2015 Military Microwaves

A SPECIAL SUPPLEMENT TO

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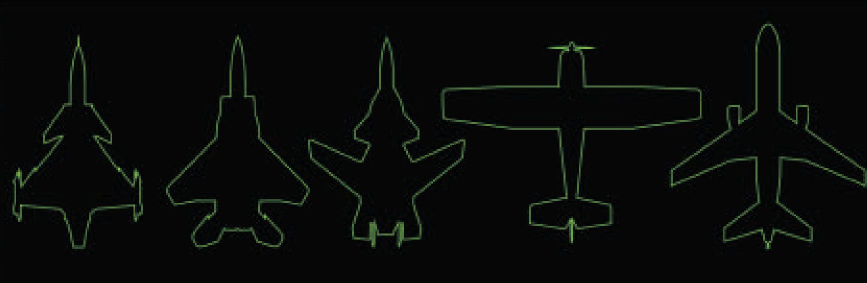

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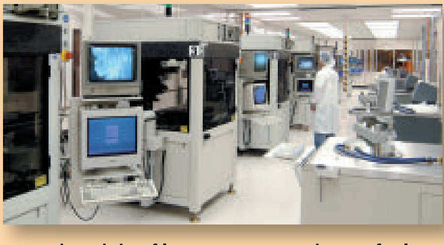

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COVER FEATURE
INVITED PAPER

Recent Advances in Radar Technology

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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

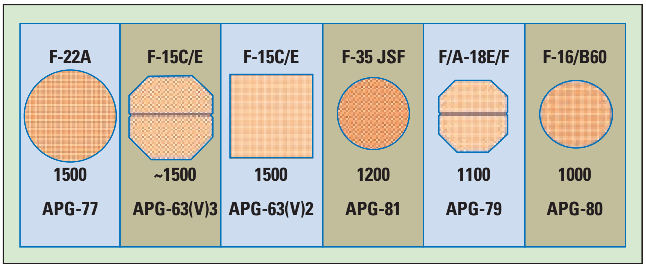
Airborne systems typically seek the best performance possible in a constrained size, weight and power (SWAP) envelope operating in a severe environment, so they tend to use the most advanced technology. A recent revision of Stimson's "Introduction to Airborne Radar"[1] provides a valuable overview.

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-

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.

Successful state-of-the-art space

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.

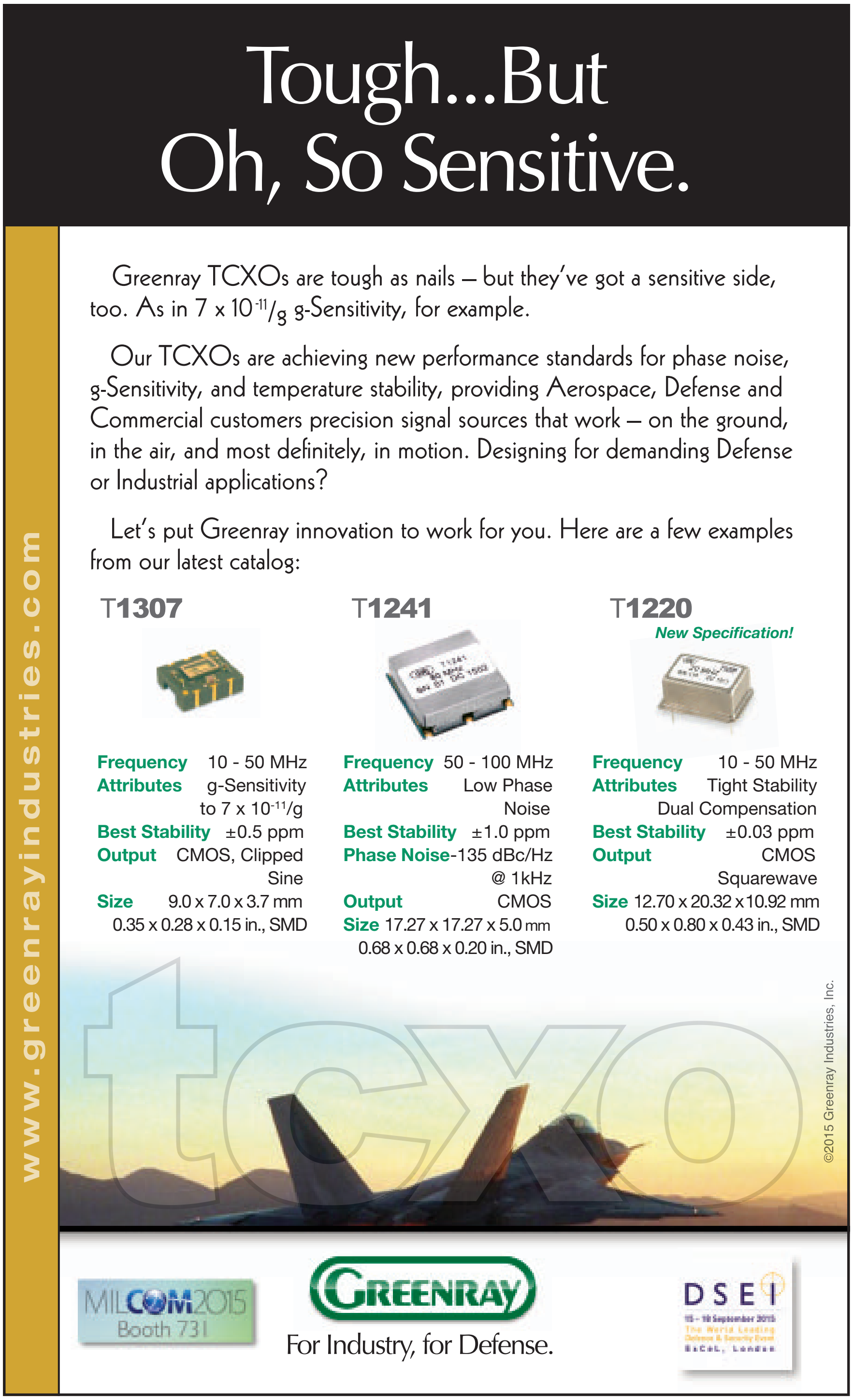
One particular problem with the extreme sensitivity of CCD is the presence of false alarms (clutter) introduced by phenomena such as low SNR (especially radar shadows) and vegetation. Newey, et al., presented two methods to improve the sensitivity of the detector while reducing the amount of false alarms.[27] 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-

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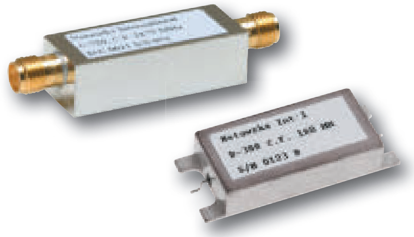

