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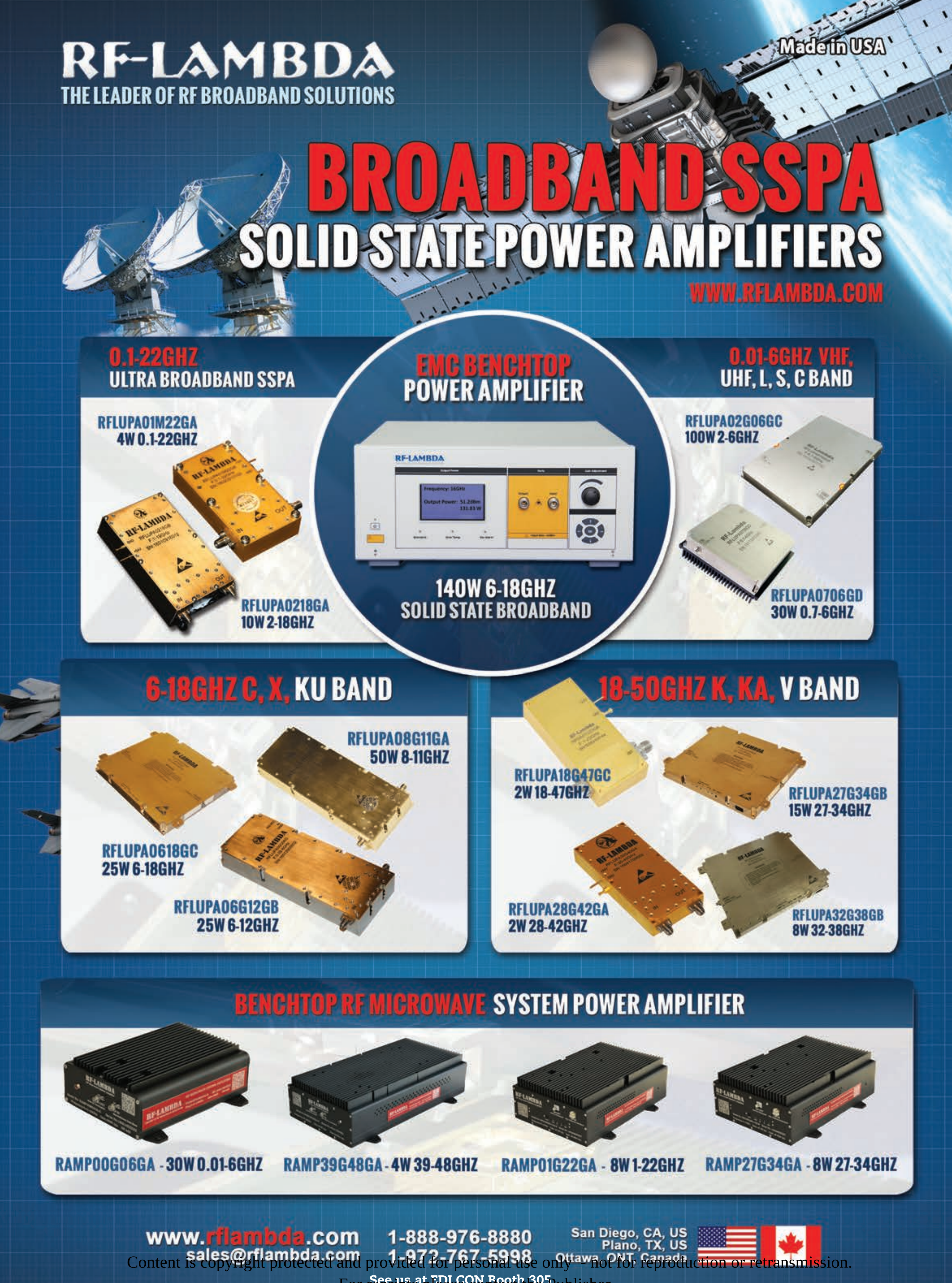
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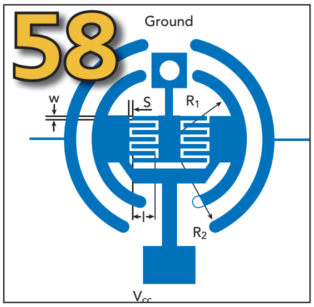

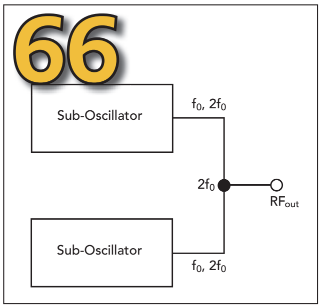

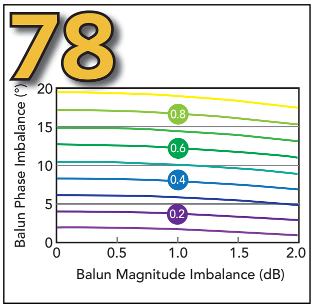

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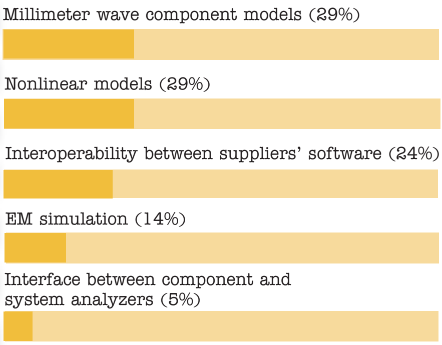

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Bruce Devine, CEO of **Signal Hound**, tells the interesting story of the company's birth and evolution. He discusses the outlook for test and measurement and how that reflects the health of the microwave industry.

