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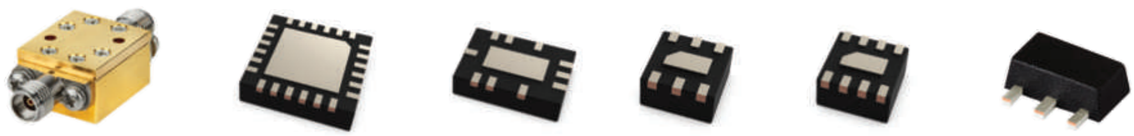

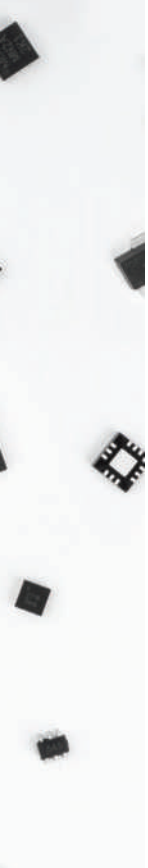

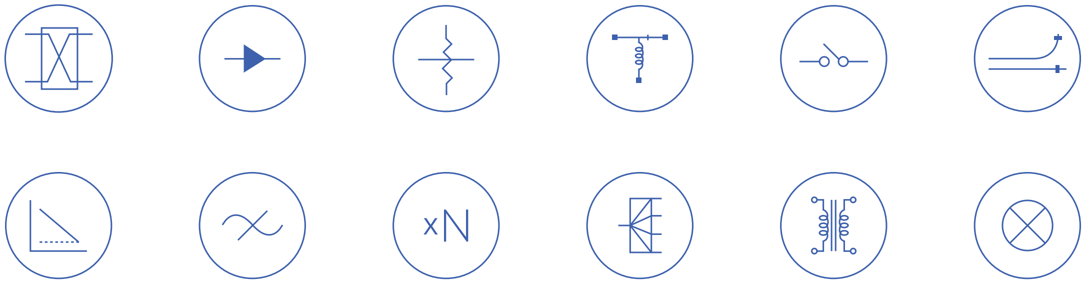

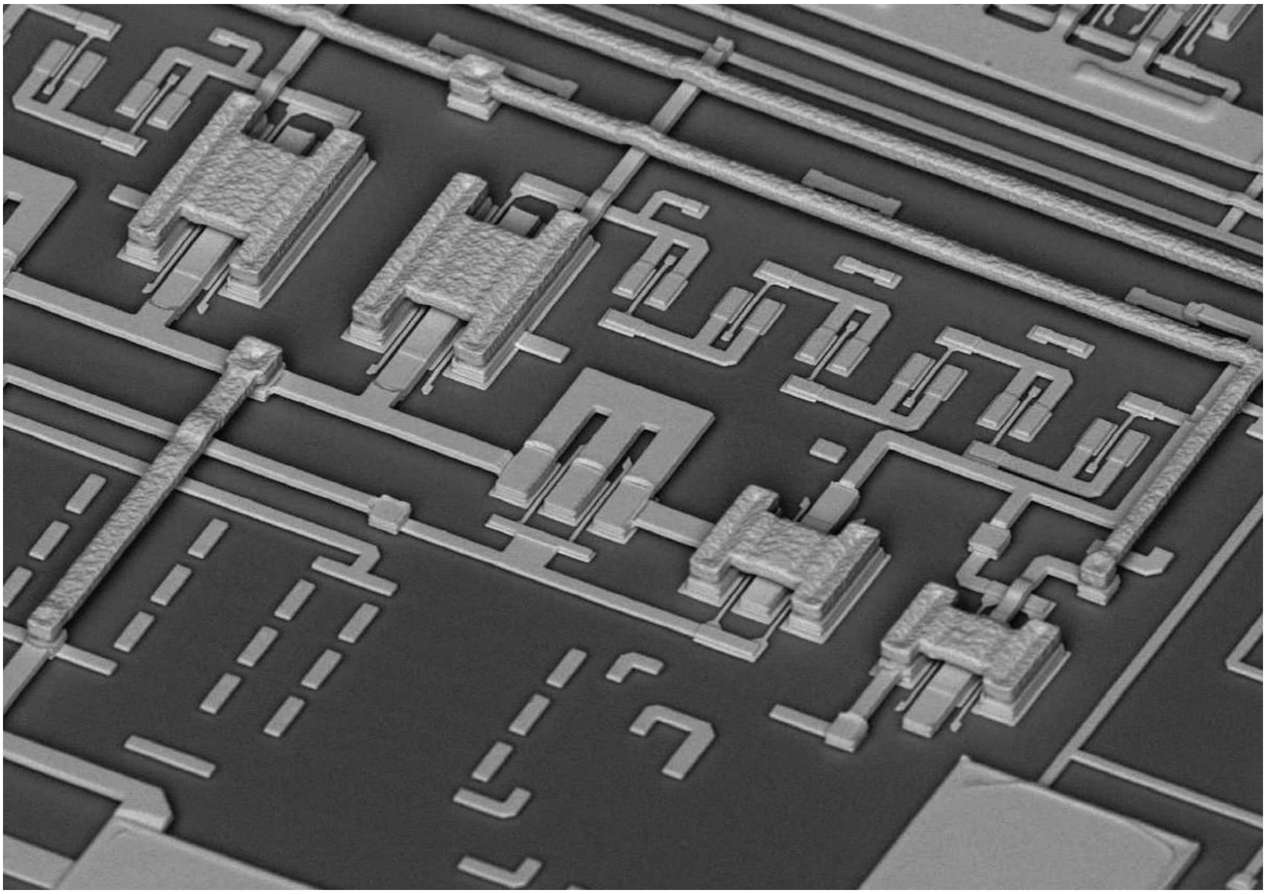

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CONTENTS

June 2022
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Semiconductors, MMICs & RFICs
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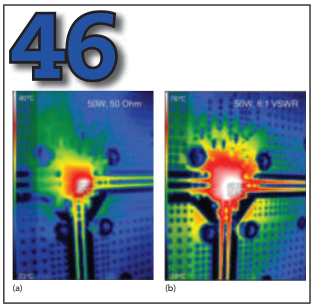

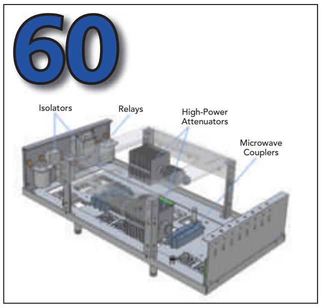

online spotlight

Look for this month's exclusive article online at mwjournal.com

Real-Time Outlier Removal in MMIC Testing Using an n-Dimensional Ellipsoid Criterion

Abigail Eisenklam and Charles Trantanella

Cover Feature

20 **SOI RFIC Tunable Filters Improve Phased Array System Performance**
Leopold E. Pellon, Otava Inc.

Technical Feature

46 **The Use of GaN RF Switches in High-Power Radio Design**
Manish Shah, Tagore Technology Inc.

Application Note

60 **The Unique Challenges of GaN Amplifier Production Test**
Devin Morris, Roos Instruments

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CONTENTS

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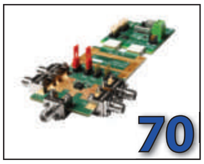

Product Feature

70 **18 GHz SP4T MEMS Switch with Integrated Driver**
Menlo Micro

Tech Briefs

74 **Small, Broadband, Cost-Effective Chip Attenuators**
RFMW and Smiths Interconnect

76 **GaN LNAs Offer High Power Handling with No Limiters, Cover 1–23 GHz**
Pasternack

Departments

17 Mark Your Calendar
35 Defense News
39 Commercial Market
42 Around the Circuit
78 Making Waves
80 New Products
86 Book End
88 Ad Index
88 Sales Reps
90 Fabs & Labs

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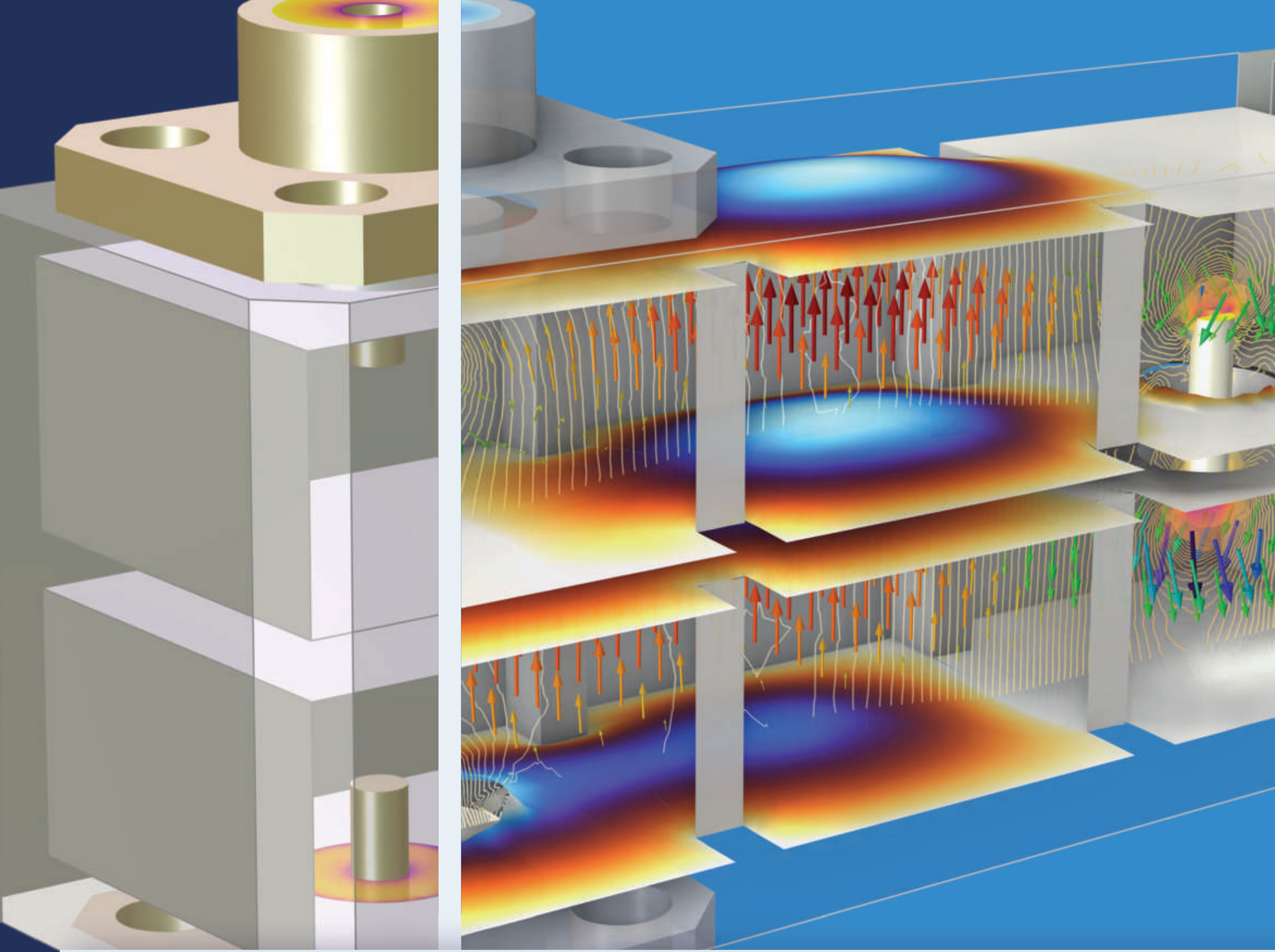

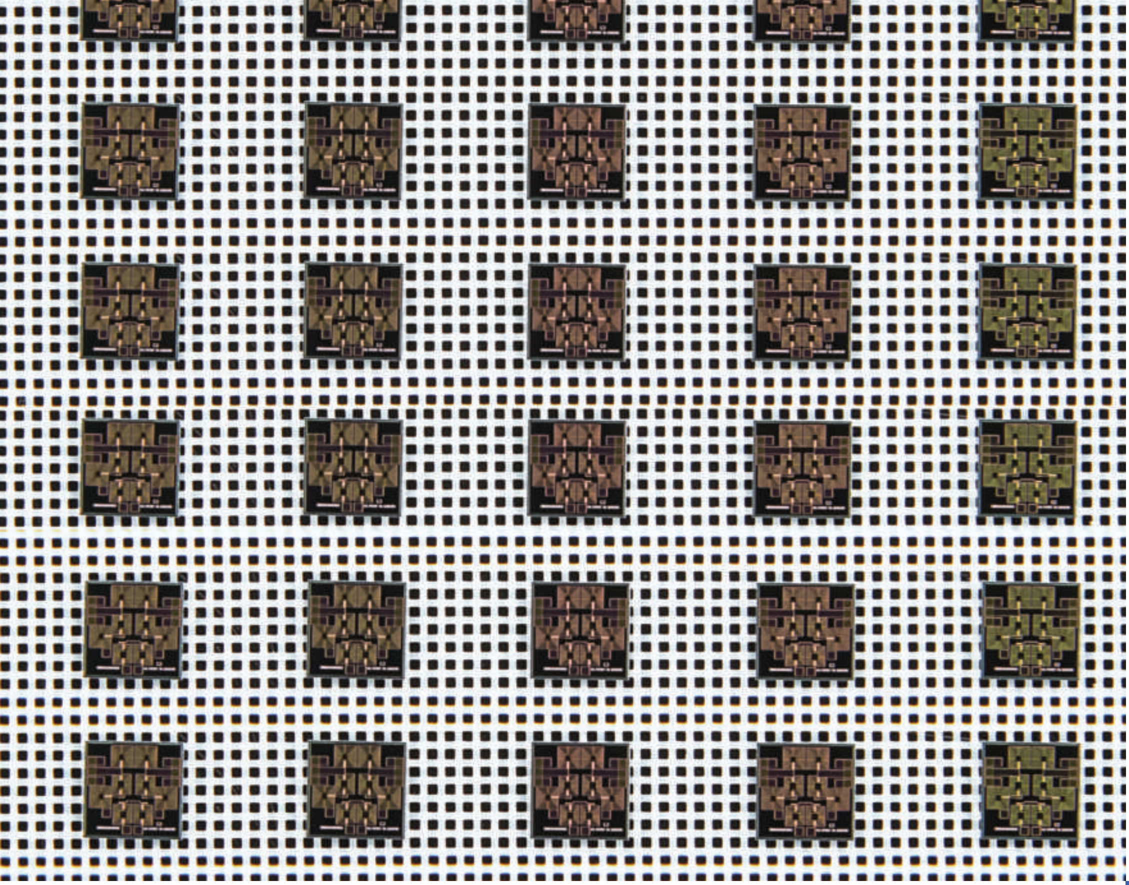

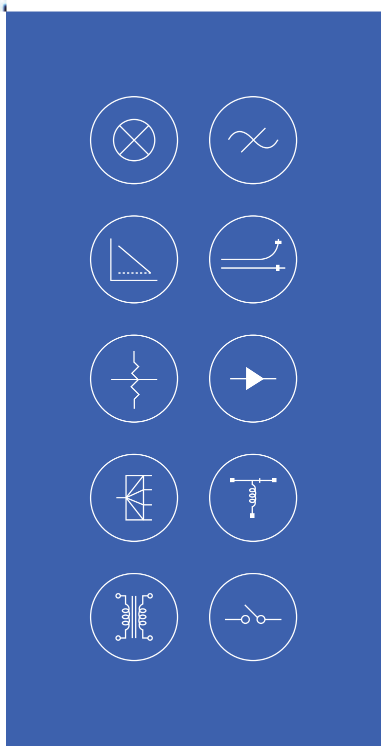

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SOI RFIC Tunable Filters Improve Phased Array System Performance

Leopold E. Pellon
Otava Inc., Moorestown, N.J.

The capabilities and impact of new silicon on insulator (SOI) tunable filter ICs on the design of the RF chains of phased arrays are discussed. These new devices provide an advancement in tunability, small size and high linearity, which supports efficient approaches addressing challenges of interference and wider operating bandwidth. These RFICs can be integrated into wideband active stages of RF front-ends (RFFEs) for wide bandwidth, software-defined arrays for cost effective multifunction systems. To illustrate the advantages, a notional wideband dynamically programmable frequency-division duplex (FDD) system operating from 4 to 8 GHz (C-Band) is discussed. To assist system architects exploring the uses and programming of this newly available set of components, software tools have been developed, including accurate behavioral tuning models, which complement evaluation kits for user prototype system development efforts. This article is an abbreviated version of an article published online at www.microwavejournal.com.

For RF applications such as communications and radar, active phased array antennas provide an efficient way to steer and direct the system's radiated RF energy to achieve the desired effective isotropic radiated power (EIRP) on transmit and the gain over noise temperature (G/T) on receive, which are required for communications link closure or the detection and measurement of mobile targets. To maximize the signal-to-noise and interference ratio (SNIR), analog, digital or hybrid beamformers shape the array antenna gain and patterns optimally based on incoming signals, calibration and sounding data. Arrays employed for both military and commercial systems range from small arrays with less than a hundred elements, which achieve moderate antenna gain, to large arrays with thousands of elements, which achieve higher gain and finer pencil beams. However, the performance and benefits of the phased array can be limited by the trade-offs of the constituent RF chains employed, particularly considering the impact of nearby interference.

Among the trade-offs for phased arrays, increasing the operating bandwidth is a necessity when considering multifunction utility and flexibility. However, widening the operating bandwidth can increase wideband emissions and increase exposure to nearby high-power transmitters, producing "blindness" or reduced sensitivity in the receiver. Therefore, the ability to reconfigure the properties of the chain to reduce emissions and the effects of interference on a selected passband within the wider operating band is desired.[1-6]

Another important trade-off is the cost effectiveness of the solution. Array hardware cost is only one consideration; one must account for the service or mission objectives as well. Other factors which are universal to consider include the supporting I/O, fronthaul and backhaul, platform (or site) space available, available power generation and heat removal. These can also drive cost effectiveness. Hence, in-

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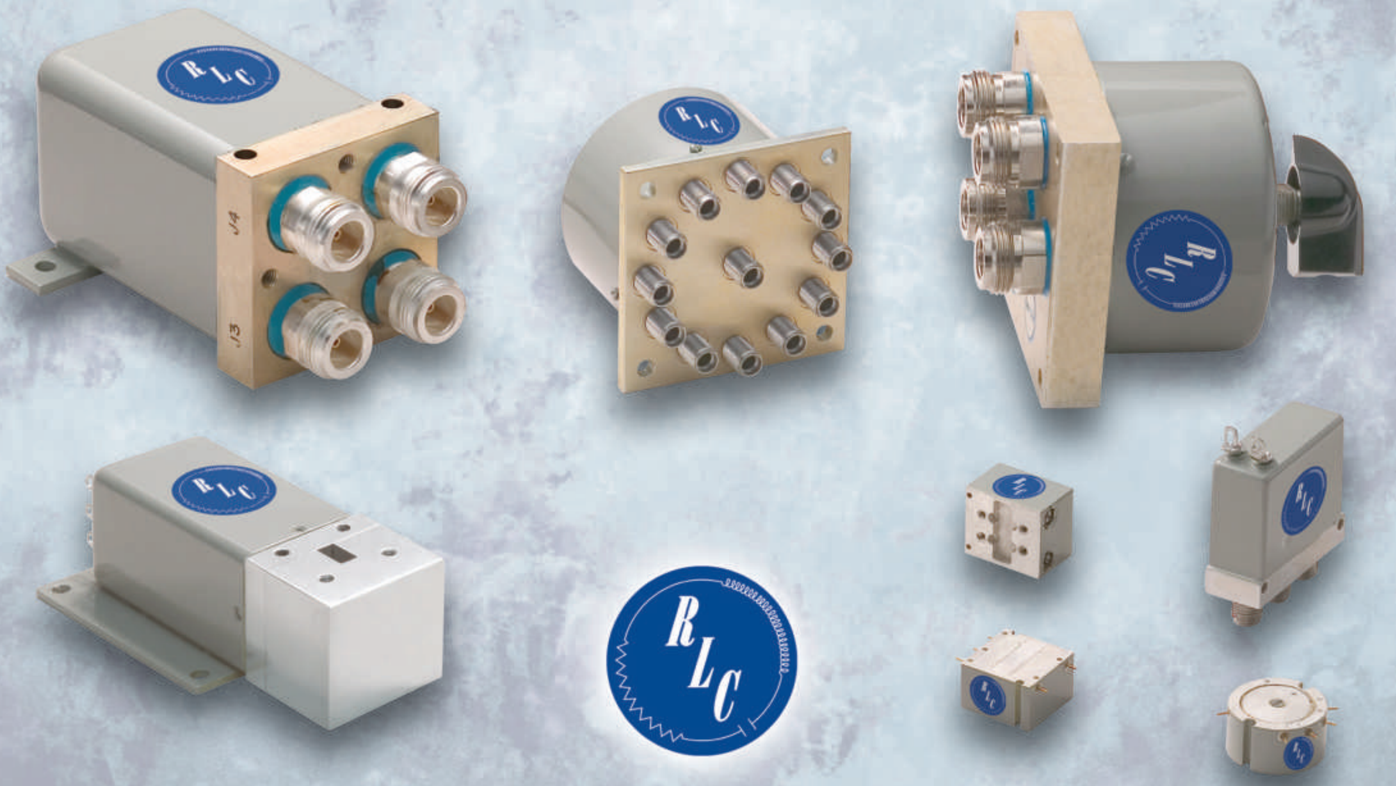

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TABLE 1
SOI TUNABLE FILTER PERFORMANCE

Parameter	*OTFL101*	*OTFL201*	*OTFL301*
Center Frequency Range (GHz)	2.5-7.5	14-24	24-40
Bandwidth Range (%)	24-16	17-15	20-16
Loss Range (dB)	5-7	5-7	5-7
Typical Return Loss (dB)	12	12	12
Power Handling (dBm)	30	30	30
IIP3 (dBm)	45	42	42
# of Tunable Resonators	5	5	5
Resonator Control States	32	16	8
Tuning Settling Time (nS)	400	400	400
Control Loading Time (nS)	500	400	300
Die Dimensions (mm)	2.3 x 1.6	1.6 x 1.6	1.6 x 1.6

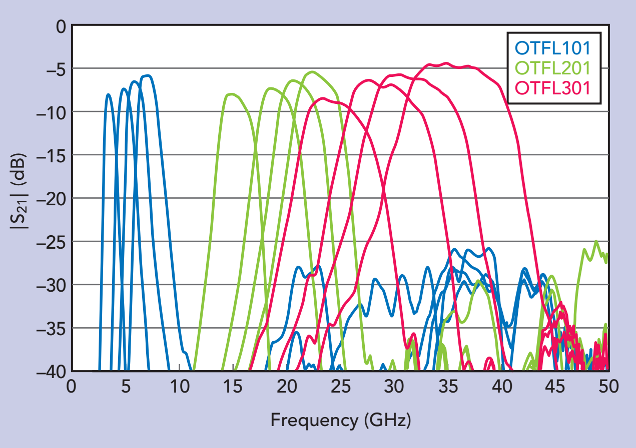

Fig. 1 Measured responses of the three tunable SOI RFIC filters.

creasing the operating bandwidth is desirable to achieve a greater return on investment for commercial systems and to improved mission effectiveness for military systems—so long as the requirements of each are satisfied simultaneously.[1-5]

WIDEBAND TUNABLE FILTERS

To fill the need for improved spectral control and agility, newly available miniaturized high linearity and tunable (or switchable) filter products are being introduced, which can be integrated into phased array front-ends. This article focuses on architectures that make maximum use of this family of components, illustrating the utility with three RFICs developed by Otava Inc. that cover 2.5 to 40 GHz (see ***Table 1***).[4] Their performance supports the thesis of this article, i.e., their linearity, power handling and tuning range provide flexible operation when the RFICs are used within active RF chains. An overlay of the measured transfer functions of the three devices is shown in ***Figure 1***. The results shown were obtained using "simple" tuning where all resonators are tuned to the same control value.

Programming is controlled through a three-wire serial interface, where each of the resonators have five-bit tuning coefficient resolution, sufficient for center frequency, and bandwidth optimization. A combined time of less than 1 µs is required for reconfiguration. Beyond the simple tuning method, the large number of degrees of freedom enables innovative approaches to optimize filter tuning. To assist system architects exploring these capabilities, a companion behavioral model, capable of predicting filter passband and sideband skirts accurately—to 40 dB attenuation as a function of user-defined control variables has been developed and is available.

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FD-30M-6M-1515	30	1000 mV/MHz	±5% Max	-10 to 0 Min	4.625” x 1.5” x 0.47” SMA (F)
FD-70M-50M-1212	70	100 mV/MHz	±5% Max	-10 to 0 Min	4.625” x 1.5” x 0.47” SMA (F)
FD-74M-10M-1212	690 - 790	100 mV/MHz	±5% Max	-10 to 0 Min	4.625” x 1.5” x 0.47” SMA (F)
FD-160M-100M-1515	160	9.5 - 10 mV/MHz	±5% Max	-10 to 0 Min	4.625” x 1.5” x 0.47” SMA (F)

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DFD-2G18G-5512	2 - 18	Digital	14 Bits	4.5 MHz (Average)	-50 to +15	5.98” X 5.79” x 1.28” SMA (F)
FD-0518-10-2G4G	2 - 4	Analog	1 V/GHz Nom	±100 MHz	10 ± 0.1	2.0”x 1.82” x 0.5” SMA (F)
FD-0518-10-3D1G3D5G	3.1 - 3.5	Analog	50 mV/GHz	±20 MHz Max	10 ± 0.1	2.0”x 1.82” x 0.5” SMA (F)
FD-0518-10-48	4 - 8	Analog	50 mV/GHz	±200 MHz	10 ± 0.1	2.0”x 1.82” x 0.5” SMA (F)
FD-0518-10-610	6 - 10	Analog	50 mV/GHz	±200 MHz	10 ± 0.1	2.0”x 1.82” x 0.5” SMA (F)
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FD-0518-10-812	8 - 12	Analog	50 mV/GHz	±200 MHz	10 ± 0.1	2.0”x 1.82” x 0.5” SMA (F)
FD-0518-10-1218	12 - 18	Analog	50 mV/GHz	±200 MHz	10 ± 0.1	2.0”x 1.82” x 0.5” SMA (F)


DFD-2G18G-5512


FD-0518-10-2G4G


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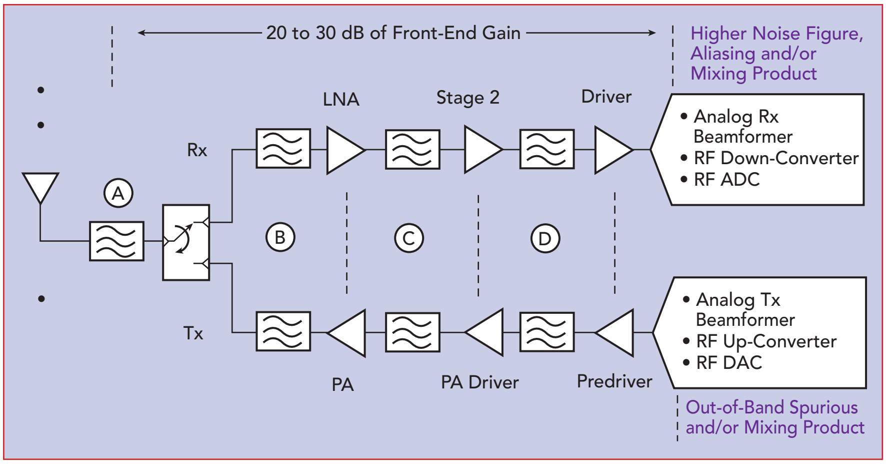


Fig. 2 Possible filter placement in a phased array.

the following elements of a phased array design: linearity and sensitivity, operating bandwidth and tuning agility, control of passband gain and interference rejection, element-to-element tracking that affects the sensitivity of the beamforming patterns to temperature variations and array packaging density.

Figure 2 shows the potential locations for filters within a phased array front-end. Perhaps the ideal location is placing the "filter first" in the common leg (position A) and/or in the separate transmit (Tx) and receive (Rx) paths (position B). Filters at these "filter first" locations, however, require ultra-low loss and high-power handling filters for Tx and ultra-low loss for Rx. Unfortunately, current technologies for wideband tunable filters do not support the losses, linearity and size required for this "filter first" architecture in a phased array.