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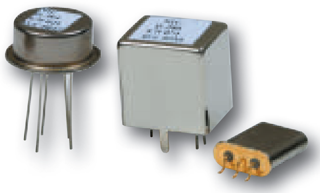

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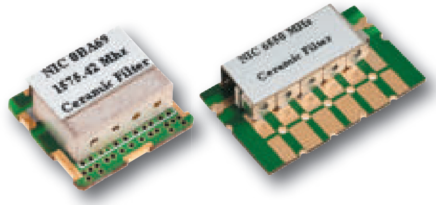

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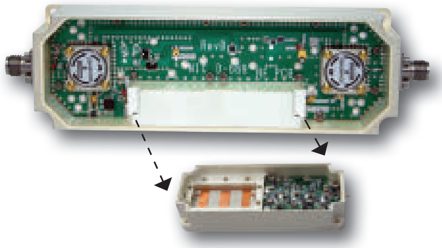

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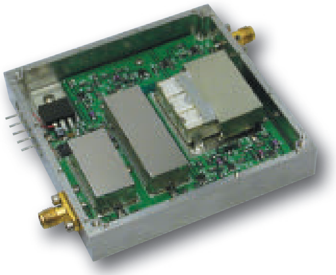

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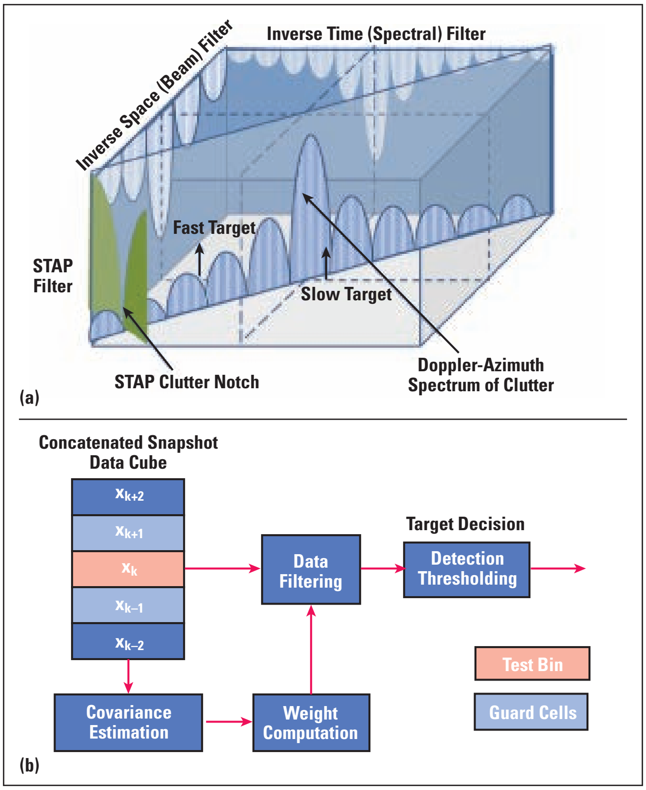
borne polarimetric SAR interferometry (Pol-InSAR) data without the disturbing effect of temporal decorrelation. Kugler, et al., assess the potential of such data for forest applications.[31] For this, single- and dual-pol data acquired over a boreal, a temperate and a tropical site were investigated 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-

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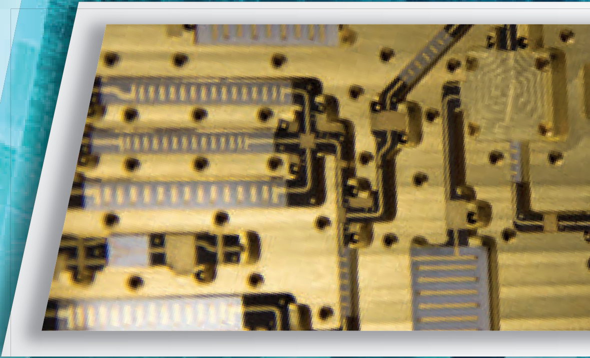

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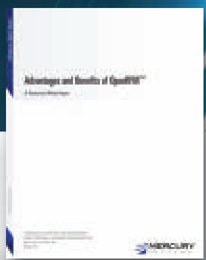
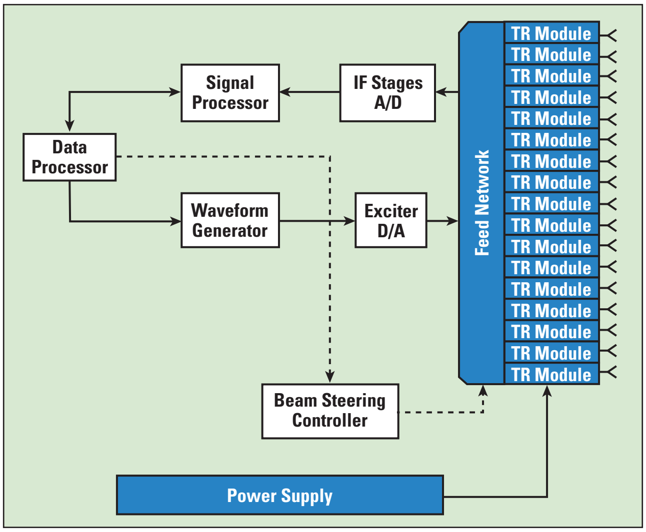


tion (C4) bumping process and is flip-chipped onto a low cost printed circuit board, achieving 50 dB isolation between the transmit and receive chains. This work represents state-of-the-art complexity for a high performance FMCW radar at millimeter wave frequencies, with simultaneous transmit and receive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

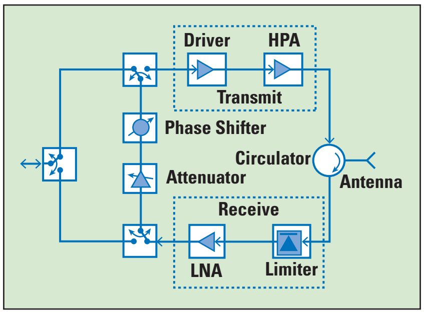
Active airborne antennas are assembled with hundreds or even thousands of transmit/receive modules (see ***Figure 4***). Rieger, et al., describe the evolution of the so-called standardized module solution based on LTCC package technology, with special regard to airborne applications and the correlated 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.