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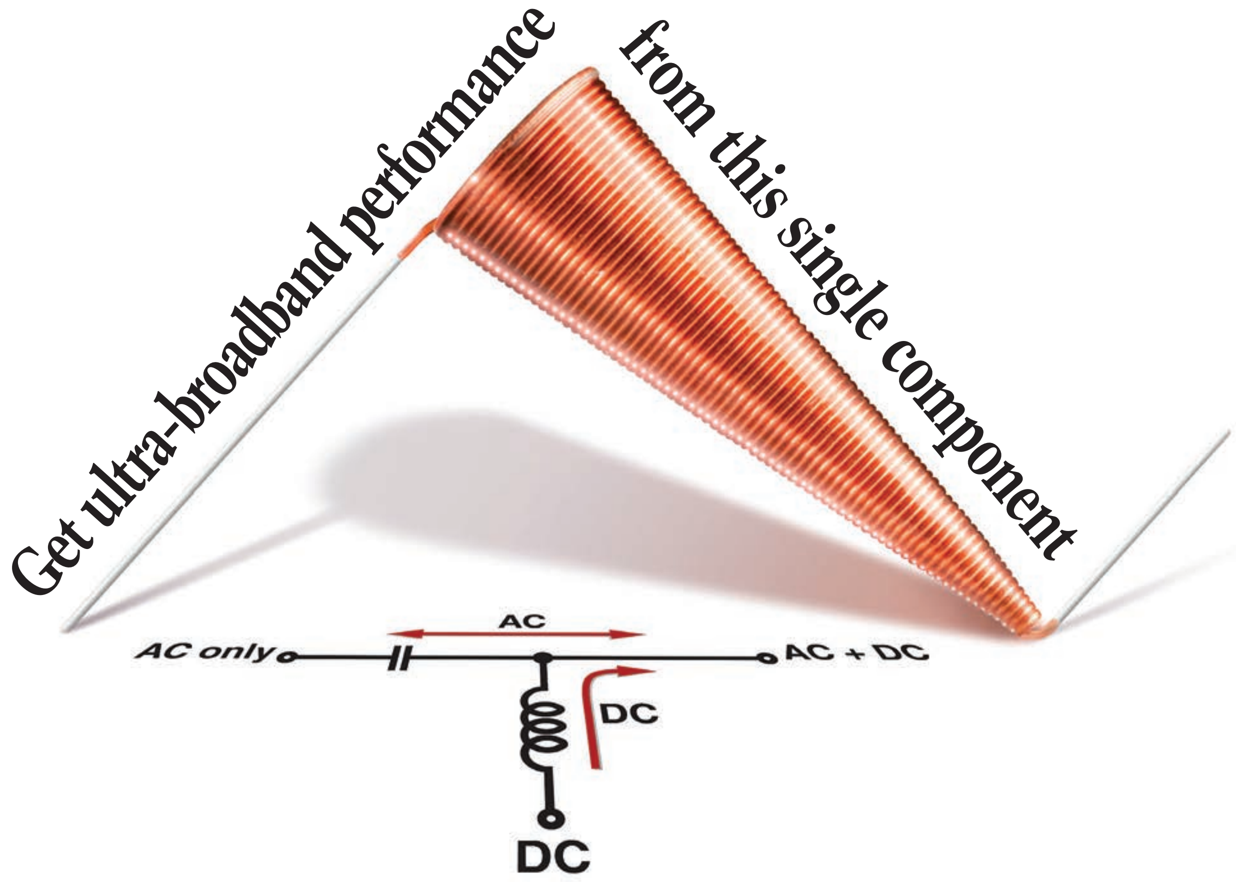

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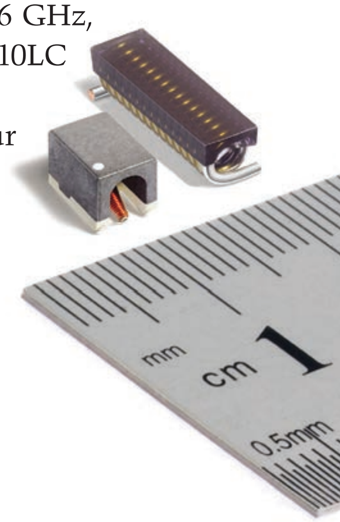

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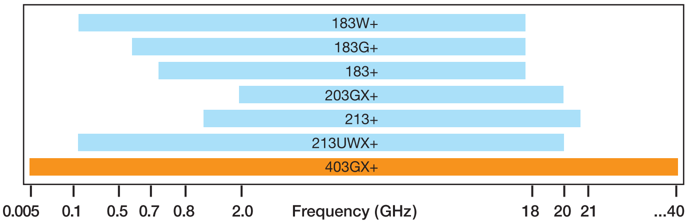

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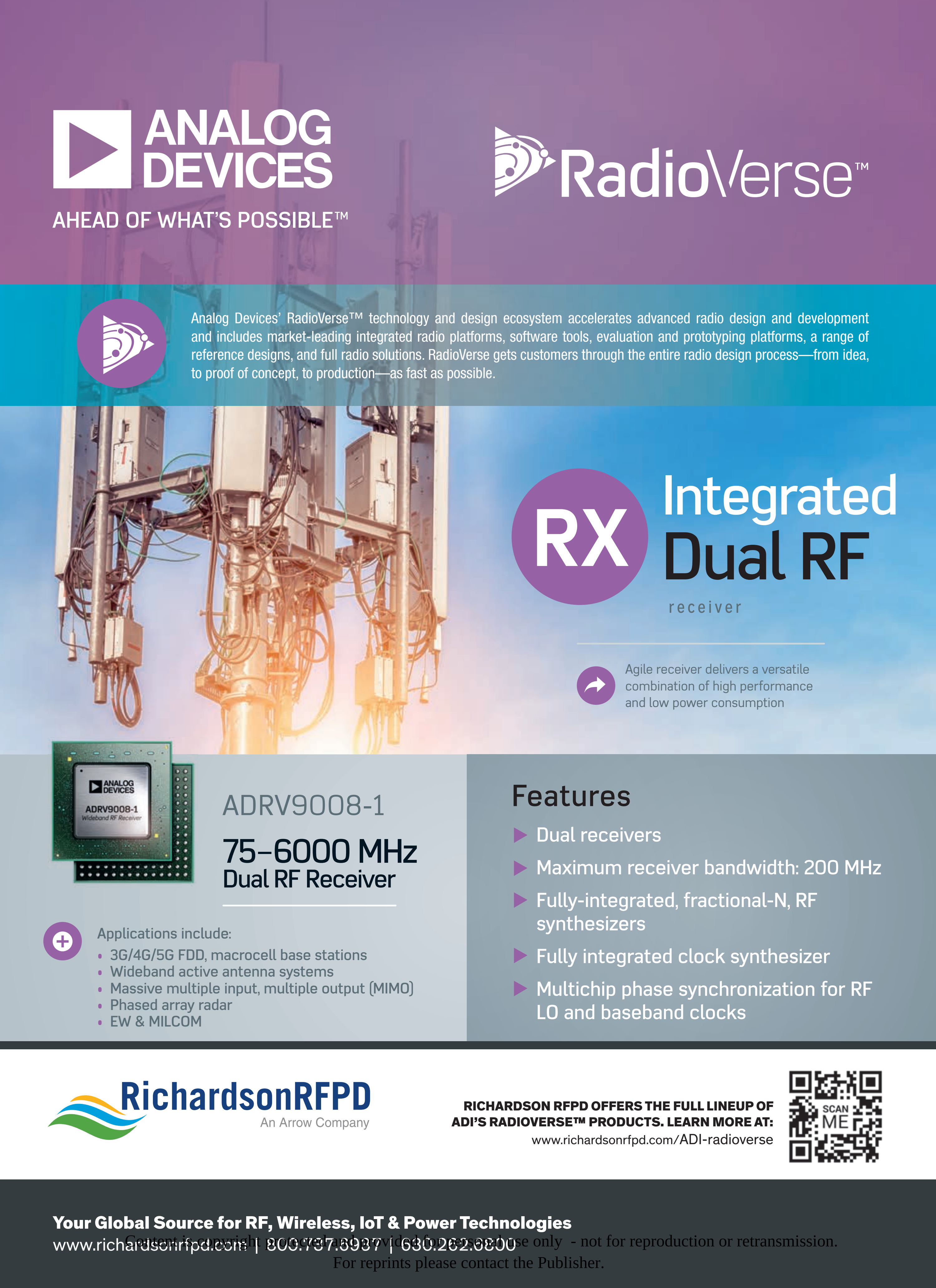
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Colosseum: A Battleground for AI Let Loose on the RF Spectrum