An alternative is employing a low gain power amplifier (PA) output stage and a low gain, low noise amplifier (LNA) input stage, both in combination with moderate loss tunable filters placed at location C. With additional gain required, adding filters at location D enables the cascade of filters to achieve a higher-order and steeper out-of-band response

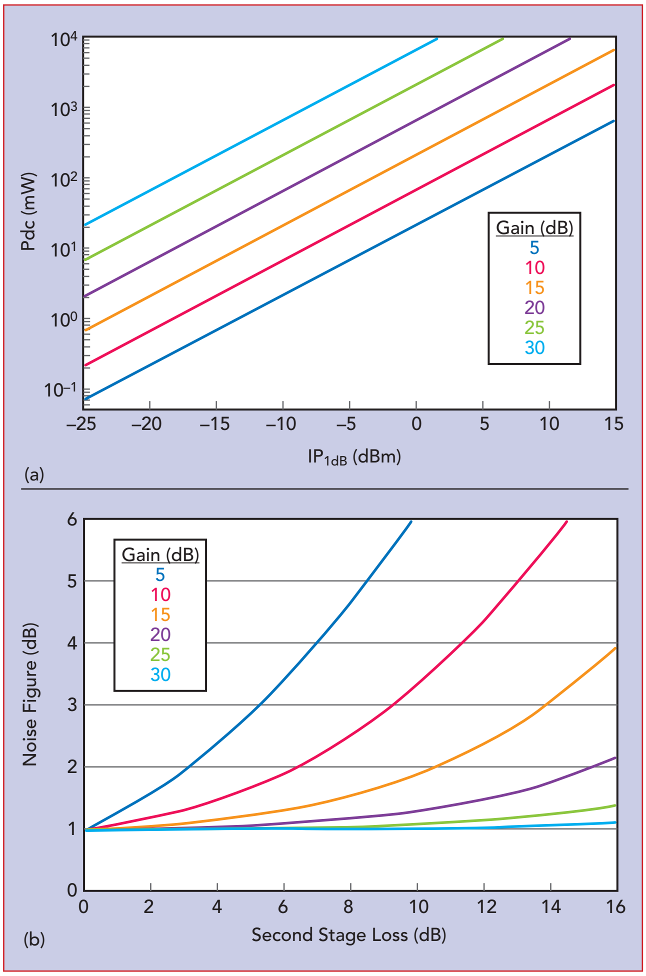
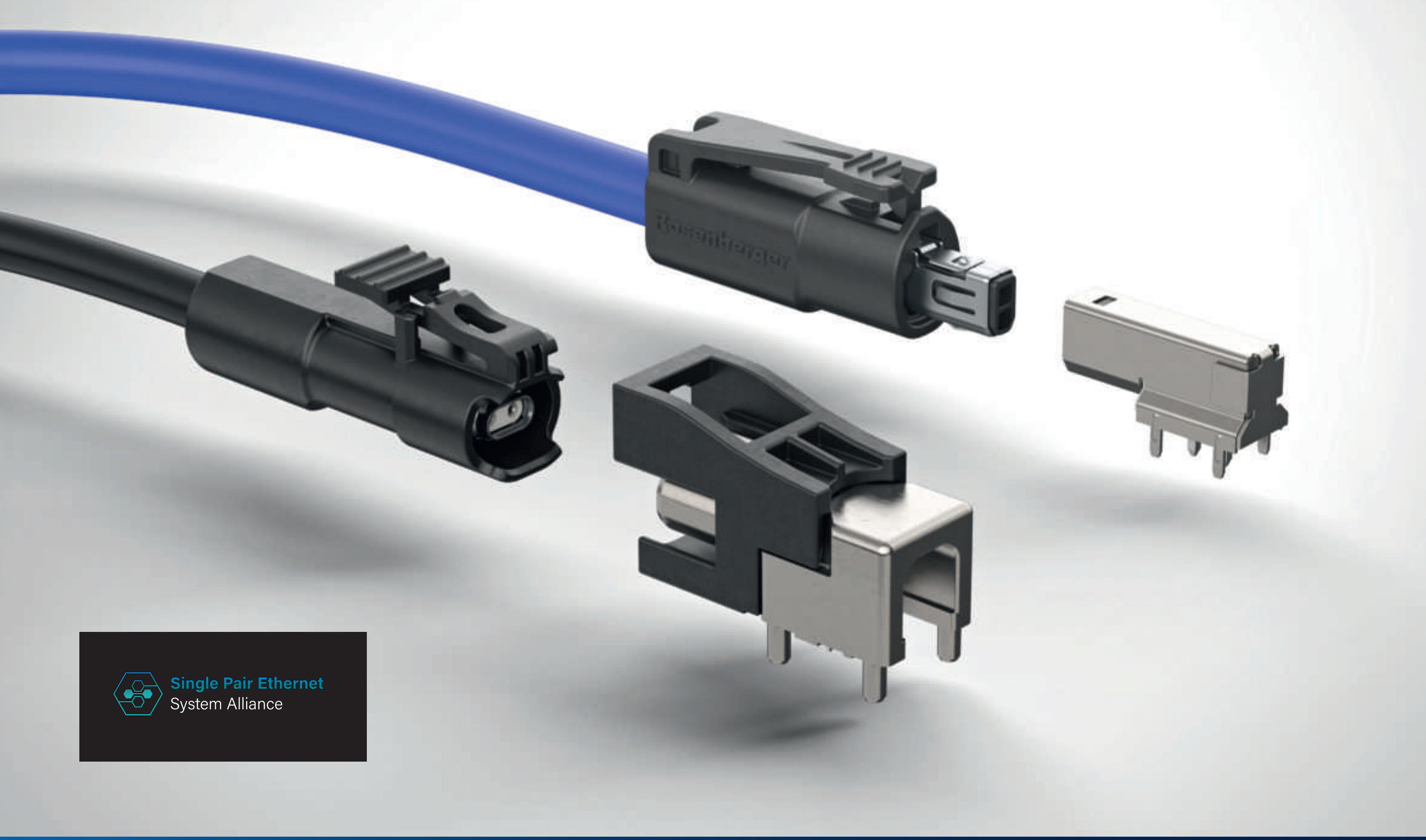


Fig. 3 Effect of LNA gain on front-end power consumption (a) and noise figure (b), assuming an LNA with 1 dB noise figure and 15 percent efficiency at the P1dB operating point.



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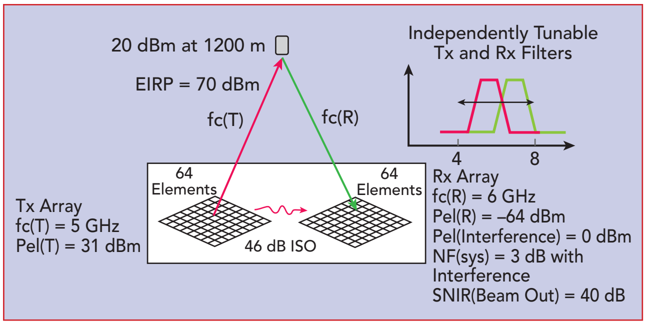

Fig. 4 Scenario with dual, colocated FDD capable arrays.

for improved performance. In the Rx path, excessive amplification of out-of-band interference is avoided by distributing the filters. Normally, an LNA employs multiple stages to achieve the 20 to 30 dB gain required, given the high noise figure of downstream components, i.e., the beamformers, mixers and analog-to-digital converters (ADCs). In this "filter last" topology, the out-of-band interference is amplified in each active stage prior to filtering, requiring high LNA power handling—although this achieves the best small signal noise figure. Under large signal interference conditions, however, noise is further degraded. By comparison, a lower LNA power handling is required for the "filter first" topology, but at the expense of the total system noise figure.

Figure 3 illustrates two of the Rx chain trade-offs for the design of a front-end consisting of an LNA first stage followed by a lossy or noisy component. Assuming an LNA with 15 percent efficiency, Figure 3(a) shows the power consumption of the LNA versus the input 1 dB compression point (IP1dB) for LNA gains from 5 to 30 dB.[7–9] Assuming the LNA has a 1 dB noise figure, Figure 3(b) plots the combined noise figure of the chain versus the loss of the following lossy component, again with LNA gains from 5 to 30 dB. To achieve 0 dBm input P1dB, the required DC power varies from 25 mW to 6.7 W over the range of gains. For example, an LNA first stage with 25 dB will consume 2 W typically to maintain dynamic range.

A more optimum choice is a distributed filter chain, where 10 to 15 dB gain in the first stage LNA is sufficient to achieve an overall noise figure under 2 dB, assuming a loss of 6 to 10 dB for each filter. The power required to achieve 0 dBm input P1dB drops by about 9x for the "distributed filter" topology compared to the "filter last" topology, while also producing a much lower noise figure than the "filter first" topology. After the first active filter stage, the power consumption downstream to maintain system linearity is greatly reduced.

The SOI RFIC filters of Table 1 are small enough to support phased array half-wavelength lattice spacing, i.e., $d = \lambda/2$. For example, the fifth order bandpass filter OTLF101 die size is 2.3 × 1.6 mm, which supports filtering for arrays up to 8 GHz while occupying only 1 percent of the available area per element. At higher frequencies, the OTFL201 occupies 6.6 percent of the available area at 24 GHz, and the OTFL301 occupies 18 percent at 40 GHz. Hence, these three devices can be integrated into distributed filter array front-ends from 2.5 to 40 GHz.

C-BAND T/R PHASED ARRAY

To illustrate the use of filter RFICs, consider a notional system composed of at least two arrays capable of FDD operation over an operating band covering C-Band, i.e., 4 to 8 GHz (see ***Figure 4***). With one of the arrays transmitting and the other simultaneously receiving, each array is programmed for a different center frequency within C-Band, accomplished with signal chains using the tunable RFIC filters at locations C and D, as shown in Figure 2. We will assume a digital beamforming architecture for this system. Combining the RFFE with an RF class ADC, a complete direct digital elemental receiver is enabled. By adjusting the RFFE transfer function and the ADC Nyquist Zone, one can cover the entire operational band while protecting the receiver from strong cosite interference. The RF chain must provide the gain and anti-aliasing filtering for driving the ADC input under multiple in-band and out-of-band conditions.

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TABLE 2
WIDEBAND FDD DUAL ARRAY SYSTEM GOALS

Parameter	Value
Operating Band (GHz)	4-8
Instantaneous Bandwidth (MHz)	200
Minimum Δf =|fc(T)-fc(R)| (MHz)	600
# Elements per Array	64
Array Antenna Gain, No Loss (dB)	24
Antenna and T/R Switch Losses (dB)	3
Tx Pelement (dBm)	31
EIRP (dBm)	70
Mean Power Aperture (dBm)	46
Pcosite at Rx Antenna Element, Case 1 (dBm)	0
Psignal at Rx Antenna Element (dBm)	–64
Out of Band Input IP3 (dBm)	20
System Noise Figure, RF to ADC Chain (dB)	3
Rx G/T (dB/K)	–7
SNIR at Beamformer Output (dB)	40

The goal is maximizing the received remote signal of interest relative to the combined noise, interference and distortion floor at the output of the ADC and the digital beamformer. The primary challenge for the Rx array is maintaining sensitivity to the desired signals in the presence of out-of-band interference within the same 4 to 8 GHz operating band. Assume the arrays operate with a frequency separation of Δf, where Δf = |fc(Tx)-fc(Rx)| and that both arrays have a 200 MHz wide passband. The allowable Tx power is determined by the spatial separation, near-field isolation and allowed frequency separation between the arrays, in addition to the performance of the Rx element chain. This wideband FDD software-defined array with two colocated apertures will be analyzed for a primary scenario (case 1) with one local transmitter.[5] A second scenario (case 2) with two local transmitters is analyzed in the longer, online article. The performance goals for the dual array system are summarized in ***Table 2***.

For in-band signals, the smaller signal of interest is received over a 200 MHz passband within the operating band. For example, a high data rate downlink uses a 20 dBm EIRP remote transmitter at 1200 m tuned to fc = 6 GHz, resulting in -64 dBm signal power into the Rx element active chain. A total system noise figure of 3 dB produces an effective -88 dBm input noise floor including ADC noise, where the RF chain is allocated a 2 dB noise figure and drives its noise floor above the self-noise of the RF ADC for a combined 3 dB system noise figure, while providing 60 dB of digitized dynamic range above this floor over the 200 MHz bandwidth. The gain required for this is nominally 25 dB for most RF ADCs. The signal-to-noise ratio (SNR) obtained at the output of the beamformer is nominally 40 dB for the smaller signal of interest in this case, which is sufficient for high spectral efficiency 5G multi-gigabit data rates.

For this scenario, out-of-band interference is defined for the Rx array operating adjacent to the 64-element Tx array transmitting 31 dBm rms per antenna element. This yields a 70 dBm EIRP main beam and aperture power of 46 dBm. From the requirements shown in Table 2, the Rx system must maintain linear and sensitive operation up to an input P1dB of 0 dBm while suppressing interference below the ADC noise floor at the output of the entire chain. The input spectrum from the antenna element is shown in ***Figure 5(a)***, and the spectrum at the ADC is shown in ***Figure 5(b)***, scaled as equivalent receiver chain input levels. Keeping the passband clear of overlapping interference terms and third- and fifth-order intermodulation distortion is enabled given the T/R band separation: Δf > 600 MHz. This provides good flexibility since 70 percent of the operating band is available for all frequency combinations. While the details of antenna isolation are beyond the scope of this article, a

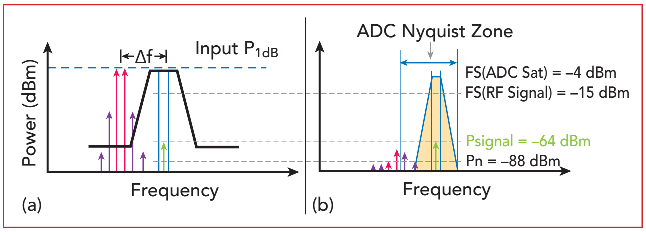

Fig. 5 **RF input spectrum (a) and effective input spectrum at the ADC (b).**

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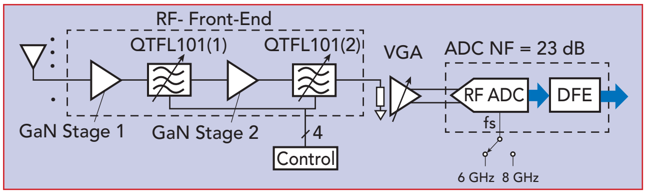


Fig. 6 Rx signal chain: RF front-end with GaN MMIC and SOI tunable filters, VGA, ADC and DFE.

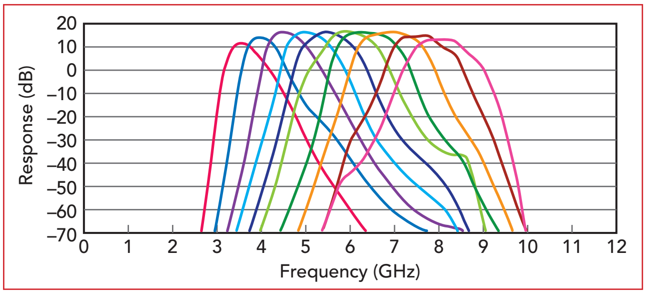


Fig. 7 Simulated center frequency tuning of the RF front-end from 3.5 to 8 GHz in 500 MHz steps.

realistic assumption is an average effective isolation between the Tx and Rx of 46 dB, which is required to achieve a 0 dBm interference level.

FRONT-END MODELING

The most critical component of the C-Band dual T/R array is its high dynamic range RFFE (see ***Figure 6***), which drives and protects a variable gain amplifier (VGA) driver and Nyquist ADC, followed by a digital front-end (DFE). The ADC can sample signals up to 8 GHz directly with a noise density of -151 dBFS/Hz (<-20 dBFS) in the higher-order Nyquist zones. By switching between 6 and 8 GHz sampling clocks, the Nyquist zones can be placed relative to the tuned passbands to cover the 4 to 8 GHz operating band.

To achieve a power efficient RFFE design with the required high linearity and low system noise figure, a GaN HEMT process is selected for the two amplifier stages. The first gain stage has a noise figure of 1.3 dB with 11.6 dB gain, compared to 14 dB gain and 2.1 dB noise figure for the second stage. Overall power consumption of the two GaN stages is 261 mW at the nominal 5 V V_{DD} bias. This RFFE can be packaged as a surface-mount hybrid module integrating a single GaN MMIC, approximately 2.2 mm × 2.2 mm in size, with the two OTFL101 tunable filter ICs, each filter 2.6 × 1.6 mm.

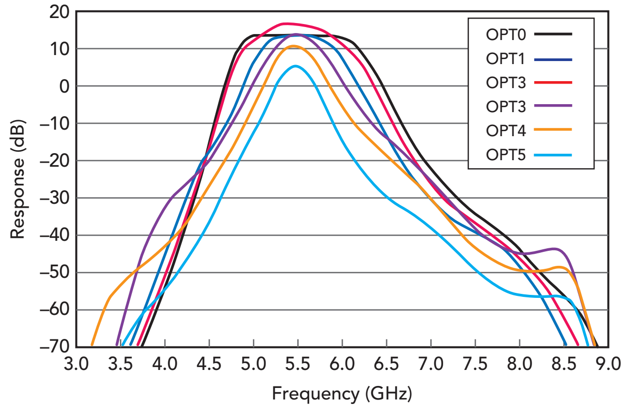
The RFFE module, using both SOI and GaN devices, was simulated as a chain in ADS. As this filter chain employs 10 resonators with independent controls, setting all tuning variables is a key factor in the design, in addition to the input and output impedances of each block. The filters can operate with all variables set to the same nominal value, which is a "simple" approach to center frequency tuning. However, the variables can also be optimized with knowledge of the resulting transfer function. ***Table 3*** summarizes the simulated results for the RFFE design for both simple and optimized cases, the latter labeled OPT2 V2. The optimized case improves all the performance parameters for a low side interferer: The passband gain increases by ~5 dB, Rstop1 reduces by 29 dB, the noise figure improves by 0.5 dB and both the out-of-band input P1dB and input IP3 improve by ~3 dB. This is evidence of improved inter-stage matching and increased power transfer between the components in the RFFE.

The simulated center frequency tuning of the RFFE is plotted in ***Figure***

TABLE 3
RF FRONT-END PERFORMANCE SUMMARY

Parameter	*Simple Tuning*	*Optimized Tuning (OPT2 V2)*
fc (GHz)	6	6
3 dB Bandwidth (MHz)	1200	800
Passband Gain (dB)	12.2	17.1
Rstop1: fc-1 GHz (dB)	-17	-46
Rstop2: fc-2 GHz (dB)	-84	-103
Noise Figure (dB)	2.7	2.2
Input P_{1dB} (dBm)	-2	1
Input IP3 at -15 dBm (dBm)	17.0	19.7
Pdc (mW)	260	260

7, which shows a set of bandpass responses covering 3.5 to 8 GHz in 500 MHz steps. Tuning is virtually continuous, given the five-bit resolution of each of the 10 resonators. At each center frequency, the bandpass characteristics can be adjusted. The best approach is through optimization, where the goals of the desired transfer functions enable adjustment of bandwidth, gain, passband shape and out-of-band attenuation. ***Figure 8*** shows simulations for the design tuned to 5.5 GHz with several bandwidth and passband states, which are described in the table within the figure.



Tuning Method	Passband	3 dB BW (MHz)	Gain (dB)	NF (dB)
OPT0	Flat	1400	13.7	2.6
OPT1	Flat	800	13.9	2.7
OPT2	Cosine	800	17.1	2.1
OPT3	Cosine	400	14.0	2.6
OPT4	Cosine	350	10.5	3.4
OPT5	Cosine	300	5.3	4.6

▲ **Fig. 8** **RF front-end tuned to 5.5 GHz showing six simulated bandwidth (BW) and passband states.**

The model-based optimization of the design used the S_{21}, S_{11} and S_{22} responses with goals or cost functions, in a combined manual and random-gradient iterative search to derive the control states. Given its accuracy, the model can provide an effective nominal set of optimized stored states, even without measurement. To compensate for manufacturing variation among units, a vector network analyzer calibration may be substituted for the model to obtain the highest accuracy.

CONCLUSION

The capabilities and impact of a new class of tunable filters based on SOI RFICs were described, with the aim to increase the operating bandwidth of the phased array. The combination of linearity, tuning time, small size, tuning degrees of freedom and reliability of the RFICs surpasses solutions using switched filter banks, PIN diodes[2] or MEMS[6] switches. RF building blocks such as front-ends, converters and synthesizers can employ this cascaded approach to realize multiple improvements. In general, these RFICs can play a role addressing difficult interference problems with commercial and military front-ends, which was illustrated with a dynamically programmable FDD system operating over 4 to 8 GHz. The example shows a combination of front-end capabilities and system benefits, addressing such issues as spectral congestion, performance and cost effective deployment. ■

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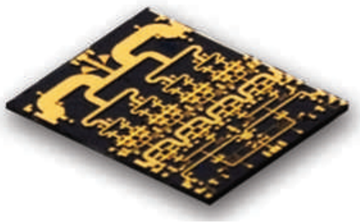

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New Techniques to Overwhelm Military Adversaries

BAE Systems is developing a new approach to defeat adversaries by overwhelming them with complexity as part of the Complexity Modeling in Multiple Domains (COMMAND) program.

BAE Systems has been awarded a $2.8 million, three-year contract from the Air Force Research Laboratory to develop this new approach to defeat adversaries: by overwhelming them with complexity.

As part of the COMMAND program, BAE Systems will develop highly complex models to capture the "decision calculus" of an adversary, provide an estimate of how different attacks will affect their ability to respond, and ultimately drive them to the point of indecision.

"The goal of the COMMAND program is to understand the imposition of complex Courses of Action against an adversary's integrated systems of systems by modeling their decision calculus," said Mike Miller, technical group lead at BAE Systems' FAST Labs™ research and development organization. "From kinetic attacks to jamming communications and cyber-attacks, determining a combination of these various attack surfaces will make it challenging for the adversary to react in a timely and coherent manner."

Source: BAE Systems PLC

As part of Joint All-Domain Operations, the U.S. Department of Defense seeks to integrate effects against targets within the adversary's observe, orient, decide and act loop to push the adversary into strategic paralysis. By using "complexity" as an attack surface, this technology will shape how information flows through an opponent's decision-making process.

DARPA Seeks Ionospheric Insights to Enhance HF Radio Capabilities

Warfighters depend on high frequency (HF) radio transmissions to operate military systems across the space, air, ground and maritime domains. Current understanding of how HF waves propagate through the electromagnetically noisy ionosphere typically depends on ground-based methods. To better understand HF propagation in space requires scientific measurements taken from within the ionosphere itself. DARPA's new Ouija program aims to use sensors on low-orbiting satellites to provide new insights into HF radio wave propagation in the ionosphere, which spans the upper edges of the Earth's atmosphere to the lower regions of space. The program seeks to quantify the space HF noise environment and improve characterization of the ionosphere to support warfighter capabilities.

"Ouija will augment ground-based measurements with in-situ measurements from space, in very low-Earth orbit (VLEO), to develop and validate accurate, near real-time HF propagation predictions," said Jeff Rogers, Ouija program manager in DARPA's Strategic Technology Office. "The VLEO altitude regime, approximately 200 to 300 km above Earth, is of particular interest due to its information-rich environment where ionospheric electron density is at a maximum. Fine-grained knowledge of the spatial-temporal characteristics of electron density at these altitudes is required for accurate HF propagation prediction."

The program includes two technical areas. The first technical area, announced in a solicitation issued April 21, 2022, seeks to develop, qualify, launch and operate multiple small satellites carrying scientific and mission instrumentation. The Ouija scientific payload will measure electron density by both direct sampling and indirectly via radio occultation using navigation satellites. It is anticipated that the scientific payload will use or adapt commercial-off-the-shelf (COTS) components, but innovative instrumentation proposals that enhance the functionality of the scientific payload over a COTS baseline are welcome.

"The HF mission payload will require a high sensitivity, high dynamic range, low noise HF measurement subsystem," Rogers said. "The antenna for this subsystem is a particular challenge, as efficient HF antennas that operate at the lower end of the frequency band are long, presenting deployment and space vehicle drag challenges."

The second technical area, which will be fully detailed in a separate solicitation at a later date, aims to develop assimilative models that ingest direct, in-situ, measurements of electron density from a satellite in VLEO. The derived electron density models will be fed into HF propagation code then validated with data measured on-orbit. The goal is to improve fidelity over current state-of-the-art assimilative models by incorporating

Source: DARPA

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high-resolution (in time and space) local measures with low latency updates.

Ouija employs a simplified Other Transactions process aimed at lowering the bureaucratic barrier for companies to make proposals, especially those seeking to work with the Department of Defense or DARPA for the first time.

First Global Aircrew Strategic Network Terminal System

Raytheon Intelligence & Space (RI&S) recently completed the installation of the first Global Aircrew Strategic Network Terminal system for the U.S. Air Force. The terminal system modernizes existing protected communications systems while adding new capabilities for nuclear and non-nuclear command and control. Global ASNT ensures robust communications to provide protected communications to nuclear bomber, missile and support aircraft crews in austere environments.

"Operating on both MILSTAR and advanced extremely high frequency satellites, Global ASNT systems use satellite communications to provide command and control, linking nuclear forces to national command authorities," said Denis Donohue, president, Communications & Airspace Management Systems, RI&S. The contract is administered through the U.S. Air Force Nuclear Weapons Center and supports U.S. Air Force Global Strike Command. The total awarded contract value for Global ASNT is nearly $600 million.

Source: Raytheon Technologies

The RI&S team is completing three additional base installs that will comprise Global Strike Command's Initial Operating Capability. As production and fielding continue, 90 terminals, including spares and support equipment, will be produced and fielded in fixed and transportable configurations by the end of 2023.

Primary work locations for this effort are in Florida and Massachusetts with major suppliers in California, Pennsylvania and Texas; the balance of the more than 200 suppliers supporting the program are spread across the U.S.

The contract is administered through the U.S. Air Force Nuclear Weapons Center and supports U.S. Air Force Global Strike Command. The total awarded contract value for Global ASNT is nearly $600 million.

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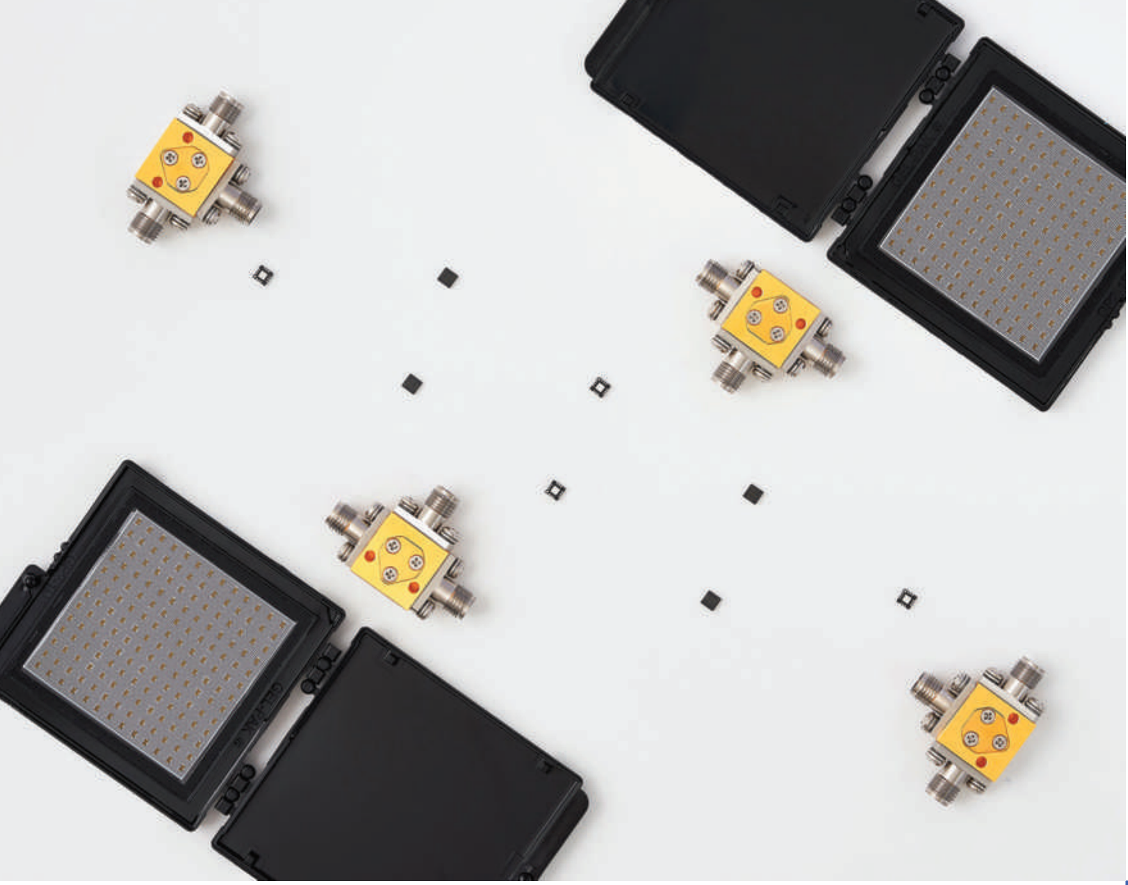

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635 New 5G Cities in 2021; 1947 5G Cities Globally

Viavi Solutions Inc. released new industry data revealing that the number of cities with 5G networks now stands at 1,947 globally. Despite the pandemic, 5G cities came online at a rate of nearly two per day, with the addition of 635 new 5G cities in 2021, according to the new VIAVI report "The State of 5G," now in its sixth year.

By the end of January 2022, 72 countries had 5G networks in place, with the newest crop of 5G countries comprising Argentina, Bhutan, Kenya, Kazakhstan, Malaysia, Malta and Mauritius, which all came online in the second half of 2021. Europe, Middle East and Africa have overtaken Asia Pacific including Greater China (APAC) to become the region with the most 5G cities at 839. APAC has 689 5G cities and the Americas has 419.

Source: VIAVI Solutions

Not surprisingly, the world's two largest economies, the U.S. and China, are the countries with the most 5G cities. China now has 356 5G cities and the U.S. has 296. The Philippines remained in the third spot globally with a total of 98 5G cities.

Currently, most 5G networks deployed are non-standalone networks, meaning that 5G equipment is added to existing 4G network infrastructure. There are currently 24 standalone (SA) 5G networks globally, meaning that they have been built using a new 5G core network. It is widely considered that many of the next-generation use cases and monetization models associated with 5G, beyond enhanced mobile broadband will only be possible when SA 5G networks built on new 5G core networks are in place.

The State of 5G also highlights the growing Open Radio Access Network (RAN) ecosystem, combining mobile operators as well as software and infrastructure vendors, seeking to develop an open, virtualized RAN with embedded artificial intelligence control. As of March 2022, 64 operators have publicly announced their participation in the development of Open RAN networks. This breaks down to 23 live deployments of Open RAN networks, 34 in the trial phase with a further seven operators that have publicly announced they are in the pre-trial phase.

"5G continued to expand, despite the headwinds of a global pandemic," said Sameh Yamany, CTO, VIAVI Solutions. "What comes next in 5G is the reinforcement of networks. This will take a couple of forms. Firstly, we expect to see more SA 5G networks, which will deliver on much of the promise of 5G, both for the operator and for the wider ecosystem of users. And secondly, we expect to see Open RAN continue its rapid development and start to become a de facto standard."

Smart City Standards are Key to Unlocking the Full Potential of Smart Cities Technologies

Since the emergence of smart cities, the promise of interoperability and connected sensors has been difficult to attain in practice as cities suffer from vendor lock-in and incompatible devices. ABI Research has found that smart city standards are the key to unlocking the full potential of smart cities technologies.

"Smart Cities technologies are advertised as able to collect data and insights into how a city is functioning through a variety of means such as weather monitoring, utilities monitoring, etc. However, there are issues with vendor lock-in and a lack of interoperability between devices, which means that the full benefit of smart cities technology is not realized," explained Lindsey Vest, Smart Cities and Smart Spaces Research analyst at ABI Research.

The standards ecosystem is still a diverse network of standards development organizations, alliances and consortia, but there is promise that with proper cooperation, they could be vital to the smart cities market. There are many different organizations and consortia that engage with standardization, including international and organizations such as ISO, IEC, ETSI and ITU-T. Furthermore, there are non-profits, consortia and alliances such as IEEE, OASC, IETF and TM Forum. The wide range of organizations involved in standardization can create a confusing and inefficient ecosystem but groups such as the Joint Smart Cities Task Force, formed by the ISO, IEC and ITU-T, promise to help combat these issues.

The companies that engage in standardization through engaging with various consortia and industry alliances can gain a strategic advantage as their solutions can be targeted to meet the requirements of, for example, interoperability with existing city systems. For example, one M2M is a service layer standard that is leveraged globally and allows for the interoperability of legacy systems along with new systems. Engaging with standards also allows industry to influence and steer the direction of standardization. It can be advantageous for both larger organizations and small and medium enterprises as they can more readily work within the complex system of a city.

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IoT Device Management Services to Reach US $36.8B in Revenues by 2026

Device management services are evolving in response to greater breadth of device technologies such as edge intelligence and connectivity technologies, as well as to customer pain points like scalability and security of IoT deployments. But forward-looking suppliers are also preparing for a world where 41.3 percent of the connected devices will be using some form of LPWA technologies by 2026. Since IoT customers increasingly need to manage a larger fleet of connected devices, ABI Research forecasts that IoT device management services will top U.S. $36.8 billion in revenues by 2026.

Standardization is beginning to play a bigger role in device management services, as more connected devices use LPWA technologies. Standardization is best exemplified by growth in adoption of LwM2M. This standard was embraced by the telcos but is now also embraced by the module, chipset and gateway suppliers. The flip side of standardization is that it will increase commoditization of device management services. "Implementing a common standard such as LwM2M can complicate a device management vendor's product differentiation strategy, but standards do address customer reservations of 'lock-in' to a proprietary platform," said Abdullah Haider, IoT Network and Services Research analyst at ABI Research.

Partnerships and collaborations between device management vendors will continue to accelerate. Device management vendors can partner with system integrators (SIs) who build an end-to-end solution. Device management suppliers can also partner with other players in the value chain.

