	+5° max	+8° max	±12° max
Power Handling	2 W max	2 W max	2 W max
Magnetic Emission	0.5 Am^2 max	0.5 Am^2 max	0.5 Am^2 max
EMI Shielding	–80 dBi max	–80 dBi max	–80 dBi max
RF Connection Interface	SMA Female	SMA Female	SMA Female
Operating Temperature Range	–55° to +85°C	–55° to +85°C	–55° to +85°C
Weight	42 g max	85 g max	270 g max
Package Size (Not Including Connectors)	1.56" × 1.01" × 0.56"	2.64" × 1.52" × 0.56"	4.00" × 1.94" × 0.54"

By combining the functionality of four or more components into one, the Iso-Divider helps meet the demands for reducing footprint with increased functionality. The device itself is packaged in a welded enclosure to assure robustness and avoid the additional space and weight required by a screw cover. The housing is vented with a small hole to assure equalization with the vacuum of space, which relieves any stress due to the internal atmospheric pressure encountered during the ascent into space. The packaging also contains magnetic shielding that is required to complete the magnetic field for the isolators and capture the fields within the device to avoid interaction with other devices on the satellite.

SPEEDING TIME TO LAUNCH

As the space industry trends more towards commercial off-the-shelf (COTS) components, the paradigm of custom designed and individually qualified passive components for satellite applications is shifting to more off-the-shelf and "family" qualified parts. These shorten lead times, reduce size, increase functionality and lower cost. The Crane Iso-Divider family will be offered with standard features and certain tests already performed to allow more prompt delivery for customer applications. In addition, Crane offers other space application COTS products under their microwave space qualified parts (MSQP).

The Iso-Divider was initially introduced as a two-way device operating at Ku-Band. Four- and eight-way Ku-Band units have since been introduced. Performance specifications of the family are shown in ***Table 1***. All of these products provide the same advanced features and compact packaging. Expansion of this product family is planned, as well as offering Iso-Combiners. The difference between a divider and combiner circuit is the sense or direction of the ferrite isolators, as Wilkinson dividers or combiners are fully reciprocal. In addition to the Ku-Band family, Ka-Band units with similar functionality are planned.

VENDORVIEW

Crane Aerospace & Electronics
West Caldwell, N.J.
www.craneae.com/isodivider

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

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

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

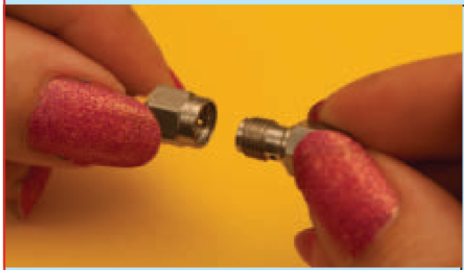
3. Push "Lock Nut" forward and engage the Push-On end of the Adapter with the mating female. Back nut must be released.

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

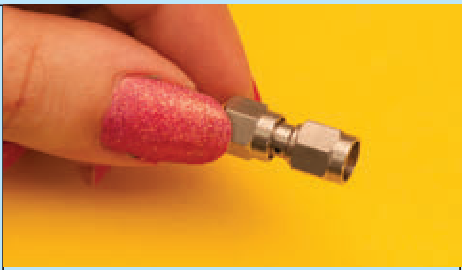
5 . To unlock (when "Back Nut" is in unlocked mode) push the "Lock Nut" forward and stop reverse movement by setting your fingers onto the "Back Nut".

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

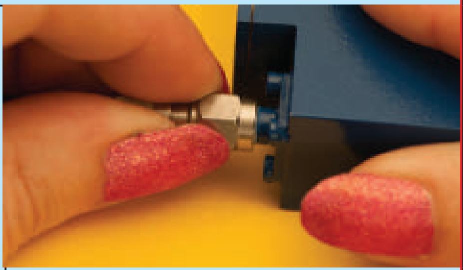
Procedure for how to use the SMA male and SMA female Push-On connectors. SMA Push-On Connectors mate with any standard connector of the same but opposite connector style.



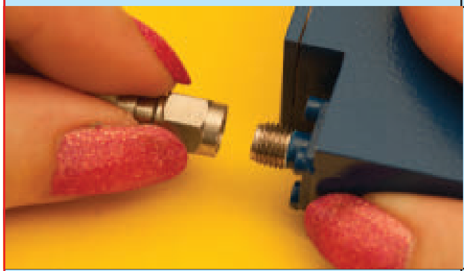
1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



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



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

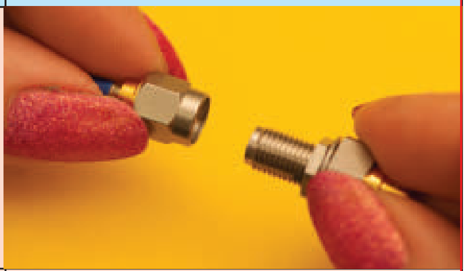


4. To disconnect, just pull the connector off.

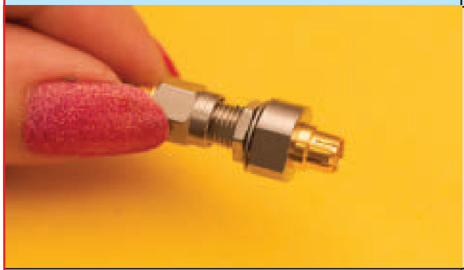
Spectrum
Elektrotechnik GmbH

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

Spectrum
Elektrotechnik GmbH

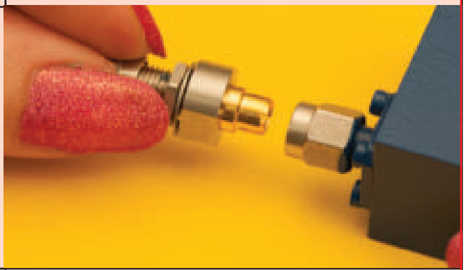


1. Convert your standard cable assembly into a Push-On Assembly by threading the standard female side of the adapter onto the male connector of the assembly.



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

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



4. To disconnect, just pull the connector off.

1M Life Cycle Electromechanical Switches Cover DC to 46 GHz

Pasternack introduces a large portfolio of in stock, general purpose, multi-market, coaxial packaged, electromechanical switches for RF, microwave and millimeter wave applications. These new electromechanical switches are uniquely qualified for use in numerous applications including satellite and military communications, radar, commercial and military aviation, test and instrumentation and medical equipment.

This product portfolio from Pasternack consists of 134 connectorized designs that are guaranteed for 1 million life cycles. These general purpose switches complement Pasternack's existing family of 2- to 10-million life cycle, high-rel, electromechanical relay switches, making the company's in-stock RF switch portfolio the largest in the industry. These relay switches are available in a variety of different connector options, including SMA, Type N, TNC and 2.92 mm, and are offered in popular configurations such as SPDT, DPDT, SP4T, SP6T, SP10T and transfer. Additional features available on specific models include latching actuators, failsafe actuators, indicators, TTL controls, terminations, pulse latching and hot switching.

The new electromechanical switches from Pasternack cover frequency ranges from DC to 46 GHz and have power ratings from 10 to 275 W. They achieve isolation up to 80 dB, switching speeds from 15 to 50 ms and insertion loss from 0.2 to 0.6 dB. All materials and finishes are in accordance with applicable MIL standards.

Pasternack's new family of 134 general purpose electromechanical switches are in-stock and available to ship today.

VENDORVIEW

Pasternack Enterprises Inc.
Irvine, Calif.
www.pasternack.com

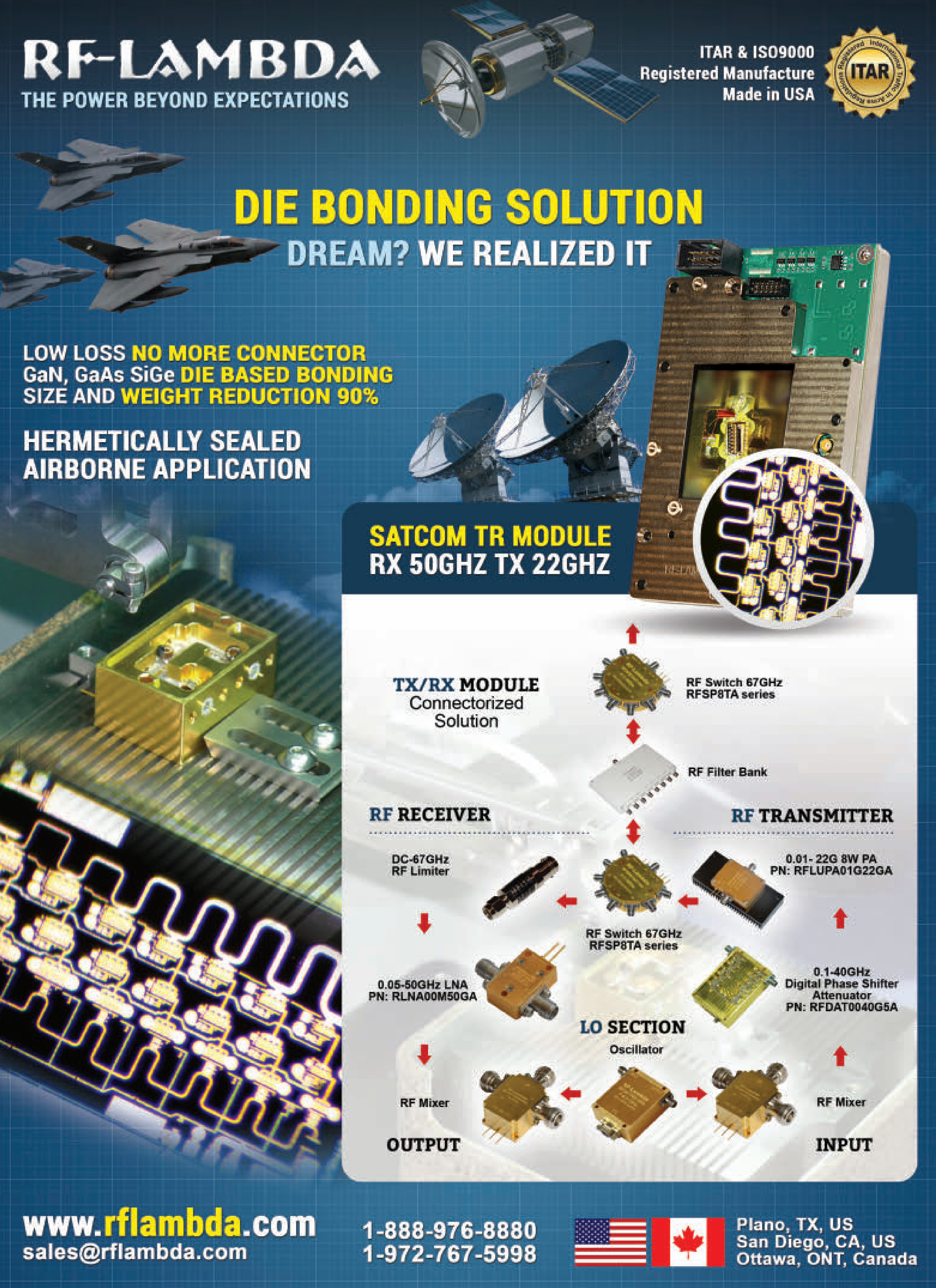
High Power Couplers Offer Breakthrough Performance

Maury Microwave's LLC series of bidirectional airline couplers represents a breakthrough in high power coupler technology. Combining precision machining with stellar electrical characteristics, the LLC series couplers offer unmatched performance: high power handling, high directivity, low insertion loss and broadband performance. The LLC18-7 handles 500 W CW or 2 kW peak to 18 GHz, and the LLC34-35 handles 150W CW or 500 W peak to 34 GHz. Unlike other models that are rated at breakdown, Maury defines power handling capability as the power at which there is no discernible change in the performance of the coupler. This level of power handling enables the couplers to be integrated in high power applications such as amplifiers and base stations, as well as test and measurement applications such as power amplifier and load-pull testing.

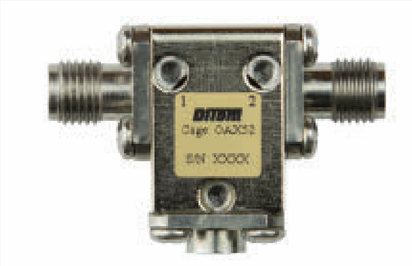
High directivity, the difference between coupling and isolation, enables highly accurate measurements by isolating the direct and coupled measurement pathways. This is especially important in a calibrated system where changing coupler characteristics due to poor directivity can invalidate the calibration and result in erroneous measurements. Low insertion loss is critical for high power applications to avoid power loss and eliminate drift due to heating. Compared with microstrip couplers that suffer losses and self-heating from metal resistivity and dielectric permittivity, the LLC series airline couplers have no added dielectric. LLC couplers have typical insertion losses of 0.15 dB at 8 GHz and 0.25 dB at 18 GHz for the LLC18-7 and 0.25 dB at 26.5 GHz and 0.3 dB at 34 GHz for the LLC34-35. When used as part of a vector-receiver load-pull setup, low insertion loss maximizes the tuning range when combined with an impedance tuner.

The broadband nature of the coupler allows it to be used for wideband applications. The LLC18-7 is rated between 0.6 and 18 GHz, yet is useable from 0.1 GHz with increased coupling. The LLC34-35 is rated between 2 and 34 GHz and is also useable from 0.1 GHz with increased coupling.

Maury Microwave
Ontario, Calif.
www.maurymw.com



RF-LAMBDA
THE POWER BEYOND EXPECTATIONS
ITAR & ISO9000
Registered Manufacture
Made in USA
ITAR
DIE BONDING SOLUTION
DREAM? WE REALIZED IT
LOW LOSS NO MORE CONNECTOR
GaN, GaAs SiGe DIE BASED BONDING
SIZE AND WEIGHT REDUCTION 90%
HERMETICALLY SEALED
AIRBORNE APPLICATION
SATCOM TR MODULE
RX 50GHZ TX 22GHZ
TX/RX MODULE
Connectorized
Solution
RF Switch 67GHz
RFSP8TA series
RF Filter Bank
RF RECEIVER
RF TRANSMITTER
DC-67GHz
RF Limiter
0.01- 22G 8W PA
PN: RFLUPA01G22GA
RF Switch 67GHz
RFSP8TA series
0.05-50GHz LNA
PN: RLNA00M50GA
0.1-40GHz
Digital Phase Shifter
Attenuator
PN: RFDAT0040G5A
LO SECTION
Oscillator
RF Mixer
RF Mixer
OUTPUT
INPUT
www.rflambda.com
sales@rflambda.com
1-888-976-8880
1-972-767-5998
Plano, TX, US
San Diego, CA, US
Ottawa, ONT, Canada



Space-Qualified Ka-Band Isolator

To support the growth of Ka-Band satellites for commercial and military applications, DiTom Microwave has developed a space-qualified isolator for use in the input multiplexer or similar low power blocks in the satellite. Covering 27 to 31 GHz, the DS1017 has a maximum insertion loss of 0.6 dB, minimum isolation of 20 dB and return loss of 20 dB or better in a 50 ohm system. RF leakage is rated at -70 dBi. The isolator will handle up to 5 watts of forward power and 30 watts peak. Without connectors, the DS1017 measures 0.5" × 0.7" × 0.5" and weighs 20 g. The isolator is interconnected with 2.92 mm female connectors.

DiTom can deliver the DS1017 isolator six to eight weeks following customer order – even sooner depending upon customer test requirements. This is significantly faster than space-qualified components from other suppliers.

DiTom Microwave designs and manufactures high quality, connectorized ferrite isolators and circulators for space and defense and is AS9100 Rev. C certified. The company offers both commercial off-the-shelf and high reliability from 400 MHz to 40 GHz.

VENDORVIEW
DiTom Microwave Inc.
Fresno, Calif.
www.ditom.com

Nano Filters: Small Size, High Performance

One of 3H Communication Systems' core missions was to develop smaller, lighter and better performing filters at competitive prices. RF filters are probably one of the most mission critical components in any wireless communication system. RF filters are used every day in handheld radios for commercial and military applications including aircraft, marine, medical and high reliability space applications. Today's customers request high performance, smaller size and lighter filter products. Up until now there has been a performance penalty for making these vital components smaller and lighter. In the past, filters were typically the largest components on a PC board and subject to manual assembly.

3H Communication Systems developed the Nano Filter series to overcome their customers' size constraints. The typical Nano series filters measure 0.65" × 0.20" × 0.08". 3H's Nano filters are designed and manufactured for automated assembly utilizing pick and place equipment. 3H can also accommodate a diplexer option in a similar package size. These Nano filters are also capable of withstanding aqueous wash and will operate under Mil-Std-202 conditions. The Nano filters have an operational frequency band from 40 MHz to 9.0 GHz and can accommodate up to 11 sections with bandwidths up to 100 percent with operational temperature range from -55° to +125° C. 3H Nano filters are available in bandpass, lowpass, highpass and band-reject configurations.

VENDORVIEW
3H Communication Systems
Irvine, Calif.
www.3hcommunicationsystems.com

Website Redesign

Anokiwave launched the redesign of their website to provide visitors, customers and partners with relevant and easy-to-find information about their new mmWave Silicon ICs, AESA ASICs and III/V products. The new look and improved functionality allows users to access new product information and the company's blog with articles authored by their engineering team. The new website also includes new product information with data sheets, company overview and leadership team bios, links to Anokiwave's social media pages and the latest company buzz.

Anokiwave Inc.
www.anokiwave.com

Modernized Websites

VENDORVIEW

AR has modernized their corporate and RF/Microwave Instrumentation websites by providing easier navigation and more comprehensive information. The menu system is easier to read and the sites are search engine friendly. Flash spotlights work with various touch screen tablets and mobile devices. The 'Find It Fast' charts are one of the most popular features. Use these comprehensive charts to quickly access the AR amplifier, TWTA, hybrid power module or antenna you are looking for. Visit www.arworld.us or www.arww-rfmicro.com/html/00000.asp.

AR RF/Microwave Instrumentation
www.arworld.us

Real-Time Spectrum Analyzers

Berkeley Nucleonics recently updated the webpage for their line of Real-Time Spectrum Analyzers with new videos of operation, demonstrating more of the great features and dynamic capabilities of the RTSA7500s; updated resource pages, having the freshly revamped GUI made available; and adding more options allowing the RTSA to become even more customizable. The RTSA7500 still comes with up to 100 MHz of RTBW along with a frequency range of up to 27 GHz for less than $14,000.

Berkeley Nucleonics Corp.
www.berkeleynucleonics.com

Website Overhaul

Cirexx International's overhaul of their website provides more information, user friendly interfaces and easier navigation. Users will find graphic examples of Cirexx products and services along with detailed explanations. Users will also be able to browse and download Cirexx's vast array of certifications and registrations, find application information and locate Cirexx contacts quicker. The most popular feature, "Get a Quote," has been enhanced to include more pertinent information and ITAR security of uploaded files.

Cirexx International Inc.
www.cirexx.com

Easier Navigation

In-Phase Technologies completely redesigned their website, revising the look and feel of the site to ease user access. The easier-to-navigate design now offers product categories that can be accessed from the home page. The home page now features highlights of markets served by In-Phase Technologies: defense electronics, satellite, medical electronics, and microwave and fiber optic components. The site also offers a series of test system case studies on topics such as fast switch matrix, medical device, microwave vector and power supply.

In-Phase Technologies Inc.
www.in-phasetech.com

Authorized Access

Intercept Technology's new website provides consumers with a fresh, new look, improved navigation and enhanced content. Visitors can search for Intercept software information by product name or specific industry design need, such as PCB, hybrid, RF or high speed, making the site easily accessible from either viewpoint. Customers can also make special use of a new, authorized access section devoted specifically for them. The new section includes the latest software releases, a continually updated knowledge base with documentation across products and services, an Intercept user forum and easy-to-use customer request page.

Intercept Technology Inc.
www.intercept.com

WebUpdate

Click and Find It

VENDORVIEW

KRYTAR'S all new website features the company's growing product line of broadband microwave components including couplers, hybrid couplers, power dividers, detectors, beam forming, coaxial limiters, coaxial adapters, coaxial termination, power meters, power sensors and custom solutions. The new website is designed for user-friendly functionality to visitors using a desktop computer, laptop, smartphone or tablet. A unique feature includes the option to sort products by frequency range while also showing performance specifications in a clean, easy-to-read format. This allows simplicity in finding the exact product to meet a designer's requirements.

KRYTAR Inc.
www.krytar.com

RF Parts on Demand

VENDORVIEW

MECA Electronics' announced its expedited online service center, the source for RF Components on Demand (RFPOD) when you need them. RFPOD processes your order and makes it available for pick up at will call or shipment within two hours from order placement to pick up time! Will call pick up hours are 9 a.m. to 5 p.m. (ET) Call customer service in advance for earlier hours at (973) 625-0661. Let MECA help solve your component problems. Orders are accepted 24 hours a day, 7 days a week.

MECA Electronics Inc.
www.e-MECA.com

Resource and Quality Information

VENDORVIEW

Passive Plus Inc. (PPI), manufactures high quality, high power passive components using state-of-the-art manufacturing techniques. Specializing in magnetic and non-magnetic HI-Q capacitors product lines, PPI supplies reliable quality components to the aerospace, telecommunications, medical semiconductor, and military industries. Resource and quality information is now available on their website. Resources include: Broadband Capacitor application note, Hand Soldering guide, PPI cross reference chart, PPI 2015 catalog, S-Parameter data, plus technical videos and presentations. Quality information includes: ISO 9001 2015, material declarations, REACH and RoHS documents, and terms and conditions.

Passive Plus Inc.
www.passiveplus.com

eCommerce Websites

VENDORVIEW

Pasternack Enterprises Inc., recently launched two new eCommerce websites, one in China and one in Japan, providing engineers and component buyers in those countries easier access to the largest selection of in-stock and ready-to-ship RF products. With the launch of www.pasternack.cn and www.pasternack.jp, Pasternack has greatly expanded its reach into two key Asian markets for RF components. Both websites are translated into local language and offer local eCommerce options, previously not available from the company's U.S. website.

Pasternack Enterprises Inc.
www.pasternack.com

Ceramic Packaging Solutions

Remtec's new website provides a graphic overview of company capabilities and products starting from its core PCTF® technology products such as leadless ceramic SMT chip carriers, substrates and packages (hermetic and non-hermetic), laser and photodiode submounts and LED submounts. It also describes other Remtec added-value ceramic technologies: low cost AgENIG® substrates, high density thick films and direct bond copper. These categories can be quickly accessed and provide engineers with examples, photos, drawings and complete technical data in a wide range of commercial, industrial and military industries.

Remtec Inc.
www.remtec.com

Ethernet POWERLINK

VENDORVIEW

SPINNER GmbH offers its customers the latest developments in the field of rotating, contactless signal and data transmission by means of capacitive rotary transmitters. Compared to solutions with slip rings, these rotary transmitters are independent of the rotational speed and are maintenance-free. Possible applications can be found in industrial plant engineering, stage engineering, in wind power plants right through to non-destructive material testing systems. SPINNER has been a member of the Ethernet POWERLINK Standardisation Group (EPSG) since July 1, 2015.

SPINNER GmbH
www.spinner-group.com/cdt

New Products

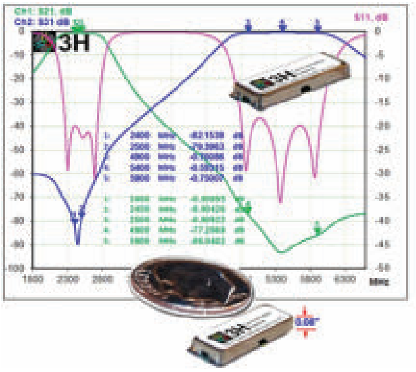
FOR MORE NEW PRODUCTS, VISIT WWW.MWJOURNAL.COM/BUYERSGUIDE

FEATURING VENDORVIEW STOREFRONTS

Components

NANO Series Wi-Fi Diplexer

VENDORVIEW



3H's miniature Wi-Fi diplexer offers high performance in the company's NANO package. The diplexer offers low passband insertion loss, and rejection levels of > 70 dB with a max. height of 0.08". The diplexers are available in tape and reel packaging. Other costumed frequency bands are available. For more information, contact: sales@3hcomm.com or call (949) 529-1583.

3H Communication Systems Inc.

www.3Hcommunicationsystems.com

Resistive Power Dividers

Model series 151-215-XXX is a family of resistive power dividers in 2, 4, 6 and 8-way configurations. These 50 Ohm, 1 W average power devices have an operating frequency range of DC to 6 GHz. Insertion loss above theoretical loss is + 1 dB nominal for 2 and 4-way configurations. Insertion loss above theoretical loss for 6 and 8-way configurations is + 1 dB nominal, DC to 5 GHz and + 1.6 dB nominal, 5 to 6 GHz. Maximum VSWR is 1.50:1 and the RF connectors are SMA female.

BroadWave Technologies Inc.

www.broadwavetechnologies.com

Space Qualified Isolator

VENDORVIEW

DiTom Microwave has released a new X-Band (7.9 to 8.4 GHz) space qualified isolator. The DS1007 is manufactured to meet or exceed environmental space-level reliability including thermal shock, sine and random vibration, temperature cycling, and thermal vacuum survivability over a specified qualification and acceptance test plan. DiTom's current space level manufacturing process allows for delivery in as quickly as four weeks depending on the test requirements. For more information, contact: (559) 225-7042 or space@ditom.com.

