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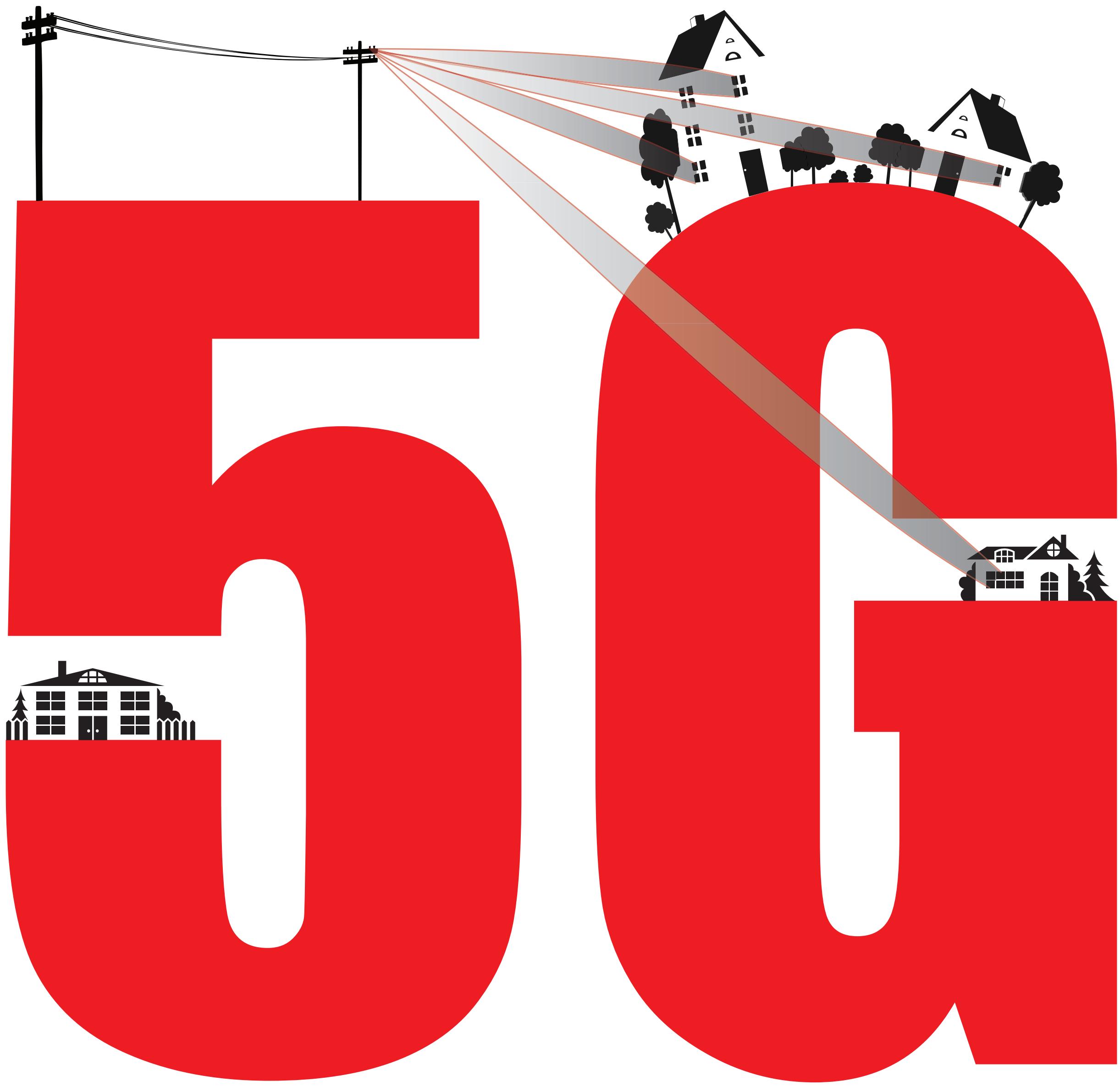
February 2018

Microwave Journal



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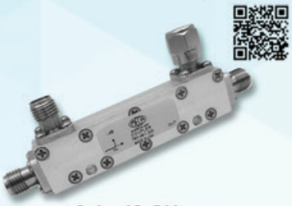

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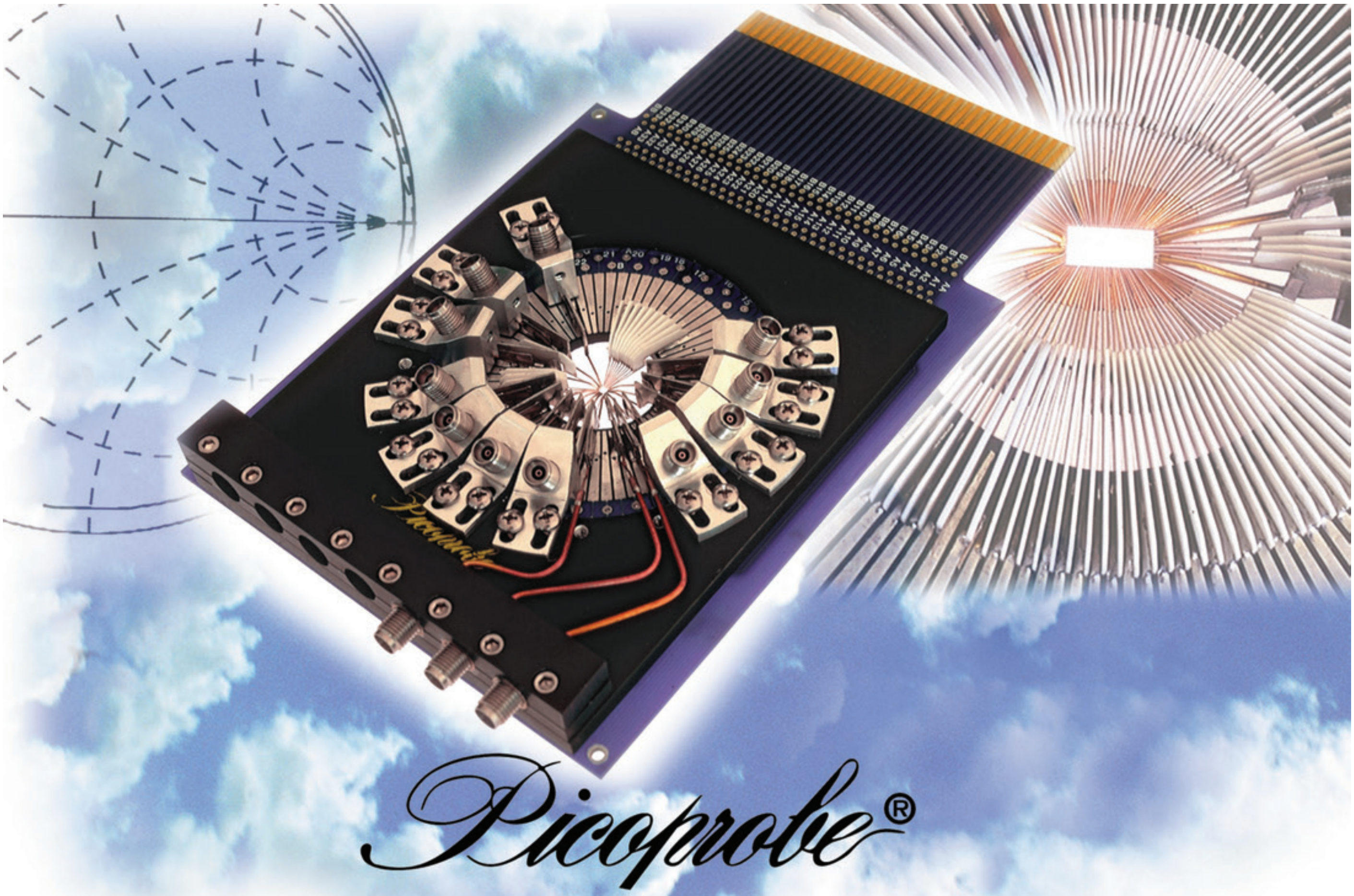

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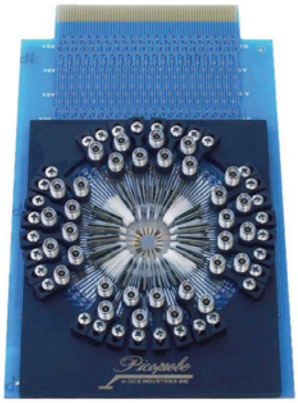

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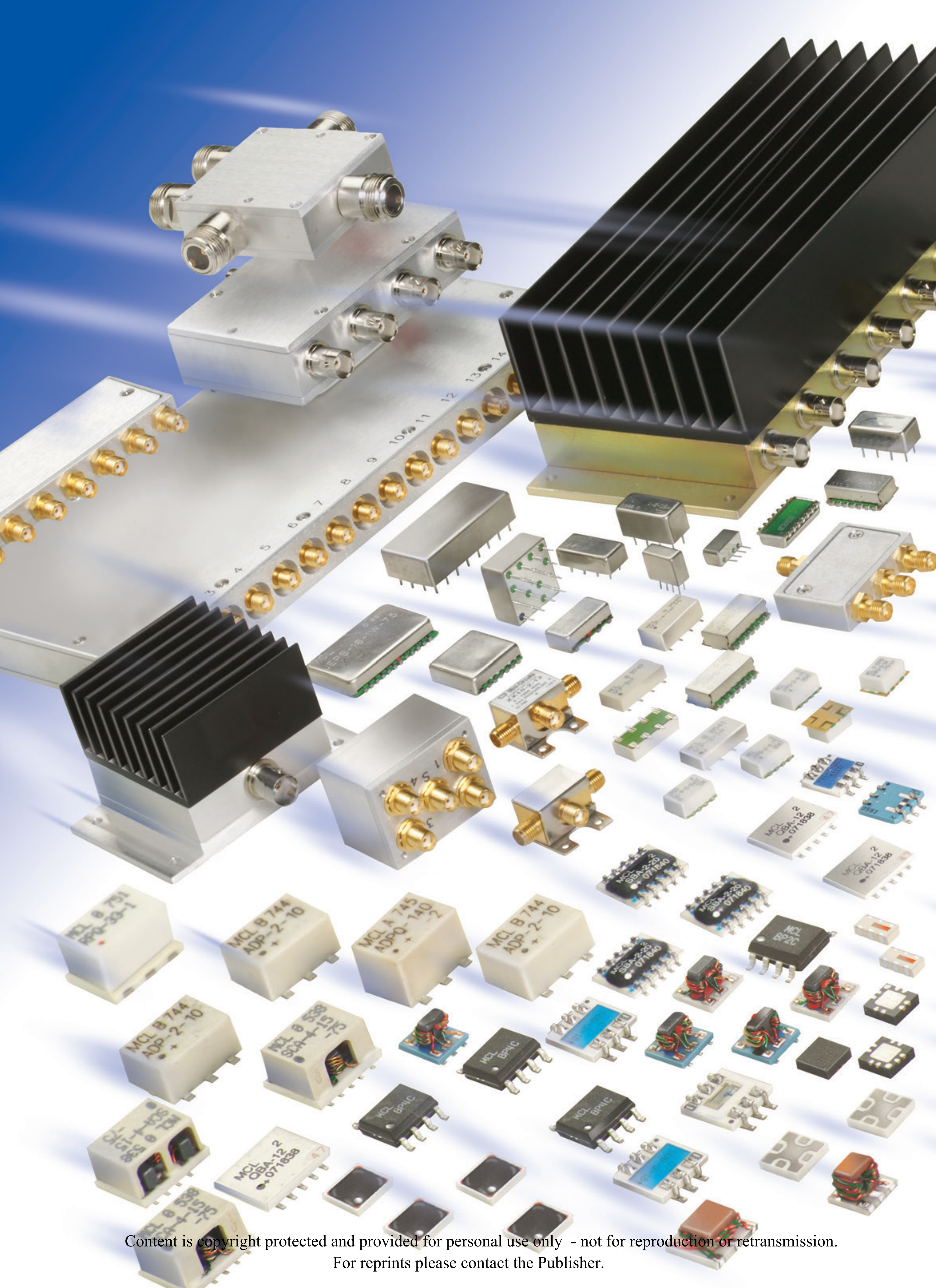

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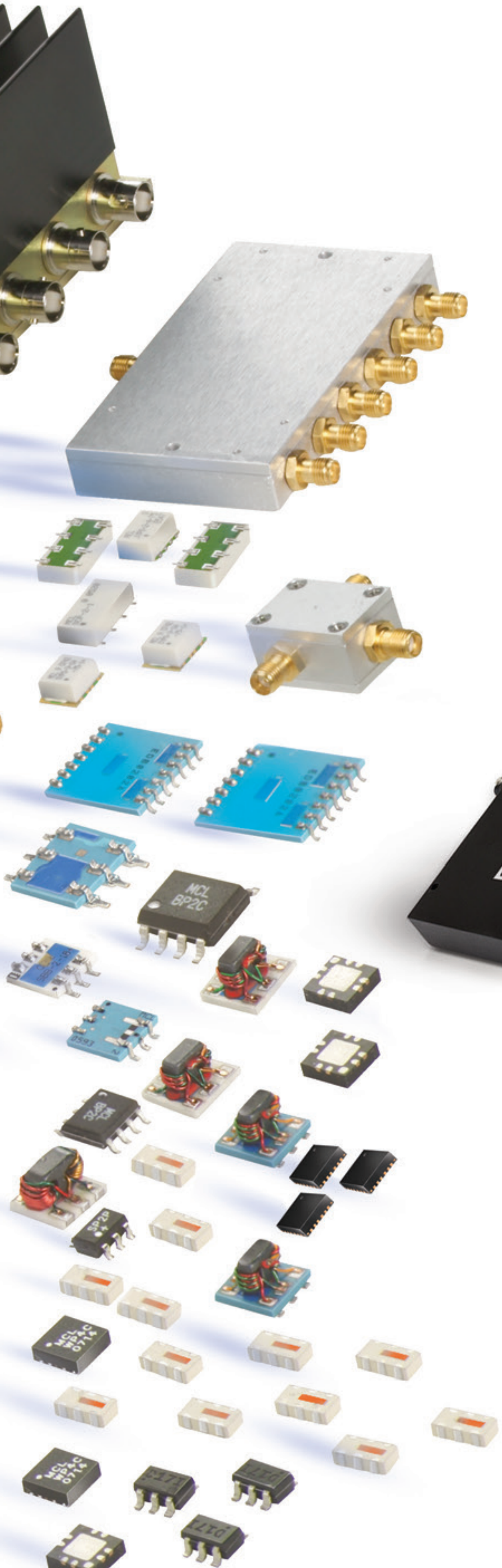

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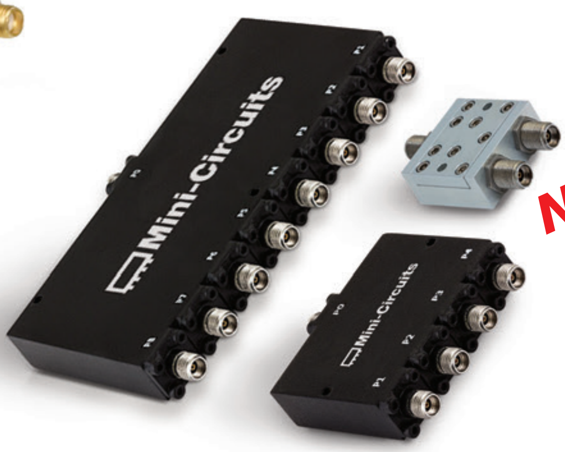

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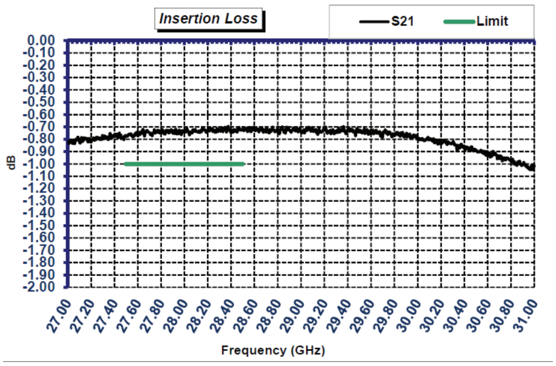

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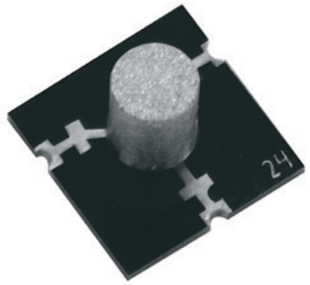

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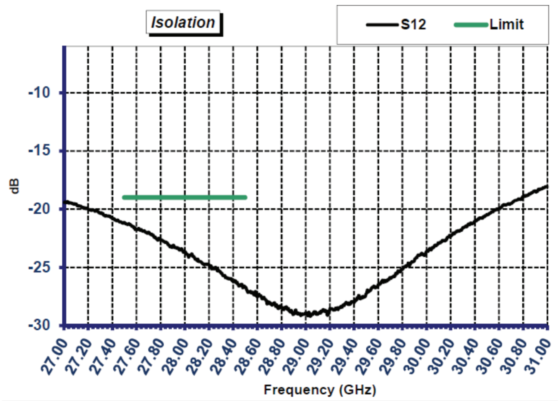

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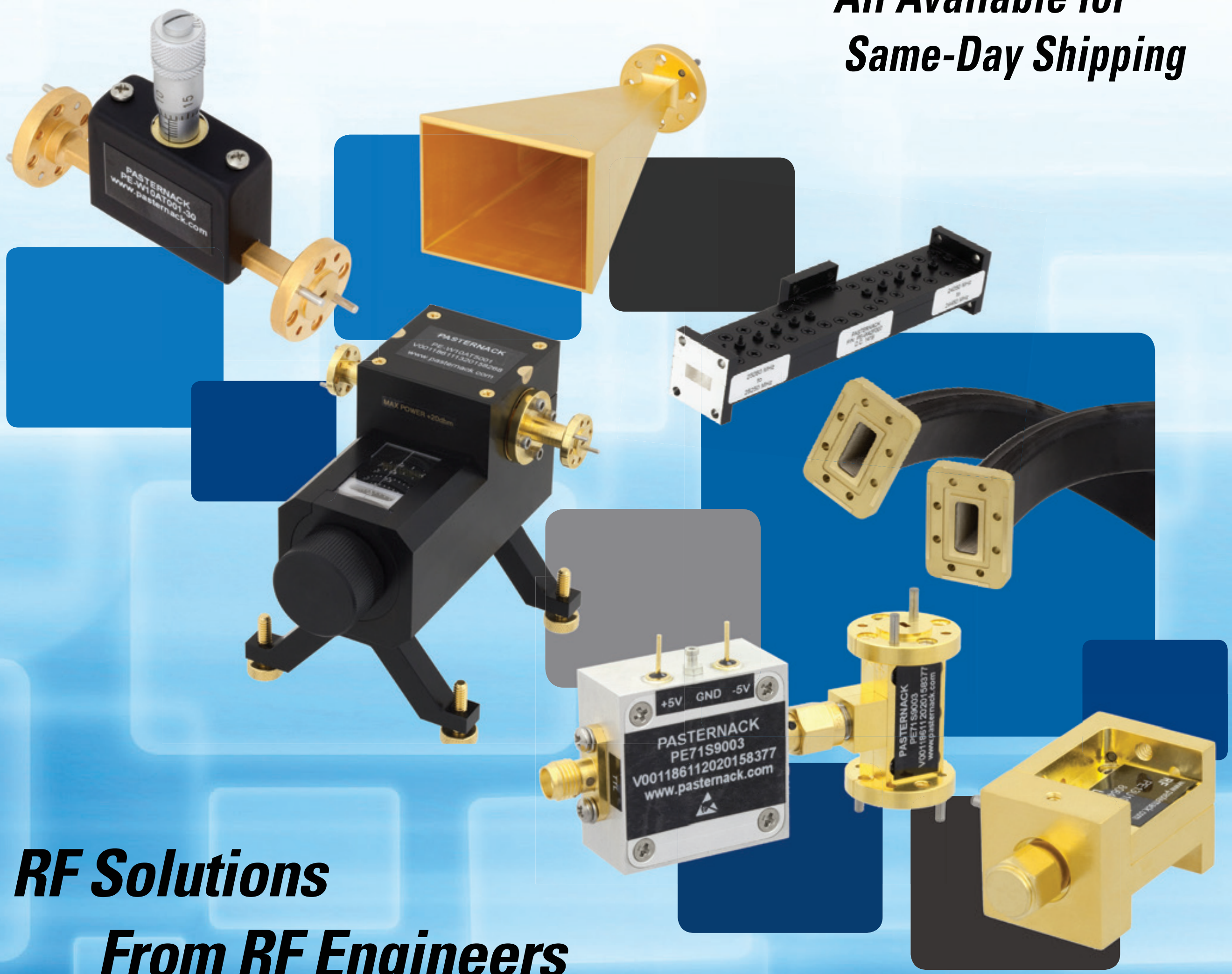

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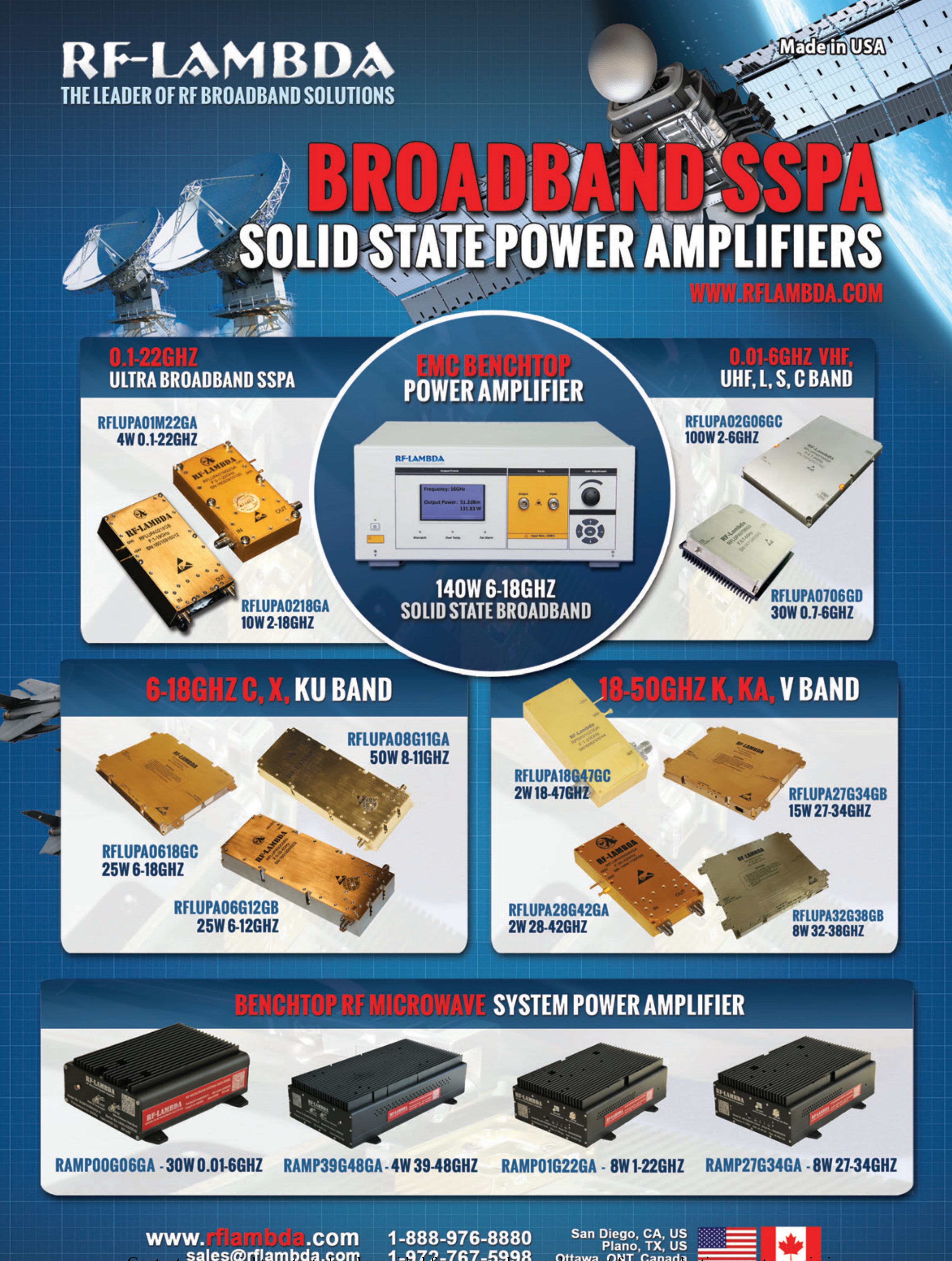

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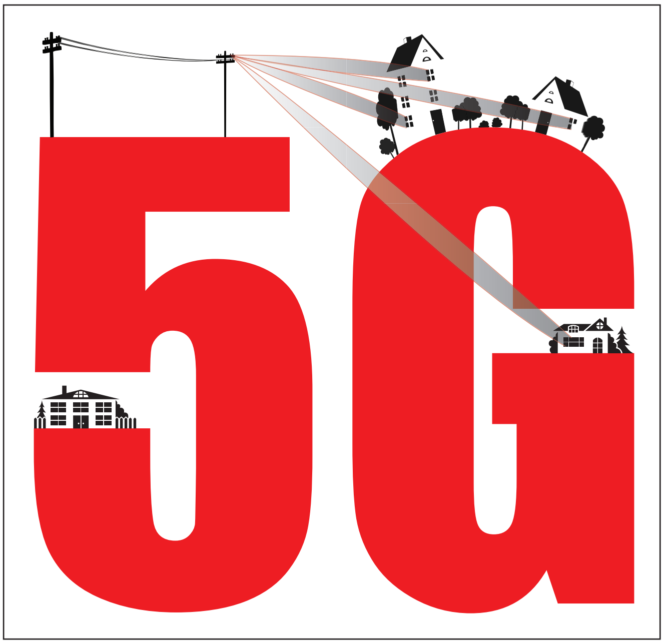

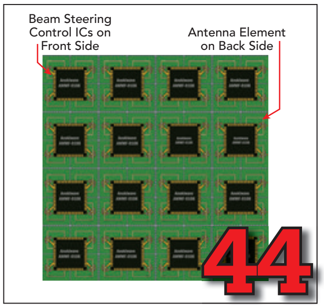

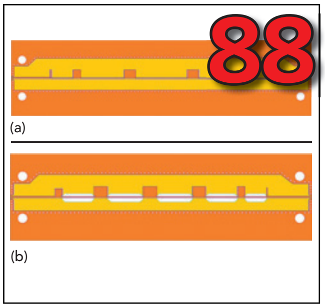

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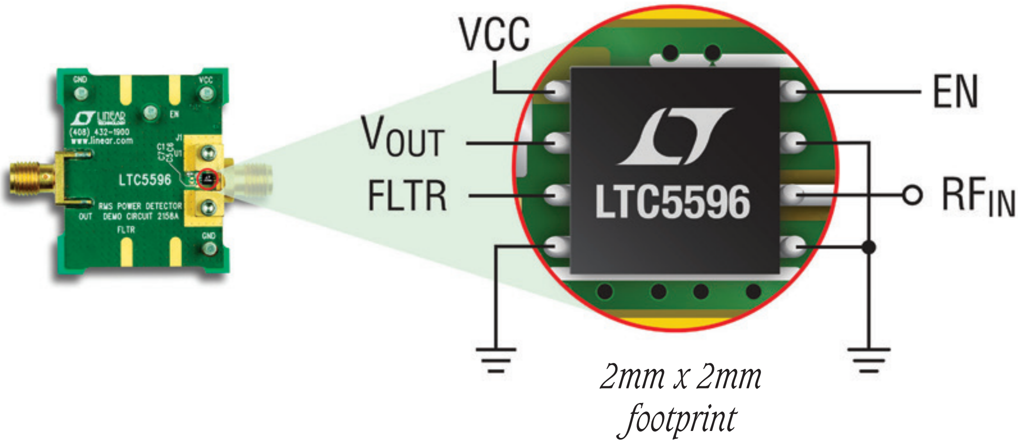

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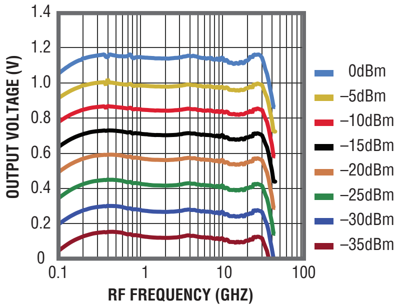

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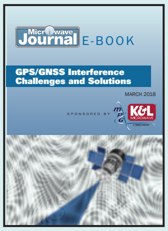
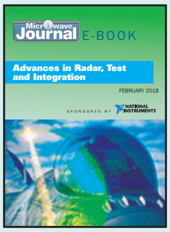


GPS/GNSS Interference Challenges and Solutions



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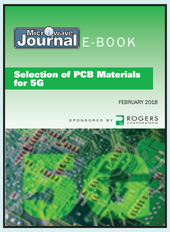

Selection of PCB Materials for 5G

Web Survey

What semiconductor technology will underlie most of the RF components in a 28 or 39 GHz fixed wireless access link?

Look for our multiple choice survey online at mwjournal.com

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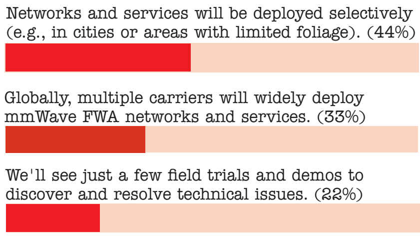

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21-22

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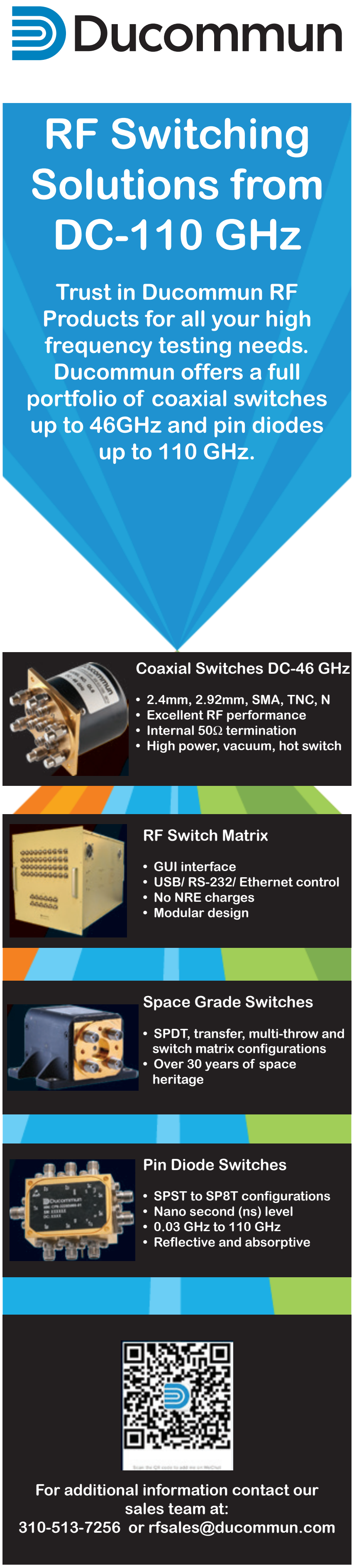

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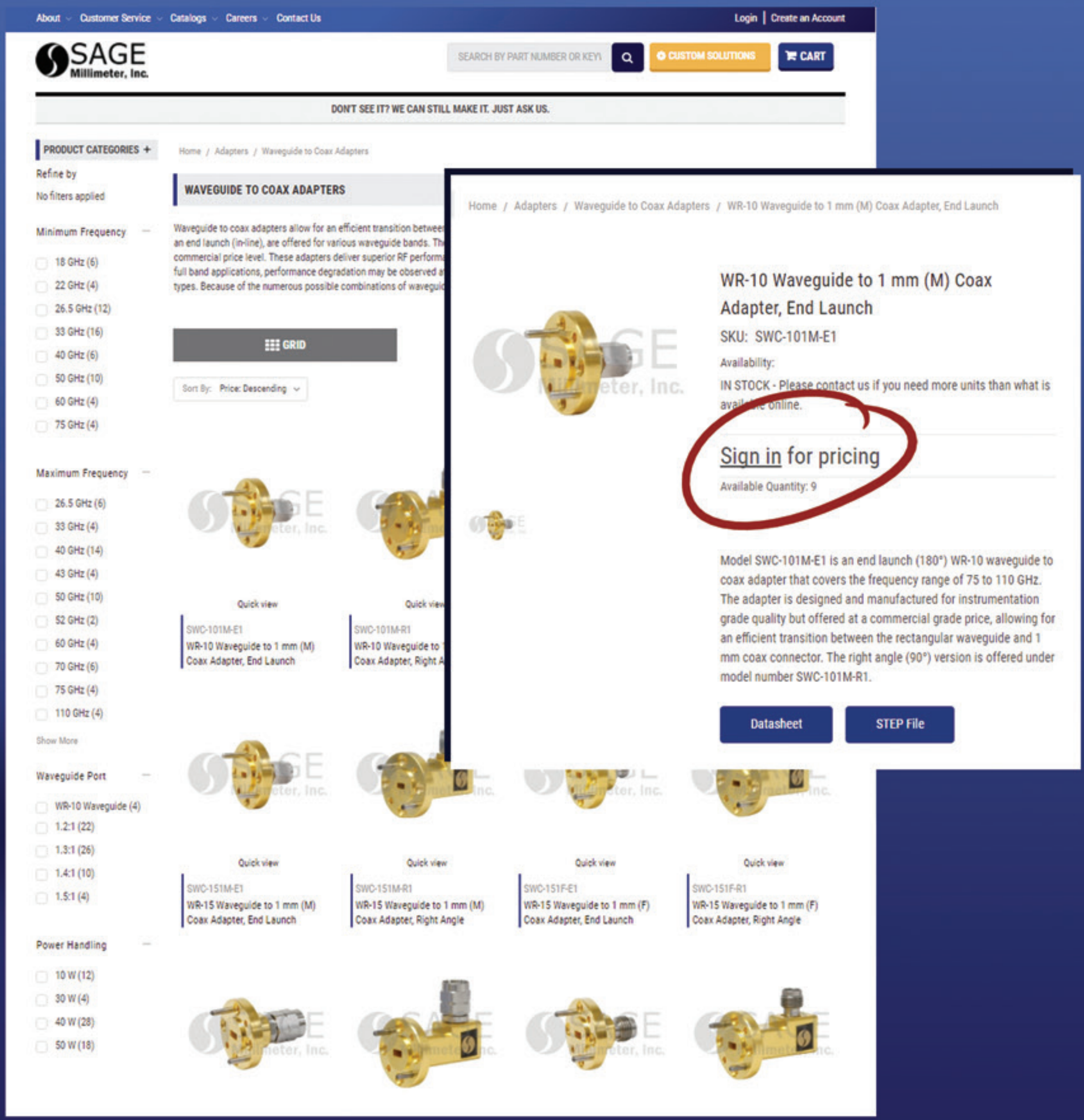

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COVER FEATURE
INVITED PAPER

Editor's Note: At the end of December, the 3GPP approved the 5G non-standalone new radio (NSA NR) specification, which defines how enhanced broadband services can be deployed using a 5G NR leveraging the existing LTE network. This NSA architecture will first be fielded—later this year—for fixed wireless access (FWA) services using mmWave spectrum, i.e., 28 and 39 GHz.

Qorvo and Anokiwave are two companies leading the development of the mmWave front-end technology for the active phased arrays that will power these FWA services. Each company has analyzed the system requirements and defined a unique approach to meeting them. Qorvo has chosen GaN, Anokiwave silicon. We are fortunate that this issue of *Microwave Journal* features articles from both, each stating the case for its technology choice. Regardless of which argument you favor, no doubt you will agree that both companies are doing excellent technology and product development, a key step to making 5G viable.

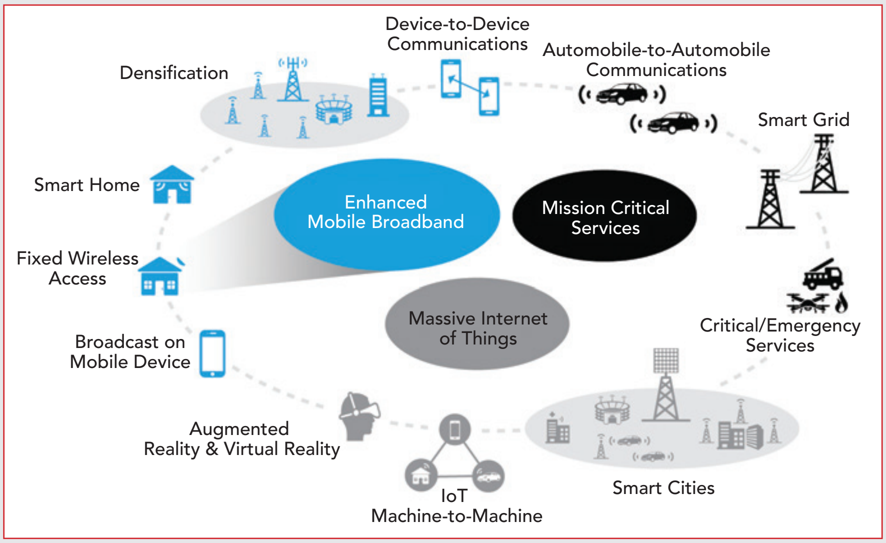
5G Fixed Wireless Access Array and RF Front-End Trade-Offs

Bror Peterson and David Schnaufer
Qorvo, Greensboro, N.C.

The vision of next-generation 5G networks is to deliver an order-of-magnitude improvement in capacity, coverage and connectivity compared to existing 4G networks, all at substantially lower cost per bit to carriers and consumers. The many use cases and services enabled by 5G technology and networks are shown in ***Figure 1***. In this first phase of 5G new radio (NR) standardization, the primary focus has been on defining a radio access technology (RAT) that takes advantage of new wideband frequency allocations, both sub-6 GHz and above 24 GHz, to achieve the huge peak throughputs and low latencies proposed by the International Mobile Telecommunications vision for 2020 and beyond.[1]

Mobile network operators are capitalizing on the improvements introduced by NR RAT, particularly in the mmWave bands, to deliver gigabit fixed wireless access (FWA) services to houses, apartments and businesses, in a fraction of the time and cost of traditional cable and fiber to the home installations. Carriers are also using FWA as the testbed toward a truly mobile broadband experience. Not surprisingly, Verizon, AT&T and other carriers are aggressively trialing FWA, with the goal of full commercialization in 2019.

In this article, we analyze the architecture, semiconductor technology and RF front-end (RFFE) design needed to deliver these new mmWave FWA services. We discuss the link budget requirements and



▲ **Fig. 1** 5G use cases.