Device management vendors from large hyper-scalers, (e.g., AWS and Microsoft Azure), established incumbent players (e.g., Eurotech, Telit and Sierra Wireless), MNOs (e.g., Vodafone, Verizon and Deutsche Telekom) and startups (e.g., EdgeIQ, Memfault and 1nce) are all looking to disrupt the IoT device management ecosystem. "One key insight is that while competition breeds commoditization, companies are still keen to differentiate their device management services. Often this entails providing security services like device attestation, and mutual authentication while other players are considering remote hardware configurability in application segments like asset tracking, telematics and condition-based monitoring. In general, more and more suppliers are adding device management services to differentiate their IoT solution suite and capture more IoT solution revenues," Haider concluded.

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Rohde & Schwarz announced that it has acquired U.K.-based **The Technology Academy**, a long-established provider of online training courses in the fields of RF, wireless and microwave engineering technology. The Technology Academy is an ideal partner to expand the existing training offerings of Rohde & Schwarz and will play a significant role in increasing the company's future professional services. The Rohde & Schwarz Technology Academy combines the expertise and industry insights of the trusted test and measurement manufacturer—currently providing live and virtual trainings from their in-house training center as well as on-site trainings for existing customers—with the web training expertise of The Technology Academy.

COLLABORATIONS

Smart antenna start-up **ALCAN Systems** and **AGC Inc.**, a leading manufacturer of glass, chemicals and high-tech materials, announced the successful development of transparent antennas for indoor mmWave Fixed Wireless Access (FWA) following rigorous demonstrations at ALCAN's head office in Darmstadt. The test results showed a real-world, effective solution to address the challenges of in-building penetration for mmWave 5G. The technology developed by ALCAN in partnership with AGC uses ALCAN's unique liquid crystal-based phased array technology which allows for a transparent solution. This will be added to existing windows with a discreet FWA unit. The FWA units give a low-cost, low-power, transparent and easy to install solution to address the challenges of mmWave penetration in-buildings.

ACHIEVEMENTS

Keysight Technologies Inc. has been granted the first Federal Communications Commission (FCC) Spectrum Horizons Experimental license for developing 6G technology in sub-THz frequency bands, between 95 GHz and 3 THz. The FCC license enables Keysight to develop cutting-edge technology used by researchers in academia and the industry to accelerate innovations that support data-intensive high bandwidth applications, imaging and sensing. Keysight is also the first company to be granted FCC licenses above 246 GHz and 275.5 GHz.

IMST is celebrating their 30-year anniversary. IMST was founded in 1992. Already in January 1995, the new IMST headquarters, with 5000 m^2 of office space and special laboratories, was completed and the staff of the very beginning moved into this modern and well-equipped building in Kamp-Lintfort. Since the very beginning, a large part of the work at the IMST has been dedicated to innovative research for industrial applications. IMST is still heavily engaged in various challenging research and development projects funded by industry or government. IMST is an active member of many national and international committees and standard organizations, like the International Electrotechnical Commission, ETSI and IEEE.

Richardson Electronics Ltd. announced it received a Gold Tier Award for exceptional performance and contributions to supply chain success for BAE Systems, Inc.'s Electronic Systems sector. Richardson Electronics was honored at a virtual ceremony and was selected from the pool of suppliers that worked with BAE Systems in 2021. **BAE Systems'** Partner 2 Win program is designed to achieve operational excellence and eliminate defects in its supply chain by raising the bar of performance expectations to meet the demand of current and future customers. As part of the program, BAE Systems meets regularly with its suppliers to transfer best practices to ensure that the components and materials that compose BAE Systems products meet the highest quality standards.

CONTRACTS

The U.S. Air Force (USAF) has selected **BAE Systems**, with support from FlexRadio, to provide software-defined radios for its Airborne High Frequency Radio Modernization (AHFRM) program. The contract, which has a value of $176 million, provides a secure alternative to satellite communication methods. The AHFRM solution maintains over-the-horizon communications while defeating jamming from potential threats in a drop-in compatible radio design that maximizes FlexRadio's commercial off-the-shelf technology.

Hughes Network Systems LLC announced the award of an $18 million contract from **The U.S. DoD** to deploy a standalone 5G network at Naval Air Station Whidbey Island in Washington state. The Other Transaction Agreement was issued through the Information Warfare Research Project consortium, a collaboration to engage industry and academia to develop and mature technologies in the field of information warfare that enhance Navy and Marine Corps mission effectiveness.

Mercury Systems Inc., a leader in trusted, secure mission-critical technologies for aerospace and defense, announced it received a $6.9 million order from a leading defense prime contractor for high performance, OpenVPX™ digital signal processing systems for a manned airborne radar application. The order was received in the company's fiscal 2022 third quarter and is expected to be shipped over the next several quarters. Mercury's advanced signal processing systems underpin customers' mission-critical programs across the globe, ultimately providing pilots with the high-resolution, actionable data required for situational awareness wherever their mission takes them.

PEOPLE

After 26 years, effective July 1, 2022, **Subi Katragadda** will step down as general manager of **Amphenol SV Microwave**. Under his stewardship, SV has experienced

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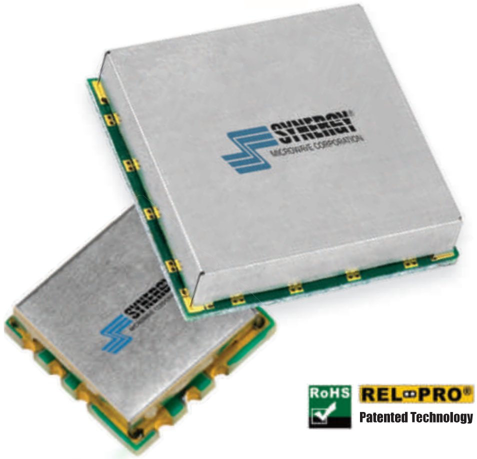

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HFSO2000-5TC	2000	0.5 - 12	+5 VDC @ 100 mA	-137
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HFSO1500-5	1500	0.5 - 12	+5 VDC @ 100 mA	-140
HFSO1200-5	1200	0.5 - 12	+5 VDC @ 100 mA	-142
HFSO1000-5	1000	0.5 - 12	+5 VDC @ 35 mA	-141
HFSO1000-5H	1000	0.5 - 12	+5 VDC @ 35 mA	-144
HFSO1000-5L	1000	0.5 - 12	+5 VDC @ 35 mA	-137
MSO1000-3	1000	0.5 - 14	+3 VDC @ 35 mA	-138
HFSO800-5	800	0.5 - 12	+5 VDC @ 20 mA	-146
HFSO800-5H	800	0.5 - 12	+5 VDC @ 20 mA	-150
HFSO800-5L	800	0.5 - 12	+5 VDC @ 20 mA	-142

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▲ *Andrew Dinsdale*

tremendous growth, diversification and organizational development. Taking up the mantle, **Andrew Dinsdale** will become the next general manager of SV Microwave, effective on July 1. Dinsdale joined SV in 2008 as an application engineer, and since then has worked as a business development manager focused on diversification into the high frequency commercial market and most recently, as director of marketing and applications engineering. In his latest role, Dinsdale has been instrumental in driving SV's wonderful performance over the last several years.


▲ *Roger Nichols*

Keysight Technologies Inc. announced that **Roger Nichols**, 6G program director at Keysight, has been appointed to the Technological Advisory Council for the FCC, an independent U.S. government agency that regulates communications within the U.S. and internationally. Roger Nichols joins a diverse group of leading technology experts selected by FCC Chairwoman Jessica Rosenworcel to provide technical expertise in several important areas, including 6G, artificial intelligence and advanced spectrum sharing, as well as emerging wireless technologies.


▲ *Alexander Chenakin*

Anritsu Company announced that **Dr. Alexander Chenakin**, director of R&D, has been elected chair of the IEEE TC-10 Signal Generation and Frequency Conversion Committee. As chair of the committee, Dr. Chenakin will lead a diverse group of recognized industry technology experts in the signal generation and frequency conversion field. It is the mission of the committee to promote the development of signal generation and frequency conversion techniques applied to circuits and systems. The committee will evaluate new developments in the fields of RF and microwave oscillators, frequency multipliers and dividers, mixers and frequency synthesizers.

REP APPOINTMENT

Kymeta announced a distribution partner agreement with **OneWeb Technologies**, a wholly owned subsidiary of low Earth orbit satellite communications company OneWeb, enabling Kymeta to resell services with its fixed and mobility hardware solutions to the U.S. government. Access to broadband connectivity services from the leading satellite connectivity platform will provide customers with an additional mission-critical connectivity resource, supplementing Kymeta's existing broadband geostationary orbit and 4G cellular service offering.

INVITED PAPER

The Use of GaN RF Switches in High-Power Radio Design

Manish Shah
Tagore Technology Inc., Arlington Heights, Ill.

GaN RF switch technology enables the efficient realization of modern high-power multi-band radios in terms of size, weight and power (SWaP) while significantly reducing complexity.

PIN diode technology has been the historic choice to realize the RF switch function in RF front-end (RFFE) high-power radio design. This technology was adequate as the number of frequency bands were limited and board space was not a constraint. Modern high-power base stations and tactical military communications radios, however, are required to cover many bands to meet demand for secure voice and data communication while optimizing SWaP.

5G base station remote radio head (RRH) design is becoming extremely complex, driven by mMIMO architectures, where many RFFEs must be implemented in limited board space. RRH units are typically mounted on tall poles, which adds additional constraints in terms of total size and weight to ease installation and maintenance of base station equipment. RFFE efficiencies and total loss budgets are also critical to manage total thermal dissipation. Lower loss in front-end filters and RF switches helps reduce total power loss and relaxes heat sink requirements, which also reduces RFFE size and weight.

High-power phased array radars are like 5G base stations, where many RFFEs are required to be integrated in a limited board space. It is becoming prohibitively difficult to realize multiple frequency bands and multiple RFFEs distributed over a wide frequency range with traditional PIN diode switch technology due to the complex biasing schemes and numerous passive components required. New RF switch technology can help solve many of these issues.

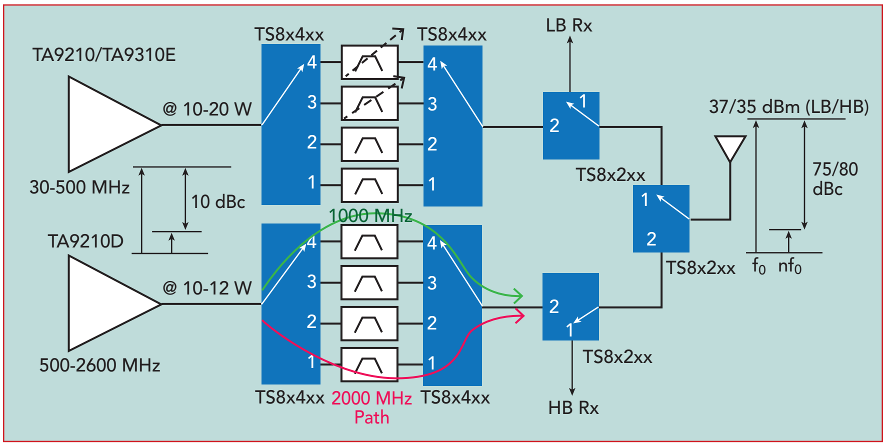

Fig. 1 Dual PA front-end for a tactical military communications (MIL-COM) radio.

TACTICAL MIL-COM RFFE REQUIREMENTS

Figure 1 represents the typical dual power amplifier (PA) RFFE lineup of tactical military communications radio. The dual PA architecture, normally with GaN-based PAs, is most common, covering a broad frequency range of 30 MHz to 2.6 GHz. Continuous frequency coverage is essential in many proprietary military software-defined radios covering 30 MHz to 2.6 GHz, for a


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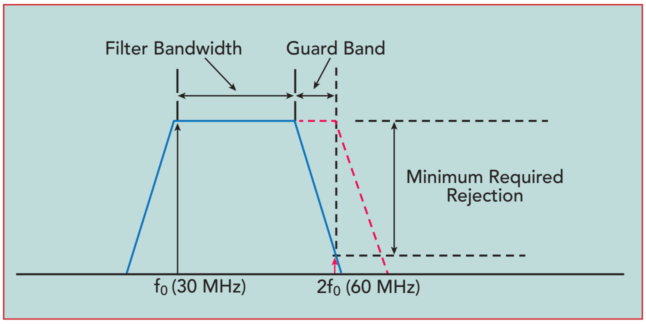

Fig. 2 Harmonic filter requirement for the tactical radio.

6.5 octave bandwidth; thus, a theoretical minimum of seven bands are needed.

A harmonic filter, however, requires a guard band to achieve the minimum required rejection for second harmonics of the lower end of the frequency within the band. For example, as shown in ***Figure 2***, the first band cannot be 30 to 60 MHz, or one octave, since the second harmonic of 30 MHz falls within the band. The first band must be 30 to 50 MHz, assuming a 10 MHz guard band to achieve the desired filter rejection to meet harmonic rejection requirements.

With a minimum 10 MHz guard band, frequency range must be split into eight discrete bands to have continuous coverage from 30 MHz to 2.6 GHz. The main function of the RF switch in this lineup is to route the RF signal to the appropriate harmonic filters and combine the signals, again, after passing through the harmonic filter to route them to the antenna. Performance of the RF switch is critical to the radio's overall performance.

Switch insertion loss is one of the most important specifications to reduce total power dissipation. Lower insertion loss of the switch also reduces total power required from the PA. A reduction in PA output power lowers PA DC power consumption, one of the biggest contributors to a system's total DC power requirement, thus improving the talk time of battery powered portable radios, which is crucial in mission-critical applications. Reduction in power loss, and thus total thermal dissipation, also helps reduce the size of the heat sink which in turn helps reduce the total size and weight of the radio, which is also very important in many military communication applications.

The second key specification is switch harmonic performance, especially switches which are used after the harmonic filters. Land mobile/private mobile radio (LMR/PMR) is specified to meet a 75 to 80 dBc harmonic requirement at rated power. PAs are operated deep into saturation for better efficiency, where harmonic levels are in the range of 10 to 20 dBc. Thus, harmonic filters are required to provide a minimum of 60 to 70 dB rejection to meet regulatory requirements.

For military radios, switches used after harmonic filters do not have the benefit of harmonic filter rejection, thus their harmonic performance needs to be better than

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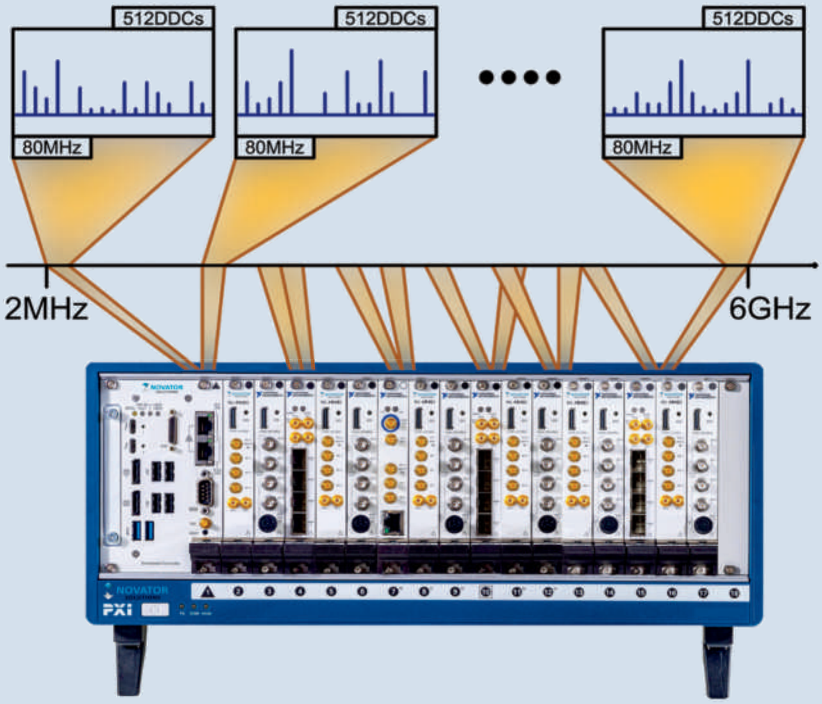

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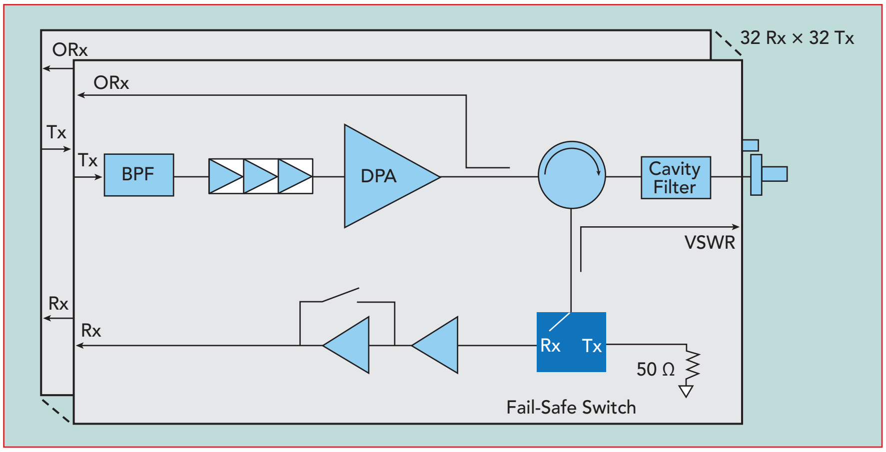


Fig. 3 Notional RRH front-end.

the overall requirement to meet the total transmit (Tx) lineup requirement. Based on the harmonic performance of the PA+ filter, the harmonic performance of switches must be better than 80 dBc to meet regulatory requirements.

Figure 1 also demonstrates another critical issue associated with switch isolation. Isolation of switches at lower frequencies is typically very high, so it is not an issue; however, it could pose a problem for higher bands. The second harmonic of the 1 GHz signal path, shown by green arrow in Figure 1, for example, could pass through the 2 GHz signal path, shown by the red arrow. The 2 GHz path harmonic filter does not provide any rejection, thus combined input and output switch isolation must be higher than the rejection provided by harmonic filter to meet the overall harmonic requirement.

BASE STATION AND RADAR RFFE REQUIREMENTS

Figure 3 represents the lineup of a typical base station or RRH unit. Modern 5G base stations use mMIMO architectures for electronic beam steering, requiring many RFFEs depending on the number of transmitters and receivers in the array. High-power phased array radars use similar architectures as well.

In both applications, RF switches provide a fail-safe function to protect the receiver in the event of a poor VSWR condition from the antenna. In the event of poor VSWR, due to damage or an object, such as a bird blocking a portion of the antenna aperture, Tx power reflects back to the radio during transmit. In the absence of a fail-safe switch, high reflected power could damage the sensitive receiver. A fail-safe switch is added in the receive (Rx) lineup to address such scenarios.

The fail-safe switch is switched to the Rx port during the Rx time slot and to the Tx port during the Tx time slot. In the event of high VSWR during Tx, the switch routes the reflected power coming from the antenna through a circulator to a 50 Ω load connected at the Tx port of the switch, thus protecting the receiver from high power.

Key RF switch requirements for the fail-safe application are low insertion loss in Rx and high power handling in Tx. During the Rx time slot, the switch falls in the Rx path, thus its loss directly impacts the overall noise figure and thus sensitivity of the receiver. During Tx, the switch must handle the maximum transmit power in the event of poor VSWR and provide high isolation to the Rx port.

The system is designed to detect poor VSWR conditions, however a switch must handle high power until the system detects a fault condition and reduces Tx power or turns-off the transmitter. This duration is typically 10 seconds before the system reacts, thus the switch needs to handle high power without damage during this interval.

Typical isolation varies from 25 to 35 dB depending on the maximum peak power of the transmitter and maximum power handling capability of the low noise amplifier. The

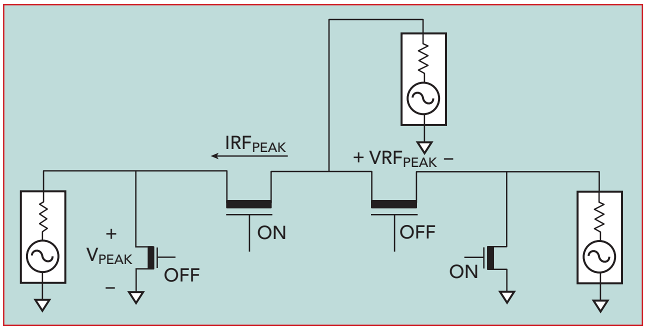


Fig. 4 GaN RF switch.

switching time requirement for a base station application is less than 1 us. For radar, the switching time requirement is more stringent as it directly impacts radar range.

GAN RF SWITCH TECHNOLOGY

GaN's benefits in high-power PAs are well known. A wide bandgap GaN device has a high power density due to its high breakdown voltage and high carrier density. GaN's benefits in high-power switch technology are not as well known; however, the properties of GaN that improve PA performance apply to the realization superior high-power RF switches as well.

As shown in ***Figure 4***, there are two requirements for RF devices used in high-power RF switches. The ON arm of the RF switch must handle very high RF current, where the OFF arm must handle very large RF voltages. ***Table 1*** lists peak RF voltage and current requirement versus RF power for RF switches.

For example, 10 W of RF power generated in a 50 Ω system produces 32 V peak and 600 mA of peak current. With a 4:1 VSWR, which is typical for the front-end section of a radio, a switch must handle more than 50 V peak and 1 A of peak current. For 100 W of RF power generated, a switch must handle 160 V peak and 3.2 A of peak current. RF switches, therefore, must handle high voltages and currents. These are key characteristics of wide bandgap devices such as GaN, and the same properties exploited to design high-power GaN PAs.

Another important parameter is the figure of merit (FoM) for high performance, high-power switches ($Ron*Coff/V_{BV}$). Where Ron is ON resistance of the switch, Coff is the off capacitance and V_{BV} is the breakdown voltage. The lower the number, the more superior the technology. Tagore's second generation of GaN technology has a FoM of 3 fs/V. As technology matures and improves, the FoM should improve further with newer generations, enabling further improvements in the switch performance.

GAN VERSUS PIN DIODE RF SWITCHES

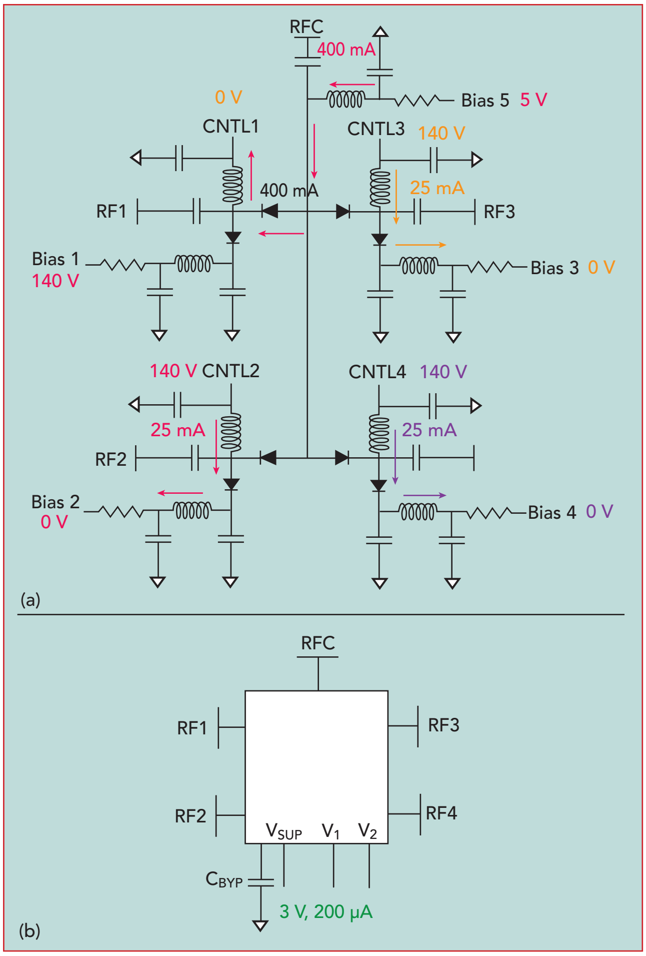
Tagore's GaN RF switches are designed with depletion mode GaN HEMT technology. The GaN HEMT with a high breakdown voltage has a saturation current close to 1 A/mm, so a 2 to 3 mm device theoretically meets the peak current requirement for 100 W of power in a 50 Ω system. The switch function is like a silicon on insulator (SOI)-based switch where the device is turned on/off by applying voltage at the gate terminal. Unlike SOI, however, where the breakdown voltage is very low, typically around 3 V, the breakdown voltage of a GaN device is very high.

A high-power switch can be realized without stacking many devices in series, which is critical for reducing Ron and Coff. Because the devices are in depletion mode, they require

TABLE 1

RF SWITCH PEAK RF VOLTAGE AND CURRENT

POWER (W)	VRF_{PEAK} (V)		IRF_{PEAK} (A)	
	50 Ω	4:1 VSWR	50 Ω	4:1 VSWR
10	32	51	0.6	1.0
30	55	88	1.1	1.8
50	71	113	1.4	2.3
100	100	160	2.0	3.2



▲ Fig. 5 PIN diode (a) and GaN (b) SP4T RF switches.

negative voltage to turn them off and zero volts to turn them on. All Tagore switches are designed with a controller die co-packaged with GaN die. The controller generates gate voltage signals to control all the GaN devices. Negative voltage is generated inside the controller, so it requires only a minimum 2.7 V (5.5 V maximum) supply and a 1.2 V (5.25 V maximum) logic signal to control the RF switch state. The only external component necessary is a bypass capacitor on the charge pump pin, as shown in ***Figure 5***.

Unlike GaN RF switches, PIN diode-based RF switch design is much more complex and requires many iterations to implement and optimize. Performance is heavily dependent on the parasitics associated with external components and board layout as many passive biasing devices are connected to the RF signal path. PIN diode control requires both high current and high voltage. The ON state resistance of the PIN diode is a function of bias current, where OFF state power handling is controlled by applying a high reverse bias voltage. It requires high forward bias current, in the range of 200 to 400 mA for 100 W switch, and high reverse bias voltage, in the range of 140 V.

Figure 5a shows a typical implementation of a PIN diode-based SP4T 100 W switch with the lowest operating frequency of 50 MHz. The figure shows the bias condition when the RF1 path is ON. To keep the ON resistance low, the ON path diode is biased at 400 mA, shown with red fonts and arrows. The OFF path shunt diodes are biased at 25 mA and the series diodes are reversed biased at 140 V. The ON state bias power requirement is 2 W (5 V × 400 mA) and the OFF state bias power requirement for each path is 3.5 W (140 V × 25 mA). The total DC bias power requirement to bias the 4T switch is 12.5 W. The majority of biasing power is dissipated in bias resistors, thus they must be capable high-power dissipation. Additional boost circuitry is required to generate the high voltage to reverse bias the diodes from low supply rail.

As shown in Figure 5, the PIN diode requires 32 passive components, not counting the boost converter circuit, while the GaN-based switch can be realized with 3 V and 200 uA current, or 0.6 mW total power consumption and two components. As RF ports are 50 Ω without any passive components connected, the design can be implemented and ported to any board, eliminating the design complexity associated with the diode switch.

GaN-based solutions require board space on the order of 1/10 of PIN diode designs—3 × 3 to 5 × 5 mm—and DC power dissipation is almost zero, which reduces heat sink requirements, further reducing overall size and weight. The MIL-COM radio RFFE shown in Figure 1 would require 176 components for a PIN diode solution, not including components for high voltage boost circuit, versus seven switches and seven capacitors for a GaN-based solution.

GAN RF SWITCH PERFORMANCE

The following examples from Tagore Technology's portfolio of GaN RF switches with integrated controllers will illustrate the performance capabilities of GaN. ***Figure 6*** shows the performance of its TS8021N 2T switch. Figure 6(a) and 6(b) show the small signal performance. It has a very low insertion loss (IL) of 0.2 dB at 1 GHz and less than 0.5 dB up to 4 GHz. Figure 6(c) shows that the switch has a $P_{CW\_}0.1$ dB of 50 dbm (100 W). Harmonic performance is better than 80 dBc up to 90 W of power as shown in Figure 6(d). The 5 × 5 mm QFN package requires only one external capacitor. The switch is ideally suited for a high-power manpack, trunk mount radio application.

Figure 7 shows the performance of a TS8242FK, 4T switch with a $P_{CW\_}0.1$ dB of 30 W, ideally suited for filter bank fanout, as shown in Figure 1, for portable 10 W LMR/PMR or military communications radios. The switch has 0.3 dB IL at 2.5 GHz and harmonic performance is better than 85 dBc at 10 W.