Ashish Chaudhari and David Squires
National Instruments, Austin, Texas

Paul Tilghman
Defense Advanced Research Projects Agency (DARPA), Arlington, Va.

Over the last four decades, the use of wireless technology has become so pervasive, both militarily and commercially, that we have come to rely upon its never-ending, and seemingly unbounded, ability to carry more and more information. Despite our ever-increasing appetite, the fundamental principles for managing access to the spectrum, established over a century ago, by and large still hold. Today, the wireless spectrum is still divvied up through a manual and time-intensive process of assignment and licensing. Over the last several years, commercial wireless use of the spectrum has been growing at a CAGR of 45 to 50 percent.[1] Yet, our radio systems remain locked into their approved frequency bands, unable to dynamically respond to the ever-changing demand placed on the wireless spectrum.

In the now fully crystallized modern era of artificial intelligence (AI), where we find AI managing stock trades, labeling pictures of faces and driving cars, it seems oddly out of place and antiquated that we do not find AI with a role in the increasingly crowded wireless spectrum. To address this obvious shortcoming, and enable continued growth and spectrum usage both militarily and commercially, DARPA created the Spectrum Collaboration Challenge (SC2). SC2 is an open competition that invites competitors to re-imagine the spectrum landscape without predetermined "lanes," instead explore the intersection of AI and software-defined radios (SDR) to enable a spectrum landscape where radio systems autonomously and collaboratively self-organize, self-govern and self-optimize the spectrum's usage—not on intolerably slow human timescales, but second-to-second, on machine timescales.

Unlike making an autonomous vehicle, making a single radio smart enough to find an unused wireless frequency is fairly trivial. However, the wireless spectrum is not one radio; it is a sea of many varied and different radios. For autonomy to be truly successful in the wireless spectrum, we need ensemble autonomy. That is, we need to answer the question: "What happens when hundreds of radios, each with their own waveforms, signal processing and distinct decision-making engines, occupy the same spectrum?" Will the spectrum turn into a chaotic bumping, colliding, trampling crowd and ultimately become unusable? Or, will order emerge like a colony of ants?

To answer these questions, we needed a new type of RF test environment, one that allows AI to interact at scale, in real-time and in an environment that emulates real world RF conditions. Our response was the creation of Colosseum, the world's largest RF channel emulator-based testbed constructed for DARPA's SC2.

In this article, we discuss the design and implementation of Colosseum, including the architectural choices and trades required to create an internet-based radio development and test environment of this scope and scale.

COLOSSEUM REQUIREMENTS

Within the context of the SC2 competition, Colosseum serves as a development and test environment for the competitors as well as a battleground to determine which AI-enabled radio design reigns supreme. A handful of key requirements guide Colosseum, enabling the SC2 competition while creating a valuable national asset for use beyond the competition:

Large scale—To study ensemble AI requires large numbers of independent actors, in our case radios, interacting in real-time. To do this, we need the ability to connect 100+ SDRs in a realistic RF environment. This requires the emulation of RF multipath that mimicks the phenomenon of a radio transmission bouncing off environmental obstacles before reaching one or more receivers.

Full mesh—The autonomous engines of each radio have the potential to impact every other radio operating in the same geographic area. This demands that Colosseum be constructed as a "full mesh," or in a way that every radio is able to hear every other radio, each through a unique RF channel.

Wideband—Even if we are successful, spectrum autonomy will not be given carte blanche access to the entirety of the spectrum initially, rather constrained to a small region of the spectrum until it has earned its stripes. To that end, Colosseum must emulate wireless interactions across a reasonably wide bandwidth of 80 MHz.

Neighborhood sized—Lastly, a congested spectrum environment, where each radio's probability of potentially harming another radio's communication is highest, is most stressful for this type of autonomy. We want the ability to emulate a reasonable, but not overly large, area of an urban neighborhood—approximately 1 sq. km.

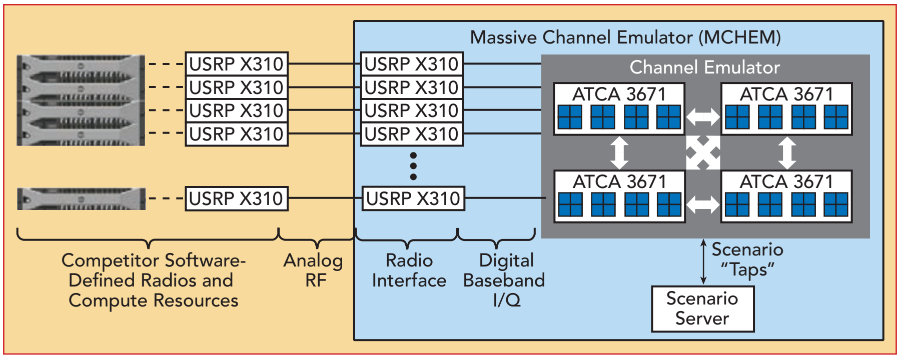

Fig. 1 **Colosseum block diagram.**

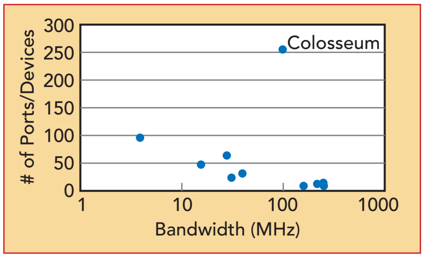

Fig. 2 **Colosseum requires modeling many more ports than existing channel emulators.**