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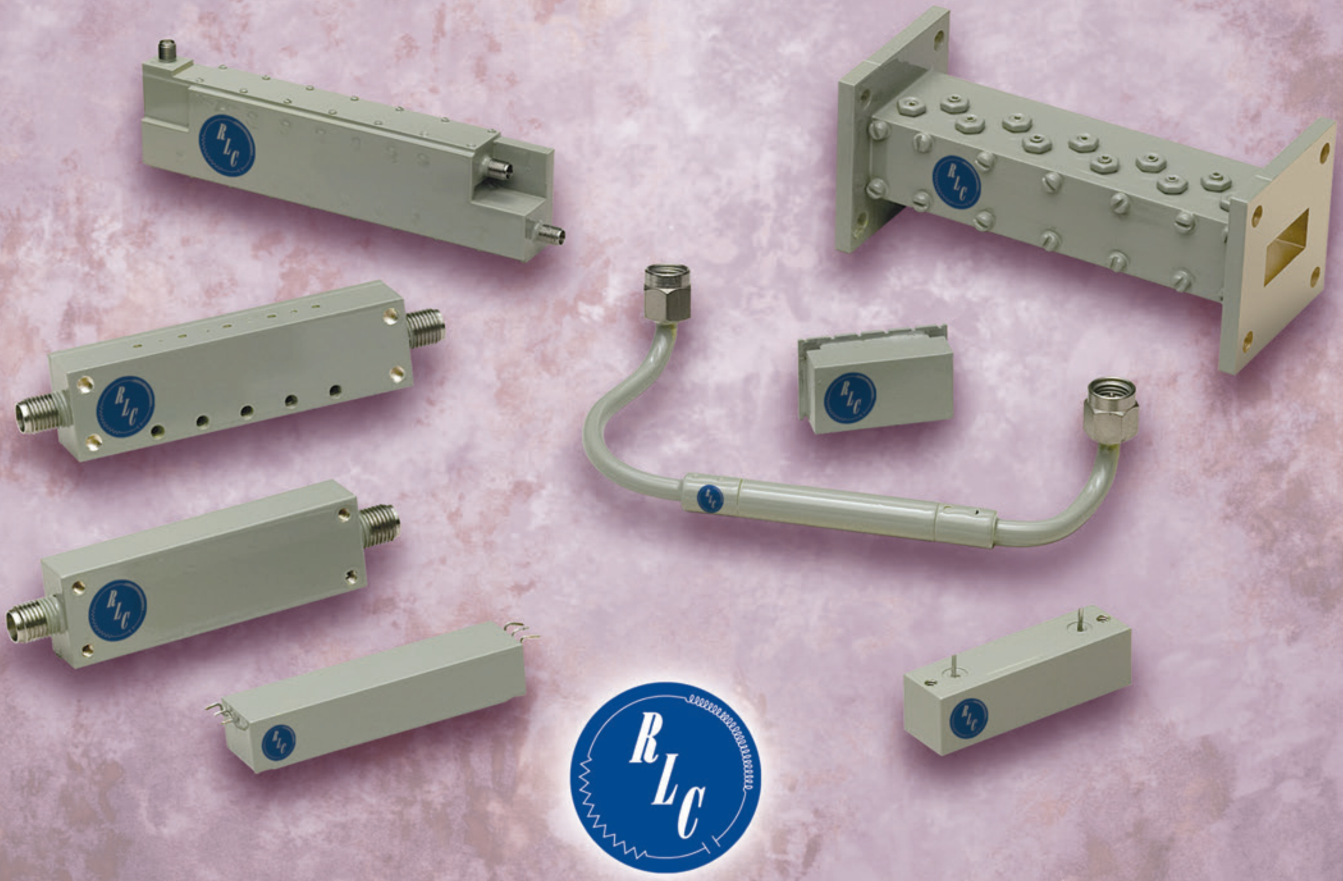

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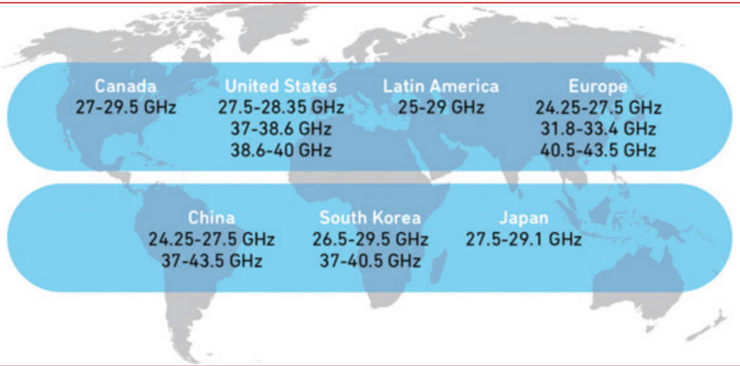

Fig. 2 Global 5G bands above 24 GHz.

walk through an example of suburban deployment. We address the traits and trade-offs of hybrid beamforming versus all-digital beamforming for the base transceiver station (BTS) and analyze the semiconductor technology and RFFE components that enable each. Finally, we discuss the design of a GaN-on-SiC front-end module (FEM) designed specifically for the 5G FWA market.

FWA DEPLOYMENT

A clear advantage of using mmWave is the availability of underutilized contiguous spectrum at low cost. These bands allow wide component carrier bandwidths up to 400 MHz and commercial BTSs are being designed with carrier aggregation supporting up to 1.2 GHz of instantaneous bandwidth. Customer premise equipment (CPE) will support peak rates over 2 Gbps and come in several form factors: all outdoor, split-mount and all indoor desktop and dongle-type units. Mobile-handset form factors will follow.

Global mmWave spectrum availability is shown in ***Figure 2***. In the U.S., most trials are in the old block A LMDS band between 27.5 and 28.35 GHz, but the plan-of-record of carriers is to deploy nationwide in the wider 39 GHz band, which is licensed on a larger economic area basis. These candidate bands have been assigned by 3GPP and, except for 28 GHz, are being harmonized globally by the International Telecommunications Union.[2]

FWA describes a wireless connection between a centralized sectorized BTS and numerous fixed or nomadic users (see ***Figure 3***). Systems are being designed to leverage existing tower sites and support a low-cost, self-install CPE build-out. Both are critical to keeping initial deployment investment low while the business case for FWA

TABLE 1

FCC POWER LIMITS FOR 28 AND 39 GHz BANDS

Equipment Class	Power (EIRP)
Base Station	75 dBm/100 MHz
Mobile Station	43 dBm
Transportable Station	55 dBm

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is validated. Early deployments will be mostly outdoor-to-outdoor and use professional roof-level installations that maximize range, ensure initial customer satisfaction and allow time for BTS and CPE equipment to reach the needed cost and performance targets.

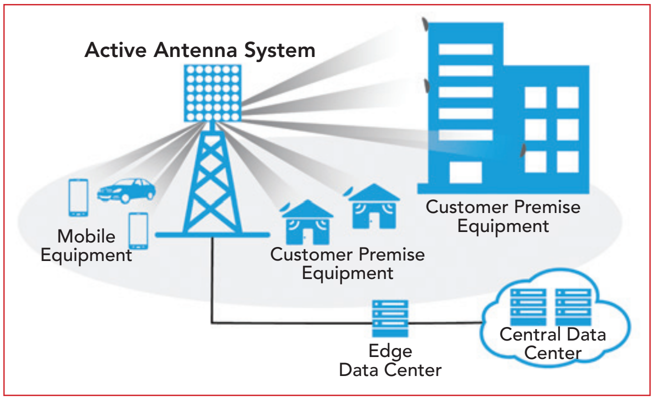

Fig. 3 End–to–end FWA network.

Large coverage is essential to the success of the FWA business case. To illustrate this, consider a suburban deployment with 800 homes/km^2, as shown in ***Figure 4***. For BTS inter-site distance (ISD) of 500 m, we need at least 20 sectors, each covering 35 houses from nine cell sites. Assuming 33 percent of the customers sign up for 1 Gbps service and a 5x network oversubscription ratio, an average aggregate BTS capacity of 3 Gbps/sector is needed. This capacity is achieved with a 400 MHz bandwidth, assuming an average spectral efficiency of 2 bps/Hz and four layers of spatial multiplexing. If customers pay $100 per month, the annual revenue will be $280,000/km^2/year. Of course, without accounting for recurring costs, it is not clear FWA is a good business, but we can conclude that as ISD increases, the business case improves. To that end, carriers are driving equipment vendors to build BTS and CPE equipment that operate up to regulatory limits to maximize coverage and profitability.

Fig. 4 FWA in a suburban environment.

In the U.S., the Federal Communications Commission has defined very high effective isotropic radiated power (EIRP) limits for the 28 and 39 GHz bands,[3] shown in ***Table 1***. The challenge becomes building systems that meet these targets within the cost, size, weight and power budgets expected by carriers. Selecting the proper front-end architecture and RF semiconductor technology are key to getting there.

FWA Link Budget

The standards community has been busy defining the performance requirements and evaluating use cases over a broad range of mmWave frequencies. The urban-macro scenario is the best representation of a typical FWA deployment: having large ISD of 300 to 500 m and providing large path-loss budgets that overcome many of the propagation challenges at mmWave frequencies. To understand the needed link budget, consider a statistical path-loss simulation using detailed large-scale channel models that account for non-line-of-site conditions and outdoor-to-indoor penetration,

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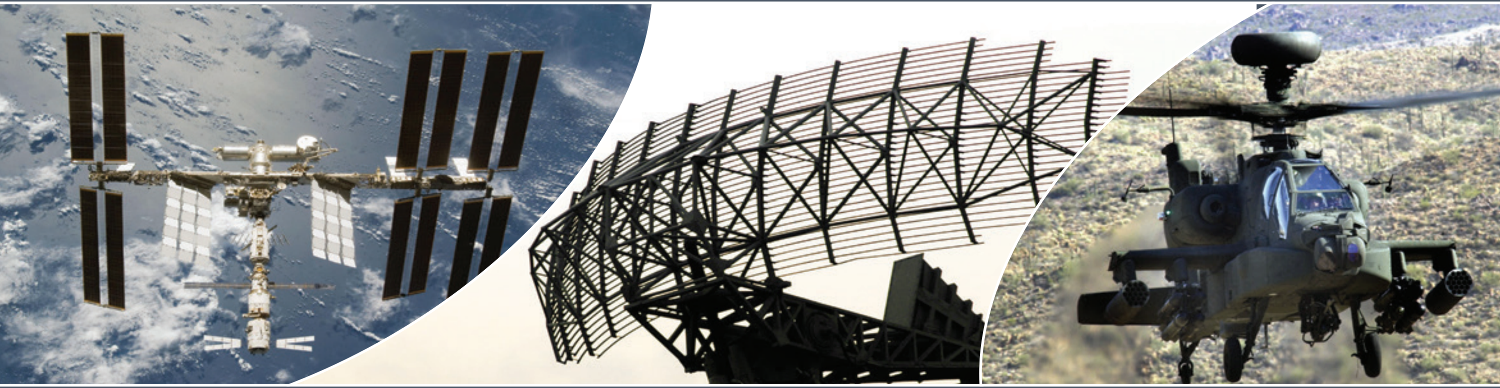

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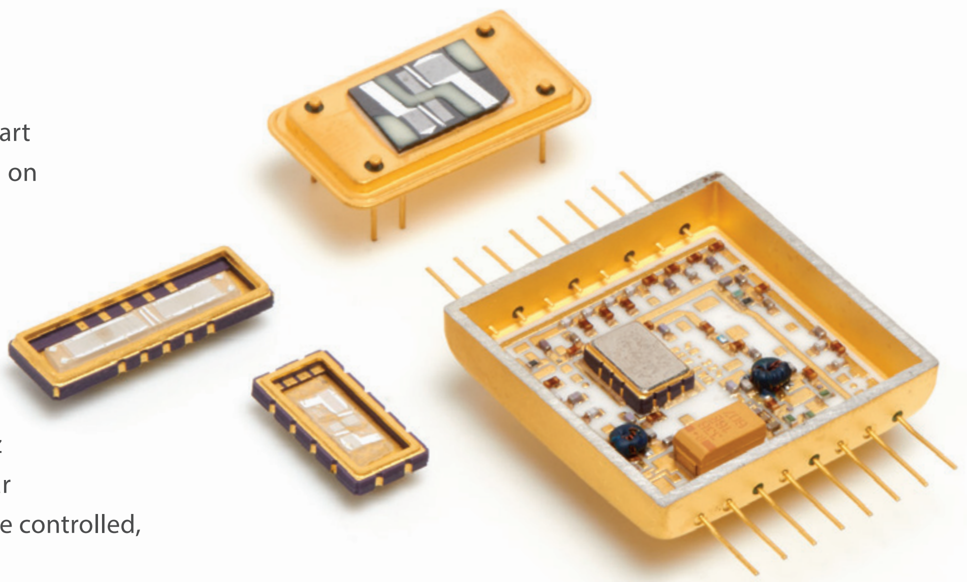

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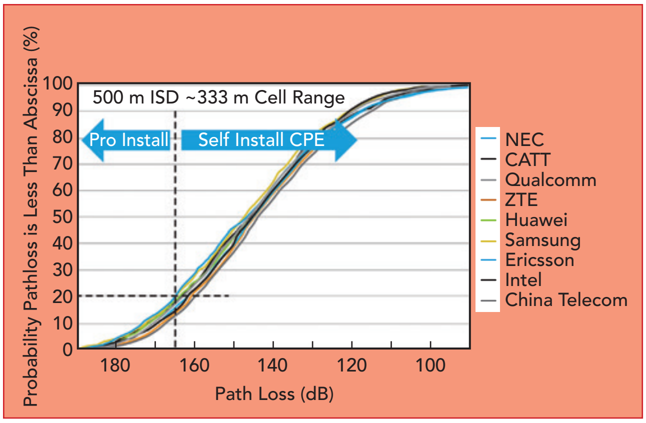
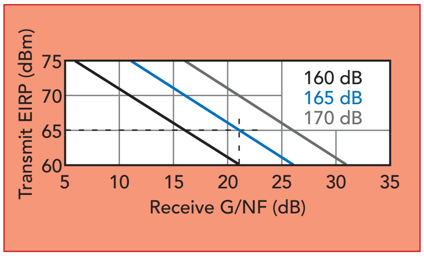
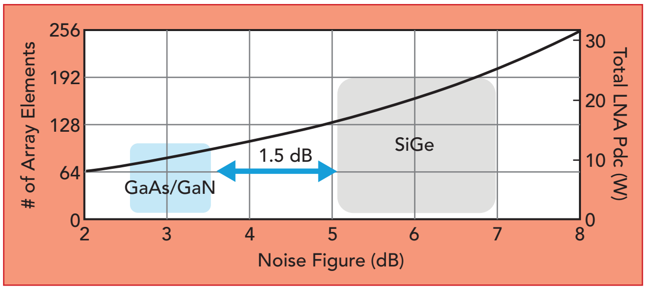


▲ **Fig. 5** **Statistical path loss simulation for urban-macro environment with 500 m ISD.**



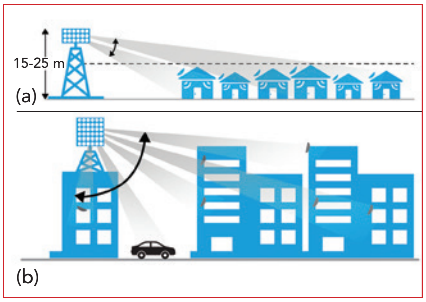
▲ **Fig. 6** **Transmit EIRP and receive G/NF vs. path-loss for 1 Gbps edge-of-coverage throughput.**



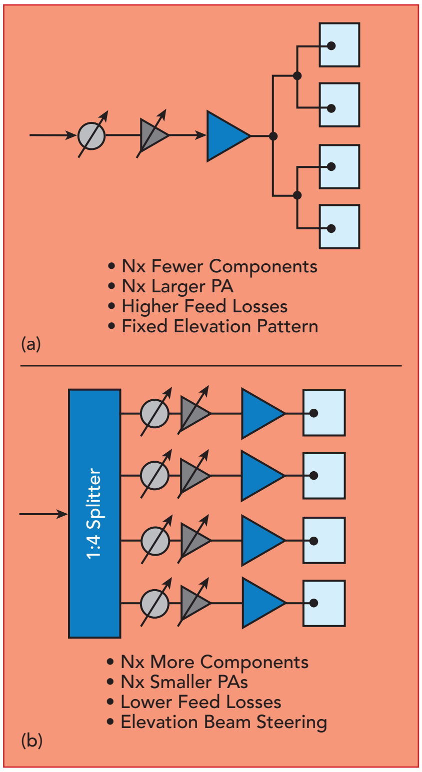
▲ **Fig. 7** **Array size vs. front-end NF and power consumption for G/NF = 21 dB.**

like those defined by 3GPP.[4] ***Figure 5*** shows the result for a 500 m ISD urban-macro environment performed by equipment vendors and operators. For this simulation, 28 GHz channel models were used with 80 percent of the randomly dropped users falling indoors and 20 percent outdoors. Of the indoor users, 50 percent were subject to high penetration-loss models and 50 percent lower loss. Long-term, carriers desire at least 80 percent of their potential users to be self-installable to minimize more expensive professional roof-level installations. The distribution curve shows the maximum system path loss to be 165 dB.

Closing the link depends on many variables, including transmit EIRP, receive antenna gain, receiver noise figure (NF) and minimum



▲ **Fig. 8** **Array complexity depends on the scanning range needed for the deployment: suburban (a) or urban (b).**



▲ **Fig. 9** **Column-fed (a) and per-element (b) active arrays.**

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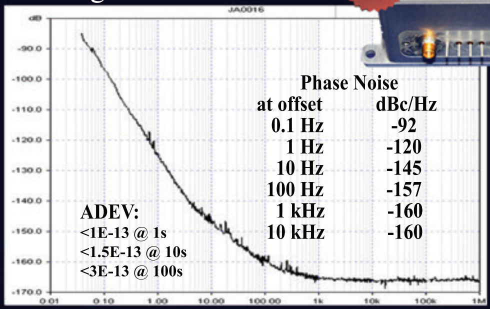
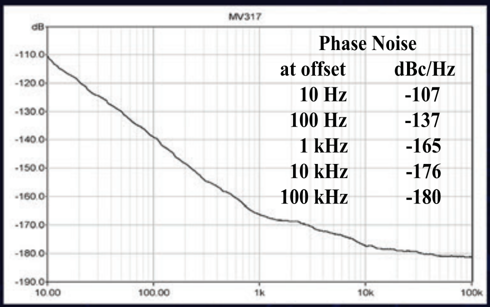
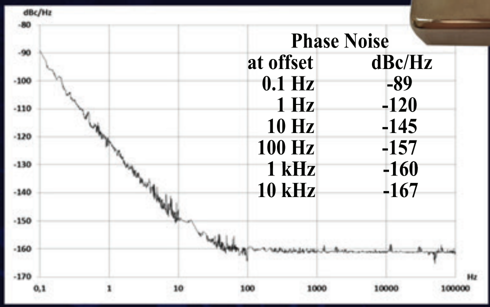


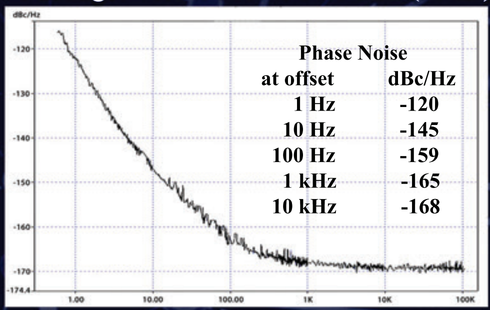
MV317 100 MHz, +5V/+12V
- Temperature Stability: 1E-8
- Aging: ±1E-7 per year
- Package: 25.8x25.8x10.3 mm



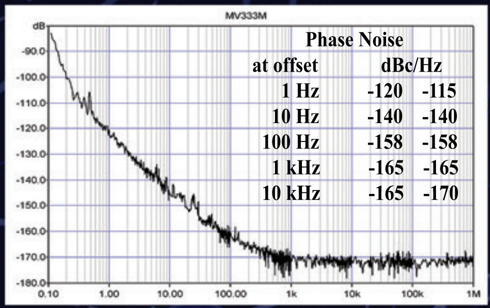
MV341 10 MHz
- Temperature Stability: 1E-9
- Allan Deviation: <2E-13 per sec.
- Package: 50.8x50.8x12.7 mm



MV272M 10 MHz
- Temperature Stability: 1E-9
- Allan Deviation: <4E-13 per sec.
- Package: 41.0 x 30.0 x 17.0 mm (SMD)



MV333M 10 MHz
- Temperature Stability: 3E-9
- Allan Deviation: <5E-13 per sec.
- Package: 25.8x25.8x12.7 or 36x27x16 mm



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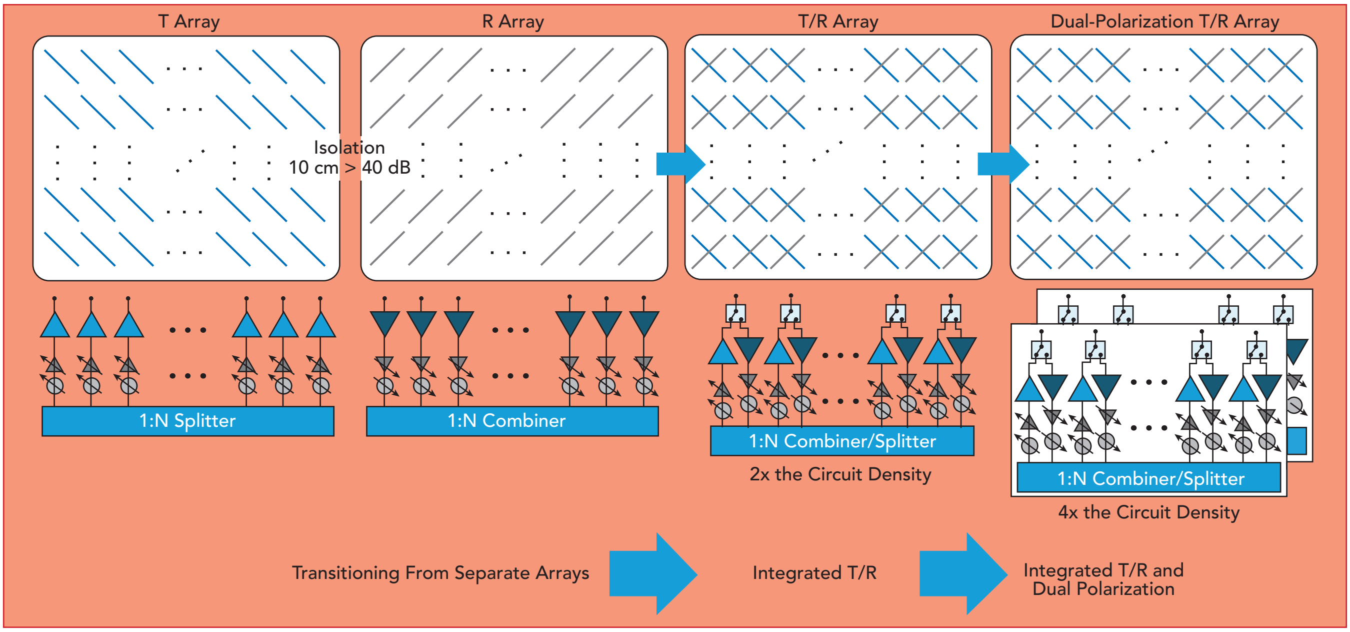
edge-of-coverage throughput. To avoid overdesign of the cost-sensitive CPE equipment and shift the burden toward the BTS, the link design begins at the CPE receiver and works backward to arrive at the BTS transmitter requirements. In lieu of the conventional G/T (the ratio of antenna gain to system noise temperature) figure-of-merit (FOM), we define a more convenient G/NF FOM: the peak antenna gain (including beamforming gain) normalized by the NF of the receiver. ***Figure 6*** illustrates the required EIRP for the range of receive G/NF to overcome a targeted path loss delivering an edge-of-coverage throughput of 1 Gbps, assuming the modulation spectral efficiency is effectively 2 bps/Hz and demodulation SNR is 8 dB. From the graph, the BTS EIRP for a range of CPE receiver's G/NF can be determined. For example, 65 dBm BTS EIRP will be needed to sustain a 1 Gbps link at 165 dB of path loss when the CPE receiver G/NF is ≥ 21 dBi.

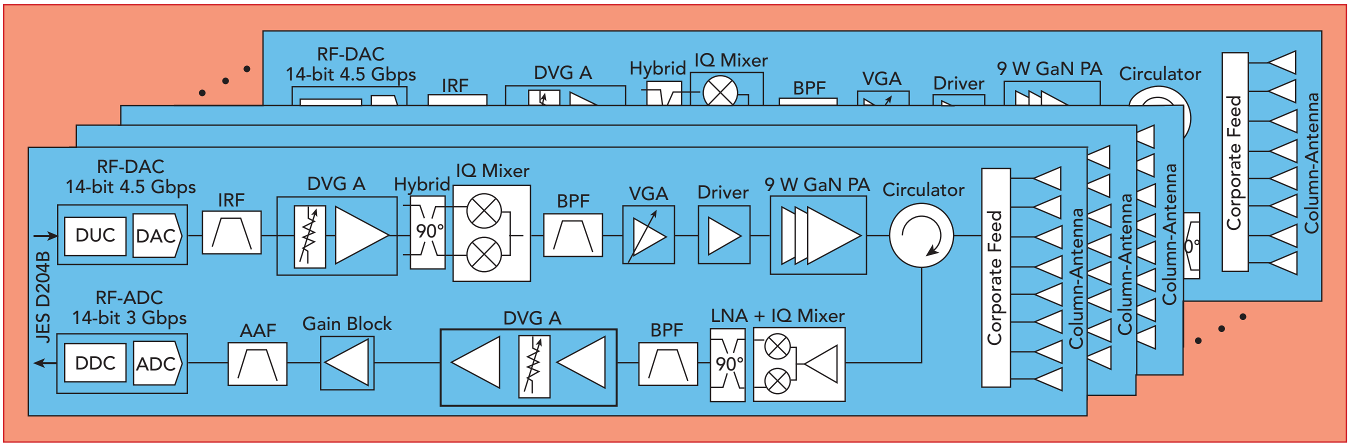
Next, we consider the impact of receiver NF by plotting the minimum number of array elements needed to achieve G/NF of 21 dB (see ***Figure 7***). We also plot the total low noise amplifier (LNA) power consumption. By adjusting the axis range, we can overlap the two and see the impact NF has on array size, complexity and power. For this example, each LNA consumes 40 mW, which is typical for phased arrays. The NFs of RFFEs, including the T/R switch losses, are shown for 130 nm SiGe BiCMOS, 90 nm GaAs PHEMT and 150 nm GaN HEMT at 30 GHz. The compound semiconductor technology provides ≥ 1.5 dB advantage, translating to a 30 percent savings in array size, power and, ultimately, CPE cost.

TABLE 2
APPROXIMATE PERFORMANCE FOR CORPORATELY FED ELEMENTS

Column Array Size	Beamwidth (°)	Gain (dB)
Single Element	102	5
2-Element	51	8
4-Element	26	11
8-Element	13	14



▲ Fig. 10 FWA antenna arrays are evolving from separate T and R arrays to integrated T/R arrays with dual polarization.



▲ Fig. 11 Array design using digital beamforming and commercial, off-the-shelf components.

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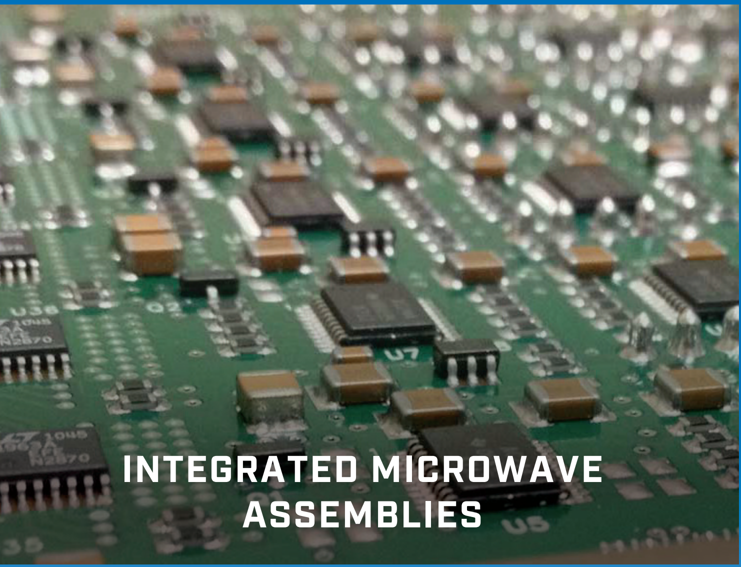

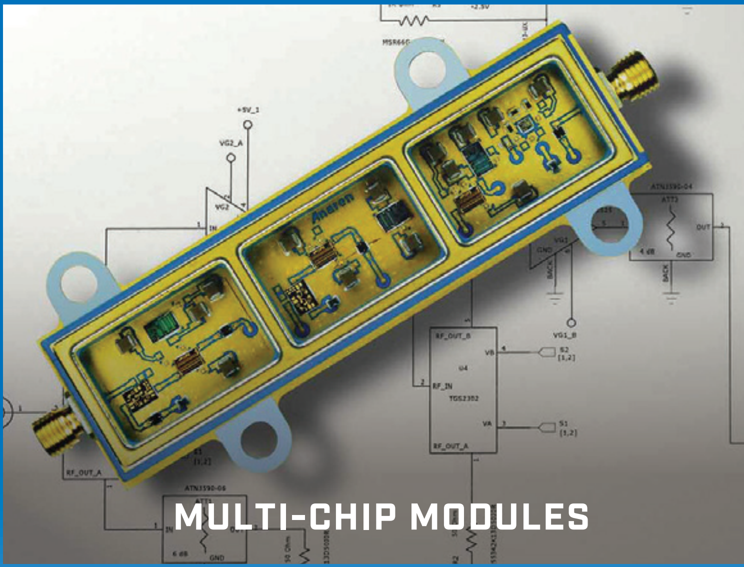

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To explore architecture trades that are key to technology selection and design of the RFFE components, we start by understanding the antenna scanning requirements. We highlight the circuit density and packaging impact for integrated, dual-polarization receive/transmit arrays. Finally, we investigate all-digital beamforming and hybrid RF beamforming architectures and the requirements for each.

1D or 2D Scanning

The number of active channels in the array depends on many things. Let's start by first understanding the azimuth and elevation scanning requirements and whether two-dimensional beamforming is required for a typical FWA deployment or if a lower complexity, one-dimensional (azimuth only) beamforming array is sufficient. This decision impacts the power amplifier (PA). ***Figure 8*** shows two FWA deployment scenarios. In the suburban deployment, the tower heights range from 15 to 25 m and the cell radius is 500 to 1000 m, with an average house height of 10 m. Just as with traditional macro cellular systems, there is no need for fully adaptive elevation scanning. The elevation beam can be focused down by corporately feeding several passive antenna elements, as shown in ***Figure 9a***. This vertically stacked column of radiating elements is designed to minimize radiation above the houses and fill in any nulls along the ground. Further, the gain pattern is designed to increase at relatively the same rate as the path loss. This provides more uniform coverage for both near and far users. The nominal half-power beamwidth can be approximated as $102°/N_{ANT}$ and the array gain by $10\log_{10}(N_{ANT}) + 5$ dBi. With passively combined antennas, the elevation beam pattern is focused and the fixed antenna gain increases, as shown in ***Table 2***. For the suburban FWA deployment, a 13 to 26 degree beamwidth is sufficient, with the passively combined column array from four to eight elements. In the urban scenario, however, the elevation scanning requirements are greater, and systems will be limited to one or two passive elements.

Figure 9b illustrates the per-element active array. Both the per-element and column-fed array architectures have the same antenna gain, but the column-fed array has a fixed elevation beam pattern. The per-element array supports wider scan angles but needs 4x as many PAs, phase shifters and variable gain components for an antenna with four elements. To achieve the same EIRP, the PA driving a column-fed array with four antennas will need to provide at least 4x the output power, which can easily change the semiconductor selection. It is reasonable to assume a suburban BTS will use antennas with 6 to 9 dB higher passive antenna gain compared to an urban deployment. As a result, the phased array needs far fewer active channels to achieve the same EIRP, significantly reducing active component count and integration complexity.

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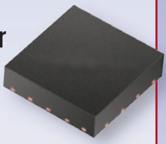

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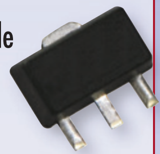

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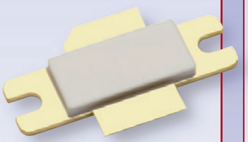

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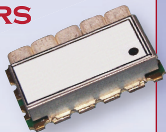

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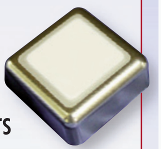

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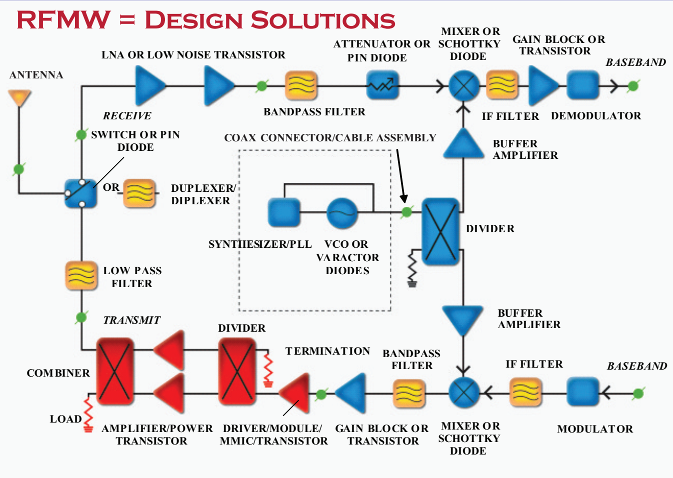

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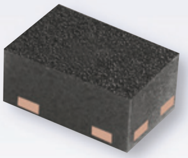

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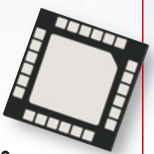

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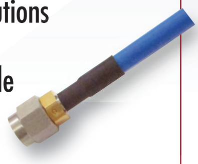

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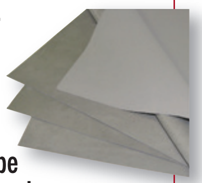

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Array Front-End Density

Early mmWave FWA BTS designs used separate, single-polarization transmit and receive antenna arrays, which allowed significantly more board area for components. These designs avoided the additional insertion loss and linearity challenges of a T/R switch. However, a major architecture trend is integrated T/R, dual-polarization arrays (see ***Figure 10***), which is driving RFFE density. The key reason is spatial correlation. Adaptive beamforming performance depends on the ability to calibrate the receive and transmit arrays relative to one another. As such, it is important to integrate the transmit and receive channels for both polarizations, so the array shares a common set of antenna elements and RF paths. The net result is a requirement for the RFFE to have 4x the circuit density of earlier systems.

At mmWave frequencies, the lattice spacing between phased-array elements becomes small, e.g., 3.75 mm at 39 GHz. To minimize feed loss, it is important to locate the front-end components close to the radiating elements. Therefore, it is necessary to shrink the RFFE footprint and integrate multiple functions, either monolithically on the die or within the package, using a multi-chip module. Tiling all these functions in a small area requires either very small PAs, requiring a many-fold increase in array size, or using high-power density technologies like GaN. Further, it is critical to use a semiconductor technology that can withstand high junction temperatures. The reliability of SiGe degrades rapidly above 150°C, but GaN on SiC is rated to 225°C. This 75°C advantage in junction temperature has a large impact on the thermal design, especially for outdoor, passively-cooled phased arrays.

ALL-DIGITAL VS. HYBRID ARRAYS

It was natural for BTS vendors to first explore extending the current, sub-6 GHz, all-digital beamforming, massive MIMO platforms to mmWave. This preserves the basic architecture and the advanced signal processing algorithms for beamformed spatial multiplexing. However, due to the dramatic increase in channel bandwidths offered by mmWave and the need for many active channels, there is a valid concern that the power dissipation and cost of such a system would be prohibitive. Therefore, vendors are exploring hybrid beamformed architectures,[5] which allows flexibility between the number of baseband channels and the number of active RF channels. This approach better balances analog beamforming gain and baseband processing. The following sections analyze the two architectures and discuss the RFFE approaches needed for each.

Digital Beamforming

Assuming large elevation scanning is not required for suburban FWA and a well-designed, column antenna provides gain of up to 14 dBi, we start with a mmWave BTS transceiver design targeting an EIRP of 65 dBm and compute the power consumption using off-the-

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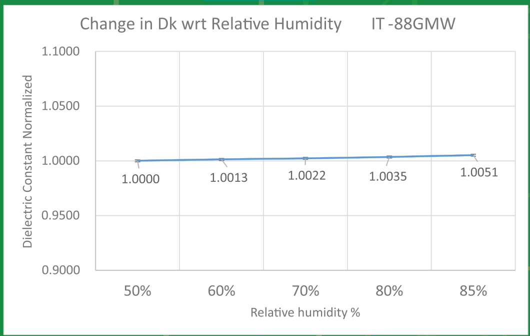

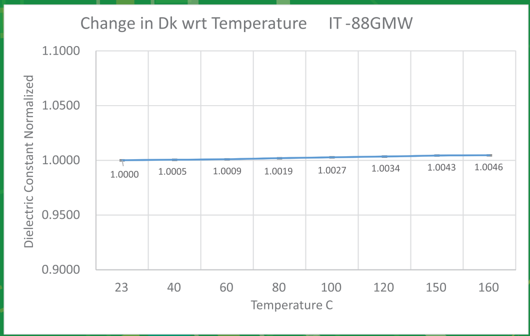

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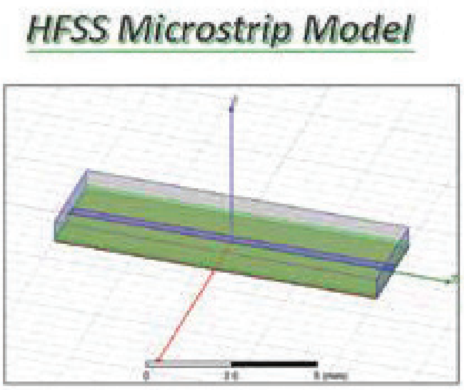

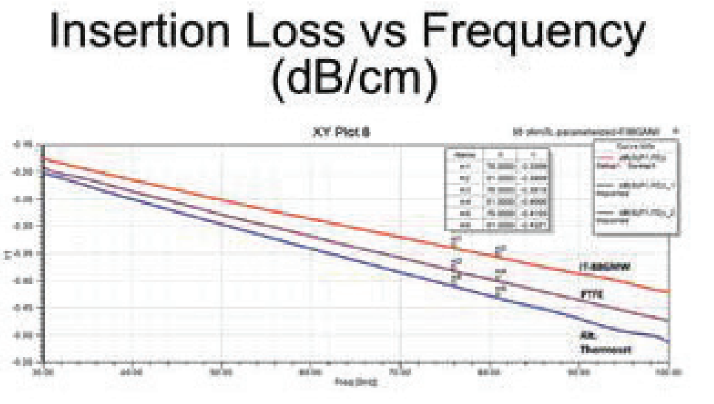

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LP18-26A	18 - 26	3.0	+9	+19
LP18-40A	18 - 40	4.0	+9	+19
LP1-40A	1 - 40	4.5	+9	+20
LP2-40A	2 - 40	4.5	+9	+20
LP26-40A	26 - 40	4.0	+9	+19

Notes: 1. Insertion Loss and VSWR (2 : 1) tested at -10 dBm.
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shelf point-to-point microwave radio components that have been available for years, including a high-power, 28 GHz GaN balanced amplifier. The multi-slat array and transceiver are shown in ***Figure 11***. Assuming circulator and feed-losses of 1.5 dB, the power at the antenna port is 27 dBm. From the following equations, achieving 65 dBm EIRP requires 16 transceivers that, combined, provide 12 dB of digital beamforming gain:

$$EIRP = G_{BF}(dB) + G_{ANT}(dBi) + P_{AVE\_TOTAL}(dBm)$$

$$EIRP = 10\log 10(N_{COLUMNS}) + 10\log 10(N_{PAs}) + G_{ANT} + P_{AVE/CHANNEL}(dBm)$$

The power consumption for each transceiver is shown in ***Figure 12***. The total power dissipation (P_{DISS}) at 80 percent transmit duty cycle for all 16 slats will be 220 W per polarization, and a dual-polarized system will require 440 W. For all outdoor tower-top electronics, where passive cooling is required, it is challenging to thermally manage more than 300 W from the RF subsystem, suggesting an all-digital beamforming architecture using today's off-the-shelf components is impractical.