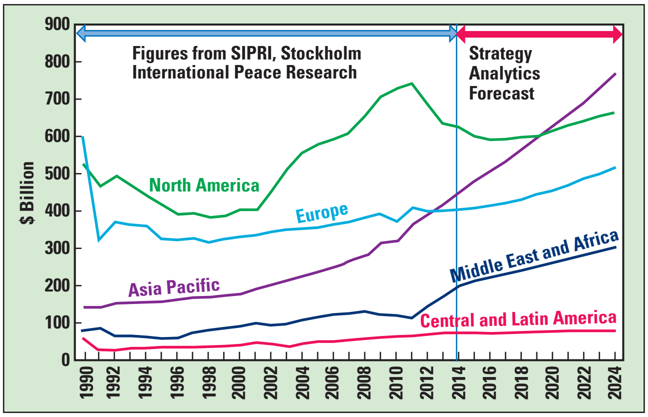
Spending Increases, Technology Differentiation Underpin Military RF Demand

Asif Anwar
Strategy Analytics

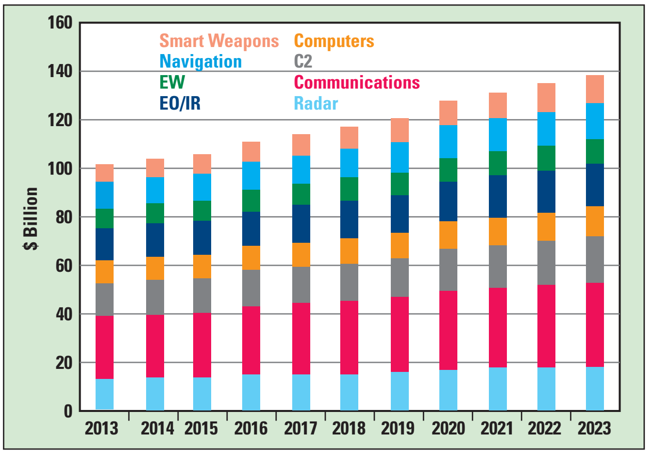
While defense budgets are uncertain, technology has a direct impact on force effectiveness which will lead to an emphasis on enhancing capabilities across radar, EW, communications and other military systems. As a result, more of the defense budget will go into electronics. While no single technology 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***).

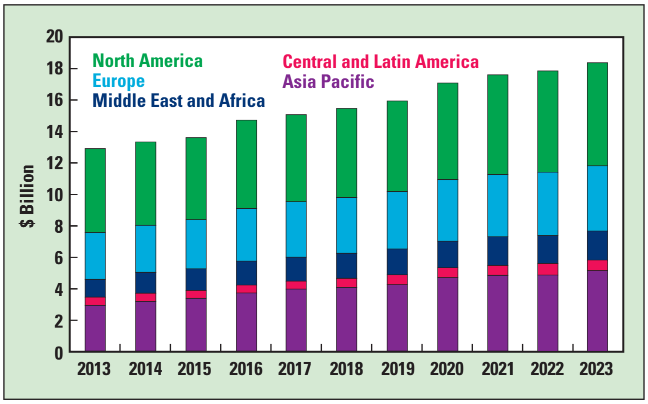
The key driver for this increase will continue to be the emphasis on gaining differentiation through technology, irrespective of whether armed forces are dealing with symmetric, asymmetric or hybrid conflicts. This has been demonstrated throughout history, by military technologies that have enabled capabilities 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-



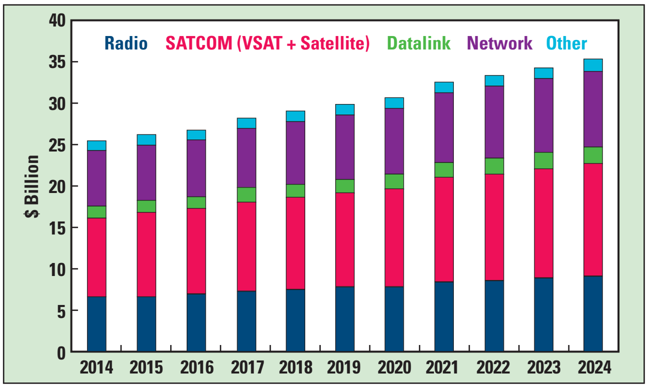
▲ *Fig. 1 Global defense spending, historical and projected.*



▲ *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.

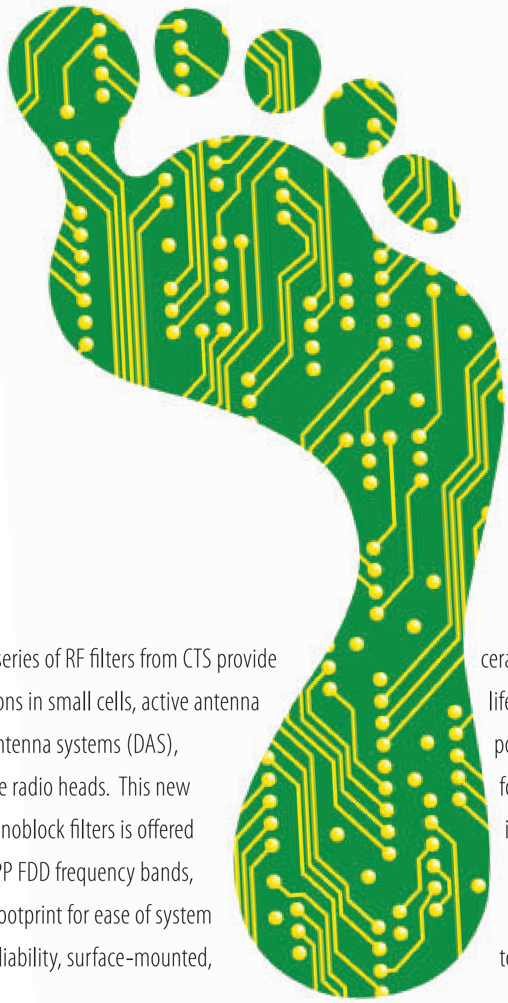
Total radar shipments are forecast to grow at a 4.1 percent CAGR through 2023, reaching 1393 systems. Fire control radar will continue to dominate the traditional mix, yet the fastest growth will be from emerging platforms such as unmanned systems as well as new radar system types.

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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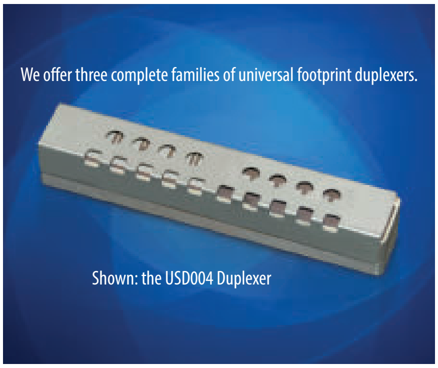

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Insertion Loss (5MHz AVG)	2.2dB	2.6dB	3.0dB
Rx Band Isolation*	80dB	72dB	63dB
Tx Band Isolation	74dB	66dB	57dB
Universal Footprint Size (mm)	62 x 44	63 x 18	44 x 18
Operating Temp Range	-40 to +85°C	-40 to +85°C	-40 to +85°C

* 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.