TS8329FK switch performance (see ***Figure 8***) is designed for a

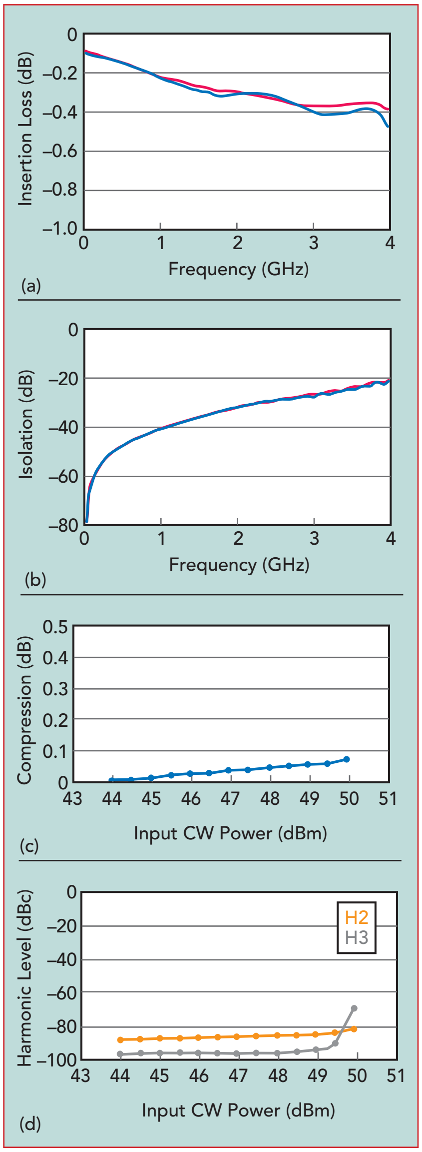
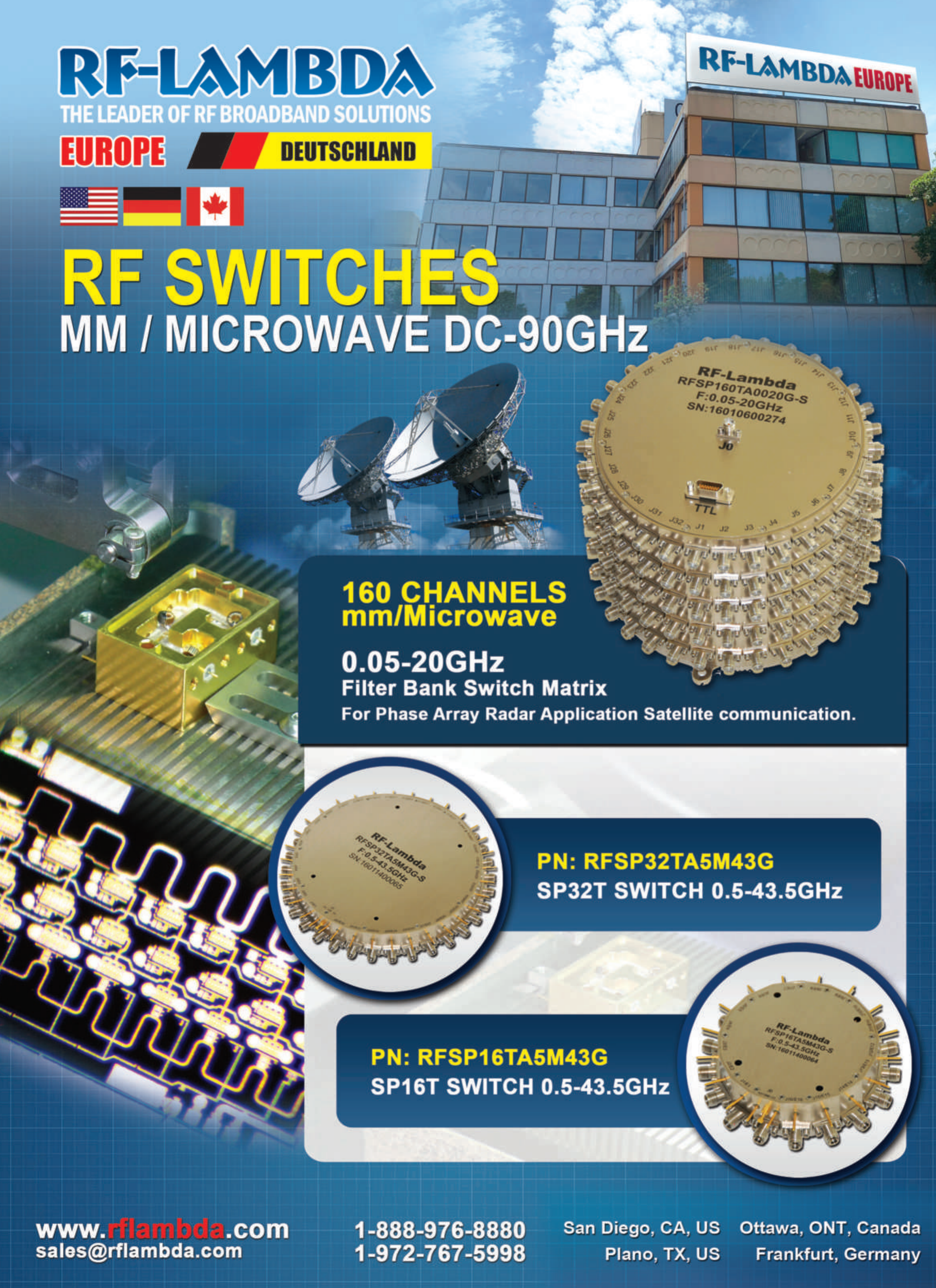


Fig. 6 TS8021N switch performance: insertion loss (a), isolation (b), compression (c) and harmonics (d).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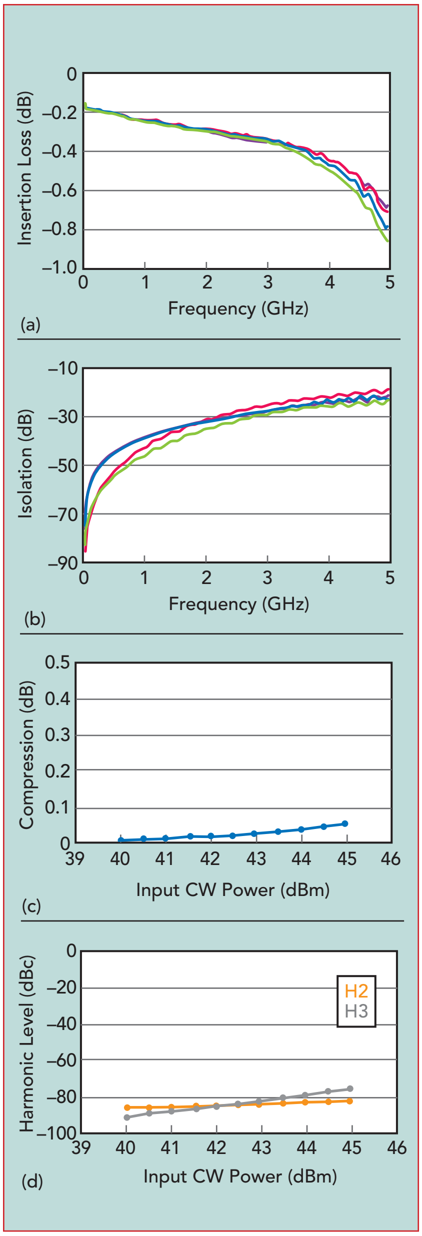
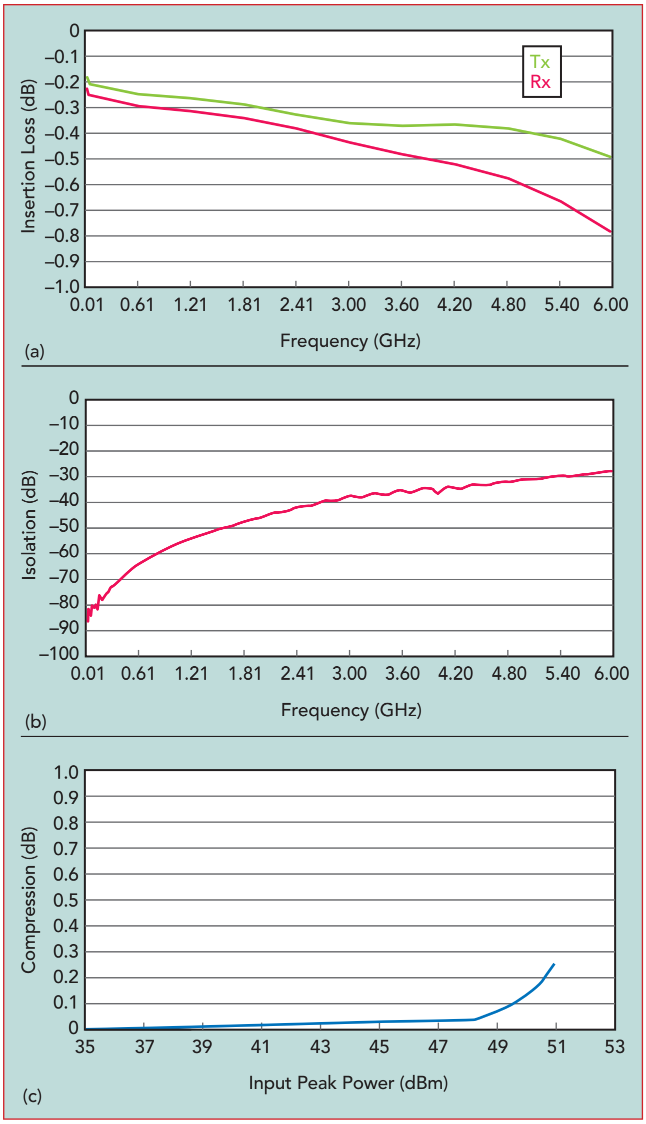


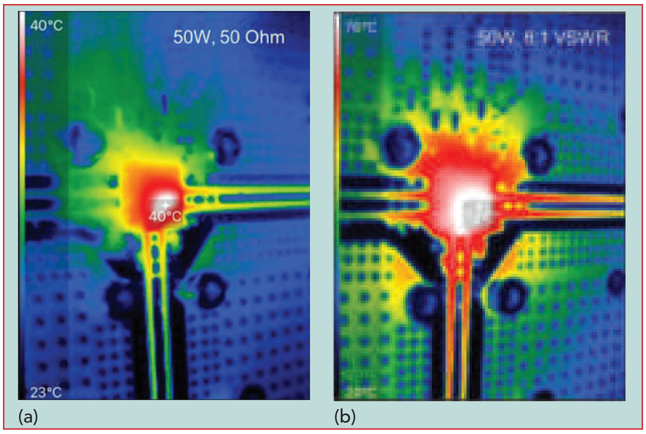
▲ **Fig. 7** **TS8242FK switch performance: insertion loss (a), isolation (b), compression (c) and harmonics (d).**

fail-safe function in massive MIMO (mMIMO) base station applications. The switch has 0.5 dB Rx IL and 35 dB isolation in the newly released 5G C-Band. It has a P_{PEAK}–0.1 dB of 100 W and a switching time of 0.5 uS. Both TS8242FK and TS8329FK switches are integrated in small 3 × 3 mm QFN packages with only one external capacitor saving significant board space compared to PIN diode solution.

High-power switches are expected to withstand very harsh conditions in terms of VSWR, especially switches close to the antenna. GaN RF switches have excellent thermal and VSWR performance. ***Figure 9*** shows the thermal performance of a TS8021N switch with 50 W of input power into 50 Ω (see Figure 9a) and with an 8:1 VSWR (see Figure 9b). The thermal image is taken after the part is exposed to this condition for 1 minute. VSWR is shown for the worst condition, in terms of power dissipation, which happens in the low impedance state. The temperature in the opposite condition, worst in terms of peak voltage, is much lower and can be easily withstood because of the characteristic high breakdown voltage of GaN devices.



▲ **Fig. 8** **TS8329FK switch performance: insertion loss (a), isolation (b) and compression (c).**



▲ **Fig. 9** **TS8021N switch temperature profile when matched to 50 Ω (a), with an 8:1 VSWR (b).**

SUMMARY

High-power front-end design using GaN switch technology has been demonstrated. GaN RF switches address major challenges associated with board space and SWaP in tactical military communications and base station radios. GaN switch technology eliminates the complexity associated with PIN diode switches for RF design engineers and makes the design portable, which is critical for mMIMO and phased array architectures, given that Tx and Rx array size continues to grow. With further technology advancement and improvements in the FoM, newer generations of GaN-based switches will open the door for many applications, such as high-power tunable matching circuits, tunable antennas and tunable filters. ■

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INVITED PAPER

The Unique Challenges of GaN Amplifier Production Test

Devin Morris
Roos Instruments, Santa Clara, Calif.

With the rollout of 5G, an important link of the new radio network infrastructure chain is the power amplifier (PA) in the gNodeB base station. The PAs are expected to operate without failure, often in extreme conditions, and the 5G standards cover broader bandwidths at higher frequencies and with higher efficiency. Accordingly, the PAs and the semiconductor devices comprising them have more rigorous and strenuous testing requirements compared to the RF front-ends in mobile devices.

Traditionally, Si laterally-diffused metal-oxide semiconductor (LDMOS) was the preferred process technology for base station PAs; however, as LDMOS has performance degradation as the frequency increases beyond 3 GHz, GaN on SiC has emerged as a competitive alternative, offering distinct advantages for high power applications. One of the most significant advantages is its larger bandgap compared to Si, which yields a larger breakdown voltage and more thermal stability at higher temperatures. Secondly, GaN on SiC has higher thermal conductivity compared to Si, which means higher efficiency at comparable operating voltage, reducing the challenge of thermal management. Lastly, GaN's breakdown field is significantly higher than Si's, with 10x the voltage handling before failure. This enables GaN devices to be manufactured with smaller die size despite the higher power density.

The advantages of this process technology bring unique test challenges to qualify the performance and robustness of RF GaN devices and MMICs. As GaN is a relative newcomer in base station PAs, production testing is a mix of process characterization, performance qualification and reliability evaluation. The higher performance characteristics and unique biasing required for GaN amplifiers add complexity compared to traditional LDMOS amplifiers. This article discusses how test systems can address this complexity.

BIASING

Compared to enhancement mode LDMOS, GaN HEMTs require both positive drain and negative gate bias from the test equipment. While the voltages are conventional, the idle state voltages of the supplies and the sequencing of the DC bias are deceptively tricky to avoid damage to the device under test (DUT) or the test equipment. As a depletion mode FET, GaN devices require a negative pinch-off voltage at the gate to keep the transistor turned off before

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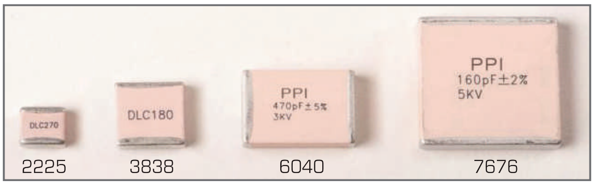

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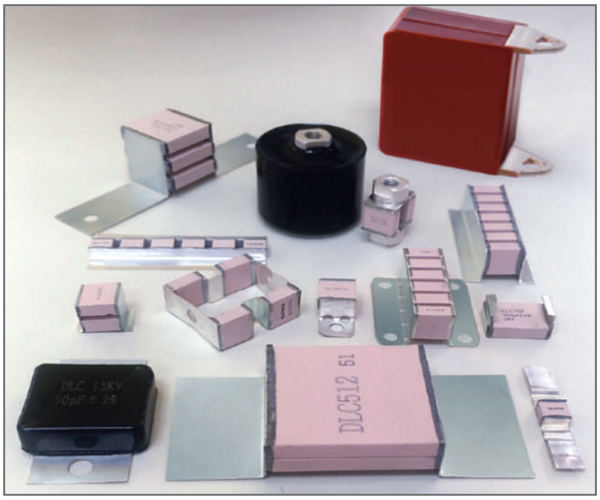

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Call us today **631-425-0938** | sales@passiveplus.com | **www.PassivePlus.com** applying the drain voltage, followed by a gate voltage adjustment to the correct bias voltage before RF testing. The reverse of this sequence must be applied at the end of testing and before the next device is tested. This requires the test equipment to have specialized sequencing and idle state control, and the device interface must provide a "fail safe" to prevent a faulty device from damaging the socket or test equipment.

With lower "on" resistance compared to Si and a high breakdown voltage, GaN devices require high voltage and low current testing. Characterization of the breakdown voltage is common, requiring voltages greater than 100 V while simultaneously measuring current in the pA to nA range. This testing requires fast and precise response times from the equipment, to abort the test once the breakdown voltage is exceeded and avoid permanently damaging or degrading the DUT.

MICROWAVE TESTING

One of the most significant challenges of testing GaN RF devices is the prominent role and requirements of microwave test in evaluating performance. As 5G standards push frequencies above 3 GHz with stringent requirements for output power, linearity and efficiency, GaN device manufacturers are relying on the RF performance to differentiate their products from LDMOS. This requires the production test environment to emulate the traditional microwave test bench. However, instead of multiple, dedicated benchtop instruments or custom load board solutions, comprehensive, integrated and modular microwave automated test equipment (ATE) solutions are favored (see ***Figure 1***). This need resulted in the development of ATE architectures delivering comparable performance to bench instruments while providing configurable test resources customizable to the application and with the flexibility to meet shifting performance requirements. This capability handles a range of microwave measurements with only a single device insertion.

Fig. 1 **Production ATE with integrated microwave test capabilities for fully testing PA devices with a single insertion.**

The challenge testing GaN base station amplifiers in production is the combination of high RF power, high frequency and high measurement precision. These factors influence multiple facets of the ATE configuration, capabilities, interface design and calibration. On the equipment side, the microwave source and measurement instrumentation have moved from the device interface into dedicated microwave instruments in the ATE combining spectrum analyzer, power meter and vector network analyzer capabilities. This integration enables broad frequency and test coverage with specified measurements and integrated calibration. It removes instrument complexity from the device interface design, so it plays a more application-specific role as the load string for high power conditions and signal provisioning for specialized measurements (see ***Figure 2***).

Amplifier measurements typically include gain, gain flatness, efficiency, adjacent channel power (ACPR), linearity (EVM) and other linearity specifications such as P_{1dB} and P_{3dB}. With 5G PAs, the performance levels and higher frequency requirements place greater importance on calibration. While the type of instrumentation and measurement will dictate whether a vector or scalar power calibration is required, the benefits and limitations of each pertaining to amplifier testing should be understood.

ATE CALIBRATION

Scalar calibration has advantages in linearity and efficiency measurements where the power accuracy is critical. Scalar calibration typically involves a broadband power meter with sensor to determine the signal power at the measurement plane. However, the power sensor does not differentiate spurious or harmonic signal power from the source power; the higher power with PA testing increases the likelihood of spurs and harmonics. To understand these sources of measurement error, the test designer must assess the test system's source distortion, the receiver's bandwidth and its out-of-band rejection.

Vector calibration has advantages for relative measurements such as gain and return loss. The calibration is able to correct for mismatch and accurately account for how much signal is absorbed or reflected from the DUT, which can affect the accuracy of power-added efficiency (PAE) measurements. PAE requires an accurate measurement of amplifier's actual input power, accounting for the often poor input match. The challenge for vector calibration is the higher signal power involved. While the small-signal model of PAs more closely

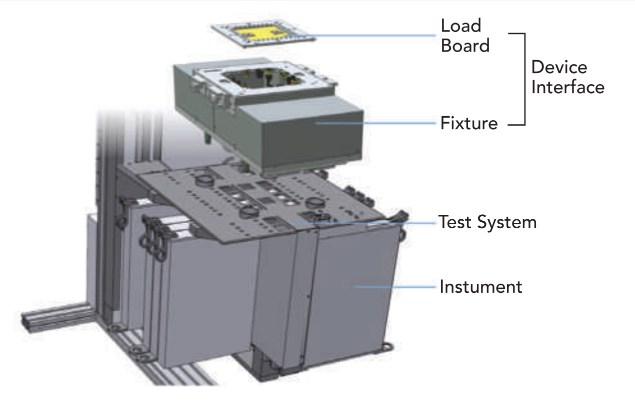

Fig. 2 **ATE architecture, where the signal source and measurement instrumentation are in the instrument, not at the device interface.**

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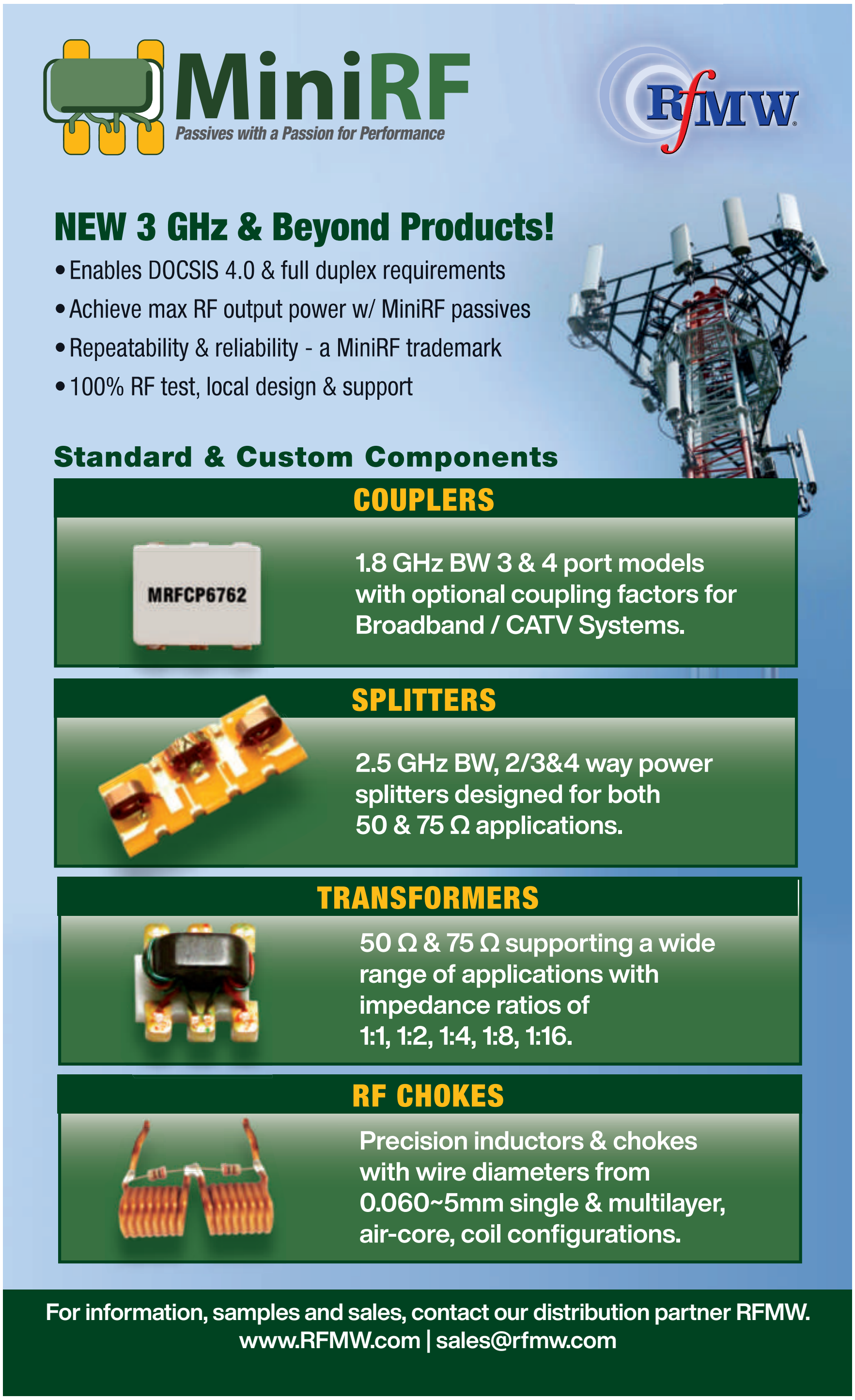
resembles a 50 Ω environment, the large-signal characteristics can differ significantly, presenting VSWRs that cause large peak-to-peak gain errors. This warrants signal conditioning in the source to reduce large reflections that can damage the test equipment or the DUT. The setup must also mirror the actual test and be repeatable, so the calibration accurately corrects matching errors during device testing.

The calibration reference plane should be as close to the DUT as possible to achieve an accurate representation of performance. This means the device interface environment must provide access to the microwave source and measurement port connections and be compatible connecting to power sensors and the open/short/load standards (see ***Figure 3***). ATE that supports multi-layer calibration software for individual instruments, multi-instrument system integration and device interfaces provide an advantage. This capability enables the ATE components to be efficiently and reliably exchanged and replaced on the production test floor.



PULSED DC/RF

Because of the high power density of GaN, the upper limits of the power and thermal handling of the device must be qualified. Despite GaN's enhanced thermal properties, heat dissipation is a problem in a production test setting, as it is impractical to provide adequate heat sinking for on-wafer testing and most packaged devices. Therefore, most testing uses pulsed DC and RF measurements, which avoids damaging or degrading the DUT while providing in-situ conditions and robust qualification.

For instance, a typical P_{1dB} or P_{3dB} measurement involves several tests, all requiring fast, stable and repeatable measurements to accurately determine linearity. The first step is to determine the DC bias conditions at normal operation and ensure it is within the expected range. With the gate and drain bias set, a sweep of input RF power at one or multiple frequencies provides the linear gain and compression characteristics. Because of process and package variations, the sweep range can vary from 5 to over 20 dB with step size under 0.5 dB to capture the linear range and compression of the power transfer characteristics. From the measured output power sweep, the input power for the 1 dB and 3 dB compression points are extracted.

Another significant measurement is efficiency or PAE, the amplifier's power conversion ability. Efficiency is defined as the ratio of RF output power to the corresponding DC input power, expressed as a percentage; PAE subtracts the RF input power from the calculation. These measurements are indicators of end-use performance and competitive differentiation. While the definition of efficiency is straightforward, the measurement can be challenging as it relies on several underlying tests. For product specifications, efficiency is typically computed at

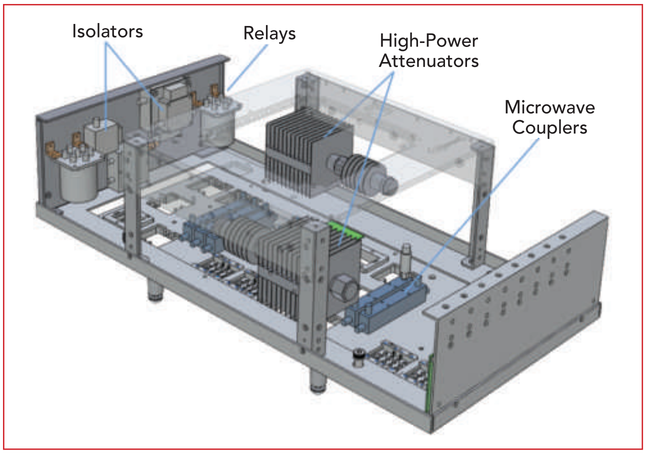


Fig. 3 Typical high-power device interface.

multiple power conditions. In production test, the measurement typically happens in two steps: 1) a sweep of input power to characterize the amplifier's power curve, followed by 2) RF and DC measurements at specific output power values: within the linear range, at 1 dB compression and 3 dB compression. Both the length of the power sweep and speed of the instrumentation must avoid thermal heating of the DUT, both to avoid degradation to the device and to maintain a consistent thermal environment when measuring the RF output power at various points, necessary to ensure accuracy of the efficiency calculation. This places the following requirements on the instrumentation:

- The sweep requires a pulsed RF source and a measurement capture of a few milliseconds.
- The measurement accuracy of the output power sweep is critical since the input power settings on the second pass depend on the measured output power. For efficiency measurements in the linear power range, a ±0.1 dB difference in measured output power translates to almost a ±0.5 point difference in efficiency. This is exacerbated when the amplifier is in compression, as each ±0.1 dB difference in measured output power translates to approximately a ±1 point difference in efficiency.
- The source linearity and measurement repeatability of the test system will affect the accuracy.
- Amplifiers generate harmonics from the high RF power and circuit design, which are undesirable and often overlooked or disregarded when measuring efficiency, despite being contributing factors to measurement uncertainty. This should be considered in the design of the test setup. For accurate efficiency measurements, a narrowband, tuned receiver is better than a broadband receiver (see sidebar).

SUMMARY

Despite the challenges described in this article, current ATE systems provide accurate microwave measurements of GaN PAs in a manufacturing environment,

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TABLE 1
TYPICAL ATE MEASUREMENT REPEATABILITY

Measurement	*Standard Deviation*
Gain	0.020 dB
P_{1dB}	0.013 dBm
Efficiency at P_{1dB}	0.309 pp
P_{3dB}	0.010 dBm
Efficiency at P_{3dB}	0.200 pp

meeting the test time, cost and reliability expectations of production. ***Table 1*** shows the measurement repeatability achievable for the most common PA measurements.

Semiconductor process development will continue to improve device performance, and production testing of these devices will remain a mix of characterization and qualification. Ensuring the quality of the test data is important to reduce process variation, improve device yield and help predict how process changes affect device reliability. Testing requirements will continue to evolve as 5G-Advanced and 6G standards move operating frequencies higher, and GaN device technology extends its advantages to higher frequencies. ■

When Power Accuracy Matters, A Tuned Receiver Is Preferred

When correlating measured power between different setups, there is often a discrepancy between power meters and tuned receivers. PAs are generally driven into compression, which means there can be significant power in the harmonics. A tuned receiver measures only at a limited bandwidth around the desired frequency and rejects signals at other frequencies. A typical power meter is untuned and measures the total combined power of the signals in its operating bandwidth.

Example: A GaN PA operating at 5.6 GHz generates harmonics at 11.2, 16.8, 22.4 … GHz. The power meter reflects the combined power of the fundamental and all harmonics in its bandwidth, while a tuned receiver reports only the fundamental power at 5.6 GHz. While both measurements are technically correct, the user usually wants just the in-band power.

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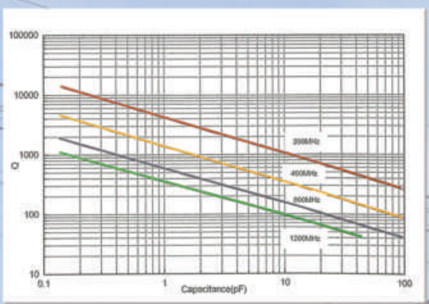
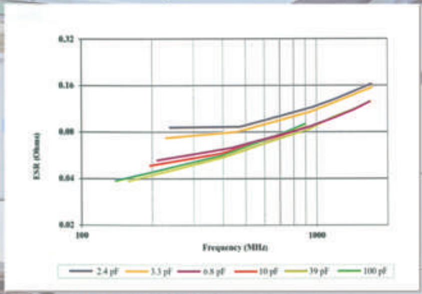


DLC70A(0505) Q Value and Capacitance Curve



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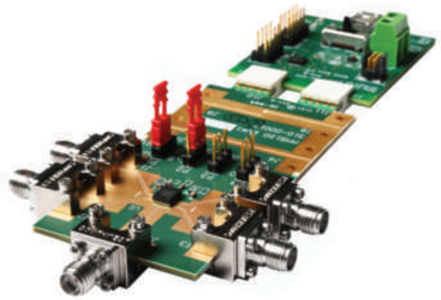

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Menlo Micro claims it's no exaggeration that MEMS technology and its Ideal Switch® have effectively reinvented RF switching. Its MEMS switches, typically mounted in a land grid array package, are orders of magnitude smaller and lighter than electromechanical relays (EMRs). They can handle high RF power levels and operate well into mmWave. They are also highly linear, have minimal insertion loss and are reliable, designed to last more than 3 billion switching cycles without performance degradation.

Menlo Micro's latest RF switch, the MM5120, exemplifies what MEMS-based switch technology can achieve (see ***Table 1***). The high-power single pole four throw (SP4T) switch operates from DC to 18 GHz and handles up to 25 W CW, 150 W pulsed power to 6 GHz, with an input third-order intercept point greater than 90 dBm. The switch's on-state insertion loss is 0.4 dB at 6 GHz and it consumes less than 5 mW of DC power, making it well suited for power-sensitive designs and applications such as switch matrices, RF front-ends, tunable filters, antenna tuners, interface boards, digital step attenuators and beam steering in both MIMO antenna arrays and AESA radars.

TABLE 1

MM5120 PERFORMANCE SUMMARY

Parameter	Unit	Minimum	Typical	Maximum
Frequency Range	(GHz)	DC		18
Insertion Loss • 6 GHz • 12 GHz • 18 GHz	(dB)		 0.4 0.6 1.2	
Input Power at 6 GHz • CW • Pulsed	(W)			 25 150

For designers, the MM5120's features enable switching solutions to be achieved in a small footprint—5 × 4 mm—that formerly required lots of board space and DC power. For example, the low power consumption of the MM5120 means that when deployed in large switch matrices, all the switches will consume less power than a single EMR, while delivering speeds 1000x faster and requiring 90 percent less space.

Menlo Micro's MEMS switches are fabricated using through glass via (TGV) packaging, i.e., short, metalized vias. TGVs enable a dramatic reduction in switch size and eliminate wire bonds which reduces package parasitics by more than 75 percent for RF and microwave applications.

While all EMRs employ a metal beam as

the actuator, MEMS switch actuators are so small their mass is negligible. This means they can deliver stable, long-term performance when subjected to extreme shock and vibration—harsh conditions in which electromechanical relays fail. The MM5120 and Menlo's other Ideal Switch devices exceed the IEC 60601/60068 standard and pass MIL-STD 810G/H stress tests for shock and vibration.

Because Menlo Micro's switches are electrostatically actuated, they need high voltage and low current biasing. To accommodate this, Menlo developed a high voltage charge pump and driver circuit and integrated it with the MM5120 and other Menlo switches. Unlike other MEMS switches, this integration eliminates the need for external components such as a discrete charge pump and driver/multiplexing circuit. Menlo's integrated high voltage charge pump and controller enables the switch's SPI and GPIO digital interfaces to control the switch from any host processor.