However, new GaN FEMs are on the horizon to help address this. As shown in ***Figure 13***, the GaN PAs integrated in the FEM apply the tried-and-true Doherty efficiency-boosting technique to mmWave. With Doherty PAs, digital pre-distortion (DPD) is needed; however, the adjacent channel power ratio (ACPR) requirements defined for mmWave bands are significantly more relaxed, enabling a much "lighter" DPD solution. The estimated power dissipation of a 40 dBm P_{SAT}, symmetric, multi-stage Doherty PA can be reduced more than 50 percent. In the above system, this improvement alone drops the total P_{DISS} below 300 W. Combined with power savings from next-generation RF-sampling digital-to-analog and analog-to-digital converters, advancement in mmWave CMOS transceivers and increased levels of small-signal inte-

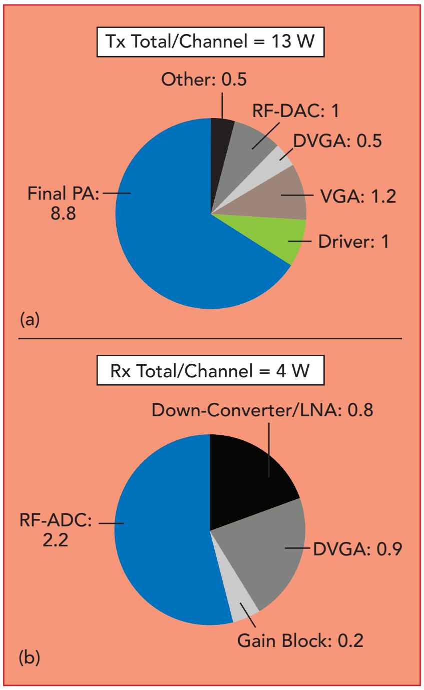

Fig. 12 Power dissipation of the transmit (a) and receive (b) chains.

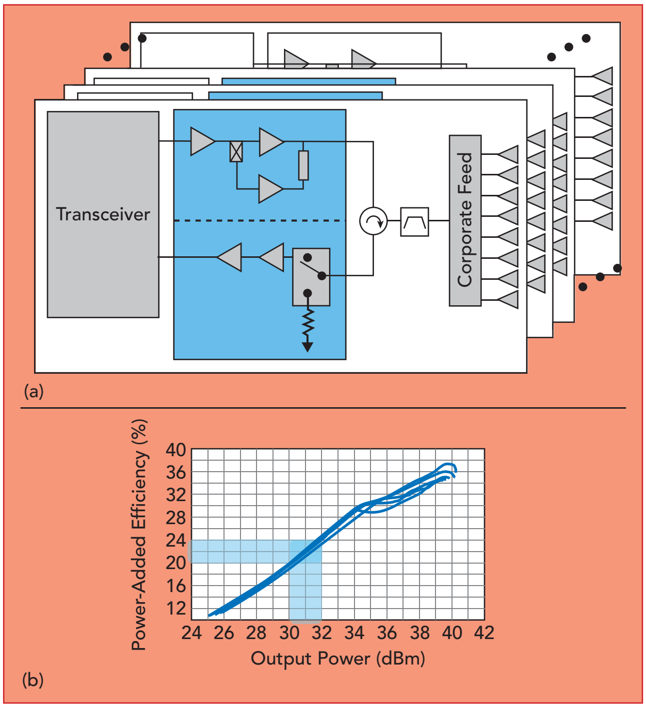

Fig. 13 Integrated FEM with symmetric GaN Doherty PA and switch-LNA (a) and PA performance from 27.5 to 29.5 GHz (b).

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gration, it will not be long before we see more all-digital beamforming solutions being deployed.

Hybrid Beamforming

The basic block diagram for a hybrid beamforming active array is shown in ***Figure 14***. Here, N baseband channels are driving RF analog beamformers, which divide the signal M-ways and provide discrete phase and amplitude control. FEMs drive each M-element subarray panel. The number of baseband paths and subarray panels is determined by the minimum number of spatial streams or beams that are needed. The number of beamformer branches and elements in each subarray panel is a function of the targeted EIRP and G/NF. While a popular design ratio is to have one baseband path for every 16 to 64 active elements, it really depends on the deployment scenario. For example, with a hot-spot small cell (or on the CPE terminal side), a 1:16 ratio single panel is appropriate. A macro BTS would have two to four subarray panels with 64 active elements, where each panel is dual-polarized, totaling four to eight baseband paths and 256 to 512 active elements. The digital and analog beamforming work together, to maximize coverage or independently, to provide spatially separated beams to multiple users.

There is an important trade unfolding, whether SiGe front-ends can provide sufficient output power and efficiency to avoid the need for higher performance III-V technology like GaAs or GaN. With good packaging and integration, both approaches can meet the tight antenna lattice-spacing requirements.

FRONT-END SEMICONDUCTOR CHOICES

The technology choice for the RFFE depends on the EIRP and G/NF requirements of the system. Both are a function of beamforming gain, which is a function of the array size. To illustrate this, ***Figure 15*** shows the average PA power (P_{AVE}) per channel needed as a function of array size and antenna gain for a uniform rectangular array delivering 65 dBm EIRP. The graph is overlaid with an indication of the power ranges best suited for each semiconductor technology. The limits were set based on benchmarks of each technology, avoiding exotic power-combining or methods that degrade component reliability or efficiency. As array size gets large (more than 512 active elements), the power per element becomes small enough to allow SiGe, which can be integrated into the core beamformer RFIC. In contrast, by using GaN for the front-end, the same EIRP can be achieved with 8 to 16x fewer channels.

System Power Dissipation

For an array delivering 64 dBm EIRP, ***Figure 16*** shows an analysis of the total P_{DISS} of the beamformer plus the front-end as a function of the number of active elements in each subarray panel. The P_{DISS} is shown for several error vector magnitude (EVM) levels, since the EVM determines the power back-off and efficiency achieved by the front-end. We assume each beamformer branch consumes 190 mW, which is the typical power consumption of core beamformers in the market.[6] The system on the far right of the figure represents an all-SiGe solution with 512 elements, with an output power per element of 2 dBm and consuming approximately 100 W. Moving left, the number of elements decreases, the P_{AVE} per channel increases and P_{DISS} is optimized to a point where beamforming gain starts to roll off sharply, and the P_{DISS} to maintain the EIRP rapidly increases. The small steps in the dissipation curves represent where the front-end transitions from a single stage to two-stage and three-stage designs to provide sufficient gain. As stages are added, the efficiency drops with the increase in power dissipation.

Designing to optimize system P_{DISS} without regarding complexity or cost, an array of about 128 elements with a two-stage, 14 dBm output PA (24 dBm P_{1dB}) is the best choice. However, if we strive to optimize cost, complexity and yield for a P_{DISS} budget of under 100 W, the optimum selection is the range of 48 to 64 active channels using a three-stage GaN PA with an average output power of 20 to 23 dBm, depending on the

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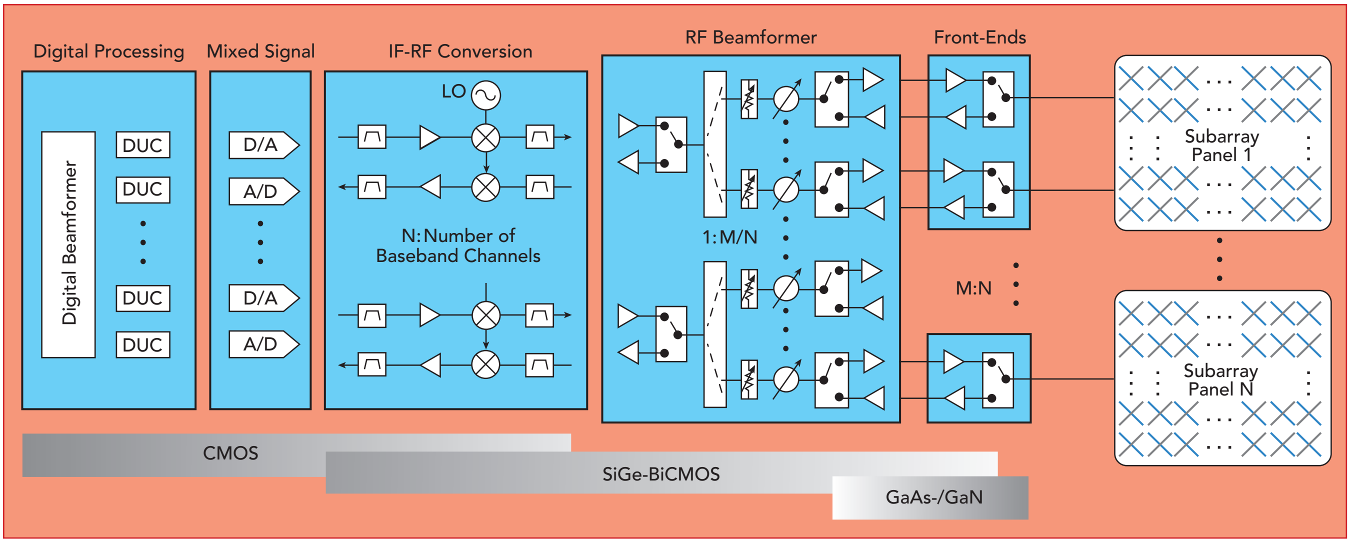

Fig. 14 Active array using hybrid beamforming.

EVM target. The trends shown in Figure 16 are less a function of PA efficiency and more a function of beamformer inefficiency. In other words, the choice to increase array size 8x to allow an all-SiGe solution comes with a penalty, given that the input signal is divided many more ways and requires linearly biased, power consuming devices to amplify the signal back up.

Cost Analysis

The cost of phased arrays include the RF components, printed circuit board material and the antennas themselves. Using compound semiconductor front-ends allows an immediate 8x reduction in array size with no increase in P_{DISS}. Even with lower-cost printed antenna technology, this is a large saving in expensive antenna-quality substrate material. Considering component cost, the current die cost per mm^2 of 150 nm GaN on SiC fabricated on 4-inch wafers is only 4.5x the cost of 8-inch 130 nm SiGe. As 6-inch GaN production lines shift into high volume, the cost of GaN relative to SiGe drops to 3x. A summary of the assumptions and a cost comparison of the relative raw die cost of the two technologies is shown in ***Table 3***. Using a high-power density compound semiconductor like GaN on 6-inch wafers can save up to 35 percent in the raw die cost relative to an all-SiGe architecture. Even though the cost of silicon technologies is lower per device, the cost of the complete system is significantly higher.

TABLE 3
RELATIVE COST OF ALL SiGe AND SiGe BEAMFORMER WITH GaN FEM

Parameter	Units	All SiGe	GaN +SiGe
Average Output Power per Channel	dBm	2	20
Power Dissipation per Channel	mW	190	1329
Antenna Element Gain	dBi	8	8
Number of Active Channels		512	64
EIRP	dBmi	64	64
Total Power Dissipation	W	97	97
Beamformer Die Area per Channel	mm^2	2.3	2.3
Front-End Die Area per Channel	mm^2	1.2	5.2
Total SiGe Die Area	mm^2	1752	144
Total GaN Die Area	mm2	0	334
	Die Cost	**Units**	**Notes**
All SiGe System Die Cost	1752	\$/x	
GaN + SiGe System Die Cost (4-inch GaN)	1647	\$/x	4-inch GaN = 4.5x
GaN + SiGe System Die Cost (6-inch GaN)	1146	\$/x	6-inch GaN = 3x

GaN FRONT-END MODULES

To validate the concept of a GaN FEM for mmWave FWA arrays, Qorvo set out to design the highest power, lowest NF FEM for the 37 to 40 GHz band. To support the trend to integrated transmit/receive arrays, the front-end includes a PA, integrated T/R switch and a low NF LNA. The module was designed with sufficient gain to be driven by core beamformer RFICs, which have a typical drive level of 2 dBm. The FEM's P_{AVE} of 23 dBm was selected from an analysis similar to that shown in Figure 16, and the P_{SAT} was determined by analyzing the needed headroom to support a back-off linearity of ≥ 33 dBc ACPR, EVM ≤ 4 percent and a 400 MHz orthogonal frequency-division multiple access (OFDMA) waveform.

A key design decision was determining if GaAs or GaN or a combination of both were needed. The

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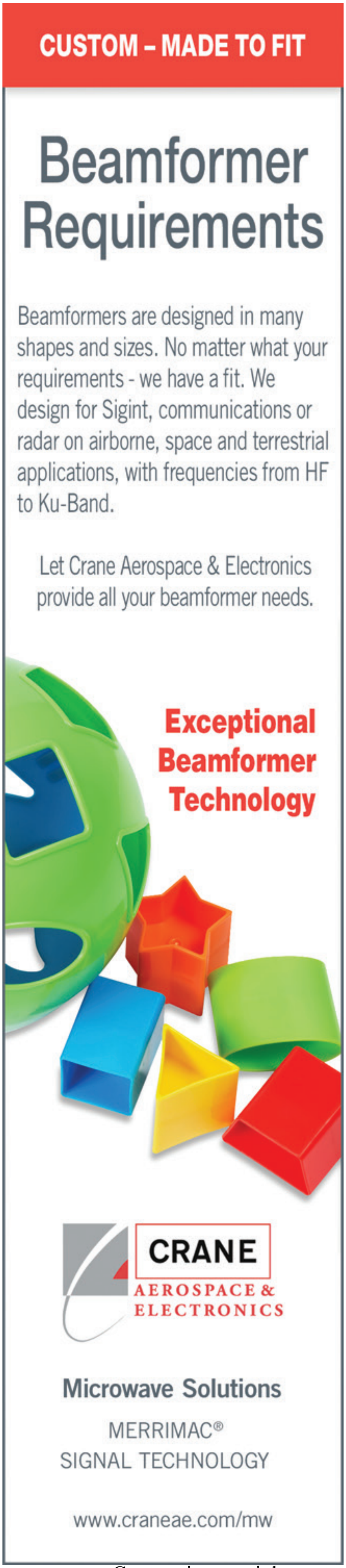

die size for a GaAs PA would not allow the FEM to meet the tight 3.75 mm lattice spacing at 39 GHz. The equivalent output power GaN PA is 4x smaller with no sacrifice in gain and a slight benefit in efficiency. Considering the LNA, the 90 nm GaAs PHEMT process was favored due to its slightly superior NF. However, the net improvement was only a few tenths of a dB once the additional bond wires and 50 Ω matching networks were considered. The trade-off analysis concluded it was better to stay with a monolithic GaN design that allowed co-matching of the PA, LNA and T/R switch. Such a design was lower risk, easier to assemble and test, and the MMIC was as compact as possible. The system thermal analysis indicated that the higher junction temperature offered by GaN-on-SiC was critical for passively-cooled arrays.

As shown in ***Figure 17***, the 39 GHz FEM integrates two of the multi-function GaN MMICs into an air-cavity, embedded heat-slug, surface-mount package, sized to meet the array element spacing at 39 GHz. Each of the GaN MMICs contains a three-stage linear PA, three-stage LNA and a low-loss, high-linearity SPDT switch. The FEM covers 37.1 to 40.5 GHz and provides 23 dBm average output power, which supports 256-QAM EVM levels, with 24 dB transmit gain. In receive mode, the NF is 4.1 dB, and receive gain is 16 dB. The package size is 4.5 mm × 6.0 mm × 1.8 mm.[7-8]

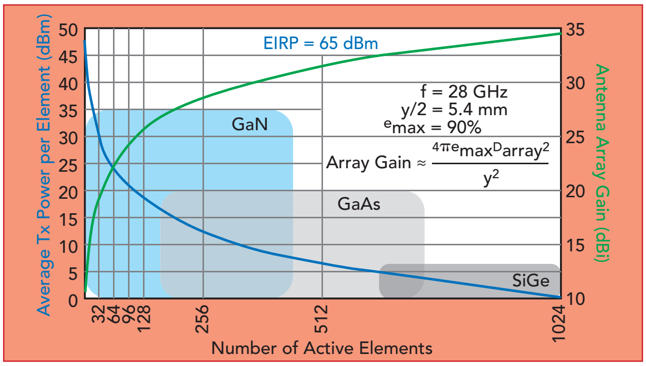

Fig. 15 Optimum RFFE technology vs. array size.

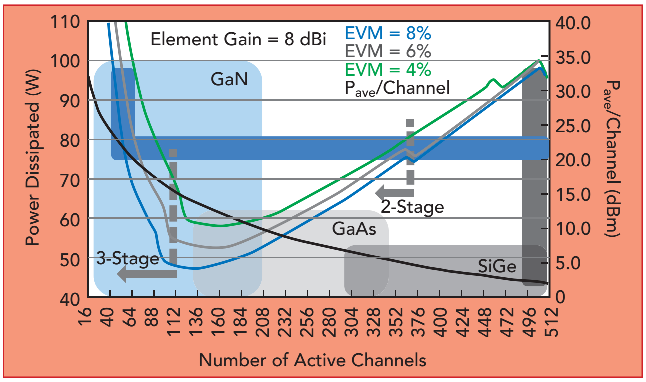

Fig. 16 System power dissipation vs. array size and EVM for 64 dBm EIRP.

SUMMARY

FWA is rapidly approaching commercialization. This is due to the abundance of low-cost spectrum, early regulatory and standards work and the opportunity for operators to quickly tap a new market. The remaining challenge is the availability of equipment capable of closing the link at a reasonable cost. Both hybrid beamforming and all-digital beamforming architectures are being explored. These architectures capitalize on the respective strengths of commercial semiconductor processes. The use of GaN front-ends in either approach provides operators and manufacturers a pathway to achieving high EIRP targets while minimizing cost, complexity, size and power dissipation. To prove the feasibility, Qorvo has developed a 39 GHz FEM based on a highly integrated GaN-on-SiC T/R MMIC and is developing similar FEMs for other millimeter wave frequency bands proposed for 5G systems.■

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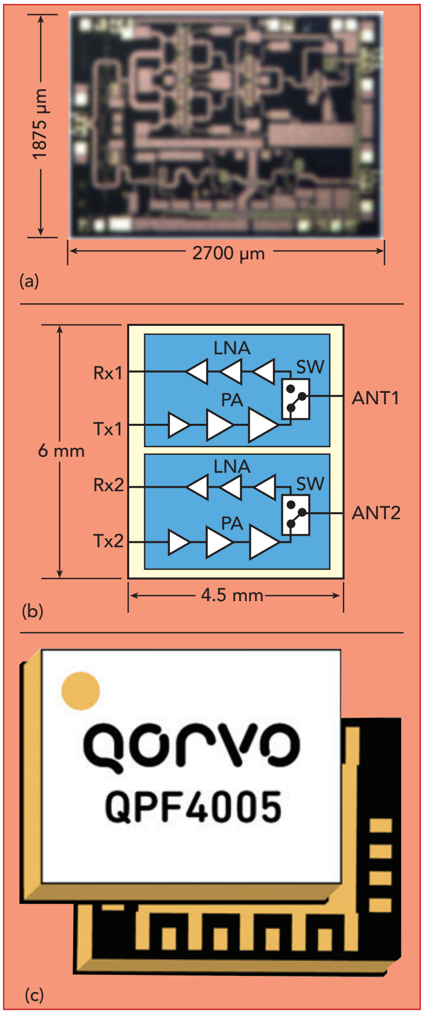
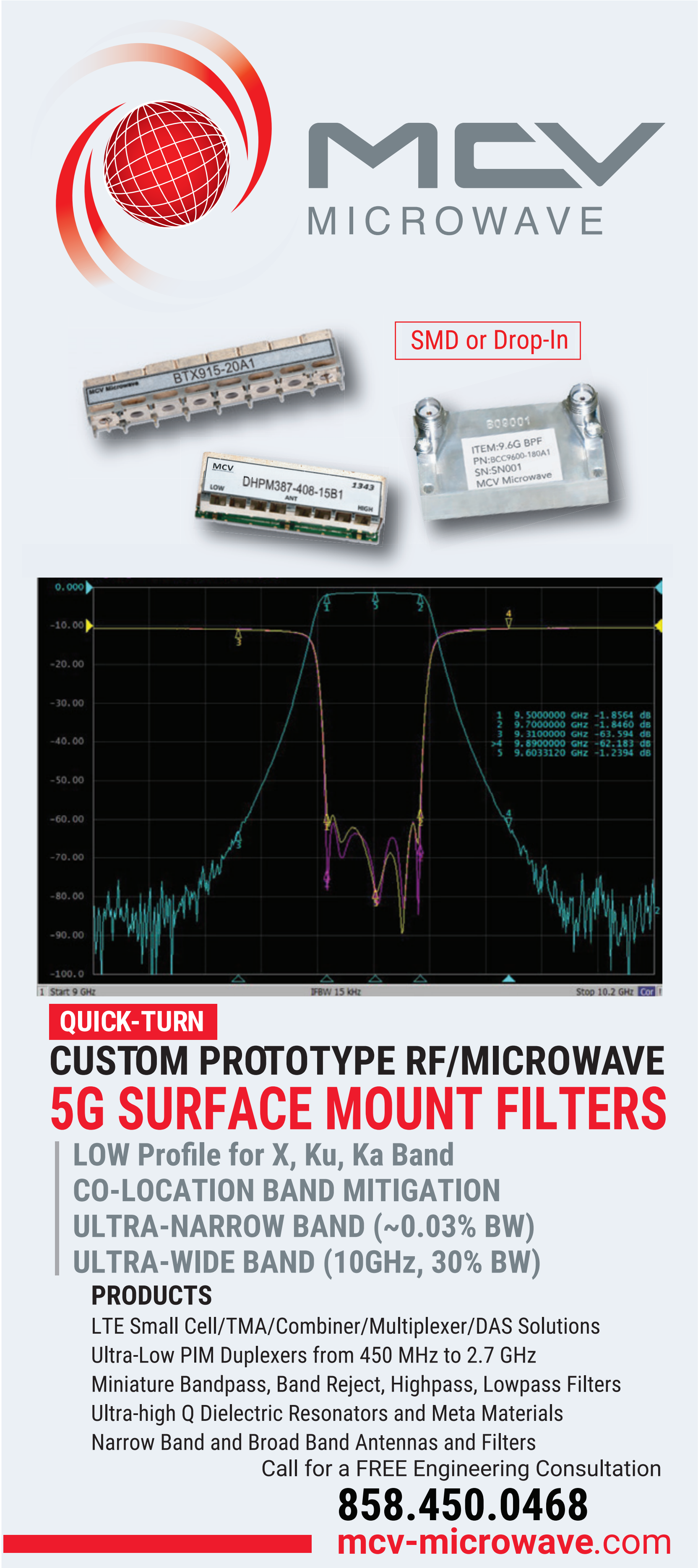


▲ Fig. 17 Integrated 39 GHz GaN front-end MMIC – intentionally blurred (a), dual-channel FEM (b) and package (c).



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Cover Feature
Invited Paper

All-Silicon Active Antennas for High Performance 5G/SATCOM Terminals

David W. Corman
Anokiwave Inc., San Diego, Calif.

Active mmWave antennas are expected to be rolled out in unprecedented volumes over the next few years, fueled by the rapidly emerging 5G telecommunications infrastructure and high throughput satellite (SATCOM) markets. mmWave spectrum is attractive for these new high-capacity systems due to the availability of large bands of contiguous spectrum.

Using active antennas allows highly-directive antenna beams to be formed by physically-small apertures, which helps offset the higher path loss associated with these high frequencies. The highly-directive beams allow spectral reuse through spatial diversity. These planar antennas offer fast, steerable beams; low size and weight; and can be cost-effectively produced in high volume. Active antennas also provide excellent reliability, since there are no moving parts, and the failure of a few elements in the array has little effect on the overall antenna performance.

This article will look at some of the key considerations for active antennas and address what is needed to make deployment successful. Two predominant architectural implementations will be compared, and analog, digital and hybrid beamforming will be discussed relative to the two implementations.

ACTIVE ANTENNA CONSIDERATIONS

As with any technology, there are considerations to effectively deploy active antennas, particularly at mmWave (see ***Figure 1***). The primary considerations are mass producibility at the lowest possible recurring cost, thermal management, technical performance—such as effective isotropic radiated power (EIRP) for the transmitter and the ratio of receive antenna gain to system noise temperature (G/T) for the receiver—and elimination of array calibration. Secondary considerations include beam scan volume, beam steering update rate and regulatory compliance (i.e., 3GPP, FCC, ETSI).

Mass producibility and elimination of array calibration affect cost, as do EIRP and G/T. If the arrays are not architected efficiently, then they must be oversized to compensate, adding hardware cost. Beam update rate and scan volume are important for waveform timing, tracking moving targets and providing maximum spatial coverage. Thermal management is critical for reliable operation of the array. Finally, compliance to regulatory requirements, such as FCC and ETSI spectral masks and off-axis emissions, are required for authorized deployment. Another key consideration is the manufacturing process. Planar construction enables low-cost, surface-mount assembly methods and mass producibility. Simple scaling the size of the antenna printed circuit board (PCB) and number of antenna elements

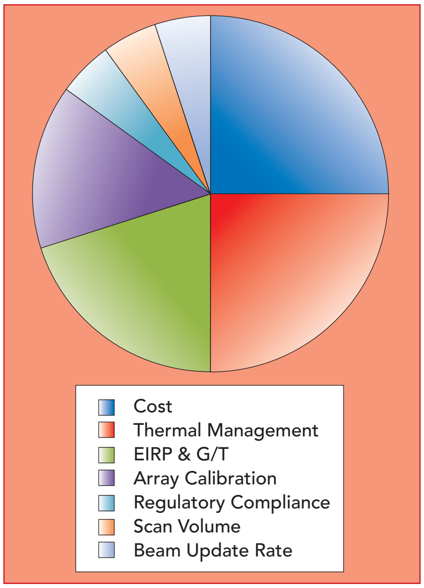

Fig. 1 **Trade-off criteria for active antennas.**

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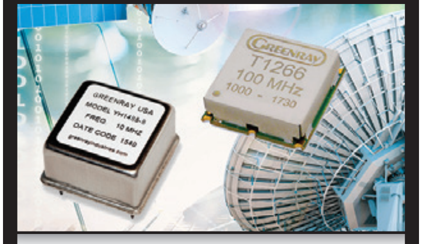

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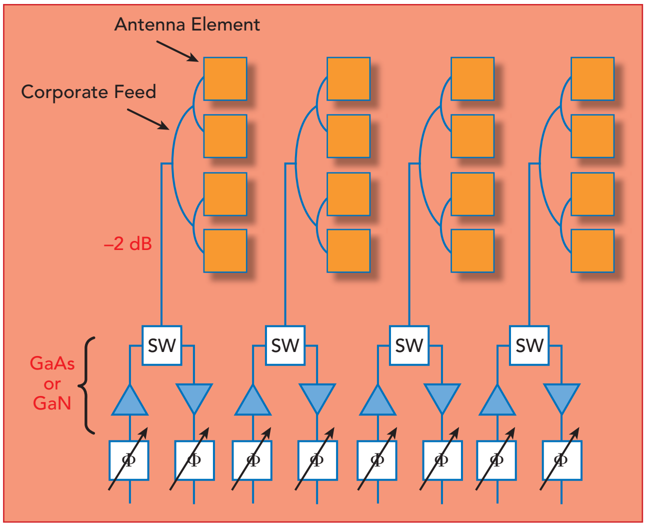
Two main planar architectures predominate for emerging mmWave active antennas. The following sections describe the two, drawing conclusions about their relative strengths and weaknesses.



▲ **Fig. 2** **Column-fed array with RF front-end outside the antenna array.**

COLUMN-FED ARRAY

The first active antenna architecture can be called a column- or row-fed array (see ***Figure 2***). In this approach, control ICs are mounted outside the array and drive a single column, with a single gain/phase setting common to all elements in the column. A corporate feed structure is typically employed between the control ICs and the radiating elements. For simplicity, Figure 2 shows just four columns with four elements per column; however, any number of columns and elements per column can be used.

The control ICs may be transmit only, receive only or may support transmit/receive time-division duplexing with a SPDT switch, as indicated in Figure 2. A key advantage to this implementation is mounting the control ICs outside the array area, so the physical size and number of ICs is not critical. This enables high RF power technologies such as GaAs or GaN to drive the column; the result is very high RF power per element, enabling high transmit EIRP from a relatively small array. By simultaneously driving the columns from both top and bottom, the array can be dual polarized. With this approach, the corporate feeds driven from one side of the array energize vertical feeds to the elements, while the corporate feeds from the other side energize the horizontal feeds.

The main advantages of this architecture are

- high RF power per element
- only N control IC RF chains are required per N columns
- the ICs are not constrained to fit within the lattice of the array, since they are outside the array area.

This last advantage is critical to GaAs or GaN solutions, as both semiconductor technologies lack the level of functional integration required to fit all of the control electronics within the typical λ/2 lattice of the array at mmWave.

The first and most obvious challenge for this architecture is that the control ICs are off the array; hence, feed lines must be used to route RF energy to and from the radiating elements. These lines add insertion loss at the worst possible location in any radio, i.e., at the front-end. Adding the ohmic loss of the corporate feed network, the impact on EIRP efficiency and G/T (receive noise figure) efficiency is profound. This increases antenna cost, since the array must be oversized to compensate for the losses. In Figure 2, 2 dB feed loss is shown; however, the actual loss will depend on how the feed lines are implemented. ***Figure 3*** shows the effect of feed loss on transmitter EIRP. As feed loss increases, the array must be oversized to achieve the required EIRP. In this example of a 256-element array with +15 dBm transmit power per element, an imbedded element gain of +5 dBi and a feed loss of 2 dB, the array must be increased to 322 elements (a 26 percent increase) to maintain the

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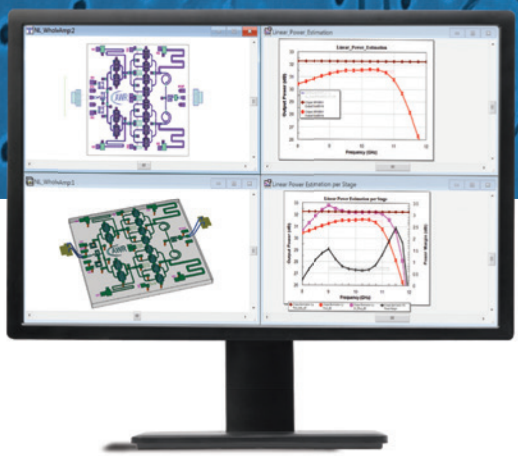

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targeted +68 dBmi EIRP. EIRP follows 20log(N), where N is the number of elements in the array, so EIRP can be recovered quickly by adding a few more elements.

However, the effect of feed loss is more significant for a receiver (see ***Figure 4***). As feed loss increases, the array must be significantly oversized to achieve the required G/T. In this example of a 1024-element array with a 4 dB receiver noise figure, an imbedded element gain of +5 dBi and a feed loss of 2 dB, the array must be increased to 2019 elements (a 97 percent increase) to maintain the targeted G/T of +8.7 dB/K. The reason feed loss hurts the receiver much more than the transmitter is twofold: receiver G/T follows 10log(N), where N is the number of elements in the array, so it takes more elements to recover front-end loss. Secondly, depending on the values of feed loss and receiver noise figure, the feed loss can affect G/T by more than 1 dB/dB as indicated in ***Figure 5***. For practical values of mmWave receiver noise figure (3 to 5 dB), G/T varies with feed loss by 1.5 to 2 dB/dB, meaning that a 1 dB feed loss degrades G/T by 1.5 to 2 dB. While GaAs- and GaN-based, column-fed, planar arrays offer high EIRP, their receive performance suffers significantly.

Another challenge with the column-fed architecture is that it only supports one-dimensional beam steering, i.e., azimuth (AZ) scanning only for the example in Figure 2. This lack of two-dimensional (2D) steering is probably acceptable for early, 5G, fixed wireless access applications; however, it is not suitable for applications such as low and medium orbit satellite (LEO/MEO SATCOM), mobile SATCOM and dense urban small cells for 5G, where 2D scan capability will be required.

Another challenge using GaAs or GaN control ICs is their inability

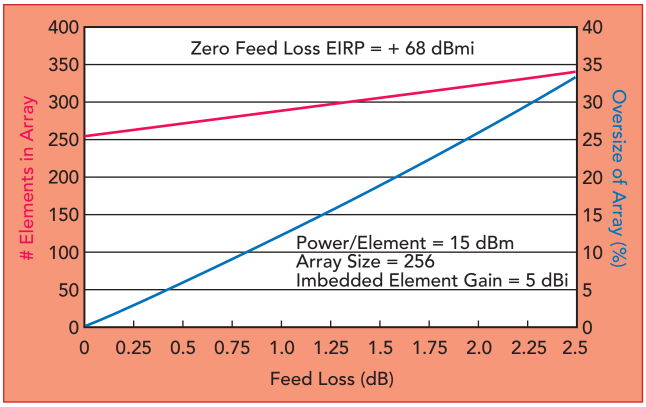

Fig. 3 To overcome feed loss, the size of the array must be increased to achieve the required EIRP.

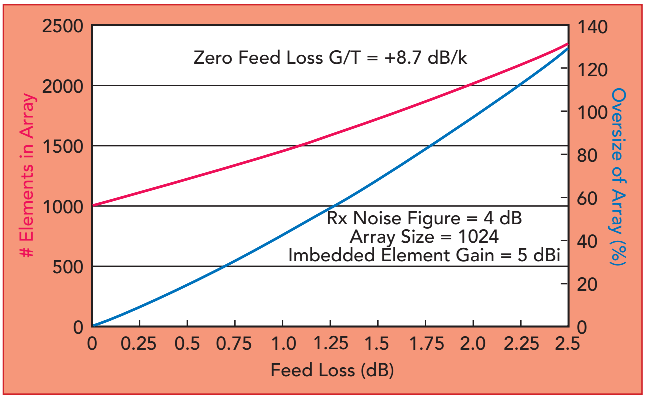

Fig. 4 To overcome feed loss, the size of the array must be increased to achieve the required G/T.

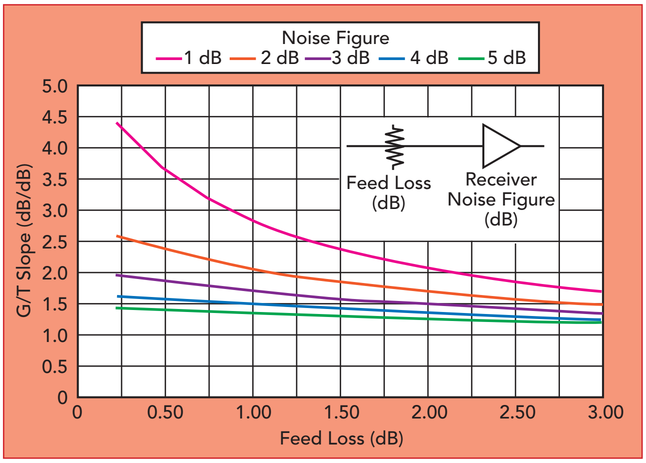

Fig. 5 Slope of G/T vs. feed loss and noise figure.

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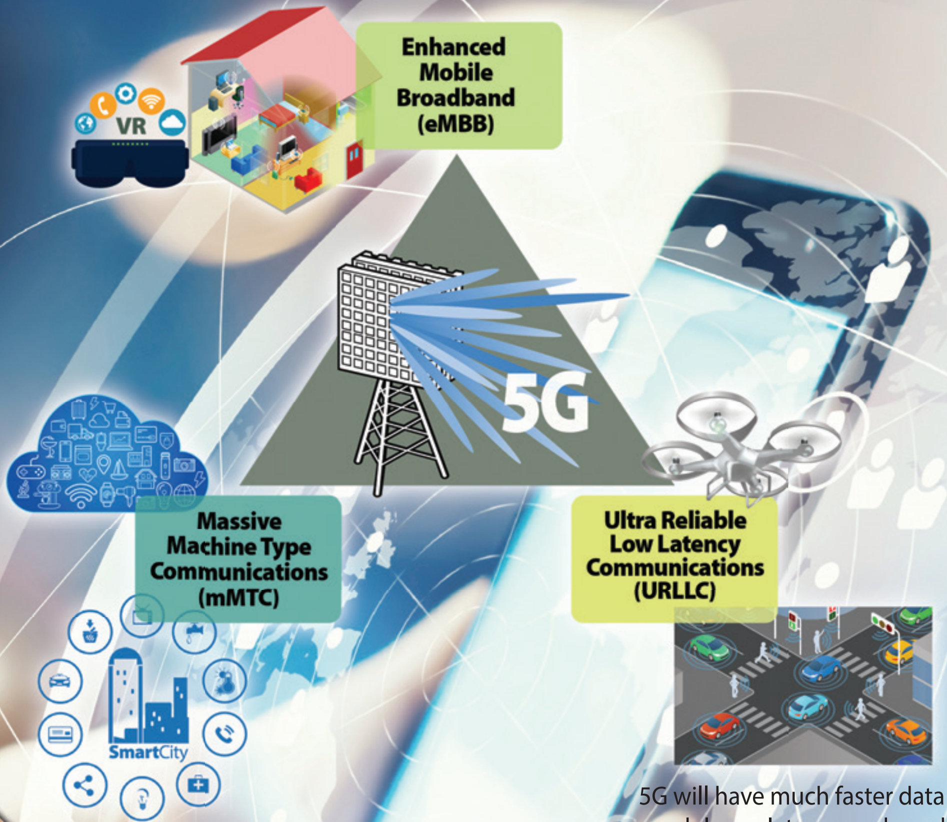

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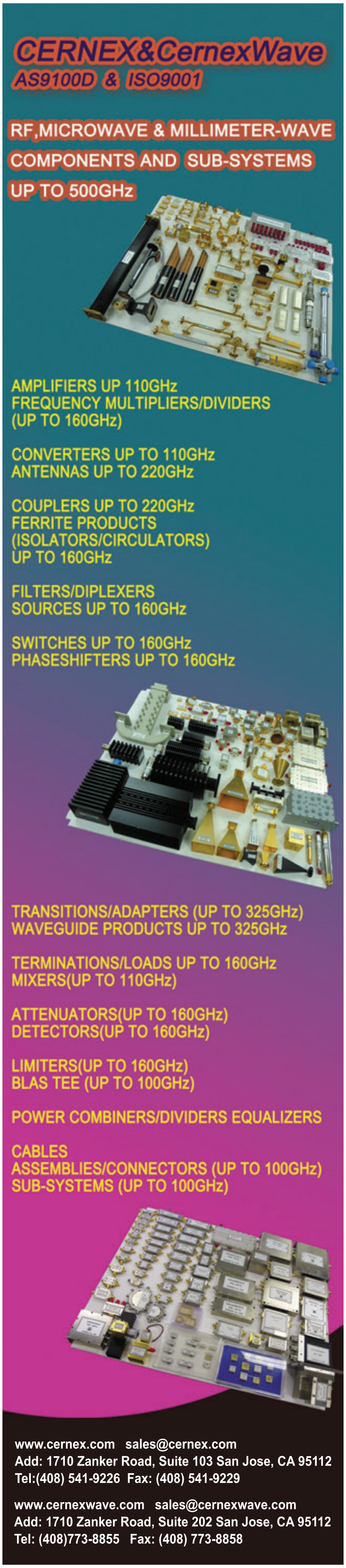

to self-compensate for the amplitude and phase variations in the ICs. Lacking the ability to correct for part-to-part variations, which can exceed ±2 dB in $|S_{21}|$ and ±100 degrees in $\angle S_{21}$, forces array calibration, which adds significant cost to the active antenna system.