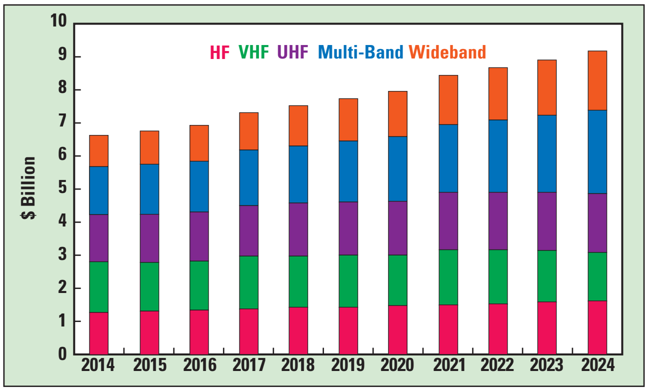
GaN ADOPTION

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.

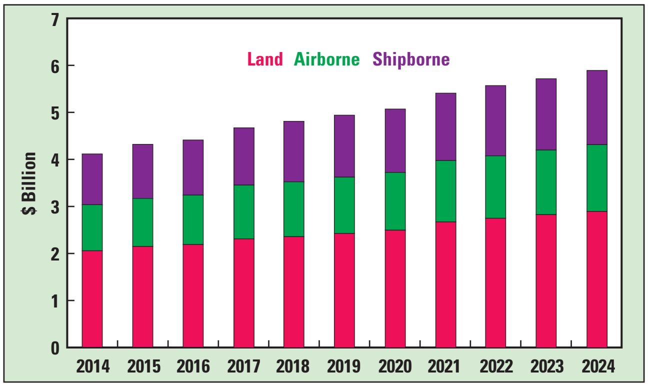
Initial defense needs for GaN have been for EW systems for electronic countermeasures (ECM), specifically land-based RF jammers designed to counter improvised explosive devices (C-IED). Although troop withdrawals from theatres such as Iraq and Afghanistan have reduced volume over the past two years, 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.

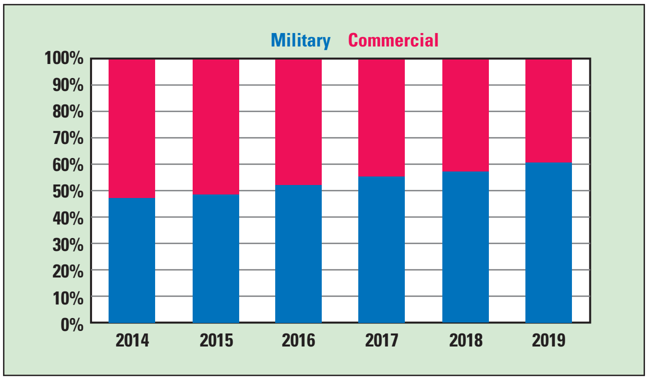
Military communications will also adopt GaN, providing a third avenue of growth for the technology. Collectively, the demand from EW, radar and communications will spur the military GaN RF market to grow at a CAGR of 28 percent, compared to 15 percent for the commercial sector



▲ *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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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.

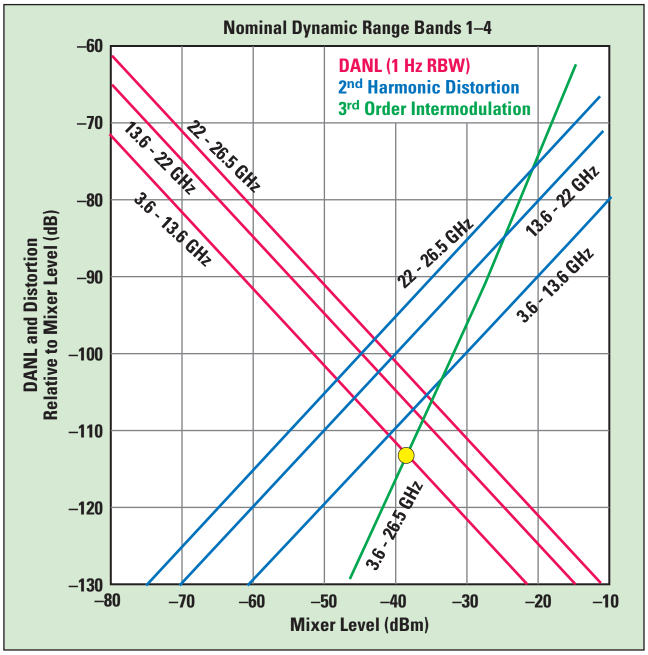
USING CALIBRATION TO IMPROVE SPURIOUS MEASUREMENTS

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.*

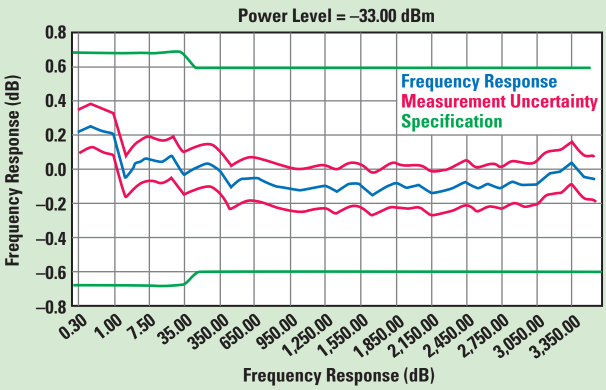
Spur	Range	Frequency	Amplitude	Limit
2	1	1.936 GHz	-81.92 dBm	-50.00 dBm
3	1	1.945 GHz	-82.18 dBm	-50.00 dBm
4	1	1.942 GHz	-82.48 dBm	-50.00 dBm
5	1	1.965 GHz	-83.11 dBm	-50.00 dBm
6	1	1.928 GHz	-83.42 dBm	-50.00 dBm
7	1	1.957 GHz	-83.44 dBm	-50.00 dBm
8	1	1.933 GHz	-83.86 dBm	-50.00 dBm
9	5	829.3 MHz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