CHALLENGE OF LARGE-SCALE CHANNEL EMULATION

Colosseum comprises two overarching constituent components (see ***Figure 1***): a pool of SDR resources, which SC2 competitors use as a common platform to build their intelligent radios, and a massive channel emulator (MCHEM) that emulates the interactions of radio waves in the physical world, with sufficient veracity so that from any one radio's perspective, it appears to be operating in an open-air environment.

The radio resource pool comprises off-the-shelf Ettus Research USRP X310 SDRs mated with commodity rack servers. The real engineering challenge in bringing Colosseum to life lies largely with the creation of the MCHEM. There are no channel emulators currently in the market capable of supporting the computation and bandwidth needed to compute the interactions of hundreds of

radios in real-time (see ***Figure 2***). As such, Colosseum had to be custom designed and built. The real-time nature, sheer data throughput and digital signal processing (DSP) computation eliminates any solution based on general purpose processors (GPP) or even state-of-the-art graphics processing units (GPU). Colosseum's channel emulation needs were met with FPGA processing hardware. Further, to keep the cost low and minimize the development time required to solve this gargantuan computing problem, Colosseum had to be based on existing off-the-shelf products.

The following sections introduce the basic principles of digital channel emulation, quantitatively expand on the computing requirements and map this design to existing hardware.

DIGITAL CHANNEL EMULATION 101

To understand what the MCHEM does, it is important to understand the basics of channel emulation. Imagine you are in a large empty hall; when you shout, your voice echoes throughout. If your friends were listening to you at different points in the building, at each point they would hear a very different version of your voice. This happens because depending on where you are listening, your voice collides with different surfaces, creating a distinct echo pattern. This same phenomenon happens when we transmit wireless communications into a complex indoor or outdoor environment. The channel is the distinct set of objects a waveform (voice or wireless) interacts with between a transmitter and receiver.

Extending our hall example a bit further, imagine 256 people in the hall, all talking at the same time and trying to pass information to each other. Some voices are deep while some are squeaky high, with perhaps a dozen different languages being spoken. The sound that each person hears is the combination of all 256 people in the room and all the reflections or echoes. Emulating this example in real-time for wireless signals is what Colosseum must do, but at a tremendous scale.

Figure 3 shows a graphic representation of four radio transmitters and four receivers operating simultaneously. The wireless channel between them governs the interactions between the various transmitters and receivers. The channel can be modeled mathematically, with each transmitter providing a unique contribution to each receiver that is identical to a dot product. When we consider multiple transmitters, this forms a matrix product where each term represents RF multipath, or the attenuation and delay created by wireless echoes.

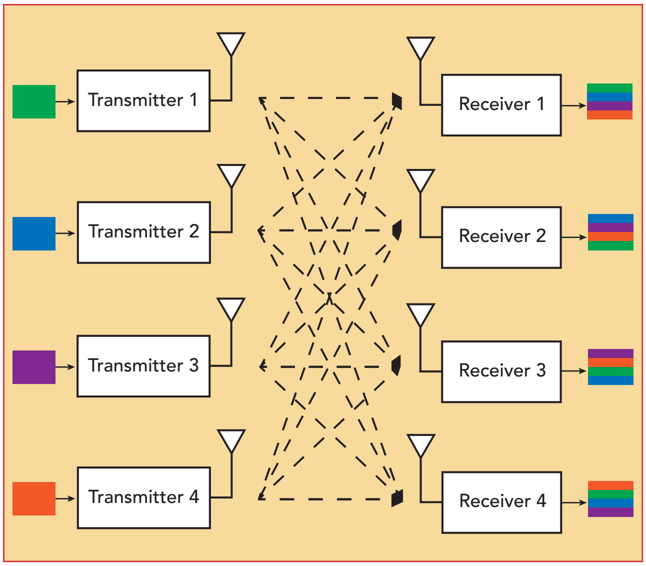

Fig. 3 Example showing contributions from each of four transmitters to each of four receivers.

KEY DESIGN PARAMETERS

To satisfy Colosseum's four key requirements, one must first comprehend the scale of computational complexity imposed by them:

To satisfy the requirement for large-scale, 256 radio inputs and outputs are used. The system has 20.48 GHz of bandwidth, input

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and output or 102.4 GB/s of data throughput.

For full mesh functionality, every transmitter must interact with every receiver. We must represent a unique RF path between every transmitter and receiver pair, thus resulting in 256^2 or 65,536 paths. This is what truly sets Colosseum apart from today's existing channel emulators. Delay paths are usually modeled in the digital world with finite impulse response (FIR) filters. A key design parameter is how many taps (i.e., unique echoes) each FIR filter should use. More taps provide a more realistic emulation, as they allow for modeling more paths between the source and receiver, but they also increase computational complexity. The 3GPP community published standard channel models for LTE testing, some with as many as nine taps (i.e., the extended vehicle model). With the primary focus of the SC2 competition on AI, the compromise was to give up some modeling fidelity and use only four taps per FIR filter. This still results in an enormous computation load of 157 tera-operations per second (TOps).

One of the key requirements is to be wideband (i.e., have high instantaneous bandwidth). Supporting 80 MHz is a reasonable compromise between bandwidth, cost and computational complexity. To achieve 80 MHz of instantaneous RF bandwidth, the MCHEM fractionally oversamples the required bandwidth to 100 MSPS. Assuming quadrature (I/Q) sampling with 16 bit samples, each MCHEM input and output has to simultaneously receive and transmit 400 MB/s.

Radio waves traverse the physical world at the speed of light. To produce accurate delay to account for the time of flight of a signal going from one end of the neighborhood to the other, memory is needed to buffer the signal. Light takes 3.33 μs to travel 1 km. To buffer 3.33 μs worth of digital samples at the chosen 100 MS/s requires a buffer of 312 samples. Rounding up to the nearest power of 2, a buffer of 512 samples is used, which equates to a maximum delay of 5.1 μs.