DiTom Microwave

www.ditom.com

High Efficiency Isolation Transformer

A new lineup of high efficiency isolation transformers from Foster Transformer provide a higher degree of isolation (as measured by leakage current to ground), improved efficiency, and reduced size and weight, which yield lower operating costs. The result of two years of development to optimize performance while minimizing size, these transformers are up to 25 percent lighter than previous generations while offering full load operating efficiencies of 97 to 99 percent. These high efficiency, isolation transformers are ideal for a wide range of commercial and industrial applications.

Foster Transformer

www.foster-transformer.com

Attenuator Systems

JFW Industries introduced its newest line of ethernet-controlled RF attenuation systems. This latest series of programmable attenuator assemblies is available in varying frequencies (as low as 30 MHz or up to 6 GHz), in 95 dB or 127 dB of dynamic range (in 1 dB steps), and with SMA or N connectors.

JFW Industries

www.jfwindustries.com

Multi Band/ Multi Market Power Dividers

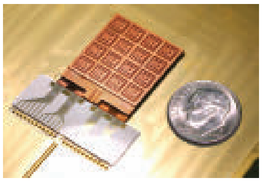
VENDORVIEW

MECA announced its latest addition to an extensive line of power dividers with (80X-X-3.250WWP); broadband models covering UHF through ISM bands. Available in 2, 4, 8 and 16-way, 30 W Wilkinson power dividers, optimized for excellent performance from 500 MHz to 6 GHz. Also available in a variety of connector styles such as Type N or SMA. IP67 rated and suited for indoor and outdoor applications. Made in the U.S. and 36-month manufacturing warranty.

MECA Electronics Inc.

www.e-MECA.com

Phase Shifter



Nuvotronics has demonstrated a high efficiency gallium nitride (GaN) HEMT digital phase shifter; greatly exceeding previously reported loss figure of Merit results while significantly increasing solid-state MMIC phase shifter power handling. This effort was funded under Navy SBIR N141-034 (Phase I). This new capability will have far reaching benefits in radar and communication systems such as phased arrays that perform electronic beam forming, steering and scanning using phase shifters. Nuvotronics' phase shifter technology uses a production-qualified GaN process.

Nuvotronics

www.nuvotronics.com

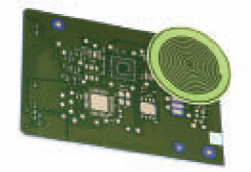
30 to 520 MHz Bandpass Filters

ERF-5W™ minimizes size, weight, power consumption and cost while covering the entire military tactical radio band of 30 to 520 MHz and maintaining high in-band RF power handling (5 W). ERF-5W is commonly used in UAV communication relay payload applications. SWaP-C reductions include a new size: 4.7"× 6.8" × 1" (119.4 × 172.7 × 25.4 mm) and new weight: 14.08 oz. (399 g). The ERF-5W combines 35 dB typical selectivity at Fc ± 20 percent, low insertion loss (2.5 dB) and 25 µs typical tune time in a ruggedized device.

POLE/ZERO

www.polezero.com

Metallized Ceramic Sensors



Remtec Inc. has expanded its process capabilities and developed new techniques to manufacture high performance metalized ceramic sensors in a variety of diverse applications. These include motion/velocity and acceleration systems, electrical measurement (capacitance and resistance), medical monitoring, diagnostic and detection, optical such as light sources, infrared detectors and fiber optics, liquid and gas flow, biosensors, temperature and thermal conductivity as well as wireless sensors.

Remtec Inc.

www.remtec.com

New**Products**

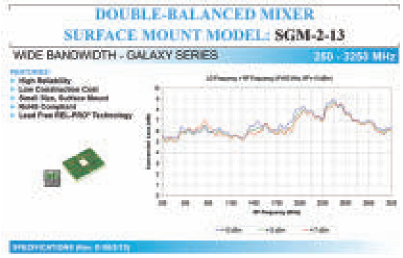
High Power Directional Couplers

RLC Electronics' high power directional couplers offer accurate coupling, low insertion loss and high directivity in a compact package. RLC offers high power couplers up to 40 GHz, with power requirements above 500 W CW, 10k W peak. The standard units are optimized for 2 octave bandwidths and are available with a choice of coupling values as well as connector types. These units are ideal for sampling forward and reflected power with a negligible effect on the transmission line and with low intermodulation products, as well as use in amplifier systems. Custom options include choice of connector type (N, SC, 7/16), modified frequency range, coupling value and additional functionality such as a sniffer port.

RLC Electronics Inc.
www.rlcelectronics.com

Double Balanced Mixer

The SGM-2-13 mixer is a wideband, surface-mount mixer designed to cover 250 MHz to 3.25 GHz. This makes it ideal for radar and fixed microwave radio and instrumentation applications. Further full band characteristics are typical conversion loss of 6.5 dB with local oscillator power of +13 dBm, typical LO to RF isolation of 25 dB, and a typical input third order



intercept point of +14 dBm. The overall dimensions of the mixer is 0.53" × 0.405" × 0.098" (L × W × H).

Synergy Microwave Corp.
www.synergymwave.com

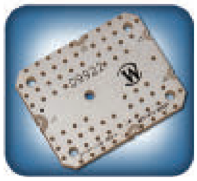
Full Band WR42 Waveguide Circulator

Model F3800-2225-38 is a full band WR42 waveguide circulator covering 18 to 26.5 GHz with 0.5 dB maximum insertion loss, 19 dB minimum reverse isolation, 1.25:1 of VSWR at input and output, and can handle 25 W of CW power. The RF ports are designed to match to UG-595/U waveguide flanges.

Wenteq Microwave Corp.
www.wenteq.com

Two-Way Combiner/Divider

The Model D9922, rated at 200 W CW, is a surface-mount 0° combiner/divider that provides low loss across the entire 2 to 6 GHz bandwidth. Ideal for amplifier houses concentrating on modules only, the D9922 is robust and measures only 1.4" × 1.1" × 0.14". Buy the engine without having to buy the entire car.



Werlatone
www.werlatone.com

Cables & Connectors

Microwave Adapters

Coaxsol (short for Coaxial Solutions) unveiled its highly anticipated and unprecedented release of over 177,000+ RF components. Products include nonexistent adapters and connectors used by the military, the aerospace and commercial markets such as wireless communications, medical, and test & measurement. Coaxsol's release represents a major milestone in the industry, having developed the "Open Cable Port Concept," a patent pending technology that enables the creation and delivery of on-demand custom components.

Coaxsol
www.coaxsol.com

High Performance Cable Assemblies

D-COAX Inc. has announced that all purchased cable assemblies include free electrical data. All D-COAX cable assemblies are 100% tested using VNA and includes s2p, tab and bmp files. High performance flexible coaxial cable assemblies are available through 65 GHz in singles and cable pairs. The standard assemblies deliver excellent return loss and low insertion loss. D-COAX has also added a "live chat" feature to help with questions in real time.

D-COAX Inc.
www.d-coax.com

Precision NMD-series Adaptors

Response Microwave Inc. announced the availability of its new series of durable between-series NMD adaptors to facilitate test applications. The new RMAD.BS.NMDxx series offers interface combinations in N18, 3.5, 2.92, 2.4 and 1.85 mm and covers the DC to 65 MHz band. These adaptors offer typical electrical performance of 0.20 dB insertion loss and 1.15:1 VSWR. Units are operational over the 0 to +85°C range and bodies are SUS303F stainless with gold plated BeCu center contacts.

Response Microwave Inc.
www.responsemicrowave.com

Crimp Tools for LMR-500 and LMR-600

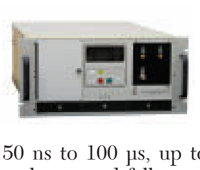
Two new fixed die crimp tools for LMR-500 & LMR-600 are now available from Times Microwave Systems. The CT-500 and the CT-600 for the LMR-500 and LMR-600 crimp connectors respectively have opposing dies that help produce an optimal crimp. The new tools also feature a safety release mechanism and have an adjustable cam dial similar to the company's existing fixed die crimp tools. The new tools are listed at $160/each.

Times Microwave Systems
www.timesmicro.com

Amplifiers

Model 187Ka TWT Amplifier

The Model 187Ka TWT amplifier has been specifically designed to operate pulsed traveling



wave tubes up to 200 W peak power at frequencies in the 34 to 36 GHz range. Grid pulse performance provides flat topped RF pulses from 50 ns to 100 µs, up to 50 percent duty cycle, with rise and fall times of less than 15 ns, and PRF up to 100 kHz. Computer control interfaces available are IEEE-488, RS-232/422 and Ethernet.

Applied Systems Engineering Inc.
www.applsys.com

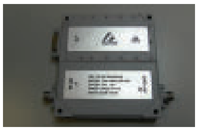
Portable Test Amplifier

VENDORVIEW

Built within a cast aluminum housing, measuring 129 × 84 × 67 mm, the 1 to 18 GHz portable test amplifier delivers 35 dB gain and +20 dBm P1 output power and comes complete with a manual on-off locking toggle switch for quick application and removal of the amplified signal. A green LED indicates an active unit. The 12 V, 525 mA DC input is applied via a sturdy XLR socket with a choice of SMA, Type N or TNC RF connectors in stainless steel with IP rating of IP66/67.

AtlanTecRF
www.atlantecrf.com

Solid-State Power Amplifier



Delta Microwave introduced its SSPA-DM-HPKU-50-101 developed for Ku Satcom/datalink applications. Specs include 14.4 to 15.5 GHz, 45 dB min., 50 W min., 60 W typical, 24 V DC, 9 A nominal, 25 percent typical and 2.5" × 2.75" × 0.45".

Delta Microwave
www.deltamicrowave.com

RF and Microwave Power Amplifiers

Fairview Microwave has released a complete portfolio of coaxial high reliability power amplifiers with broadband frequencies ranging from 0.5 MHz to 20 GHz that can operate over extreme temperatures across -55° to +85°C. These high-rel amplifiers are commonly used in demanding environments for applications involved with electronic warfare, instrumentation, military communications, radar, point-to-point radio, telecom, test & measurement, medical and SATCOM industries.

Fairview Microwave Inc.
www.fairviewmicrowave.com

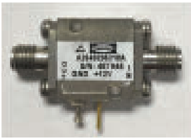
LDMOS Transistor

Freescale's MRF8VP13350N 50 V RF power LDMOS transistor is designed to deliver high RF output power in industrial, scientific and

medical (ISM) applications. These applications range from industrial heating and material welding at 915 MHz to particle accelerators at 1300 MHz. In narrowband operation at 915 MHz, the new RF power transistor can deliver 350 W CW (continuous wave) with 20.7 dB of gain and 67.5 percent efficiency.

Freescale
www.freescale.com

mmWave Amplifier



Herotek offers a wideband millimeter wave amplifier. Model A2640205010A operates from 26 to 40 GHz and matched for low VSWR. It has gain of 20 dB with max. gain variation of ±2.5 dB, noise figure of 5 dB, P1dB output of +10 dBm, and current draw of 180 mA at +12 V bias. This amplifier comes in a hermetically sealed package with removable connectors for drop in assembly and designed for both military and commercial applications.

Herotek Inc.
www.herotek.com

GaN Power Amplifier

Microsemi announced the AML218P4013, a GaN power amplifier product supplied in a compact hermetic 3.5" × 1.9" × 0.45" connectorized module housing. Ideal for electronic warfare, radar and test and measurement applications, the AML218P4013 power amplifier provides frequency coverage from 2 to 18 GHz, and delivers 38 dB gain, and 20 W of saturated output power at 16 percent PAE. The power amplifier operates from a +32 V DC single bias supply and is specified for operation over the -40° to +85°C military temperature range.

Microsemi
www.microsemi.com

NewProducts

Portable Amplifier

VENDORVIEW

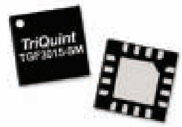
PMI model no. PTB-60-120-5R0-10-115-VAC-SFF is a portable amplifier that operates over the 1 to 20 GHz frequency range. This model provides 60 dB of typical gain with an OP1dB of +10 dB minimum. This amplifier features an on/off switch that is located on the front panel and operates on 120 VAC.

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

GaN on SiC HEMT

VENDORVIEW

Richardson RFPD Inc. announced the availability and full design support capabilities for a new discrete GaN on SiC HEMT from TriQuint/Qorvo. The 10 W (P3dB), 50 Ω input-matched TGF3015-SM operates from 0.03 to 3 GHz. The integrated input-matching network enables wideband gain and power performance, while the output can be matched on board to optimize power and efficiency for any region within the band. The device is housed in an industry-standard 3 × 3 mm package.



Richardson RFPD Inc.
www.richardsonrfpd.com

E-Band High Power Amplifier

VENDORVIEW

Model SBP-8138632520-1212-E1 is an E-Band high power amplifier with a small signal gain of 25 dB and a P1dB of +20 dBm minimum in the frequency range of 81 to 86 GHz. The DC power requirement for the amplifier is +6 to +12 VDC/1,000 mA. The input and output port are inline configuration as shown in the photo with both WR-12 waveguides and UG387/U flanges. SAGE Millimeter also offers many other low noise, ultra-broadband, power amplifiers in the frequency range of 1 to 110 GHz.

SAGE Millimeter Inc.
www.sagemillimeter.com

Systems

Solid-State Ku-Band SATCOM Transceiver

Advantech Wireless announced that its solid-state Ku-Band transceiver system has successfully undergone the Indian Defence Environment Standard (JSS 5555). This is the first ground based solid-state amplifier system that passed this standard in India. The equipment has also undergone successfully the tests as per MIL-STD- 461E requirement matrix specified for Indian Ground Airforce. The Advantech Wireless' range of Ku-Band transceivers provides the ultimate in performance and user friendly operation at a very competitive price.

Advantech Wireless
www.advantechwireless.com

Sources

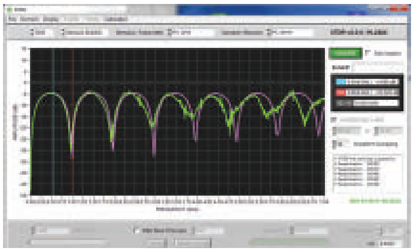
RF/Microwave Signal Generator

Berkeley Nucleonics released a high performance, robust and extremely cost effective high power RF/microwave signal generator. The model 845-H, defines a new class of microwave source instrumentation capable of producing in excess of 23 dBm from 100 KHz to 20 GHz, with low phase noise, fast switching speeds, extensive modulation capabilities in a portable lightweight benchtop package. With a compact, sealed enclosure, and a rechargeable internal battery option, this instrument offers the widest array of features to meet almost any application requirement in the lab, ATE or field.

Berkeley Nucleonics Corp.
www.BerkeleyNucleonics.com

Software

XTDR Version 2.0



HYPERLABS has added S-parameter capabilities (S11, S21) to version 2.0 of its XTDR™ software. These features complement the existing time domain features (TDR, TDT, NEXT and FEXT) already found in the HL2200 and HL5200 series signal path analyzers. The latest version of XTDR™ is available as a free download from the HYPERLABS website.

HYPERLABS Inc.
www.hyperlabsinc.com

Test Equipment

Signal Quality Analyzer Modules

VENDORVIEW

The MP1861A MUX and MP1862A DEMUX modules for the MP1800A signal quality analyzer will expand the functions of the MP1800A 32G Bit Error Rate Tester (BERT) to support 56 G and 64 G bit error rates (BER) measurements required for evaluating high speed serial transmission devices. When used in conjunction with the MP1800A, the two new modules support a gen-

NewProducts

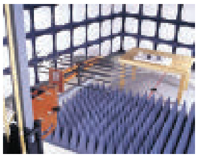
eration of NRZ Data and BER measurements up to 64.2 Gbit/s.

Anritsu Corp.
www.anritsu.com

Electromagnetic Safety Products

VENDORVIEW

AR RF/Microwave launched a line of safety products including handheld safety meters, a wide range of safety sensor heads and safety software. These products are designed to measure exposure levels of a variety of products and systems such as industrial ovens, RF medical devices, power plants, ground transport systems, wireless telecommunications and base stations.



AR RF/Microwave Instrumentation
www.arworld.us

Integrated Frequency Counter and Power Meter

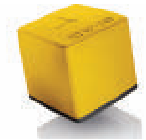
VENDORVIEW

Mini-Circuits' FCPM-6000RC integrated frequency counter and power meter is a pocket-sized (5.00" × 2.66" × 1.36") precision test device controlled via USB or Ethernet (HTTP and Telnet protocols) or operated as stand-alone test instrument. It simplifies test setups by enabling synchronized frequency and power measurements from a single device. The unit features an LCD display allowing convenient readings directly off the measurement head, while the company's user-friendly GUI software enables easy remote test management via USB or ethernet.

Mini-Circuits
www.minicircuits.com

FFT Analyzer

The EHP-50F is an FFT analyzer for assessing low frequency electric and magnetic fields considering aspects of human safety. It covers the entire range from 1 Hz to 400 kHz that is relevant for sensory effects. It evaluates complex signal shapes in the time domain using the weighted peak method, which is specified in the latest standards such as the EMF Directive 2013/35/EU. It uses built-in three-axis probes to detect electric and magnetic fields isotropically (non-directionally), is battery operated and can be connected to the Narda NBM-550 HF measuring set.



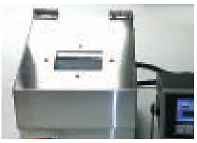
Narda Safety Test Solutions GmbH
www.narda-sts.com

High Speed 5 GS/s LXI Digitizers

For applications where fast electronic signals in the GHz range need to be remotely acquired and analyzed, Spectrum has extended its popular digitizer NETBOX series of LXI based instruments and released eight new models. Available with two, four or eight fully synchronous channels the new units feature sampling rates up to 5 GS/s, bandwidth in excess of 1.5 GHz and on-board acquisition memory up to 8 G samples. This unique combination makes the digitizers ideal for capturing long complex high frequency signals and for characterizing fast timing events that go down to the nano- and sub-nanosecond ranges.

Spectrum Systementwicklung Microelectronic GmbH
www.spectrum-instrumentation.com

Hybrid Temperature Chamber/Platform



TotalTemp Technologies offers a better way to do thermal testing. TotalTemp offers the first true hybrid temperature chamber/platform. The floor of the chamber is a temperature controlled hot/cold plate that operates independently or in conjunction with the chamber. Benefits include faster throughput, improved gradient control and verification capabilities, benchtop accessibility with left and right feedthrough apertures and wide temperature range.

TotalTemp Technologies
www.totaltemptech.com

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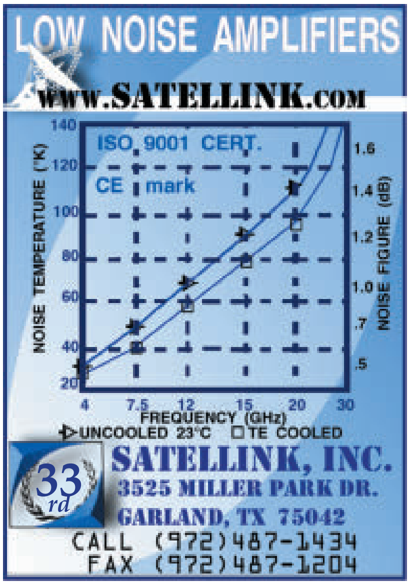
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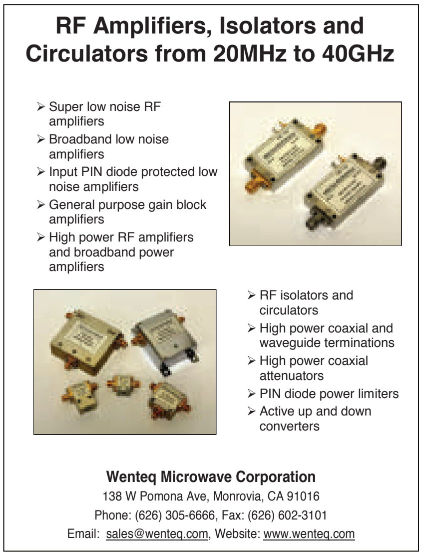
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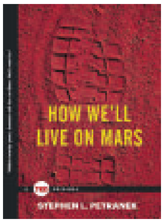
How We'll Live On Mars

Stephen Petranek



In 1952, Werner von Braun – the German rocket pioneer who was transplanted to the U.S. following World War II to aid America's fledgling missile development program – published "Das Marsprojekt." It was one part vision, one part engineering blueprint for transporting humans to Mars. Yet it wasn't until 1969 that a human stepped onto another celestial body, the moon, and instead of going on to Mars, the U.S. retreated from manned planetary exploration.

In 2002, Elon Musk – serial entrepreneur, inventor and visionary – formed SpaceX to reduce the cost of rocket launches and space flight by a factor of 10. One of stated goals: enabling humans to land on Mars. He foresees a colony of 80,000 on the Red Planet by around 2040. Crazy?

In "How We'll Live On Mars," author Stephen Petranek describes how humanity will indeed colonize Mars, arguing that we already have most of the needed technology. Private companies like SpaceX and an abundance of high-tech capital are leading government investment and, perhaps more importantly, the human vision. In a fascinating narrative, Petranek discusses how thousands will be transported to Mars; how the early settlers will find water and survive the lack of oxygen, wide temperature range and extreme radiation; and how succeeding generations will ultimately terraform the planet.

Beyond discussing the engineering to establish a new habitable home, the book raises intriguing questions about civilization and human psychology. Petranek writes "the first humans who emigrate to Mars are our best hope for the survival of our species," arguing that human life on earth will ultimately perish. Should we leave the planet to ensure our survival? Is it ethical to colonize another planet and change its environment? Would you personally take the risk to make the 243 day voyage to Mars, knowing you would never return to see family and friends on Earth? What if one of your children wanted to go? How far into the book will it take you to realize this is no longer science fiction?

Stephen Petranek has written about science, nature, technology, politics and economics. He was editor-in-chief of Discover magazine and the editor of The Washington Post's magazine. He's also well known for his TED talk, "10 Ways the World Could End."

To order this book, contact:

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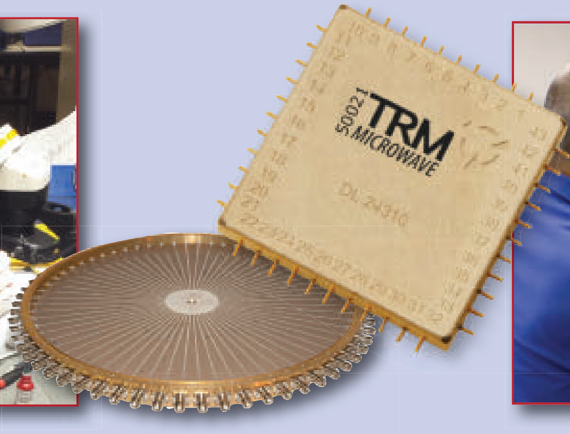
TRM Microwave



All companies have the goal of being customer focused. Maintaining that goal as the business grows is challenging; it's difficult to sustain relationships as the number of customers expands. TRM Microwave chose a different path to grow: keeping the customer list fairly small and doing more business with each. This approach requires both competency and transparency that, if successful, builds trust and leads to long-lasting relationships.

Started by three guys who were tired of working for a large company, TRM Microwave was formed as Technical Research & Manufacturing Inc. in 1970. Discouraged by the waste he saw within large organizations, Tony Tirollo, one of the founders, left his job to follow his entrepreneurial spirit. He and his co-founders leased an old Radio Shack at Grenier Field (now the Manchester-Boston regional airport) and began developing high-end components for cable television. The company name reflected the start-up's aspirational competencies.

During the ensuing years, the company became TRM Microwave, switched markets from CATV to defense and moved to a larger, 11,000 square-foot building. Tony became the sole owner, married Wendy, and she began learning the business. Wendy led the company's effort to achieve ISO certification, served as the director of human resources and became CEO in 2010 – allowing Tony to devote his time to the technical work he loves.

Tony's expertise is reflected by TRM's product portfolio of passive RF and microwave components, integrated assemblies and subsystems comprised of beam formers, power dividers, couplers and hybrids. These components can also be space-qualified, with the space market now contributing about 30 percent of the company's revenue. TRM's customers include all the U.S. defense primes, and their products fly on most U.S. fighters as well as the MUOS, TDRS and WGS satellites.

TRM Microwave was recently certified as a woman-owned small business, one of only a few in the RF/microwave industry. According to Wendy, "We polled our top customers regarding the impact this change would have on them, and the response was overwhelmingly positive. They all have supplier diversity requirements dictated to them, and they struggle to meet their goals."

Tony and Wendy's management philosophy is to hire the best, empower people and trust that each person will be accountable for meeting the customer's needs. They also believe in being open with their customers, even when the inevitable technical and schedule problems surface. Mark Schappler, TRM's chief operating officer, explains this philosophy by saying, "We're proud to explain the problem, how we fixed it and what we've done to prevent it in the future."

That philosophy combined with the performance of their products seems to be working. TRM Microwave is growing rapidly, expanding their team by 33 percent within the past year. Revenue grew 17 percent during the first six months of 2015. To support this growth, the company leased a 7,500 square-foot building across the street until the main building can be expanded.

Asked about the future, Wendy says, "TRM just celebrated its 45th anniversary, and my vision is to continue growing and expanding the business for the next 45 years and beyond. TRM Microwave will continue to design ground-breaking RF/microwave components, using technology and unique design approaches which continue to perplex our competition, and build our business by partnering with our valued customers and helping them to reach their goals."