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

Report Number
1-5204581261-1-3YLY

Freq Resp 300 kHz to 3.6 GHz Preamp On

Model N9030A Serial US51380102 Test Date 20-Jun-2013 Test Result PASS



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

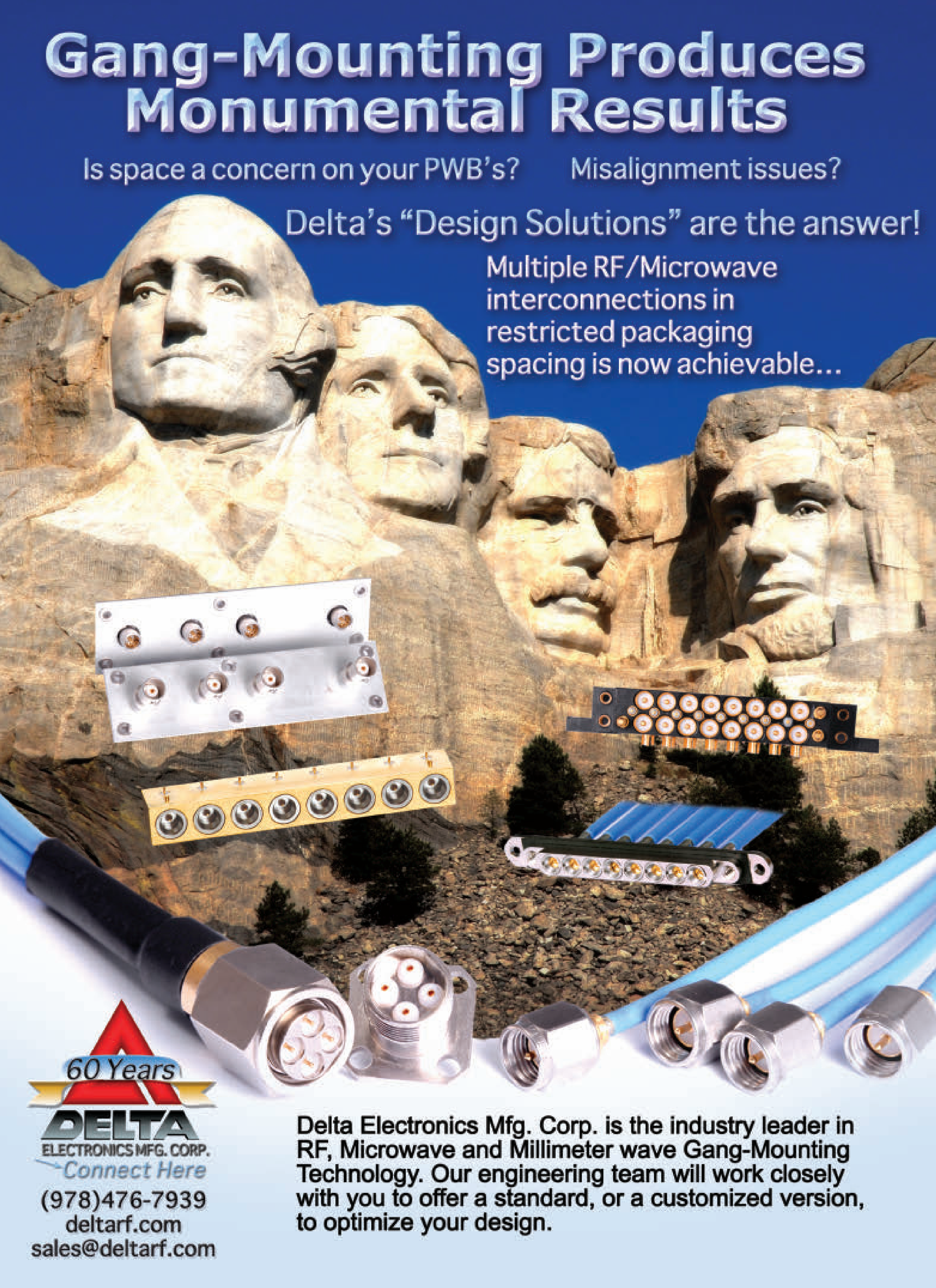
noise level (DANL) of -148 dBm. Because DANL is typically normalized to a 1 Hz RBW, the actual specification is -108 dBm when using a 10 kHz RBW. Residual responses are specified to have a level of -100 dBm or less. Related to this, third-order intermodulation (TOI) is specified to be -90 dBm. Understanding 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. ■

INVITED PAPER

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State-of-the-Art Spectrum Monitoring Technologies

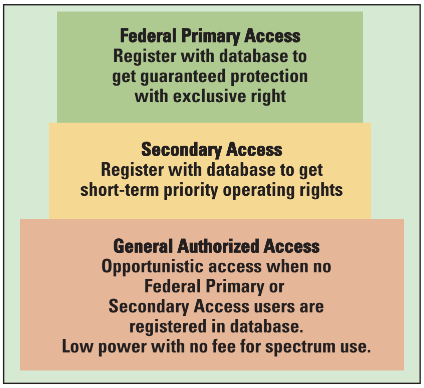
Abhay Samant, Tanim Taher and Ian Wong
National Instruments, Austin, Texas

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

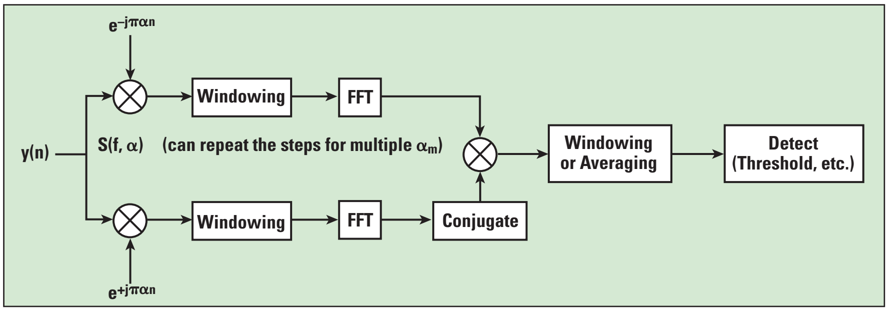
Cyclostationary feature detection (CFD) uses the "spectral correlation function" signal processing technique to detect low power received signals that are often below the noise floor of the spectrum monitor. Modulated information carrying signals are typically modeled as a cyclostationary process. Typically, 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.*

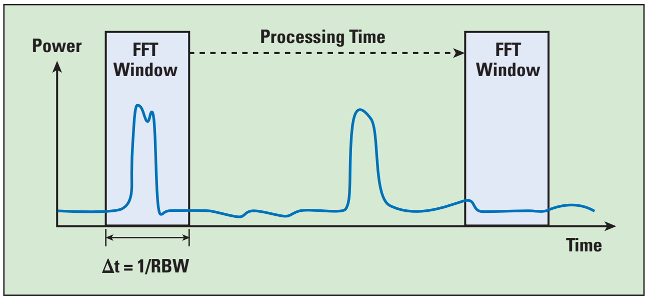


Fig. 3 With a pulsed jamming signal, the identification of subsequent jamming pulses is difficult without continuous acquisition.

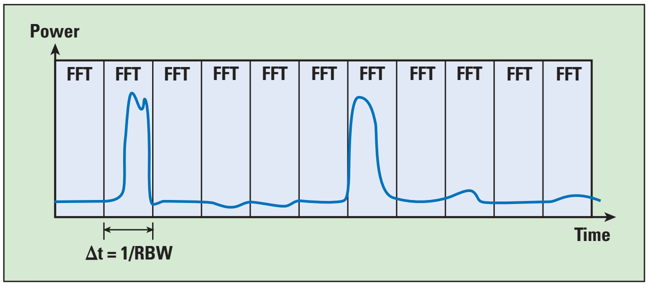


Fig. 4 Post-processing a pulsed jamming signal using FFT analysis.