MAPPING THE MCHEM ONTO HARDWARE

Using the parameters from the previous section, Colosseum's MCHEM is mapped onto hardware (see Figure 1). From the image, we note the need for 256 RF inputs and outputs. MCHEM achieves this by using 128 USRP X310 radios populated with UBX RF daughterboards (see ***sidebar***), each with two transmit and two receive channels, thus creating 256 in total. These radios are responsible for digitizing the RF and passing it on to the channel emulating backbone, which does FIR filter-based computation. The channel emulation's heavy lifting is handled by 16 ATCA-3671 accelerator blades (see sidebar). Each ATCA-3671 has four Virtex-7 FPGAs, 64 FPGAs in total, to meet the requirements.

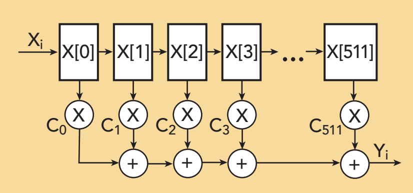

Fig. 4 **Dense 511-tap FIR filter, requiring 511 complex-value multiplies, 510 complex-value adds, storage and routing for all the coefficients.**

The system is organized into four groups, or quadrants, of 64 inputs and outputs powered by four accelerator blades (16 FPGAs). Each quadrant has a powerful ×86 Dell server that handles command-and-control and loading of the channel coefficients into the emulator. The radios and accelerators in each quadrant connect to the server via 10 Gigabit Ethernet distributed through a layer-2 Dell Ethernet switch.

The biggest challenges to digitally emulating the interactions of the physical world lie in the computational burden. The chosen MCHEM hardware has 64 total FPGAs available to bear the weight of this burden. At first blush, this may seem like overkill, but in fact this is not actually sufficient for a naïve implementation of channel emulation. Without some key observations about the structure of the math behind the underlying model, resulting optimizations in data movement, computation and key architectural and implementation choices, this problem could not be solved with the chosen hardware.

FIR filters, like those at the core of our design, normally operate at the system sample rate, which in our case is 100 MSPS. ***Figure 4*** shows a "dense" 511-tap FIR filter with delay elements of 10 ns, which is the delay between consecutive samples. The resources required to build such a large filter are substantial and would quickly exhaust those in our 64 FPGAs. The solution is to use a sparse FIR filter, as shown in ***Figure 5***. Here the resources are dramatically reduced because most of the multipliers and adders present in a fully populated FIR filter are not used.

The key FIR filter computation is a series of complex-valued multiply accumulates (CMAC). This maps well to the DSP slices in our core FPGAs. A CMAC can be implemented using three real multiply accumulates (MAC). Each 4-tap FIR filter thus needs to perform 12 MACs. Using the sparse FIR filter as the core DSP component, the overarching design can now be viewed as a large array of tiled sparse FIR filters and adders, as shown in ***Figure 6***. In total, 65,536 filters are needed for the 256 inputs and outputs. This equates to 786,432 MACs per sample, 78.6432 TMAC/s or 157 TOps. Each ATCA accelerator blade consists of four Virtex-7 FPGAs with a total of 14,400 DSP blocks.

Assuming that the DSP blocks are running at the system sample rate (100 MHz), then we would require over 50 accelerator blades (200 FPGAs) to do the computation in real-time! However, by overclocking the FGPA by a factor of four (i.e., running it at 400 MHz) it is possible to get the computation to fit into our 64 FPGAs. The lingering question, however, is how to get the data where and when it is needed to effectively use all 64 FPGAs.

DATA MOVEMENT TOPOLOGY

Now that we know the cadre of 64 FPGAs is capable of handling the computational needs of our wireless channel model, we must address the challenge of moving all this digital data between the 64 FPGAs. Using the most straightforward approach to compute one transmitter's contribution to each of the 256 receivers, we need to co-locate (i.e., copy) the data from all the channels before

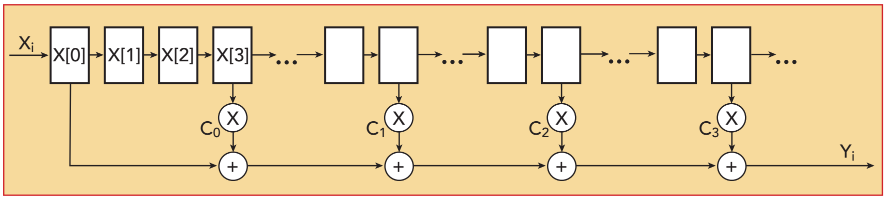

Fig. 5 **Sparse FIR filter design with 511 delay elements and four sparse taps, requiring four complex-value multiplies, three complex-value adds, storage and routing for the four coefficients.**