The technology that made these MEMS switches viable is the result of more than 12 years of research and development (R&D) conducted by General Electric (GE) for the company's power systems. Menlo Micro's founders played an integral role pioneering this MEMS switching technology at GE. Recognizing that its switch innovations could benefit multiple industries, GE spun out the technology, creating Menlo Micro in 2016. Backed by $225 million in funding, Menlo Micro's founders leveraged GE's MEMS and material science R&D to develop MEMS technology with the goal of transforming electronic switching, which led to Menlo Micro's Ideal Switch.

Ongoing development in collaboration with partners has yielded MEMS switches able to handle kilowatts of power, high temperatures and operating lifetimes in decades. Menlo Micro's switch portfolio includes models that operate to 40 GHz; new designs will extend the frequency range to 60 GHz.

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Small, Broadband, Cost-Effective Chip Attenuators

The demand for communication and data transmission in the digital age has created a huge market for broadband connectivity, leading to requirements for components with wide frequency coverage, small size and higher power ratings. Responding to this need, Smiths Interconnect's TSX series of fixed chip attenuators offer broadband performance to 50 GHz in a small 0604 surface-mount package, with 1 to 3 W CW power handling. The TSX series offers attenuation values from 1 through 10 dB in 1 dB steps, as well as 15 and 20 dB. Accuracy is specified as ±0.5 dB through 40 GHz, ±0.5 dB to 50 GHz for the 1 through 10 dB attenuators and ±3.0 dB between 40 and 50 GHz for the 15 and 20 dB attenuators. VSWR is a maximum of 1.2:1 through 40 GHz and 1.25:1 between 40 and 50 GHz.

The TSX attenuators were designed using 3D electromagnetic simulation software; 3D and S-parameter models are available from Modelithics. The attenuators are fabricated on alumina substrates using a thin film tantalum nitride material for the resistors and gold over nickel metallization, coated with Si nitride passivation. This results in a product able to withstand harsh environments, such as space and military systems. The wide frequency coverage of the TSX series enables designs to use a single attenuator for multiple applications, which reduces the bill of material count and inventory cost.

Smiths Interconnect provides a wide selection of chip attenuators covering DC to Q-Band. To meet the thermal needs of various applications, the chip components are fabricated on alumina, aluminum nitride, beryllium oxide and CVD diamond. Smiths Interconnect products are available from RFMW, a specialty electronics distributor exclusively serving customers requiring RF/microwave components and semiconductors.

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GaN LNAs Offer High-Power Handling with No Limiters, Cover 1–23 GHz

Pasternack has released three GaN low noise amplifiers (LNAs), which withstand high input power without requiring a protective limiter. LNAs using more sensitive semiconductor technologies, such as PHEMT, typically require a protective limiter at the input; however, the limiter adds loss before the LNA, degrading the noise figure.

The three GaN LNAs added to Pasternack's portfolio cover 1 to 7, 5 to 13 and 1 to 23 GHz. The 1 to 7 GHz LNA has 1.5 dB typical noise figure, 42 dB small-signal gain, 22 dBm output power at 1 dB compression, 31 dBm output IP3 and maximum input power handling of 30 dBm CW. The 5 to 13 GHz design has 1.8 dB noise figure, 44 dB small-signal gain, 22 dBm output power at 1 dB compression, 31 dBm output IP3 and maximum input power of 34 dBm CW. The 1 to 23 GHz amplifier has 3.5 dB noise figure, 29 dB small-signal gain, 20 dBm output power at 1 dB compression, 32 dBm output IP3 and input power handling of 40 dBm CW. The GaN LNAs are biased with 24 V_{DC} and draw from 160 to 250 mA. They are assembled in housings with SMA connectors.

These three GaN LNAs complement Pasternack's lower frequency LNAs, providing a complete family of options for virtually any RF/microwave application. As with all Pasternack products, the GaN LNAs are in stock and available for immediate shipping with no minimum order quantity required.

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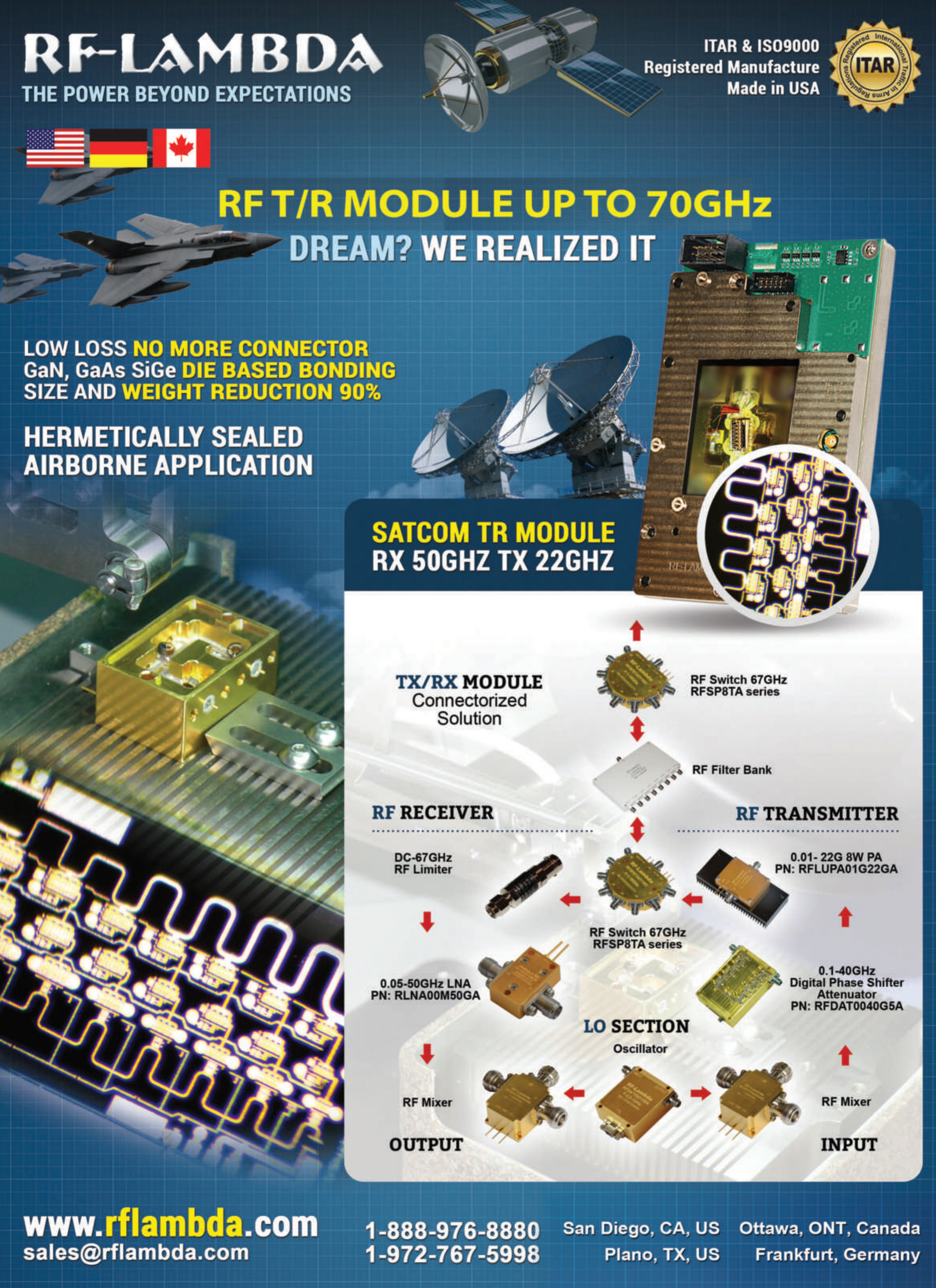

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PN: RLNA00M50GA
0.1-40GHz
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Attenuator
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Oscillator
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RF Mixer
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1-972-767-5998
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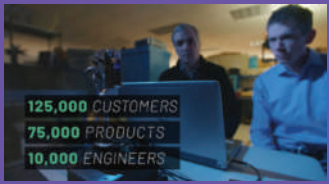
ADI IMA Capabilities Get You to Market at Record Speed

This video showcases ADI's ability to integrate at any level, making them uniquely qualified to help you attain optimal performance, SWaP and reliability.



Analog Devices, Inc.

www.youtube.com/watch?v=XdbkvzOcLt8

Video Demonstration

MilliBox, the leading benchtop mmWave OTA testing solutions, demonstrates its integration of MBX02 modular chamber with GIM04-230x 3D positioner working with Copper Mountain Technologies Cobalt FX USB VNA and FET1854 frequency extenders

Millibox

https://bit.ly/3MmnP0x

Mathematical Tools of the Trade Poster by AR

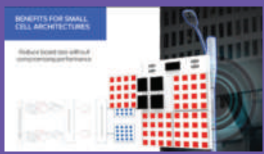
AR's updated Mathematical Tools of the Trade Poster provides a reference for EMC engineers to use on a daily basis in the lab or at the desk.

AR RF/Microwave Instrumentation

https://bit.ly/3M35Ufc

Mini-Circuits Video: LTCC Meets 5G

Mini-Circuits has combined advances in material science, circuit topologies, simulation capabilities and fabrication techniques to develop the widest selection of mmWave LTCC filters for 5G bandwidths.



Mini-Circuits

www.youtube.com/watch?v=Y3HXDnefA-Q

Free Advanced Simulation Models for 150+ Mini-Circuits Parts

Modelithics expands their partnership with Mini-Circuits, the Modelithics COMPLETE Library now includes over 100 advanced models representing 150+ Mini-Circuits parts. 32 3D models for Mini-Circuits components are also available for download from the Modelithics COMPLETE+3D Library.

Modelithics

www.modelithics.com/mvp/minicircuits

What Do MSL Ratings Mean?

A Moisture Sensitivity Level (MSL) indicates the amount of time a moisture-sensitive device can be exposed to ambient conditions prior to reflow. Learn more here.

RFMW

https://rfmwblog.com/2022/02/14/what-do-msl-ratings-mean/

MAKING WAVES

Fresh New Website

Spectrum Instrumentation launched a completely new website. It's now even easier to find out all about the 200+ digitizer and generator products. Or check out the new "parameter search" to find exactly your perfect fit solution.

Spectrum Instrumentation

www.spectrum-instrumentation.com

Edge Lock RF PCB Connectors

SV Microwave's Edge Lock PCB connector series is developed to form an interference fit between the conical alignment pin and the PCB thru-hole, thus pulling the contact lane of the connector in to the edge of the PCB.

SV Microwave

https://youtu.be/p2nf54CsQrM

Wolfspeed Opens New SiC Fab

Wolfspeed, Inc. officially opened its state-of-the-art, Mohawk Valley Silicon Carbide fabrication facility in Marcy, N.Y., with a ribbon cutting ceremony featuring federal and state officials. The 200 mm wafer fab will help lead the industry-wide transition from silicon to SiC semiconductors.

Wolfspeed

www.wolfspeed.com

NEW PRODUCTS

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COMPONENTS

High-Power Directional Coupler

MIcable D3005H005060 is a 0.5 to 6 GHz 30 dB high-power directional coupler that offers 250 W power handling capability. It has 1.3:1 maximum VSWR, 0.6 dB maximum insertion loss, 30±0.7 dB maximum coupling, ±1 dB maximum flatness and 15 dB minimum directivity. It is ideal for test, instrument and other high-power systems applications.
Fujian MIcable Electronic Technology Group Co. Ltd.
www.micable.cn

High Speed Threshold Detector

VENDORVIEW

PMI Model No. TD-1G12G-RL-CD-SFF is a high speed threshold detector designed to operate over the 1 to 12 GHz frequency range. It has an adjustable threshold level of -30 to -10 dBm and a VSWR of 3.0:1 maximum. This unit comes in one size with field removable SMA connectors on the input and output and has active low output.
Planar Monolithics Industries
www.pmi-rf.com

Ka-Band Cavity Filters

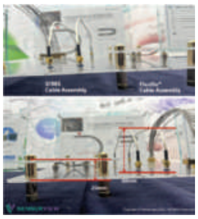
RLC Electronics is manufacturing several Ka-Band cavity, comb line and interdigital bandpass filters. These high Q filters offer the sharpest response (greatest stopband attenuation), lowest insertion loss and can be provided with relative 3 dB bandwidths ranging from 0.2 to 67 percent. The unit pictured operates from 30 to 36 GHz, with less than 1.5 dB of loss and > 23 dB at ±600 MHz from the band edges. Connectorized and surface mount versions available.
RLC Electronics
www.rlcelectronics.com

Ka-Band Transceiver

Spacek Labs Ka-Band transceiver, model TRKa-10 features a phase-locked LO chain shared by the transmit and receive channels. The transmitter converts the 4 to 17.5 GHz IF signal to 26.5 to 40 GHz RF output, conversion gain 30 dB typical. The receiver includes an isolator, balanced crossbar mixer and LPF which rejects the upper sideband and LO by > 60 dB, converting a 26.5 to 40 GHz RF input to 4 to 17.5 GHz IF output, 8 dB typical conversion loss.
Spacek Labs
www.spaceklabs.com

CABLES & CONNECTORS

Flexible Micro Bend Cable



Sensorview is offering a new innovative microwave cable solution into the market. Sensorview's Innovation allows you a minimum bend radius of 1.5 mm and low insertion loss and with the high phase stability the FlexiBe® series is the right answer for the demand of more flexibility for mmWave range. In addition to the antenna segment, Sensorview provides an extensive range of self-invented microwave cable assemblies including FlexStable, UltraRG and Aeroflon and Micro multi-ganged cable, covering the operating frequency from DC to 70 GHz.
Sensorview Europe GmbH
www.sensor-view.com

Coaxial Cable Assemblies

VENDORVIEW

Smiths Interconnect announced the release of the SpaceNXT™ QT Series of flexible coaxial cable assemblies, ideal for a variety of commercial space designs. The QT Series is part of Smiths Interconnect's SpaceNXT™ initiative to create an entire range of high performance, high reliability space products that eliminate the customer's need to undertake extensive qualification processes. The QT Series also responds to the customers' demand for cable assemblies with more consistent electrical performance over higher frequencies, larger temperature extremes and across higher volumes.
Smiths Interconnect
www.smithsinterconnect.com

DuraWave™ RF Cable Assemblies

Swift Bridge Technologies' DuraWave™ RF cable assemblies are now available for purchase on Digi-Key. The initial launch includes cable assemblies with operation frequencies of 18, 26.5, 33 and 40 GHz. These assemblies utilize N-type, SMA, 3.5 and 2.92 mm connectors. Each unique combination is currently available in two lengths, 0.6 and 1 m. In addition to the configurations available on Digi-Key, DuraWave™ RF assemblies are also available with other ruggedized connectors in both male and female versions. i.e. 7/16, DIN 9.5 and TNC.
Swift Bridge Technologies
www.swiftbridgetechnologies.com

AMPLIFIERS

Pulsed Microwave Power Module

The dB-3774B from dB Control is a pulsed microwave power module (MPM). This MPM operates in the 6 to 18 GHz frequency range and provides 1 kW peak power at 5 percent maximum duty cycle. It is designed for high performance electronic warfare applications. A periodic permanent magnet-focused, conduction-cooled mini traveling wave tube (TWT) is used for power amplification and a solid-state driver amplifier provides the required RF gain.
dB Control
www.dBControl.com

TWT Replacement

VENDORVIEW

Exodus AMP2033-LC is designed for replacing aging TWT technology. A broadband, rugged EMC Class A/AB linear design for all modulations and industry standards. Covers 6 to 18 GHz, produces > 100 W minimum, 50 W P1dB, with a minimum 50 dB gain. Excellent flatness, optional monitoring parameters for forward/reflected power, VSWR, voltage, current and temperature sensing for superb reliability. Exodus Quiet-Cool technology in our compact 5U-chassis weighs a nominal 75 lbs.
Exodus Advanced Communications
www.exoduscomm.com

Amplifier Powers 2000 to 2400 MHz

VENDORVIEW

Mini-Circuits' model ZHL2G02G4125+ Class AB amplifier delivers +51 dBm (125 W) typical saturated output power from 2000 to 2400 MHz. It achieves 51 dB typical power gain with ±1 dB gain flatness. The RoHS-compliant amplifier is unconditionally stable and consumes 16 A at +28 VDC. Ideal for communications and test systems, it features internal protection against reverse polarity and overheating and measures 110 × 70 × 30 mm with SMA input connector and Type N output connector.
Mini-Circuits
www.minicircuits.com

MiCable

T26 Series High Reliable & Durable Test Cable

PASSED

After 150K Bending Cycles

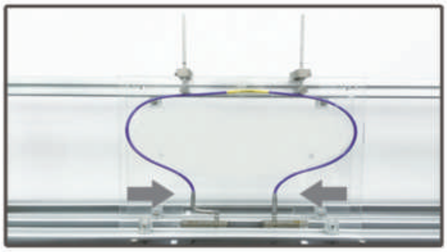
@26.5GHz

- Phase Stability vs. Flex. <±2° ✓
- Amplitude Stability vs. Flexure <±0.04dB ✓
- Insertion Loss <2.53dB/m ✓
- VSWR <1.25:1 ✓

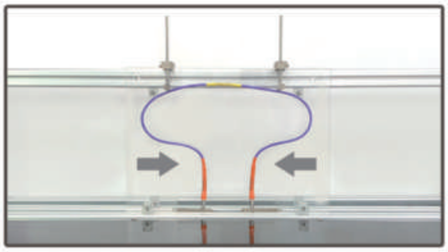
90°Connectors Available

In Stock !
1 day to 1 week

T26 Cable Assembly Test (90°Connectors)

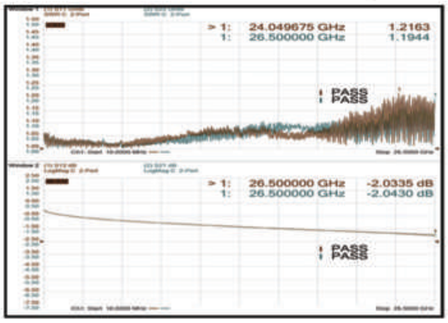


T26 Cable Assembly Test (Straight Connectors)

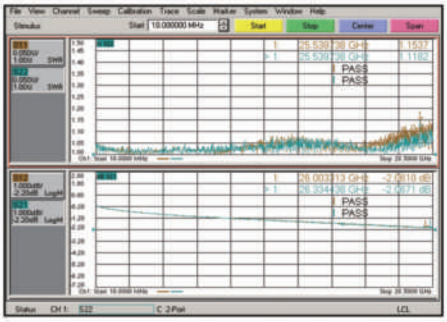


T26 Series DC~26.5GHz

DC~ 26.5GHz（SMA M - SMA MRA, 3FT）



(3.5mm M - 3.5mm M, 1 Meter)



Low Noise Amplifier Expansion

VENDORVIEW

Pasternack's new series of input protected low noise amplifiers feature broadband frequency coverage ranging from 1 KHz to 40 GHz, GaAs pHEMT semiconductor technology with high gain and noise figure levels as low as 1 dB typical. Input protected designs have up to 1 W CW RF power handling, high gain: 45 dB typical, high gain from 25 to 60 dB. Output P1dB up to +21.5 dB typical operating temperature -40°C to +85°C, rugged and compact mil grade aluminum package designs support female SMA or 2.92 mm connectors.

Pasternack
www.pasternack.com

SYSTEMS

mmWave Wireless Connectivity Solution

VENDORVIEW

The ADMV9621 and ADMV9611 is a complete mmWave wireless connectivity solution in a small, printed circuit assembly format. All mmWave signals are confined to the printed circuit assembly, simplifying implementation. Wireless transmission is achieved using the integrated circularly-polarized omnidirectional patch antenna array, which enables communication in many applications, including rotation. These solutions are ideal for industrial robotics applications to replace mechanical connectors and wireless slip rings.

Analog Devices Inc.
www.analog.com

Compact IF Receiver

The CMT compact IF receiver modules are ideal for radio astronomy projects. The module incorporates many features into a small package. Features include high gain (70 to 90 dB), a five-bit digital programable attenuator, integrated bandpass filters, output total output power detector and overload protection. Noise figure of 1 to 1.5 dB is typical. An RF test port is also included. These modules operate from a single supply. Applications include IF chain for THz SIS mixers.

Cosmic Microwave Technology Inc.
www.cosmicmicrowavetechnology.com

Bluetooth Low Energy 5.1 Module

VENDORVIEW

Würth Elektronik presents the Bluetooth low energy 5.1 module Proteus-III-SPI. The module, measuring only 8 × 12 × 2 mm, with a payload of up to 964 bytes, integrated antenna, encryption technology and six configurable IO pins, is based on the Nordic Semiconductor nRF52840 chipset. It can be used for IoT and M2M applications, for example, to build radio-based maintenance interfaces and sensor networks. The WE-ProWare firmware from Würth Elektronik, which has been industrial proven over many years, makes the module extremely versatile.

Würth Elektronik
www.we-online.com

SOURCES

Indirect Synthesizer

Kratos General Microwave enhanced its series of fast switching (1 usec) indirect synthesizers with the addition of the Model SM6220 with frequency modulation capability

covering the full band 2 to 20 GHz. It can provide a frequency deviation of 1 GHz at up to a 10 MHz modulation rate and can be modulated with either analog or digital inputs. Of special significance; the synthesizer output frequency remains fully locked even while in the FM mode. Its small size and high reliability make it ideal for use in demanding airborne environmental conditions as well as simulators and test systems.
Kratos General Microwave
www.kratosmed.com

RF Signal Generator

RIGOL Technologies introduces the DSG3000B Series RF signal generator offering high purity signal generation and modulation. The DSG3000B is available in 6.5 and 13.6 GHz models with optional built-in IQ baseband generator and OXO time base with standard AM/FM/ØM analog modulation up to 3.6 GHz, and I/Q modulation and I/Q baseband output up to 6.5 GHz. High signal purity with phase noise measuring < -116 dBc/Hz at 20 kHz (typical) and a wide output amplitude range of -130 to +25 dBm with an amplitude accuracy of < 0.5 dB (typical).
RIGOL Technologies
www.RIGOLna.com

Fixed Signal Generator

Z-Communications announced the FSG series of fixed signal generator products geared for the automated test equipment market. The FSG is a low noise, fixed signal oscillator that is offered between 500 MHz to 16 GHz. Housed in a sturdy SMA connectorized metal enclosure, the unit is meant for bench testing or field use. This portable signal generator operates off a power supply between 5 to 15 V. For further ease of operation an internal 100 MHz reference is included, or the user may connect an external 100 MHz source.
Z-Communications
www.zcomm.com

ANTENNAS

Dual Polarized Antenna

VENDORVIEW

Ideal for antenna measurement ranges, Model SAV-0434031428-KF-U5-QR is a dual polarized quad ridge horn antenna that yields continuous frequency coverage from 4 to 40 GHz. Equipped with two female 2.92 mm (K) connectors, the antenna provides vertical and horizontal illumination with an average gain of 14 dBi and a 3 dB beam width of 28 degrees. Typical cross-polarization is -28 dB. Isolation between vertical and horizontal ports is better than 23 dB with 28 dB typical. Maximum continuous RF power is 10 W.
Eravant
www.eravant.com

TEST & MEASUREMENT

5G mmWave Production Test Solutions

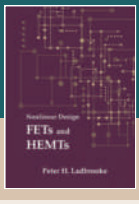
Marvin Test Solutions' TS-900e-5G Series mmWave semiconductor device test systems deliver unrivaled production test speeds ideal for demanding outsourced semiconductor assembly and test applications. Up to 20 independent vector network analyzer (VNA) channels with proven gap-free performance to 44 GHz and beyond ensure the most accurate and repeatable production VNA/S-parameter test performance. The flexible receiver is compatible with virtually any wafer prober and device handler.
Marvin Test Solutions
www.marvintest.com/5G

Next-Generation PCIe Digitizers

VENDORVIEW

Two new digitizer cards from Spectrum Instrumentation raise the standard of PC-based instrumentation performance. The cards are capable of streaming acquired data over the PCIe bus at an impressive 12.8 GB/s—nearly twice as fast as any other PCIe digitizer currently on the market. It means they can continuously run at their maximum sampling rate of 6.4 GS/s, with 12-bit resolution, streaming this massive data to CPUs or CUDA GPUs for real-time processing.
Spectrum Instrumentation
www.spectrum-instrumentation.com

MICRO-ADS



Bookend

Nonlinear Design: FETs and HEMTs

Peter H. Ladbrooke

"Nonlinear Design: FETs and HEMTs" by Peter H. Ladbrooke should be on the bookshelf of every III-V semiconductor device engineer, modeling engineer and circuit designer. What I particularly like about this book is it focuses more on the practicality of nonlinear device modeling rather than strictly theoretical constructs which are far less digestible to the practicing engineer. Don't let my statement fool you though, there is plenty of meat in this book even for the theoretical junkie! Those looking to "connect the dots" between device characteristics, device modeling and circuit performance should read this book.

Part I discusses commercially available nonlinear models as well as digging into the practical details of device behavior and model parameter extraction. Part II proposes a reformulation of the device model and proceeds to dig into the finer details of parameter extractions as well as presenting some results with practical circuits. Part III is perhaps the most detailed section, providing extreme depth on FET device characteristics, current and charge conservation and charge storage while also introducing macro-cell simulators.

As a MMIC design engineer, I found this book rather useful in understanding the finer details of how accurately (or inaccurately) modeling device characteristics impacts my circuit performance. In addition, I found it useful for understanding the connection of basic device characteristics and circuit performance. I see this being a valuable, frequently consulted reference for those deeply involved in the III-V semiconductor community.

Reviewed by:
Michael Roberg, Ph.D.
MMIC Design Engineer
Fellow at Qorvo

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Advertising**Index**

Advertiser	Page No.
Agile Microwave Technology Inc.	52
Analog Devices	45, COV 3
API Technologies	7
Artech House	86
AT Microwave	29
Atlanta Micro, Inc. (A wholly owned subsidiary of Mercury Systems, Inc.)	31
Avtech Electrosystems	84
B&Z Technologies, LLC	11
Boonton Electronics (a Wireless Telecom Group Company)	36
Cernex, Inc.	32
Ciao Wireless, Inc.	34
COMSOL, Inc.	15
Dalian Dalicap Co., Ltd.	69
dBm Corp, Inc.	48
Dielectric Laboratories Inc.	71
Eclipse MDI	24
EMV 2022	82
ERAVANT	18-19, 59, 75
ET Industries	28
EuMW 2022	87
Fairview Microwave	54, 55
Fujian MIcable Electronic Technology Group Co., Ltd.	41, 81
GGB Industries, Inc.	3
H6 Systems	26
Herotek, Inc.	30
HYPERLABS INC.	51
IEEE EMC + SIPI 2022	68
IEEE MTT-S International Microwave Symposium 2022	83
Impulse Technologies	65
Knowles Capacitors	71
LEONARDO	53
Master Bond Inc.	84
MCV Microwave	72
Mercury Systems, Inc.	31
Microwave Components Inc.	44
Microwave Journal	76, 79, 85
Mini-Circuits	4-5, 16, 38, 89
MiniRF Inc.	64
Networks International Corporation	6
Norden Millimeter Inc.	56
Novator Solutions	49
Nxbeam	33
OhmWeve	26
OML Inc.	47
Passive Plus, Inc.	61
Pasternack	8
Pulse Genex	26
QML Inc.	COV 2
Quantic PMI (Planar Monolithics)	23
Reactel, Incorporated	37
RF-Lambda	9, 27, 57, 77
RFMW	13, 64, 71
Richardson Electronics, Ltd.	63
RLC Electronics, Inc.	21
Rosenberger	25
Simon Elektronika Technologio	40
Space Tech Expo Europe 2022	74
Special Hermetic Products, Inc.	84
Synergy Microwave Corporation	43, 73
Tecdia, Inc.	22
Weinschel Associates	50
Wenteq Microwave Corporation	84
Wenzel Associates, Inc.	72
Werlatone, Inc.	COV 4
West Bond Inc.	66
Z-Communications, Inc.	67

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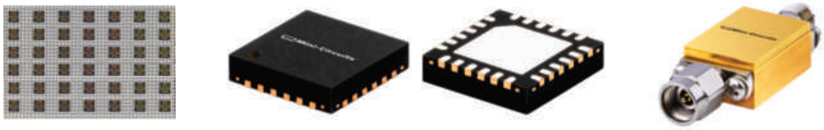

FABS and LABS

Vicor ChiP™ Fab – Automated and Sustainable Manufacturing





Vicor has expanded its manufacturing capacity by 2.5x with the opening of its new 90,000-square-foot, state-of-the-art converter housed in a package (ChiP) fabrication facility in Andover, Mass. This new fab is the first of its kind, leveraging a proprietary and highly scalable approach like semiconductor wafer fabs. This vertically integrated fab utilizes patented processes enabling Vicor to set the standard for high-quality, low-cost and reliable power module manufacturing in the U.S.

Leveraging Semiconductor Fab Approaches

Similar to semiconductor OEMs, Vicor has implemented proven and stringent fab facility processes from the ground up to ensure the highest quality. Designed with longevity in mind, the facility is equipped with industry-leading environmental controls for temperature, humidity and electrostatic discharge. The two-story building is optimized to handle immediate and future process requirements to accommodate the sophisticated ChiP manufacturing.

Vicor pioneered the proprietary panel-based manufacturing that uses a standard-size PCB, analogous to a Si wafer, in a highly automated approach to production. Multiple instances of the same high performance power module are produced simultaneously with pick-and-place capabilities for up to 420,000 components per hour on a patented substrate without compromising the accuracy or quality of the finished product. This enables Vicor to achieve 50 percent improvement in accuracy with significant increase in throughput over conventional methods. The line employs printing capabilities to achieve industry-best placement accuracy followed by advanced automated optical inspection techniques exceeding the most stringent quality standards to ensure zero-defect manufacturing.

The fab will also include specialized equipment to develop the terminal interfaces to support Vicor's proprietary vertical power delivery solution as well as supporting ball grid array requirements that Vicor aerospace and satellite communications customers require.

Automated, Sustainable Plating System

The second floor has been equipped to achieve vertical integration using state-of-the-art final packaging process steps (PPS) with capacity 5x greater than the outsourced capabilities. The vertically integrated PPS operations leverage the latest advancements in automation, handling and fluid spray technology. The operation will be tied seamlessly into the Vicor central computer-integrated manufacturing architecture enabling fully automated continuous operation. The PPS operation will be maintained by a new on-site chemical process laboratory.

Vertical Integration with Sustainability

With a focus on environmental sustainability, the operation is designed for zero wastewater and air discharge. All wastewater will be recycled into ultra-pure deionized water that is re-used in normal operation. It is estimated this new sustainable wastewater process will save up to 20 million gallons of water each year. The new plating operation will support all the Vicor SM-ChiP™ and CM-ChiP™ package designs.