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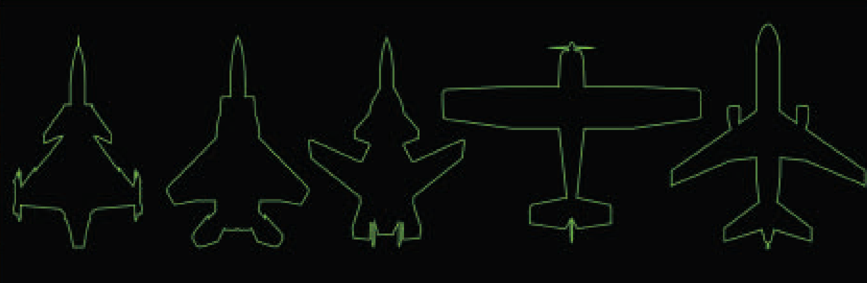

MILITARY MICROWAVES

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COVER FEATURE
INVITED PAPER

Recent Advances in Radar Technology

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4ward Sciences, San Diego, Calif.

Many think that radar is a mature technology where nothing has changed over the past decade. But many new developments have taken place and radar is still evolving today. As the technology advances, new applications appear in both military and consumer markets. Sometimes the need pulls the technology along, and sometimes new technology makes a new application possible.

Radar has been highly influenced by microwave technology and, likewise, the development of microwave technology has been significantly affected by the needs of radar. Exciting developments have occurred over the last few years in system architecture and algorithms, waveforms, signal processing, materials, circuits, electromagnetics and device design, some of which will be addressed in the following sections.

Radar requirements and design adjust to meet the mission needs and the constraints of the operating platform. New technology that boosts performance to more effectively meet customer needs is phased in as it becomes practical, meeting an acceptable technology readiness level.

▲ *Fig. 1 Raytheon AN/APG-79 AESA (courtesy of the U.S. Navy).*

AIRBORNE SYSTEMS

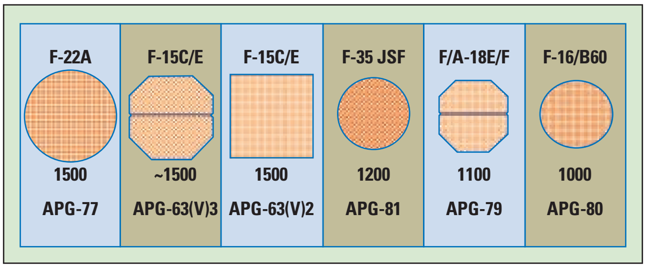
Airborne systems typically seek the best performance possible in a constrained size, weight and power (SWAP) envelope operating in a severe environment, so they tend to use the most advanced technology. A recent revision of Stimson's "Introduction to Airborne Radar"[1] provides a valuable overview.

Active electronically scanned arrays (AESA) are revolutionizing the performance of modern radar systems, enabling an unprecedented degree of operational flexibility. AESA technology is particularly advantageous in fighter radars due to the overall superiority in terms of performance, reliability and life cycle cost. With the development of device and packaging technology such as GaN MMICs, conformal radar, digital array radar, MIMO architecture and integrated RF systems are anticipated trendsetters for future advancement.

Fighter attack radars on newer aircraft are all AESA multifunction systems, typically at X-Band (see ***Figure 1***). These radars are being retrofitted onto older airframes, such as the F-15E, to keep them competitive. Radars on stealth aircraft such as the AN/APG-81 on the F-35 and the F-22's AN/APG-77 must be designed so that they do not compromise the host platform radar cross section (RCS). ***Figure 2*** shows the array sizes for some typical platforms.

Russia's military radar industry has advanced considerably since the end of the Cold War, largely resulting from access to Western technologies in the global market. This has seen significant advances in basic technology, especially in such key areas such as radar signal processing, radar data processing, embedded software, GaAs semiconductors for low noise receivers and HEMT transistors used in AESAs. This sustained improvement in basic technology has been reflected in ongoing growth in the capabilities of the various radars deployed in Russian Air Force and export variants of the Sukhoi Flanker fighter.

Airborne early warning (AEW) aircraft benefit from a wide horizon at high altitude but must



▲ *Fig. 2 Array sizes and module count for various aircraft platforms (source: Defense Science Board, September 2001).*

have sophisticated signal processing to cope with clutter and a vast surveillance volume. They use a mix of hybrid mechanical/AESA scanning technologies. Newest are the UHF AN/APY-9 on the E-2D and the all AESA Multi-Role Electronic Scanned Array (MESA) E-7A Wedgetail. The E-2C/D Hawkeye and E-3 AWACS AEW radar platforms are most plentiful.

Unmanned aircraft carry mission radars to collect tactical data. An extreme case is China's Divine Eagle, a high altitude UAV designed to detect stealth aircraft at long range, using special purpose radars.[2] It has seven radars, including UHF and X-Band airborne moving target indicator (AMTI) AESA radars on the front and two UHF and X-Band AMTI, synthetic aperture radar (SAR) and ground moving target indicator (GMTI) AESA radars on the twin booms. There are two other UHF/X-Band AMTI AESA radars on both sides of the engine nozzles and two more on the end of the booms.

A more typical mission sensor is the AN/ZPY-3 Multi-Function Active Sensor (MFAS) on the MQ-4C.[3] The AN/ZPY-3 MFAS is a 360 degree field-of-regard AESA radar designed for maritime surveillance. The X-Band two-dimensional sensor uses a combination of electronic scanning and a mechanical rotation, allowing the radar to spotlight a geographic area of interest for longer periods to increase detection capabilities of smaller targets, particularly in sea clutter. The AN/ZPY-3 MFAS sensor covers both open oceans and littoral regions from extremely long ranges, with mode agility to switch between various surveillance modes. These include:

- Maritime surface-search (MSS) for tracking maritime targets
- Inverse synthetic aperture radar (ISAR) for classifying ships
- Image-while-scan capability to interleave very short duration ISAR functions (ISAR snapshot and high range resolution) during MSS scans
- Two SAR modes for ground searches: spot for images of the ground and stationary targets and strip for images along a fixed line.

On the GA-ASI MQ-9 Predator B, the mission radar sensor is a Ku-Band AN/APY-8A Lynx SAR/GMTI radar, just redesigned with enhanced capabilities for ground and maritime surveillance.[4] Thales offers a smaller, lighter weight I-Master radar with lesser performance.

An additional radar capability required by UAVs is sense and avoid (SAA) radar to allow them to exercise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due regard for other aircraft in international waters and avoid collisions with other non-cooperative aircraft. NavAir has restarted the MQ-4C SAA effort. GA-ASI is providing an SAA radar for NAS testing by a team including the FAA, NASA and Honeywell. The Army is installing a ground-based SAA radar at its training bases in the U.S.

SPACE RADAR SYSTEMS

Radar is one of the primary sensors for observation of earth and space exploration. Spaceborne SAR is the only imaging sensor technology that can provide all-weather, day-and-night and high resolution images on a global scale. SAR data are used for a multitude of applications ranging from geosciences and climate change research, environmental monitoring, 2D and 3D mapping, change detection, 4D mapping (space and time) and security-related applications up to planetary exploration. With the launch of the SAR satellites TerraSAR-X and TanDEM-X, COSMO-SkyMed constellation, Radarsat-2 as well as Sentinel-1a, a new class of SAR satellites was introduced with image resolution in the meter regime. However, a paradigm shift is taking place in spaceborne SAR systems. By means of the development of new digital beam forming and waveform diversity technologies in combination with large reflector antennas, future SAR systems will outperform the imaging capacity of current systems by at least one order of magnitude. In addition, there are efforts to apply SAR payloads on nano and micro-satellites.[6,7,8]

Since the beginning of the space age, radars have been used for tracking space vehicles, satellites, space debris and ballistic missiles. In the last few years, these capabilities have advanced mainly using extremely large AESAs for major space powers, spreading to more countries such as Israel and India.

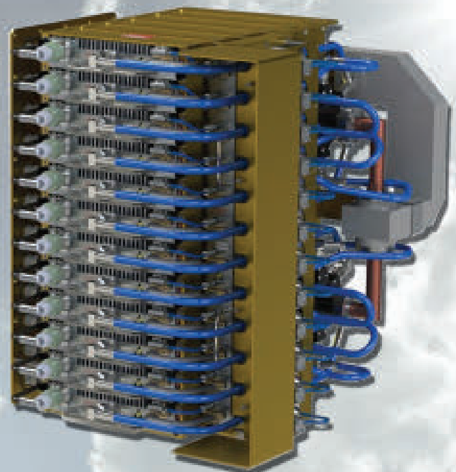
GROUND TO AIR SYSTEMS

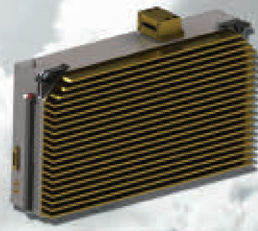
Starting with the British Chain Home radar in the first integrated air defense system to the post war era air traffic control (ATC) systems, radar and microwave technology have fed on each other. Recent advances in this type of radar have been either mechanically positioned or multi-faceted 2D AESAs. The next generation ATC is moving away from radar for aircraft tracking, using Mode S ADS-B and GPS based cooperative tracking. The Multifunction Phased Array Radar (MPAR) will be used primarily for weather detection and tracking and to supplement the cooperative systems.[9]

The FAA is also modernizing L-Band air route surveillance radars (ARSR). The design of a service life extension program that is being applied to the modernization of continental U.S. ARSR known as the long range radar (LRR) network is presented by Wang, et al.[10] The LRR network consists of 69 L-Band radars that are used for the joint purposes of air traffic control and surveillance. The upgrades include new hardware and innovative signal processing algorithms. The upgraded radar consists of a solid-state transmitter, a digital receiver and a signal data processor. With advanced signal processing algorithms, the upgraded radar system provides 200 mile coverage in natural interfer-

Solid State Power Amplifiers

S-Band





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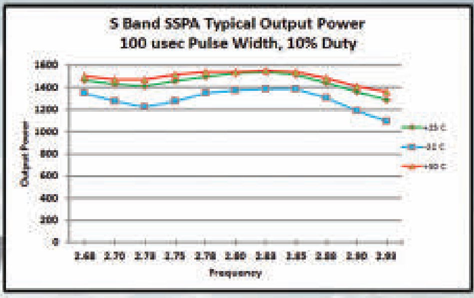

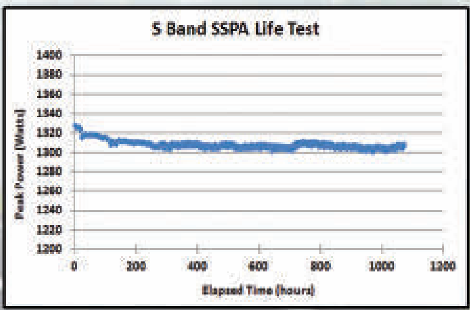

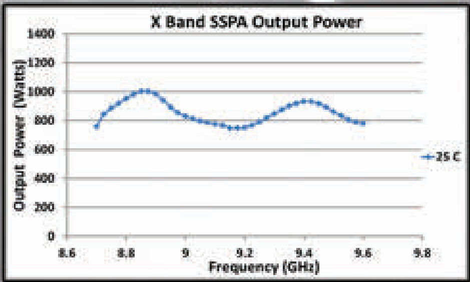

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ence environments while minimizing the false alarms. The radar has also been upgraded to enhance weather detection performance.

NAVAL AND MARITIME SYSTEMS

Ship-mounted radars for air and surface target detection and track were some of the earliest applications of radar. International Maritime Organization (IMO) requirements for S- and X-Band radars for maritime safety make this the largest user of small magnetron radars. Recent changes introduced by the IMO to the regulations covering S-Band radar for commercial shipping are deliberately designed to encourage the introduction of "new technology" radar sensors.[11,12]

For Naval air defense, radars have evolved to multi-faceted three, four and six face phased array variants of the Aegis AN/SPY-1, developed for China, Japan, Australia, the Netherlands and the U.S.[13] Israeli and Australian "Aegis" AESAs have an analog-to-digital converter (ADC) at every element using rapidly advancing GaN technology. The next generation of U.S. Navy radars is the DDG-1000 and CVN 78 Dual Band Radar (DBR) being developed by Raytheon. This radar suite is a single, integrated radar system combining the AN/SPY-3 Multi-Function Radar at X-Band and AN/SPY-4 Volume Search Radar at S-Band.

COMMERCIAL APPLICATIONS

Most people think of police with radar speed guns, if you ask them what radar is good for other than detecting aircraft. Google "microwaves" and you are likely to find out about magnetron-driven microwave ovens. Radar has proven to be an extraordinarily versatile technology with established uses now in vehicles, weather monitoring, aerial reconnaissance, security and even seeing through walls. The proliferation of low cost systems and higher frequency millimeter wave bands with large bandwidth and limited range has allowed non-traditional roles for radar, such as ground penetration, smart vehicles, industrial monitoring, search and rescue and security of airport or port areas.

The usage of millimeter wave radar systems has widened to include civil applications such as:

- Airborne radar for obstacle avoidance
- Altimetry and landing aids
- Automotive radar for collision avoidance
- Driving safety support and autonomous vehicle control
- Meteorological radars
- Remote sensing applications
- Medical imaging and diagnostic.

Recent advances use radar sensors to detect the vital signs of a human subject. A number of front-end architectures, detection methods, and system-level integration have been reported to improve detection accuracy and enhance system robustness. The advantages of noncontact vital sign detection draw attention in various applications such as health-care monitoring and rescue searching. Several portable systems and integrated circuits have been demonstrated recently. Integrating the radar chip to achieve compact size and lower power consumption, combined with signal

processing techniques to increase detection accuracy, will be the future focus for researchers.

ARCHITECTURE AND ALGORITHMS

Radar design has been evolving with better components and materials to improve system function, waveforms and computational ways of analyzing reflected signals at lower cost with reduced SWAP. As digital system performance has improved, more functionality has been moved from RF/analog to the digital domain.

In selecting algorithms for radar in the design stage, a quantitative comparison of system requirements is needed. Yee, et al., presents a systematic methodology that rates the effectiveness of each tracker configuration or signal processing algorithm in a radar system.[14] The approach uses a linear additive model for aggregating selected measures of performance (MOP), with the relative importance of each MOP determined through the application of the analytic hierarchy process (AHP). With the aggregate MOP score, track pairings based on an established baseline identifies differences in track data and obtains the measures of effectiveness (MOE) of the algorithm/configuration being evaluated. The results are used to help determine the "return on investment" in implementing signal processing or tracker parameter changes. The approach is generic and applicable to evaluating updates to the signal processing schema or tracker of any radar system.

Current radar signal processors (RSP) lack either performance or flexibility needed for advanced radar implementation. Custom soft-core processors exhibit potential in high performance signal processing applications, yet remain relatively unexplored in research literature. Broich and Grobler developed a new soft-core streaming processor architecture.[15] The data paths of this architecture are arranged in a circular pattern, with multiple operands simultaneously flowing between switching multiplexers and functional units each cycle. By explicitly specifying instruction-level parallelism and software pipelining, applications can fully exploit the available computational resources. The proposed architecture exceeds the clock cycle performance of a commercial high-end digital signal processor (DSP) by an average factor of 14, over a range of typical operating parameters in an RSP application.

While Moore's Law has continued to provide smaller semiconductor devices, the effective end of uniprocessor performance scaling has instigated mainstream computing to adopt parallel hardware and software. Based on their derivation from high performance programmable graphics architectures, modern graphics processing units (GPU) have emerged as the most successful parallel architecture. Today, a single GPU has a peak performance of over 650 GFlops and 175 GB/second of memory bandwidth. The combination of high compute density and energy efficiency (GFlops/W) has motivated the fastest supercomputers to employ GPUs. Keckler describes the fundamentals of contemporary GPU architectures and the high performance systems that are built around them.[16] Three substantial challenges

that face the design of future parallel computing systems are the power wall, the bandwidth wall and the programming wall. NVIDIA's Echelon research project is developing architectures and programming systems that aim to address these challenges and drive continued performance scaling of parallel computing from embedded systems to supercomputers.

A recent study shows that computation per kilowatt-hour has doubled every 1.57 years, akin to Moore's Law. While this trend is encouraging, its implications to high performance computing (HPC) are not yet clear. For instance, DARPA's target of a 20 MW exaflop system will require a 56.8-fold performance improvement with only a 2.4-fold increase in power consumption – which seems unachievable in light of the above trend. Subramaniam, et al., analyze current trends in energy efficiency from the Green500 and project expectations for the near future.[17] They first provide an analysis of energy efficiency trends in HPC systems from the Green500. Then they model and forecast the energy efficiency of future HPC systems. Next, a holistic metric to measure the distance from the exaflop goal is described. Finally, efforts to standardize power measurement methodologies in order to provide the community with reliable and accurate efficiency data are discussed.

For embedded signal processors in radar, particularly in airborne applications, as processing speed grows, power and thermal constraints are key. The DARPA Ubiquitous High Performance Computing (UHPC) program has a goal of 100 to 1000 times reduction in computer required power by 2018. The increase in on-chip transistor density exacerbates power/thermal issues in embedded systems, which necessitates novel hardware/software power/thermal management techniques to meet the ever increasing, high performance embedded computing demands in an energy-efficient manner. Munir, et al., outline typical requirements of embedded applications and discusses state-of-the-art hardware/software, high performance, energy-efficient embedded computing (HPEEC) techniques that help meet these requirements.[18] Modern multicore processors that leverage these HPEEC techniques to deliver high performance per watt, design challenges and future research directions for HPEEC system development are discussed.

To minimize cost, speed, schedule and control support needs, embedded radar processor designers frequently use COTS modular structures and busses as the framework for their design. AXIe shares many of the features of PXI (open modular structure, PCI Express fabric, similar software) while deploying a large board size, power and cooling matching that are found in high performance instruments. It adds one very unique aspect: the AXIe local bus. Desjardin and Viitas describe the local bus capabilities and real world implementations and applications that demonstrate breakthrough system performance utilizing the local bus.[19] These capabilities include real-time streaming and processing in excess of 40 GB/s per link, with up to 12 links per chassis. Real time high speed streaming enables a number of applications previously unrealized. Radar is an example, where data is streamed indefinitely from high speed digitizers into a data processing module or redundant array of independent disks (RAID). There is a broad range of data acquisition applications where long data streams need to be recorded or processed while searching for an intermittent event. The AXIe local bus enables this capability at previously unattainable speeds.

IMAGING

Originally, radar was used to detect the presence and location of reflecting targets. The image most radar operators were familiar with was the plan position indicator (PPI). In the analog displays, operators were able to do some level of target classification. As they have developed, however, radars have been able to image terrain and identify targets as well. While millimeter wave radars can directly generate images, most radar images are generated by forming a synthetic aperture, which requires some level of relative motion of the target or platform.

Inverse synthetic aperture radar (ISAR) uses the rotational motion of targets such as ships, aircraft and ground vehicles and analyzes the resultant differential Doppler shift of the target's components to create target images independent of range, depending on processing time and angle rate of rotation.[20] On a compact test range with known rotation, this allows for precise analysis of the RCS reflection centers of a target.[21] For an unknown target, these images are distorted by unknown target motion. Principal components formed from prominent scatterers' track history have been used to determine unknown target motion and thus provide motion compensation for ISAR images.[22]

Lazarov and Kostadinov deal with the implementation of ISAR method to extract an image of a sea target with high resolution.[23] The sea target is presented as an assembly of discrete point scatterers whose intensities are interpreted as an image function of the object observed. Analytical geometrical expressions to define a range distance from the radar to each point scatterer from the object space are derived. In order to realize high range resolution on the line of sight, an informative linear frequency modulated waveform is applied. An ISAR signal modeled as a superposition of signals reflected from the target's point scatterers is described and graphically illustrated. Image extraction from ISAR signal returns is performed by implementation of Fourier transformation on both range and cross-range coordinates. Image enhancement is accomplished by an iterative polynomial focusing procedure and entropy as a cost function.

During the last decade, SAR became an indispensable source of information in Earth observation. This has been possible mainly due to the current trend toward higher spatial resolution and novel imaging modes. A major driver for this development has been and still is the airborne SAR technology, which is usually ahead of the capabilities of spaceborne sensors by several years. Today's airborne sensors are capable of delivering high quality SAR data with decimeter resolution, which allows the development of novel approaches in data analysis and information extraction from SAR. Information extraction from high resolution airborne SAR imagery has achieved a mature level, turning SAR technology more and more into an operational tool. Such abilities, which are today mostly limited to airborne SAR, will likely become typical in the next generation of spaceborne SAR missions.

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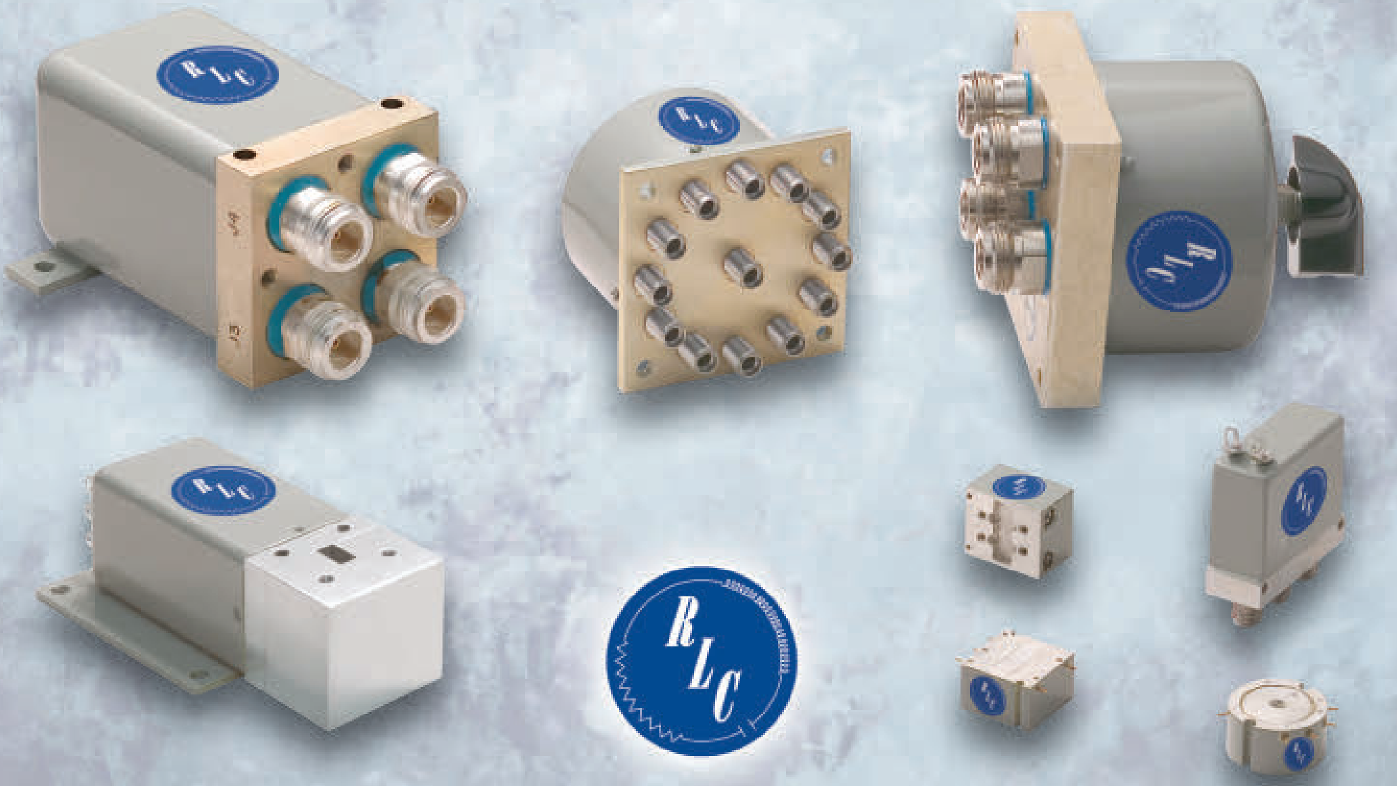

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SAR systems based on AESAs have reached a high degree of operation flexibility and performance. Nevertheless, the possibility to provide wide-swath images with high resolution is still a challenge requiring the application of new concepts and system architectures. Multiple channel-based SAR systems have become the perfect trend to follow in next-generation SAR programs, as they will permit overcoming the resolution/coverage tradeoff by enabling the application of digital beamforming (DBF) or multiple-input-multiple-output (MIMO) techniques. del Castillo, et al., present a multichannel reconfigurable SAR system prototype concept for next generation SAR operation and applications, enabling the use of DBF on receive or MIMO SAR.[24] System architecture and key subsystems are described, with emphasis in reconfigurable capabilities and internal calibration. Example performance results for practical application of presented architecture are also provided.

SAR images as initially generated are coherent. This results in speckle noise but also means that additional information can be extracted. Several detection statistics have been proposed for detecting fine ground disturbances between two SAR images, such as vehicle tracks. The standard method involves estimating a local correlation coefficient between images. Other methods have been proposed using various statistical hypothesis tests. One of these alternative methods is a generalized likelihood ratio test (GLRT), which compares a full correlation image model to a no correlation image model. Barber expanded the GLRT to polarimetric SAR data and derives the appropriate GLRT detection statistics.[25] He explored relaxing the equal variance/equal polarimetric covariance assumptions used in previous results and found improved performance on macroscopic scene changes.

SAR coherent change detection (CCD) images reveal subtle changes on the ground, such as the ground disturbance caused by vehicle tracks. The automatic detection of vehicle tracks is a challenging problem as CCD images have numerous problems. Phillips focused on detecting likely activity, with the assumption that an activity of interest has one or more tracks.[26] Even if the automatic track detector has many false alarms and missed detections, enough track segments are located to accurately detect activity. This work developed a mathematical framework that detects activity based on the spatial proximity of several individual track segments. Experimental results show a large improvement in the detection performance of images containing activity when the new method is employed.