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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FEATURED MILITARY POWER AMPLIFIERS

	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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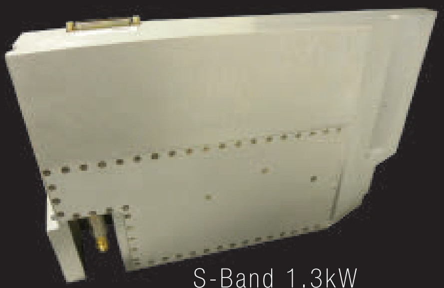

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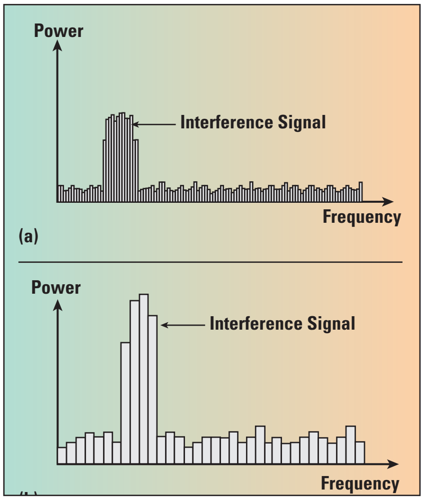


▲ *Fig. 5 Pulsed jamming signal power spectrum with a small (a) and large (b) RBW.*

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"

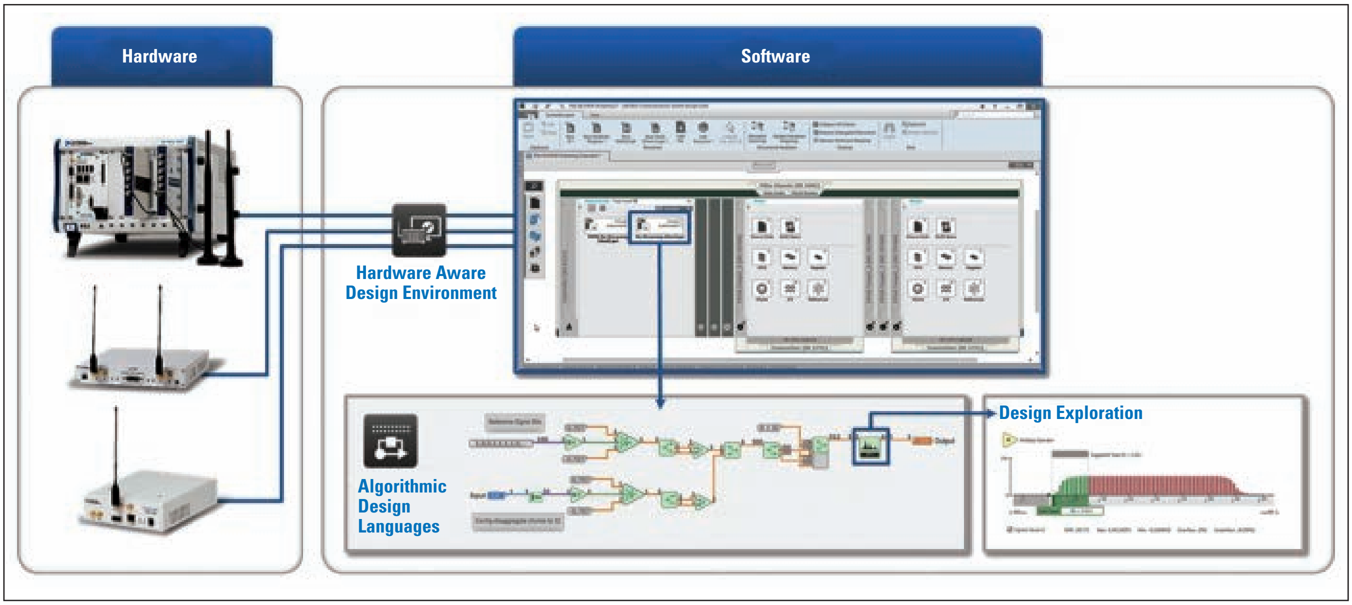
A second type of interference is a pirating or piggybacking communication signal. Here the interferer attempts to use the existing telecommunications infrastructure to illegally transmit by having the repeater rebroadcast an unauthorized signal. Since the repeater simply amplifies a specified spectral 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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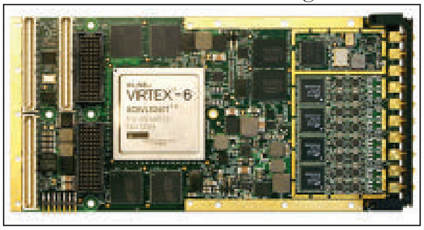
INVITED PAPER

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.

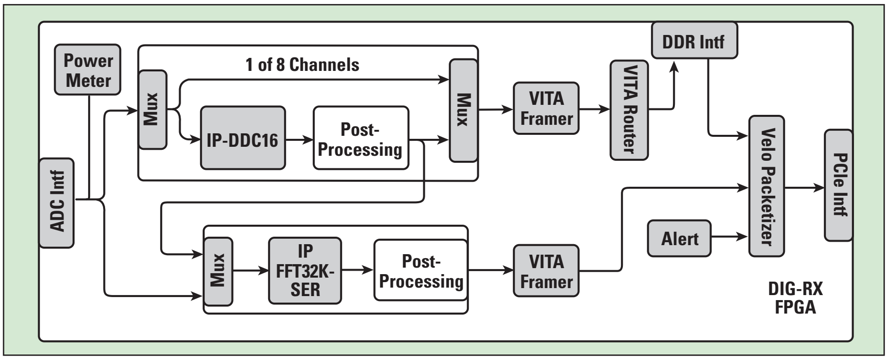


Fig. 2 Digital receiver block diagram.

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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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

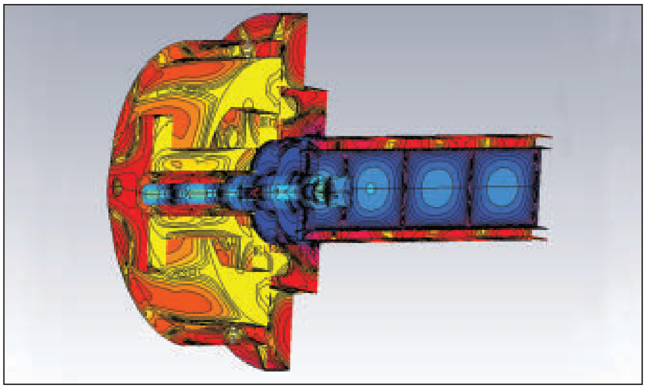
Link Microtek Ltd.
Basingstoke, UK

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.