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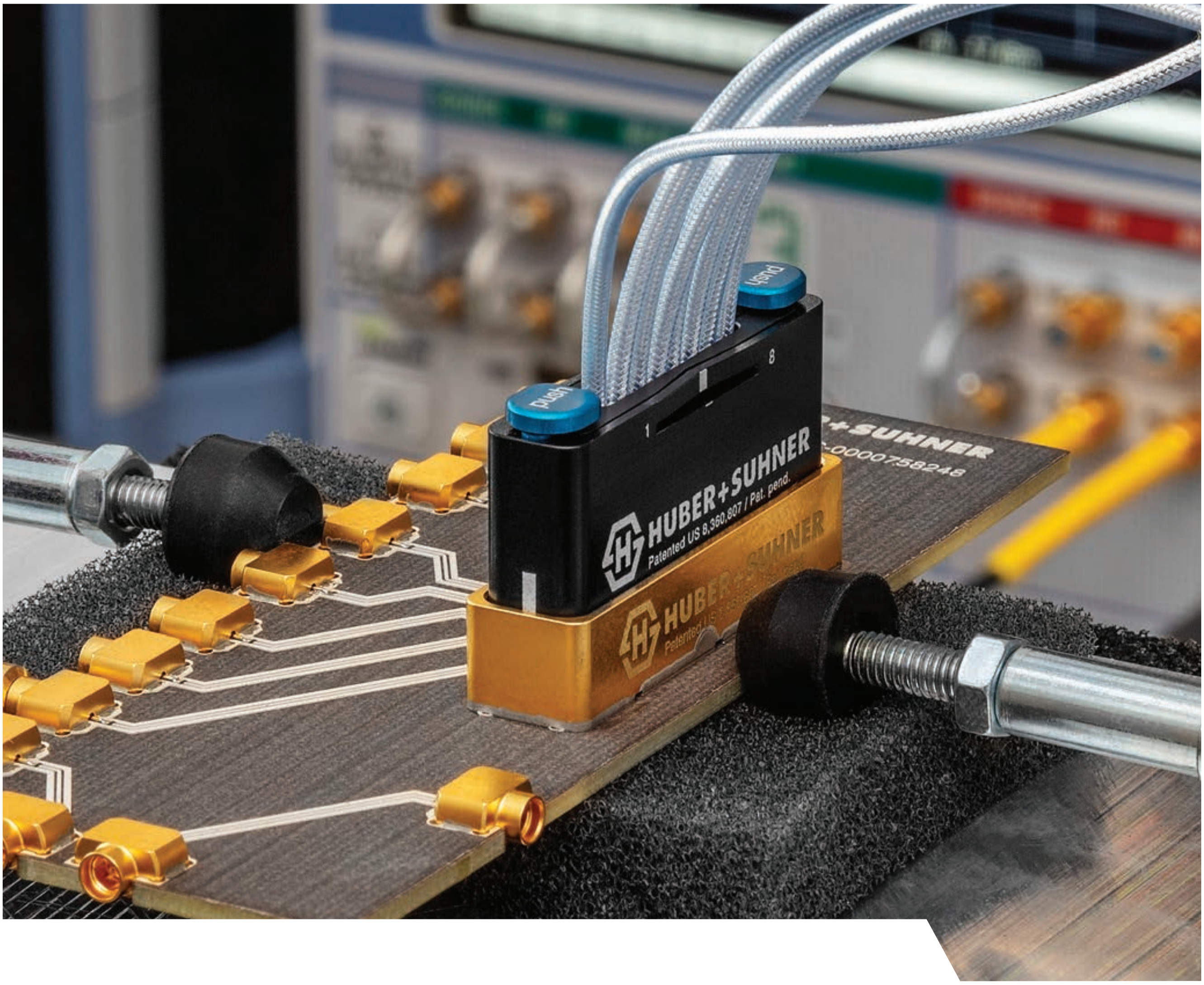

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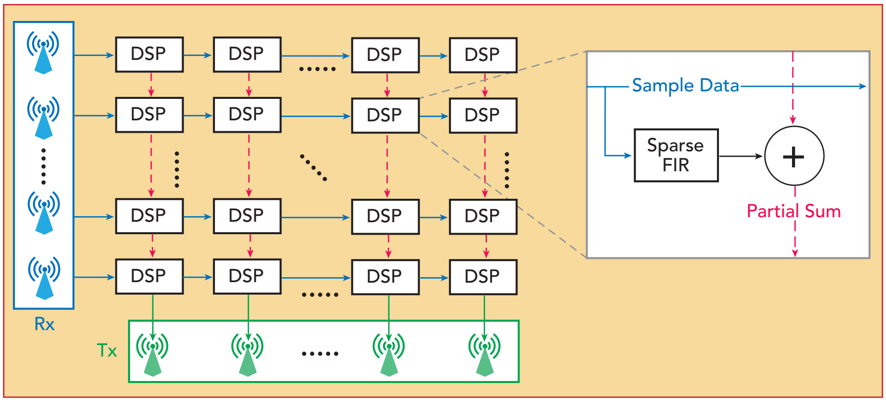

Fig. 6 **MCHEM's core digital signal processing as an array of tiled sparse FIR filters and adders.**

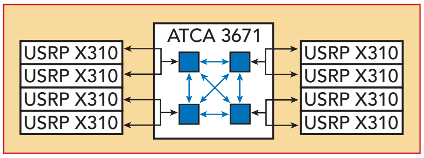

Fig. 7 **FPGA connectivity to the radio interface (USRP X310).**

even attempting to process it. That means getting 102.4 GB/s of time-aligned sample data in one place for processing, just for one channel out of 256 (or a total data bandwidth of 26.2 TB/s)! To effectively partition the computation among the 64 FPGAs, we must divide-and-conquer to reduce the required I/O bandwidth to a tenable level.

To address the challenge of data movement we have to understand the physical connectivity between the 64 FPGAs. From ***Figure 7***, we see that each Virtex-7 FPGA in one of the accelerators connects to two radios, where each radio has two channels. Thus, each FPGA is responsible for four inputs and four outputs. Each accelerator blade has four FPGAs that are connected in a 2 × 2 mesh configuration using printed circuit board traces. The four FPGA accelerators within a single quadrant are connected in the same 2 × 2 mesh topology using QSFP+ cables (see ***Figure 8***).

To reign in the data movement requirements, consider the data needs of a single FPGA. We will enumerate the FPGAs as FQAN, where Q is the quadrant where the FPGA resides, A is the accelerator blade where the FPGA resides and N is the FPGA number. A depiction of all 64 FPGAs are shown and labeled in ***Figure 9***.

Recall that the FPGA receives four input channels but needs the data from all 256 channels before

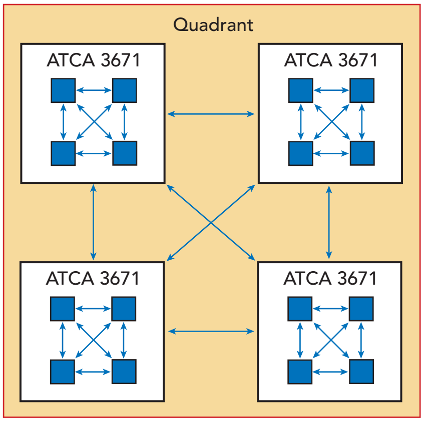

Fig. 8 **FPGA accelerator (ATCA 3671) connectivity within one quadrant.**

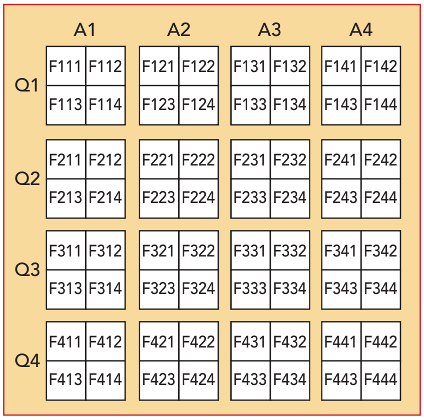

Fig. 9 **MCHEM's 64 FPGAs enumerated by quadrant, accelerator blade and FPGA number.**

computing its four outputs. From FPGA F111's perspective, for example, to acquire all necessary data, we must follow a series of data movement steps:

Step 1—Acquire RF data from the four radios directly connected to us.