One particular problem with the extreme sensitivity of CCD is the presence of false alarms (clutter) introduced by phenomena such as low SNR (especially radar shadows) and vegetation. Newey, et al., presented two methods to improve the sensitivity of the detector while reducing the amount of false alarms.[27] The first uses a generalized likelihood ratio test for change detection which incorporates noise explicitly in its models. The second combines two CCD images, generated from three SAR passes of the same area, to cancel out false alarm regions and show only changes from man-made activities of interest, such as vehicle tracks. They found that the algorithms are effective at reducing the amount of false alarms while increasing the sensitivity of the detector.

Fine details revealed by SAR CCD, such as footprints, require SAR imagery with both high resolution and precision. These large data requirements are at odds with the low bandwidths often available for SAR change detection systems, such as those that utilize small unmanned aerial vehicles (UAV). Cha, et al., investigated the interplay between SAR data compression and SAR CCD performance. As the data are compressed further, the ability to detect changes decreases. However, there is redundant information contained in SAR imagery that is not necessary for change detection, and removing it makes SAR compression possible. In this paper, they introduced a new model-based compression method that leverages the known distribution of SAR data for compact storage, while improving change detection performance. They showed experimentally that the CCD using the decompressed SAR pair not only yielded significant improvement in change detection over the CCD using the decompressed SAR after block adaptive quantization (BAQ), but also

over the CCD using the original SAR data. Experimental results showed the effectiveness and robustness of the proposed algorithm for SAR compression and change detection.

Speckle noise is one of the banes of SAR imagery, as it is inherent in coherent processing. Reducing it without losing resolution detail or requiring additional passes is a long standing problem with many attempts at solution. Automatic interpretation of SAR images is often difficult due to speckle noise. Appearing as a random granular pattern, speckles seriously degrade the image quality and affect the task of human interpretation and scene analysis. For this kind of speckle removal problem, one of the difficulties is to overcome the tradeoff between noise reduction and preserving significant image details. A new theory of SAR image restoration and enhancement with independent component analysis (ICA) was proposed by Chen.[29] He assumed that the speckle noise in SAR images comes from a different signal source, which accompanies but is independent (their statistical characteristics are not same) of the "true signal source" (image details). Thus the speckle removal problem can also be described as a "signal source separation" problem. Then, in order to enhance the "true signal source," classify the basis images and span them into two different signal subspaces, namely a "true signal subspace" and "speckle subspace." Finally, different nonlinear estimators are built in each signal subspace to recover the original image. In the experiments, the SAR images consist of nine channels of images. They compare their method with two other well known speckle reduction approaches, and the results show that with their method, the speckle noise is efficiently removed while, at the same time, important details (edges in particular) are retained without introducing artificial structures. They calculate the ratio of standard deviation to mean (SD/Mean) for each image and use it as a criterion for image quality, finding that the improvement with their method is more evident for images with "high level speckle noise."

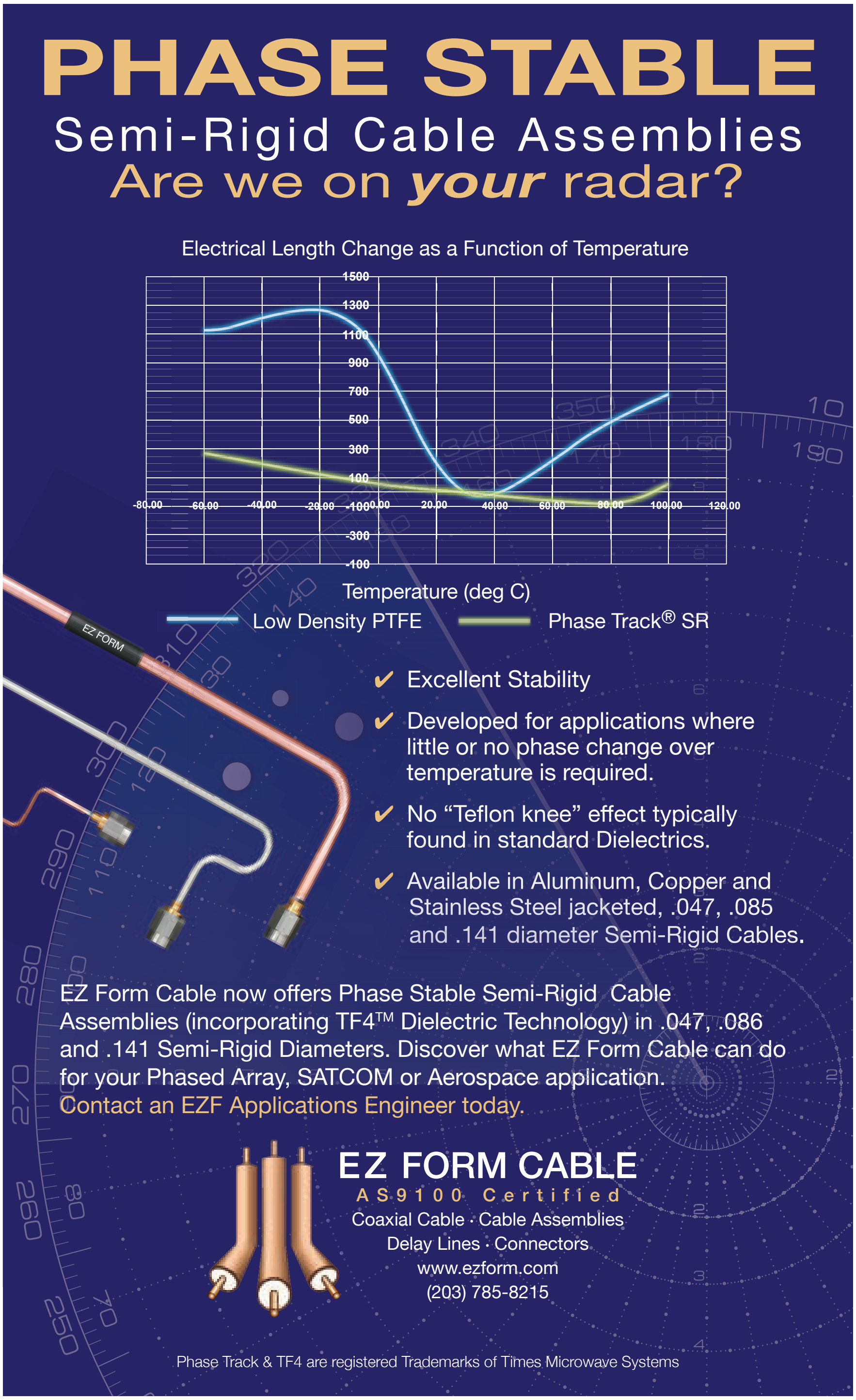
Despeckling of complex polarimetric SAR images is more difficult than denoising of general images due to the low signal-to-noise ratio and the complex signals. A novel stochastic polarimetric SAR despeckling technique based on quasi Monte Carlo sampling (QMCS) and region-based probabilistic similarity likelihood has been developed.[30] The despeckling of complex polarimetric SAR images is formulated as a Bayesian least squares optimization problem, where the posterior distribution is estimated by QMCS in a nonparametric manner. The QMCS approach allows the incorporation of the statistical description of local texture pattern similarity. Experiments on two benchmark quad-pol SAR images demonstrate that the proposed QMC texture likelihood sampling (QMCTLS) filter outperforms referenced methods in terms of both noise removal and detail preservation.

InSAR

TanDEM-X and TerraSAR-X platforms form together the first spaceborne single-pass polarimetric interferometer in space. This allows, for the first time, the acquisition of space-

borne polarimetric SAR interferometry (Pol-InSAR) data without the disturbing effect of temporal decorrelation. Kugler, et al., assess the potential of such data for forest applications.[31] For this, single- and dual-pol data acquired over a boreal, a temperate and a tropical site were investigated to characterize X-Band penetration and polarization diversity of the interferometric coherence measurements. Pol-InSAR forest height inversion schemes have been implemented for the single and dual-pol cases and cross validated against LIDAR reference measurements for all sites.

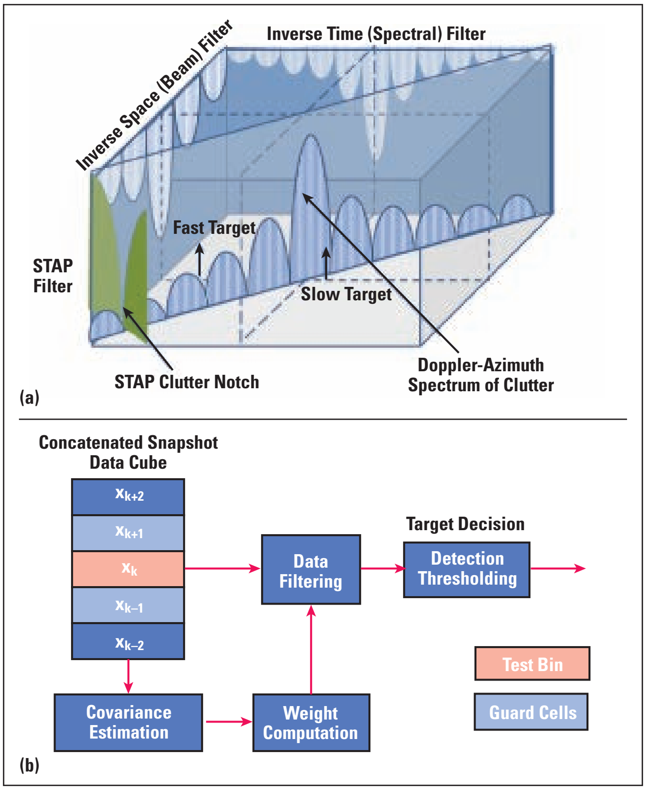
Danudirdjo and Hirose present a method for removing spikes in digital elevation models (DEM) caused by residues in interferometric synthetic aperture radar (InSAR) phase image.[33] They consider that the scattering mechanism is properly modeled by the small perturbation method for fractal surfaces and present a model that relates the phase and magnitude in InSAR image. This data model provides the regularization term of the method, without directly enforcing smooth phase or magnitude. Noise models are given by additive Gaussian for the phase and multiplicative non-unit-mean gamma for the magnitude. Experiments with simulated and real L-Band data show that the proposed method considerably improves DEM accuracy and simultaneously suppresses speckle and phase noise.



MOVING TARGET DETECTION/ CLUTTER REJECTION

If sufficient power, aperture and low receiver noise figure are implemented in a radar, required noise limited range against small targets can be achieved, but frequently the target return will be submerged in reflections from other environmental reflectors. By using the Doppler shift induced by target motion, moving target detection (MTD) radars can detect desired targets and reject clutter. This places requirements for high linearity and wide dynamic range on the RF components and controlled sidelobes on the antenna.

Space-time adaptive processing (STAP) uses the combined spatial and spectral characteristics of clutter to reduce false alarms by an order of magnitude. STAP is a family of algorithms frequently employed in surface moving target indication radar systems to enable detection of moving objects in the presence of fixed (i.e., nonmoving) clutter (see ***Figure 3***). Fertig developed two new closed-form expressions that quantify the loss associated with the STAP notch centered on clutter in terms of system parameters of interest.[33] Although there are many excellent reports, books and papers focused on STAP, a simple yet accurate approximation for the STAP notch has not previously appeared. It is also shown that a new, accurate approximation for the important STAP metric known as minimum detectable velocity may be derived from the STAP notch expression. Furthermore, Fertig derived accurate expressions that predict when "aperture-limited" STAP performance may be obtained. This work provides the first analytical, unifying connection between these STAP metrics. As they are implemented in compact closed-form expressions, the new results are attractive for



▲ *Fig. 3 GMTI STAP filter separates a slow target from ground clutter.[42] STAP two dimensional filtering (a) and computational flow (b).*

system design. The significant computational benefits associated with these new results can be very advantageous in trade studies or large simulations in which STAP performance estimates must be computed thousands of times. With accurate, analytical expressions, system engineers can now implement accurate predictions of STAP performance without the necessity of constructing patch-based analysis tools that estimate STAP performance by computing the notch associated with hundreds to thousands of clutter patches.

A new airborne cognitive radar mode was introduced that addresses the problem of high false alarm rates due to strong clutter discretes in the radar field of regard.[34] The new mode takes advantage of emerging cognitive and fully adaptive radar (CoFAR) architectures that support rapid adaptation of the radar space-time transmit waveform. The new mode exploits this flexibility to both rapidly characterize strong clutter discretes and minimize their impact on target detection performance, while minimizing impact to the radar timeline. The new mode leverages a MIMO probing approach that rapidly characterizes the clutter discretes in the scene and uses the received signals to form an appropriate space-time waveform response that minimizes their radar return and impact on radar performance during the processing of subsequent radar pulses. They provide details about the processing algorithms and present a performance assessment based on a simulation of an airborne GMTI radar system.

Moving targets appear defocused within SAR images and their detection is challenging, especially in the case of ground targets that are embedded in strong ground clutter. STAP methods show optimal results in the clutter and interference suppression when the signal environment is stationary. This improves detection performance and allows for the application of ISAR based techniques which are then used to obtain high resolution images of moving targets. However, in bistatic system geometry, clutter echo returns are not stationary but range dependent. This situation degrades significantly the STAP performance due to the fact that data are not independent. By modeling the dynamic behavior of the beam forming weight, the losses in performance may be recovered at the expense of doubling DoFs and then significantly increasing the computational cost. Gelli, et al., combines bistatic STAP and ISAR techniques to obtain a well focused image of non-cooperative moving targets with a lower computational cost with respect to the classical bistatic STAP technique.[35] They addressed two principal issues: first, a clutter model in the bistatic geometry is developed; second, a suboptimal implementation of the extended sample matrix inversion (ESMI) to clutter mitigation is proposed. Results of the proposed processing applied to simulated data are provided in order to show the effectiveness of the proposed technique.

Wang, et al., proposed a new STAP method based on the structured sparse recovery of radar clutter spectrum.[36] Besides the spatial-temporal sparsity, they introduce the structured property of the clutter spectrum in STAP based on the pattern of two dimensional clutter spectrum. An elliptical clustering model is given to describe the structured sparsity, in which a novel sparse recovery STAP method named SSR-STAP is developed. In this new method, the clutter structured property is modeled a priori based on a Markov random field. An improved focal underdetermined system solution (FOCUSS) algorithm, named Elliptical Clustering FOCUSS, is proposed, introducing a priori information of clutter spectrum structure into an iterative Bayesian estimation process of weight coefficients. Simulation results show that the performances of the SSR-STAP method are superior to the previous sparse recovery-based space-time adaptive p (SR-STAP) method both in clutter suppression and moving target detection.

PACKAGING AND ASSEMBLY

For any radar, packaging and assembly are the keys to a successful implementation. As radar applications proliferate, cost becomes critical. For millimeter wave automotive and UAV, in particular, cost and packaging are being addressed.

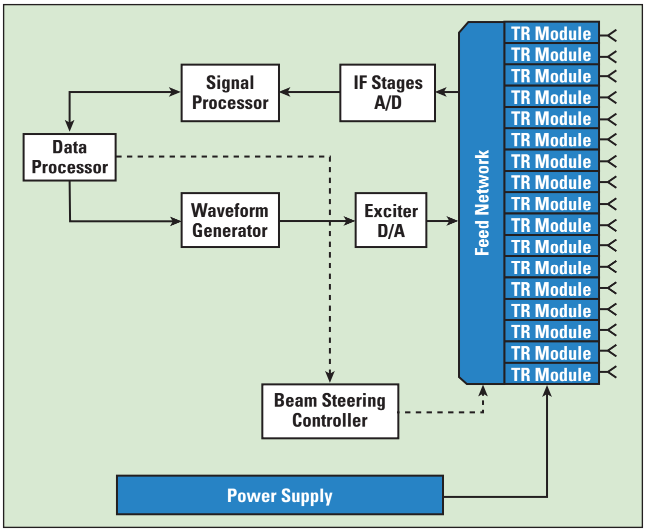
Single chip radars and multi-channel T/R modules are becoming feasible. For example, a SiGe transmit-receive phased-array chip for automotive radar applications at 76 to 84 GHz has been developed.[37] The chip is based on an all-RF beam forming approach and contains eight transmit channels, eight receive channels and a complete built-in-self-test system. Two high linearity quadrature mixers, with an input P_{1dB} of +2.5 dBm, allow simultaneous sum and difference patterns in the receive mode. The chip operates in either a narrowband frequency-modulated continuous-wave (FMCW) mode or a wideband mode with greater than 2 GHz bandwidth. A high linearity design results in an input P_{1dB} of -10 dBm (per channel), a system noise figure of 16 to 18 dB and a transmit power of 4 to 5 dBm (per channel). The chip uses a controlled collapse chip connec-

tion (C4) bumping process and is flip-chipped onto a low cost printed circuit board, achieving 50 dB isolation between the transmit and receive chains. This work represents state-of-the-art complexity for a high performance FMCW radar at millimeter wave frequencies, with simultaneous transmit and receive operation.

Typical ultra-wideband (UWB) FMCW ground penetrating radars (GPR) operate at low frequencies that require a wide sweep bandwidth, necessitating complex architectures and bulky broadband antennas. This poses unique challenges to system portability, especially for manual, wide-area outdoor measurements. Traille, et al., present the first design, fabrication and characterization of a complete conformal and miniaturized radar system to be rolled up in a "poster-like" container using additive printing technology.[38] As the lumped or distributed passives, the active devices and the Rx/Tx antennas may share the same flexible substrate, the proposed radar technology is considered to be monolithic. The presented proof-of-concept system performs the most fundamental operations of the FMCW radar, including signal generation and amplification and correlation of the LO and RF signals for the GPR frequencies. It outlines ultra low cost system integration, packaging and experimental verification of a flexible/conformal monolithic radar system with almost identical performance for different degrees of flexing.

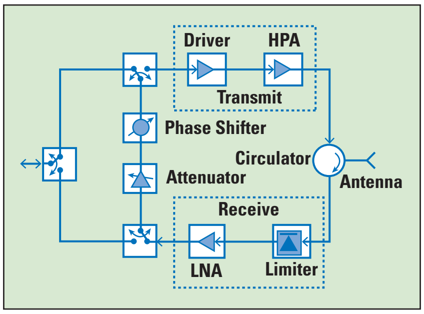
Active airborne antennas are assembled with hundreds or even thousands of transmit/receive modules (see ***Figure 4***). Rieger, et al., describe the evolution of the so-called standardized module solution based on LTCC package technology, with special regard to airborne applications and the correlated needs. They show the module's evolution through the last few years and give an outlook towards future developments for airborne applications.[39] This evolution especially contains significant optimization steps concerning area, weight and cost. By realization of a surface-mount T/R module suitable to a folded plank concept, a significant reduction of installation depth can be achieved. As the module weight is dominated by its package, technology evaluation and implementation of advantageous concepts and materials was performed. Cost reduction is always a key focus of T/R module evolution, as the modules still represent a big part of the antenna's production cost. Some steps have been realized, both on the technology and component level. The next generation of AESA antennas will result in a combination of different operating modes within the same antenna front-end, including radar, communication (data links) and jamming (electronic warfare). This leads to higher demand for MMICs (see ***Figure 5***). The RF section of today's T/R modules for AESA applications is typically based on GaAs technology. During the last 10 years, there was much progress in the development of disruptive semiconductor materials, especially GaN and SiGe BiCMOS, which have the potential to challenge or even replace GaAs technology.

Limiti, et al., summarize the activities performed towards the realization of a single-chip front-end (SCFE) operating in C-Band, integrating the high power,



▲ *Fig. 4 Typical AESA functional block diagram.*

low noise amplification and switching functions for space SAR applications.[40] The technologies adopted in this project are provided by United Monolithic Semiconductors (UMS) and Selex Electronic Systems (SLX). The GH25-10 0.25 µm gate length process was from UMS and the 0.5 µm gate length GaN process from SLX. At the completion of the design phase, the two SCFEs were designed in the two technologies, each in two slightly different versions, and demonstrated state-of-the-art performance. In transmit, both designs provided approximately 40 W output power, 36 dB large-signal gain and 38 percent/27 percent power-added efficiency, respectively, for the UMS and SLX versions. In receive, the modules demonstrated 2.5 dB noise figure. The die measured 6.9 × 5.4 mm^2 (UMS) and 7.28 × 5.40 mm^2 (SLX).



▲ *Fig. 5 Basic T/R module block diagram.*

CONCLUSION

We have discussed recent advances in radars from UHF up to millimeter wave and from industrial process monitoring to exploring the solar system. The major trend in high performance radar is the AESA and multiple imaging modes. While many areas of radar technology have matured in the last half century, reflected in reduced SWAP and cost, new technology and algorithms continue to enable new performance levels in existing applications and the emergence of new applications.■

Editor's Note: Due to the extensive number of references, they will only be available with the online version of this article at www.microwavejournal.com/radartech.

Spending Increases, Technology Differentiation Underpin Military RF Demand

Asif Anwar
Strategy Analytics

While defense budgets are uncertain, technology has a direct impact on force effectiveness which will lead to an emphasis on enhancing capabilities across radar, EW, communications and other military systems. As a result, more of the defense budget will go into electronics. While no single technology will be the panacea for all requirements, architectural changes in military electronics will require broadband performance, higher operating frequencies and digitization over the next decade.

Defense spending was essentially flat year-on-year from 2012 to 2013, with a sharp increase in 2014 triggered by the changing geopolitical threat environment (both state and non-state activity). Strategy Analytics predicts that global defense spending will increase 2 percent year-on-year in 2015 and will grow at a compound annual growth rate (CAGR) of almost 3 percent to reach $2.4 trillion in 2024. Excluding spending related to personnel, operations and administration, support, training and infrastructure, we expect the available market for procurement and support of platforms, systems and the associated spending on subsystems and enabling technologies will reach $767 million in 2024 (see ***Figure 1***).

The key driver for this increase will continue to be the emphasis on gaining differentiation through technology, irrespective of whether armed forces are dealing with symmetric, asymmetric or hybrid conflicts. This has been demonstrated throughout history, by military technologies that have enabled capabilities such as stand-off, force projection, stealth and intelligence. Gaining advantage through technology remains true today, although increased spending must also be cost effective in light of the tightening budgetary environment. Strategy Analytics forecasts spending on defense systems will approach $140 billion by 2023 (see ***Figure 2***), which translates into a substantial opportunity for component technologies sup-

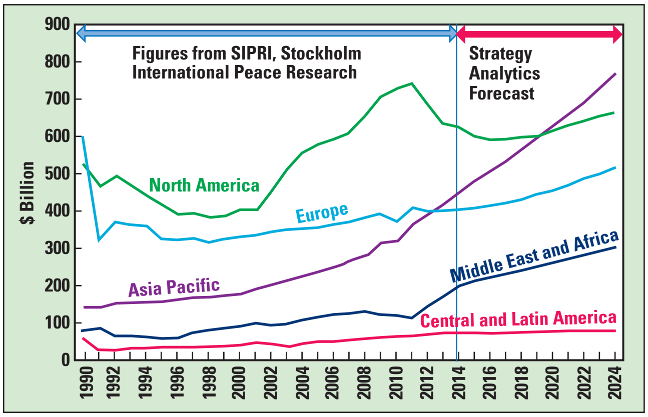


Fig. 1 *Global defense spending, historical and projected.*

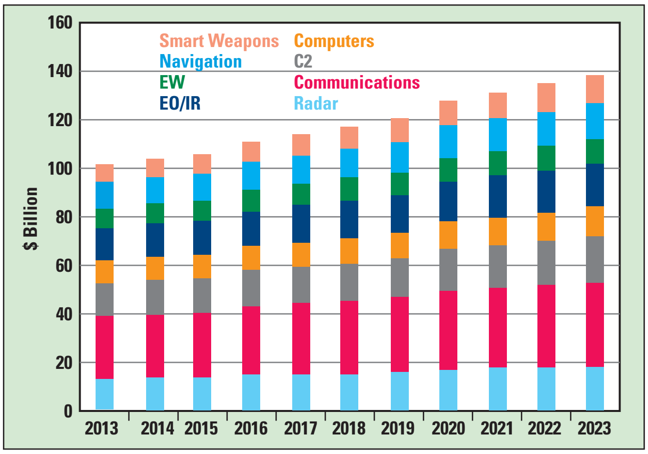


Fig. 2 *Forecast for global defense system spending by system type.*

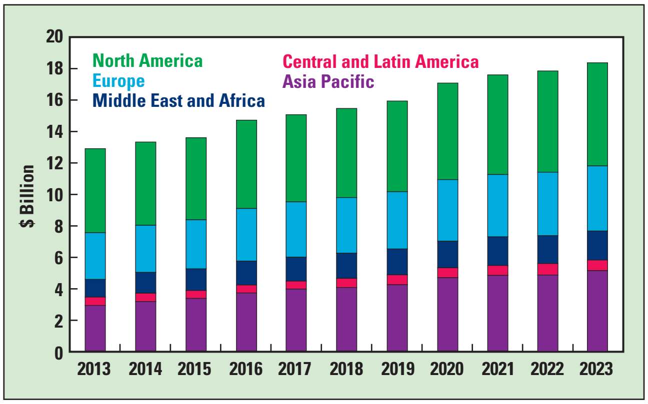


Fig. 3 *Military radar forecast by region.*

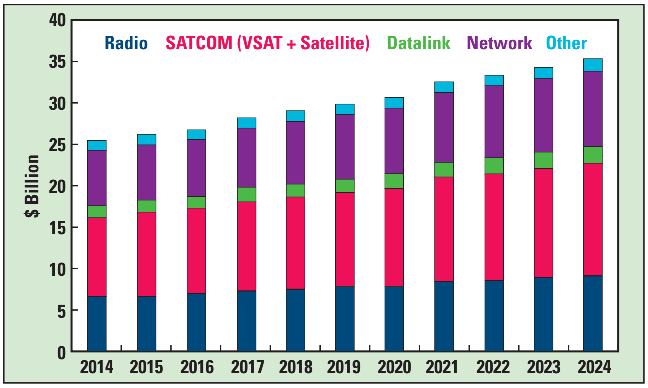


Fig. 4 *Military communications forecast by system.*

porting radar, communications, EW and other military applications.