For over 40 years Vicor has been designing and manufacturing its best-in-class, high density power solutions in Andover, Mass. As the leading designer and manufacturer of high performance power module solutions, the new facility will support a new era of growth, advancement and innovation for decades to come.

www.vicorpower.com


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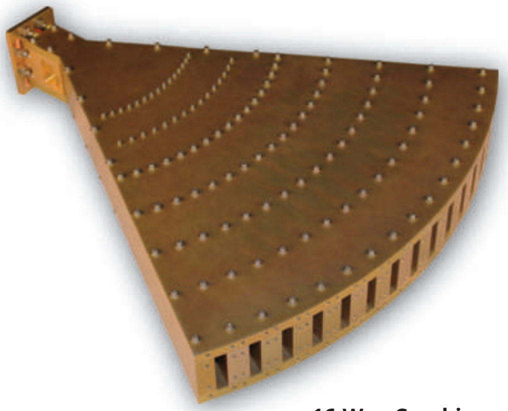


16-Way Combiner
5300 - 5900 MHz
12,000 W CW, 2.5 MW Peak
WR159 Output, Half Height WR159 Inputs

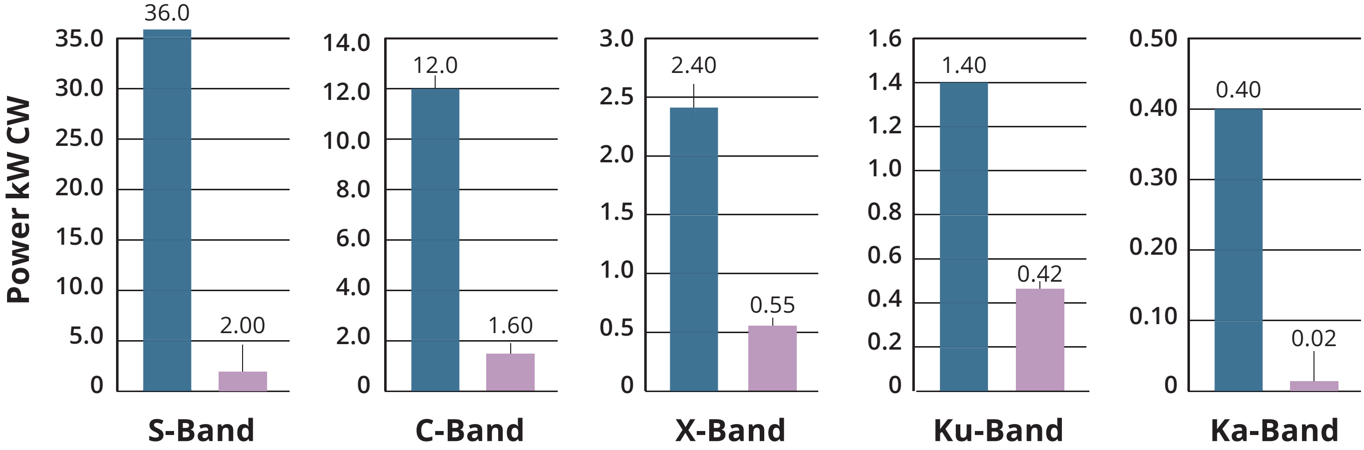
A New Class of Patented Microwave Power Combiners with Extremely High Power Handling Capability.

WERLATONE's new N-Way E-Plane Combiner architecture is ideally suited for emerging High CW Power/ High Duty Cycle Solid State Radar requirements.

Whereas an N-Way Radial Combiner design is limited in CW output power due to the diameter of the central output coaxial section (based on TEM Mode Operation), the E-Plane Combiner is limited only by the CW power rating of the respective waveguide size. This results in an N-Way Combining architecture which handles multiples higher in power at respective frequencies.

- Higher CW Power and Higher Duty Cycle
- High Power Density and Low Loss
- Space Efficient, Planar Structure
- Ideal for S, C, X, Ku, Ka Bands

CW Power ■ E-Plane Combiner vs. ■ Radial Combiner



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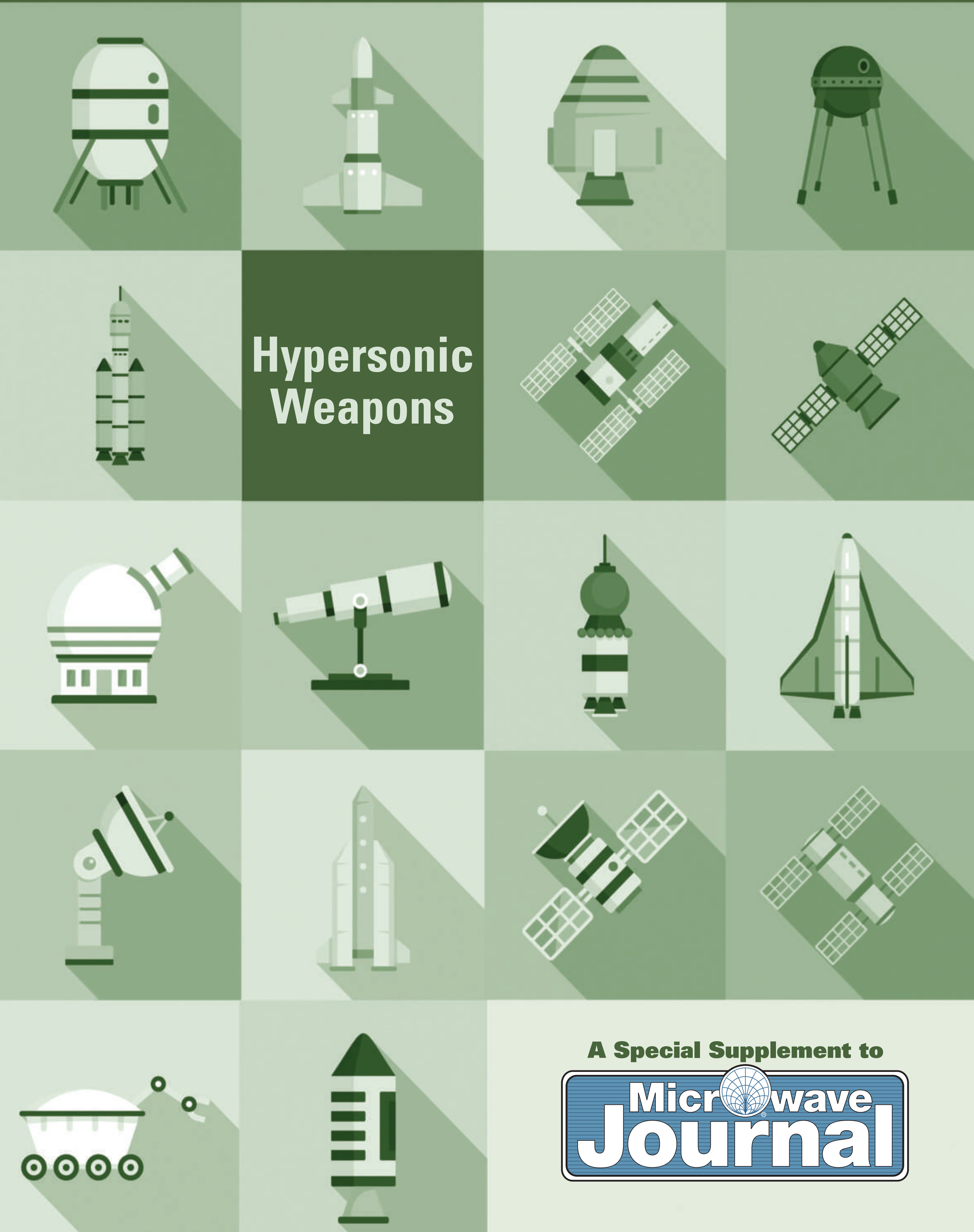

Hypersonic Weapons

A Special Supplement to

Microwave Journal

Aerospace & Defense
TABLE OF CONTENTS

Cover Feature

6 **The Age of Hypersonic Weapons is Upon Us**
Eric Higham, Strategy Analytics

Special Reports

20 **Advancing EW with New Silicon and Standards**
Rodger Hosking, Mercury Systems

30 **LEO Constellations: The New Military Frontier**
Nancy Friedrich, Keysight Technologies

Product Feature

36 **Integrated RF Digital Engineering Tools Support the Defense System Lifecycle**
Information Systems Laboratories, Inc.

Tech Briefs

40 **Temperature Compensated Amplifier Portfolio**
Fairview Microwave

41 **22 GHz Synthesizer: Multi-Channel, Phase Coherent Configurable**
AnaPico AG

42 **Lid Clip System Stops Thin Semiconductor Die from Migrating**
Gel-Pak

43 **Ku/K-Band MPM Optimizes Satellite Downlinks**
Stellant Systems

44 **Extensive Line of Drop-In Circulators and Isolators, from 100 MHz to 30 GHz**
CernexWave

45 **Phase Stable Cable Assemblies**
EZ Form Cable

Company Showcase

46 **Company highlights featuring aerospace & defense products and literature**

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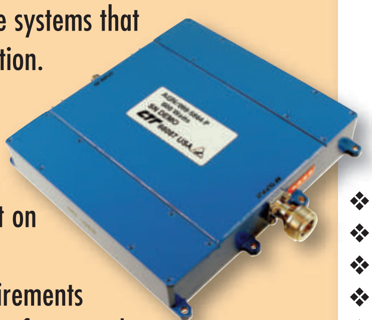

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The Age of Hypersonic Weapons is Upon Us

Eric Higham
Strategy Analytics, Needham, Mass.

Hypersonic missiles have risen to the forefront of conversations about global weapons arsenals. Attaining hypersonic speed is not new, with V2-powered missiles achieving hypersonic velocities in the late 1940s, and Russia's Sputnik 1 satellite reaching space orbit in 1957. What is new and responsible for elevated interest and concern comes from a series of recent events.

The world took notice when, in 2021, reports surfaced of a Chinese nuclear-capable hypersonic missile circumnavigating the globe before impacting near its target. The missile missed the target by 24 miles according to reports. What is most interesting, though, is these reports did not become public until several months after launch, indicating the Chinese missile was undetected during its flight. In the ongoing Russia-Ukraine war, reports have Russia deploying at least one of their Kinzhal hypersonic missiles in Ukraine toward the end of March 2022. In early April, The U.S. Defense Advanced Research Projects Agency (DARPA) announced the second successful test flight of its Hypersonic Air-Breathing Weapon Concept missile.

Hypersonic weapons technology ushers in a new era of disruption and destabilization. As technologists solve the missile challenges and the offensive technology evolves, defensive systems must keep pace. A significant imbalance between the offensive and defensive capabilities of a new weapons technology could easily upset the uneasy deterrence among nuclear countries.

This article will explore the technology, challenges, spending forecasts and electronics opportunities for hypersonic weapons.

MACH 5

The term "hypersonic" is a bit imprecise. General agreement defines hypersonic velocity as the speed where air molecules start to break apart and ionize. This happens over a range of speeds and will vary depending on the airframe design, so the accepted convention has become to define hypersonic velocity as a minimum of Mach 5 (~3836 mph).

Hypersonic weapons developments fall into two categories: hypersonic cruise missiles (HCM) and hypersonic glide vehicles (HGV). HCMs derive their thrust to propel past Mach 5 from an air-breathing supersonic-combustion ramjet engine—a "scramjet." Conventional ramjet engines use the forward speed of the vehicle to generate thrust. As the vehicle surpasses the speed of sound at Mach 1, the leading edges produce shock waves that slow the incoming air into the engine. In a ramjet engine, the intake passage compresses and ignites the incoming air to produce thrust. Current thinking has ramjet engines capable of reaching hypersonic speeds to Mach 6; however, at these speeds, the losses associated with the shock waves and the temperature increases from compressing the air make the technique very inefficient producing net thrust.

In the 1960s, NASA began addressing this challenge. Their solution was simple: compress the incoming air for subsequent combustion at higher speeds than a ramjet engine. While this was conceptually elegant and simple, severe design, material and coating challenges had to be solved to bring the idea to fruition. Implementation took four decades until the X-43A successfully demonstrated scramjet propulsion in March


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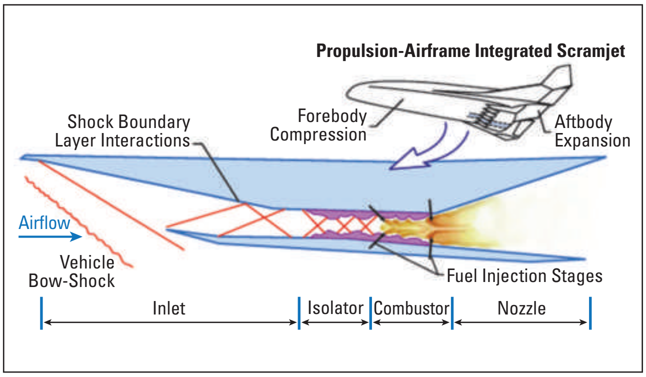


▲ Fig. 1 Scramjet engine concept. *Source:* NASA

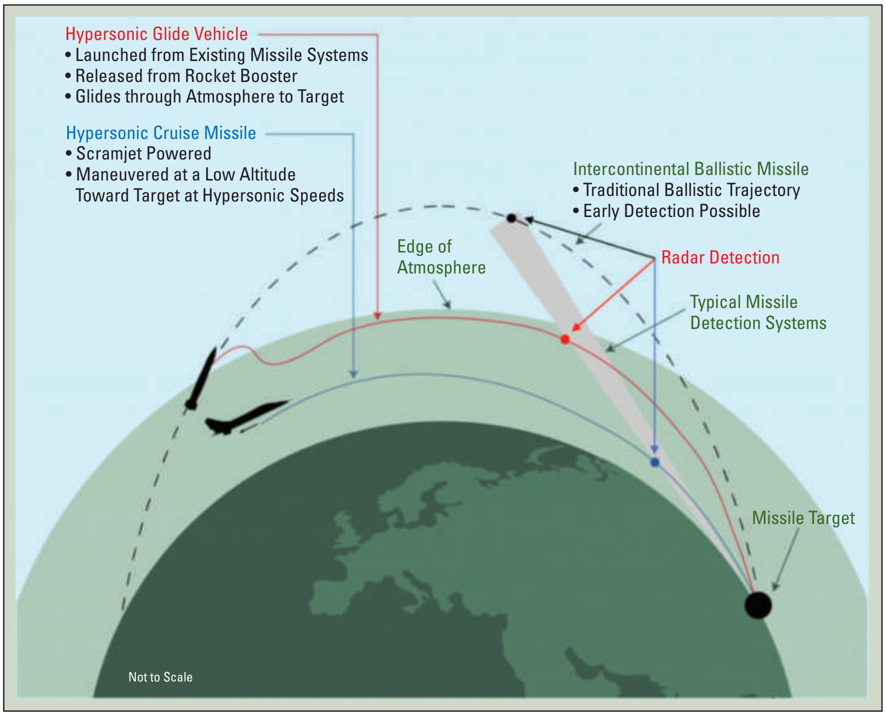
2004. ***Figure 1*** shows the basis for a supersonic-combustion ramjet. The design minimizes losses associated with slowing the air flow, so the engine can produce the net thrust required for a hypersonic vehicle. This concept has become the basis for engines working at speeds from Mach 5 to Mach 15. The engines still require air, which limits their theoretical altitude to the Kármán line at the edge of space, some 330,000 ft. above sea level. From a practical standpoint, HCMs have an altitude limit of ~100,000 ft.

HGVs are based on a different approach. Conventional rocket boosters launch these vehicles to a predetermined altitude, often just outside the atmosphere. Once the booster reaches this altitude, the HGV separates from the booster and the HGV begins picking up momentum and kinetic energy as it re-enters the atmosphere and glides to a target. During this glide phase, an HGV will use aerodynamic forces and control surfaces or small thrusters to "surf" the atmosphere between the Kármán line and altitudes of ~120,000 ft. ***Figure 2*** shows China's DF-17 hypersonic glide vehicle during one of that country's military parades.

▲ Fig. 2 Chinese DF-17 hypersonic glide vehicle. *Source:* nationalinterst.org

THE HYPERSONIC THREAT

Understanding the rudimentary theory of hypersonic weapons outlines the threat. Even though HCMs have an engine, they will be part of the weapons arsenal of a fighter jet

▲ Fig. 3 Projectile trajectories and the likelihood of detection. *Source:* Plowshares.ca

or the payload on a missile, which will get the weapon to hypersonic speed more quickly. While either type of hypersonic vehicle can rely on simple kinetic energy as its destructive payload, more likely a hypersonic weapon will include a conventional or nuclear warhead. These weapons have flexible mission profiles, with either type capable of launching from and targeting air, land or sea-based platforms. This gives them the ability to target high value targets in any domain. In particular, the U.S. battle philosophy relies on aircraft carriers and their accompanying battle groups to establish naval superiority; hypersonic weapons present a big threat to those large, high value targets.

It is worth noting that the threat of hypersonic vehicles goes beyond their speed, operating altitude and ability to carry nuclear weapons. The world has coexisted with the threat of intercontinental ballistic missiles (ICBM) since the late 1950s. These missiles can carry nuclear warheads with velocities more than Mach 15, meaning a missile can reach any target on the globe within 30 minutes. The threat of hypersonic weapons stems from their attack profile (see ***Figure 3***) and the difficulty detecting them.

Figure 3 shows the trajectory of a ballistic missile with a nuclear or a conventional payload, following the parabolic black dashed line trajectory to its target. The ballistic missile may also carry an HGV as a payload, with the HGV's trajectory shown by the solid red line. The diagram also shows a fighter jet firing an HCM, with the trajectory shown by the solid blue line. The large black dot represents the target, which has a radar with a cone of detection shown by the light gray triangle. The smaller, colored dots in the figure show where the radar would likely detect the incoming projectiles. With no over-the-horizon capability, detection range becomes a function of altitude: the radar detects the ICBM first, while the hypersonic vehicles get much closer to the target before the radar can detect them. While the diagram shows the HCM at a lower altitude than the HGV, which may typically be true, both vehicles are maneuverable and capable of overlapping mission altitudes and profiles.

Detection networks are usually more sophisticated than the simplified illustration in Figure 3; they incorporate over-the-horizon and space-based systems to enable early detection of missile launches. In addition, ballistic missiles have a parabolic trajectory that will be known as soon as sensors identify the missile signature. This means earlier warning than the diagram predicts, which helps maintain the stasis among the nuclear ICBM-equipped countries. Hypersonic vehicles threaten to disrupt this equilibrium because they follow un-

predictable trajectories, compress the time between detection and decision-making and present the uncertainty of whether the payload is a conventional or nuclear warhead.

HYPERSONIC DEVELOPMENT CHALLENGES

While hypersonic weapons are a threat and pose challenges to conventional defense systems, their development must overcome several hurdles before the weapons become mainstays of defense arsenals around the globe. Among these challenges:

Heat: Both types of hypersonic weapons systems operate in the atmosphere, and this means friction. Industry experts have estimated that friction caused by air resistance can easily increase skin temperature to more than 2200°C. This is several hundred degrees higher than the melting point of many of the lightweight metals used in projectiles. The rate and breadth of deployment of these weapons will require developing lightweight, easily manufactured airframe materials. The heat generated by internal electronics adds to the thermal problem; the internal electronics need to be protected from the heat generated on the vehicle.

Maneuverability: A big differentiator for hypersonic weapons is their unpredictable path, making them harder to detect and track. Mission profiles for these weapons have them operating in contested environments, facing a range of hostile defense systems. Implementing course changes requires taking advantage of vehicle aerodynamics or using small onboard thrust engines. These course changes, however small, will place enormous forces on the control surfaces and the vehicle frame.

These two challenges, coupled with aerodynamics and integration, fall in the realm of mechanical and materials expertise. In addition to the challenges of designing and manufacturing a vehicle that can achieve hypersonic speed, maneuver and prove cost effective and dependable, there are other challenges that relate to the mission profile of the weapon. These added challenges, which fall within the capabilities of the electronics industry, include the following:

Communications: The threat of a hypersonic weapon relies on its speed and unpredictability. This means that the command, control and communications infrastructure must be fast enough to implement course modifications and targeting information with little signal latency. Earlier, we defined the term "hypersonic" to be the velocity at which air molecules begin to ionize. Ionization creates a plasma shield around the hypersonic vehicle, and this atmospheric dissociation disrupts GPS, communication and telemetry signals. This is a fundamental problem, but there are developments aimed at tuning receiving antennas to enhance incoming communications signals during hypersonic travel. The Chinese are reportedly investigating THz communication networks to solve this problem.

Navigation, Timing and Accuracy: These challenges are related to communications. The sensors and internal electronics are stressed by the speed and the mission profile of the hypersonic vehicle, with the added complication of accuracy. If the hypersonic weapon is carrying a nuclear warhead, the destruc-

tive blast radius may accommodate some targeting inaccuracy, although this is an area for improvement. Initially, the U.S. is developing hypersonic weapons carrying only kinetic or conventional payloads, increasing the importance of accurate targeting systems.

DETECTION

To this point, the discussion has been on the benefits and challenges of the hypersonic vehicle as an offensive weapon. For the world to remain in that slightly uneasy state of weapons détente, defensive capabilities must be roughly equivalent to the offensive capabilities. An imbalance increases the likelihood of a hypersonic weapons first strike.

While much of the development has been on solving the offensive weapons challenges, military planners and government defense agencies are not overlooking the importance of defensive capabilities. As Figure 3 illustrates, hypersonic weapons flying faster at lower altitudes with less predictable flight paths compress the time for the conventional identify/decide/execute kill-chain analysis of military engagements. In addition to less time, decision-makers face much larger consequences and repercussions because the detected hypersonic vehicle may be carrying a kinetic, conventional or nuclear payload. Another concern is that decreasing the time to evaluate an incoming projectile increases the likelihood of a decision that escalates the situation.

In response, defense agencies are envisioning and developing defensive networks that incorporate and interconnect assets from the land, air, sea and space domains (see ***Figure 4***). The figure shows two hypersonic weapons launched from a plane and a land-based launcher, shown by the red flight paths. The illustration shows various satellite, AWACs-type reconnaissance planes, fighter jets, ground- and ship-based radars identifying the launches, triggering interceptor missiles launched from ground, ship- and air-based assets. This multi-layered solution integrates space-based and ground-based sensor systems to identify weapons launches earlier in their flight paths.

The U.S. Department of Defense (DOD) recently announced it will begin evaluating the Long-Range Discrimination Radar homeland missile defense system for tracking intercontinental ballistic missiles and enabling next-generation threats like hypersonic weapons to be detected at longer ranges. The U.S. Missile Defense Agency (MDA) is moving forward with a system that will integrate into the Aegis Combat System on naval vessels. This system will use two space-based sensor systems

▲ Fig. 4 Integrated hypersonic defense network. *Source*: www.airforcemag.com/article/hypersonics-defense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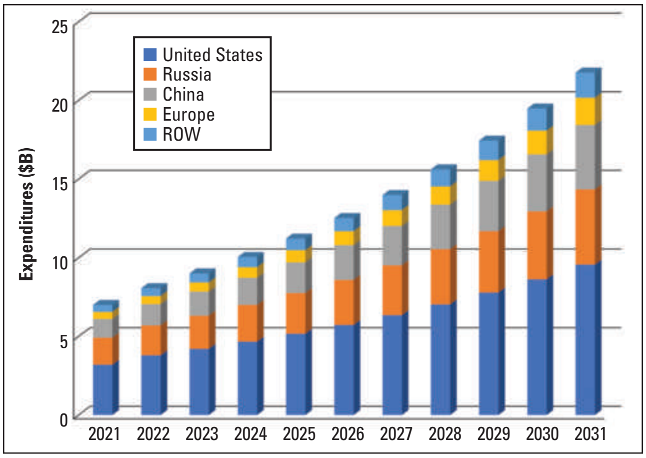
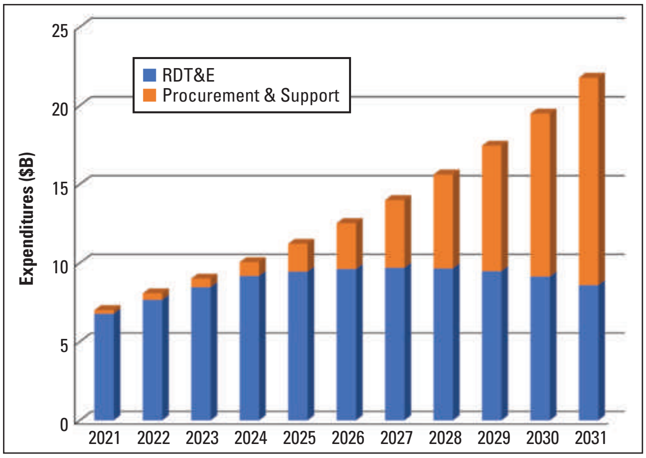


▲ Fig. 5 Global hypersonic weapons spending forecast by country. *Source:* Strategy Analytics



▲ Fig. 6 Global hypersonic weapons spending forecast, RDT&E vs. procurement and support. *Source:* Strategy Analytics

to detect the launch of hypersonic threats, tracking them before they separate from their boosters.

In addition to conventional missile-based responses to hypersonics weapons, the defense community is developing a next-generation response. The MDA has selected several U.S. defense companies to develop an interceptor specifically designed to defeat hypersonic threats. The Glide Phase Interceptor program will develop a weapon to intercept and defeat hypersonic weapons in the glide phase of flight as they are maneuvering toward their targets. Several countries, including the U.S. and the U.K., are developing high-energy laser weapons to help defeat hypersonic weapons.

SPENDING FORECASTS

Not surprisingly, a credible new threat with the potential to disrupt the balance of power requires an in-kind development response. ***Figure 5*** shows Strategy Analytics' latest forecast for hypersonic weapons spending. We anticipate total spending on hypersonic weapons will reach nearly $22 billion in 2031 and believe the U.S. will be the largest spender, accounting for slightly more than the combined expenditures of China and Russia over the forecast period. The U.S. response reflects the size of its defense budget, but it also reflects a concern that U.S. hypersonic weapons development lags the efforts in China and Russia. These three countries will account for nearly 85 percent of total spending, with some development by other countries.

We have characterized hypersonic weapons as an old technology that has been repurposed to a new mission profile. The forecast in ***Figure 6*** reflects the anticipated global spending profile. As with any new application, early funding is largely research, development, test and evaluation (RDT&E); until 2025, we expect more than 90 percent of funding will go toward development. Even though spending on RDT&E will peak in the middle of the forecast period and fall off, global defense agencies will still be spending more money on RDT&E for hypersonic weapons in 2031 than in 2021. As designers meet the challenges and the technology matures, we anticipate procurement spending on working hypersonic weapons will grow quickly. We expect militaries will spend slightly more than $13 billion on global procurement and support in 2031.

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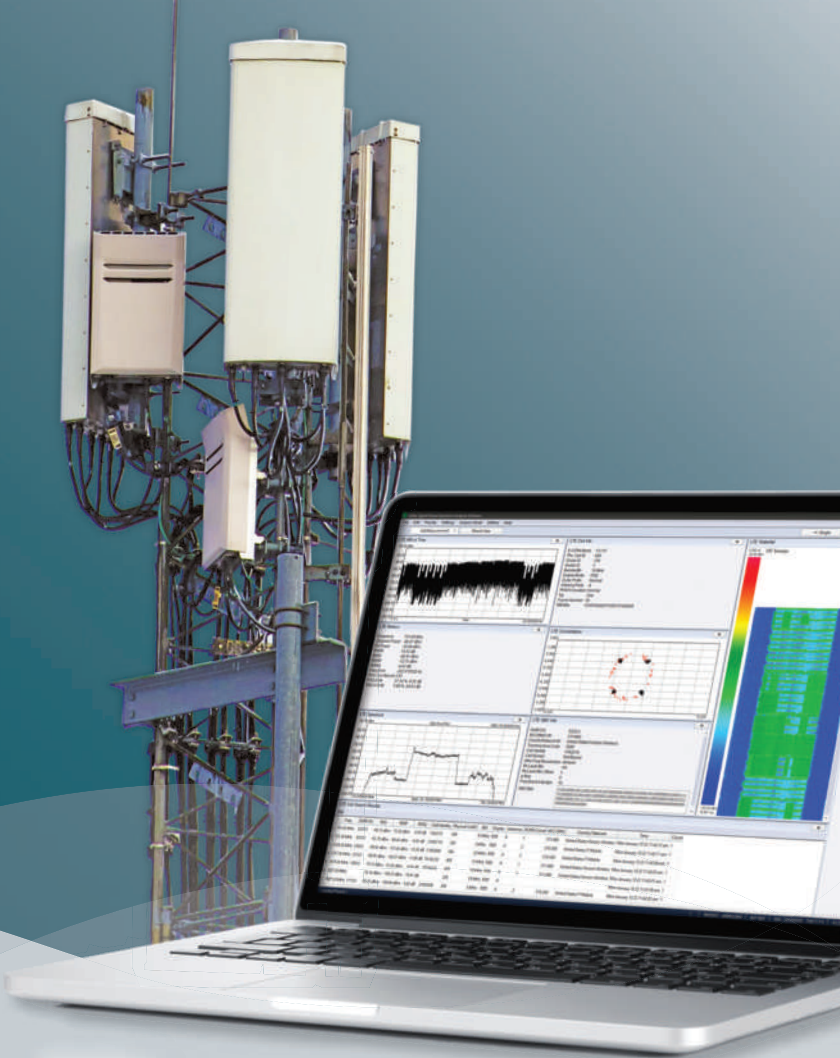

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SUMMARY

This article has discussed the background, technology and development path for hypersonic weapons. Despite steady progress toward widespread deployment, there is a body of thought believing hypersonic weapons will prove too expensive and the technical challenges too great for them to be widely deployed. While this assessment may prove valid, the recent activities from China and Russia have demonstrated actual deployment and use of these weapons, highlighting the implications and threat of hypersonic technology.

Weapons using hypersonic technology have the potential to disrupt the uneasy global balance of power by tipping the scales toward countries that have hypersonic weapons capabilities. The anticipated speed, maneuverability and flexibility of hypersonic weapons strains the conventional decision loop by forcing a shorter command decision cycle. Since the same hypersonic glide vehicle or cruise missile can carry kinetic, conventional or nuclear payloads, these weapons also increase the risk of escalating a situation.

The stakes are high and, in response, defense agencies around the world are accelerating their offensive and defensive capabilities. We have identified $7 billion of hypersonic weapons expenditures in 2021, and we believe this will grow to nearly $22 billion in 2031. The scope and breadth of the development challenges mean that most of this activity is RDT&E, with the ecosystem for hypersonic weapons programs being government-funded programs awarded to large defense companies and research institutions, either alone or in teams.

While material and aerodynamic developments will be important, electronics and solid-state semiconductors will play a significant role in the success of hypersonic weapons. Communicating through the plasma shield created by hypersonic velocity becomes a critical need. Electronics must be robust to withstand high internal temperatures, while adding as little heat as possible to the ambient temperature. Networking capabilities in these extreme environments will become important if the mission requires multiple hypersonic weapons launches.

Early identification of hypersonic weapons is of paramount concern for defensive systems. This means longer range radars with increased linearity. Satellites will play an integral role in the detection network, leading to more sensitive, higher power sensors. The defense "network" will become a web, incorporating multiple domains and military branches, as we see with the U.S. DOD's Joint All-Domain Command & Control program. Both offensive and defensive hypersonic development areas seem ripe for incorporating artificial intelligence and machine learning to reduce the time in the decision and command process.