Step 2—Share the four channels of data with FPGAs in other accelerator blades in our quadrant (F121, F131 and F141). We have just shared data along the X dimension

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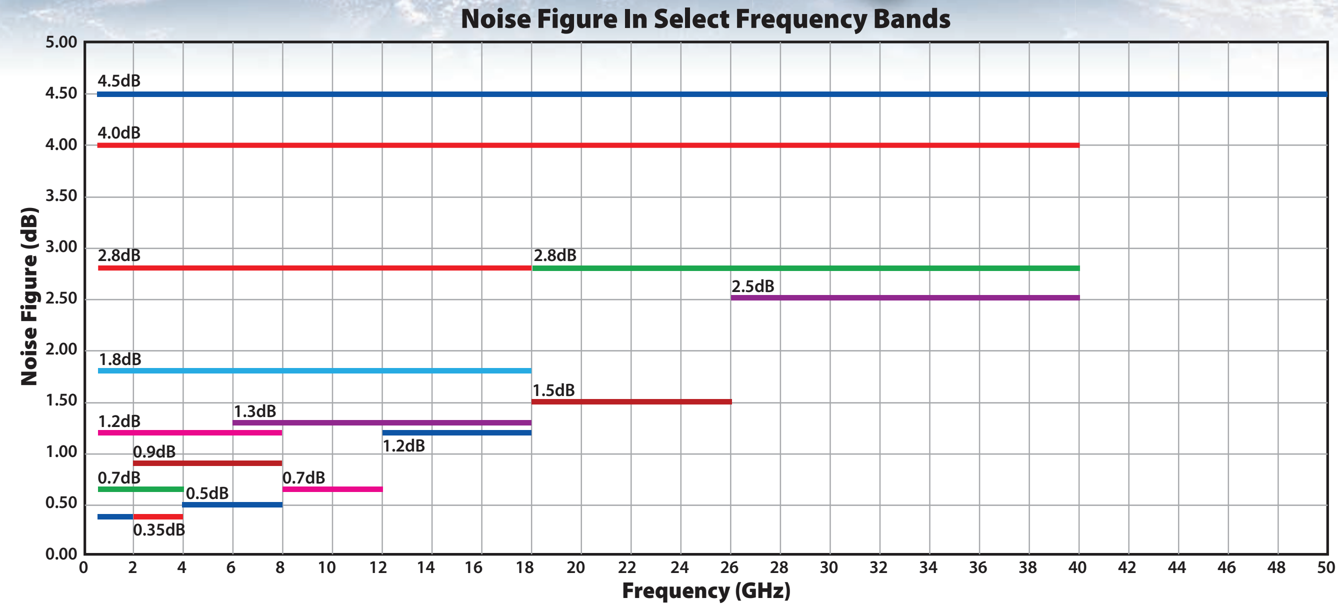

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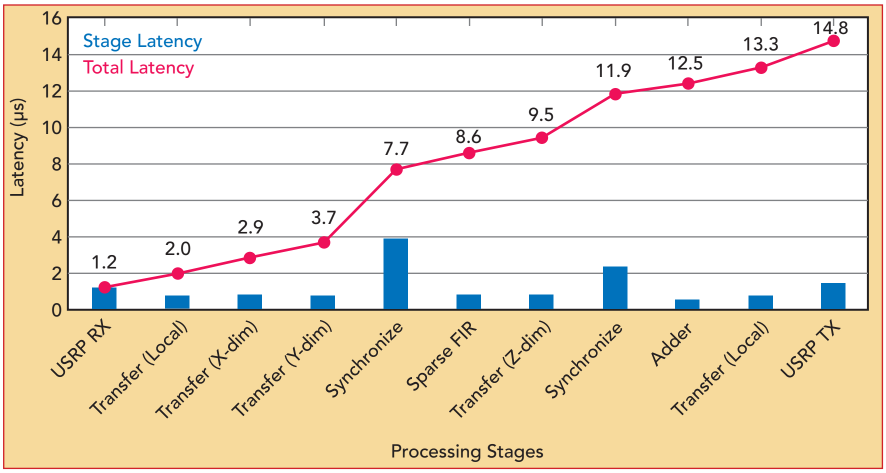

Fig. 10 **Simulated network latency, showing the delay for each hop as data moves through MCHEM.**

in our three dimensional topology, and we are now in possession of 16 channels of data.

Step 3—Share our 16 channels of data with FPGAs in the same accelerator (F112, F113, F114), which transfers data along the Y dimension. All FPGAs in quadrant 1 are now in possession of 64 channels of data.

At this point in the process, due to bandwidth restrictions, we cannot continue this same process to acquire the remaining 192 channels. However, we can take advantage of the structure of the channel-modeling problem to reduce the data we need to transmit. Consider the following: if we sent all 64 channels of data to quadrant 2's FPGA (F211), after applying the appropriate FIR filters, F211 would simply sum all the outputs of the filters. So rather than send all 64 channels of data, we can apply the same FIR filters to the 64 channels we currently have, sum the result and send only the sum, reducing the data transmission by 64x. Doing this allows us to move onto the next step.

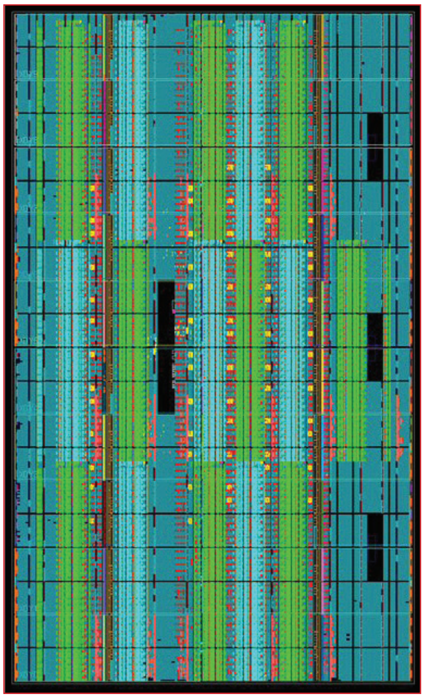

Fig. 11 **MCHEM FPGA "floor plan."**

Step 4—Apply the appropriate FIR filters to channels 1 to 64, summing the result to produce a 64 channel partial sum. Also, compute the 64 channel partial sums for F211, F311 and F411.