Military radar spending will increase with the continued implementation of active electronically scanned array (AESA) technology, which is enabling systems that can support multifunctional operations. Using solid-state technologies such as GaAs and GaN, AESAs can be scaled across a range of domains and platforms.

Trends in military communications include higher operating frequencies, multi-band and multi-mode operation and IP, data-centric operations with the flexibility to create ad hoc networks in the field. Similar to developments in the commercial sector, these trends are driving the need for high power, linearity and efficiency.

Electronic warfare (EW) systems are also evolving to enable control of an increasingly complex spectrum environment. The argument for stealth in lieu of EW is no longer viewed as viable, which will renew investment in EW systems over the next decade. Systems will adopt AESA architectures and technologies that support wider band, higher power, greater sensitivity and selectivity and digital control.

RADAR

Strategy Analytics forecasts that the global military radar market will grow at a CAGR of 3.6 percent from 2013 until 2023, reaching over $18.5 billion in 2023 (see ***Figure 3***). This forecast encompasses system shipments for land, air, sea and space and reflects the following assumptions and estimates:

- North America will continue to be the largest regional market; however, the fastest growth will be in the Asia-Pacific region.
- Airborne radar will be the largest segment, both in dollars and shipments.
- Early warning, surveillance and fire control radars will account for around 76 percent of the systems.
- L-, S- and C-Band will represent the largest market, used for surveillance and early warning radar, followed by X-Band, used for fire control.
- The associated market for semiconductors and other components will grow from $1.2 billion to $2.1 billion.
- GaN will become an established technology, as it grows at a 26 percent CAGR and is used across all radar systems.

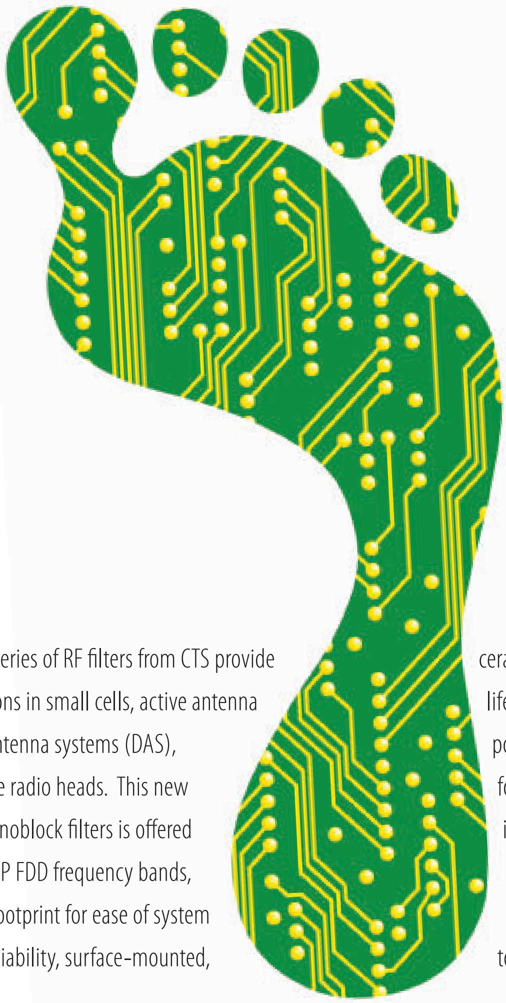
Total radar shipments are forecast to grow at a 4.1 percent CAGR through 2023, reaching 1393 systems. Fire control radar will continue to dominate the traditional mix, yet the fastest growth will be from emerging platforms such as unmanned systems as well as new radar system types.

COMMUNICATIONS

The forecast for the communications sector includes radios, communications satellites, VSAT terminals, datalinks, networks and other systems. Network-centric IP-based communication is primarily driving increased spending, which is forecast to be $35.3 billion in 2024 (see ***Figure 4***). This represents a CAGR of 3.4 percent. The forecast reflects the following assumptions and estimates:

- North America, historically the largest regional market, will be superseded by demand from the Asia-Pacific region beginning in 2016.

Universal Footprint RF Duplexers



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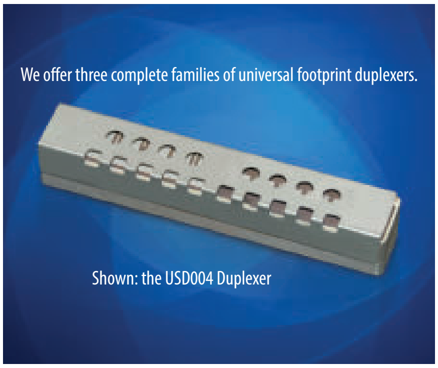
Filters with Industry-leading insertion loss and rejection.



	UMB/UMD Pair of Bandpass Filters For Metro Cell	USD DUPLEXER For Small Cell	UPD DUPLEXER For Pico Cell
Input Power Rating	20W Avg 200W Pk	6W Avg 60W Pk	1.5W Avg 15W Pk
Insertion Loss (5MHz AVG)	2.2dB	2.6dB	3.0dB
Rx Band Isolation*	80dB	72dB	63dB
Tx Band Isolation	74dB	66dB	57dB
Universal Footprint Size (mm)	62 x 44	63 x 18	44 x 18
Operating Temp Range	-40 to +85°C	-40 to +85°C	-40 to +85°C

* Note: "Difficult" bands may have 2dB lower worst case Rx band isolation.

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- Land-based communication will represent the largest market, both in dollars and total shipments.
- Spending in the military communications sector will be dominated by satellite communications systems (comprising the satellites as well as their ground-based terminals), with a steady launch schedule for military communications satellites over the forecast period.
- The increasing emphasis on IP-centric communications for data and voice will coincide with systems that operate across multiple modes and bands.
- System trends and requirements will require technologies that support broadband performance, higher frequencies and digitization.

These system trends will ensure continued spending on military radios. Strategy Analytics forecasts the market for radios will exceed $9 billion by 2024 (see ***Figure 5***). The forecast assumes:

- The Asia-Pacific region will drive spending on tactical radios for land-based communications, the largest region over the entire forecast period.
- Land-based radios will be the largest market, both in dollars and shipments.
- Radio shipments will grow at a CAGR of 3.5 percent through 2024 to reach 172,867 units.
- While the traditional HF, VHF and UHF frequencies will continue to be used, the emphasis will shift to systems that support multi-band and/or wideband operation – with these systems accounting for 47 percent of the military radio market in 2024.
- Handheld radios will drive volume in the land-based military market, which will grow to $6.5 billion.
- Radios for smaller platforms such as fast attack craft, offshore patrol vehicles, helicopter and light aircraft will drive the volume in the shipborne and airborne segments.
- The associated market for component technologies will grow from $710 million to almost $1.1 billion.
- As with radar systems, GaN will become an established technology, growing at a CAGR of 33 percent.

The continuing demand for satellite communications will see increased spending on military satellite terminals, approaching $6 billion in 2024 (see ***Figure 6***). In forecasting this growth, Strategy Analytics assumes:

- North America will have the largest demand at the beginning of the forecast period, however the Asia-Pacific region will lead from 2017.
- Demand from the other regions will also grow, with spending in the Middle East and Africa forecast to grow at a 4.3 percent CAGR.
- Land-based terminals will represent the largest market in dollars, accounting for 49 percent of the total market, and will also represent the bulk of shipment volume.
- Terminal shipments will reach over 8000 units, a CAGR of 3.8 percent through 2024, with portable and dismounted terminals driving the volume in the land sector and unmanned aircraft systems (UAS) in the airborne sector.

As well as the trend to higher frequencies (e.g., Ka-Band terminals), systems that can support multiple bands and/or wideband operation will affect component technology choice and demand.

ELECTRONIC WARFARE

The flip side of the unprecedented capabilities offered by next-generation radar and communications systems is the challenge to the EW community. The increasingly congested and complex spectrum environment will require that EW systems operate across wider bandwidths to protect critical assets. The strategy will shift back towards reestablishing airborne EW capabilities to counter anti-access, area-denial systems. The renewed focus on electronic attack (EA) capabilities will provide opportunities for conventional platforms dedicated to EW, such as Boeing's EA-18G and other fast jet and aircraft platforms. The Next Generation Jammer (NGJ) will be supplemented by the capabilities that fifth generation platforms such as the F-35 will bring as well as air-launched, podded and towed systems. The Surface Electronic Warfare Improvement Program (SEWIP) will upgrade the capability of shipborne EW. Digital flexibility will be a common theme across land, air and shipborne platforms, which will demand digital RF memory (DRFM) jammers. This, in turn, will impose requirements for higher performing field-programmable gate arrays (FPGA), analog-to-digital converters and more capable RF front-ends.

Given this need for enhanced performance, Strategy Analytics expects EW spending will grow to over $18 billion in 2024, a CAGR of 3.3 percent from 2014 through 2024.

GaN ADOPTION

While no one technology can meet all requirements, architectural changes that require broadband performance, higher operating frequencies and digitization will increase the funding for military electronics, including solid-state technologies such as GaN. Defense is the best market for GaN to "attack" and prove its maturity, with opportunities across all sectors.

Initial defense needs for GaN have been for EW systems for electronic countermeasures (ECM), specifically land-based RF jammers designed to counter improvised explosive devices (C-IED). Although troop withdrawals from theatres such as Iraq and Afghanistan have reduced volume over the past two years, demand will return from airborne and shipborne platforms. In addition to the U.S. systems previously noted, international programs such as Saab's wingtip jammer for the Gripen E will utilize GaN.

Radar systems will also utilize GaN to achieve higher power across a wide range of operating frequencies. GaN will compete with both TWT and GaAs power amplifiers for land and shipborne radar, spreading to airborne and space-based radars. Raytheon has demonstrated the increasing maturity of the technology, inserting it in the Patriot air and missile defense system and the U.S. Navy's next-generation integrated air and ballistic missile defense radar, named the Air and Missile Defense Radar (AMDR). In parallel, European activity includes Saab's Giraffe 4A land radar.

Military communications will also adopt GaN, providing a third avenue of growth for the technology. Collectively, the demand from EW, radar and communications will spur the military GaN RF market to grow at a CAGR of 28 percent, compared to 15 percent for the commercial sector

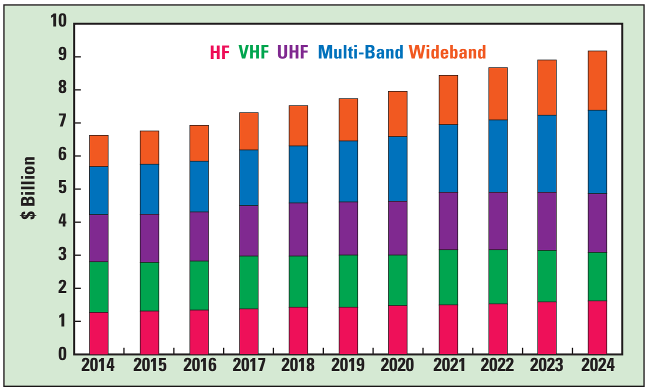

Fig. 5 *Military radio market forecast.*

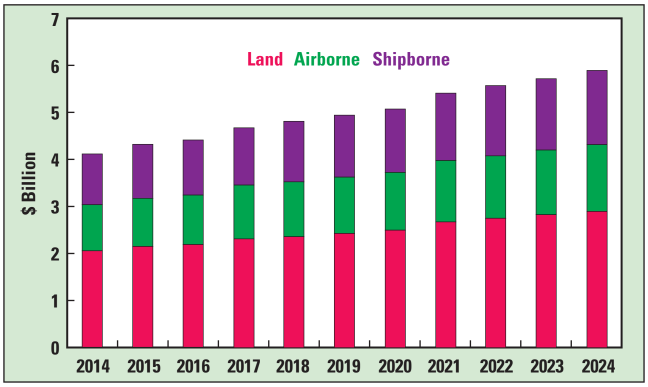

Fig. 6 *Military satellite terminal forecast.*

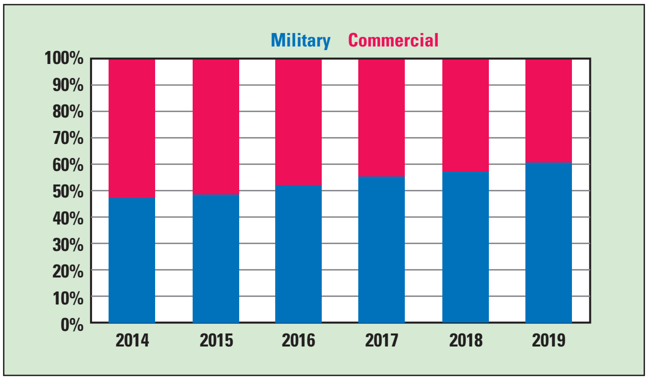

Fig. 7 *GaN market growth will be driven by military applications.*

and 20 percent overall. The total market is estimated to be greater than $500 million in 2019, of which military applications will represent 60 percent of the total (see ***Figure 7***). GaN will still be in a relatively early stage of deployment in 2019, so the potential for growth will extend over many years.

While defense budgets are uncertain, technology has a direct impact on force effectiveness and will lead to enhancing capabilities in radar, EW, communications and other military systems. More of the defense budget will go into electronics. While no single technology will serve all the requirements, the architectural changes demanding broadband performance, higher frequencies and digitization will provide opportunities for RF/microwave sensors and technologies such as GaN. ■

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INVITED PAPER

Using Calibration to Optimize Performance in Crucial Measurements

Dipti Chheda
Keysight Technologies, Santa Rosa, Calif.

Every engineer responsible for a test system is also responsible for the accuracy and repeatability of the measurements it makes. Repeatability, perhaps more than pure accuracy, is often the key to success in design, manufacturing and ongoing operations. In a test system, repeatability is also the foundation of the warranted performance of the included instruments. This is especially true for crucial equipment such as network analyzers, signal analyzers, power meters, oscilloscopes and signal generators. If any specified parameter is out of tolerance, measurement results can be negatively affected.

An accurate, professional and accredited calibration is the bedrock that ensures reliable and repeatable results. Calibration and metrology are a specialized subset of engineering, and relatively few engineers have been trained in these topics. Fortunately, developing familiarity with a few fundamental concepts will improve measurement performance, enhance the interpretation of results and, ultimately, reduce the risks associated with every decision that is based on measured results.

MEETING MEASUREMENT REQUIREMENTS

A test system supports a test plan, and the essential first step is to identify the crucial specifications that characterize the performance of the device under test (DUT). Each specification will have an associated set of tests, tolerances and accuracy requirements. The development of the test plan includes the selection of hardware elements that provide the necessary features and functions. For an engineer, the natural response is to thoroughly understand the choices and tradeoffs in the various hardware alternatives.

Typically, less time is spent considering the calibration and repair services needed to sustain the warranted specifications of each instrument. It's easy to assume that periodic calibration is all that's needed to ensure measurement integrity over the long term. In reality, test equipment ages and drifts, and sometimes it breaks. What's more, calibration is not a generic commodity, and the process of ensuring long-term measurement repeatability is not as simple as "set it and forget it." Taking a proac-

tive stance can have a significant impact on the ongoing accuracy and repeatability of the test system, not only reducing the risk of out-of-tolerance measurements, but actually improving the system's effective accuracy. This can help ensure the performance of the DUT and enhance overall productivity in manufacturing.

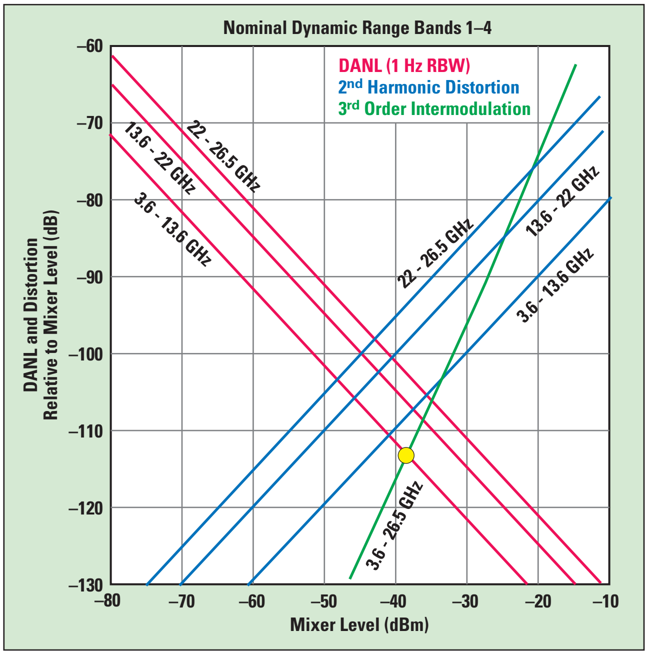
USING CALIBRATION TO IMPROVE SPURIOUS MEASUREMENTS

An example focused on the pursuit of spurious signals using a signal analyzer will show how to ensure greater confidence in results. This is an illustration rather than a tutorial on spur detection. Unwanted spurious signals are present in all types of radio frequency (RF) and microwave applications, such as wireless communications, radar and electronic warfare (EW). Many spurs come from the increasingly crowded spectral environment and, depending on the situation, may be expected or unexpected. Other spurious signals may occur within the DUT. This is especially problematic in devices that contain multiple transmitters with close physical spacing. The smaller the distance between any two transmitters, the greater the likelihood and magnitude of interference. Some measured spurs may be generated inside the spectrum or signal analyzer itself. These may be understood to the extent that the manufacturer can program the analyzer to reduce the effect on measurement results.

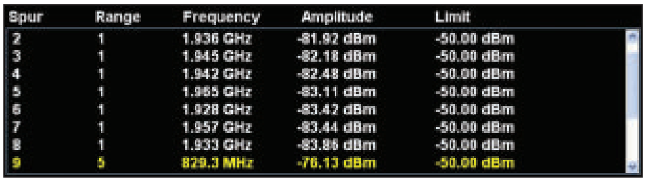
Collectively, spurs are the source of many potential problems. In a radar system, spurs may obscure the system's ability to see small return signals, which can affect the believability of what's on the screen. For those performing sensitive field operations, self-generated spurs emanating from a receiving antenna may betray their presence and location. Thus, when making a measurement, the key question is when a spur appears, is it real?

A spur search is usually a matter of finding small signals in the presence of much larger ones. Thus, the key specifications are spurious-free dynamic range and sensitivity. Because the frequencies of spurious signals are generally not known in advance, the process starts with a wideband spectrum measurement. The best setting for input attenuation depends on the magnitude of the largest signal in the widest span. With this combination of wide span and the likely presence of larger signals, many low-level signals will be missed due to insufficient frequency resolution and a higher-than-desired effective noise floor. To increase the available dynamic range, input attenuation should be minimized while remaining sufficient to prevent analyzer-generated signals, such as harmonics and intermodulation, from interfering with the measurement. The resolution bandwidth (RBW) should be just narrow enough to reduce the effective analyzer noise floor and resolve closely spaced spurs while providing sufficient measurement speed.

A useful example is the verification of spurious-free dynamic range (SFDR) in a radar exciter. The carrier fundamental is at 10 GHz. The exciter's SFDR must be 80 dB below the carrier (-80 dBc), and this equates to -65 dBm relative to an exciter with a +15 dBm output level. These are the key specs for the DUT. Characterizing those parameters depends on the signal analyzer's dynamic range, and that depends on specifications related to noise and spurs. Suppose a signal analyzer has a specified displayed average

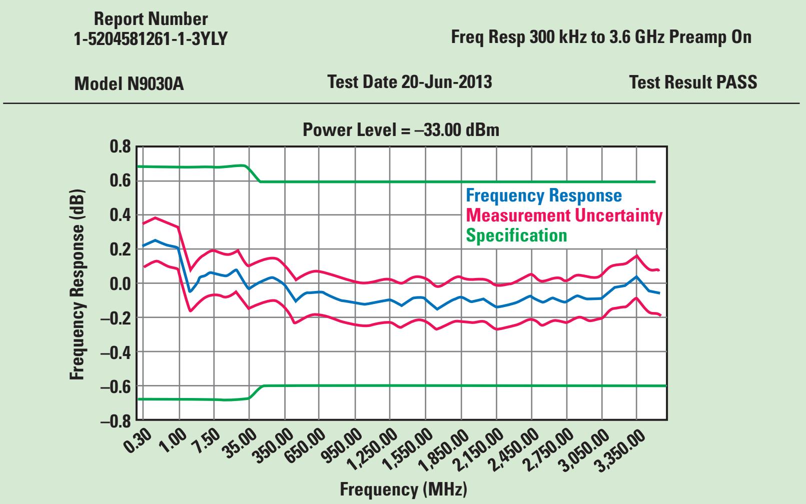


▲ *Fig. 1 Knowing the nominal performance of DANL and TOI helps to optimize spur searches.*



Spur	Range	Frequency	Amplitude	Limit
2	1	1.936 GHz	-81.92 dBm	-50.00 dBm
3	1	1.945 GHz	-82.18 dBm	-50.00 dBm
4	1	1.942 GHz	-82.48 dBm	-50.00 dBm
5	1	1.965 GHz	-83.11 dBm	-50.00 dBm
6	1	1.928 GHz	-83.42 dBm	-50.00 dBm
7	1	1.957 GHz	-83.44 dBm	-50.00 dBm
8	1	1.933 GHz	-83.86 dBm	-50.00 dBm
9	5	829.3 MHz	-76.13 dBm	-50.00 dBm

▲ *Fig. 2 A spurious signals measurement application provides the spur results for a DUT.*



Frequency (MHz)	Frequency Response (dB)	Frequency Uncertainty (± dB)	Specification (± dB)	Result
0.30	0.224	0.129	0.68	PASS
0.50	0.258	0.127	0.68	PASS
0.75	0.227	0.127	0.68	PASS
1.00	0.209	0.127	0.68	PASS
2.50	–0.044	0.127	0.68	PASS
5.00	0.036	0.127	0.68	PASS

▲ *Fig. 3 Calibration data for an instrument can assist with the interpretation of measurement results.*

TABLE I

SIGNAL ANALYZER IF PATH SPURIOUS TEST RESULTS

Image/Multiple/Feedthru Spurs STD IF Path					
Spurious Freq. (MHz)	**Source Freq. (MHz)**	**Spur Amplitude (dBc)**	**Measurement Uncertainty (±dB)**	**Specification (dBc)**	**Result**
225	10,470	-139.71	0.44	-80	PASS
1,100	1,745	-105.25	0.44	-80	PASS
5,500	6,145	-121.99	0.45	-80	PASS
2,000	12,645	-128.12	0.45	-80	PASS
5,000	15,645	-128.39	0.45	-80	PASS

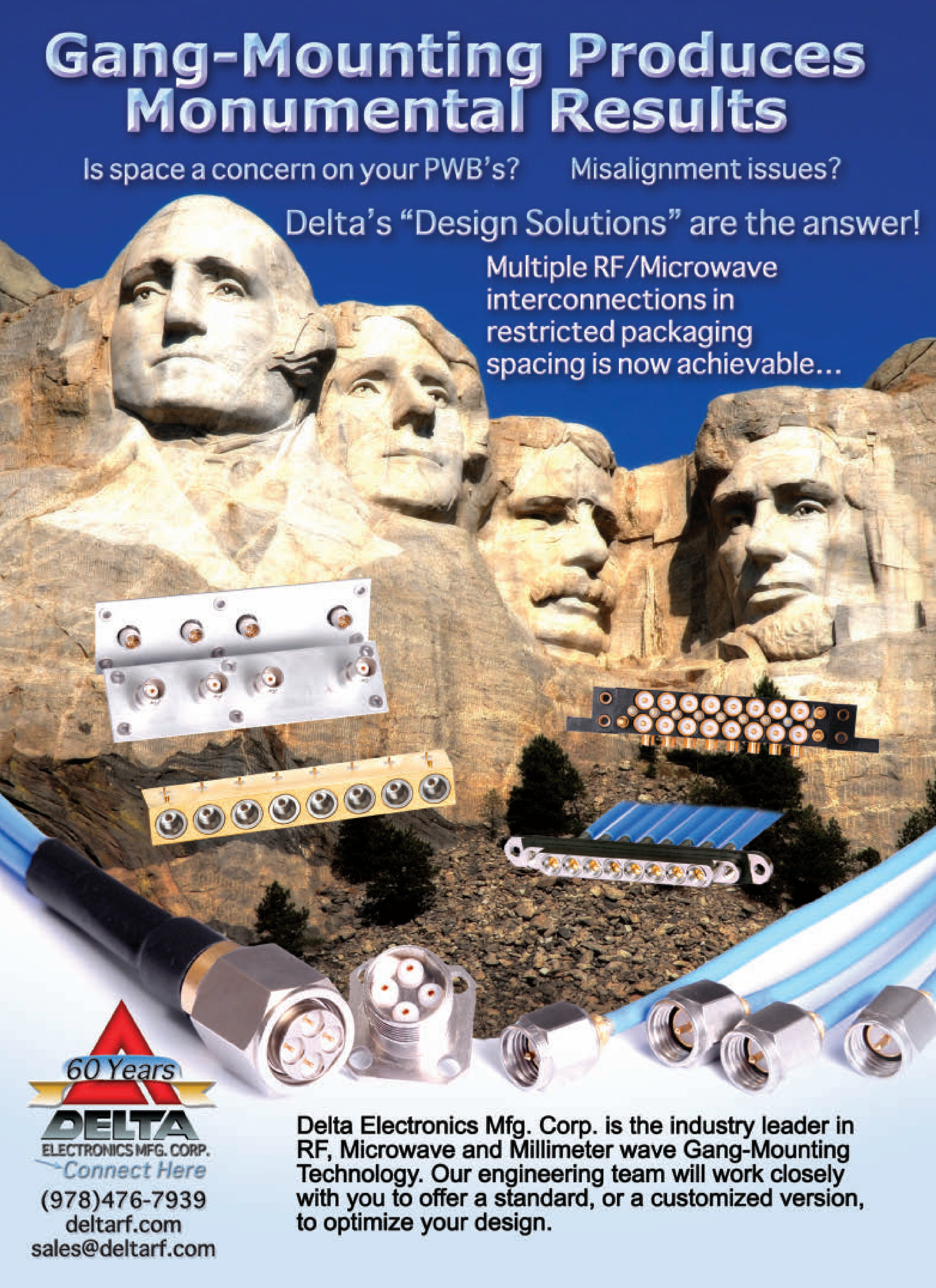
noise level (DANL) of -148 dBm. Because DANL is typically normalized to a 1 Hz RBW, the actual specification is -108 dBm when using a 10 kHz RBW. Residual responses are specified to have a level of -100 dBm or less. Related to this, third-order intermodulation (TOI) is specified to be -90 dBm. Understanding the trade-off between expected DANL (not a hard specification) and TOI is important when setting input attenuation and mixer level for a spurious measurement (see ***Figure 1***). Beyond the generic specifications, it would also be helpful to know the actual performance of an individual analyzer. Is it below spec, at spec or better than spec? If better than spec, how much better is it? This information is essential to enhancing the ability to interpret the actual measurement results from the analyzer.