There is also a concern that relying on 6-inch GaAs and GaN technologies, only available from a small group of global suppliers, limits how cost-effective these solutions can be in volume production. The ability to achieve low cost is limited by the need for precision lithography for millimeter wave frequencies, such as e-beam gate definition. Finally, using depletion-mode semiconductor technologies such as GaAs or GaN requires dual-supply voltages, positive and negative, which adds system cost. To protect these devices during turn-on and turn-off, DC sequencers are needed to prevent applying a positive voltage without the negative voltage, which increases system complexity and cost.

ALL-SILICON ARRAY

The second active antenna architecture is an all-silicon array, where the beam steering control ICs reside within the lattice (see ***Figure 6***). The beam steering control ICs contain the transmit output, receive input, gain control and phase control electronics, integrated on a single silicon die. The die may be transmit only, receive only or half duplex transmit/receive. Locating the die within the lattice of the array yields low feed loss between the die and the radiating element. With this planar construction, the control ICs are mounted on one side of a multilayer PCB, and the radiating elements are on the opposite side of the board. As shown in Figure 6, each control IC drives four radiating elements.

Advantages of this architecture include the lowest possible feed loss, which maximizes transmit EIRP and receive G/T efficiency. Since the individual radiating elements have unique amplitude and phase settings, this approach provides for full 2D scan, required for LEO/MEO SATCOM, mobile SATCOM and high density, urban applications. Another advantage of this architecture is using only high-yield

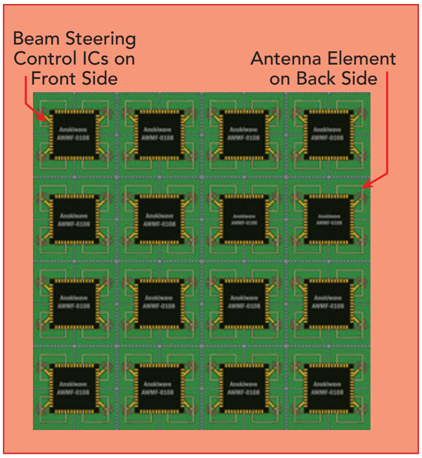

Fig. 6 **All-silicon architecture enables the RF front-end to be imbedded within the lattice of the array, i.e., on the backside of the antennas.**

silicon processes, the lowest cost processes in the industry, widely available from mainstream global suppliers. A typical silicon wafer size is 12 inches, which offers four times the wafer area compared to 6-inch GaAs and GaN. The high levels of integration available with silicon allow system on a chip (SoC) capability, where features can be imbedded to eliminate the need for array calibration. These are essential to meet the aggressive cost targets required by mass markets, such as mmWave SATCOM and 5G active antennas. Additional advantages of this architecture are

- silicon ICs can provide telemetry to the host system, which is useful for health and status reporting and scheduling preventative maintenance
- only a single power supply voltage is needed
- no DC sequencers are required, simplifying system cost and complexity.

Challenges with the all-silicon architecture are

- the number of ICs required per array is N/4, where N is the number of radiating elements in the array and each control IC drives four antenna elements
- transmit power per element is typically limited to +20 dBm, much lower than what is achievable with GaAs or GaN processes.

However, the need for more ICs with this architecture is more than offset by using the lowest cost

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	K/Ka-Band Active Antennas	AWMF-0129 AWA-0134 AWA-0142	Planar Active Antenna	28 GHz 64 Element Innovator Kit 28 GHz 256 Element Innovator Kit 26 GHz 256 Element Innovator Kit
mmW Communications and Sensing Applications	Ku/Ka-Band Si Core ICs	AWMF-0117 AWMF-0116	Wafer-Level Chip Scale	Ku-Band Multi-Function Core IC Ka-Band Multi-Function Core IC
RADAR and Communications Active Antennas	X-Band Silicon Core IC Solutions	AWS-0101 AWS-0103 AWS-0104 AWS-0105 AWMF-0106	QFN Plastic	Dual Beam Low NF Quad Core IC Dual Beam High IIP3 Quad Core IC Single Beam Low NF Quad Core IC Single Beam High IIP3 Quad Core IC Medium Power Front End ASIC
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semiconductor processes. The lower transmit power per element can also be compensated for by enlarging the array, taking advantage of the 20log(N) EIRP characteristic of transmit active antennas. Enlarging the transmit array is not necessarily "bad," since a larger array allows lower transmit power per element, which spreads the heat over a larger area and helps the thermal design. By enlarging the array and using aperture gain to develop EIRP, rather than the RF power per element, reduces the overall DC power consumption of the array.

Fig. 7 Anokiwave 256-element, all-silicon array.

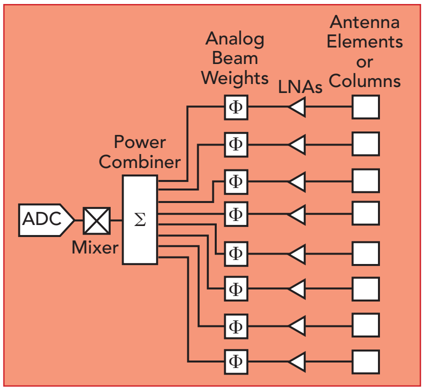

Fig. 8 Analog beamforming.

Measured data on Anokiwave's 256-element, all-silicon array (see ***Figure 7***) validates the performance of the all-silicon array architecture. At 28 GHz, the array provides a G/T of -1.1 dB/K in receive and an EIRP of +59.7 dBmi in transmit. Comparing the measured results with theoretical calculations, the transmit EIRP is calculated from

$$EIRP = 20\log(N) + Ge + Power_{element} - Losses$$

where N is the number of elements in the array, Ge is the imbedded element gain (+5 dBi for a λ/2 lattice), $Power_{element}$ is +8.5 dBm and losses total 1.5 dB for the combined feed loss, element ohmic loss and radome loss. The calculated EIRP is

$$EIRP = 20\log(256) + 5 + 8.5 - 1.5 = 60.2\ dBmi$$

which is within 0.5 dB of the measurement. Similarly, the receive G/T is calculated from

$$\frac{G}{T} = 10\log\left(\frac{Ge}{To(LF-1)}\right) + 10\log(N) \quad (1)$$

where N and Ge are the same as for the transmit array, To is the 290°K reference temperature, L is the sum of the front-end losses (1.5 dB total or 1.41) and F is the noise factor of the receiver. Using 256 elements, +5 dBi imbedded element gain (3.14), 1.5 dB in losses and 5 dB NF (F = 3.16),

$$\frac{G}{T} = 10\log\left(\frac{3.14}{290(1.41\times 3.16-1)}\right) + 10\log(256) = -1\ dB/k \quad (2)$$

which closely agrees with the measured results for the array.

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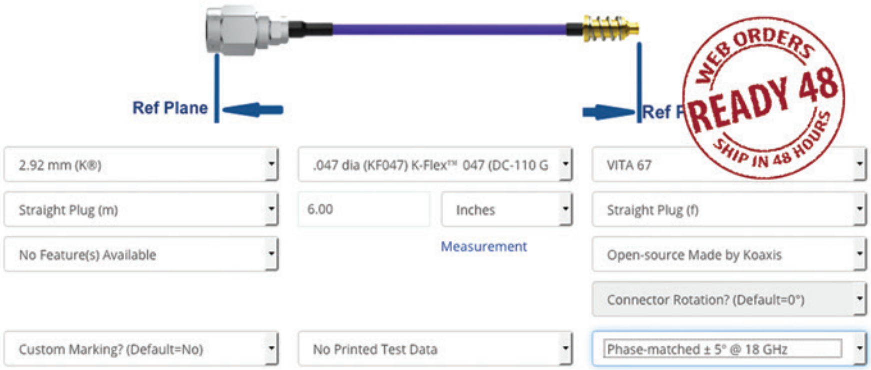

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BEAMFORMING

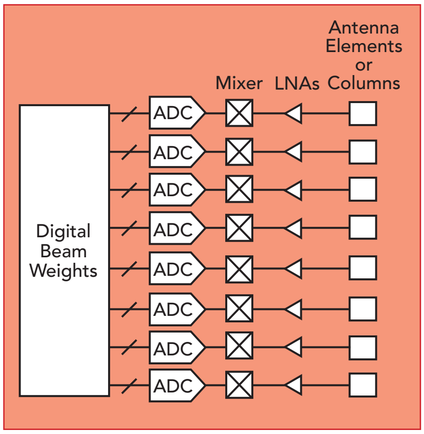
Three general beamforming architectures are used in active antennas: analog, digital and hybrid beamforming. This section describes each approach at a high level, compares their pros and cons and discusses how the column-fed and all-silicon architectures are impacted. While the following block diagrams denote receivers, transmitter block diagrams look similar, just reversed in direction and using digital-to-analog converters (DAC) instead of analog-to-digital converters (ADC).

TABLE 1 ANALOG BEAMFORMING

Advantages	*Disadvantages*
Simplest hardware implementation	Number of beams fixed in hardware
Hardware can fit within the lattice at high frequencies (all-silicon array only)	
Beam benefits from the full array gain	
Lowest system DC power	

Analog beamforming (see ***Figure 8***) uses an analog beam weight at each element in the array with the all-silicon architecture or at each column in the array with the column-fed architecture. After the analog beam weights are applied, a coherent power summation forms the beam, followed by a suitable frequency down-converter and ADC to complete the receive antenna system. ***Table 1*** summarizes the advantages and disadvantages.

With digital beamforming (see ***Figure 9***), the beams are formed using complex digital weights rather than analog weights. To do this, a full receiver chain from antenna element to digits is required at every element in the array with the all-silicon architecture or at every column in the array with the column-fed architecture. For full 2D scanning in planar arrays, this is only practical at low frequencies, such as S-Band, where the lattices are large, with room to place the required hardware within the array. This approach is not practical for 2D scanning at mmWave frequencies, since inadequate real estate exists with the tight lattices. Since the column-fed architecture is limited to 1D scanning, it can implement digital beamforming because the electron-



▲ Fig. 9 Digital beamforming.

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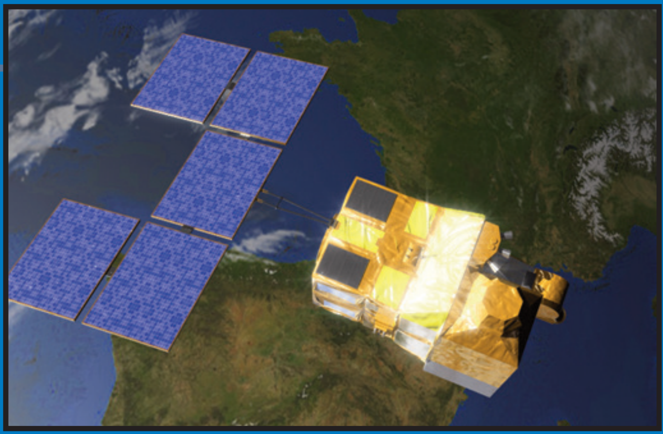

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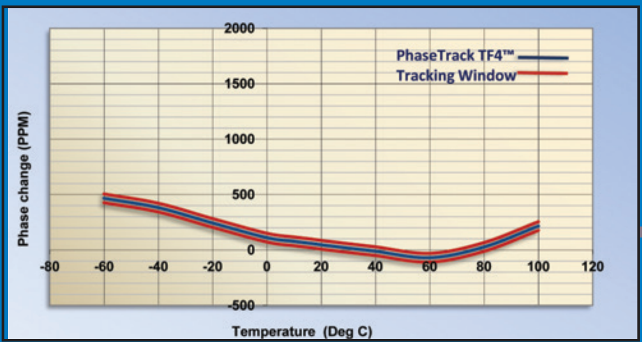

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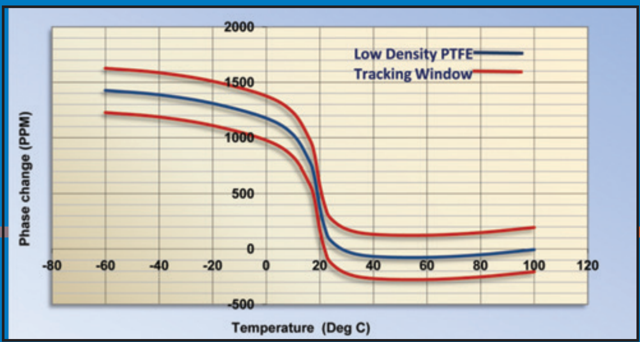

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TABLE 2 DIGITAL BEAMFORMING

Advantages	*Disadvantages*
Extreme flexibility with number of beams and nulls	Highest DC power
Can provide high number of beams	I/Q signal routing complexity
Number of beams can be changed dynamically with no change in hardware	LO signal routing complexity
Each beam benefits from the full array gain	Highest hardware complexity: full RF chain per element or column in the array
	Hardware cannot fit within the lattice at high frequencies (no 2D scan capability for planar arrays)

ics resides outside the array. Additionally, since a full receiver is only required at every column, rather than at every element, DC power consumption is reduced.

Other significant challenges with digital beamforming include high DC power consumption, especially if large bandwidths are digitized; signal routing complexity, where multiple bits of I and Q data must be routed off the array to the digital processor; and local oscillator (LO) signal routing within the array. On the plus side, if these challenges can be addressed, then this architecture is the most flexible, since multiple beams and nulls can be formed dynamically with no change in hardware, and each beam benefits from the gain of the full array. The advantages and disadvantages are summarized in ***Table 2***.

Hybrid beamforming is a cross between analog and digital beamforming (see ***Figure 10***). An array with hybrid beamforming forms an analog beam from a portion of the full array (sub-array), with the resulting beams as illustrated in ***Figure 11***. The figure shows the wide beam of the imbedded element, the nar-

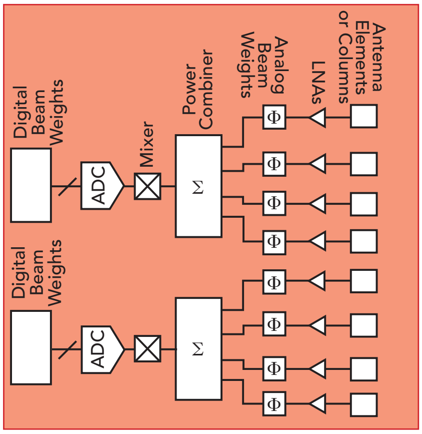

Fig. 10 Hybrid beamforming on the receive path.

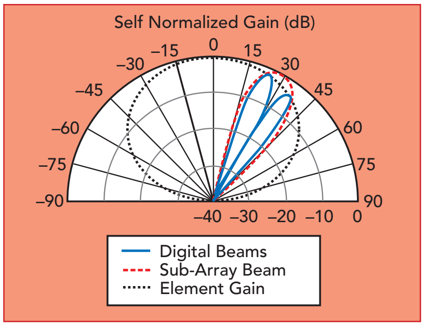

Fig. 11 Example beams with hybrid beamforming.

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TABLE 3 HYBRID BEAMFORMING	
Advantages	***Disadvantages***
Extreme flexibility with number of beams and nulls	Each beam only benefits from the gain of the sub array
Can provide high number of beams	
Number of beams can be changed dynamically with no change in hardware	
Hardware can fit within the lattice at high frequencies (all-silicon array only)	
No complex signal routing	
No LOs to distribute in the array	

rower beam formed by the analog sub-array and two digitally-formed beams. For simplicity, only two digital beams are shown, but many beams can be formed within the analog beam. Both the all-silicon and column-fed architectures can use hybrid beamforming. The beauty of hybrid beamforming is it

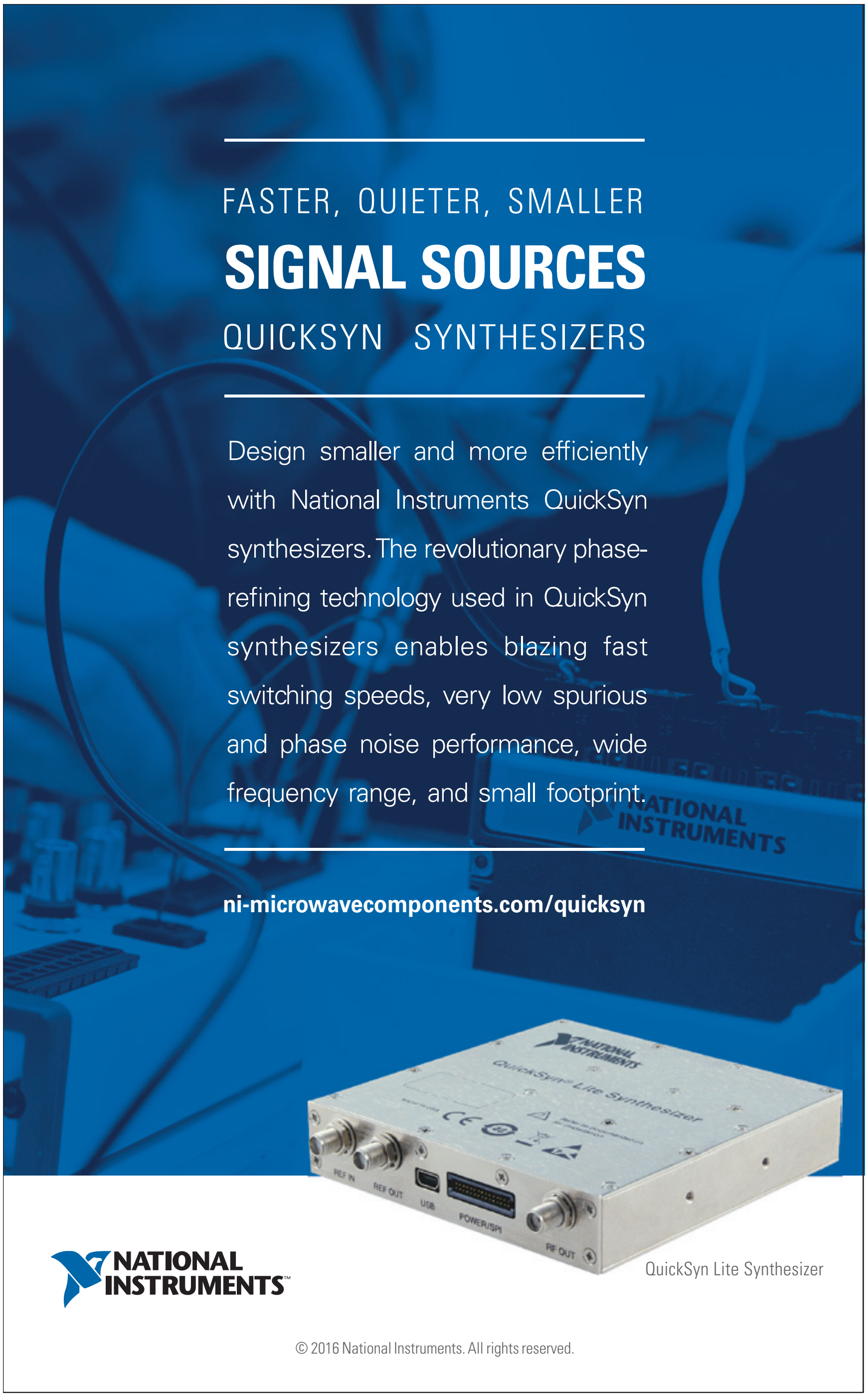
- can be used at mmWave frequencies
- provides the digital flexibility of being able to dynamically form many beams and nulls with no change in hardware
- does not require a full RF chain per element, only a full RF chain per sub-array.

The main downside is that no single beam benefits from the gain of the full array. However, with the many advantages that hybrid beamforming offers, it is no wonder that this is the most popular beamforming approach used in emerging 5G communications systems today. The advantages and disadvantages are summarized in ***Table 3***.

CONCLUSION

Active mmWave antennas for 5G and satellite communications will reach unprecedented production volumes over the next few years, and two predominant planar architectures have emerged. One is based on GaAs or GaN ICs located off the array and the other uses silicon ICs imbedded within the array. While the GaAs/GaN solution offers very high EIRP capability, the approach has significant limitations, including poor receiver performance from high feed loss and the inability to self-calibrate. The architecture is limited to 1D scanning, requires bias support circuitry such as DC sequencers and offers a challenging path to low production cost.

In contrast, all-silicon active antennas overcome these limitations. While limited in transmit power per element, the architecture offers a clear path to high volume manufacturability and ultra-low production cost, while meeting all key considerations for active mmWave antennas.■



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NOW HIRING

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Innovative Semiconductor Company Makes Big Push to Attract the Best and Brightest

An Interview with CEO Stefan Wolff by JT Konstanturos

Stefan Wolff is someone who tells it like it is. The pragmatic CEO of pSemi™, a company with 30 years of RFIC history and backed by electronics giant Murata, speaks with passion and a deep understanding of what is expected to attract top engineers in today's competitive marketplace. Wolff's direct, no-nonsense demeanor makes a strong case for anyone looking for a workplace that encourages people to reach their highest potential while working on products that will shape our connected world.

JTK: Thanks for taking the time to speak to me. Tell me about the new name, pSemi, and what the future holds.

SW: The pleasure is mine. I thrive on the exciting time this is for pSemi, and it is a privilege being its CEO. pSemi was formed to provide focus and resources to take semiconductors to the next level. Our new name is derived from Peregrine Semiconductor and reflects its proud 30-year RFIC history. Fast-forward to the present: We are a Murata company with the backing and integrity of that electronics giant. Murata has challenged us to broaden our scope, increase our IP and grow on a global scale to support inventions that are coming in our not-so-distant future.

JTK: What sets pSemi apart from other semiconductor companies, and what's different now?

SW: We are innovation junkies—pure and simple. With well over 500 issued and pending patents, our patent portfolio was named one of the technology world's most valuable portfolios by the *IEEE Spectrum* "Patent Power Scorecard" for the last two years. What that says is our patents are not only innovative but very useful to the industries we serve. So, what is different now? The industries we serve are growing. Smaller, faster, lighter is the mantra we hear all the time from inventor companies, and we are rising to meet that challenge through very novel and intelligent semiconductor integration and packaging.

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JTK: Sounds like quite a challenge. When will you reach your goal?

SW: The honest answer to that question is never. You can't stand still in this time of electronic revolution. You have to keep moving forward at all times to succeed. We have never shied away from the tough challenges, and now is not the time to start.

JTK: What does pSemi have to offer the best and brightest engineers?

SW: We are growing, and we are hiring. pSemi offers an engineering-driven environment with fascinating projects for challenging applications like 5G, IoT and battery management. Since our inception, we have invented breakthrough technologies for emerging markets, such as switches and antenna tuners for smartphones in the 2000s, and today, we are spearheading Murata's efforts in new semiconductor growth markets. The foundation of our whole-person support is a work-hard, play-hard philosophy. Yes, that means we have wellness programs, parties and special-recognition dinners, and yes, our headquarters are near beautiful beaches with the perfect San Diego lifestyle.

And yes, we do take full advantage of it all! Even beyond San Diego, pSemi has offices around the world—and plans to have offices—wherever there is a hub of semiconductor talent that supports our growing "dream team."

JTK: How do you plan to build your "dream team" of engineers?

SW: Well, we are already making it happen. With the right people, we will get there even faster. This year alone, we have acquired businesses and hired entire teams. Chip designers frequently do not leave a job they hate because they love their team. We say, "No problem. We will take the entire team too if they are the right fit." We are leaning on our "dream team" to design the products of the future. Think smartphones, small cells, portable computing, data centers, smart homes, electric vehicles and healthcare. It is an exciting time in our industry, and we are grateful to have the backing and support of Murata in this next chapter.

"We are growing, and we are hiring. pSemi offers an engineer-friendly environment with fascinating projects...and a work-hard, play-hard philosophy."

JTK: Any last words?

SW: Definitely! I do not pretend to know everything about our industry; no one does. I ask a lot of questions, and I really want to hear what our employees think. I do have a few expectations of our employees. First and foremost is respect. We expect it at all levels. Not far behind is integrity. That means we tell the truth. You can expect me to tell the truth, and I will expect the same. The truth has no politics and no taboo subjects. If it will make the company better, it should be talked about candidly. Third is quality and customer satisfaction. We strive for it in everything we do. Our customers expect it, our parent company is known for it, and it makes us proud of our efforts. Last, but not least, is teamwork. Without it, we can't do any of this. We are so fortunate that our parent company not only shares these values but has weaved them into every aspect of their business.

If you would like to join our team, I would like to hear from you. Please send your resume to Stefan@psemi.com. For more about pSemi and our innovative products, please go to psemi.com.

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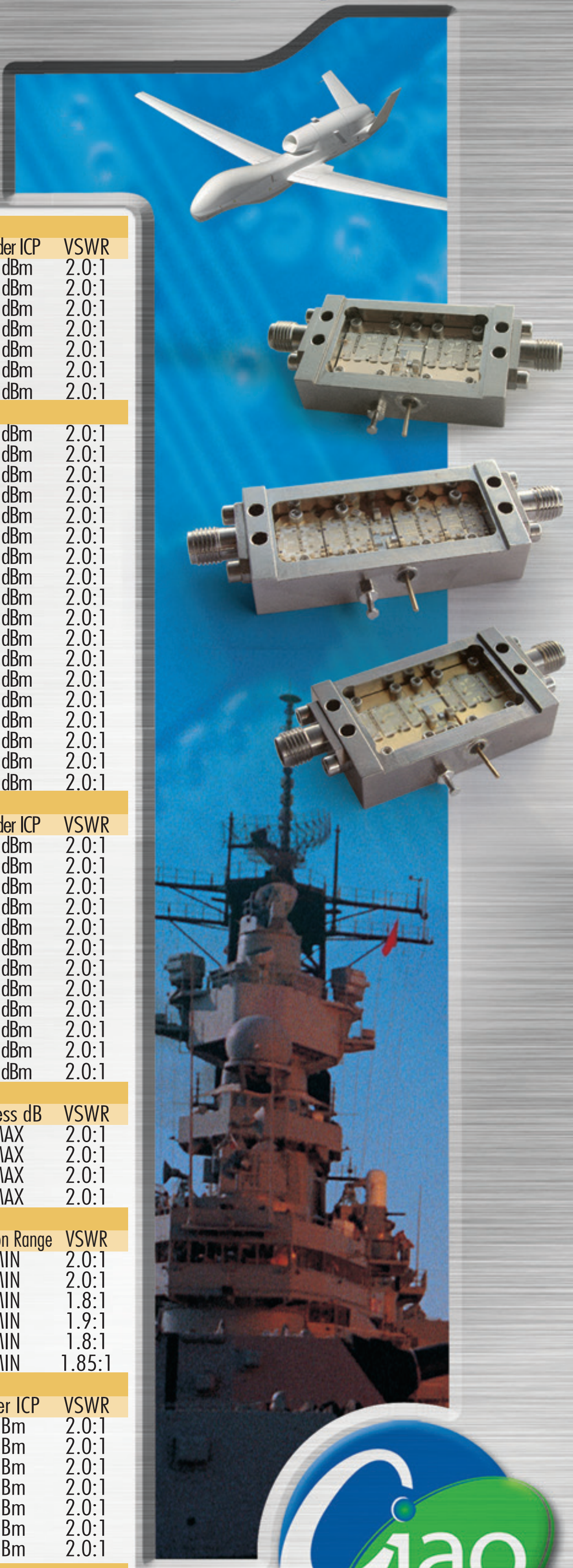

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Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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Detecting Danger at a Safe Distance

HRL Laboratories LLC has developed a high-resolution, low power radar antenna array—coded aperture subreflector array (CASA)—that potentially can see weapons or explosives concealed on a person at tactically safe distances. With a CASA scanner, someone concealing a suicide bomb could be detected while they were still far enough away to make a sudden detonation far less effective. The low power usage and scalability of the CASA array gives it versatility for many possible uses, from the aforementioned security scanners to being part of the eyes and ears of robots or autonomous vehicles.

One constraint in this type of coded aperture radar technology is that it tends to be more useful for shorter ranges, but that makes it ideal for such uses as security screening at safe distances, as current airport scanners require subjects to walk through the apparatus to be scanned. Radar can also see through smoke and dust, so CASA could be useful for seeing approaching people or vehicles in low visibility situations. It could also help helicopters navigate through dust, other atmospheric obscurants or darkness by imaging landing areas with high resolution.

The CASA was developed by HRL researchers under the Defense Advanced Research Project Agency (DARPA)'s program Advanced Scanning Technology for Imaging Radars (ASTIR).

"With this program, DARPA's goal was high-resolution radar imaging of the quality of a synthetic aperture radar, or SAR, but in a smaller, stationary system," said Jonathan Lynch, HRL's principal investigator on the project. "Normally SAR is on a moving platform, an aircraft for example, that flies over its target collecting desired radar images. These are very high-resolution images, such as very detailed 2D maps. The ASTIR program aimed at developing similar high frequency radar technology that does not require the moving platform to collect high-resolution 3D images."

The CASA radar array scans high-resolution 3D images with a digitally synthesized beam, which means the array itself does not need to be moving, but creates the images by digitally processing the data collected by the beam's reflection off targets. The team, from HRL's Microelectronics Laboratory, used a tiling approach to make the radar antenna array, with 1-inch-square RF tiles.

"The tiles make the array scalable to whatever size is needed for a particular task. You can add more tiles over a fairly large area and get thousands of pixels in your images. Also, we fabricated the tile arrays with wafer-scale integration that really keeps costs in line," Lynch said.

The CASA array operates at a very high frequency because the higher the frequency, the narrower the radar beam and the greater the image resolution. "With such high frequency, we fabricated a 1,024-element radar antenna array that is about an inch on a side. The little antenna elements are only 700 microns (one micron equaling one thousandth of a millimeter) apart, based on spacing them half a wavelength apart. That's how small the wavelength of the beam is," Lynch said.

HRL's world-leading capabilities in microelectronics made the CASA possible by combining coded aperture radar with GaN T4 monolithic microwave integrated circuits (MMIC) and 3D integration. "The heart of the technology is our GaN T4 MMIC," said HRL researcher Hasan Sharifi. "These circuits operate at very high frequency, 235 GHz, allowing us to pack many elements into a tiny area."

"On the hardware side, we are able to fabricate smaller, lower power circuits using 3D integration," said HRL researcher Florian Herrault. "With this technology we stack the circuits in three dimensions that in the past would be placed side-by-side, greatly reducing device size and increasing efficiency. The CASA devices operate on extremely low power, with each element dissipating about 20 microwatts."

ONR Announces Successful Final Helicopter Autonomous Flight Demo

Autonomy options for the Marine Corps have taken a major step forward, as the Office of Naval Research (ONR) officials recently announced a successful final helicopter flight demonstration with autonomous capability at Marine Corps Base Quantico, Virginia, part of the Autonomous Aerial Cargo/Utility System (AACUS) program.

AACUS is a partnership between ONR and technology company Aurora Flight Sciences, and will enable the Marine Corps to rapidly resupply forces on the front lines using cutting-edge technology sponsored by ONR.

The system consists of a sensor and software package that can be integrated into any manned or unmanned rotary-wing aircraft to detect and avoid obstacles (like telephone wires, other vehicles or large ground ob-

AACUS (Source: U.S. Navy)

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jects) in unfavorable weather conditions or to facilitate autonomous, unmanned flight. This capability will be a welcome alternative to dangerous convoys or manned aircraft missions in all types of weather.

"This is more than just an unmanned helicopter," said Dr. Walter Jones, ONR executive director. "AACUS is an autonomy kit that can be placed on any rotary-wing platform and provide it with an autonomous capability. Imagine a Marine Corps unit deployed in a remote location, in rough terrain, needing ammunition, water, batteries or even blood."

"With AACUS, an unmanned helicopter takes the supplies from the base, picks out the optimal route and best landing site closest to the warfighters, lands and returns to base once the resupply is complete—all with the single touch of a handheld tablet."

The need for this capability surfaced during Marine Corps operations in Afghanistan and Iraq, experts say. Cargo helicopters and resupply convoys of trucks bringing fuel, food, water, ammunition and medical supplies to the front lines frequently found themselves under fire from adversaries or the target of roadside bombs and other improvised explosive devices.

AACUS is designed for simple use; an operator with minimal training can call up the supplies needed and order the flights using only an intuitive handheld tablet. During the December 13 demonstration tests at Quantico, a Marine with no prior experience with the technology was given a handheld device and 15 minutes of training.

The Marine was able to quickly and easily program in the supplies needed and the destination, and the helicopters arrived quickly—even autonomously selecting an alternative landing site based on last-second no-fly-zone information added in from the Marine. The demonstration featured a UH-1 "Huey" flying autonomously on multiple missions.

"We've developed this great capability ahead of requirements and it's up to us to determine how to use it," said Lt. Gen. Robert Walsh, commanding general, Marine Corps Combat Development Command. "The young Marines today have grown up in a tech-savvy society, which is an advantage. We've got to keep pushing and moving this technology forward."

Officials say AACUS represents a leap-ahead technology for the Marine Corps and Navy, moving unmanned flights far beyond the current standard, which requires a specialized operator to select a landing site and manually control an unmanned aircraft via remote.

"AACUS gives revolutionary capability to our fleet and force," said Dennis Baker, AACUS program manager. "It can be used as a pilot aid to operate in GPS- and communications-denied arenas or allow fully autonomous flights in contested environments-keeping our pilots and crews out of harm's way."

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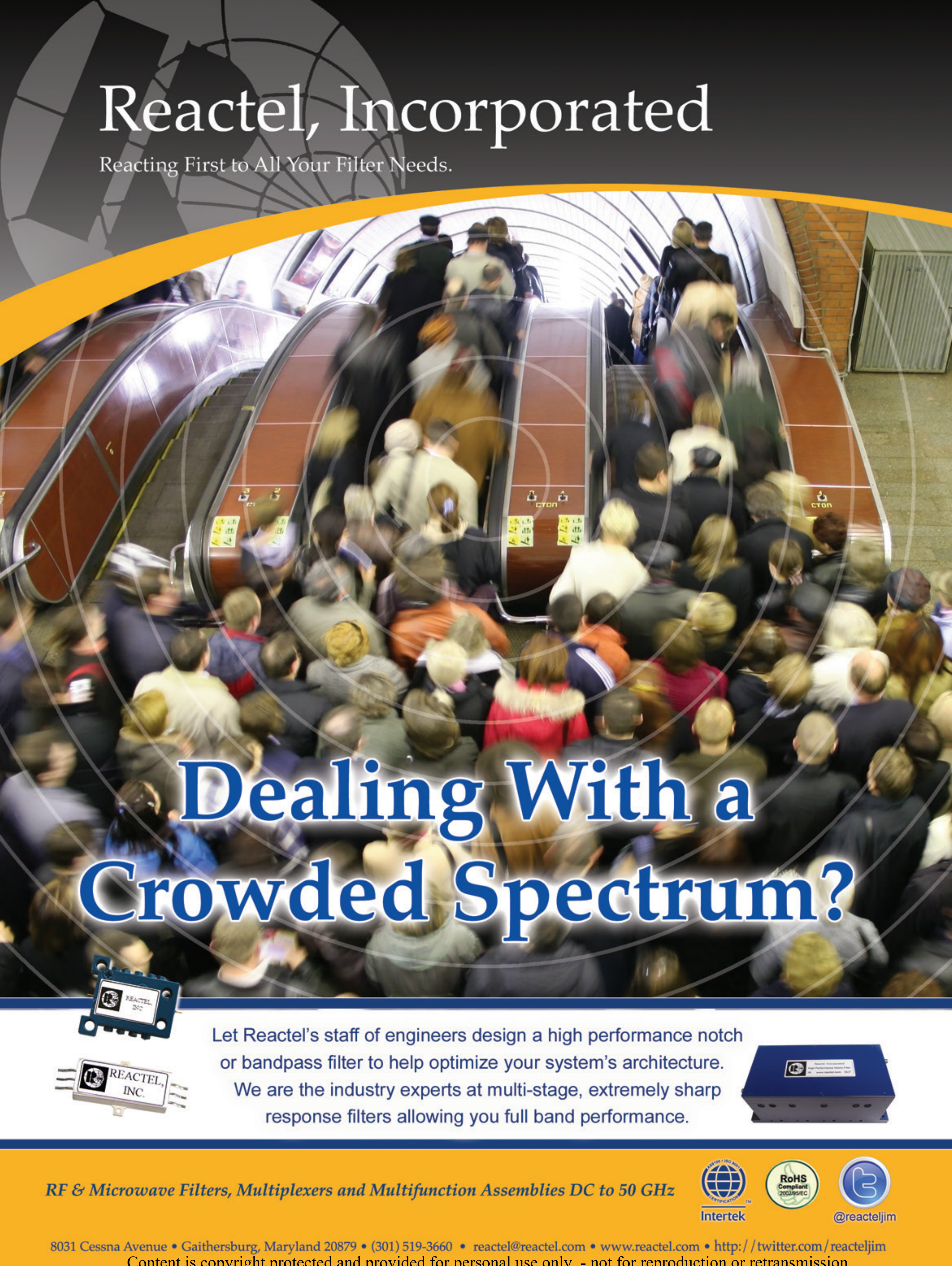

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OCEAN2020–European Defence Fund's First Research Initiative

OCEAN2020 is the European Defence Fund's first initiative, and is designed to boost technological research in the naval domain via the integration of unmanned platforms in surveillance and interdiction missions in naval systems. Aimed at advancing Europe's defence capabilities, OCEAN2020 was issued by the European Union under the "Preparatory Action on Defence Research" programme and is the first example of a cross-European military research programme.

The OCEAN2020 team, which will be led by Leonardo, comprises 42 partners from 15 European countries.

OCEAN2020 will see unmanned platforms of different types (fixed wing, rotary wing, surface and underwater) integrated with naval units' command and control centres, allowing for data exchange via satellite, with command and control centres on land. The joint and cooperative use of both manned and unmanned vehicles will also be demonstrated.

"...advancing Europe's defence capabilities..."

In addition to complex simulation work, OCEAN2020 will involve two live demonstrations of maritime surveillance and interdiction operations, conducted by European fleets using unmanned aircraft, surface vessels and underwater systems. The first demo, scheduled to take place in the Mediterranean Sea in 2019, will be coordinated by the Italian Navy and will see Leonardo's "Hero" and "Solo" unmanned helicopters operate from Italian naval units alongside other European partners.