Some have referred to the use of hypersonics weapons as a "Sputnik moment," where a country falls behind or spends to catch up. The threat of this technology is too great to ignore, so we expect countries will spend to maintain their leads or to close the capabilities gap. As militaries commit to hypersonic weapons, future spending plans will create opportunities for electronics and compound semiconductors as militaries look to restore a global balance of power. ■

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Recent advances in silicon technology have aggregated many essential functions required by electronic warfare (EW) systems within a single device. These highly integrated components not only simplify traditional EW design architectures, but also improve critical performance metrics. Because of reduced size, weight and power (SWaP) and cost, they also open new markets and applications that were previously impractical. In addition, emerging standards for embedded systems offer opportunities to harness these benefits.

Presented with diverse challenging requirements and tight schedules, EW system designers must take advantage of any new suitable resources, design strategies and standards to meet these increasingly difficult goals. This article discusses how these advantages can advance the capabilities of new EW platforms.

THREE CLASSES OF EW

The overarching mission of EW is the exploitation of any part of the electromagnetic spectrum to achieve superiority over the adversary, across virtually every deployed military platform in every warfighting arena, including land, sea, underwater, air and space. The hallmark of EW is the never-ending escalation of techniques and capabilities to gain an advantage over the opponent—before they counter the challenge with a new design.

Electronic Attack (EA)	Electronic Protection (EP)	Electronic Support (ES)
Classic Offensive Goals to Disrupt, Deny, Degrade, Destroy or Deceive	Seeks to Thwart the Effectiveness of Electronic Attack	Harvest Signal Information to Improve Decision-Making
▪ Active Countermeasures	▪ Cognitive EW	▪ Signal Identification
▪ Jamming	▪ Adaptive Spectrum	▪ Decoding, Decryption
▪ Spoofing	▪ Spread Spectrum	▪ Cognitive Radio
▪ High Energy Transmission	▪ Multi-Static Systems	▪ Passive Radars
▪ AI and Machine Learning	▪ AI and Machine Learning	▪ AI and Machine Learning

▲ Fig. 1 While the three generic classes of EW systems require diverse capabilities, they share underlying technologies.

EW is roughly divided into the three major classes (see ***Figure 1***). Electronic attack (EA) promotes offensive objectives to disrupt, deny, degrade, destroy or deceive, while electronic protection (EP) offers defensive tactics to thwart the effectiveness of EA. Electronic support (ES) exploits signal information to extract actionable intelligence of all types to improve both strategic and tactical decision-making. Although these three classes have different objectives, they all benefit from improvements in digital signal processing, so effective new technology deployed in one class is often quickly adopted by the others.

OPERATIONAL REQUIREMENTS

Modern EW systems are shifting away from older dish antennas, which are large, heavy and cumbersome to rotate and elevate to aim the transmit/receive beam pattern in a particular direction. Instead, phased array antennas now offer many significant advantages for virtually all platforms. They consist of a linear or two-dimensional planar array of antenna elements. By adjusting the relative phase of each element's signal, the beam pattern can be electronically steered to any angle—virtually instantaneously—without having to mechanically turn the array. When installed on the surface of an aircraft or the belly of an unmanned vehicle, a phased array antenna can quickly adapt to threats and track multiple targets without the bulky mechanical structures required for a dish. Although ideally suited for airborne and unmanned aerial vehicle radars, where size is critical, larger phased arrays are extremely effective for precision ground and maritime radars, especially for fire control and countermeasure systems.

Phased array systems require extensive digital signal processing (DSP) resources to acquire and generate the signals for each of the many elements, precisely control the relative phase shifts between the elements and implement beamforming algorithms. This poses several challenges for the traditional EW system architecture, where the antenna array is mounted in

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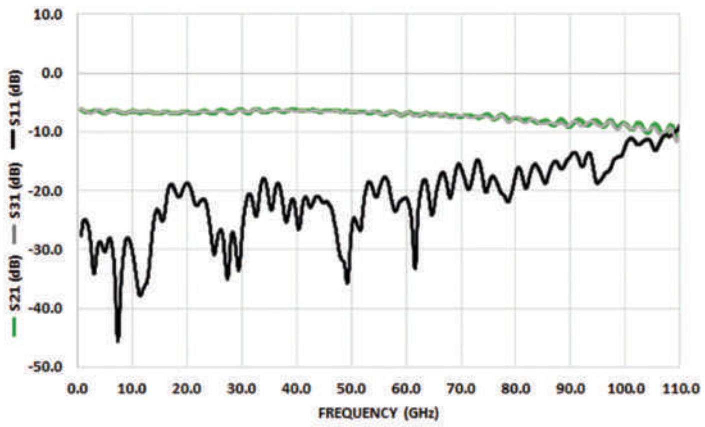

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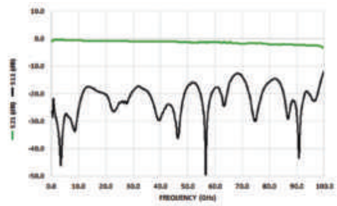

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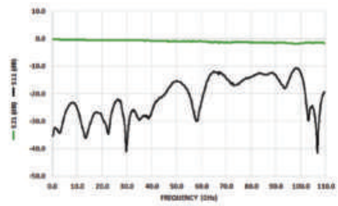

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a location best suited to capture signals—perhaps on an antenna mast—and connected to an equipment bay through dozens of long RF cables for the many elements. To ensure beam steering integrity, accurate and stable phase matching between the cables is essential, despite temperature fluctuations, cable movement, aging and maintenance. Adding to the challenges, analog signals flowing from remote antennas or sensors suffer signal degradation from cable losses and susceptibility to interference from powerful antenna transmitters, inter-channel crosstalk and power generation equipment.

Signal latency is often critical to many EA and EP systems dedicated to fire control and countermeasures. Here, a signal is received, a counter response signal is computed and transmitted, all with minimum overall delay. This latency often defines the limiting performance of such systems. Unfortunately, the latest analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) with the highest sampling rates favor gigabit serial JESD204 interfaces. Even though they achieve high instantaneous bandwidth, the serial interfaces on these devices rule out their use in low latency EW applications.

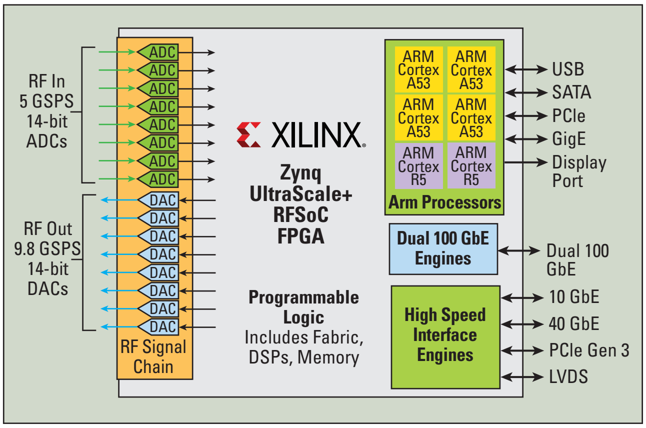
New EW techniques often require significant increases in RF signal complexity to confront and overcome the latest threats and to further exploit targets. Here, sophisticated radar pulse waveforms are developed to extract more information from targets in the presence of noise, jamming and other countermeasures. Signals are now more heavily encrypted for enhanced security against interception and eavesdropping. For low latency EA and EP systems, this means more real-time DSP to maintain computational throughput for an appropriate counter response with minimal delay. This is usually accomplished with FPGAs, although some of the higher complexity tasks can require GPUs or artificial intelligent (AI) engines.

Finally, phased array systems magnify the data converter and signal processing issues described because each of the numerous elements now requires its own dedicated ADC, DAC and DSP functions. All the requirements and challenges above will only grow as EW systems evolve, so it is imperative to identify and exploit new technologies, architectures and techniques to maintain competitive advantage.

BENEFITS OF NEW SILICON

Fortunately, Xilinx offers two advanced FPGA families that combine several of the critical EW functions defined above within a single device. The first is the highly popular RF system-on-chip (RFSoC) that went into production in 2018. The RFSoC is part of the Xilinx UltraScale+ FPGA Zynq architecture based on a 14 nm silicon geometry (see ***Figure 2***). Now in the Gen3 revision, it includes eight 14-bit ADCs sampling at 5 GSPS to support direct RF digitization of input signal frequencies up to 6 GHz, and eight 14-bit DACs sampling at 9.8 GSPS.

Each ADC is equipped with direct digital down-converters with programmable frequency tuning and decimations of ×1, ×2, ×4 and ×8. An additional decimation stage of ×16 is implemented in the FPGA, providing a maximum



▲ Fig. 2 The AMD Xilinx RFSoC has the essential signal processing elements needed for EW systems.

overall decimation of ×128 for narrower signal bandwidths. The DACs are equipped with matching digital up-converters with interpolation settings of ×1, ×2, ×4 and ×8. These two 8-channel RF data converters are connected directly to the Zynq FPGA fabric, eliminating the power, connections, complexity and latencies of the traditional interfaces to external discrete data converters.

An onboard, multicore ARM processor serves as a system controller, providing control, status, I/O and a 1 GbE interface to an external host. Two 100 GbE interfaces connect the RFSoC FPGA fabric to external devices at data transfer rates up to 24 Gbps in both directions.

Originally developed for the massive MIMO antenna requirements of 5G wireless, the RFSoC supports the key functions for eight elements of a phased array, including direct transmit/receive RF conversion, real-time DSP and control. By effectively addressing so many vital requirements, this new FPGA architecture was immediately attractive to EW designers. Its small size shrinks SWaP and cost, especially critical for air vehicles and small EW countermeasure systems, and it enables new system architectures providing significant performance enhancements.

This technology enables compact, small form factor (SFF) enclosures integrated within or behind the antenna array to hold the RFSoC devices and the RF circuitry for converting RFSoC L-Band signals to and from higher frequency antenna signals. Inside the RFSoC, digitized samples from the data converters connect directly to the FPGA fabric, drastically reducing latency compared to external discrete devices with serial JESD204 interfaces. DSP functions within the FPGA can locally apply the required phase shifts to the elements for beam steering receive and transmit signals and handling signal acquisition, triggering, waveform generation, time stamping and digital up- and down-conversion. These real-time front-end operations significantly offload back-end processing tasks.

Sensitive RF circuitry and data converters are now inside the SFF enclosure, eliminating the need for long analog RF cables with their many disadvantages. Instead, digitized payload signals are connected to the host system using gigabit serial links, a popular trend for embedded system interconnections. The RFSoC supports this architecture by providing two 100 GbE interface engines, each with four, full-duplex 25 Gbaud lanes. By equipping each subsystem with optical transceivers, multi-mode fiber-optical cables can deliver data at 24 Gbps across distances up to 100 m. These links are not only lighter, smaller and less expensive than RF cables, they are impervious to electromagnetic interference and maintain full signal integrity.

Because the RFSoC is a complete software radio subsystem on a chip, it opens many EW uses impractical with earlier technology. These include standalone SFF systems (see ***Figure 3***) for monitoring stations, troop protection, agile countermeasures, fire control systems and smart munitions.

▲ Fig. 3 A ruggedized RFSoC enclosure for mounting directly behind a phased array EW antenna delivers digitized signals across dual 100 GbE optical interfaces using the VITA-49 data protocol.

SOSA™ AND EW

The Open Group Sensor Open Systems Architecture (SOSA™) Consortium released its long-awaited SOSA Technical Standard 1.0 in September 2021, defining the SOSA Reference Architecture. To comply with the Department of Defense (DoD) mandate for use of open systems architecture, its rules describe a limited set of well-defined open standard designs to be used in embedded defense systems. Drawing heavily on VITA standards, including OpenVPX, SOSA's benefits include easier insertion of new technology, faster reaction to new defense threats and requirements, improved interoperability across vendors, longer lifecycle and lower cost for acquisition and maintenance.

With so many existing EW platforms in need of upgrades and a growing need for new, more capable EW systems, adopting SOSA is an obvious solution. SOSA specifies a subset of OpenVPX slots and module profiles for both 3U and 6U VPX, defining backplane pins for data, control and expansion planes to promote vendor interoperability. Most traffic flows across these planes use Gigabit Ethernet at rates of 1, 10, 40 and 100 Gbps, all popular standards widely used in commercial enterprise markets.

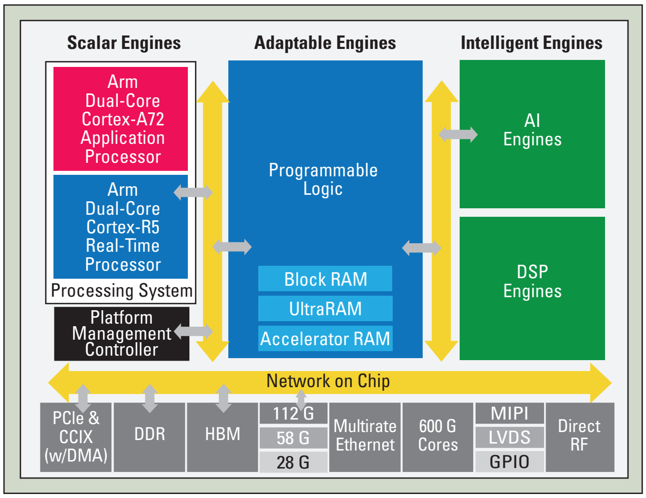
Another significant SOSA requirement is that all analog and digital I/O must flow through backplane connectors instead of the front panel, intended to simplify maintenance and improve reliability. This has a major impact on EW because of the high number of antenna signals required for phased array designs. Foreseeing this dilemma, engineers in VITA developed some remarkable new backplane connectors to handle devices like the RFSoC on SOSA plug-in cards with eight analog inputs, eight analog outputs and four clock and timing signals.

Now adopted by SOSA, these backplane connectors support products like the Mercury 5553 SOSA aligned RFSoC processor (see ***Figure 4***). The unit has no front panel connectors (left) and two VITA 67.3 metal blind-mate backplane housings are visible in the rear (right). Each housing includes 10 coaxial nano-RF connectors rated for 20 GHz signal bandwidth, which support all the analog I/O signals from the RFSoC. Each housing has a 24-lane optical fiber ferrule supporting the two 100 GbE ports of the RFSoC.

▲ Fig. 4 An RFSoC SOSA aligned 3U OpenVPX plug-in card has 20 VITA 67.3 backplane RF coaxial connectors and two 100 GbE optical I/O ferrules.

NEW PROCESSOR AIDS EW

Xilinx's latest Versal Adaptive Compute Acceleration Platform (ACAP) family adds capabilities for EW systems. The members of the family provide different blends of three processing resources: scalar processors (ARM CPUs), adaptable logic (FPGAs) and vector processors (GPUs and DSPs), as



▲ Fig. 5 AMD Xilinx Versal AI Core ACAP heterogeneous processor integrates adaptable FPGA, DSP, AI engines, multicore ARM processors, network-on-chip, multi-rate Ethernet I/O and other system interfaces. *Source:* Xilinx.

shown in ***Figure 5***. Following the RF integration inspired by the success of the RFSoC, an upcoming version of ACAP will offer onboard direct sampling RF ADCs and DACs.

Of the many requirements for the EW classes shown in Figure 1, AI and machine learning (ML) will be used by all three: EA, EP and ES. AI capabilities such as inference, image processing, pattern recognition and signature detection are appropriate for EW and many other defense applications. ML is a subset of AI that can help automate and improve decision-making by assisting or replacing human operators, resulting in faster and more accurate responses.

The heterogeneous mix of ACAP resources enables designers to assign a task to the most suitable processing engine and adaptively reassign the resources as required. This flexibility of ACAP delivers up to 10x the performance compared to dedicated processors. Onboard, flexible high bandwidth memory (HBM) boosts the processing bandwidth for all the engines. To interconnect all these resources, ACAP includes an extremely wideband, configurable network-on-chip with a uniform interface and protocol to simplify system integration.

▲ Fig. 6 SOSA aligned 6U OpenVPX conduction-cooled plug-in card with two ACAP Versal AI devices with heterogeneous scalar, vector and logic processing for AI, DSP and ML EW applications.

Versal development tools support high-level design entry from frameworks, models, C-language and RTL coding. Users can create a custom development environment to suit project needs and programming preferences. Other Versal hardware/software platforms will evolve to speed EW development and support high-complexity and extreme performance requirements.

The flexibility of ACAP aligns with SOSA's objectives for reusability and adaptability to new threats. As an example, the Mercury SCFE6931 (see ***Figure 6***), is a 6U VPX SOSA aligned processor plug-in card containing two ACAP Versal AI Core Xilinx VC1902 devices.

SUMMARY

Since EW is an increasingly significant cornerstone of all defense organizations, the rapid adoption of new technologies and standards is imperative. Integrating data converters, FPGA resources and processors into a single RFSoC affords major benefits to performance while reducing SWaP and cost. Creating a heterogeneous mix of specialized processing resources afforded by the ACAP device enables a single, flexible platform to support a wide range of advanced AI and ML applications and deployment scenarios.

By adopting the newly released SOSA Technical Standard 1.0, system designers can comply with the DoD's open systems architecture mandates to lower acquisition costs and extend system lifecycle. Harnessing these new complex technologies requires development tools that support high-level design entry and the flexible migration of tasks across many resources. Expect ongoing development of these tools and other new technologies to meet the constantly evolving EW needs of the warfighter. ■

LEO Constellations: The New Military Frontier

Nancy Friedrich
Keysight Technologies, Santa Rosa, Calif.

Satellite applications for government and military range from ultra-secure communications to tracking and early warning of ballistic and hypersonic missiles. As space becomes a more highly contested arena, satellites will play an increasingly crucial role in maintaining superiority.

Traditionally, aerospace and defense organizations used geostationary orbit (GEO) and higher-orbit satellites, very complex systems with longer development and production cycles. While low Earth orbit (LEO) constellations were considered, the benefits of numerous small satellites in multiple orbits connected as a single network were not proven and the challenges significant. However, once development efforts began to overcome size, weight, power and cost constraints, LEOs started a new space race.

Military and government organizations are increasingly eying LEO satellites for military applications. In the U.S., for example, the president requested a $24.5 billion budget for the U.S. Space Force and Space Development Agency for fiscal year 2023. However, the viability of LEOs for aerospace and defense will depend on performance assurance throughout development, launch and the mission. This task has two challenges: proving capabilities for military applications and verifying performance at higher frequencies and wider bandwidths.

LEO CHALLENGES

Like the commercial world, aerospace and defense agencies are generating and consuming more data. With global reach, they need to transmit and receive information through satellite networks, both for communication and data transfer. A distributed LEO constellation spreads the reliability risk and cost across hundreds or thousands of satellites; however, this brings security risks for the hardware as it passes over unfriendly territories. National security needs require cyber protection and novel operation to protect this infrastructure when deployed in space.

In addition to ensuring security, LEOs must maintain exacting performance despite challenges from weather, the environment—even motion. LEO satellites move at some 17,000 mph as they orbit the Earth. Though such constellations have many advantages for low latency communications, Doppler shift and fading must be accommodated in the link design. Unlike satellites in GEO, LEO satellites have a limited field of view because of their lower altitude and speed (see ***Figure 1***). More satellites are needed to provide coverage of the globe and any given region.

Communicating with a LEO constellation requires the ground terminals to switch among satellites and antenna beams to maintain un-

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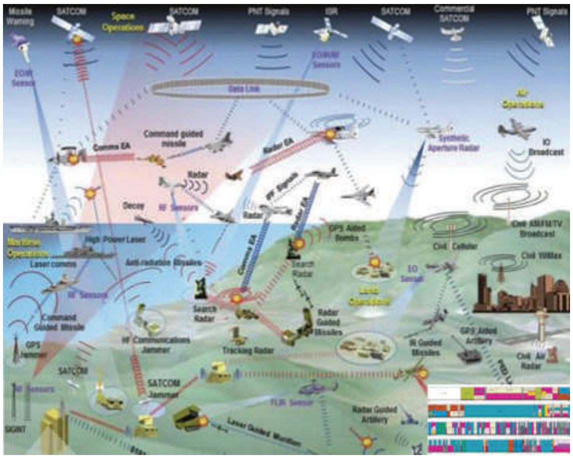

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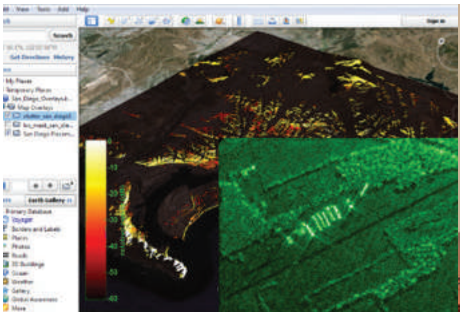
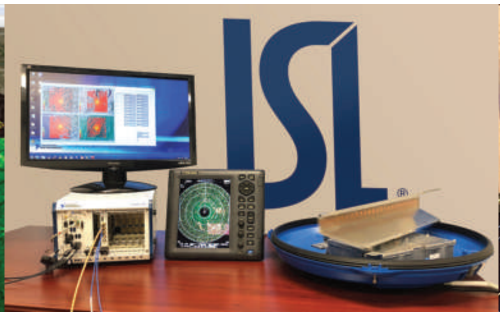
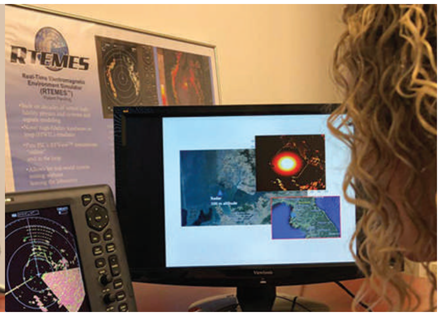
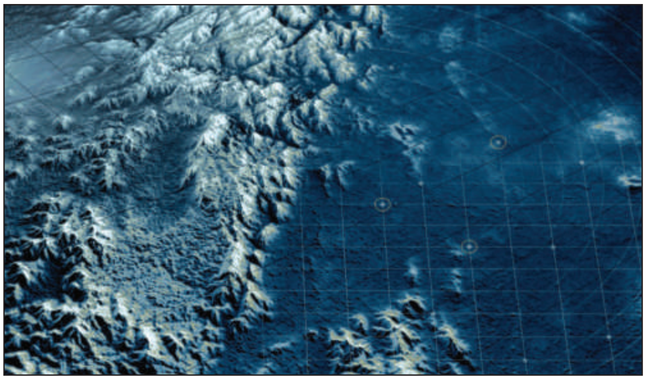
RFVIEW® PHYSICS-BASED MOD&SIM → RFVIEW® HWIL (RTEMES) = AFRL SBIR SUCCESS STORY









▲ Fig. 1 As each LEO satellite has a limited field of view, multiple satellites are needed to continuously cover the surface of the Earth.

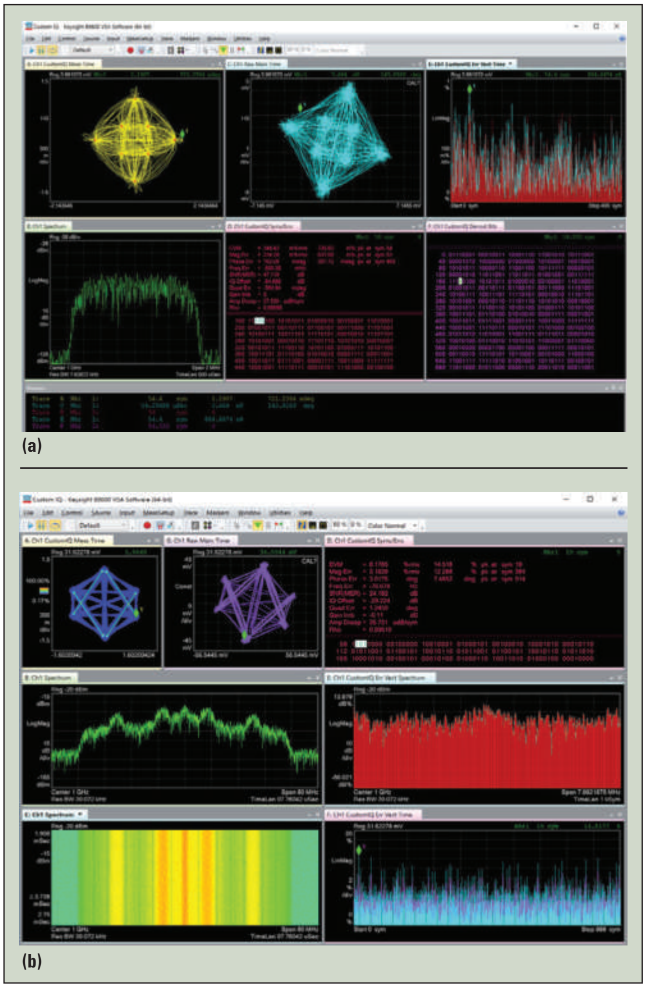
interrupted communication. Because of the speed of the satellites, coordination between terminals and the individual satellites must occur automatically. The terminal must track one satellite, then a second as the first satellite goes out of view, and the connection must seamlessly switch between the two. Phased array antennas perform this task well, able to track multiple LEO satellites simultaneously, so no connectivity is lost. A phased array comprises many antennas in a matrix—each antenna element phase shifted so the radiated waves add constructively or destructively—maximizing gain in desired directions, minimizing in undesired directions. Phased arrays provide features and characteristics not achievable with a single antenna.

Spectrum crowding is another challenge for LEOs. Limited availability in reserved satellite bands and requirements for wider bandwidth in satellite links have increasingly pushed deployment to higher frequencies, including for aerospace and defense applications. This demand for data rates is driving satellites to use more complex modulation, as well. However, wider bandwidth and higher-order modulation can limit link quality at mmWave frequencies.

ASSURING PERFORMANCE

The viability of LEOs for aerospace and defense applications depends on assuring performance throughout the mission. This requires proving the system has the capabilities for military applications and verifying the performance at the operating frequency and bandwidth. To achieve higher data rates, wireless communication systems typically increase signal bandwidth and use higher-order modulation, increasingly using mmWave frequencies because of the available wider bandwidth. However, wide bandwidth, higher-order modulation and mmWave frequencies pose challenges:

Link budget: As the operating frequency increases, so does the path loss between the transmitter and receiver. To



▲ Fig. 2 Proprietary communications signals can be developed using signal analyzers with advanced modulation analysis capabilities.

achieve adequate signal-to-noise in the link, the transmit power and noise figure of the receiver must be designed to match available component technologies for the distance. Fortunately, LEO constellations have less path loss than GEO satellites, and advances in cost-effective phased array architectures enable targeted spot beams that increase gain and the effective radiated power.

Noise: Wideband systems have more noise power and are more susceptible to spurious signals within the band. The receiver must be designed to have sufficiently low spurs and a low noise floor to achieve the required spur-free dynamic range and error vector magnitude with the chosen modulation.

Test complexity: High frequency, wide bandwidth signals can be difficult to test, requiring the most capable test systems. The signal generator that drives the device under test and the signal analyzer that processes the output signal must cover the appropriate frequency band and have sufficient instantaneous bandwidth, output power, noise figure and linearity—with margin. For example, characterizing power amplifiers with digital predistortion requires linear power and wide measurement bandwidth.

The LEO system may use proprietary modulation—unique geometric forms, even asymmetric—which the signal generator must be able to synthesize and the analyzer demodulate (see ***Figure 2***). The test system should be flexible, able to accommodate differing modulation and channel bandwidths of multiple satellite systems. Also, it should be easy to configure, minimizing the time to generate and analyze complex signals. For the user, developing and maintaining synchronization, signal quality and hardware connectivity algorithms can be time-consuming; the equipment should ease this burden.

TEST SYSTEM EVOLUTION

To support the rapid development of LEO satellite systems for commercial, government and military applications, test systems for wideband signal transmission through dynamic channels must offer users the ability to characterize future systems: new frequencies, bandwidths, signals and technologies. As system complexity grows, the test system should not limit or slow development.

▲ Fig.3 A low noise, high frequency signal generator (shown) paired with a signal analyzer are useful tools for developing the communication links of satellite systems.

Fortunately, continuously improving processors, mmWave components and software are enabling test, measurement and calibration systems to meet the needs of these LEO satellite constellations, whether in development or not yet defined. The current generation of signal analyzers provides coverage to 54 GHz with 2.5 GHz of instantaneous bandwidth, 5 GHz with channel bonding (see ***Figure 3***). Adding high performance up-converters extends the frequency range to 110 GHz with low phase noise.

Ease of use is also a priority. For example, for multitone group delay tests, current systems enable the user to set everything up on the analyzer; the analyzer sends the appropriate configuration to the source, i.e., tone frequencies and spacing, bandwidth and power. An easy setup using a single graphical interface controls both instruments, which ensures no mismatch between the source and analyzer.

SUMMARY

LEO satellite systems have introduced new design and test challenges: higher frequencies, wider bandwidths and system complexity. A microwave signal generator with signal generation software can accelerate system design, optimization and validation, keeping pace with compressed development times to launch. The signal generators and analyzers must provide signal purity, linear output power and low noise to support the goal of mission assurance. Once a satellite is launched and deployed, it can't be returned to Earth to fix. The test systems must assure accurate, repeatable and traceable results. ■

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Integrated RF Digital Engineering Tools Support the Defense System Lifecycle

Information Systems Laboratories, Inc.
San Diego, Calif.

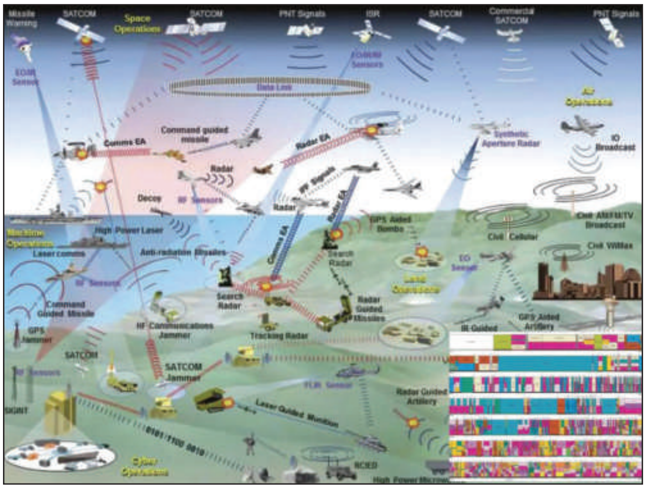


Fig. 1 Replicating the "fog of war" of the battlefield in field tests is infeasible or prohibitively expensive.

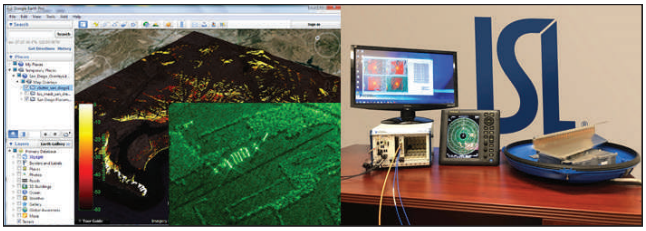
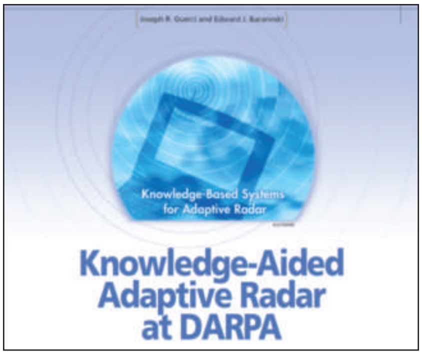


Fig. 2 ISL's RFView HWIL solution enables real-time virtual field testing in environments as complex as a designer's imagination.