Back to the fundamental question, when I see a spur, is it real? This is easier to answer with the addition of information that improves the effective performance of the measurements. For example, calibration results can be applied and then used to improve measurement performance and speed. ***Figure 2*** shows the output of a spurious signal measurement application built into a signal analyzer. Its tabular output shows spur number, measurement range, spur frequency, spur amplitude and the user-entered measurement limits.

Comparing the DUT results with actual calibration data for the signal analyzer makes it possible to apply in-hand knowledge and thereby adjust measurement settings to ensure greater confidence in results. ***Table 1*** shows the measurement data from the calibration of a high performance signal analyzer. The worst-case spur is at 1.1 GHz with a level of -105.25 dBc. From this, the attenuation and RBW settings can be adjusted to achieve a lower noise floor and provide greater certainty that any displayed signals are real.

USING CALIBRATION DATA TO IMPROVE PERFORMANCE

It's reasonable to expect that a full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calibration will test and verify all warranted specifications for all possible configurations of an instrument. Unfortunately, not every provider of calibration services is quite so thorough. It can certainly be a challenging task. For example, the calibration of one typical midrange signal analyzer requires 36 individual tests to ensure the instrument is performing as expected. After performing all these tests, the lab should provide a full measurement report along with traceability to (and compliance with) recognized calibration standards. Verification of testing, test results and standards compliance is essential to knowing the analyzer is meeting its warranted specifications. ***Figure 3*** shows an example of a calibration report that can be used to improve measurement performance. The table contains the measured frequency response of a signal analyzer, including measurement uncertainty and the applicable instrument specifications. This data can be used to achieve tighter DUT specifications, wider manufacturing margins, faster test throughput or improved yield. In R&D, this data can help optimize designs and avoid the need to reconcile inconsistent results from different teams.

Although a single engineer is often responsible for ensuring measurement performance, he or she is typically not the only person involved in obtaining calibration services. A few suggestions can ensure companies are getting what they need, while avoiding situations that undermine the ability to achieve the expected levels of instrument performance. First, it is important to be explicitly clear about expectations for calibration. This means specifying which warranted performance parameters must be verified every time the instrument is calibrated. It's also important to ensure others understand the limits of "performance verification." Even with adjustments, it isn't the same as an actual calibration. Instead, it's better to request that every warranted specification for every installed option be checked every time. For additional assurance, it's best to verify that the following is always included:

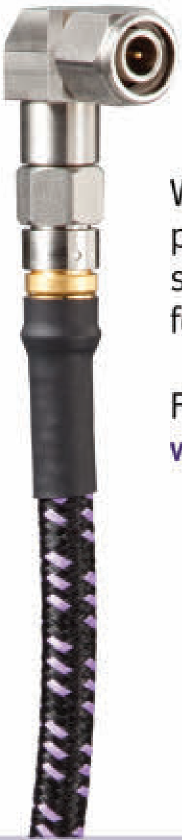
- Audit calibration reports
- Full test results
- List of all calibration equipment and verification that it has been tested
- Confirmation that the calibration meets traceability requirements.

As a final suggestion, it can be worthwhile to determine the economic value of this "insurance." For example, the ability to meet or exceed a target yield rate can reduce the number of DUTs that are scrapped or sent back for rework. This type of information can be an effective way to help management and procurement personnel appreciate the value of high quality calibration.

CONCLUSION

Opting for the most dependable calibration provider is the best way to ensure that test equipment continues to provide the performance that led to the purchase decision. In a commercial setting, this often translates into better throughput, margin and yield. In the aerospace and defense environment, it increases the likelihood of mission success. In any setting, reliable calibration ensures consistent results that make it easier to pinpoint product or design problems thereby minimizing delays in development and manufacturing. ■

Proven Performance



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State-of-the-Art Spectrum Monitoring Technologies

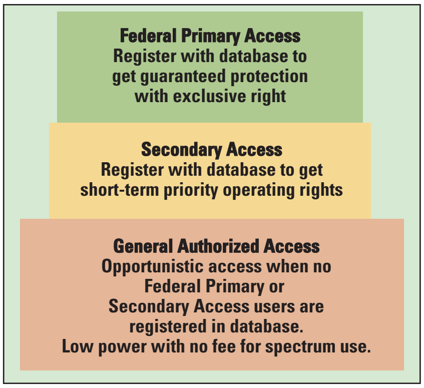
Abhay Samant, Tanim Taher and Ian Wong
National Instruments, Austin, Texas

Spectrum monitoring, that is, sensing for signal occupancy in the RF spectrum, constitutes one of the four key spectrum management functions – the others being spectrum planning, spectrum engineering and spectrum authorization. Spectrum monitoring helps spectrum managers identify utilized and underutilized radio bands. The results are then used to effectively plan and allocate frequencies, avoid incompatible usage and identify sources of harmful interference. As the number of connected devices continues to grow exponentially with the growth of 4G cellular, Wi-Fi and IoT technologies, spectrum monitoring plays an increasingly important role in commercial, regulatory and military applications. Real-time spectrum analysis (RTSA) is often considered one of the key enabling technologies for spectrum monitoring, with heavy emphasis on visualization aspects, such as persistence, waterfall displays and spectrograms. This article discusses additional powerful inline or post-processing spectrum monitoring algorithms, such as cyclostationary feature detection, frequency based event detection and intelligent signal identification. The article describes how these applications are enabled by the recent developments in software, processing units and high throughput data movement bus technology.

Due to the proliferation of portable wireless electronics and the bandwidth intensive applications that they enable, radio spectrum is becoming increasingly crowded. Today, wireless technologies such as cellular LTE, Bluetooth enabled wearable electronics, and Wi-Fi enabled first generation IoT devices are a big driver of economic growth in the commercial domain. E-commerce and social networking, and the economic benefits that come alongside, have been popularized due to the wide proliferation of always-on wireless portables. Similarly, in the public safety and military usage domains, newer video based applications require extensive wireless bandwidths to provide the necessary mission-critical performance. The RF spectrum, despite bringing so much value to the economy, is a finite, limited resource. Hence, the cost to access the spectrum itself has skyrocketed in recent years. In 2009, the auction of the 700 MHz band by the Federal Communications Commission (FCC) raised \$19.5 billion, and the 2014 auction of the AWS-3 band netted \$44.5 billion.[1] Spectrum monitoring provides valuable data that policy makers can use to determine which frequency bands are underutilized and hence, can be reallocated or repurposed through auctions and/or policy changes. Particularly, data

from long-term continuous spectrum monitoring stations is crucial in helping spectrum policy makers and planners make informed decisions.[2] Spectrum monitoring is also important for enforcement purposes – to identify unauthorized users infringing on the expensive spectral resource, detect interference and ensure compliance with spectral masks.

Due to recent policy adoptions in Europe and in the U.S., the importance of continuous spectrum monitoring is set to increase with new spectrum sharing policy models.[3] Long-term spectrum monitoring studies[4,5] have shown that although the proverbial "spectrum crunch" exists in certain commercial bands, like the cellular and 2.4 GHz ISM bands in high population areas, most of the other bands are underutilized. Armed with this empirical knowledge of actual usage and the knowledge that resource reallocation is a time-consuming and expensive process, a paradigm shift in spectral policy has recently taken place to allow dynamic shared spectrum access. In a shared spectrum environment, secondary users can operate in the same band as the incumbent spectrum licensee, subject to interference constraints. To this end, the European Commission (EC) has recently identified Licensed Shared Access (LSA) as a regulatory approach that allows secondary users to access an incumbent user's band and receive a certain Quality of Service (QoS), in accordance with sharing rules negotiated between them. The U.S. has adopted a different three-tiered hierarchical model for spectrum sharing (see ***Figure 1***). The 3550 to 3650 MHz frequency region has been selected in the U.S. as a fast-track band to deploy the three-tier model. Spectrum sensing is a key enabling technology for updating the database that controls shared access to the band. Hence, spectrum monitors that permit such sensing are critical. The next few sections list signal processing techniques that enhance the capabilities and sensitivity of spectrum monitors.



▲ *Fig. 1 Three-tiered model adopted in the U.S. for sharing spectrum.*

CYCLOSTATIONARY FEATURE DETECTION

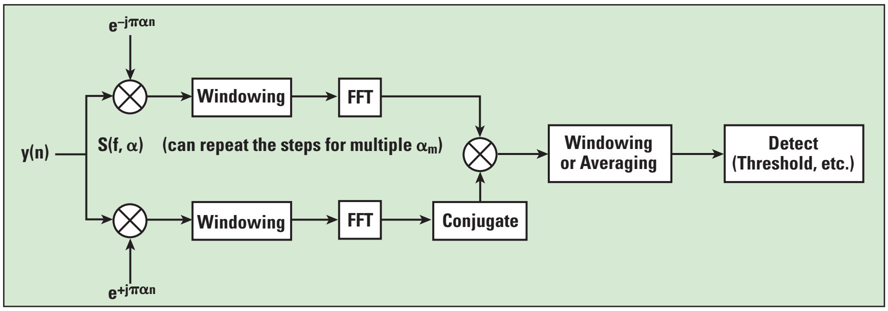
Cyclostationary feature detection (CFD) uses the "spectral correlation function" signal processing technique to detect low power received signals that are often below the noise floor of the spectrum monitor. Modulated information carrying signals are typically modeled as a cyclostationary process. Typically, a digital modulated signal carries information over fixed symbol periods, such that the signal exhibits the features of periodic statistics and spectral correlation. CFD makes extensive use of fast Fourier transforms (FFT) to identify the spectral correlation features (see ***Figure 2***).[6] The important thing to note is that CFD is robust to noise uncertainties and performs better than energy detection in low noise conditions. This is because noise is uncorrelated, while the information bearing signal has spectral correlation features that show up after the CFD analysis.

In a shared spectrum environment, many cognitive radio researchers use CFD because it allows the detection of far away (hence low received power) incumbent transmissions. A spectrum monitor armed with CFD capability is better able to detect low power signals compared to a threshold based simple energy detector. In a scenario where assessments need to be constantly made of whether a radio frequency is presently occupied by a user, such as in a shared spectrum environment, the measurement from a CFD enabled spectrum monitor is more reliable and gives confidence to the occupancy assessment results.

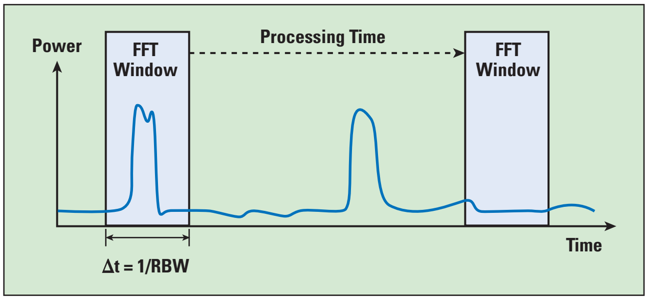
Inline CFD computation is a processor-intensive operation that requires access to the real-time time domain samples (I/Q data) captured by the spectrum monitor. Software-defined radio implementations have used host-side processing to perform CFD calculations on I/Q data at limited bandwidths,[7] but FPGA implementations of the CFD can provide improved performance at real-time speeds. As the monitoring bandwidth for CFD increases, so does processing time. In such cases, single or multi-channel sub-span extraction through digital down conversion (DDC) is applicable to reduce the spectrum bandwidth subjected to the CFD calculation. For example, in a scenario where the spectrum monitor measures a 100 MHz wide bandwidth, yet where weak signals exist below the noise floor for only 20 percent of that region, DDC can extract that 20 MHz section with low received signal power. CFD is then only performed on that 20 MHz sub-span, greatly reducing overall processing requirements.

Frequency Based Event Detection

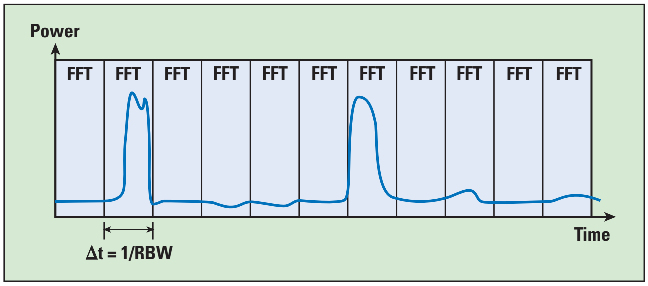
Particularly in military scenarios, it is often necessary to identify interference from systems attempting to obstruct a communications channel. Frequently called "jamming" signals, this type of interference signal is able to jam a communications signal by producing unwanted power within the band of interest. Common types of jamming signals include single tones, random white noise, pulsed, frequency hopped and modulated "fake" communications signals. From a jamming perspective, they differ in terms of effectiveness, power requirements, generation complexity and difficulty of detection. For example, the gen-



▲ *Fig. 2 Block diagram of the cyclostationary feature detection process.*



▲ *Fig. 3 With a pulsed jamming signal, the identification of subsequent jamming pulses is difficult without continuous acquisition.*



▲ *Fig. 4 Post-processing a pulsed jamming signal using FFT analysis.*

eration of a single carrier in an existing communications channel is relatively simple, but jamming wise, the signal is often ineffective and easily identifiable. Alternatively, the generation of broadband white noise can be extremely effective at obstructing a communications link.

Some of the more interesting types of jamming signals are pulsed or frequency hopped signals. These types of jamming signals are generally effective and can be difficult to detect using a traditional spectrum analyzer. The difficulty lies in the need to capture both time and frequency information regarding the signal of interest. As a result, stream-to-disk systems are commonly used to capture a dedicated portion of RF bandwidth over several hours. Once the signal is recorded, it is possible to use two methods to analyze the power, frequency and timing characteristics of jamming signals: FFT-based analysis and joint time-frequency analysis (JTFA).

When performing an FFT-based analysis of a jamming signal, either inline or post processing can be used. While inline processing provides immediate results, post processing offers the richest data set. ***Figure 3*** illustrates a pulsed jamming signal, showing that the identification of subsequent jamming pulses is difficult in the absence of continuous acquisition. The solution is to record the RF data for a period of time and analyze it after the acquisition is complete. In this scenario, a chunk of RF spectrum is acquired over a long period of time and then analyzed in blocks (see ***Figure 4***). The FFT size can be customized to give the most accurate characterization of the pulse's spectral information.

The resolution bandwidth (RBW) is inversely proportional to the signal's acquisition time. In the frequency domain, this affects the displayed power level of a transient signal. The burst might last just a few microseconds, and if a narrow RBW (long acquisition time) is used, the detected power

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	MODEL NUMBER	Freq (GHz)	Freq (GHz)	Gain (dB)	Pout (Watts)	PAE (%)	Operation	Voltage (V)	Size (inches)
SATCOM	DM-HPL-35-101	1.625	1.85	20	40	40%	CW	28	4.0 x 4.00 x 1.00
SATCOM	DM-HPS-35-101	2.2	2.5	20	40	35%	CW	28	4.0 x 4.00 x 1.00
SATCOM	DM-HPC-60-101	5.5	8.5	50	50	25%	CW	28	2.5 x 2.75 x 0.45
SATCOM	DM-HPX-100-105	9.75	10.25	50	100	30%	CW	28	7.4 x 4.30 x 1.65
SATCOM	DM-HPKU-40-105	13.75	14.5	45	50	20%	CW	24	4.5 x 4.00 x 0.78
SATCOM	DM-HPKU-40-101	14.4	15.5	45	30	15%	CW	28	2.5 x 2.75 x 0.45
SATCOM	DM-HPKA-10-102	29	31	50	12	15%	CW	20	3.1 x 3.00 x 0.78
SATCOM	DM-HPKA-20-102	29	31	50	20	15%	CW	20	3.5 x 4.50 x 0.78
RADAR	DM-HPL-1K-101	1.2	1.4	50	1000	40%	100 µs, 10% d.c.	50	6.0 x 6.00 x 1.50
RADAR	DM-HPS-1K-102	2.9	3.1	45	1300	35%	100 µs, 10% d.c.	32	14.0 x 8.00 x 1.75
RADAR	DM-HPS-1K-103	2.9	3.3	45	1500	35%	100 µs, 10% d.c.	50	9.5 x 9.50 x 1.50
RADAR	DM-HPS-1K-104	3.1	3.5	45	1300	35%	100 µs, 10% d.c.	50	9.5 x 9.50 x 1.50
RADAR	DM-HPC-50-105	5.2	5.8	50	50	35%	100 µs, 10% d.c.	32	3.0 x 3.00 x 0.60
RADAR	DM-HPC-200-101	5.2	5.9	50	200	40%	100 µs, 10% d.c.	50	4.5 x 4.50 x 0.78
RADAR	DM-HPX-140-101	7.8	9.6	50	140	40%	100 µs, 10% d.c.	40	3.6 x 3.40 x 0.67
RADAR	DM-HPX-400-102	8.8	9.8	50	450	35%	100 µs, 10% d.c.	50	7.0 x 4.50 x 1.65
RADAR	DM-HPX-800-102	8.8	9.8	50	900	35%	100 µs, 10% d.c.	50	9.0 x 6.00 x 1.65
RADAR	DM-HPX-250-101	9.4	10.1	50	250	40%	100 µs, 10% d.c.	50	3.6 x 3.40 x 0.67
RADAR	DM-HPX-800-101	9.4	10.1	50	900	35%	100 µs, 10% d.c.	50	9.0 x 6.00 x 1.65
RADAR	DM-HPX-20-101	9.9	10.7	46	20	30%	100 µs, 10% d.c.	32	3.6 x 3.40 x 0.67
RADAR	DM-HPX-50-101	9.9	10.7	50	50	30%	100 µs, 10% d.c.	40	3.6 x 3.40 x 0.67
ELECTRONIC WARFARE	DM-HPMB-10-103	0.1	6	55	10	20%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPLS-50-101	1	3	50	50	30%	CW	45	4.3 x 3.50 x 0.45
ELECTRONIC WARFARE	DM-HPLS-160-101	1	3	16	160	25%	CW	45	6.3 x 6.00 x 0.78
ELECTRONIC WARFARE	DM-HPSC-50-101	2	6	50	50	30%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPSC-80-101	2	6	50	80	25%	CW	28	4.5 x 4.00 x 0.78
ELECTRONIC WARFARE	DM-HPSC-150-101	2	6	60	150	25%	CW	28	6.5 x 6.50 x 0.78
ELECTRONIC WARFARE	DM-HPMB-10-101	2	18	45	10	15%	CW	32	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPMB-40-101	6	18	50	30	15%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPX-25-101	8	11	45	25	30%	CW	28	2.5 x 2.75 x 0.45
ELECTRONIC WARFARE	DM-HPX-50-102	8	11	50	50	30%	CW	28	2.5 x 2.75 x 0.45

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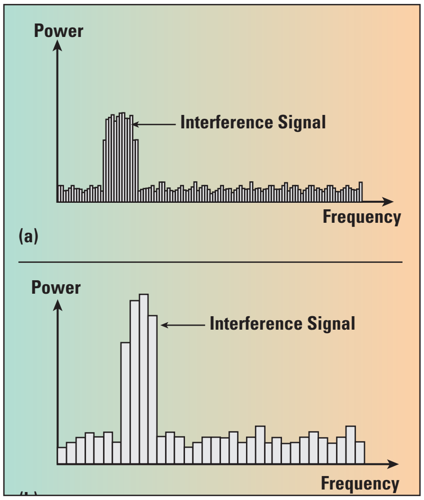


▲ *Fig. 5 Pulsed jamming signal power spectrum with a small (a) and large (b) RBW.*

spreads out over frequency. ***Figure 5*** compares the spectrum of a jamming burst using two FFTs: a larger acquisition window (smaller RBW) vs. a smaller acquisition window (larger RBW). A longer acquisition time narrows the RBW of the measurement and reduces the amplitude of the jamming pulse – which may cause the jamming signal power to fall below the noise floor and escape detection. Thus, for frequency-based detection, the FFT parameter size should be properly selected.

While FFT-based analysis provides useful frequency domain information, to obtain timing statistics about the jamming pulse, joint time and frequency techniques are needed, such as a spectrogram. The spectrogram exposes the timing dimension necessary to identify additional characteristics such as pulse inter-arrival gaps, pulse duration, bandwidth and amplitude. The drawbacks of post-processing are the large storage space and non-real-time identification of the jammer. Such an application can benefit from multi-core and FPGA-based spectrum monitoring hardware. With these technology enablers, it is straightforward to do continuous acquisition, i.e., the FFT and JTFA processing of data in real-time: for example, an existing real-time signal analysis implementation that outputs both the FFT power spectrum and the spectrogram.

INTELLIGENT SIGNAL IDENTIFICATION – "PACKET SNIFFING"

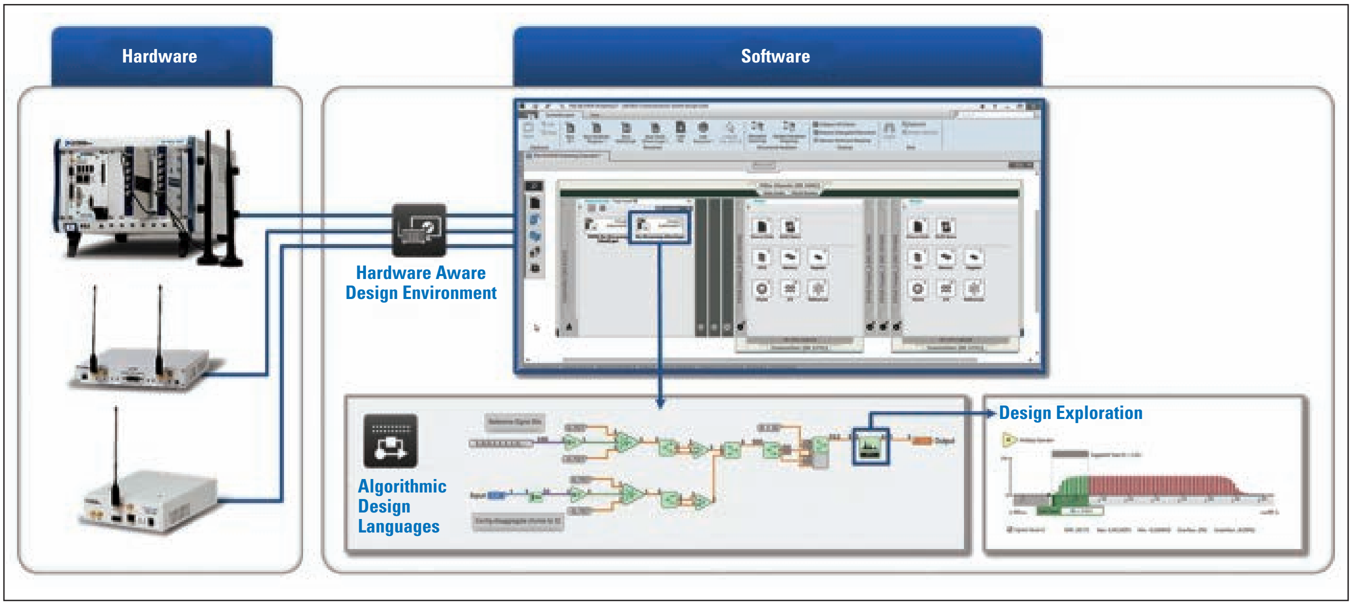
A second type of interference is a pirating or piggybacking communication signal. Here the interferer attempts to use the existing telecommunications infrastructure to illegally transmit by having the repeater rebroadcast an unauthorized signal. Since the repeater simply amplifies a specified spectral band, the interferer can use it to amplify the unauthorized channel communication with the intended signals.