The second demonstration, which will take place in 2020 in the Baltic Sea, will be coordinated by the Swedish Navy. The data collected by various systems during these two demos will be processed and sent to a prototype European command and control centre in Brussels.

OCEAN2020 (Courtesy of Leonardo)

3GPP Completes First 5G NR Standard

On 21 December 2017, the 3GPP TSG RAN Plenary Meeting in Lisbon, Portugal successfully completed the first implementable 5G NR specification, with participating companies issuing a statement that the completion of the first 5G NR standard has set the stage for the global mobile industry to start full-scale development of 5G NR for large-scale trials and commercial deployments as early as 2019.

Those participating companies are: AT&T, BT, China Mobile, China Telecom, China Unicom, Deutsche Telekom, Ericsson, Fujitsu, Huawei, Intel, KT Corporation, LG Electronics, LG Uplus, MediaTek Inc., NEC Corporation, Nokia, NTT DOCOMO, Orange, Qualcomm Technologies Inc., Samsung Electronics, SK Telecom, Sony Mobile Communications Inc., Sprint, TIM, Telefonica, Telia Company, T-Mobile USA, Verizon, Vodafone and ZTE.

"...full-scale development of 5G NR..."

This standard completion is an essential milestone to enable cost-effective and full-scale development of 5G NR, which will greatly enhance the capabilities of 3GPP systems, as well as facilitate the creation of vertical market opportunities. 3GPP plans to continue to develop Release 15, including the addition of support for Standalone 5G NR operation.

The 5G NR lower layer specifications have been designed so that they can support Standalone and Non-Standalone 5G NR operation in a unified way, to ensure that 3GPP benefits the global industry with a large-scale single 5G NR ecosystem.

ETSI Signs MoU with Broadband India Forum

The European Telecommunications Standards Institute (ETSI) has signed a Memorandum of Understanding (MoU) with the Broadband India Forum to promote topics such as 5G, M2M and IoT, IPRs as well as privacy and security related matters in India.

The Broadband India Forum addresses activities such as training, research, study, promotion and the establishment of convergent technologies and projects based on Internet Protocol (IP), broadband and SATCOM-broadcasting, particularly over wire line and wireless. The Forum also performs a vital role as a bridge between industry and government and regulatory bodies.

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> "...standards-based communication technologies..."

Through the Seconded European Standardization Expert for India (SESEI) project and the EU-India project on ICT standardization, ETSI is already actively involved in India and the country's standardization activities. Signing a MoU with the Broadband India Forum will allow ETSI to leverage its activity at a government level in India, and for the Broadband India Forum to promote the use of standards-based communication technologies in India.

Vodafone and Huawei Trial Spectrum Sharing in Turkey

Vodafone Group's Networks Centre of Excellence team and the Huawei Mobile Innovation Centre tested a dynamic way to help address spectrum constraints in Turkey. The teams have completed the world's first trial of GSM/LTE (GL) 900 MHz dynamic spectrum sharing on Vodafone's commercial networks in the Black Coast city of Trabzon.

> "Spectrum is an extremely precious asset."

In 2017, the two companies achieved unparalleled overlap by GSM (2G) and LTE (4G) services within the 900 MHz spectrum band. Now they have shown that it is possible to assign that spectrum dynamically, i.e. available 900 MHz can be allocated between 4G and 2G services based on customer demand.

In the trial, which took place over several months, dynamic sharing allowed Vodafone Turkey to provide up to 10 MHz of 4G capacity and throughput in a very effective way. 4G KPIs clearly show the improvement in network performance and better user experience. The test cases showed that download and upload throughput improved by 20 percent.

Mallik Rao, Vodafone Turkey's CTO, said: "Spectrum is an extremely precious asset. This new network optimization technique improves spectral efficiency and enhances the experience of Vodafone customers."

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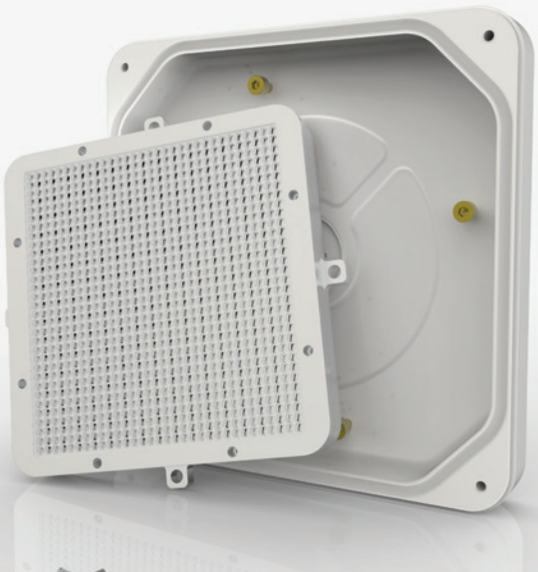

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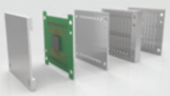

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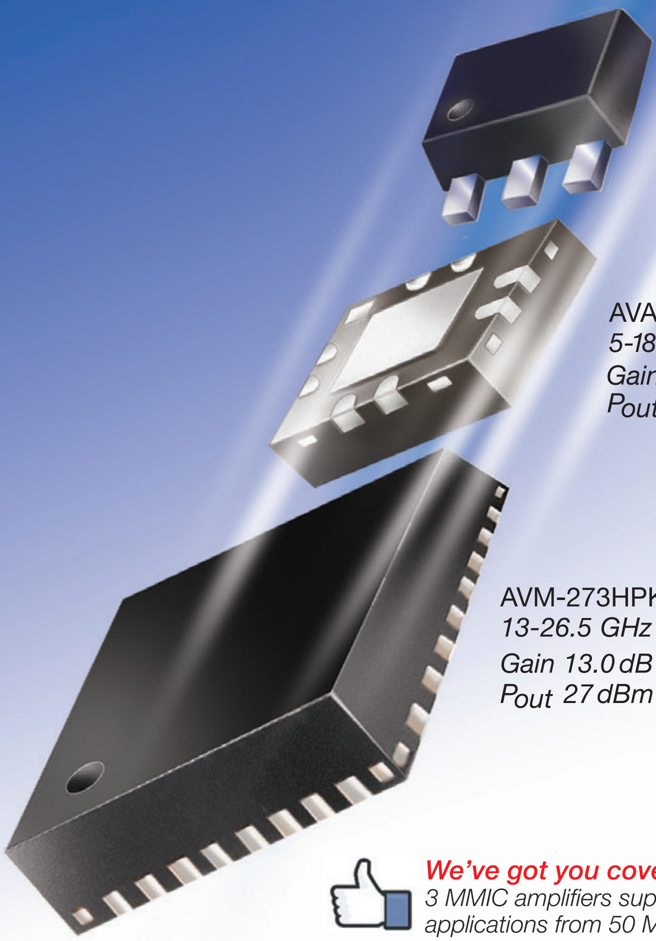

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Sensor Data Sharing, Driverless Vehicle Remote Control to Boost Cellular V2X Technologies

While the IEEE 802.11p V2V standard delivers basic non-line-of-sight (NLOS) safety features, advanced Vehicle-to-Vehicle (V2V) capabilities for sharing of raw vehicle sensor data and remote control of driverless cars will require enhanced Device-to-Device (D2D) and network-based cellular V2V technologies to be defined in 5G standards. ABI Research forecasts that 5G cellular Vehicle-to-Everything (V2X) connections based on end-to-end network slicing will exceed 10 million by 2027.

"However, the overall momentum created by the mobile ecosystem will drive uptake of 4G cellular V2X implementations competing directly with IEEE 802.11p before 2020 with Qualcomm's 9150 C-V2X chipset available for commercial sampling in the second half of 2018. From a complementary and redundancy point of view, the coexistence of both technologies is a likely scenario though implementations may differ between regions and car OEMs," says Dominique Bonte, vice president at ABI Research. "Due to incompatibility, both technologies will be required to reach high penetration levels to be relevant, though Vehicle-to-Infrastructure (V2I) services can provide preliminary benefits."

> IEEE 802.11/DSRC Versus Cellular V2X: Tech Battle or Complementary Solutions?

A wide consensus has been reached among automotive players around the need for V2X in terms of adding NLOS collective perception capabilities guaranteeing safe operation of driverless vehicles, but also supporting future cooperative mobility requirements. Euro NCAP is planning to add V2X to its safety rating framework by 2020.

However, competition between both sets of V2X standards might still result in a tech battle that risks slowing down adoption. The automotive industry seems increasingly divided in two camps with GM, Toyota and VW and many Tier One suppliers backing DSRC, while Audi, BMW, Ford and others support cellular V2X through the 5G Automotive Association (5GAA). The timing of deployments will depend on multiple factors including the resolution of spectrum sharing issues, the nature of the V2V mandate in the U.S., 5G standardization and regional ITS frameworks.

Global Commercial Telematics System Revenue to Reach USD$24B by 2022

The explosive growth stimulated by the Electronic Logging Devices (ELD) Mandate in the U.S., emerging market opportunities and last mile delivery, is providing tremendous upside for numerous telematics service providers.

"According to the Federal Motor Carrier Safety Administration (FMCSA), in 2017, 67 percent of U.S.-based fleets had 20 or fewer units. Many of these fleets were without telematics units, providing a significant upside this year for ELDs," says Susan Beardslee, senior analyst at ABI Research. "Substantial growth in e-commerce is putting further emphasis on last mile delivery and the need to manage capacity for fleets, both in North America and across multiple geographies."

> Opportunities for further telematics penetration exist, especially for segments such as services, government and public transport, with CAGRs all between 16 to 19 percent.

ABI Research anticipates global commercial telematics system subscriptions to rise across trucking segments from 33 million this year to over 67 million by 2022. The industry continues to develop innovative solutions, targeted to specific geographies and/or verticals as well as evolve existing technologies to support Advanced Driver-Assistance Systems (ADAS) and regulatory requirements. Companies such as Verizon, Omnitracs, G7, Trimble, TomTom Telematics, Gurtam, Geotab and MiX Telematics are addressing many of these segments.

"Commercial telematics providers will continue to expand their market presence through the introduction of connected, secure and scalable innovations including gateways, prognostics, open APIs/SDKs and ecosystem marketplaces. More nascent technologies such as blockchain, autonomy and electrification will impact the industry in the coming years," concludes Beardslee.

Next-Gen Asset Tracking Infrastructure Worth USD$4.5B by 2022 But Consolidation Looming

A new report by ABI Research forecasts that the worldwide indoor positioning market for next-generation asset tracking will reach USD$4.5 billion by 2022 with a CAGR of 32 percent, as large enterprises seek to deploy next-generation asset tracking technologies to improve operational efficien-

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cies. As the hugely fragmented market develops, the location supply chain will become very complex with the boundaries between the different nodes blurring.

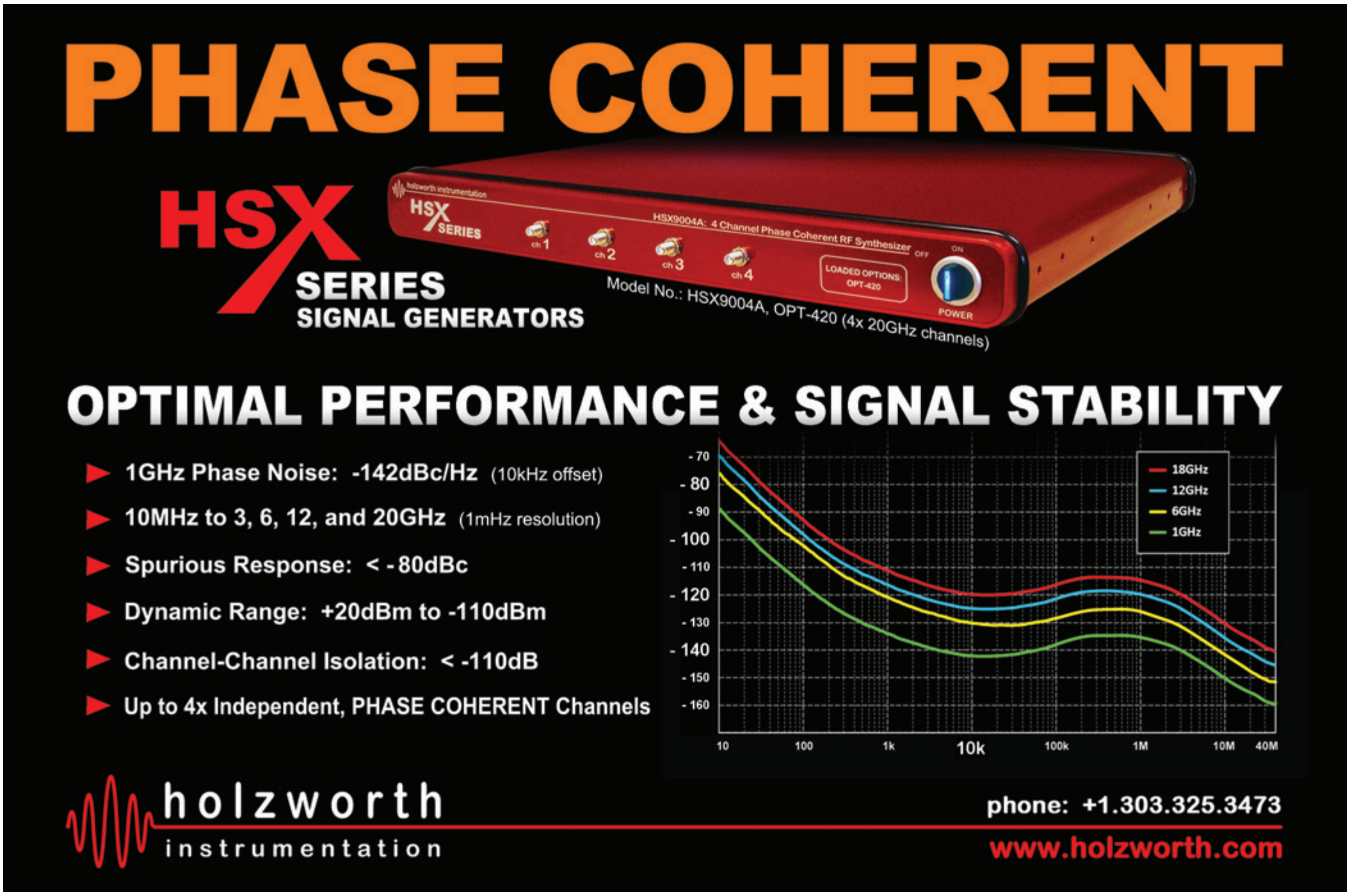
Next-generation asset tracking solutions based on Bluetooth Low Energy (BLE) and Ultra-Wideband (UWB) will rapidly replace expensive legacy systems such as passive Radio Frequency Identification (RFID) while providing increased location granularity. "Although Bluetooth is quickly becoming the go-to standard for indoor asset tracking use cases, the choice of Real-Time Location System (RTLS) technology is dependent on many factors including the number of assets being tracked, the coverage area required, the level of accuracy required for each use case and the overall cost of the solution including both infrastructure and implementation costs," says Samuel McLaughlin, research analyst at ABI Research. "Many smaller companies simply cannot afford the costs associated with RFID systems. A ruggedized BLE tag will cost USD$20 today, which may seem expensive, but this is offset by reduced anchor point costs per square meter."

Bluetooth hardware infrastructure for asset tracking is forecast to reach USD$2.3 billion by 2022, which will represent 52 percent of the total infrastructure of asset tracking market. However, UWB is the fastest growing technology in this environment, with a compound annual growth rate of 52 percent between 2017 and 2022.

Major beacon companies arrived late to target the asset tracking space because they were focusing on consumer-facing applications. This has given rise to customized solutions from companies like Fathom, Quuppa, Onyx Beacon, Bluvision, H&D Wireless and PLUS Location Systems. This market is characterized by many small-to-medium sized suppliers that are steadily obtaining deployments with local customers.

However, these vendors will struggle to generate scale in the long term. Targeting small to mid-size businesses across a variety of segments and use cases is a good starting point for these companies, but it will not be enough for them to survive in such a highly competitive landscape. Asset tracking customers often have specific requirements and ask for highly customizable equipment, which most vendors could hardly cope with in the long-run.

This trend means market consolidation is looming and survivors will be pushed to come up with more hybridized technologies that will allow them to generate the required scale. These players will also have to adapt their business models and align their strategy if they want to maximize profits from their innovative technologies. "Asset tracking as a service is becoming increasingly popular as an alternative to the traditional model whereby vendors ship their solutions as a one-time sale opportunity," concludes McLaughlin.



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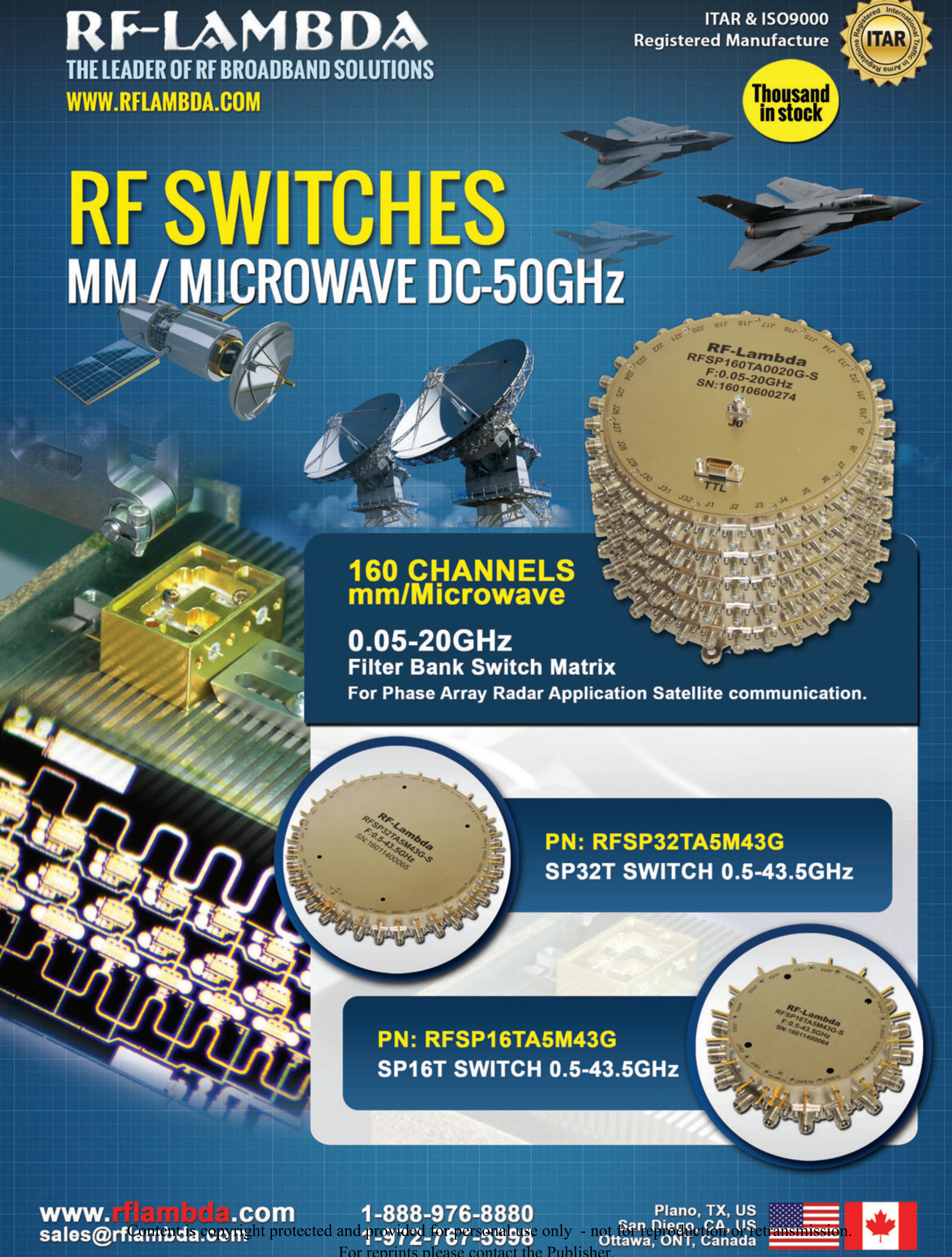

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Mercury Systems Inc. announced that it has signed a definitive agreement to acquire **Themis Computer**. Based in Fremont, Calif., Themis is a designer, manufacturer and integrator of commercial, SWaP-optimized rugged servers, computers and storage systems for U.S. and international defense programs. Pursuant to the terms of the agreement, Mercury will acquire Themis for an all cash purchase price of $180 million, subject to net working capital and net debt adjustments. The acquisition and associated transaction expenses are expected to be funded through Mercury's existing revolving credit facility.

I.F. Engineering Corp., located in Dudley, Mass., announced the acquisition of **American Sub Assembly Producers (ASAP) Inc.**'s assets. ASAP has been a long time supplier to I. F. Engineering Corp. The products and capabilities of ASAP complement those of IFE and include contract manufacturing services, both turnkey and consignment, as well as build-to-print. Capabilities include, but are not limited to, two automated SMT lines, through-hole assembly, hand soldering, toroid winding, mechanical assembly, sheet metal fabrication and coaxial cables.

King Engineering has acquired **Criser Troutman Tanner Consulting Engineers (CTT)**, a North Carolina-based full-service engineering firm. CTT specializes in civil and structural engineering for private and public-sector clients. With the addition of CTT, King Engineering, which recently merged with Ardurra Group, the company has ~300 professionals throughout 15 offices serving the Gulf Coast, the Southeast and Mid-Atlantic. CTT will continue to operate as CTT in the North Carolina market from offices in Wilmington, Raleigh and Charlotte.

Nordson Corp. has acquired **Sonoscan Inc.**, an Elk Grove Village, Illinois-based designer and manufacturer of acoustic microscopes and sophisticated acoustic micro imaging systems used in a variety of microelectronic, automotive, aerospace and industrial electronics assembly applications. The transaction is not material to Nordson results, and terms of the deal were not disclosed. Sonoscan will operate within Nordson's Advanced Technology Systems segment. Since its inception, Sonoscan has been the most trusted authority on the application of Acoustic Microscopy, also known as Acoustic Micro Imaging (AMI) technology, to nondestructively find and characterize physical defects such as cracks, voids, delaminations and porosity that occur during manufacturing, environmental testing or even component operation.

COLLABORATIONS

HUBER+SUHNER and **KOSTAL Kontakt Systeme** have reached a framework agreement for a strategic collaboration with a focus on the technology fields of cables and contact/connector systems for automotive applications. The two companies, represented by Reto Bolt, COO of the HUBER+SUHNER Radio Frequency Division, and Dr. Markus Bergholz, CEO of KOSTAL Kontakt Systeme GmbH, have signed a Memorandum of Understanding and plan to work together to implement novel solutions for the transmission of high data rates in cars, buses and commercial vehicles.

Renesas Electronics and **Airbiquity®** announced a secure, high performance automotive solution with over-the-air (OTA) capabilities, targeting advanced driver assistance systems (ADAS), vehicle-to-everything (V2X) and automated driving applications of the future. To prepare for the upcoming autonomous-driving era, the companies are integrating Airbiquity's OTAmatic™ cloud-based OTA software and data management service delivery solution on Renesas' high performance, low power R-Car H3 automotive computing platform. The combined solution based on the R-Car H3 system on a chip (SoC) that is compliant with the ISO 26262 safety functionality (FuSa) standard, brings a powerful, efficient and secure automotive computing platform with highly targeted and scalable on-demand OTA software update and data management capabilities.

Nokia, **T-Mobile** and **Intel** have reached a major milestone in their 5G collaboration by bringing a 28 GHz outdoor 5G commercial radio system on air in the busy downtown corridor of Bellevue in Washington state. A data session was conducted on a 28 GHz radio in a field test environment using the Nokia 5G commercial AirScale solution and the 5G Mobile Trial Platform (MTP) from Intel, enabling T-Mobile to deploy its first inter-vendor 5G network. This collaboration furthers the T-Mobile's goal to drive standards, enhance the 5G ecosystem of chipsets and devices and develop the best network experience for its customers.

Advanced RF Technologies (ADRF) has announced its acceptance into the **Sirqul's Strategic Alliance Partner Program**. By collaborating with ADRF, Sirqul has enhanced its IoT platform capabilities by incorporating data from the cellular connections ADRF provides. Sirqul is an engagement-as-a-service IoT provider that offers software and a bundled set of vertical solutions, which combine with mesh networks to track and identify an individuals behavior, location and intent. This can range from identifying the exact whereabouts of a fan at a sports stadium to deliver food to enabling autonomous robots to navigate industrial warehouses and factories, as well as be monitored.

Molex and **Excelfore** have teamed up on the development of a 10 Gbps Ethernet Automotive Network designed to accelerate data bandwidth in intelligent

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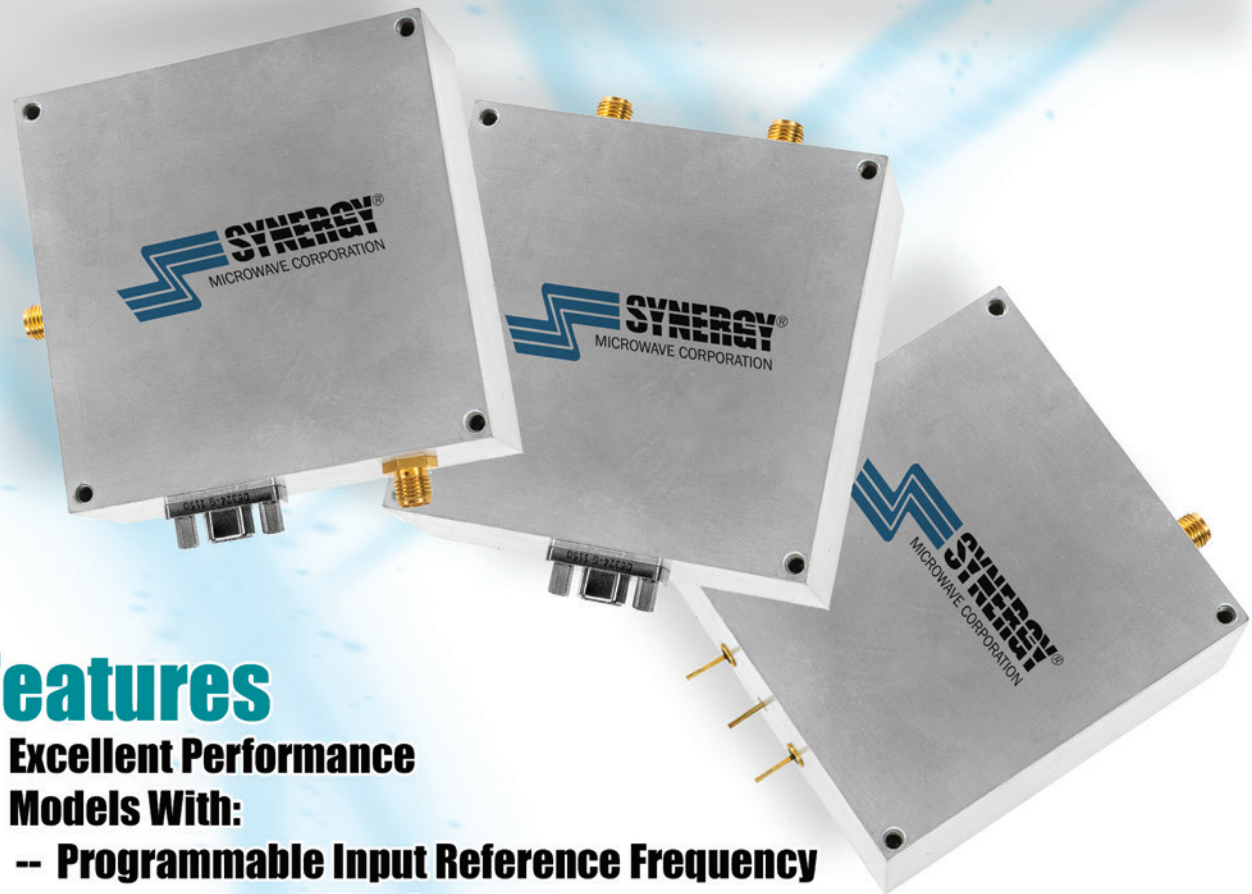

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connected vehicles. Headquartered in Silicon Valley, Excelfore provides innovative middleware solutions for in-vehicle and vehicle-to-cloud smart mobility networks, enabling automotive OEMs to build the next generation of connected cars. The Molex demonstration at CES 2018 showcased how Excelfore solutions streamline integration and over-the-air (OTA) diagnostics, firmware and software updates to different automotive devices, from different vendors, running different operating systems, across multiple networks.

PoLTE Corp. and **Riot Micro** announced a technology collaboration to enable ultra-low power LTE IoT solutions with highly accurate location positioning for indoor and outdoor applications. The collaboration combines the advantages of Riot Micro's RM1000 with those of PoLTE's recently announced Lite-Touch location architecture. Riot Micro will support PoLTE's location interface in the RM1000, the industry's lowest power baseband modem chip for the cellular IoT. Riot Micro's innovative design approach can cut the power consumption of similar modem chips in half, at price points comparable to short-range wireless systems.

ACHIEVEMENTS

International Manufacturing Services (IMS) Inc. in Portsmouth, R.I. announced the company has achieved quality certification to AS9100D. The AS9100D certification is an internationally recognized quality management standard for aerospace, aviation and defense industries, managed by the International Aerospace Quality Group (IAQG). It encompasses the ISO 9001:2015 standards with additional requirements specific to the aerospace industry and is endorsed worldwide by all major aerospace OEMs and suppliers. Upgrading to AS9100D was the result of a lengthy audit process conducted by TUV Rhineland N.A., demonstrating a level of excellence in all areas of the company's quality management system.

TechPlus Microwave Inc., a designer and manufacturer of RF/microwave filters is now AS9100D certified. The certification was performed by Advantage International Registrar, Inc. AS9100D is the most recent, internationally recognized quality management system standard specific to the aerospace, aviation and defense market segments.

Emerson has been named the "Industrial IoT Company of the Year" by IoT Breakthrough. The award recognizes Emerson's extensive innovation and leadership in driving Industrial Internet of Things (IIoT) technologies and strategies for customers in manufacturing industries, including oil and gas, food and beverage, chemical, life sciences and others. Today's industrial business challenges include fast-changing market dynamics, technical complexity and the relentless pressure to do more with less. To help overcome challenges, Emerson has harnessed the power of IIoT for customers through its Plantweb™ digital ecosystem to enable broader process automation and deeper data insights that can improve operations.

CONTRACTS

Northrop Grumman Corp. has received a $124.7 million award for production of AN/APR-39D(V)2 digital radar warning receiver and electronic warfare management systems. The award followed the successful completion of engineering and manufacturing development activities, including a series of rigorous tests that verified the system's readiness for production and the demands of combat operations. The AN/APR-39D(V)2 is a small, lightweight digital radar warning receiver and electronic warfare management system that provides 360-degree coverage to detect and identify radio frequency threats to an aircraft. As an electronic warfare management suite, the APR-39D(V)2 can display data from multiple onboard sensors and automatically initiate countermeasures to protect aircrews.

Kratos Defense & Security Solutions Inc. announced that it has recently received $3.3 million in unmanned aerial drone and electronic system contract awards. Kratos is an industry leader in the rapid design, demonstration and fielding of affordable unmanned aerial drone systems for tactical, combat and target applications, related ground control systems and microwave electronics. Work on these recent contract awards will be performed at secure Kratos manufacturing facilities. Due to competitive, customer related and other considerations, no additional information will be provided related to these contract awards.

Comtech Telecommunications Corp. announced that during its second quarter of fiscal 2018, its Orlando, Fla.-based subsidiary, **Comtech Systems Inc.**, which is part of Comtech's Government Solutions segment, has received an additional $1.5 million contract from the **Brazilian Military** for satellite spares to support an existing system. Comtech Systems Inc. specializes in system design, integration, supply and commissioning of turnkey communication systems including over-the-horizon microwave, line-of-sight microwave and satellite. Comtech Telecommunications Corp. designs, develops, produces and markets innovative products, systems and services for advanced communications solutions. The company sells products to a diverse customer base in the global commercial and government communications markets.

BAE Systems has been contracted by the **Ministry of Defence's (MOD) Maritime Combat Systems (MCS)** team to ensure the combat management systems, tactical networks and shared infrastructures aboard 38 Royal Navy platforms will remain available, coherent, safe and secure. The Joint Support Solution 2 (JSS 2) programme will maintain high levels of equipment availability, overcome obsolescence and improve combat systems reliability and flexibility, building on the success of the original JSS contract signed in 2010.

Orbital ATK announced the company has been awarded a contract by **Intelsat** to build the Galaxy 30 communications satellite. The satellite will be based on

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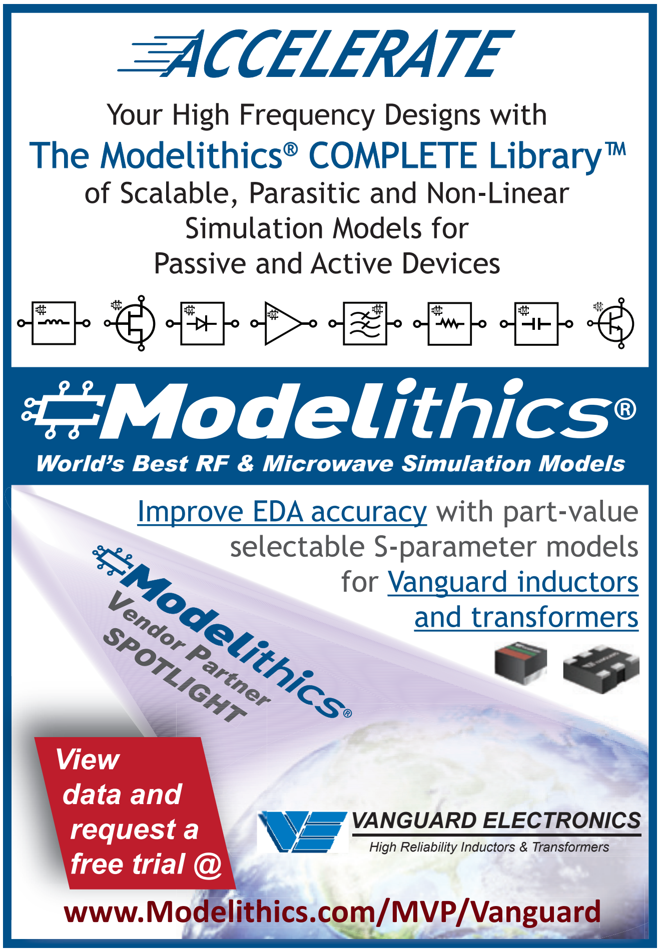

Orbital ATK's highly successful GEOStar-2™ satellite platform. Galaxy 30 will be designed, built and tested at Orbital ATK's state-of-the-art satellite manufacturing facility in Dulles, Va., and will primarily serve video markets in North America. The satellite is scheduled to launch in early 2020. Galaxy 30 will be the 41st commercial spacecraft built by Orbital ATK for customers around the world.

DLT Solutions announced that it was awarded an enterprise software initiative (ESI) blanket purchase agreement (BPA) on behalf of the **U.S. Department of Defense (DoD)** to help secure data from traditional and IoT-connected devices, and accelerate automated incident response to breaches, with ForeScout software and services. Gartner forecasts that by 2020 the number of IoT devices could reach a staggering 20.4 billion. Adoption in the public sector is also accelerating.

PEOPLE

Axus Technology announced that **John J. Cerilli** has joined the company as General Manager. Based in the Chandler, Ariz. facility, Cerilli's new role will provide management, logistics, sales, marketing and business development support to Axus' global customer base and sales team. In the past year, Axus has experienced substantial growth, and the addition of Cerilli in the role of GM will allow him to apply his industry and management experience to support Axus as it continues to grow and reach new markets. Cerilli is a semiconductor professional with more than 40 years of experience in the industry.

NAI announced the appointment of **Eric Emley** to the position of vice president of Global Supply Management. In his new role, Emley will develop new strategies to align NAI's supply chain with the overall business strategies of the company. The new VP Global Supply Management will form the requisite supply chain to accelerate these company traits and maintain the ease of doing business with NAI that customers enjoy today. To help accomplish these goals, Emley will interface with NAI's plants and external customers to understand their requirements and provide the appropriate supply chain structure to create a competitive advantage in the marketplace.

▲ *Eric Emley*

Modelithics shared the news and congratulated **Dr. Thomas Weller**, the company's co-founder, on being named IEEE Fellow by the Institute of Electrical and Electronics Engineers. This high designation is given by the IEEE Board of Directors to persons having a history of significant accomplishments in the fields of electrical engineering. Dr. Weller has been recognized for his extensive contributions in the area of advanced RF and microwave modeling techniques for surface mount and passive IC electronic components.

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▲ *Jennifer Ricklin*

Carnegie Mellon University's Software Engineering Institute (SEI) announced the appointment of **Dr. Jennifer Ricklin** as director of the SEI's Software Solutions Division. Carnegie Mellon University's Software Engineering Institute announced the appointment of Dr. Jennifer Ricklin as director of the SEI's Software Solutions Division. Dr. Ricklin has extensive experience as a researcher and leader in federal defense and civil agencies and in the private sector. A federally funded research and development center (FFRDC), the SEI helps government and industry organizations develop and operate software systems that are secure and reliable.

REP APPOINTMENTS

Amplical Corp. announced the appointment of the following regional manufacturer's sales representatives: **Robtron Inc.** covering upstate New York and **Mission Critical Sales LLC** covering New England. Amplical is a supplier of high quality RF and microwave components to 40 GHz. Utilizing state-of-the-art design and manufacturing techniques, Amplical focuses on producing high performance amplifiers, switches, modulators, attenuators, phase shifters and limiters at affordable prices. Amplical serves the defense, aerospace, communications, test and instrumentation markets.

NoiseWave Corp. announced the appointment of the following regional manufacturer's sales representatives: **Robtron Inc.** covering upstate New York, **Mission Critical Sales LLC** covering New England and **Amtele Communication AB** covering Sweden, Finland, Denmark, Norway, Estonia, Lithuania and Latvia. NoiseWave is a leading supplier of noise sources and noise test equipment to 110 GHz.

PLACES

Diamond Microwave, a specialist in high performance microwave power amplifiers, has relocated its design and laboratory facility to the historic Salts Mill in Saltaire, near Shipley, in the U.K.

Parker Aerospace, a business segment of **Parker Hannifin Corp.**, announced the opening of its second global Customer Response Center (CRC) in Singapore. Located inside Parker's existing customer support operation in Singapore, the new CRC location provides worldwide customer support to its maintenance, repair and overhaul (MRO) customers—24 hours a day, seven days a week, 365 days a year. The value of Parker Aerospace's service for customers will be further strengthened with additional local insight to speed the handling of technical, business and service calls requiring immediate attention.