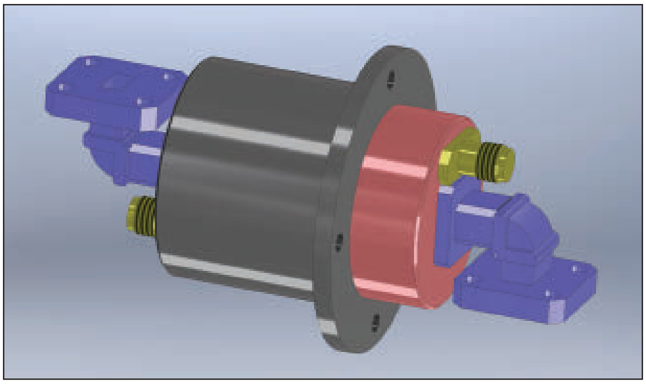
In order to track the satellite, each moving vehicle is equipped with a satcom antenna system mounted on a three-axis, stabilized pedestal. As it is essential for the main axis of rotation to have unlimited 360° movement, cables cannot be used to feed signals to and from the antenna reflector; the only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

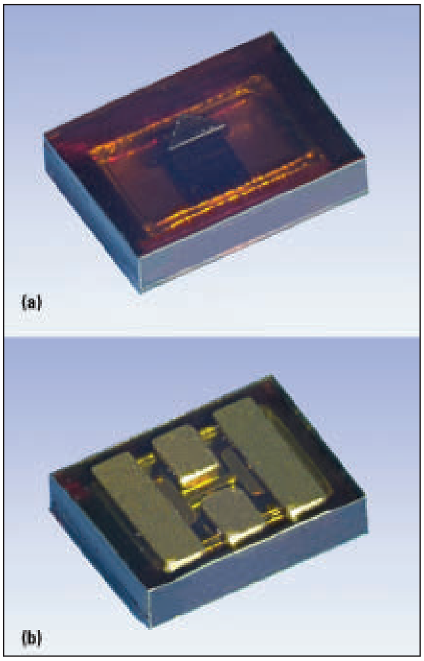
Other configurations of the Ka-Band dual-channel rotary joint can be supplied on request, customized to suit specific antenna requirements. The 3D CAD drawing in ***Figure 2*** shows one possible alternative, utilizing space-saving right-angle WR28 waveguide bends on both sides of the transmit channel.

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

Ka-Band Packaged Schottky Barrier Diode

YOKOWO Co. Ltd.
Tokyo, Japan

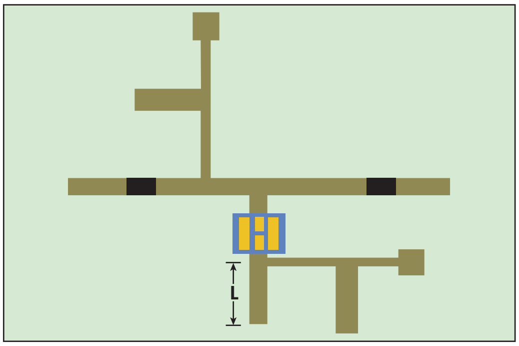
Monolithic ICs have been the trend for millimeter wave circuits. However, improvements in assembly technologies and the fabrication of passive circuits make hybrid IC approaches using discrete devices more feasible at millimeter wave frequencies. The hybrid approach is quite flexible and less expensive 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.*

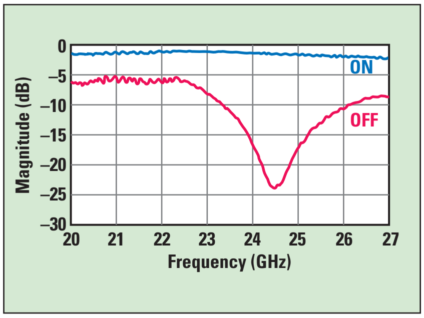


Fig. 3 *SPST switch performance.*

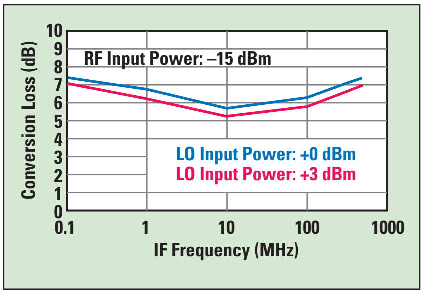


Fig. 5 *Single balanced mixer conversion loss.*

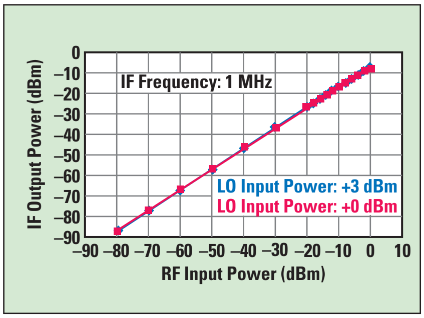


Fig. 6 *Single balanced mixer sensitivity.*

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

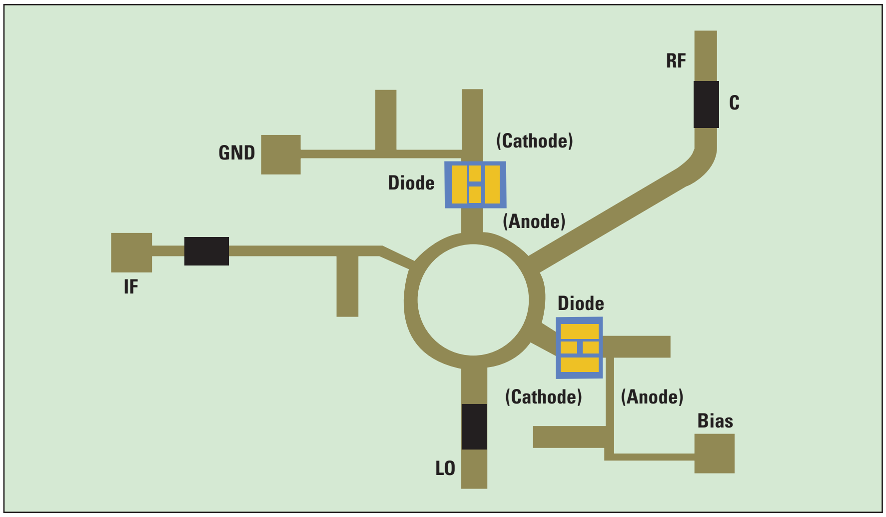


Fig. 4 *24 GHz single balanced mixer layout.*

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).

YOKOWO Co. Ltd.
Tokyo, Japan
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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.

Mercury Systems Inc.
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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.

Through innovative design and engineering, BNC is transcending the power of the laboratory bench and providing power and versatility to field personnel. In doing so, the company has enabled new solutions for applications in electronic countermeasures, bug hunting, electronic warfare and more.

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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.