The "packet sniffing" of such an interference signal can be accomplished by either processing the signal inline or recording a specified bandwidth and post processing the data. Once captured, this data can be post-processed with a variety of methods. Just as with jamming signals, analysis via FFT and JTFA is applicable to identify frequency, power and amplitude information about the interferer. However, for "packet sniffing" applications, the baseband waveform can be demodulated, although demodulating an unknown carrier is not trivial. To accurately demodulate a digital signal, it is important to know the carrier's symbol rate. This can be estimated by observing the channel bandwidth, but often the symbol rate must be experimentally determined by using the characteristic knowledge of known communications standards.

By demodulating the interfering radio signal, the bit stream being transmitted over the communications channel can be obtained. In some cases, this information is decodable by matching it with known preamble information. However, the greatest challenge occurs in decoding meaningful information from a bit stream, especially if the data is encrypted. Nonetheless, through demodulation and decoding, it is easy to identify the interference signal as a rogue transmitter operating outside authorized broadcasts.

CONCLUSION

This article highlighted several advanced analysis techniques that can enhance the spectrum monitor, transforming it to a more powerful RF measurement tool that doubles as a highly capable signal detector. Re-



▲ *Fig. 6 The integrated, hardware-aware design environment of the LabVIEW Communications System Design Suite can speed the development of spectrum monitoring and analysis systems.*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searchers are constantly coming up with more powerful and efficient signal processing techniques, while manufacturers continue to leverage newer computing and processing technologies to allow the hardware to keep up with the requisite bandwidth and computational requirements. As the necessity of spectrum monitoring becomes more widespread, due to recent trends in spectrum management – like high-priced auctions and policy changes favoring spectrum sharing – the methodologies discussed and others like them will see greater adoption.

Fortunately, spectrum monitoring software and hardware technologies are keeping pace with trends in the spectrum field. To achieve such capabilities, the spectrum monitoring platform has to be flexible enough to permit advanced signal processing. The hardware platform must have fast parallel cores, a high-speed bus for data transfers and/or support FPGA processing capabilities. Additionally, the platform should have the capability to perform advanced programming (including demodulation and decoding codecs) to permit intelligent signal identification.

One barrier to introducing new spectrum monitoring and analysis methods is dealing with multiple non-integrated processes while prototyping and deploying novel techniques. These include designing, simulating, prototyping, deploying to real-time in-line processing hardware and testing. An engineer working with the tools in one of these steps may not have the tools or skill set for the other steps. A tightly integrated software and hardware platform that instructively brings together all these discrete processes would greatly facilitate researchers and reduce the time to develop and deploy new spectrum monitoring algorithms. As one example, the LabVIEW Communications System Design Suite (see ***Figure 6***) brings together the discrete research, development and deployment steps within a single tool. This flexible software suite tightly integrates with software-defined radios, including one with a programmable FPGA. The suite is especially suited for designing and implementing spectral monitoring systems that benefit from the power of an FPGA. ■

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INVITED PAPER

Optimizing Digital Receivers for Signal Monitoring Platforms

Jim Henderson and Billy Kao
Innovative Integration, Camarillo, Calif.

This article provides an overview of the application trends and high level challenges of signal monitoring that system engineers are facing as well as a drill-down into the critical factors and trade-offs that need to be taken into consideration for successful deployment.

The challenges of designing signal monitoring and digital receiver applications are multiplying with escalating field deployment scenarios. System engineers are facing increasingly complex functionality and performance specifications for signal capture and analysis, while simultaneously coping with a variety of size, mobility, environmental, ruggedization, communications and software integration requirements. The high cost and inflexibility of conventional monolithic spectrum analyzers is too much for most of today's field deployment scenarios (e.g., remote facilities monitoring, mobile spectrum analysis, software defined radio, surveillance, signals intelligence). On the other hand, trying to build the entire system from the chip-level up is impractical for most system integration projects, where the design engineers need to keep focused on the big picture objectives, with both schedule and budget also being critical factors. To meet the demands of today's requirements while providing an adaptable basis for tomorrow, system engineers need access to a variety of digital receiver and signal processing building block choices, along with system integration options and standards-based modular software.

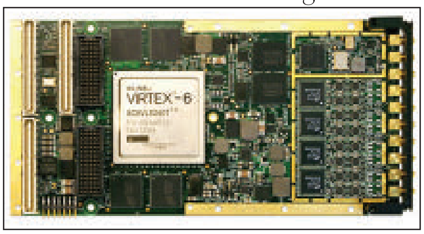

Fig. 1 XMC FPGA-based digital receiver.

ESCALATING APPLICATION DEMANDS

Across a widening range of industry segments and specialized applications, high-end digital receiver functions and signal analysis applications have migrated beyond traditional fixed location installations into more mobile "go anywhere" platforms that support a variety of field deployment activities. In both military and commercial applications, the need to put highly flexible signal monitoring systems out in the field has become critical for surveillance, software-defined radio (SDR), GSM front-end receivers, digital receiver/recorders, spectrum monitoring and regulatory enforcement activities. The various usage scenarios can include vehicle-based deployments, airborne, shipboard, cell tower, mobile transportable modular monitoring stations or fully ruggedized systems.

An increasingly important segment is within military and covert agencies to provide surveillance and signals analysis, such as capturing the RF signature for a particular environment and then monitoring in real-time for changes that may indicate attempted intrusions or security breaches. This can require a great degree of frequency-hopping flexibility and overall system adaptability. Depending on the scenario, covert signal analysis systems may require mobility and extended field deployment with the flexibility to track specific software-defined parameters that are unique to each situation. For example, a system might need to scan for signals at certain frequencies and then begin recording the streamed data only under those conditions. Some covert scenarios could even require the software to recognize specific patterns of associated frequencies, modulations and/or signals activity to trigger actions by the computing platform.

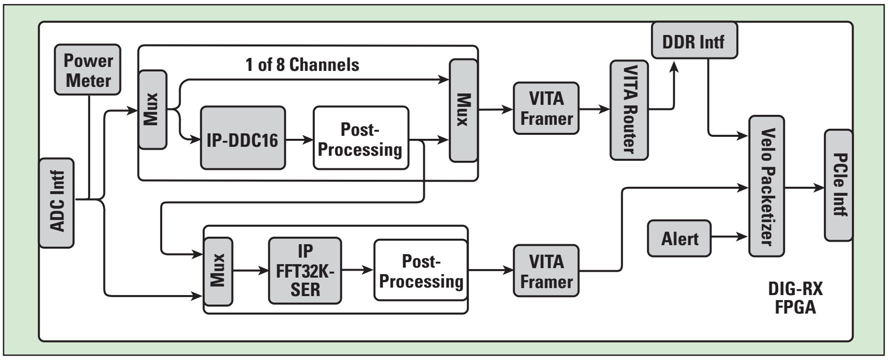

Fig. 2 Digital receiver block diagram.

If real-time streaming and recording of RF data is a requirement, the system implications are significant, because the hardware must be capable of sustained conditioning and digitizing of I/Q data on-the-fly. Also, real-time recording will require significantly more local storage, such as large, fast solid-state drives (SSD). If streamed and recorded data needs to be quickly communicated from remote locations, the networking structures and communications bandwidth also become critical.

SYSTEM ARCHITECTURE & DIGITAL RECEIVER OPTIMIZATION

In general, most of the above applications consist of two key functions: the digital receiver and the digital processor. The digital receiver is responsible for digitizing, tuning, down-converting and filtering the desired signal. The digital processor is responsible for manipulating the baseband data to extract the desired information, such as demodulation, and managing the actions to achieve the overall application objectives. The key to successful system design is breaking up the various system elements into the optimal building blocks for meeting the application performance specifications while also achieving size, weight, power and cost objectives.

One important element that can often be segmented and optimized is digital receiver functionality. Since this function is relatively the same for any signal monitoring, SDR or spectrum analysis application, it can be effectively handled by a turnkey digital receiver approach – as long as the receiver meets the performance specifications for the primary application and integrates seamlessly within the overall system architecture. Using a turnkey digital receiver approach also has the advantage of enabling systems engineers to keep focused on the big picture design objectives and not worry about reinventing digital receiver functionality from the ground up. The digital receiver thus provides the heart of the signal monitoring process flow, allowing engineers to focus on building the rest of the applications functionality around it.

To provide maximum flexibility for configuring a variety of different systems for various deployment scenarios, it is advantageous to implement the digital receiver subsystem on a standards based format at the lowest possible building block level. For example, a solid foundation for effectively integrating digital receiver functionality into virtually any higher level system design can be achieved by implementing a field-programmable gate array (FPGA) based digitizer module with multiple digital down-converter (DDC) channels and integrated fast Fourier transform (FFT) functionality in a single block that can be installed on a standard XMC-PCIe mezzanine board. The key is providing sufficient performance and flexibility within the basic module level to meet the application's frequency range, sampling rates, bandwidth, signal-to-noise ratio (SNR) and streaming transfer rate requirements.

Figure 1 shows such an XMC-based digital receiver module built around a Xilinx Vertex-6 FPGA with 128 DDC channels integrated with eight, 14-bit 250 MHz analog-to-digital converters (ADC). Each DDC has its own programmable tuner, lowpass filtering and programmable decimation rate, thereby supporting 128 independent output bandwidths up to 800 kHz. This gives system engineers a variety of options to record data directly from the ADCs or to down-convert the modulated analog RF channels to the target IF band. ***Figure 2*** illustrates the process flow through the digital receiver module. The data is packetized in standard VITA 49 format by the framer, with accurate timestamps and synchronization to the external pulse-per-second (PPS) signal. An embedded power meter monitors power levels at the ADC inputs in order to give designers the option to incorporate analog gain control in the external front-end device.

By interfacing the XMC-based module with an appropriate external front-end RF-to-IF analog-capture device and a standard PC system via the PCIe interface, engineers can

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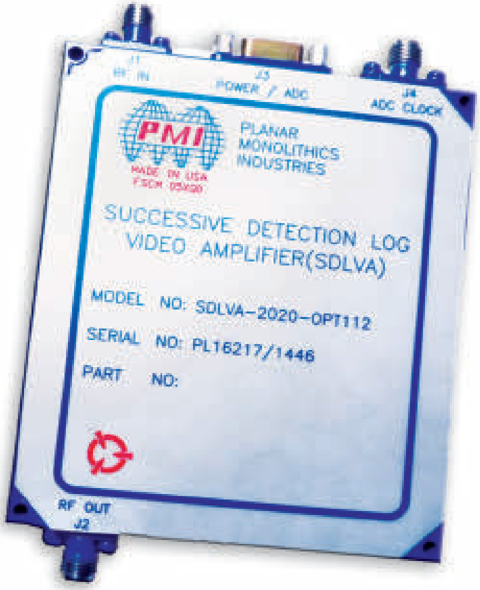

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Fig. 3 Building blocks for a signal monitoring platform can be integrated into a rack-mountable or stand-alone box.

quickly create a full signal monitoring or spectrum analysis system. In addition, the ability of the VITA router to interface directly with a digital data recorder (DDR), serving as virtual first in first out (FIFO) for data buffering, allows for easy configuration of high speed sustained streaming to the recorder. The ability to embed custom firmware in the IP cores also allows the same module-level digital receiver hardware to be adapted for specialized functions if required.

SYSTEM-LEVEL INTEGRATION

Of course, the basic system described above needs to be adapted to the specific requirements of each application scenario. Using a commercial off-the-shelf (COTS) approach, many application requirements can be addressed by integrating all of the other elements within a rack-mountable or stand-alone PCIe-based enclosure (see ***Figure 3***). This allows system engineers to take a true building-block approach to put together all of the hardware components and focus primarily on the application software. However, in some instances it may be necessary to further reduce size, weight and power or to simplify deployment and field service by creating small, fully self-contained systems. In these instances, the same core FPGA-based digital receiver module functionality can be easily embedded with the associated processor and other elements within a "brick" module. This can be especially useful for many military or covert surveillance applications that require either a high degree of portability or installation in confined spaces, for airborne or vehicle deployments.

If digital recording of the data is a requirement, then the system design needs to take into account the size, location and interfacing of the appropriate recorder and storage functions. Key considerations include off-loading the main processor and keeping it from being a bottleneck in the data flow. The ability to interface the FPGA-based digital receiver module directly to a recorder helps to overcome both of these issues. Depending on the amount of recorded data that has to be stored locally, the appropriate amount of SSD storage can be interfaced to the recorder and accessed by the main processor. To maximize performance, it may be necessary to dedicate specific SSDs to the recorder, rather than using them as shared system resources.

Other issues that come into play with system design include environmental factors, which may call for ruggedization, shock mounting and/or conformal coating. Depending on the nature of the specific application, these requirements may be addressed at the module, system level or both. Here again, the modular nature of the turnkey FPGA-based approach offers flexibility for easily adapting the digital receiver functionality within the overall environmental system strategy.

CONCLUSION

System flexibility is a critical factor for implementing today's signal monitoring and spectrum analysis functions, especially for military, covert and security applications. The ability to leverage powerful modular building blocks along with industry standards and software interoperability can often be the key to timely development and successful systems design.

System designers generally don't have the time, skill-set or resources to build every basic function, such as digital receivers, from the ground up. They also don't have the luxury to compromise on system performance or to hassle with the inability to customize functions for their particular application requirements. Instead, they need to leverage adaptable building block solutions that are optimized for performance, functionality and integration flexibility. This approach enables designers to optimize hardware integration by minimizing space, power and complexity while maximizing system differentiation through firmware and systems-level software customization for specialized features. ■

Dual-Channel Rotary Joint for Ka-Band SOTM Systems

Link Microtek Ltd.
Basingstoke, UK

While large satellite-on-the-move (SOTM) communication systems operating at S-, C- and X-Band frequencies have been widely deployed in naval applications, the latest SOTM developments are focusing on much smaller configurations for tanks, armored personnel carriers and airborne platforms such as unmanned aerial vehicles (UAV). As well as a reduction in physical size, there is also a requirement for higher capacities and data rates, particularly for real-time high-definition video feeds, so Ka-Band frequencies are becoming the preferred choice. The Ka-Band SOTM terminal market is still in the early stages of prototype system build, test and qualification, but it is destined to develop over the coming years.

In order to track the satellite, each moving vehicle is equipped with a satcom antenna system mounted on a three-axis, stabilized pedestal. As it is essential for the main axis of rotation to have unlimited 360° movement, cables cannot be used to feed signals to and from the antenna reflector; the only option is a microwave rotary joint.

A key design goal for SOTM antenna manufacturers is to reduce the footprint and profile of antenna systems for the emerging Ka-Band applications. This is achieved by using small reflector antennas or flat panels and by changing the traditional antenna topology, moving the block up-converter (BUC) – which converts data at L-Band frequencies into a Ka-Band signal for transmission to the satellite – from the rotating side to the fixed side below the antenna pedestal (i.e., inside the tank). However, this does mean that the microwave rotary joint now has to handle the transmit frequency at full power with, of course, minimal loss. Downconverting the incoming signal from Ka-Band to L-Band is performed by a low-noise block converter (LNB), but since this is quite a small device, it can usually be accommodated above the pedestal without any difficulty.

To address these Ka-Band SOTM requirements, Link Microtek has added model AM28CORJD to its family of microwave rotary joints. This miniature dual-channel device features a high-power transmit channel implemented in a right-angle WR28 waveguide on the fixed (input) side and a female K-type coaxial connector on the rotating (output) side, while the receive channel uses two female SMA connectors. Located on the main axis of rotation of the antenna, the rotary joint measures 31.75 mm in diameter by 74.68 mm in height (excluding the 50 mm diameter UBR320 standard bulkhead flange) and normally has to fit within a confined space at the centre of the bore of a slip ring assembly that powers the

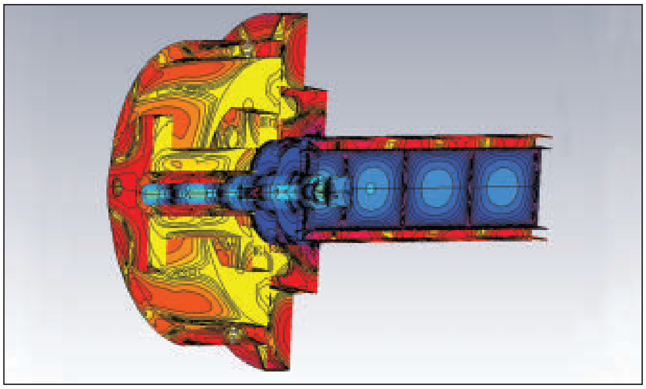


Fig. 1 *Electromagnetic simulation of internal waveguide-to-coax transition.*

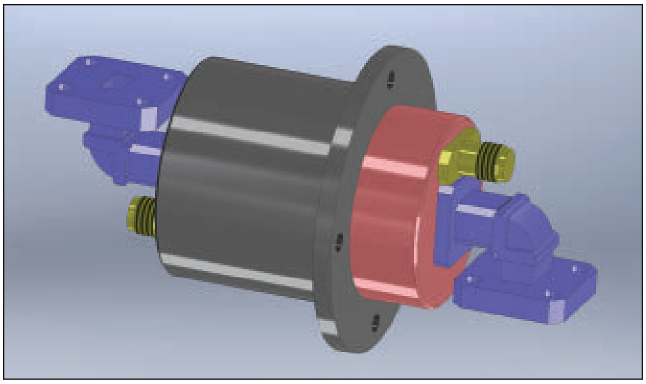


Fig. 2 *Alternative configuration with two right-angle WR28 waveguide bends.*

antenna's DC motors and other parts.

The central transmit channel of the AM28CORJD covers Ka-Band frequencies from 29 to 31 GHz and delivers excellent microwave performance, with a maximum power rating of 40 W CW, a typical insertion loss of only 0.6 dB and a maximum VSWR of 1.25:1. The L-Band receive channel uses two female SMA coaxial connectors and normally operates over the 950 to 2150 MHz frequency range. It offers a microwave power rating of 1 W CW, a maximum DC current rating of 500 mA (for powering the LNB), an insertion loss of 0.25 dB and a typical VSWR of 1.5:1. Ka-Band SOTM systems utilize expensive solid-state power amplifiers to produce the output that is necessary to cope with adverse weather conditions or when the satellite is low down near the horizon. It is vital to avoid any significant loss of power in the path between the amplifier and the antenna, so insertion loss is a critical parameter for the rotary joint.

Link Microtek uses electromagnetic simulation as part of the design process for its rotary joints (see ***Figure 1***) in order to optimize the insertion loss, power-handling capability and other specifications. The simulation shows the internal waveguide-to-coax transition – a key section of the rotary joint – with the various colors representing field strengths ranging from high (blue) to very low (red). Akin to a mechanical watch, the internal construction of the rotary joint consists of over 40 very small individual parts, which are crafted to high precision and tight tolerances before being assembled and tuned by hand.

Despite its intricate design, the AM28CORJD is robustly constructed to withstand the particular mechanical stresses associated with SOTM systems – namely, occasional rapid movement when locking on to the satellite or if the vehicle turns a corner, combined with continual dither as the stabilized platform adjusts to maintain best lock on the satellite. Fabricated from aluminum to minimize weight, the rotary joint has an Iridite finish and its performance under extreme environmental conditions either meets or exceeds the requirements of MIL-STD-810G.

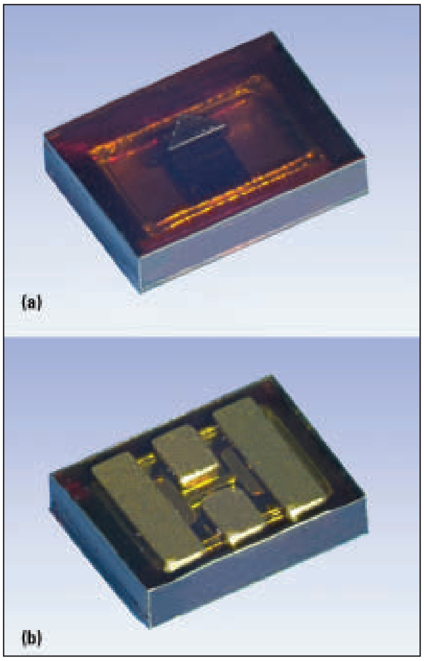
Other configurations of the Ka-Band dual-channel rotary joint can be supplied on request, customized to suit specific antenna requirements. The 3D CAD drawing in ***Figure 2*** shows one possible alternative, utilizing space-saving right-angle WR28 waveguide bends on both sides of the transmit channel.

Link Microtek Ltd.
Basingstoke, UK
www.linkmicrotek.com

Ka-Band Packaged Schottky Barrier Diode

YOKOWO Co. Ltd.
Tokyo, Japan

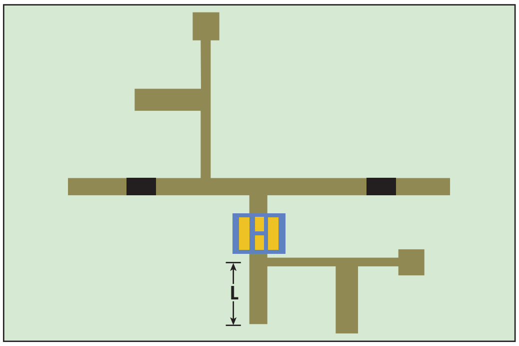
Monolithic ICs have been the trend for millimeter wave circuits. However, improvements in assembly technologies and the fabrication of passive circuits make hybrid IC approaches using discrete devices more feasible at millimeter wave frequencies. The hybrid approach is quite flexible and less expensive than monolithic integration, with performance largely determined by the packaged devices that are used.



▲ *Fig. 1 Top (a) and bottom (b) view of the YSD040SLPP01.*

YOKOWO has developed a low cost packaged Schottky barrier diode for millimeter wave applications. The YSD040SLPP01 operates from X- into Ka-Band. With a junction capacitance as low as 30 fF typical at Vc = 0 V, the diode is suitable for detector, switch and mixer applications. The diode package is made of a laminated polymer film with an internal cavity that effectively suppresses the extrinsic capacitance (see ***Figure 1***). The flat, surface-mount package, 1.6 × 1.2 mm, can easily be attached to a circuit board by solder reflow. In addition to the cathode and anode pads, the device provides two ground pads forming a ground-signal-ground (GSG) transmission line to provide a better signal feed at the I/O pads. No package resonance is observed up to 40 GHz. This packaging approach offers several advantages over bare die: ease of handling, storage, assembly – including high volume production, repair and durability in a chemical environment.

A SPST switch for the 24 GHz ISM-Band was developed to demonstrate the performance of the YSD040SLPP01. The circuit design uses a single diode in shunt with a series transmission-line reflector (see ***Figure 2***). The length of the line L is designed so that the re-



▲ *Fig. 2 24 GHz SPST switch layout.*

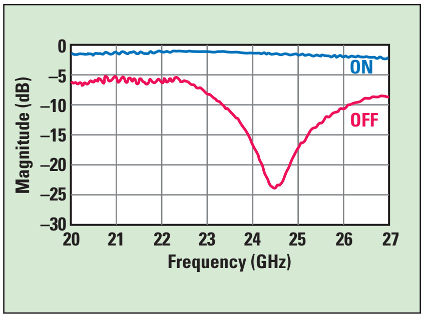


Fig. 3 SPST switch performance.

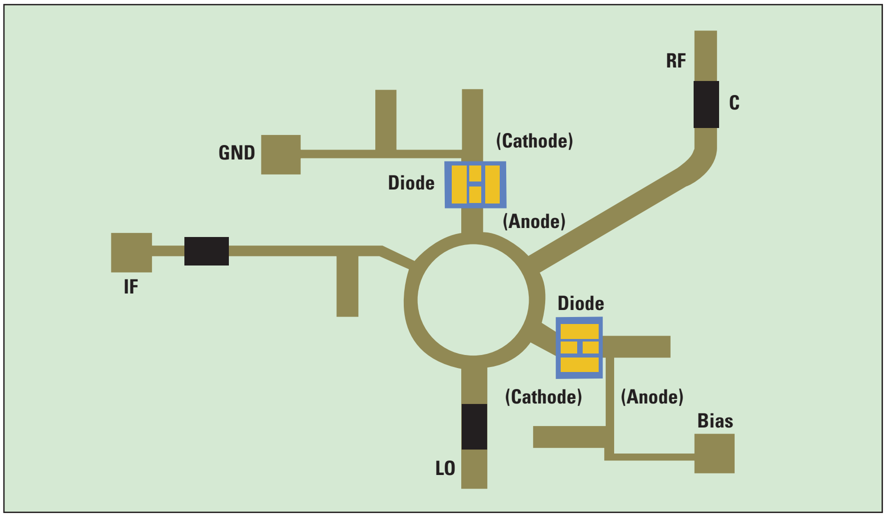


Fig. 4 24 GHz single balanced mixer layout.

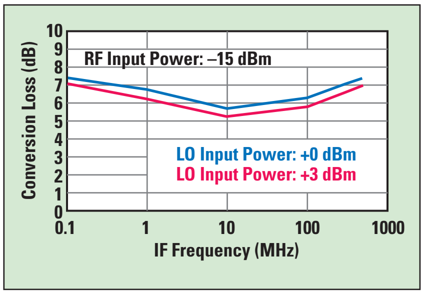


Fig. 5 Single balanced mixer conversion loss.