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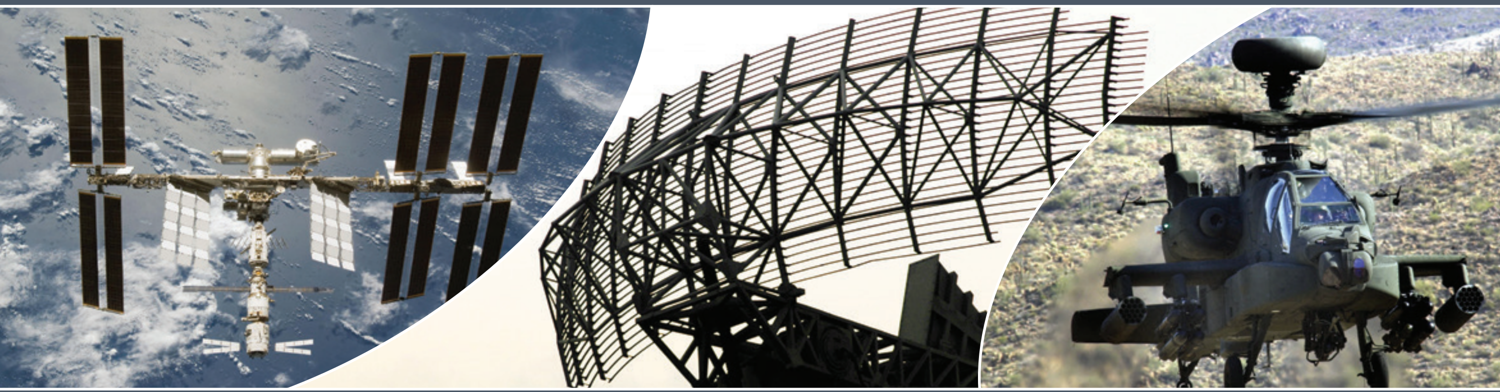

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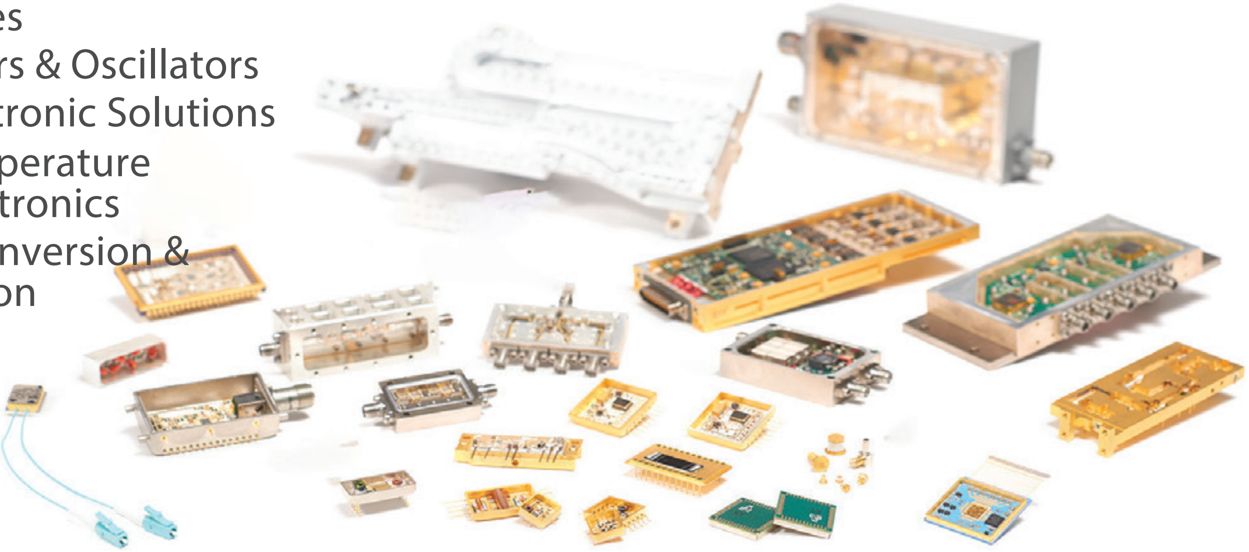

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EDI CON China 2018 Preview

Janine Love, Technical Program Director, EDI CON China 2018

This March 20-22, EDI CON China returns to Beijing at the China National Convention Center. Attendees return to EDI CON each year to see the latest products on the exhibition floor and to benefit from its technical conference, made up of peer-reviewed technical sessions as well as workshops, plenary keynote speeches, panels and a short course with industry-leading experts. Organized in multiple tracks, the technical conference provides practical information on how to complete the latest designs using available materials, tools, products and techniques.

This year's event returns with its unique, high-quality technical conference with learning and training opportunities for engineers in the Beijing area. In addition to the conference, EDI CON China features a show floor of exhibitors demonstrating the latest in RF, microwave and high speed digital products and services. Attendees come to EDI CON to find solutions, products and design ideas that they can put into immediate practice for applications in the communication, defense, computer, consumer electronics, aerospace and medical industries.

PLENARY KEYNOTE SPEECHES

EDI CON China 2018 will hold plenary keynote sessions on both Tuesday and Wednesday. The plenary sessions include an invited talk from Dr. Klaus Werner, executive director of the RF Energy Alliance and the owner of kw tec b.v., a company active in the fields of metrology, automation and consultancy. Dr. Werner's talk, "Solid State RF Energy is the Smart Technology Solution for 2018," will address the exciting markets for solid-state RF energy, including appliances as well as lighting, medical and automotive applications. Other invited speakers include Bertram Arbesser-Rastburg, president of the Austrian Institute of Navigation (AIN/OVN), who will discuss how the newest satellite systems (Galileo and Beidou) complement the existing systems (GPS and GLONASS). EDI CON China has also invited Dr. Guochun (GC) Liang, president and CEO of Pivotone Communications Technologies Inc. in Wuxi, China, who will address the challenges and benefits of innovation and being an entrepreneur.

Attendees will also hear a plenary talk from Renato Lombardi, Huawei Fellow, head of Italy Research Center, VP Microwave Product Line, who will discuss mmWave technology. Other plenary keynotes will be given by representatives from EDI CON China's Host Sponsor, Keysight Technologies, as well as Diamond Sponsor, Rohde & Schwarz and Corporate Sponsor, National Instruments, who will speak on the latest technology trends and challenges, including insights into 5G.

TECHNICAL SESSIONS & WORKSHOPS

Papers and workshops in the conference will cover simulation, design, layout, test and verification across topics such as 5G, automotive electronics, radar, antennas, EMC/EMI, IoT, amplifiers, serial interfaces and the latest semiconductor material technologies. Planned tracks for this year's event include: RF & Microwave Design; High Speed Digital Design, including Power Integrity and Signal Integrity; Measurement & Modeling; Systems Engineering; 5G Advanced Communications; EMC/EMI; IoT Design; Radar Communications; and Semiconductors.

Each day of the conference features 40-minute workshops and panels, as well as 20-minute technical sessions. At the end of the first day of the conference and exhibition, delegates can enjoy a wel-

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come reception starting at 1730 that is sponsored by Keysight Technologies. Day 3 will also include a special short course (included in the delegate conference pass) presented by Dr. Eric Bogatin entitled, "Essential Principles of Power Integrity Measurements." This tutorial will look at the five most important measurement challenges, including how to extract the important figures of merit for any power rail, both under nominal conditions and under stimulated transient loading.

This year, EDI CON China will also partner with American Certification Body (ACB) EMC experts who will conduct training sessions on FCC/RED/ISED/MIC Regulatory, as well as EMC training for iNARTE exam on Tuesday, March 20 and Wednesday, March 21.

PANELS

This year's EDI CON China panel discussions will include panels on mmWave Over the Air Testing and 5G MIMO, moderated by *Microwave Journal*'s Patrick Hindle, and a panel on GaN, moderated by *Microwave Journal*'s Gary Lerude. In a special session, the RF Energy Alliance's Dr. Werner will speak on "Solid State RF Energy–Inroads to the Industrial Market," followed by a panel of industry leaders for discussion and questions regarding RF energy.

EXHIBITION

EDI CON China 2018 will also include three-days of exhibition that features demonstrations from EDI CON China's many sponsors, including Keysight Technologies, Rohde & Schwarz, National Instruments, Focus Microwaves Group, Maury Microwave, Mini-Circuits, Sichuan YiFeng Electronic Science & Technology Co. Ltd., WIN Semiconductors Corporation and Xiamen Sanan Integrated Circuit Co. (see the complete list at: www.ediconchina.com/whoexhibit.asp). On Tuesday at 1720, we will announce the winners of the EDI CON Innovation Awards as well as a Lucky Draw.

Registration is open, and hotels are now available. We look forward to seeing you in Beijing!

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INVITED PAPER

Microstrip Defected Ground Structures Without Radiation Loss Using Multilayer PCB Technology

John Coonrod
Rogers Corp., Chandler, Ariz.

A multilayer circuit design using defected ground structures is used to enhance filter performance without concern for leakage and isolation.

Microstrip defected ground structures (DGS) have been a part of high frequency circuit design for many years and are also used with stripline and coplanar waveguide circuits.[1-3] While DGS circuit design approaches can provide benefits in the performance and miniaturization of resonator-based RF/microwave components, such as antennas and filters, the technology is limited by serious drawbacks, including low isolation and excess electromagnetic (EM) radiation. DGS-based circuits can radiate EM energy, resulting in electromagnetic interference. Lack of isolation can also result in undesirable interaction with neighboring RF/microwave components and circuits. Fortunately, because of the increasing use of multilayer circuit configurations in modern RF/microwave circuit designs, it is possible to design and fabricate microstrip DGS circuits with little or no concern for radiation or isolation. This multilayer approach is demonstrated with a lowpass filter (LPF) design and some readily available commercial circuit materials.

DGS OVERVIEW

Perhaps the easiest way to understand a DGS is to consider a ground plane as a continuous structure, with no breaks or interruptions. The electrical characteristics of a transmission line, such as microstrip, assumes this ground plane continuity. By purposely forming a defect, such as an isolated opening etched in the ground plane, the transmission line's RF characteristics are altered. Capacitance and inductance can change significantly in the area of the DGS.

A simple example is an H-shaped feature etched in the ground plane of a microstrip transmission line (see ***Figure 1***). The microstrip structure shown in Figure 1a has two copper layers. The dark orange color represents circuit features on the top copper layer (the signal layer), and the light orange color depicts circuit features on the bottom copper layer (the ground plane). The H-shaped DGS produces a bandstop or band-reject characteristic, as shown in Figure 1b. The response is similar to a one-pole Butterworth lowpass

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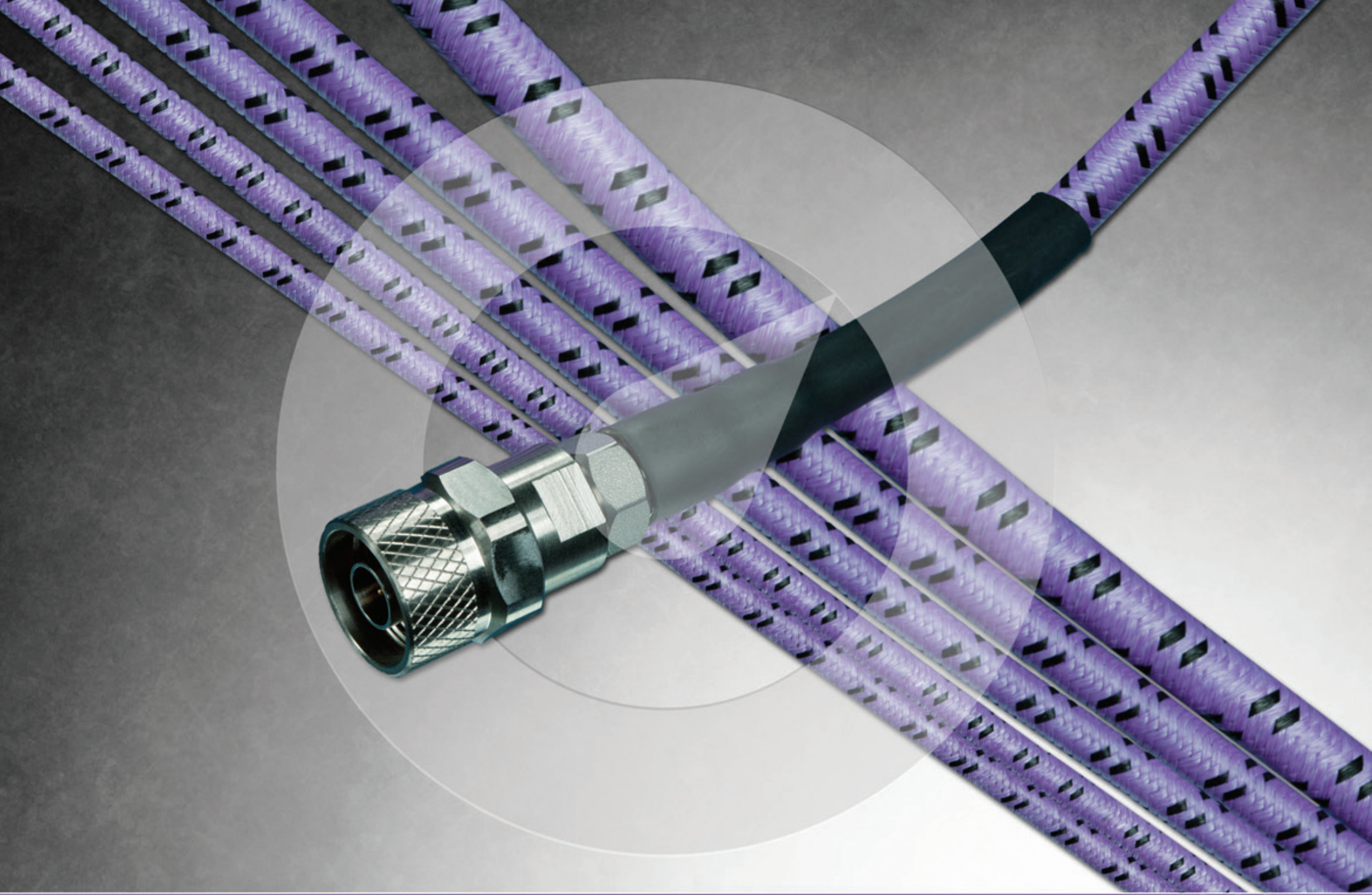

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filter (LPF). The DGS pattern can be altered to generate a very narrowband bandstop response, which is sometimes added to a filter design to improve isolation in the stopband portion of the filter. As will be shown with a practical LPF design, the effective use of a microstrip DGS not only improves a filter's stopband response but greatly improves a filter's spurious harmonic responses.

A DGS can enhance the performance of many RF/microwave components, including LPFs, bandpass filters (BPF), patch antennas and other resonant circuits. A search of the IEEE Xplore® Digital Library yields many white papers where a DGS is used in these applications. DGS structures can also be used to reduce circuit size, with the ability to implement slow-wave effects.

OVERCOMING DGS RADIATION AND ISOLATION

With the growing complexity and integration found in modern RF/microwave circuits, multilayer circuit construction is often employed. Proper design of a multilayer printed circuit board (PCB) circuit containing a microstrip DGS can minimize or even eliminate EM radiation and isolation. Multilayer PCBs can be constructed in many shapes and sizes.

For the sake of simplicity, a multilayer PCB with three copper layers is used as an example to demonstrate a method for minimizing DGS radiation and isolation (see ***Figure 2***). The figure shows a multilayer PCB with two different substrate materials having dielectric constants ε_{r1} and ε_{r2}. For an ideal DGS, the dielectric constant of the lower substrate material, ε_{r2}, is a value equivalent to that of air, i.e. $\varepsilon_{r2} = 1.0$. It is possible to embed an air cavity within a multilayer PCB, but it is difficult and typically expensive to fabricate. A compromise is to use a substrate with a low value of ε_{r2} that is robust enough to tolerate PCB manufacturing processes. The benefits of using substrate materials with different ε_r values are explained later in this article.[4,5]

The top two copper layers are microstrip and its defected ground plane. They may appear as grounded coplanar waveguide transmission lines, but they are actually loosely coupled to behave as microstrip. The use of ground planes with plated-through-holes (vias) connecting all three ground layers ensures that the system ground connects the top and bottom ground planes and provides a suitable connection to the buried microstrip (defected) ground plane on copper layer 2. Proper grounding of this buried layer is essential for optimum microstrip and DGS performance. For a traditional

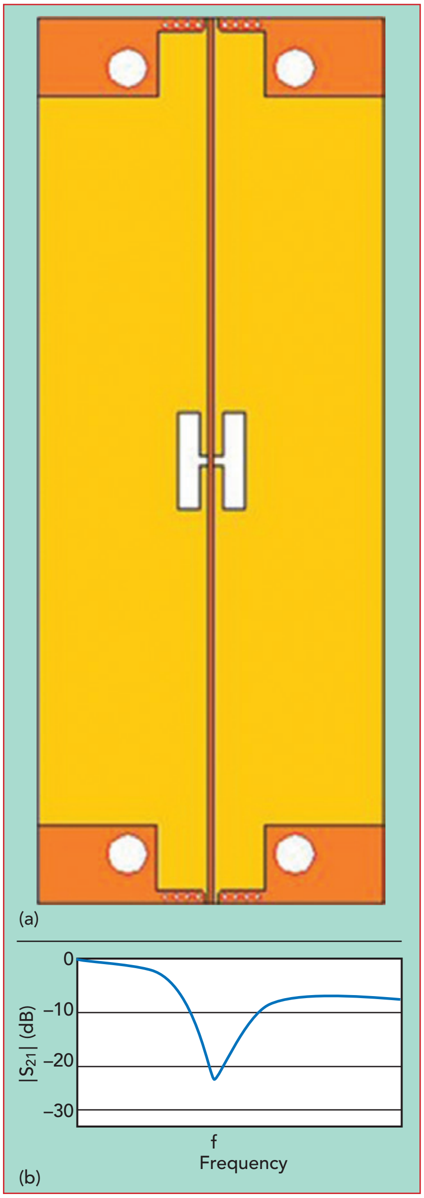

Fig. 1 Top view of a microstrip transmission line with an H-shaped DGS etched in its ground plane (a) and $|S_{21}|$ for this structure (b).

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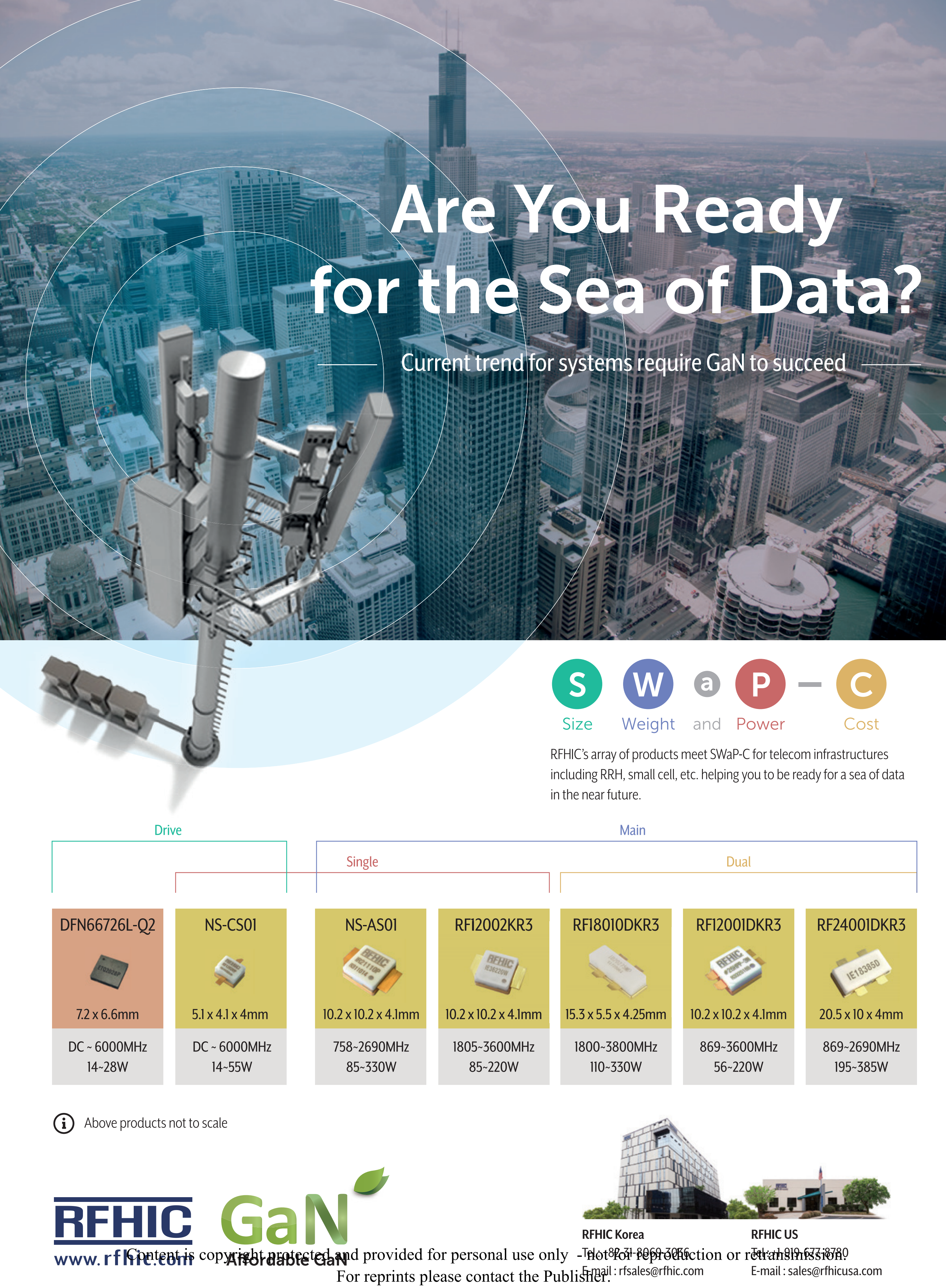

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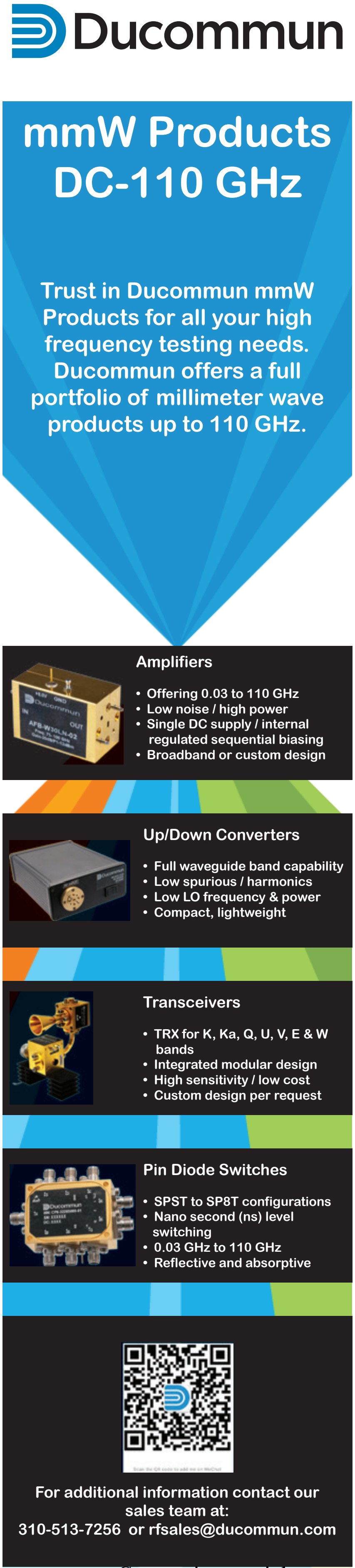

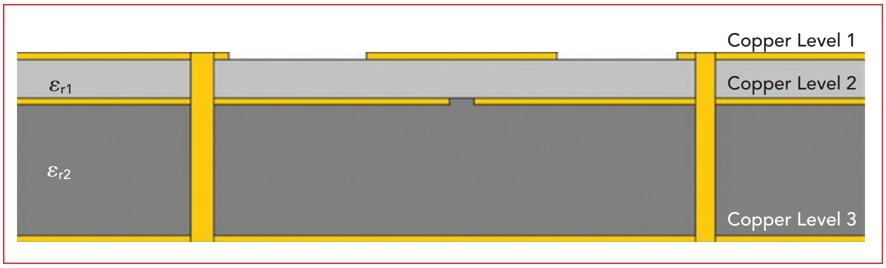

Fig. 2 Cross-section of a PCB with three copper layers used to realize a microstrip DGS without radiation and isolation concerns.

microstrip DGS structure with two copper layers, the ground plane with the DGS opening can radiate energy to the nearby environment. However, with the multilayer construction shown in Figure 2, the radiated energy is captured within the circuit, due to the ground on copper layer 3 and its repetitive grounding vias.

MICROSTRIP STEPPED-IMPEDANCE LPF

A microstrip stepped-impedance structure provides a way to demonstrate the effectiveness of using a microstrip DGS approach for a LPF without encountering radiation or isolation problems. The circuit consists of low-impedance sections cascaded with high-impedance sections in a repeated pattern. When designed properly, these low- and high-impedance sections produce capacitance and inductance values in different sections of the filter, resulting in a LPF function.

Using a microstrip stepped-impedance format, the difference between the high- and low-impedance sections has an effect on the spurious harmonic performance of the filter. A larger difference between the high- and low-impedance values results in less spurious harmonic content and better isolation in the stopband; however, there are limits to the impedance range that can be realized. For example, if the low-impedance circuit element is too wide, it can cause unwanted resonances that distort filter performance. As a general rule, the width of this structure should be no greater than λ/8 at the frequency of interest. Conversely, high impedances require narrow conductors difficult to fabricate in microstrip. Another general rule is that the minimum microstrip conductor width should be 4 mils or more to provide a circuit design that PCB fabricators can manufacture practically and repeatably.

To achieve high-impedance sections, DGS circuit design features are incorporated to increase the impedance of a circuit section without resulting in conductor widths that are too narrow to fabricate. One of these features is an etched opening in the microstrip ground plane under a narrow conductor. The etched opening significantly increases the substrate thickness in the area, with a resulting increase in impedance.

DGS technology can also be used to enhance filter stopband performance and minimize spurious harmonic responses. This can be done with a DGS that causes a bandstop response in the range of frequencies of the spurious harmonic responses or in the range of frequencies where the filter's stopband must be improved. In general, to control a filter's spurious harmonic responses without degrading other filter performance parameters, a narrow bandstop response is created in the frequency range where the harmonic or spurious responses are known to occur. With a DGS, it is typically better to use a wide bandstop configuration within the frequency range of interest.

To better illustrate the benefits of DGS circuit techniques for enhancing the performance of a high-frequency filter, a study of the effects of a DGS on a microstrip stepped-impedance LPF is described. EM modeling is performed using several design approaches and considerations. Physical circuits are fabricated and tested, and the measured performance is compared to the simulated performance from the EM models. To fully understand DGS effects, filters are fabricated using specific combinations of high- and

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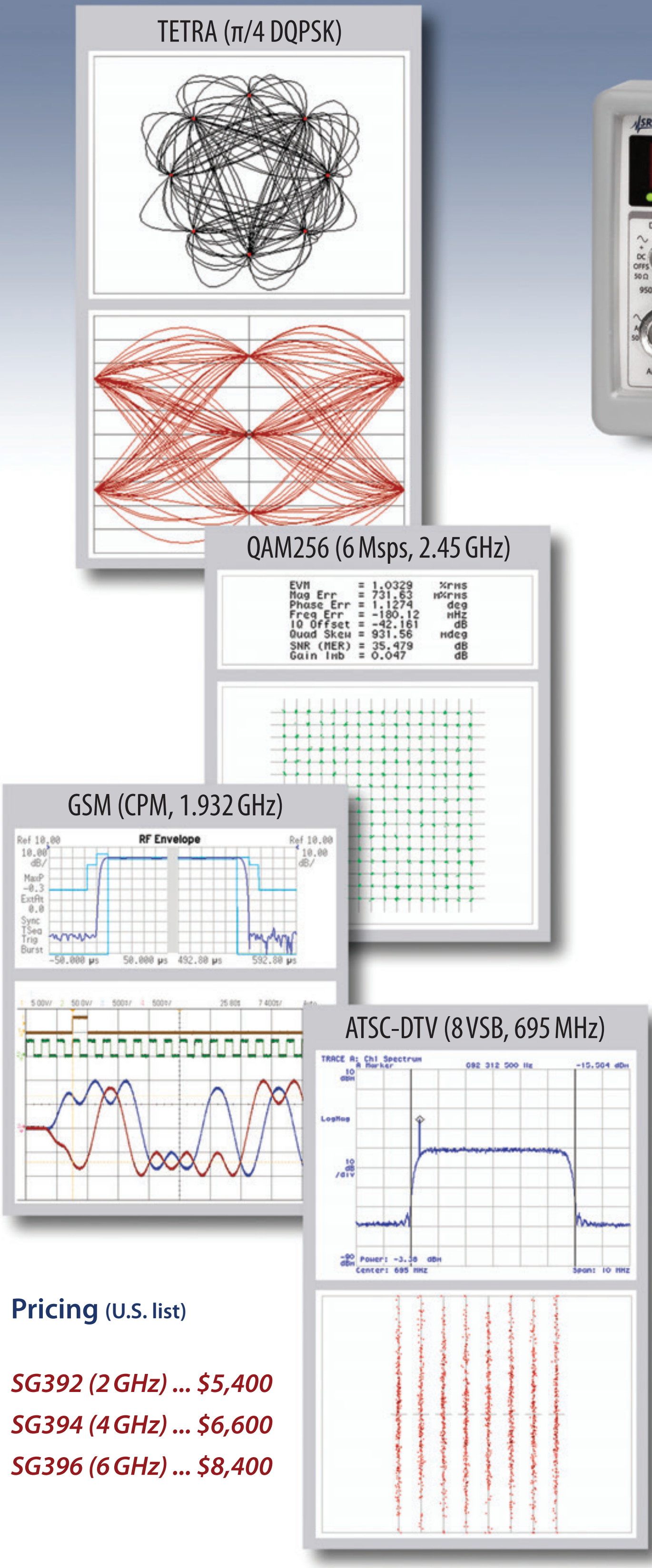

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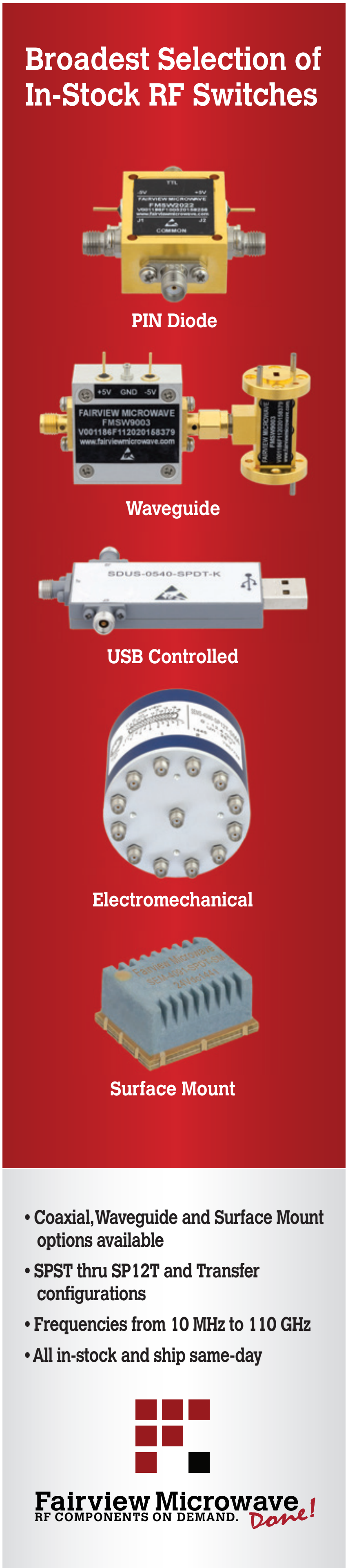

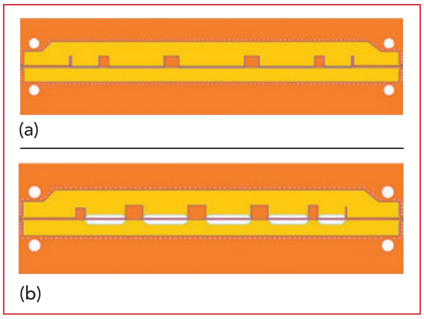

Fig. 3 Conventional microstrip stepped-impedance LPF (a), and a circuit with the same design specifications but with DGS openings in copper layer 2 to achieve high-impedance circuit features (b).

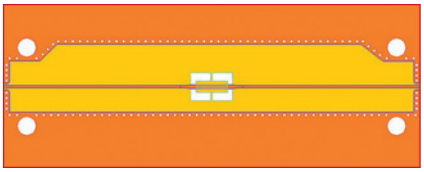

Fig. 4 Prototype microstrip transmission line with an optimized DGS bandstop feature to provide good passband return loss and high rejection at 8.4 GHz.

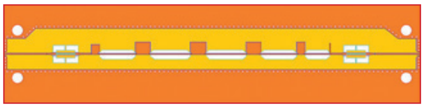

Fig. 5 Final microstrip DGS LPF circuit design, including the transmission line structure for enhanced rejection at 8.4 GHz.

low-ε_r substrate materials to demonstrate how the choice of circuit materials impacts the performance of a microstrip DGS component.

FILTER DESIGN AND MODELING

The LPF design is based on a Chebyshev transfer function with 0.1 dB ripple and a 3 dB cutoff at 2.2 GHz. Several versions of the filter were designed and fabricated. The first is a reference, designed without a DGS. The second targets the same specifications but with two different DGS approaches and with a particular combination of high-ε_r and low-ε_r substrate materials, to form the multilayer structure of the three-copper-layer, microstrip DGS circuit.

The high-ε_r substrate material used for this study is 8-mil-thick RO4360G2™ laminate from Rogers Corp. It has a design Dk of 6.4.

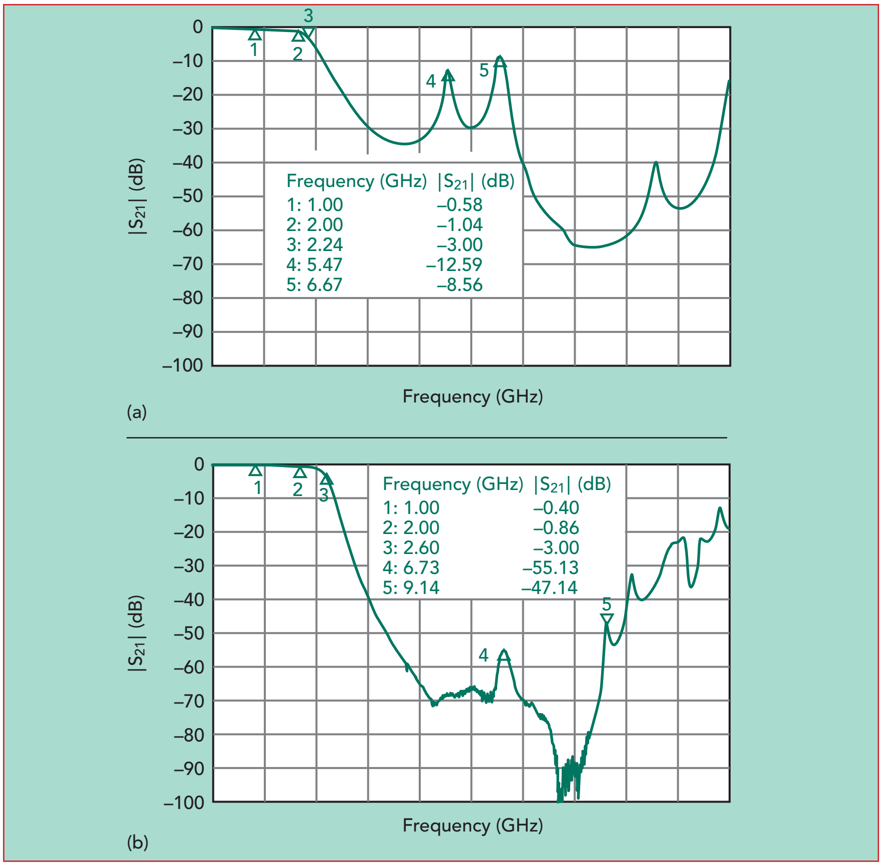

Fig. 6 $|S_{21}|$ of the circuits in Figure 3a without a DGS (a) and LPF in Figure 5 (b).