VENDORVIEW

Analog Devices Inc.
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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).

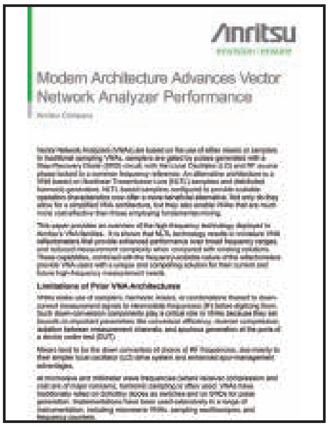
The AMP4002P incorporates an internal filter to keep harmonics better than -60 dBc. Built-in functions include TTL gate control inputs, RF output detector and an over-temperature alarm. Internal circuitry ensures the system is fully protected against all failures. The power amplifier (PA), which is assembled 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

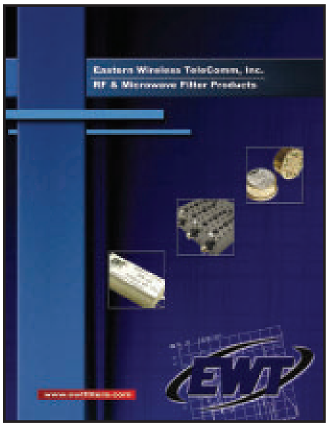
Check out CTT's four-page power amplifiers short form catalog. The catalog features more than 75 models developed for radar, EW and multi-function systems design. The amplifiers feature narrowband CW, narrowband pulsed, wideband (CW) and ultra-wideband (CW) coverage. Frequency coverage is from 0.1 to 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

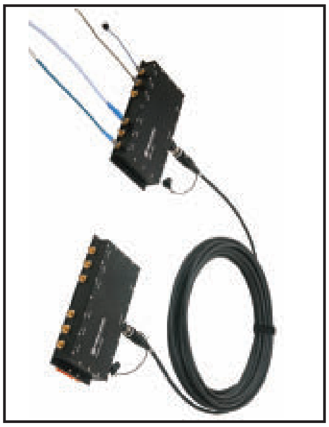


RF & MICROWAVE FILTER PRODUCTS

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



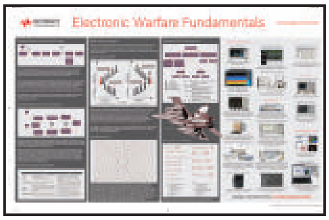
WE'RE ALL OVER!

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.

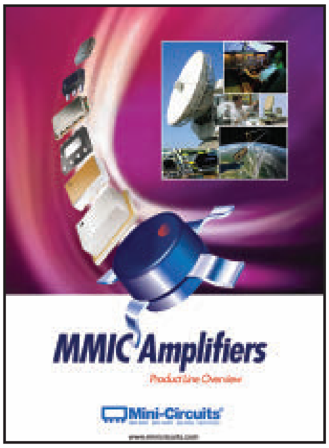
www.keysight.com/find/ew-focus

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

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

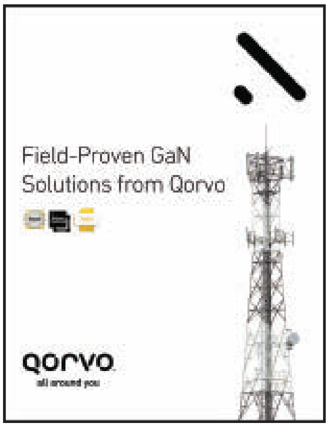
COMPANY SHOWCASE

TRIFOLD BROCHURE

VENDORVIEW

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.

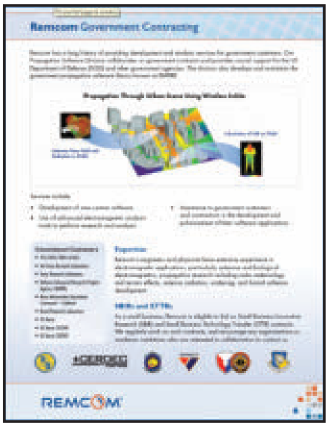
Qorvo Inc.
www.qorvo.com/defense

FILTERS, MULTIPLEXERS AND MULTI-FUNCTION ASSEMBLIES

VENDORVIEW

When being first to react makes all the difference in the world, choose Reactel for your mission-critical filter requirements. You can count on Reactel to satisfy the most demanding requirements for units used in extremely harsh environments. 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.

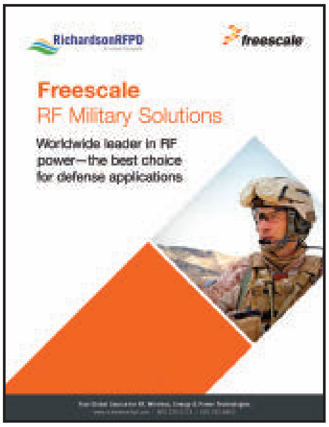
Reactel Inc.
www.reactel.com



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

VENDORVIEW

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.

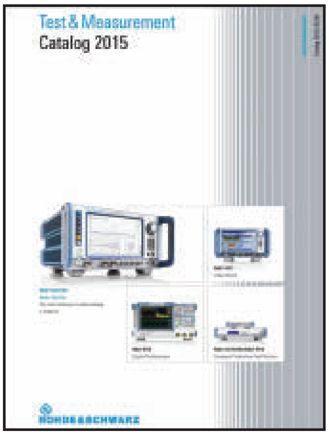
Richardson RFPD
www.richardsonrfpd.com

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

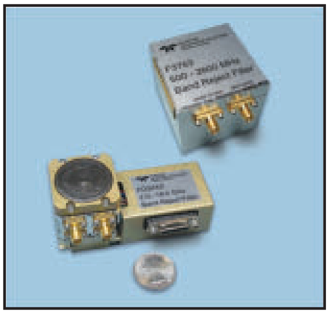
The BB60C is a broadband real-time spectrum analyzer and RF recorder that captures and displays RF events as short as 1 µs. It has selectable IF streaming bandwidths from 250 kHz up to 27 MHz. With accurate operation from 9 kHz to 6 GHz over its entire temperature range (-40° to +65°C available), the 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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Explore the limits.
T&M solutions for aerospace and defense.
Today's aerospace and defense technologies demand ever more sophisticated test and measurement solutions to stretch the limits of what is feasible. As a full-range supplier, Rohde & Schwarz offers a broad portfolio that proves its capabilities in even the most demanding applications. Our leading-edge expertise in microwave, RF and EMC helps customers assess performance, optimize platforms and get the most out of systems. Convince yourself.
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R&S®FSW signal and spectrum analyzer
Models up to 67 GHz NEW
Up to 500 MHz analysis bandwidth NEW
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Pulse parameters at a fingertip
Unmatched low phase noise of –137 dBc (1 Hz) at 10 kHz offset (1 GHz carrier)
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