The RF environment for many advanced RF applications is increasingly congested and possibly contested (see ***Figure 1***). Emulating this environment in field tests can be very costly and, in some cases, is not feasible.

Information Systems Laboratories' (ISL's) RF Digital Engineering family of tools, known as RFView®, can facilitate the life cycle of advanced RF systems—radar, electronic warfare (EW), electronic intelligence (ELINT) and other advanced RF applications—from development through sustainment (see ***Figure 2***). With ISL's RFView hardware-in-the-loop (HWIL) solution, for the first time, actual flight hardware can be integrated into a high fidelity modeling and simulation (M&S) environment via an RF analog or digital interface.

ISL's technology began with seminal projects at the Defense Advanced Research Projects Agency (DARPA) and the Air Force Research Laboratory (AFRL). In 2000, DARPA/AFRL initiated the Knowledge-Aided Sensor Signal Processing and Expert Reasoning (KASSPER) project,[1] a predecessor to what today is called cognitive radar.[2–4] Its goal was to create a new generation of "smart" radar capable of adapting to complex



▲ Fig. 3 DARPA's KASSPER project, a predecessor of cognitive radar, provided an impetus for advanced RF M&S and "digital twinning."

environments too stressing for traditional adaptive radar (see ***Figure 3***).

From the start, it was clear that a new generation of high fidelity, physics-based RF M&S tools would be required to develop, evaluate and test the methods developed in the KASSPER project. To fill this gap, ISL was selected to apply the advanced M&S tools it had already begun to develop. Beginning in the early 2010s, AFRL initiated the Cognitive Fully Adaptive Radar (CoFAR) project under the Small Business Innovation Research (SBIR) fund, with a sister project focused on M&S to support the effort. So successful, it resulted in a rare Phase III award focused on transition.[5–6] (see ***Figure 4***).

A fully commercial set of products has since been created that form a fully integrated set of digital engineering tools supporting the whole product lifecycle, from requirements and analysis-of-alternatives, through design/prototyping, test and evaluation, training, mission planning and sustainment (see ***Figure 5***). This environment is ideal for artificial intelligence and machine learning systems, which require voluminous training data and/or environments to ensure robust performance. ■

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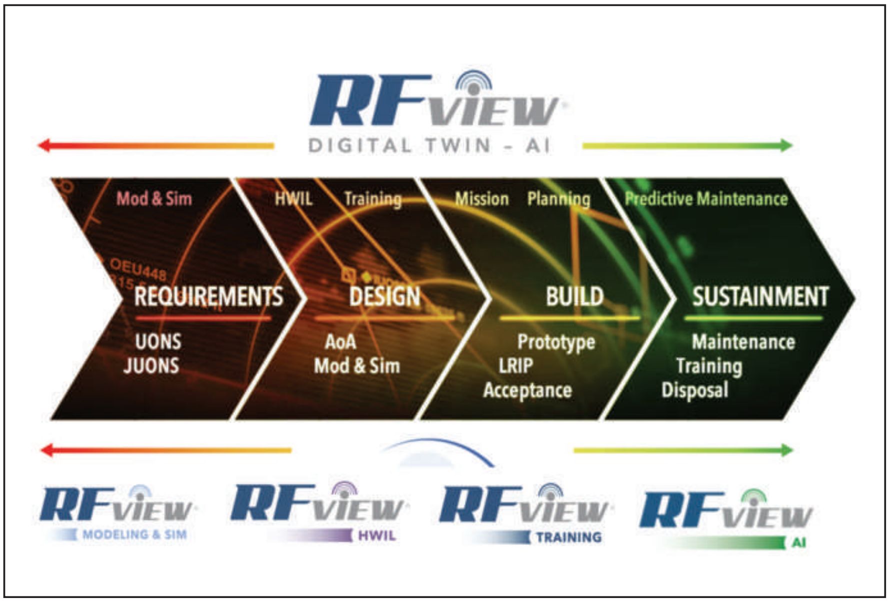
▲ Fig. 4 AFRL's CoFAR project was an SBIR success story.



▲ Fig. 5 ISL's RFView Digital Engineering tools support the product lifecycle.

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Temperature Compensated Amplifier Portfolio

Since semiconductor device performance is a function of temperature, an amplifier's small-signal gain will change as the temperature varies, decreasing as the temperature increases and increasing as the temperature decreases. This can adversely impact the performance of a system if this gain variation is not accounted for. To help designers address this variability, Fairview Microwave offers a family of temperature compensated amplifiers that operate from -55°C to +85°C and reduce gain variation by 2x to 3x compared to an uncompensated amplifier at +85°C, the gain of the compensated amplifier will be 1.0 to 1.5 dB lower than the room temperature (+25°C) gain; at -55°C, it will be 1.0 to 1.5 dB higher. Temperature compensation is accomplished by using voltage-controlled attenuators driven by thermistor circuitry, located between the amplifier's gain stages.

Fairview's temperature compensated portfolio comprises 12 models covering frequency ranges from 500 MHz to 40 GHz, all with minimum gains of 35 dB over the full temperature range. The 50 Ω amplifiers are assembled using MMICs and thin film circuits in housings with coaxial feeds, either SMA or 2.92 mm. As examples of the amplifiers in the family, the FMAM5101 at +25°C provides 47 dB typical gain from 500 MHz to 4 GHz, with gain flatness less than ±1.75 dB, maximum noise figure of 4.5 dB and typical P1dB of 21 dBm. For mmWave applications, the FMAM5108 provides 45 dB typical gain from 26.5 to 40 GHz, with ±3 dB flatness, less than 8.5 dB noise figure and 18 dBm typical P1dB.

Fairview's amplifier modules provide repeatable performance and high reliability, suitable for demanding applications such as aerospace and defense, test and measurement, communication systems and general R&D.

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Aerospace & Defense
TECH BRIEF

22 GHz Synthesizer: Multi-Channel, Phase Coherent Configurable

AnaPico Switzerland recently introduced a compact, broadband frequency synthesizer for generating accurate and stable CW and pulsed signals between 100 kHz and 22 GHz. The APMSYN22 achieves –132 dBc/Hz phase noise at 20 kHz offset from a 1 GHz carrier, and subharmonics are below –60 dBc. Frequency resolution is 10 mHz, and the synthesizer switches between frequencies within about 10 µs. The unit's output power range is –40 to +25 dBm and can be set with a resolution of 0.5 dB.

The synthesizer supports external references of 100 MHz and 1 GHz. Multiple units can be synced to create phase-coherent sources. One synthesizer will generate a 1 GHz reference that is looped through the other synthesizers. To illustrate the performance, with all channels set to 5 GHz, the inter-channel phase difference variation will remain within approximately ±0.5 degrees over 10 hours.

An Ethernet interface enables connection to a local or remote PC, where the unit can be controlled using AnaPico's GUI software or SCPI commands. The synthesizer is enclosed in a compact, well shielded, flange-mountable housing measuring 125 x 100 x 20 mm and weighing less than 0.5 kg. It consumes just 17 W so the design uses passive cooling.

The APMSYN22 is suitable for many applications, including as a system clock source or in multi-channel phase-coherent configurations for radar, beamforming, spectroscopy and quantum computing. The combination of phase coherence and fast switching also, makes the synthesizer well suited for electronic warfare applications.

AnaPico AG
Zurich, Switzerland
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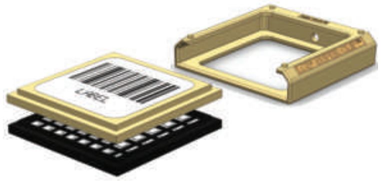
Lid Clip System Stops Thin Semiconductor Die from Migrating



Compound semiconductor die are getting thinner, and standard waffle packs aren't designed to contain them. The result is die migration, resulting in higher cost from yield loss, rework labor and returned material to suppliers. Gel-Pak® and BAE Systems® designed a new lid clip system that works with standard waffle pack chip trays and eliminates die migration. LCS2 is a patented lid clip system that ensures uniform compression across the lid of the waffle pack, which prevents components from escaping their pockets. Using static dissipative materials to enhance protection from electrostatic discharge, LCS2 ensures valuable devices arrive defect-free and are ready for assembly.

Gel-Pak and BAE Systems designed LCS2 with the goal to prevent die migration by sealing every pocket in a waffle pack. Choosing materials for the lid clip system, they began by selecting a low outgassing, static dissipative, low density polyurethane foam and industry approved interleaf material. These are assembled into a static dissipative, injection molded lid using a silicone-free pressure sensitive adhesive. The patented "gold" lid is combined with a patented, highly engineered "gold" clip design that uniformly compresses the lid onto the tray, ensuring complete contact of the entire interleaf against the surface of the waffle pack tray. The static dissipative material used for the lid and clip was tested per ANSI/ESD S11.11 to ensure ESD Class 000 protection for semiconductor devices with the lowest voltage susceptibility thresholds.

The resulting design keeps thin die in place in the waffle pack, eliminating past defects caused by die migration, either during transport or during assembly. The LCS2 lid clip system improves overall manufacturing yields and reduces the amount of troubleshooting, rework and overage, leading to improved manufacturing cycle time and reduced product cost.

Gel-Pak
Hayward, Calif.
www.gelpak.com/lcs2/

Aerospace & Defense
TECH BRIEF

Ku/K-Band MPM Optimizes Satellite Downlinks

Stellant Systems' Quad Space nano microwave power module (MPM®) is an RF power amplifier for Ku/K-Band satellite downlinks, designed for a new generation of software-defined satellites that use phased array antennas to increase on-orbit flexibility. The nanoMPM has four amplifier chains, each combining a solid-state amplifier driving a small travelling wave tube (TWT) output amplifier, with all four chains powered by a proprietary electronic power conditioner (EPC) that converts the satellite bus voltage to the biases required by the driver and mini-TWT. The solid-state driver provides high gain with predistortion to linearize the amplifier chain.

The Quad Space nanoMPM covers the 17.3 to 20.5 satellite downlink band and provides 30 W linear output power (60 W saturated) with a nominal input power of -24 dBm. The MPM has 35 percent efficiency at a 15 dB noise power ratio.

Two amplifier chains are packaged in a housing—with two housings for the four amplifiers—and the EPC is in a separate housing. Each dual-channel amplifier has a mass of 1.25 kg, including the high voltage bias cable and the mass of the EPC is 2.3 kg. The nanoMPM provides full control of its operation, with telemetry to monitor the operating status, temperature, currents and the RF output power of each channel. In addition, the structural output power of each amplifier chain can be adjusted on-orbit over a 2 dB window.

The combination of a solid-state driver and mini-TWT bridges the gap between solid-state amplifiers and the traditional linearized channel amplifier TWT used in many satellites. By tapping the best of solid-state and TWT technologies, the Quad Space nanoMPM balances the output power, linearity, efficiency, bandwidth, size and mass for next-gen satellite applications.

Stellant Systems manufactures critical components for defense, space, medical, scientific and industrial customers around the globe.

Stellant Systems
Torrance, Calif.
www.stellantsystems.com

Extensive Line of Drop-In Circulators and Isolators, from 100 MHz to 30 GHz

CernexWave offers an extensive line of drop-in circulators and isolators that can be customized to a project's needs. Start with a catalog including narrowband, broadband, octave and multi-octave models covering frequency bands from under 100 MHz to over 30 GHz. CernexWave's designs span power levels from a few milliwatts to over a kilowatt, offering high isolation and performance in extended temperature environments. To minimize printed circuit board footprint, the circulators and isolators are designed to be as small as possible, down to a few millimeters in diameter.

CernexWave's catalog includes the CID09090525-01, a narrowband isolator covering 9.2 to 9.6 GHz with 25 dB isolation and less than 0.5 dB insertion loss. The model CCD08120618G is a broadband circulator covering 8 to 12 GHz and providing 18 dB isolation. The CCD01010320-07 is a high-power model tuned for 1.2 to 1.4 GHz with power handling of 700 W and greater than 20 dB of isolation.

Used to protect sensitive components from reflected signals, CernexWave's high-quality ferrite devices are also low cost. Delivery times are short, even for large quantities—whether a catalog product or customized for a program. CernexWave supports the global marketplace for wireless communications, satellite communications, radar systems, antenna signal distribution and test labs.

CernexWave, founded in 2011 and sister company Cernex, formed in 1988, supply active and passive RF/microwave components. The company's quality management system meets the requirements of ISO9001:2015.

CernexWave
San Jose, Calif.
www.cernexwave.com

Aerospace & Defense

TECH BRIEF

Phase Stable Cable Assemblies

EZ Form Cable, a Trexon company, has added phase stable dielectric cores to its product offering, which will reduce the "knee" characteristic seen with cable assemblies using Teflon™ cores. The phase stable cable will initially be available with a 0.086 in. core (EZ-PT86), although EZ Form plans to add other sizes in the future. The EZ-PT phase stable cables are available as build-to-print cable assemblies or as bulk cable with optional RF connectors.

The phase of a coaxial cable assembly changes with temperature variation, which usually needs to be compensated by system hardware or software. This adds complexity to the design and may require additional calibration, increasing test time and cost. Phase changes can be particularly problematic with multi-channel systems, where phase matching among the channels is required. Using a more phase stable material improves system performance and reduces the need for hardware or software compensation.

EZ Form Cable is an AS9100D certified manufacturer of coaxial cable, coaxial cable assemblies, RF connectors and coaxial delay lines, with experience building phase matched cable assemblies and delay lines. EZ Form Cable meets ITAR and NIST requirements for security, and the company's cable assemblies have been qualified on many military and aerospace systems. Its products have also been fielded in telecommunications, medical and test and measurement applications.

EZ Form Cable
Hamden, Conn.
www.ezform.com/phasestable/

Aerospace & Defense
COMPANY SHOWCASE

New 16-Channel ADC for Phased Array Radar Applications

VENDORVIEW

The AD9083 is a 16-channel, 125 MHz bandwidth continuous time sigma delta analog-to-digital converter with a best-in-class power consumption of 0.09 W per channel. The integrated digital signal processing, on-chip PLL, flexible JESD204B interface and compact 9 x 9 mm package make it an ideal solution for large, phased array radar and digital beamforming applications where phase-coherent multi-chip synchronization is critical.

Analog Devices Inc.
www.analog.com/AD9083

Wideband and Compact-Size Frequency Synthesizer up to 22 GHz

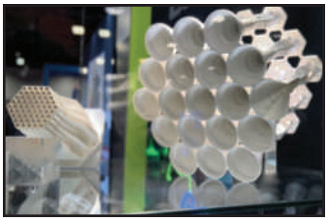
AnaPico Switzerland recently introduced a new, compact-size broadband frequency synthesizer for the generation of accurate and stable signal in both CW and pulse form, covering a frequency range of 100 kHz to 22 GHz, with a fast-switching time of about 10 us, the output power of -20 to 25 dBm. The phase noise at 1 GHz and 20 kHz offset is -131 dBc/Hz. Multiple units can be connected together for phase-coherent channels.

AnaPico Switzerland
www.anapico.com

Design Your Own Filter

The QuEST tool allows you to design lowpass, highpass, narrow bandpass and wide bandpass filters using different technologies to realize narrowband and wideband performance. Select the parameters based on your desired technology type, insertion loss and return loss, and then submit your request for a quick proposal a custom filter configured to your custom specifications and application.

BSC Filters
www.bscfilters.com/quest



3D Printed Components

In April, CAES opened a state-of-the-art Additive Manufacturing Lab in Exeter, N.H., focused on making space-ready 3D printed components. The lab supports CAES' partnership with SWISSto12, the leading provider of 3D printed technology for RF applications, and is dedicated to bringing additive manufacturing solutions to the U.S. aerospace and defense industry. "This flight proven technology will allow us to rapidly go from design to manufacturing with much more complex components," said CAES CEO Mike Kahn. For more information visit our website.

CAES
https://caes.com/3dprinting

CernexWave Coaxial Circulators and Isolators

CernexWave's coaxial circulators and isolators are an ideal solution for broadband or narrowband signal control at a wide range of power levels. They can be tailored to the exact frequency and power you need while maintaining low insertion loss and high isolation. We can also customize the input and output ports to fit perfectly in your system. The model COIU2U40916-01 coaxial isolator has a frequency range of 225 to 400 MHz with 16 dB isolation and can handle over 50 W of power.

CernexWave
www.cernexwave.com

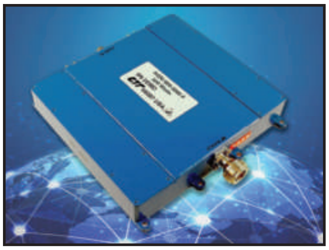
Wideband SSPA Module 4-18 GHz 50 W Model BME69189-50

COMTECH PST offers wideband solid-state power amplifier (SSPA) modules for communications, electronic warfare (EW) and radar transmitter applications. This compact module measures 6.5" x 3.5" x 0.8" and weighs less than 2 lbs. The unit features built-in test with over current and temperature fault. The unit operates on +28 VDC. This military grade SSPA module features highly efficient and reliable GaN solid-state technology. Other frequencies and power levels are available.

COMTECH PST
www.ComtechPST.com

Aerospace & Defense

COMPANY SHOWCASE



Solid-State GaN Power Amplifier Offers 630 W for SAR Applications

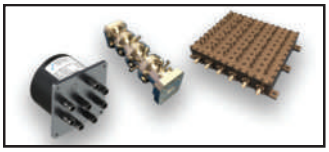
Specifically designed for—and currently operating in—multifunctional SmallSat and airborne synthetic aperture radar (SAR) systems, CTT Model AGN/099-5860-P is a GaN-based SSPA. Operating frequency is 9.4 to 9.9 GHz with a pulse power output of 630 Watts, small signal gain is 60 dB, minimum and noise figure is +10 dB. The compact amplifier is 6.17" L × 6.35" W × 0.82" H and weighs less than 2 lbs. Higher power option is available. CTT will be at booth 6017 at IMS2022.

CTT Inc.
www.cttinc.com

I- and Ka-Band Integrated Stabilized RF Sources

Integrated stabilized RF sources (ISRFS) designed for radars, radar simulation, ECM, EW threat simulation, test and measurement. dB Control designs and manufactures ISRFS units: dB-9003 (8 to 12 GHz and 30 to 36 GHz) and dB-9005 (30 to 36 GHz) which are customizable. Featuring four types of modulation (AM, FM, Pm and Pulse), high accuracy and wide temperature operating ranges. They can be controlled and set up with a digital port.

dB Control
www.dBControl.com



High Performance Passive Components

VENDORVIEW

Exceed Microwave provides custom high performance passive microwave component designs up to 110 GHz for defense, space and commercial applications. Exceed Microwave is AS9100 certified and ITAR registered, providing high-quality, high performance passive components. We provide various types of designs, each with its own unique values and are designed and made in U.S. Many of our designs offer extremely high Q factor, allowing very low insertion loss and high-power handling.

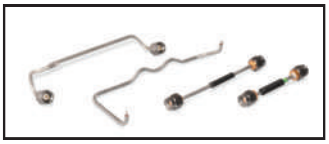
Exceed Microwave
www.exceedmicrowave.com

Exodus AMP2080D, 10 kHz to 250 MHz, 500 W

VENDORVIEW

Exodus AMP2080D, ideal for broadband EMI-Lab applications. Class A/AB linear design for all modulations and industry standards. Covers 10 kHz to 250 MHz, produces 500 W minimum, 700 W typical with 57 dB minimum gain. Excellent flatness, optional monitoring parameters for forward/reflected power indication, VSWR, voltage, current and temperature sensing for superb reliability and ruggedness. Integrated in our compact 8U chassis weighing approximately 45 kg.

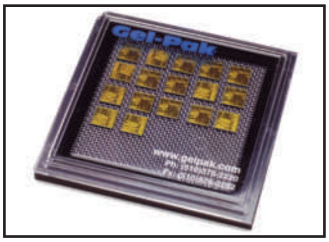
Exodus
https://bit.ly/39oMun4



EZ Form Phase Stable Cable

EZ Form Cable, a Trexon Company, is proud to announce the addition of phase stable dielectric cores to its standard product offering. Initially offered in its 0.086" sizes, this phase stable core will reduce the Teflon "knee" found in solid core cables.
EZ Form phase stable cable is available in both build-to-print applications or as bulk cable.

EZ Form Cable, a Trexon Company
www.ezform.com/phasestable



Gel-Pak's Vertec Polyurethane Device Carriers

Gel-Pak's new VRP product line consists of a proprietary crosslinked polyurethane film membrane over a mesh material that holds components in place until they are released "on-demand" by applying vacuum to the underside of the tray. The new polyurethane Vertec® Vacuum Release (VR) Tray provides the same appearance and functionality as the traditional Gel VR Tray, yet is both Si-free and static dissipative. It handles components from 250 µm to 300 mm, immobilizes and protects valuable devices during shipping and handling and is ideal for high volume automated device pick and place applications.

Gel-Pak
www.gelpak.com/product-spotlight/gel-pak-vrp

Aerospace & Defense

COMPANY SHOWCASE

End & Vertical Launch Connectors

VENDORVIEW

HASCO, Inc., a global supplier of just-in-time RF and microwave components, is expanding its line of End and Vertical Launch Connectors, manufactured by Southwest Microwave. These high performance connectors feature a solderless, clamp-on concept; designed to provide the lowest VSWR and mode-free wide responses up to 110 GHz for single and multilayer microstrip. Both the end and vertical launch connectors are available in multiple launch configurations, provide the best possible match to circuit layout and works on microstrip and GCPW designs.

HASCO, Inc.
www.hasco-inc.com

2-18 GHz Reference Design Featuring HL9333 Harmonic Down-converter

HYPERLABS is proud to announce its newly redesigned 20 GHz harmonic down-converter IC packaged in a 4 mm QFN package. Boasting 18 GHz RF bandwidth and optimized for LO sampling rates from 100 MHz to 2.5 GHz, the HL9333 features excellent linearity, low noise and improved RF-IF conversion response that is considerably flatter than the previous generation HL9313 harmonic mixer. The HL9333, shown here in a 2 to 18 GHz reference design, is ideally suited for use in Nyquist folding receiver and other under-sampled broadband receiver systems.

HYPERLABS
www.hyperlabs.com/product/hl9333/

Intelliconnect: Specialist Supplier of RF, Microwave and Cryogenic Connectivity

Intelliconnect Group is a specialist designer and manufacturer of RF, microwave, waterproof and cryogenic connectors adapters and cable assemblies suitable for applications including quantum, wearable technology, medical, telecoms, satcoms, military, aerospace, space, general microwave communications, rail traction, oil and gas and marine. Intelliconnect also manufacture the market leading Pisces range of waterproof RF connectors, coaxial adaptors to facilitate inter-series connection and gender change, dust-caps and offer value added services. Intelliconnect are a leading supplier of cryogenic cable assemblies for quantum computing.

Intelliconnect Group
www.intelliconnectgroup.com

Virtual RF Hardware-in-the-Loop Flight Testing

ISL's real-time hardware-in-the-loop (HIL) RTEMES® system enables for the first time, virtual flight testing of advanced RF systems for radar, ELINT and EW applications. It supports multichannel RF systems from VHF to Ku-Band and is based on a cost-effective digital COTS transceiver/FPGA architecture. RTEMES® is designed to seamlessly integrate with ISL's RFView® RF Digital Engineering tools including high fidelity, physics-based modeling and simulation.

ISL
www.islinc.com

Directional Coupler Covers 26.5 to 40.0 GHz with 30 dB Coupling

VENDORVIEW

KRYTAR Model 264030 offers 30 dB of nominal coupling covering 26.5 to 40 GHz (Ka-Band), in a compact and lightweight package. The coupler lends itself to wireless designs and many T&M applications within Ka-Band frequency. Ka-Band is used for commercial and military satcom. Frequency sensitivity of ±0.5 dB, insertion loss of 1.3 dB, directivity greater than 12 dB, maximum VSWR is 1.7. Measures 1.12 (L) x 0.40 (W) x 0.62 in. (H) and weighs 1.0 ounces. KRYTAR will be at IMS2022 at booth 7072.

KRYTAR
https://krytar.com/products/couplers/directional-couplers/

RF Power Sensors

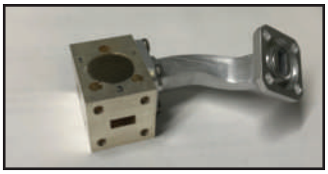
VENDORVIEW

LadyBug Technologies' LB5944A, a 44 GHz USB power sensor, offers several features specifically designed for defense users. These include Option MIL, which prevents the storage of information inside the sensor; and Option SEC, a secure erase feature that allows sensitive users to erase any settings, offsets or data that have been stored within the sensor prior to the sensor leaving the secure environment. Additionally, the sensor utilizes LadyBug's patented active thermal stabilization which eliminates drift associated with accurate low power measurements.

LadyBug Technologies
www.LadyBug-Tech.com

Aerospace & Defense

COMPANY SHOWCASE



High Performance Components Since 1988

M Wave Design Corporation has been supplying low loss, high performance Ferrite and Waveguide components since 1988. M Wave specializes in high-mix, low volume microwave components. The unit illustrated above was a system design "afterthought" by a customer who ran out of space. M Wave solid modeled and built the WR28 full-band circulator and waveguide run into their package constraints and "on time and in budget." M Wave Design Corporation designs and manufactures a broad range of custom passive microwave hardware from 100 MHz to 50 GHz.

M Wave Design Corporation
https://mwavedesign.com

New GPS Notch Filter for Space, Aerospace, Defense and Military Industries

MCV notch filters are designed with 3D EM simulation and built under strict high reliability and quality standards. A 50 W GPS notch filter exhibits 35 dB rejection from 1560 to 1590.8 MHz with less than 0.2 dB insertion loss and 20 dB return loss in passband covering 1340 to 1525 MHz and 1625 to 2320 MHz. The small package size of 5.5" x 4.1" x 2.37" and around 2 lbs. of weight make it very useful to hi-rel communication systems. A video demonstrates how easily this filter is produced in production.

MCV Microwave
https://youtube.com/watch?v=OpAJ08wrWiQ&feature=share

Norden Millimeter's 18 to 40 GHz Down-Converter

VENDORVIEW

The NDC1840I0217N14 is an 18 to 40 GHz down-converter, part of Norden Millimeter's expanding line of catalog and custom frequency converters. This product is available with a 0.5 to 18 GHz bypass channel and hermetic case. Custom designs incorporate temperature compensation, variable gain and meet military environmental requirements. Norden can also provide RF and microwave assemblies which include frequency conversion, switch matrices, amplifiers, LNAs and filters.

Norden Millimeter
www.NordenGroup.com

High-Power, Compact (3U) Traveling Wave Tube Amplifiers

The new 9103 series is offered as 3U rack mountable amplifiers, with standard models providing frequency coverage of 2 to 8 GHz and 6.5 to 18 GHz, with output power ratings of 300 Watts CW or 1.5 to 2 kW pulsed. All of Quarterwave's amplifiers feature low noise, high PRF, optional touch screen interface and are fully customizable. Other models of amplifiers are capable of covering 0.8 to 40 GHz, with an output rating of up to 50 kW.

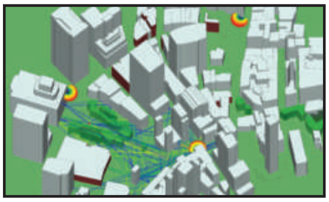
Quarterwave
www.quarterwave.com

Filters, Multiplexers & Multifunction Assemblies

VENDORVIEW

Reactel manufactures a line of filters, multiplexers and multifunction assemblies covering up to 67 GHz. Reactel's talented engineers can design a unit specifically for your application, from small, lightweight units suitable for unmanned flight or portable military systems to high-power units capable of handling up to 25 kW, connectorized or surface-mount.

Reactel
www.reactel.com



Wireless Propagation Predictions for Military, Defense and Commercial Communications

VENDORVIEW

Remcom offers products and consulting services for wireless propagation applications ranging from military defense to commercial communications. Remcom's Wireless InSite® software provides efficient and accurate predictions of radio wave propagation and communication channel characteristics in complex urban, indoor, rural and mixed path environments. Propagation projects that Remcom can simplify include 5G MIMO, 5G NR, ad-hoc and temporary networks, base station coverage analysis, indoor Wi-Fi, microcell coverage, LTE and WiMAX throughput, moving vehicle or aircraft and tower placement in urban environments.

Remcom
www.remcom.com/wireless-propagation

AD INDEX

Analog Devices .... COV 4
AnaPico AG 9
CAES (Cobham Advanced Electronic Solutions) .... COV 2
Cernex, Inc. 10
Coilcraft CPS 11
Comtech PST Corp. 18, 45
Comtech PST Corp. (Control Components Division) 18, 45
CPI (Communications & Power Industries) 40
CTT Inc. 5
dB Control Corp. 22
EDI CON ONLINE 2022 .... COV 3
ERZIA Technologies S.L. 25
Exceed Microwave 16
Exodus Advanced Communications, Corp. 23
EZ Form Cable Corporation 33
Gel-Pak 41
HASCO, Inc. 8
HYPERLABS INC. 21
Information Systems Laboratories 31
Insulated Wire, Inc. 37
Intelliconnect Ltd. 42
KRYTAR 26
KVG Quartz Crystal Technology GmbH 32
KYOCERA AVX 15
LadyBug Technologies LLC 28
M Wave Design Corporation 44
MCV Microwave 24
Microwave Products Group (a Dover Company) 12
Mini-Circuits 19, 35, 39
Norden Millimeter Inc. 14
Orolia USA, Inc. 43
Qorvo 3
Quarterwave Corporation 34
Reactel, Incorporated 7
Remcom 29
Rosenberger 13
Signal Hound 17
Spinner GmbH 27

Aerospace & Defense

COMPANY SHOWCASE

Aerospace, Security & Defence

Rosenberger provides a comprehensive product portfolio of high-reliable interconnect components and devices which is in accordance with the stringent requirements of MIL-PRF 39012, DIN EN 9100 or ESCC Certification of the European Space Agency. The wide product portfolio qualified for aerospace, security and defense applications includes RF coaxial components, microwave components and cable assemblies, RF test and measurement products or fiber optic interconnect components. A brochure is available for download from the Rosenberger website.

Rosenberger Group

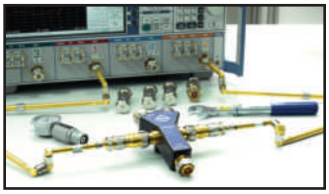
www.rosenberger.com/markets/spaceflight-aerospace-defence/

Unrivaled Value in RF Test Equipment

In business since 1996, we've built our company on years of test equipment repair, service, hardware & software development, and manufacturing experience. We're a small company with big goals—and a commitment to providing our customers with outstanding experiences when buying and using our products. Our much-anticipated SM435B (coming soon) has an increased tuning range of 100 kHz to 43.5 GHz, 160 MHz of instantaneous bandwidth and ultra-low phase noise to expand your reach into mmWave spectrum analysis.

Signal Hound

https://signalhound.com



How to Increase the Accuracy of RF Test Results

VENDORVIEW

Accurate calibration is a must for reliable results. SPINNER supplies top-quality calibration kits with OPEN, SHORT, LOAD and THROUGH lines for performing top-quality measurements in labs, on production lines and on site at customers. All SPINNER calibration kits are mechanically highly robust and optimized for high repeatability of connections. They include calibration data for various accuracy levels of the electrical modeling.

SPINNER

www.spinner-group.com