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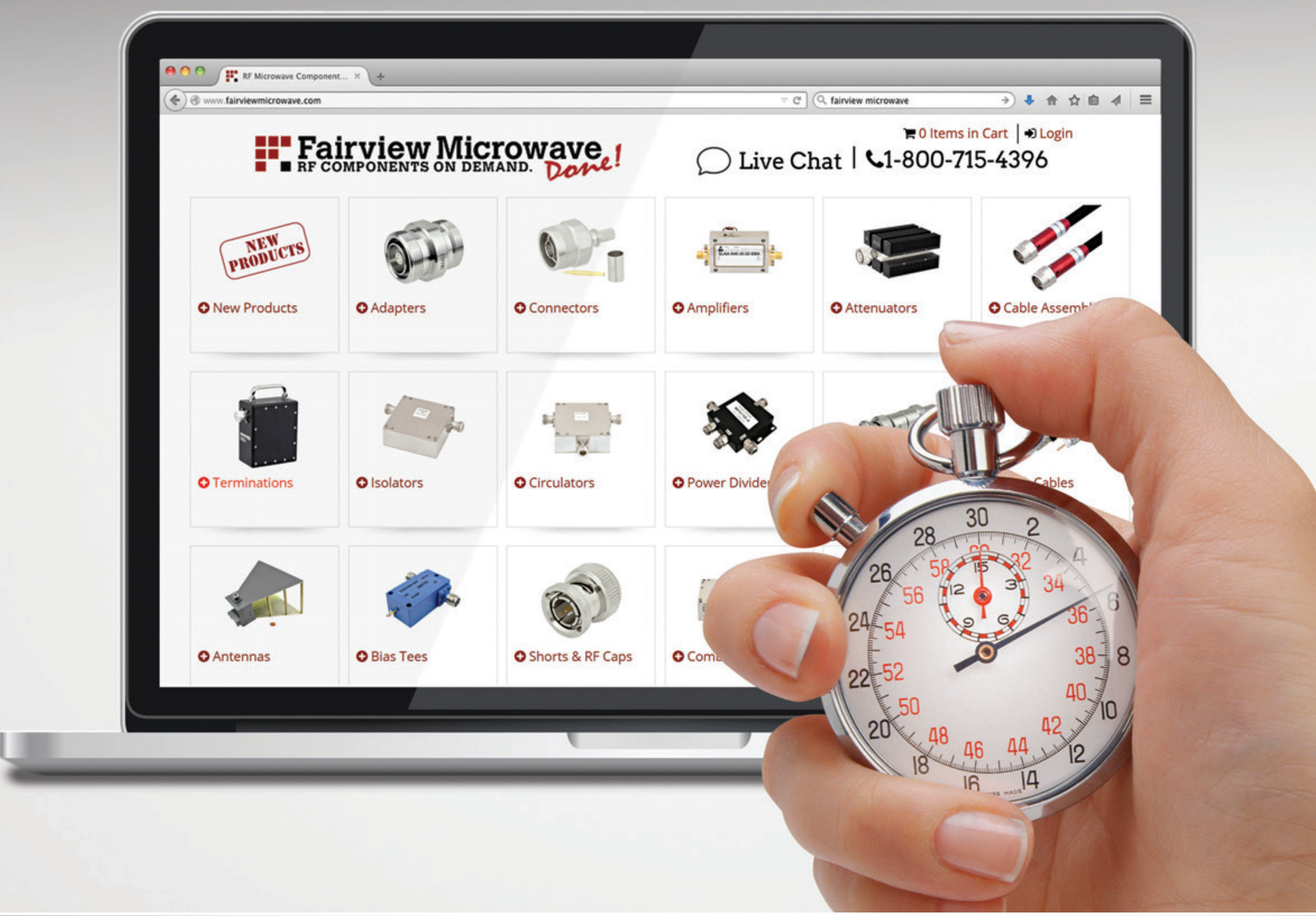

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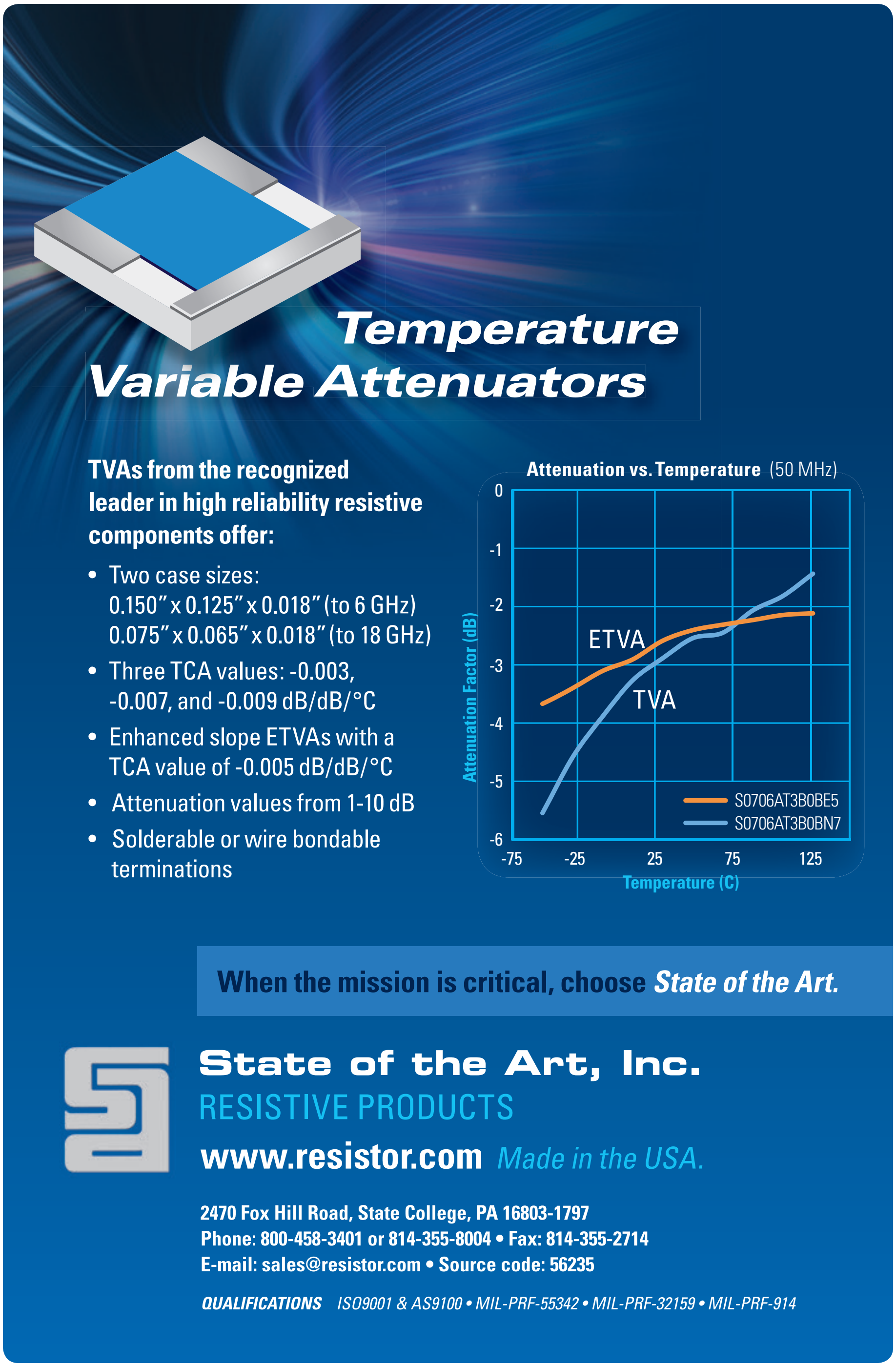
This is the relative permittivity or dielectric constant, ε_r, as perceived by the circuit (shown as ε_{r1} in Figure 2). The low-ε_r substrate is a 22-mil-thick 2929 bondply material, also from Rogers. It has a design Dk of 2.9 (shown in Figure 2 as ε_{r2}). A benefit of this material combination for the stepped-impedance microstrip DGS design is the use of the high-ε_r material for the low-impedance sections; low-impedance circuit features are achieved solely by using the higher ε_r material. When an etched opening is formed in the microstrip ground plane on copper layer 2 to construct the high-impedance circuit features, the circuit behaves as if it is based on a much thicker substrate; the thicker substrate has a combination of ε_r values from the two different substrate materials with design Dk values of 6.4 and 2.9. Considering the thicknesses of the two substrate materials, the combination yields a composite design Dk of about 3.4. The thicker substrate, with its lower ε_r value, is used to form a higher impedance circuit feature than is possible with the 8-mil-thick substrate alone.

Figure 3a is a top view of the first LPF circuit design while the same circuit design with ground openings in copper layer 2 is shown in ***Figure 3b***. The color coding shows the top copper layer (copper layer 1, the signal layer) as dark orange and copper layer 2 (the buried microstrip ground plane) as light orange. There are many repetitive grounding vias (shown as white dots) around the periphery of the circuit features. This ensures that the buried ground plane, the top ground plane and the bottom ground plane are consistently grounded together. The bottom ground plane (copper layer 3, shown in white) is below the microstrip buried ground plane (copper layer 2). If Figure 3b were a true microstrip DGS, with only two copper layers, the white area would represent a pathway where energy could radiate to the outside world. With the bottom ground plane (copper layer 3) present, radiated energy is minimized.

To demonstrate additional benefits of this DGS design approach, assume that excellent rejection is needed at 8.4 GHz. To achieve that performance in the LPF, during the modeling phase of the project, a simple microstrip transmission line is simulated with a specially designed ground opening on copper layer 2 as a DGS; the intent is to achieve a broadband bandstop function at 8.4 GHz. The model is optimized for the best return loss over the LPF's passband, from DC to 2.2 GHz. For improved isolation at 8.4 GHz, the circuit of ***Figure 4*** is included in the final DGS LPF design in the area of the filter's 50 Ω feedline. ***Figure 5*** shows how these circuit features combine to form the final DGS LPF design.

PERFORMANCE

Figure 6 shows $|S_{21}|$ responses of the LPF circuit without DGS features (see Figure 6a) and with DGS features (see Figure 6b). Comparing the filter responses, note that the



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VSWR	3.0:1 (@ 50.0 GHz) Typ - Measured 2.54:1
Isolation	70 dB (0.1 to 1.0 GHz) Typ - Measured 103.7 dB 100 dB (1 to 18.0 GHz) Typ - Measured 107.8 dB 80 dB (18.0 to 40.0 GHz) Typ - Measured 90.8 dB 80 dB (40.0 to 50.0 GHz) Typ - Measured 95.9 dB
RF Input Power	20 dBm Max

Package: 1.0"x0.75"x0.40"
Finish: Gold Plated
RF Connectors: 2.4mm female
DC Voltage: +5 V @ 88 mA
-5 V @ 63 mA
Switching Speed: 33 ns

Model P4T-100M50G-100-T-RD, Absorptive, SP4T

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Frequency	0.1 to 50.0 GHz
Insertion Loss	5.0 dB (0.1 to 18.0 GHz) Typ - Measured 3.2 dB 8.0 dB (18.0 to 40.0 GHz) Typ - Measured 6.2 dB 14.0 dB (40.0 to 50.0 GHz) Typ - Measured 9.1 dB
VSWR	3.0:1 (@ 50.0 GHz) Typ - Measured 2.75:1
Isolation	70 dB (0.1 to 18.0 GHz) Typ - Measured 110.5 dB 100 dB (18.0 to 40.0 GHz) Typ - Measured 102.2 dB 80 dB (40.0 to 50.0 GHz) Typ - Measured 95.9 dB
RF Input Power	20 dBm Max

Package: 1.25"x1.25"x0.40"
Finish: Gold Plated
RF Connectors: 2.4mm female
DC Voltage: +5 V @ 154 mA
-5 V @ 135 mA
Switching Speed: 45 ns

Model: P16T-100M50G-100-T-I, Absorptive, SP16T

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Frequency	0.1 to 50.0 GHz
Insertion Loss	8.0 dB (0.1 to 18.0 GHz) Typ - Measured 12.5 dB 12.5 dB (18.0 to 40.0 GHz) Typ - Measured 17.0 dB 18.0 dB (40.0 to 50.0 GHz) Typ - Measured 20.0 dB
VSWR	3.5:1 (@ 50.0 GHz) Typ - Measured 3.5:1
Isolation	70 dB (0.1 to 18.0 GHz) Typ - Measured 84 dB 90 dB (1.0 to 18.0 GHz) Typ - Measured 92 dB 80 dB (18.0 to 40.0 GHz) Typ - Measured 72 dB 70 dB (40.0 to 50.0 GHz) Typ - Measured 61 dB
RF Input Power	20 dBm Max

Package: 12.00"x5.50"x0.65"
Finish: Gold Plated
RF Connectors: 2.4mm female
DC Voltage: +5 V @ 710 mA
-5 V @ 680 mA
Switching Speed: 90 ns

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filter circuit with DGS was not optimized to achieve the 3 dB cutoff frequency design goal. The 3 dB cutoff frequency for the reference filter circuit (i.e., the circuit with no DGS) is 2.243 GHz (marker 3 in Figure 6a), while the 3 dB cutoff frequency for the filter circuit with DGS is 2.604 GHz (marker 3 in the Figure 6b).

Comparing the $|S_{21}|$ responses of the filters, the most notable differences occur in the stopband beyond the 3 dB cutoff points. For the circuit without the DGS, markers 4 and 5 indicate frequencies where unwanted resonances are causing poor stopband performance. Marker 4 is at a resonant peak associated with the middle section of the high-impedance conductor, and marker 5 is a spurious harmonic at approximately $3f_0$, where f_0 is the 3 dB cutoff frequency. The resonance at marker 4, which is at approximately 5.47 GHz, is due to the high-impedance, narrow conductor in the middle of the circuit, which has a physical length of nearly λ/2 at 5.47 GHz, causing a standing-wave resonance for that wavelength and frequency. For the LPF circuit containing the DGS, the high-impedance sections are physically shorter and the wavelength is different in that area because the conductor experiences a thicker substrate which has a relative permittivity of the combined materials (ε_{r1} of 6.4 and ε_{r2} of 2.9). Additionally, the DGS openings produce a slow-wave effect, which allows the circuit features to be shorter. Due to these differences, the λ/2 resonance at 5.47 GHz is eliminated with the DGS structure.

Having a spurious harmonic at $3f_0$ is a natural byproduct of a microstrip stepped-impedance filter. It is well known that this spurious harmonic can be significantly suppressed if the high-low impedances of the stepped-impedance circuit features have a wider range. Marker 5 at $3f_0$ (6.671 GHz) for the circuit without the DGS shows a loss response of 8.6 dB, where the circuit with the DGS (marker 4 at $3f_0$) shows a loss response of 55.1 dB. Also note the stopband improvement at 8.4 GHz with the filter having the DGS. High losses of almost 90 dB are shown between markers 4 and 5, in the vicinity of 8.4 GHz.■

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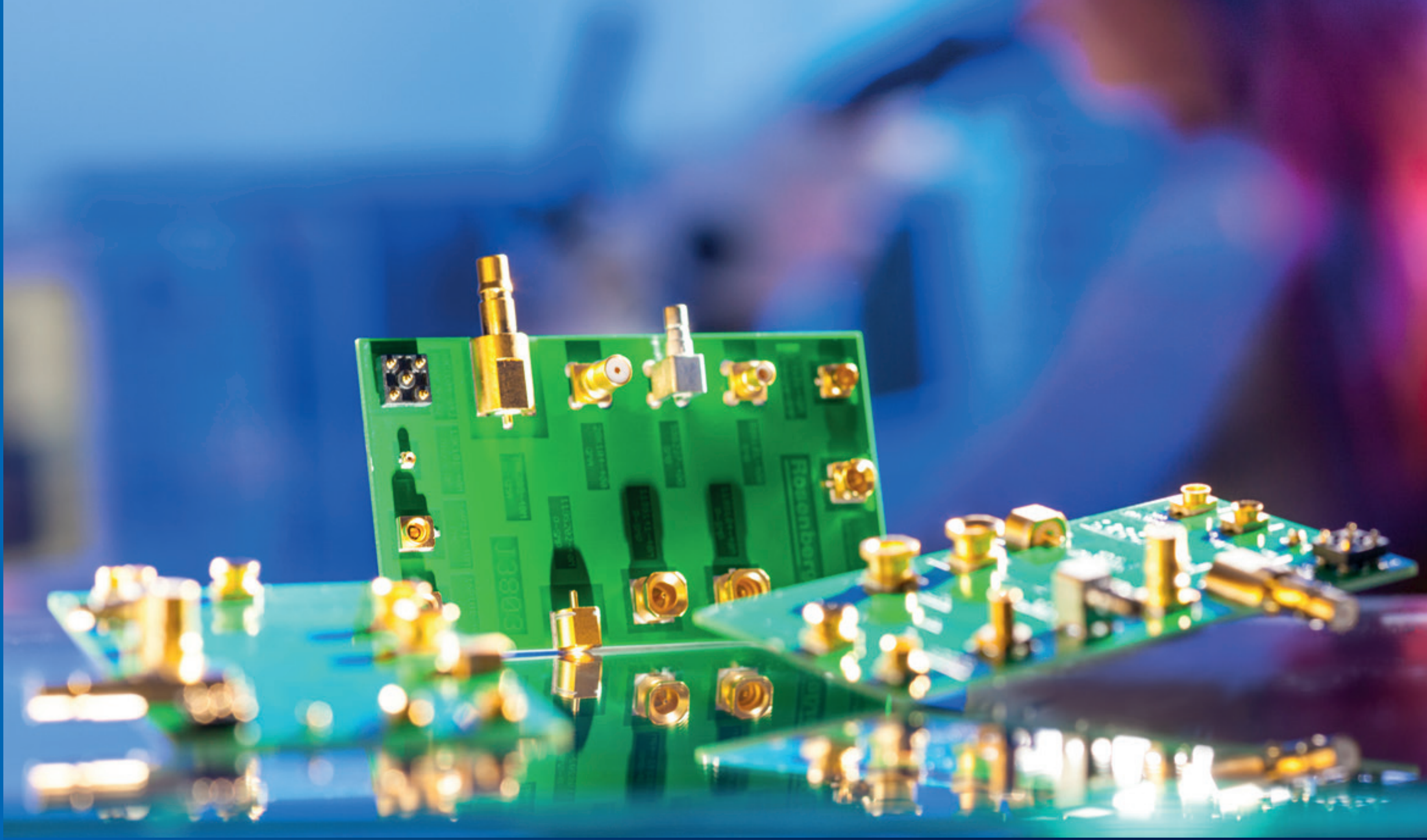

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Multi-Path Simulator Simultaneously Tests Two SATCOM Links

AtlanTecRF
Braintree, U.K.

There has never been a better time to be talking about simulation of satellite transponders. These high flyers are incredibly expensive "pieces of kit," not just to build but also to launch and operate. While there is a strong and concerted effort to drive down the cost of low orbit vehicles and to provide alternative fixed geo-position platforms, such as high-altitude platform stations (HAPS), still the majority of high data rate traffic is cornered by the multi-billion dollar geostationary "birds." Using those for testing ground stations of any size does not make economic sense. The current alternative of convenient-to-use, comparatively low-cost satellite simulators has begun to have an impact on just about every SATCOM application, from commercial satellite news gathering (SNG), to in-flight internet connectivity, to military secure communications.

After addressing these markets with a range of products, AtlanTecRF is introducing the MSS Multi-Path Satellite Simulator, to tackle the needs of equipment manufacturers where the program requires delivery of portable, ground/mobile terminals as part of a civilian or defense communications network. This Simulator offers the capability to simultaneously test two terminals, proving the entire

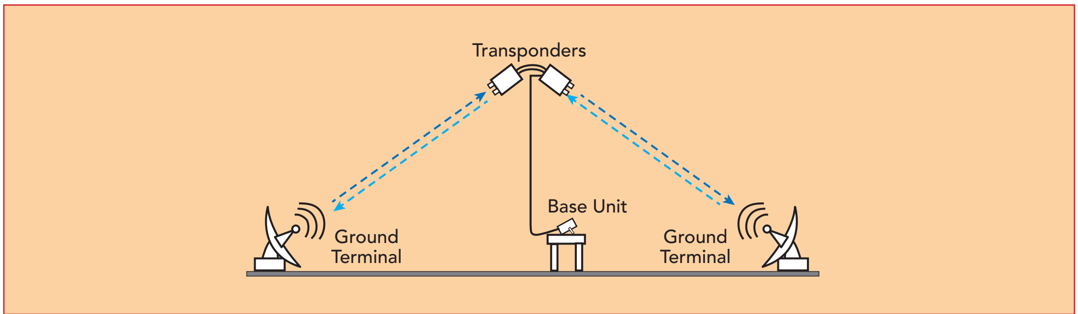

Fig. 1 The AtlanTecRF MSS Multi-Path Satellite Simulator simultaneously talks to two sets of ground equipment, enabling the user to run extensive and prolonged tests without the need to go "live" on a satellite.

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Fig. 2 The MSS Multi-Path Satellite Simulator comprises two interconnected modules, each capable of communicating with a fixed or mobile terminal at Ka-, Ku- or X-Band. The Ka-Band version is shown.

contract hardware with a minimum of satellite interaction. ***Figure 1*** shows the MSS Multi-Path Satellite Simulator setup. The system talks to two sets of ground equipment simultaneously, enabling the user to run extensive tests without the need to go "live" on a satellite. The whole network can be set up to a deliverable state, with contract performance achieved in an extremely cost-effective manner.

Satellite Simulators in the MSS series consist of two interconnected modules (see ***Figure 2***), each capable of communicating with a fixed or mobile terminal at either Ka-, Ku- or X-Band with the ability to vary the path attenuation, thereby reducing the real-world atmospheric effects. Taking the uplink or transmit (Tx) carrier from one ground-based system, the MSS re-transmits on the receive (Rx) carrier frequency for the downlink. But instead of sending the signal back to the same ground station, the MSS contacts a second ground terminal, completing the satellite link from point A to point B without any satellite being involved. The MSS Multi-Path Satellite Simulators accommodate the appropriate polarizations of the various carrier configurations, with horizontal and vertical being the most favored at Ku-Band and right- and left-handed circular the norm at Ka-Band.

Internally, the Satellite Simulator has the architecture of a high performance microwave frequency converter, which includes variable input attenuation to simulate the naturally-varying effective isotropic radiated power (EIRP) levels experienced in a typical 44,000 mile round-trip satellite link through the Earth's atmosphere. The other variable parameter is the local oscillator (LO) frequency, which is adjustable to ensure coverage of every likely satellite transponder link. Control of the attenuation and frequency are achieved through AtlanTecRF's proprietary digital control technology which, via Ethernet, provides the user with the choice of a PC graphical user interface or remote programmed control for automated test schedules. With such a Satellite Simulating Test System, the program provider can test multiple Tx

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Fig. 3 Side view of the Ka-Band Multi-Path Satellite Simulator, showing the antennas.

and Rx paths over the full envelope of frequency regimes, gathering data to verify the deliverable performance criteria in a timely and cost-effective way.

The MSS Satellite Simulator Systems are typically supplied as a two-module set to point to each of a two-terminal communications link. Each module has waveguide horn antennas, of nominal 15 dB gain, whether of linear or circular polarization (see ***Figure 3***). The internal input attenuator is controllable in 0.5 dB steps to 60 dB, while the frequency range of the LO enables all the standard operating bands to be explored. The base conversion is selectable through options from -20 to +10 dB. LO frequency stability is determined by either an internal, very high grade, low phase noise, oven-controlled crystal oscillator (OCXO) or from an input from the general system's 10 MHz reference. Other optional features include phase shift and time delay, further emulating the true and likely conditions encountered in the application. Importantly, ease of use is key with no complex menu chains, rather a quick reacting setup and responsive controls.

In addition to the issues of economics and speed, there may also be other critical considerations when employing this off-air testing using the MSS. If the projected use of the multi-location communications system is to carry confidential commercially or military information, there is much to be gained by carrying out link path testing in a secure environment, rather than in public on an open satellite transmission. This effectively deprives competitors or the enemy the heads-up on encryption techniques before real and vital data is sent. Also, by testing privately across the available Ka-, Ku- and X-Band spectrum, the actual frequencies to be used are not divulged, and the operator, once again, stays ahead of the game.

VENDORVIEW

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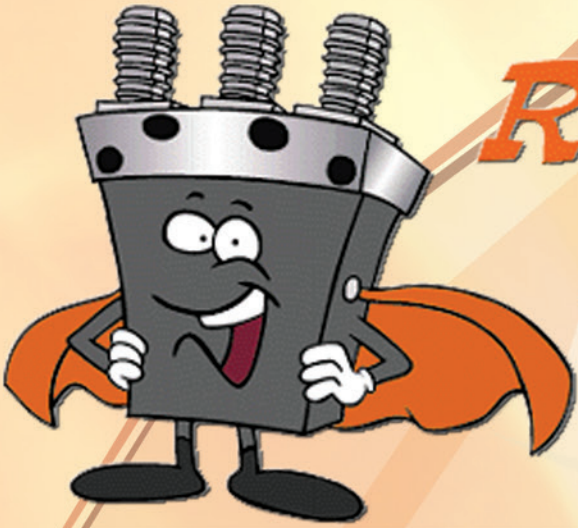

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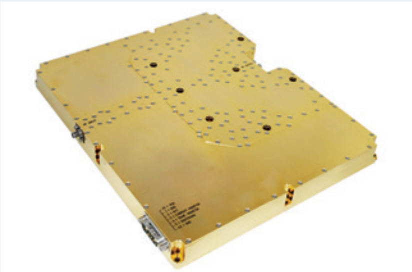

40 W, 6 to 18 GHz, GaAs FET Power Amplifier

Exodus Advanced Communications has extended its portfolio of solid-state high-power amplifiers (HPA) with the AMP1121, a linear GaAs FET design that provides 30 W at 1 dB compression and 40 W saturated, with an instantaneous bandwidth from 6 to 18 GHz. The amplifier has 45 dB minimum power gain and 4 dB maximum peak-to-peak flatness when driven with a constant input of 0 dBm.

The AMP1121 is biased with +12 VDC and draws a maximum of 42 A. The stand-alone amplifier measures 300 mm × 300 mm × 27 mm and is also available in a standard 19-inch rack chassis configuration with self-contained air cooling and AC power. An optional controller with a front panel touch-screen LCD supports Ethernet TCP/IP, RS422 or RS485 and, if requested, GPIB or Bluetooth connectivity.

Suitable as a TWTA replacement, the solid-state HPA may be used in a variety of applications, such as EMI/RFI susceptibility testing, jammers and X-/Ku-Band communications. Other standard products include 10 and 20 W PAs within the same family of 6 to 18 GHz amplifiers and PAs up to 50 W covering 2 to 18 GHz. Exodus Advanced Communications' full portfolio of solid-state power amplifiers covers frequency bands from 100 kHz to 51 GHz, with output power greater than 1 kW for modules and 10 kW for complete systems.

Exodus PAs use discrete LDMOS, GaAs and GaN devices assembled with hybrid chip-and-wire technology and ceramic substrates. In-house capabilities include RF circuit design; system mechanical, electrical and digital circuit design; control software development; and prototype verification.

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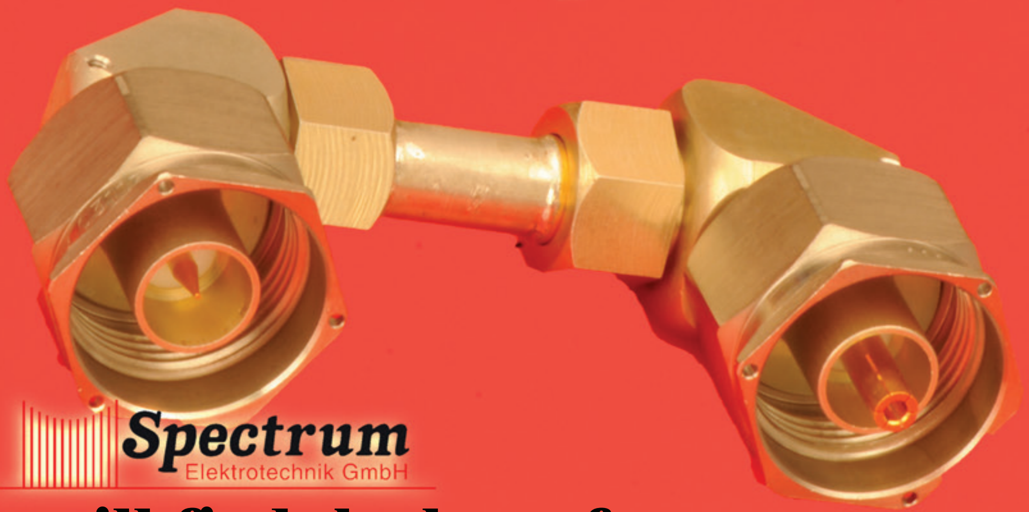

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Multi-Channel Radar Modules for 24 GHz ISM Band

Frequency modulated continuous wave (FMCW) radar measures distances and relative velocity of targets, but the angular position of an object inside the viewing area of the radar antenna cannot be determined by a simple one transmit and one receive antenna per channel configuration. However, the angle is an important measurement parameter in many applications, requiring transmit and/or receive channels to be added to the radar.

IMST is addressing this issue with multi-channel radar modules for the 24 GHz ISM band, currently focusing on the development of the sR-1200e certified module and two development modules, the sR-14MP and the sR-1800e. The sR-1200e 24 GHz radar module comprises one transmit and two receive channels enclosed in a waterproofed housing (IP65), either black or transparent. The receive channels measure I/Q data, with the A/D conversion, signal processing, ramp generation and parameter setting done by an integrated TI digital signal controller. The radar module features an Ethernet (Power-over-Ethernet) interface, and other interfaces can be supported if requested.

In cases when the elevation angle measurement is also required, at least a third receive antenna is needed. Such a configuration has been developed by IMST by applying the monopulse (MP) technique to the sR-14MP module, which features one transmit and four receive channels. The four receive antennas are placed in a square formation close to the transmit antenna. Evaluating the time-of-arrival from the pair of two vertically-displaced antennas, calculation of the elevation angle becomes possible, in addition to the azimuth angle, which is determined by the pair of two horizontally-separated antennas.

The latest radar design, the sR-1800e, features a 14-element receive antenna array connected to eight receiver channels by a Rotman lens beamforming network (BFN). This passive BFN divides the 72 degree azimuth field-of-view into eight, 9 degree, fixed angular sectors, making FMCW distance measurements simultaneously available in all sectors and avoiding angular ambiguities, increasing the reliability of the radar, e.g., in security applications.

IMST, Kamp-Lintfort, Germany
www.radar-sensor.com
www.IMST.com

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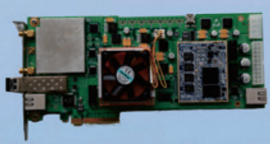

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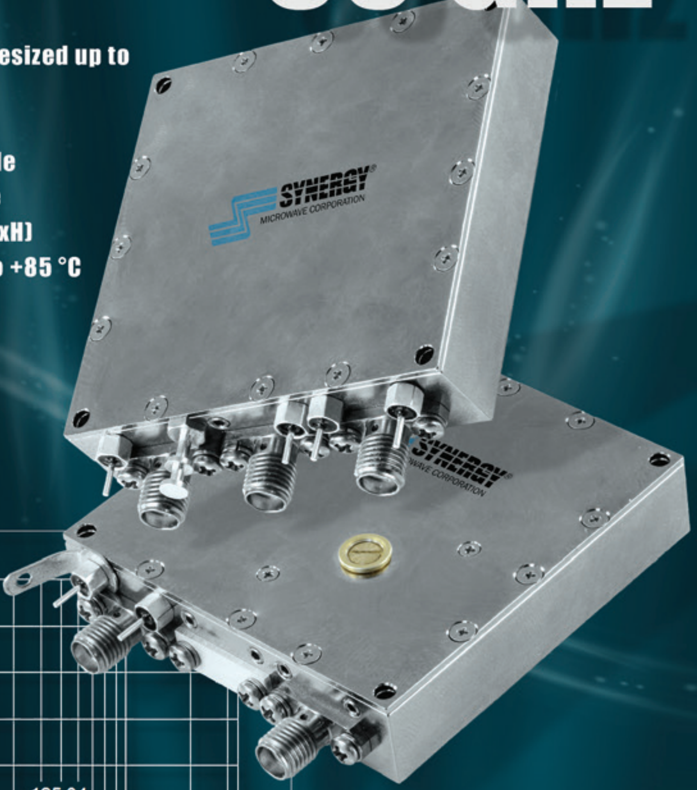

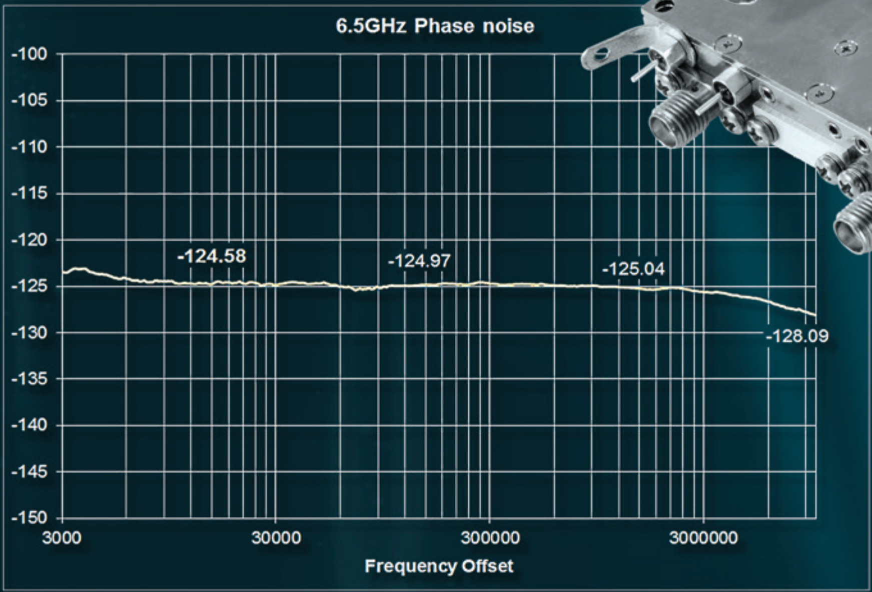

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Affordable Signal/ Spectrum Analyzers From 4 to 67 GHz

Ceyear, the new brand name of the China Electronics Technology Instruments Co. Ltd. (CETI), makes powerful measurement solutions at attractive prices, enabling businesses with tight equipment budgets to afford more measurement capability.

The AV4051 signal and spectrum analyzer is one example, offering excellent dynamic range, phase noise and test speed and available with nine upper frequency options, from 4 to 67 GHz. Coverage to 500 GHz is possible with an external mixer. The displayed average noise level (DANL) of the analyzer is -156 dBm/Hz at 1 GHz, -141 dBm/Hz at 50 GHz and -135 dBm/Hz at 67 GHz. The AV4051 has three analysis bandwidth options: 10, 40 and 200 MHz, adjustable to more than 40 levels from 10 Hz to the maximum bandwidth. With 4 GB of memory, data streams can be recorded from 2 s to several hours, depending on the selected bandwidth.

The instrument's spectrum analysis capabilities include sweep and FFT sweep, zero span fast sweep (1 μs), frequency counting with 0.001 Hz resolution and test functions for occupied bandwidth, channel power, adjacent channel power, harmonic distortion and third-order intercept. The AV4051 performs transient analysis, with time-domain and frequency-domain correlation, and provides a waterfall display showing spectrum changes versus time. Phase noise testing is also part of the analyzer's capabilities.

The unit has a 10.1-inch LCD display with 1280 × 800 pixel resolution and supports USB, LAN and GPIB interfaces. Outputs include digital, 1× or 4× optical fiber and a real-time interface for recording I/Q data. An external digital recorder supports SSD and HDD media.

AV4051 pricing starts at $25,500, which is very competitive with other signal and spectrum analyzers.

VENDORVIEW

Ceyear, U.S. Distributors: TopDogTest and Custom-Cal Globaltech
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Down-Converter Extends Cellular Equipment Coverage to mmWave

To help mobile operators, field technicians and wireless equipment providers monitor and test the mmWave devices and networks being developed for 5G, ThinkRF offers the D2030 Downconverter, which enables the 27 to 30 GHz frequency band to be tested using existing equipment covering the sub-6 GHz cellular bands. ThinkRF developed the D2030 collaborating with VIAVI Solutions, so it works with VIAVI's 2G/3G/4G CellAdvisor and other third-party test equipment.

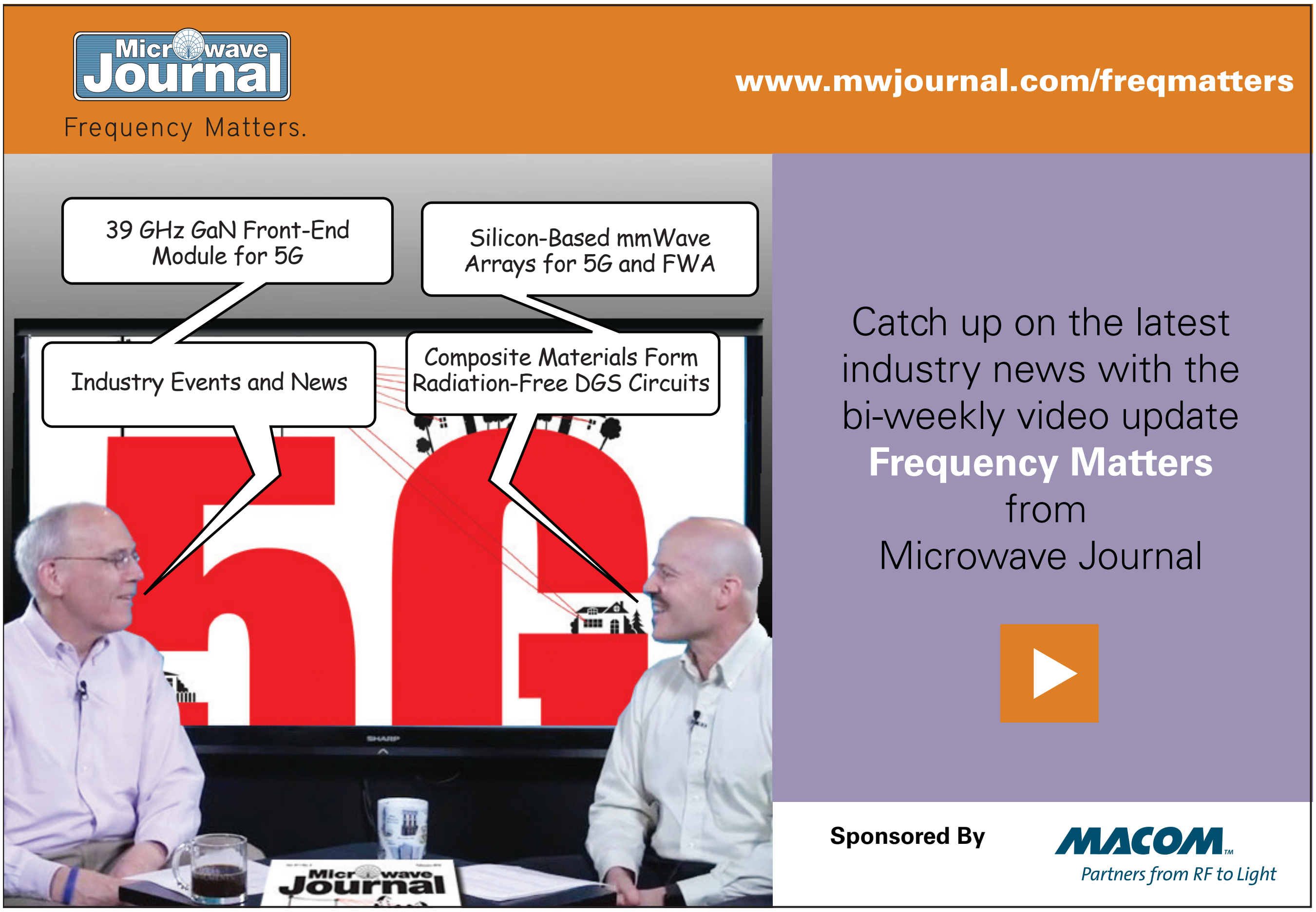
Using patented, software-defined radio technologies, the D2030 is controlled via Ethernet from either a spectrum analyzer or PC and uses the standard software commands for programmable instruments (SCPI) interface. The IF output from the down-converter can be 3.55 or 5.6 GHz, with a real-time bandwidth of 160 MHz and 100 kHz tuning resolution. Multiple units can be synchronized using 10 MHz input and output clock reference signals.

The D2030 Downconverter's conversion gain is nominally 0 dB, or 10 dB using the internal preamplifier. The noise figure is nominally 25 dB, dropping to 10 dB with the preamplifier on. Phase noise across the 27 to 30 GHz band is -72 dBc/Hz at 10 kHz offset, -80 dBc/Hz at 100 kHz offset and -105 dBc/Hz at 1 MHz offset. With the preamplifier off, the third-order intercept is typically +10 dBm, with input-related spurious signals a minimum of 53 dBc at an RF input level of -30 dBm. The maximum operating RF input level is -20 dBm.

The ThinkRF D2030 Downconverter is a compact design, measuring 7.5 in. × 8.5 in. × 1 in. and weighing less than 2 lbs, making it portable, versatile and easy to use without adding significant size, weight or power requirements. The unit is biased with +12 VDC and dissipates 6 W.

ThinkRF develops software-defined spectrum analyzers that monitor, detect and analyze signals for wireless, signals intelligence, surveillance countermeasures and test and measurement applications.