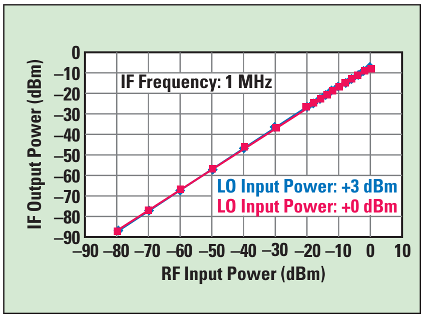


Fig. 6 Single balanced mixer sensitivity.

actance of the series connection of the positively-biased diode and the line is zero at 24 GHz. The circuit board is a commercially available material with ε_r = 3.5 and tan δ = 0.002. The performance of the SPST switch is shown in ***Figure 3***. The control voltage is 0 V for off and +3 V for on. At 24.5 GHz, the insertion loss is 1.5 dB, and the isolation 23 dB. An on/off ratio of over 20 dB is achieved.

Another application demonstrating the diode is a 24 GHz mixer. The circuit design (see ***Figure 4***) is a simple single balanced mixer using a rat-race power combiner/divider. The bias for the diodes is applied in series. The circuit board material is the same as used for the SPST switch, and the diodes are attached to the board by solder reflow. Conversion loss vs. LO power is shown in ***Figure 5***. Less than 7 dB is measured with LO power of 0 to 3 dBm across an IF range of 1 to 100 MHz. The sensitivity of the mixer (see ***Figure 6***) is -80 dB or better, which is excellent and sufficient for radar/sensor applications.

These simple hybrid circuits using one or two packaged diodes show excellent performance, confirming that the YSD040SLPP01 Schottky diode is suitable for detector, switching and mixer applications up to Ka-Band. In addition to the YSD040SLPP01, YOKOWO provides bare die diodes with performance in Ka-, U-, V-, E- and W-Band (the YSD080SLBD01 and YSD110SLBD01).

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Modular OpenRFM Microwave Tuners: Flexibility for EW

The OpenRFM™ Ensemble® RFM-1RS18 single-channel tuner family is designed for use in EW applications and is available in four configurations that cover 2 to 18 GHz. Two down-converter tuners convert signals to a lower frequency IF for processing, and two transmit up-converter tuners convert an IF to a user-selectable frequency between 2 and 18 GHz. All four are composed of up to three OpenRFM modules and require only a single 6U VXS slot. They can be used as stand-alone units or paired, dramatically reducing the time required to configure application-specific subsystems.

One of the two down-converter tuners has an instantaneous bandwidth of 1.5 GHz; its output is split into four IF outputs, each with a 375 MHz bandwidth centered at 745 MHz. The other has a single 1 GHz wide output centered at 1.875 GHz and includes a fast switching direct digital synthesizer (DDS). Both tuner up-converters have single outputs, a tunable range of 2 to 18 GHz and can accept 1 GHz of bandwidth centered at 1.875 GHz. One model also has a DDS.

The different configurations demonstrate the versatility of the OpenRFM architecture. For example, the up-converter tuner without a DDS can be paired with the down-converter model with a DDS, sharing the down-converter tuner's synthesizer to provide locked tune frequencies. The up-converter tuner with a DDS can be used as a stand-alone unit, or it can be paired with the single output down-converter tuner to provide an RF transmit/receive solution with independent tuning capabilities in both transmit and receive paths.

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Spectrum Analyzer and Signal Sources Serve Bench and Field

Berkeley Nucleonics' RF/microwave real-time spectrum analyzer and signal sources prove that it is possible to bridge the instrument gap between the bench and field. BNC's innovative design approach to these instrument lines meets the performance requirements of benchtop units along with the durability, portability and reliability demands of the field. In addition to delivering the highest degree of test environment flexibility, these commercial off-the-shelf instruments offer an outstanding price-to-performance ratio.

The 7500 series real-time spectrum analyzer weighs less than 7 lbs. and offers a frequency capture range of up to 27 GHz, 100 MHz of instantaneous bandwidth (IBW) and 100 percent probability of intercept (POI) at 1.02 µs. With an available rechargeable battery, the RTSA7500 makes powerful spectrum monitoring in the field easier than ever. At under $14,000, the power-to-price ratio is unparalleled.

BNC's family of signal generators offers portability with high performance and may be especially useful for organizations striving to use the same standard operating procedures in the field as in the lab. Compact and robust – yet powerful – RF/microwave signal sources in this line feature complete analog modulation, excellent phase noise, switching speeds under 30 µs, sweeping and high power outputs (-120 to +27 dBm). They are offered in a variety of frequency ranges to 27 GHz, and all models are available in sealed, fan-less enclosures with internal battery options.

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Single 50 W GaN PA Covers 2 to 18 GHz

Targeting radar, electronic countermeasures, and test and measurement applications, Analog Devices has developed a power amplifier (PA) that provides 50 watts across an instantaneous bandwidth of 2 to 18 GHz. This band has historically required two amplifiers, one for 2 to 6 GHz and a second for 6 to 18 GHz. Covering the full band with a single amplifier significantly reduces the size, weight and power of the system, which is particularly important for airborne applications.

The KHPA-0218 50WA delivers 50 watts of saturated CW power and can be configured for pulsed operation. Other output power levels are available to meet customer requirements. The heart of the PA is a proprietary GaN MMIC which was optimized for power, bandwidth and efficiency. The amplifier is packaged in a compact copper chassis with an SMA female input connector and Type N female output connector. Input and output VSWR are 1.5:1. Noise figure is typically 5 dB, and the maximum out-of-band spurious noise is -70 dBc. MTBF is rated at 200,000 hours over the operating temperature range of -20° to 75°C. The amplifier is biased with a +48 V power supply, with +28 V optional.

Power sequencing, a remote inhibit control, and a TTL-level power supply state monitor are incorporated in the design to facilitate control and monitoring of the PA.

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www.analog.com

500 W Pulsed X-Band GaN PA

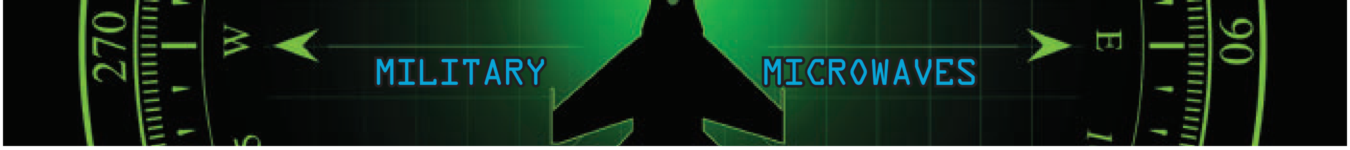
Exodus Advanced Communications has released the latest in a family of very high power, X-Band solid-state amplifiers. With a GaN, Class AB design to achieve maximum output and high efficiency, the AMP4002P delivers 500 watts pulsed output power, 400 watts minimum, from 9.1 to 9.5 GHz. The pulse width can range from 0.35 to 50 µs, measured at the 50 percent transitions, with a 20 percent duty cycle, 5 kHz pulse repetition frequency and 75 ns rise and fall times. The amplifier has a minimum power gain of 56 dB with flatness of 2 dB peak-to-peak (maximum).

The AMP4002P incorporates an internal filter to keep harmonics better than -60 dBc. Built-in functions include TTL gate control inputs, RF output detector and an over-temperature alarm. Internal circuitry ensures the system is fully protected against all failures. The power amplifier (PA), which is assembled in a 19-inch wide housing, features a state-of-the-art controller capable of supporting Ethernet TCP/IP, RS422/485 and remote Bluetooth connectivity. A front panel touchscreen is available as an option.

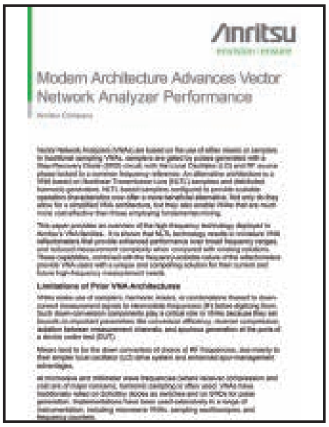
The AMP4002P has been tested and fully qualified for the following environmental conditions: operating temperature from -20° to +55°C, humidity to 95 percent at 40°C, shock and vibration per MIL-STD-810F, altitude per MIL-STD-810F and EMI/EMC per MIL STD 461E.

Exodus Advanced Communications designs and manufactures solid-state RF power amplifiers covering frequency bands from 10 kHz to 40 GHz, achieving module output power greater than 1 kW and complete systems exceed 10 kW. Other standard X-Band products include a 400 watt PA covering 9.5 to 10 GHz and a 1 kW, 9.1 to 9.5 GHz design. Exodus PAs integrate discrete LDMOS, GaAs and GaN devices with ceramic substrates using chip and wire (hybrid) assembly processes. In-house capabilities include RF circuit, system mechanical and electrical and digital circuit design, control software development and prototype verification.

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



COMPANY SHOWCASE



MODERN VECTOR NETWORK ANALYZER

VENDORVIEW

Modern Vector Network Analyzer (VNA) architectures such as those based on Nonlinear Transmission Line (NLTL) samplers and distributed harmonic generators now offer a beneficial alternative to traditional sampling VNAs. They allow for a simplified architecture and also enable VNAs that are much more cost effective. It is shown that NLTL technology results in miniature VNA reflectometers that provide enhanced performance over broad frequency ranges and reduced measurement complexity, providing VNA users a unique and compelling solution for their high-frequency measurement needs.

Anritsu Co.
www.goanritsu.com/VNAFam

RF AND MICROWAVE PRODUCTS

CPI's Beverly Microwave Division (BMD) designs and manufactures a broad range of RF and microwave products for radar, communications, electronic warfare and scientific applications. BMD has been located in Beverly, Mass. since 1947. CPI BMD is the world's largest manufacturer of receiver protectors and magnetrons. They also manufacture TWTs, CFAs, transmitter assemblies, scientific systems, high-power solid-state switches and switch assemblies, pressure windows, plus a wide variety of multifunction components and integrated microwave assemblies.

Communications & Power Industries
Beverly Microwave Division
www.cpii.com/bmd

CABLE ASSEMBLIES AND CONNECTORS

Cinch Connectivity Solutions has a wide range of connectors, microwave components, cable assemblies and fiber optic connectivity products for military, aerospace, wireless communications, data networking, test & measurement and broadcast applications. Their Midwest Microwave, Stratos, Trompeter, Semflex and Fibreco lines offer high performance products for harsh environments qualified to M3933, M5015, M26482, M39030, M49142 and M83526 specifications. The company also provides custom solutions with a creative, hands-on engineering and end-to-end approach. Learn more at cinch.com or call 800-247-8256.

Cinch Connectivity Solutions
www.cinch.com

POWER AMPLIFIERS CATALOG

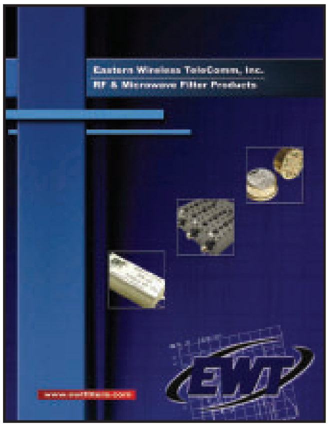
Check out CTT's four-page power amplifiers short form catalog. The catalog features more than 75 models developed for radar, EW and multi-function systems design. The amplifiers feature narrowband CW, narrowband pulsed, wideband (CW) and ultra-wideband (CW) coverage. Frequency coverage is from 0.1 to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

CTT Inc.
www.cttinc.com

KU SATCOM/DATALINK APPLICATIONS

Delta Microwave introduces SSPA model DM-HPKU-50-101 developed for Ku Satcom/Datalink applications. Specs include: 14.4 to 15.5 GHz, 45 dB min, 50 W min, 60 W typ, 24 VDC, 9 A nom, 25% typical, 2.5" × 2.75"× 0.45". Delta Microwave designs and manufactures filters, multiplexers, LNAs, SSPAs (GaAs and GaN), filter/amplifiers and integrated microwave assemblies. Key customers include BAE, Ball Aerospace, Boeing, EADS Astrium, Exelis (ITT), L3 Communications, Lockheed Martin, NASA, NEC Space, Northrop Grumman, JPL, Orbital Sciences, Raytheon, SpaceX and SPAWAR among others.

Delta Microwave Inc.
www.deltamicrowave.com

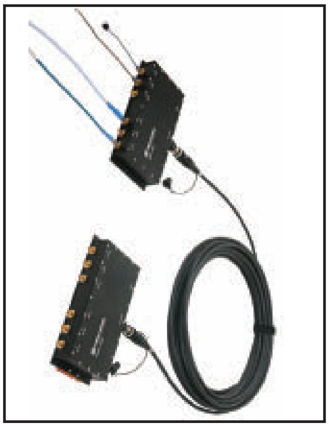


RF & MICROWAVE FILTER PRODUCTS

EWT's short form catalog features a sampling of the company's RF and microwave filter products to 40 GHz utilized in military, commercial, wireless and space applications. The catalog also highlights some of the company's diverse filter design and manufacturing capabilities. EWT has over 60 years of combined experience in the design, development and high volume manufacturing of cavity and waveguide filters to 50 GHz and lumped element filters up to 10 GHz.

Eastern Wireless TeleComm Inc.
www.ewtfilters.com

COMPANY SHOWCASE



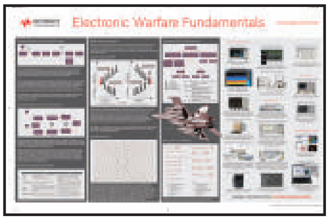
WE'RE ALL OVER!

VENDORVIEW

The RF-over-Fiber Series enables the use of radio frequency and fiber optics in a single system. With these two technologies forming a part of HUBER+SUHNER's core technology offering, the company is using their vast experience and expertise to deliver best-in-class conversion modules. Key benefits of combining radio frequency and fiber optics in a single solution – No changes required to existing RF infrastructure, secure, lightweight, covers greater distances (>100 km) with less loss, wide frequency ranges available, flexible connectivity options, reduced total cost of ownership and future-proof.

HUBER+SUHNER

Aerospacedefense.hubersuhner.com



ELECTRONIC WARFARE FUNDAMENTALS

VENDORVIEW

Keysight Technologies' new Electronic Warfare Fundamentals poster contains a radar warning receiver and DRFM based jammer block diagrams, a compare and contrast of radar versus EW, basic equations, cross-eye jamming, modern jamming techniques, three areas of EW, common acronyms and the latest hardware and software for electronic warfare test and measurement. Keysight's expertise in measurement science and test processes can help you fulfill today's mission and manage the transition to what comes next.

Keysight Technologies Inc.

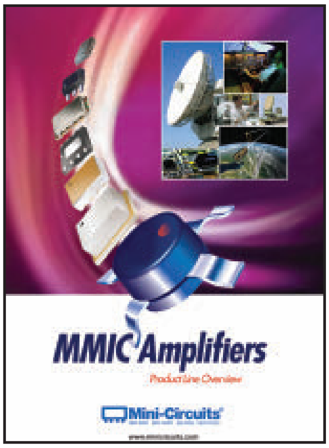
www.keysight.com/find/ew-focus

BENEFITS OF OPENRFM

OpenRFM™ is a proposed standards-based, modular open architecture that enables the integration of RF and digital elements by standardizing electromechanical and thermal interfaces, software and control plane protocols. Ideal for EW, radar and SIGINT systems, OpenRFM not only meets DoD MOSA requirements but it also enables rapid tech upgrades to keep up with rapid technology changes. This technical paper provides a discussion regarding the OpenRFM architecture and concludes with an EW application-specific case study using OpenRFM standard functional building blocks.

Mercury Systems Inc.

www.mrcy.com/openrfm



MMIC AMPLIFIERS BROCHURE

VENDORVIEW

Mini-Circuits announced the publication of its MMIC Amplifiers Product Line Overview, a 24-page, full-color brochure showcasing their extensive MMIC amplifier product line. The new brochure provides a complete overview of their MMIC amplifier offerings and highlights key differences in design approach between Mini-Circuits' MMIC amplifiers and typical products on the market. It features helpful details on semiconductor materials, circuit architectures, qualification processes, advanced packaging technology and other informative content. With over 170 different MMIC amplifier models covering DC to 26.5 GHz, chances are Mini-Circuits has your application covered.

Mini-Circuits

www.minicircuits.com

SWITCHED FILTER BANKS

NIC introduces its product line of high performance custom 2 to 10 channel switched filter banks ranging in frequency from 1 to 18,000 MHz. These integrated devices use PIN diode or GaAs switches which offer lower insertion loss and higher isolation. The TTL-compatible filter banks offer optimized VSWR and passband flatness in a compact form factor. Laser sealed ruggedized packaging makes these devices a perfect fit for high reliability military and space applications.

Networks International Corp.

www.nickc.com

NI AWR Design Environment

CO-SIMULATION TECHNICAL PAPER

VENDORVIEW

NI (formerly AWR Corp.) announces a new NI AWR Design Environment™ white paper that describes how Visual System Simulator™ (VSS) system design software and LabVIEW can co-simulate, enabling system designers to better analyze, optimize and verify complex RF systems inclusive of digital signal processing (DSP) blocks. "Co-Simulation with Visual System Simulator and LabVIEW for Enhanced Signal Processing" can be downloaded (registration required) at: www.awrcorp.com/solutions/technical-papers.

NI (formerly AWR Corp.)

www.awrcorp.com

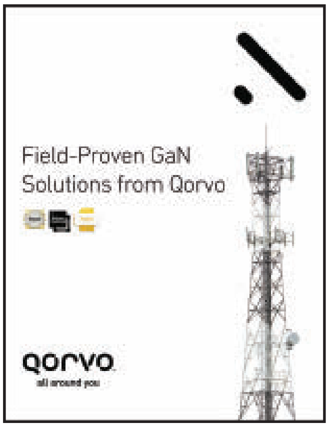
COMPANY SHOWCASE

TRIFOLD BROCHURE

Planar Monolithics Industries recently updated its 2014-2015 Trifold Brochure. PMI is a leading manufacturer of RF/microwave components and integrated RF assemblies. The company's offerings include: amplifiers, variable solid-state attenuators, limiters, detectors, detector log video amplifiers, solid-state switches and switch matrices, phase shifters, filters and switch filter banks, couplers, dividers and more up to 40 GHz for commercial and defense applications.

Planar Monolithics Industries Inc.

www.pmi-rf.com



FIELD PROVEN GaN SOLUTIONS

Qorvo's high-performance GaN technology supports products from DC through Ka-Band for military and commercial applications. Qorvo continues to build on its 15-year GaN legacy of innovation and reliability by offering new products and foundry services that strive to meet their partners' demanding system requirements. Their partners benefit from the 'trusted' supplier status and MRL-9 classification. Only Qorvo delivers performance, quality and reliability that sets the standard in the industry. For more information, visit www.qorvo.com/defense.

Qorvo Inc.

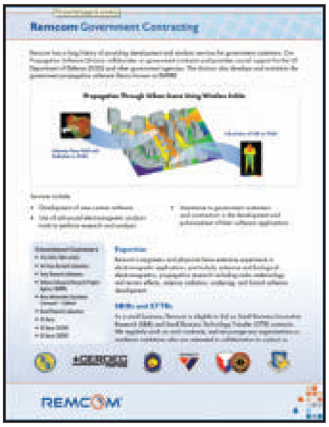
www.qorvo.com/defense

FILTERS, MULTIPLEXERS AND MULTI-FUNCTION ASSEMBLIES

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

Reactel Inc.

www.reactel.com

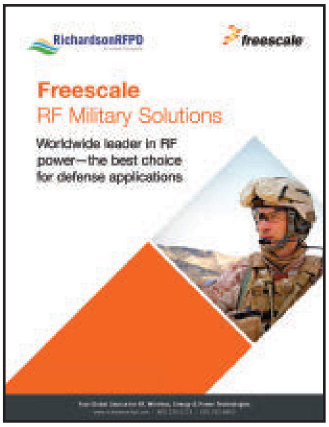


GOVERNMENT CONTRACTING

Remcom has a long history of providing development and analysis services for government customers. Their Propagation Software Division collaborates on government contracts and provides crucial support for the U.S. Department of Defense (DoD) and other government agencies. The division also develops and maintains the government propagation software library known as EMPIRE. As a small business, Remcom is also eligible to bid on Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) contracts.

Remcom Inc.

www.remcom.com



AEROSPACE AND DEFENSE PORTFOLIO

Freescale's RF aerospace and defense portfolio encompasses a range of high-power solutions, including GaN, GaAs and LDMOS transistors and ICs, that support a wide variety of needs for military applications, such as avionics, HF through L- and S-Band radar, communications, electronic warfare and identification, friend or foe (IFF). With leading-edge products and technology, a dedicated military products team, and its product longevity program, Freescale is your go-to source for aerospace and defense application needs. Brought to you by Richardson RFPD.

Richardson RFPD

www.richardsonrfpd.com

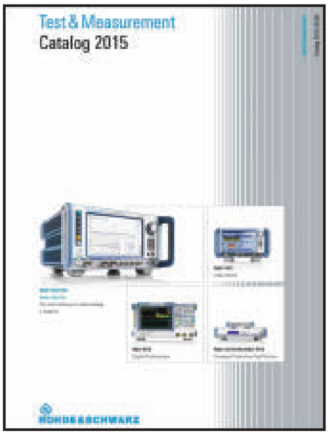
PRECISION MICROWAVE COMPONENTS

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

RLC Electronics Inc.

www.rlcelectronics.com

COMPANY SHOWCASE



TEST & MEASUREMENT CATALOG 2015

VENDORVIEW

The Rohde & Schwarz Test & Measurement Catalog 2015 features more than 200 pages of information about Rohde & Schwarz test & measurement instruments, systems and software. It includes a short description and photos of each product, the most important specifications and the ordering information. You can download this catalog as a PDF from the Rohde & Schwarz website or order from customer support (Order number: PD 5213.7590.42 V 05.00).

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

REAL-TIME SPECTRUM ANALYZER/RF RECORDER

VENDORVIEW

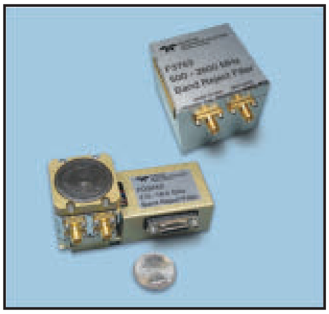
The BB60C is a broadband real-time spectrum analyzer and RF recorder that captures and displays RF events as short as 1 µs. It has selectable IF streaming bandwidths from 250 kHz up to 27 MHz. With accurate operation from 9 kHz to 6 GHz over its entire temperature range (-40° to +65°C available), the BB60C is well-suited for lab or field use. It sells for $2879 and includes an API for custom software development.

Signal Hound
www.signalhound.com

MULTIPORT CONNECTORS

Spectrum's most innovative and most recognized family of multiport connectors, Series IQ-, BQ-, CQ-, SQ-, TQ- and RQ-, featuring circular and rectangular coaxial multiport connectors, has been increasing constantly. The new released designs are operating to 65 GHz. The TQ-09 Multiport incorporates 9 coaxial cable assemblies in a MIL-DTL 38999 housing of size 13, while in the circular TQ-19, using the MIL-DTL 38999 shell of size 25, 19 coaxial cable assemblies have been placed for perfect operation to 65 GHz.

Spectrum Elektrotechnik GmbH
www.spectrum-et.com



CLOSER TO THE PERFECT NOTCH

VENDORVIEW

Engineers realize the 'perfect notch' is unachievable; however Teledyne Microwave Solutions (TMS) has developed a patented YIG Tuned Notch Filter Line that brings technology closer to notch perfection. It's a TMS Design Trifecta: wider notch bandwidth + greater notch depth + narrower 3 dB bandwidth. Add improved performance at lower frequencies with reduced spurious responses and TMS will be your one source for demanding YIG band-reject filter requirements.

Teledyne Microwave Solutions
www.teledynemicrowave.com

HARNESS INFORMATIONAL BRIEFING

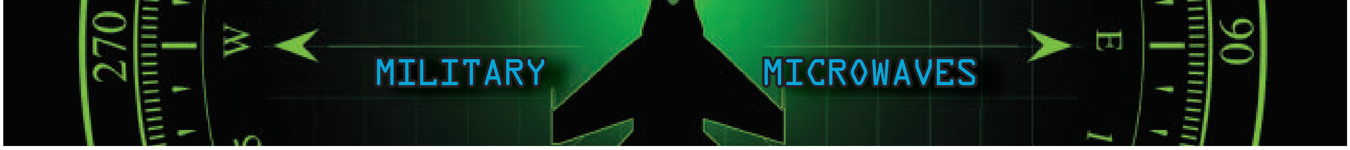
Harnesses provide a multi-channel connectivity solution that requires minimal installation tools, delivers a compact connector footprint, removes the risk of crossed channels and misconnection, enables fast installation or replacement, and simplifies wire management and routing. This briefing discusses benefits, applications, design components, qualification testing and range of tailored harness solutions – both flexible and semi-rigid – that are available from Teledyne Storm.

Teledyne Storm Microwave
www.teledynestorm.com

GORE-FLIGHT MICROWAVE ASSEMBLIES

GORE-FLIGHT ™ Microwave Assemblies 6 Series are lightweight cable solutions for airframe assemblies in military and civil aircraft applications. These new assemblies deliver the lowest insertion loss before and after installation, ensuring reliable performance for the life of the system. Their robust construction reduces total costs by withstanding the challenges of installation, reducing costly production delays, field service frequency, and the need for purchasing replacement assemblies. The 6 Series are also lightweight, which improves fuel efficiency and increases payload.

W. L. Gore & Associates
www.gore.com/simulator



ADVERTISING INDEX

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