ThinkRF
Ottawa, Ontario
www.thinkrf.com



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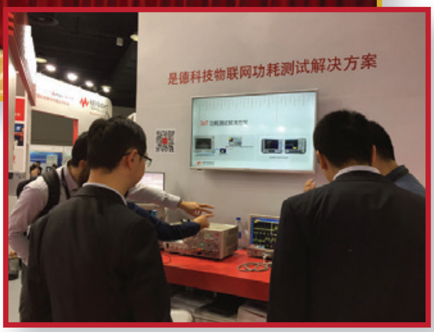

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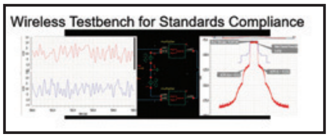
Software and Mobile Apps

Updated Spectre® RF Option



Cadence's Spectre® RF Option offers high performance circuit simulation using a patented time-domain engine with superior VCO phase-noise simulation and a frequency-domain engine delivering fast, accurate RFIC verification. The latest version supports wireless standards including: 802.11ax, 802.11p, LTE Downlink and TDD and Bluetooth Classic, as well as enhancements to Bluetooth LE and EDR. Its updated PNOISE analysis capability supports additional measurements and new use models. It is also integrated into the Virtuoso® Analog Design Environment for more complete design validation.

Cadence
www.cadence.com

CST STUDIO SUITE 2018

The electromagnetic (EM) simulation software CST STUDIO SUITE is used by industry-leaders to design, analyze and optimize components and systems across the EM spectrum. The 2018 release of CST STUDIO SUITE develops on previous success with a range of new features, including a new Assembly Modeler for system simulation, coupling matrix optimization for filter tuning and the new Hybrid Solver Task which allows a bidirectional link between the Time Domain Solver and Integral Equation Solver for efficient hybrid simulation.

CST - Computer Simulation Technology
www.cst.com/2018

K&L Filter Wizard®

K&L Microwave's Filter Wizard® synthesis and selection tool streamlines identification of RF and microwave filters, meeting customer requirements across a large portion of K&L's standard product offerings. Filter Wizard® accelerates user progress from specification to RFQ over an ever-increasing range of response types, bandwidths and unloaded Q-values. Provide the application with desired specifications, and the software returns a list of products that match, placing response graphs, outline drawings and downloadable S-parameters at your fingertips. Visit the site via computer or mobile device to get started.

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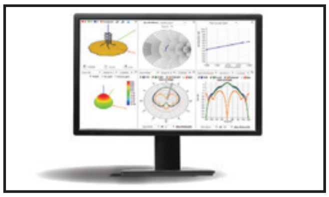
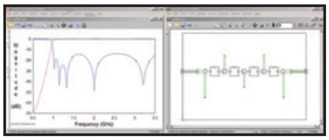
AntSyn Adds New Features and Enhancements



Over 30 new features and enhancements have been added to the latest release of AntSyn™ automated antenna design, synthesis and optimization software. Of particular note are 39 new additions to the antenna design library, including a suite of multifunction, computer-generated mesh antennas for MIMO wireless devices. A complete list of new features and enhancements is available in the What's New documentation on the AntSyn customer portal. To learn more visit their website.

National Instruments
www.awrcorp.com/antsyn

Filter Design Software from Nuhertz



FilterSolutions® from Nuhertz Technologies integrates highly accurate lumped element models created by Modelithics® into Sonnet Software's popular Sonnet Suites®. The marriage of these three outstanding programs creates one easy-to-use design solution. Modelithics capacitor models are useful in designing highpass and bandpass planar filters requiring series capacitors. The user selects the desired capacitor family, FilterSolutions then selects the Modelithics model that most closely matches the ideal value and then installs that model into the Sonnet Schematic.

Nuhertz Technologies
www.nuhertz.com

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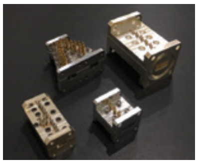
COMPONENTS

SPDT RF Switch

Aethercomm model number SSHPS 0.100-0.500-400 is a high-power symmetrical SPDT RF switch, which is employed in communication systems where high-power, low loss and excellent isolation are required. This unit operates across the military UHF communication range. The switch operates from +28 V DC supply with 550 mA maximum current draw.

Aethercomm
www.aethercomm.com

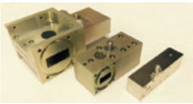
Compact Waveguide Filters



Exceed Microwave's WC-Series waveguide bandpass filters are high performance filters that come in small sizes. The typical length is half of the standard H-Plane Iris Coupled waveguide filters. Compared to standard waveguide filters, the WC-Series filters are capable of achieving very wide passbands and at the same time provide excellent high frequency rejection, including higher order modes above the waveguide cutoff frequency. Typical return loss is 20 dB or better across the entire passband. The WC-Series filters are an excellent choice when space is limited and need high performance.

Exceed Microwave LLC
www.exceedmicrowave.com

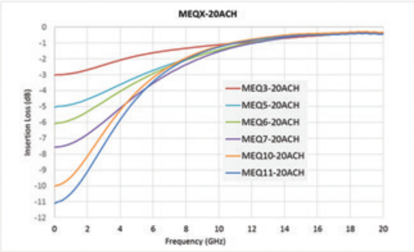
Waveguide Isolators



The 62IJ1211PM is a WR62 isolator with a -50 dB power monitor that samples reverse/reflected power. This unit operates at 80 W avg./80 Kw peak with 0.2 dB loss and 23 dB isolation typical. M Wave Design Corp. offers waveguide isolators and circulators from 1 to 65 GHz. This series boasts power handling up to 1 Kw average and 800 Kw peak (depending on guide size).

M Wave Design Corp.
www.mwavedesign.com

GaAs MMIC Equalizers



Marki Microwave has expanded their line of passive GaAs MMIC equalizers to cover all applications from L- to Ka-Band. The MEQ series equalizers are an ideal solution for compensating for low pass filtering effects in RF/microwave and high speed digital systems. Optimized for excellent return loss over the entire band, the MEQ series equalizers provide consistent unit-to-unit performance in a small low-cost form factor. All MEQ equalizers are available in 1.25 mm² die.

Marki Microwave
www.markimicrowave.com

Public Safety/Rail & Transportation Combiners

VENDORVIEW

Components and equipment are designed for the challenging environmental conditions of the public safety, rail and transportation industries. Many of MECA's products meet IP 67/68 ratings and are subjected to harsh winters (extremely low temperatures and road salt) and summers (hot and humid) under public safety applications. MECA's low frequency addition to the H-Series, 100 W Wilkinson high-power combiner/dividers. Available in 2- and 4-way configurations covering 5 to 500 MHz. VSWR of 1.30:1 accommodating load VSWR's of 2.0:1 or better. N and SMA connectors.

MECA Electronics Inc.
www.e-MECA.com

2-Way, 90° Power Splitter

VENDORVIEW

Mini-Circuits new 2-way, 90° power splitter, QCH-63 capable of handling up to 200 W with amplitude unbalance of ±1.0 dB typ. and phase unbalance of ±1.5 deg. typ. Operating over a frequency range of 2000 to 6000 MHz, the outstanding phase and amplitude unbalance make this component a versatile building block for use in a variety of systems and sub-system designs from balanced amplifiers and antenna feeds to military applications and more.

Mini-Circuits
www.minicircuits.com

Coupler

VENDORVIEW

The MRFCP0015 coupler is designed for applications that require very small, low cost and highly reliable surface mount components. Applications may be found in broadband, wireless and other communications systems. These units are built lead-free and RoHS compliant and feature welded wire construction for increased reliability.

MiniRF
www.minirf.com

Hi-Q/Low ESR Capacitors

Passive Plus Inc. now offers extended-values for the traditional NPO, Hi-Q 0505 (0.055 in. x 0.055 in.)--now available up to 1000 pF; and 1111 (0.110 in. × 0.110 in.--now available up to 10,000 pF (0.01 uF). The 0505 and 1111 have an increased operational temperature up to 200°C. These parts exhibit low ESR/ESL, low noise, high self-resonance as well as ultra-stable performance over temperature. Usually used for wireless broadcasting equipment, mobile base stations, GPS, MRI and radar applications and offered in magnetic and non-magnetic terminations.

Passive Plus Inc.
www.passiveplus.com

Programmable Attenuators

RLC Electronics' PA series attenuators are binary programmable step attenuators designed to operate from DC to 18 GHz. RLC offers two basic models; One type with 0 to 15 dB attenuation range in 1 dB steps, and the other type with 0 to 70 dB attenuation range in 10 dB steps. The attenuators are available with failsafe or latching operation, 12 or 28 V coils, optional TTL drivers, and a choice of frequency ranges, with typically less than 1 dB of loss over the DC to 18 GHz range.

RLC Electronics Inc.
www.rlcelectronics.com

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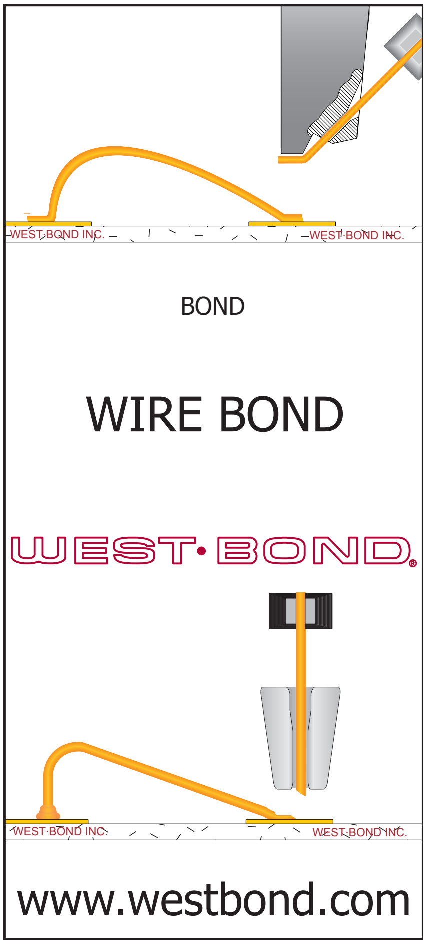
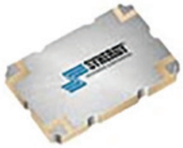


NewProducts

High-Power Bi-Directional Coupler



The SCS-8012D is a small footprint, surface mount, 20 dB bi-directional coupler operating in the frequency range of 800 to 1200 MHz. Coupling flatness across this band is ±0.6 dB maximum and the mainline loss is 0.25 dB maximum. Directivity from 815 to 960 MHz is 22 dB typical and full band is 18 dB. VSWR across the band is typically 1.25:1. The power handling capability is 100 W and the package size is 0.56 in. × 0.35 in. × 0.65 in. Other models are available in the same series.

Synergy Microwave Corp.
www.synergymwave.com

CABLES & CONNECTORS

Rugged Test Cables

Pasternack has launched a new series of handheld, RF analyzer, rugged, phase-stable cable assemblies. Typical applications include field testing, tower measurements, base station analyzers, handheld network analyzers, portable spectrum analyzers, distance-to-fault measurements and site maintenance. Pasternack's new line of test cables for handheld RF analyzers consists of 19 models designed to deliver optimal amplitude and phase stability with flexure. They boast VSWR as low as 1.2:1 and maximum operating frequency of 27 GHz, depending on the configuration.

Pasternack
www.pasternack.com

Solderless Edge Launch Connectors

SV Microwave's new solderless edge launch connectors mount fast and easy for rapid prototyping. SV's unique design adjusts to accommodate multiple PCB thicknesses and is available in their high frequency SMA, 2.92 mm, 2.4 mm and 1.85 mm connector series. COTS versions available through distribution.

SV Microwave
www.svmicrowave.com

AMPLIFIERS

X-Band Radar Solid State Power Amplifier

COMTECH PST introduces a new GaN amplifier for applications in the X-Band pulsed radar market. The AB linear design operates from 9 to 9.9 GHz frequency range over any instantaneous bandwidth of 500 MHz. Development of this product is intended for use in ruggedized radar applications. The amplifier design features self protection for load VSWR, duty factor, pulse width, temperature, as well as a graceful degradation in case of a RF power module failure. Custom configurations and features are available as well as specific power levels up to 16 kW.

COMTECH PST
www.comtechpst.com

Solid Power Amplifier Module

Exodus Advanced Communications is introducing the AMP1147, 500 to 6000 MHz, 10 W, 40 dB, 28 V module. This class AB linear state of the art solid state high-power amplifier features instantaneous ultra-broadband GaN design in a small form-factor, lightweight aluminum housing, and built-in protection circuits for high-reliability and ruggedness.

The AMP1147 is suitable for all single channel modulation standards and for typical applications including communication systems, manpack and airborne jammers, UAV applications, HPA's driver and general laboratory and testing applications.

Exodus Advanced Communications
www.exoduscomm.com

50 W, 8.5 to 11 GHz, Fully-Matched GaN/SiC Transistor

Model number IGT9010M50X-PR1 is designed for X-Band radar applications, this upcoming high-power GaN-on-SiC HEMT transistor is being previewed with preliminary data as follows: Fully-matched to 50 Ohms, 50 W of peak pulsed output power at 42 V drain bias, with 11 dB gain and 42 percent efficiency, at 10 GHz, 100 microseconds and 10 percent pulse conditions.

Integra Technologies
www.integratech.com

High-Power Amplifier

The ZHL-15W-422+ is a Class A, high-power amplifier providing 15 W saturated power over the 700 to 4200 MHz band, ideal for a variety of high-power test set-ups as well as applications including communications, radar and more. The ruggedly-designed amplifier provides unconditional stability and built-in self-protection against reverse polarity, shorting/unshorting and overheating. It is capable of withstanding short and open circuits at output while continuously delivering 10 W of power.

Mini-Circuits
www.minicircuits.com

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NewProducts

Low Noise Amplifier

VENDORVIEW

PMI Model No. PE2-30-1R018R0-4R5-22-12-SFF-1 is a 1 to 18 GHz, low noise amplifier that typically provides 30 dB of gain while maintaining a maximum gain flatness of ±1.5 dB over the operating frequency. The noise figure is 4.5 dB maximum and offers an OP1dB of 22 dBm minimum. Operating voltage is +12 to +15 V DC with a typical current draw of 500 mA. The unit is supplied with removable SMA(F) connectors in its standard PE2 housing.

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

Darlington Pair SiGe Gain Blocks

VENDORVIEW

RFMW Ltd. announces design and sales support for a series of Darlington pair SiGe gain block amplifiers from Qorvo. Operating over a frequency range of DC to 4500 MHz, these gain blocks (QPA5389A, QPA6489A and QPA7489A) offer gain and output power options for applications in LTE infrastructure, repeaters, test & measurement and defense. With single supply operation, these cascadable gain blocks are available in SOT-89 packaging.

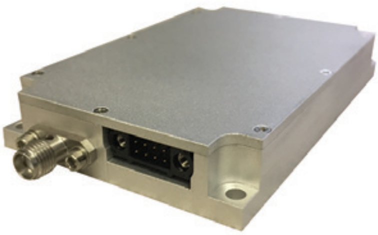
RFMW Ltd.
www.rfmw.com

2 W Power Amplifier Module

Richardson RFPD announced the availability and full design support capabilities for a new power amplifier module from NewEdge Signal Solutions Inc. The ETX115 delivers high gain and high-power across a wide RF transmit bandwidth. This 2 W, compact module can be used for a wide range of applications, including LTE signals for use in tactical communication, test and measurement or electronic warfare systems. It uses a single +12 V supply.

Richardson RFPD
www.richardsonrfpd.com

Wideband GaN Bi-Directional Amplifier



Triad has released the TTRM1190, a wideband GaN BDA that operates from 30 to 2700 MHz and produces over 8 W of Tx power. This feature rich BDA is also one of the most efficient. While producing 8 W of RF power, it only consumes 24 W of DC power. It also produces over 2 W of linear 16 QAM with < 9 percent EVM. In order to operate on various existing platforms, the unit features a wide DC input range of +11 to +28 V DC.

Triad RF Systems
www.triadrf.com

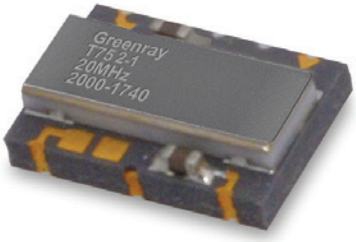
SOURCES

High-Performance USB-Controlled PLL Synthesizers

Fairview Microwave Inc. has launched a new line of USB-controlled, phase locked loop (PLL) frequency synthesizers. In RF and microwave communications systems where signal integrity is priority, PLL synthesizers offer superior frequency stability and accuracy with exceptional phase noise characteristics that allow components in the signal chain to perform at their optimal levels. These new PLL synthesizers are ideal for applications that involve electronic warfare, signal generators, benchtop test and measurement and microwave radios.

Fairview Microwave Inc.
www.fairviewmicrowave.com

T752 TCXO



Greenray Industries Inc. has announced the availability of the T752 Series TCXO.The new TCXO (temperature compensated crystal oscillator) is available from 9 to 52 MHz with CMOS or clipped SINE output and features acceleration sensitivity down to ≤ 0.2 × 10^{-9}/g. The T752 is available with +3.3 or +5 V DC supply and features a low-profile, 5 mm × 7mm package. The TCXO offers temperature stability down to ±0.5 ppm and EFC with sufficient pull range to cover the total stability of the oscillator over the lifetime of the part. The T752 Series has been designed for mobile

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IMS Plenary Session Speaker (Monday, 11 June 2018):

"The Hitchhiker's Guide To the Healthcare Galaxy: The Actions That Changed the Healthcare Landscape in America From 2017-2027"

Stephen K. Klasko, MD, MBA, President and CEO, Thomas Jefferson University and Jefferson Health

IMS Closing Session Speaker (Thursday, 14 June 2018):

"Extreme Platforms for Extreme Functionality"

Nader Engheta, PhD, H. Nedwill Ramsey Professor at the University of Pennsylvania

RFIC Plenary Session Speakers (Sunday, 10 June 2018):

"Compact Silicon Integrated mmWave Circuits: From Skepticism to 5G and Beyond"

Zachary J. Lemnios, Vice President, Science, Technology & Government Programs, IBM T.J. Watson Research Center

"The Road Ahead for Autonomous Cars – What's in for RFIC"

Lars Reger, Automotive Chief Technology Officer (CTO), Business Unit Automotive, NXP Semiconductors

IMBioC Opening Session Speaker (Thursday, 14 June 2018):

"Renal Denervation for Uncontrolled Hypertension: Complexity After Symplicity"

Dr. Nicholas J. Ruggiero II, MD

IMBioC Closing Session Speaker (Friday, 15 June 2018):

"Is There a Fundamental Law of Health and Disease?"

Dr. Chung-Kang Peng, Director of the Center for Dynamical Biomarkers at Beth Israel Deaconess Medical Center / Harvard Medical School (BIDMC/HMS)

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The 19th annual IEEE Wireless and Microwave Technology Conference (WAMICON 2018) will be held in Clearwater Beach, Florida on April 9-10, 2018. The conference will address up-to-date multidisciplinary research needs and interdisciplinary aspects of wireless and RF technology. The program includes both oral and poster presentations, as well as tutorials and special sessions. The conference also features an active vendor exhibition area and an array of networking opportunities.

CALL FOR PAPERS

The technical program's central theme is "mm-Waves and Internet of Things (IoT) for Commercial and Defense Applications". Prospective authors are invited to submit original and high-quality work for presentation at WAMICON 2018 and publication in IEEE Xplore.

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- Passive Components and Antennas
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Greenray Industries Inc.

www.greenrayindustries.com

Ka- Through W-Band Precision Waveguide Noise Sources

NoiseWave Corp. has released a line of precision millimeter waveguide noise sources. The NW-W series of waveguide noise sources covers all major millimeter waveguide bands with high output, excellent flatness and ripple-free response. Designed for both built-in test and laboratory applications, these units can also replace outdated gas tube noise sources. Models are available up to 110 GHz (W-Band) with output ENR from 6 to 50 dB. Applications include noise figure measurement, mmWave radiometers, automotive radar as well as research and development in high frequency broadband wireless applications. NoiseWave's waveguide noise sources are ideally suited for 5G and autonomous vehicle system test and verification.

NoiseWave Corp.

www.noisewave.com

SOFTWARE

NB-IoT Software

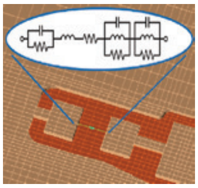
VENDORVIEW

Anritsu Co. introduces Narrowband-IoT (NB-IoT) software for its universal wireless test set MT8870A. The NB-IoT Uplink Tx measurement MX887067A software and NB-IoT downlink waveforms MV887067A package support 3GPP RF measurement tests for NB-IoT chipsets, modules and devices during production. Installing the NB-IoT software options in the MT8870A enables accurate and efficient evaluation of communications equipment with built-in NB-IoT functions, as well as tests of the RF TRx characteristics of modules and devices.

Anritsu Co.

www.anritsu.com

Circuit Co-Simulation in XFdtd Electromagnetic Simulation Software



Remcom announces circuit co-simulation and expanded signal integrity capabilities in the latest update to XFdtd® 3D Electromagnetic Simulation Software. Circuit co-simulation facilitates a more realistic analysis of device performance by including imported circuit components within the electromagnetic simulation. The schematic for a desired component may be imported into XF via a netlist file, with support for SPICE elements such as resistors, capacitors, inductors, coupled inductors and subcircuits. Netlist components can also be assigned as a matching circuit embedded within a feed, simplifying matching network design.

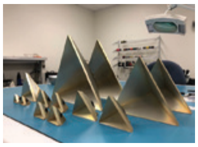
Remcom

www.remcom.com

ANTENNAS

Trihedral Corner Reflectors

VENDORVIEW



SAGE Millimeter offers standard and custom trihedral corner reflectors for radar applications to various industries. They feature a rugged aluminum construction with a gold chemical film finish. The trihedral reflector simulates a radar target precisely and is widely used for radar system calibration. SAGE Millimeter offers many standard trihedral corner reflectors from 1.8 to 16 in.

SAGE Millimeter

www.sagemillimeter.com

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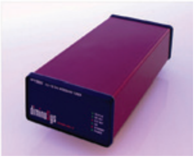
TEST & MEASUREMENT

Low Noise Tuner



The compact MP518B500 wideband tuner from diminuSys spans 0.5 to 18 GHz with 500 MHz instantaneous bandwidth, fast tuning, low phase noise, control flexibility, output versatility and mobility. Overall tuner gain is adjustable from -40 to +20 dB. The MP518B500 offers input preselection with bypass mode. Its wideband output is centered at 1000 MHz with auxiliary ports at 900, 120 and 21.4 MHz. All four outputs are synchronous and without frequency inversion. Control is by a simple command set via the tuner's USB interface.

diminuSys
www.diminuSys.com

Power Sensor

VENDORVIEW

The LB479A 10 MHz to 8 GHz high dynamic range RF and microwave pulse power sensor. The sensor processes the signal and delivers a variety of pulse measurements including statistical peak power, pulse power, average power and duty cycle. The sensor utilizes a 10 MHz video filter, making it ideal for many applications including radar, IoT, manufacturing test and more.

LadyBug Technologies
www.ladybug-tech.com

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Response Microwave Inc. is pleased to announce the availability of a complete offering of adaptors, terminations, cables and tooling to facilitate test applications. The new TESTKITZ™ line offers discrete or bundled components operating over the DC to 65 GHz frequency range. Interface selections within the multi-functional offering are available in SMA27, N18, TNC18, 3.5 mm, 2.92 mm, 2.4 mm, 1.85 mm and NMD to address the current diversity of today's test equipment. This line will assist the test manager in supporting R&D and production needs with many of the products available from stock.

Response Microwave Inc.
www.responsemicrowave.com

Vector Signal Generator

VENDORVIEW

Rohde & Schwarz introduces a new real-time control interface software option for simulated radar scenarios based on pulse descriptor word (PDW) streaming. The radar scenario simulator streams the PDWs to the R&S SMW200A vector signal generator directly via LAN. Equipped with the new software option, the vector signal generator processes these signals to simulate highly agile and dense radar signal environments. The R&S SMW200 acts as an agile signal source that generates the highest pulse rates with superior RF performance.

Rohde & Schwarz
www.rohde-schwarz.com

Volta Series Probe Heads

Smiths Interconnect announced the release of the Volta Series probe heads optimized for wafer level chip scale package testing. As phones and smart devices get more powerful, so do the integrated chips that support them. Volta is used for testing the chips (while in their wafer form) that are behind everything from Bluetooth and power management to digital display controllers. Volta helps customers deliver higher quality products by ensuring the chips in them are up to specification and perform as they should.

Smiths Interconnect
www.smithsinterconnect.com

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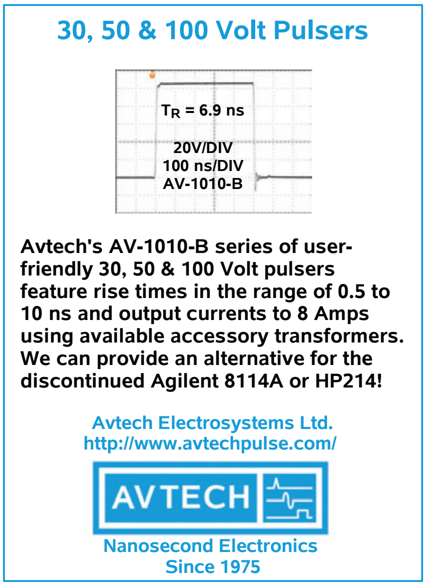

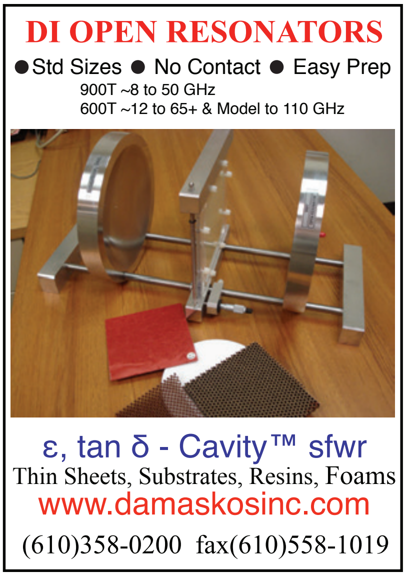

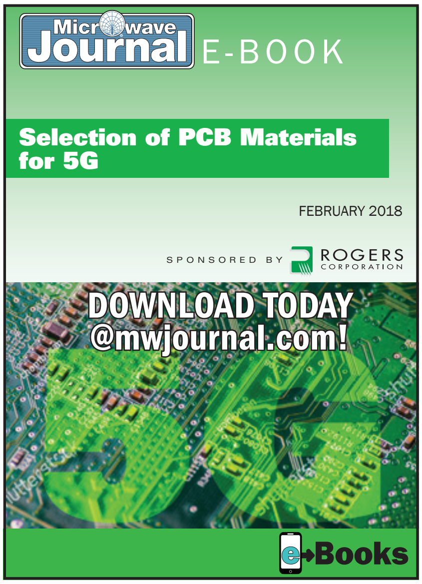

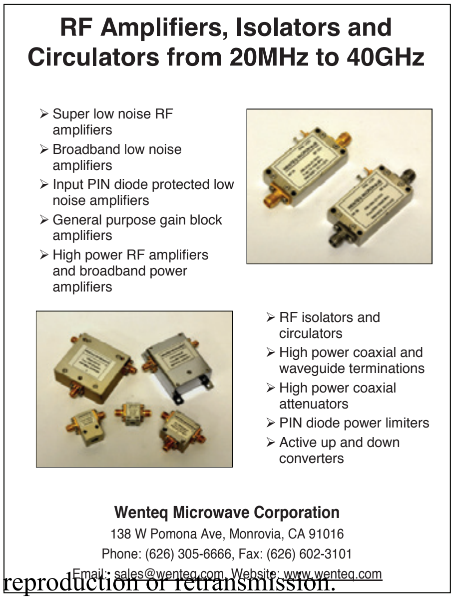

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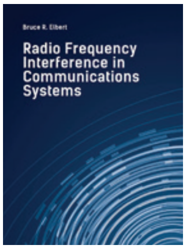

Radio Frequency Interference in Communications Systems

Bruce Elbert

This authoritative resource describes how to assess and mitigate RF interference (RFI) in radio systems and presents effective methods to identify and resolve RFI before, during and after its appearance.

Authored by a leading authority in the field, this book provides engineers and managers with the knowledge they need to control radio frequency interference.

Readers find practical guidance in an array of critical areas, including engineering of radiocommunication and wireless systems in light of RFI, identifying RFI modes, electromagnetic compatibility and spectrum sharing. Key concepts in evaluating radio frequency interference, propagation on obstructed paths, interference protection radio and RFI resolution and mitigation techniques such as filtering, spectral capture, radiolocation, cancellation and cognitive radio are covered in this book.

Contents: The What and Why of RFI in Radio and Wireless Communications; The Radiocommunication System in an Interference-limited Environment; Key Concepts of Evaluating Radio Frequency Interference; Link Properties Under Free Space Conditions; Propagation on Obstructed Paths; Interference Protection Radio (C/I) and Its Application; RFI Resolution and Mitigation Techniques; How to Identify, Prevent and Fix Common RFI problems; Prospective RFI Resolution in Future Radiocommunication Systems.

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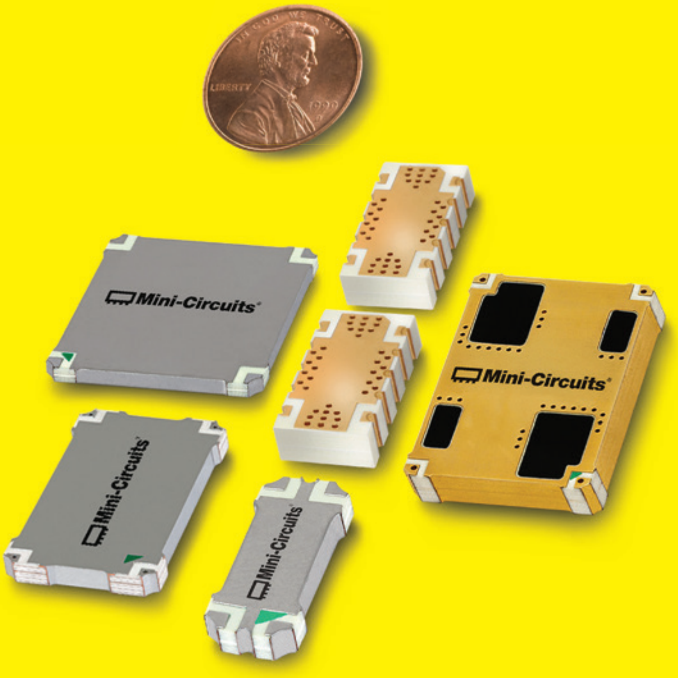

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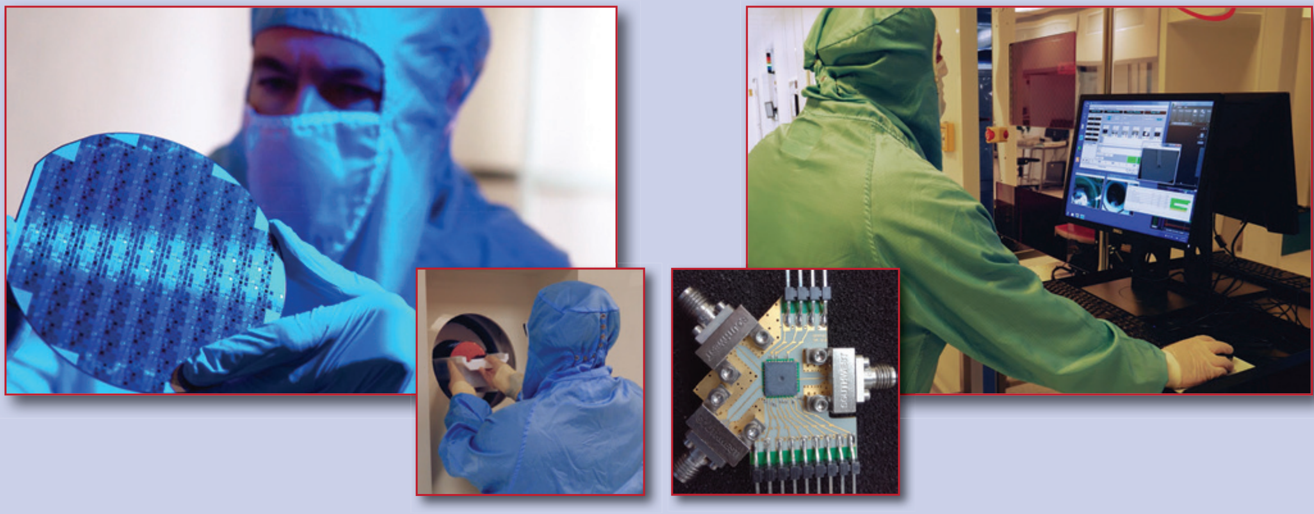
OMMIC Creates a First Designed to Last



In September 2017, OMMIC inaugurated the first European, 6-inch GaN production line and the world's first GaN-on-Si production line at its facility in Limeil-Brévannes, near Paris. After passing several qualification processes, the new line is scheduled to become fully operational by March 2018. This timing is critical: although 5G is still in development, it is expected to take off in 2019, with large-scale consumer adoption in 2020. With the new production line fully up and running in the second half of 2018, OMMIC will be in phase with the needs of the first 5G networks.

The inauguration of this significant semiconductor production line is the result of funds raised in June 2016 with the support of Bpifrance, BNP Paribas, Banque Populaire and Financière Victoire. This critical investment enabled the construction of a leading-edge factory for III-V semiconductors that will multiply OMMIC's annual production capacity by seven, with ambitious plans for that to increase 15-fold by 2020.

The initial recruitment of more than 35 technicians and engineers will be supplemented significantly in the future, not only to facilitate the deployment of the new line but to adapt to market demand. By recruiting new staff, the company is affirming its commitment to the continuation of its activities in Limeil-Brévannes and the revival and boosting of the French high-tech industry close to Paris, positioning itself as a French industrial flagship at the leading edge in the development of the European telecommunications market.

The construction of a new 1600 ft² clean room, with the advantage of easier maintenance, was accompanied by the renewal and upgrading of facilities and the purchase of 25 new machines, which will enable the company to improve yields and competitiveness. Thanks to this new production line, OMMIC will place itself as a leader in Europe to cover the needs of 5G antenna systems at 28 and 40 GHz, as well as continuing to serve and assist its current clients with more modern equipment. The company's processes can be used at frequencies above 15 GHz with output power that has not been reached before. Important for continuity, though, it will keep its current 3-inch line, which has been space qualified by the European Space Agency (ESA), for small volume markets and space products.

At the heart of OMMIC's success is the development of a very versatile and scalable GaN process. A single process design kit (PDK) contains all of the company's GaN processes: GaN-on-Si and GaN-on-SiC, with 100, 60 and, in the future, 40 nm gate lengths. With its GaN processes providing high gain, high output power, low noise and similar lag effect compared to traditional GaAs PHEMTs, the company predicts that its GaN technology will replace all GaAs PHEMT devices by around 2020. OMMIC first proffered this view at IMS2017, presenting the world's first GaN T/R chip that features a PA, LNA and SPDT switch on a single die, covering 25 to 36 GHz with a Pout of 4 W and 2.7 dB NF.

OMMIC is currently the fifth-ranked company for the manufacture of MMICs and identified the need for a facility that will help meet the growing market demand. With €14.5 million turnover in 2016 and a backlog of more than €20 million in 2017, this new capability will enable the company to move to its stated goal of becoming the third-largest GaN manufacturer by 2020, with sales over €100 million.

www.ommic.com

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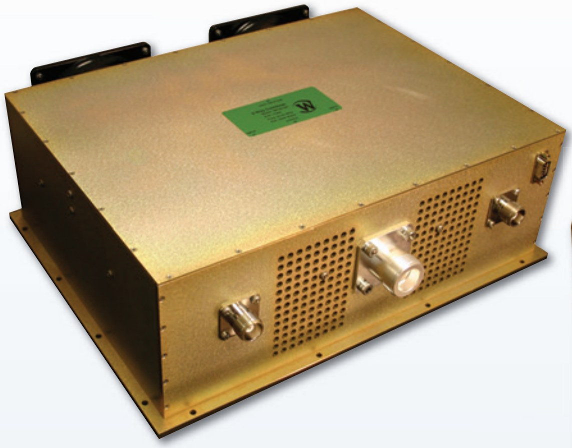

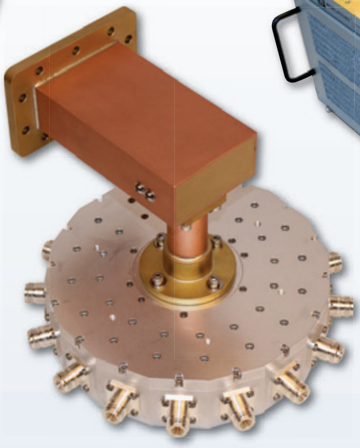

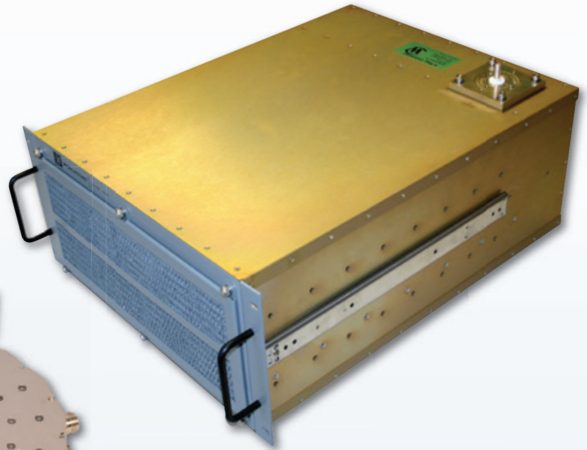

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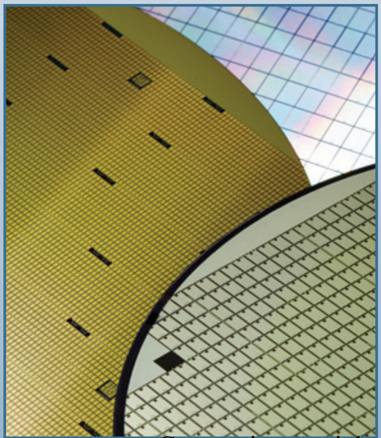
BIG STUFF! Werlatone offers a full line of High Power Combiners & Dividers for frequency bands covering HF through S-Band, at power levels to **20 kW CW and 100 kW Peak.** Our low loss designs are ideal for Coherent Combining applications (when the inputs offer equal frequency, power, and phase) and for Non-Coherent Combining applications (when all is not equal). Our **BIG STUFF** is built to withstand high unbalanced input powers and operate into severe Load Mismatch conditions.

RADIAL COMBINERS

Werlatone ***Mismatch Tolerant***® High Power **Radial Combiners** are ideal for Radar, EW and Telecom systems. **Werlatone's** full line of Radial Combiners and Dividers address multiple high power, amplifier applications. Our designs range from 3-Way to 32-Way Solutions, from VHF through C-Band, up to 10:1 Bandwidth, at power levels to **64 kW CW, and 200 kW Peak!**

ABSORPTIVE FILTERS

Werlatone Low Pass **Absorptive Filters** are Non-Reflective! Out-of-band signals are internally terminated and are not reflected back to the source. Designed for HF, VHF, UHF, and 800 MHz applications, our Absorptive Filters are less susceptible to temperature change, and reduce the dependency of the system on the length of interconnecting cable between two non-perfect components. Send us your specs for custom designs!



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