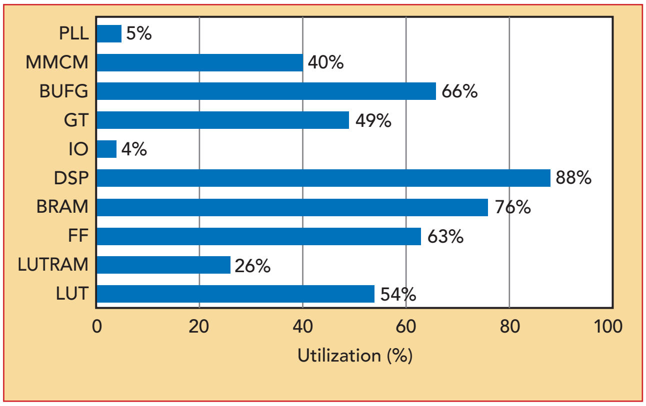

Fig. 12 **FPGA utilization.**

Step 5—Share the partial sum with F211, F311 and F411 and receive the respective sums from them. We have now shared across the Z dimension and we are in possession of 256 channels worth of partial sums.

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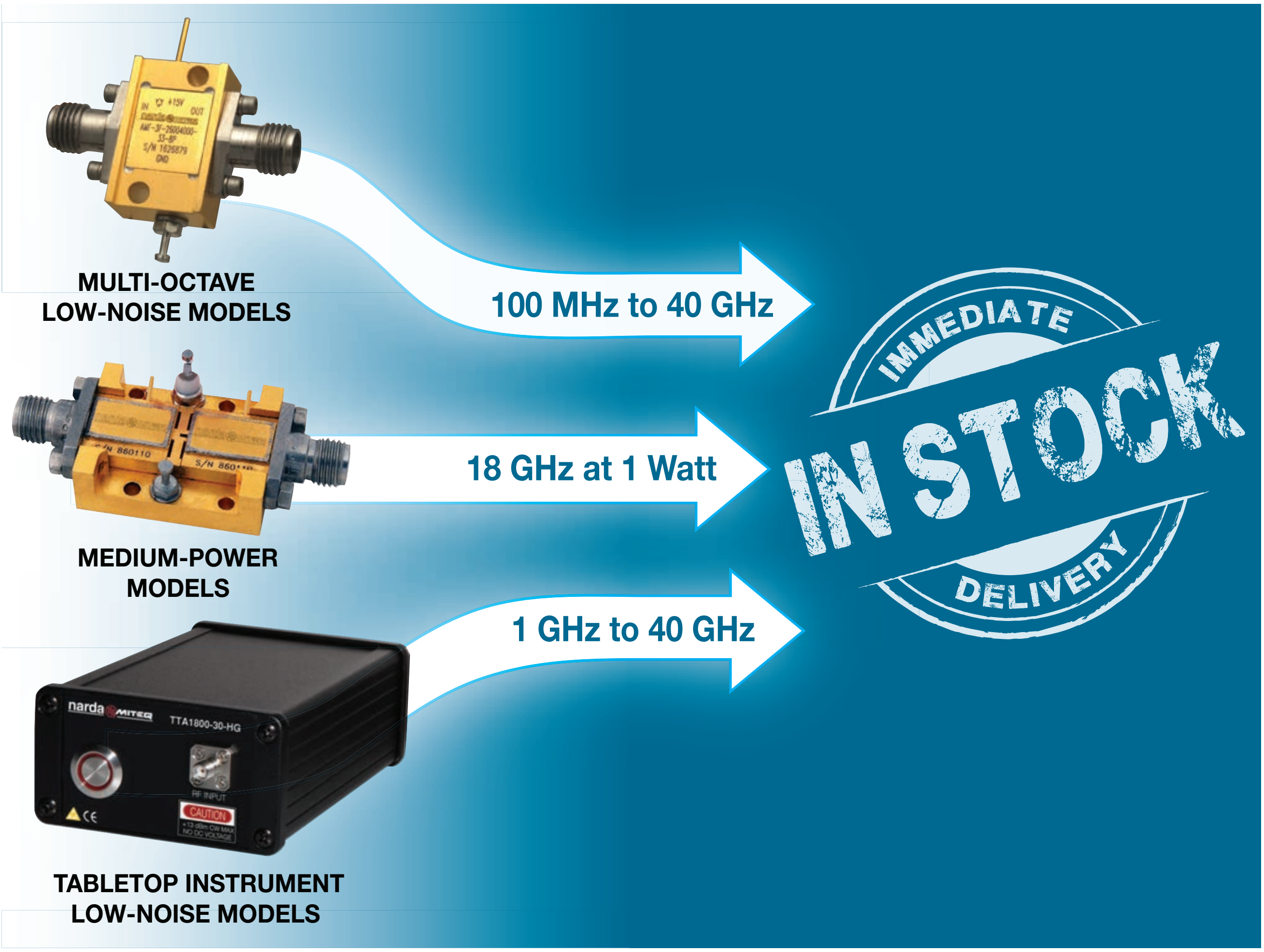

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Step 6—Add up all the partial sums computed locally and received from other FPGAs. We are now in possession of the final data streams for the four directly connected radio channels.

Step 7—Transfer the data to the appropriate radios and transmit out the RF ports.

Of course, there is no free lunch. As shown in ***Figure 10***, all of these data movement steps cost time and incur a latency of approximately 15 μs.

IMPLEMENTING THE FIRMWARE DESIGN

Now that we can get all the data where it needs to be, we still need to synthesize an FPGA image that fits the requisite number of FIR filters in each FPGA. We divide the 65,536 sparse FIR filters across the 64 FPGAs for a total of 1,024 filters per FPGA, resulting in almost 90 percent of the DSP resources and about 80 percent of RAM resources being used in each FPGA. Anyone familiar with FPGA design will realize that a design with such high resource utilization and a high clock rate (400 MHz) is extremely difficult to implement in a repeatable way while still satisfying all functionality, timing and power constraints. For that reason, the FIR filter block had to be hand crafted and the filter array, which is just a collection of filter blocks, had to be hand placed on the chip. The equivalent challenge in a strictly software paradigm would be creating a very tight assembly code routine to achieve the highest possible performance.

Figure 11 shows the completed FPGA design. The filter blocks are highlighted in green and cyan. The final per FPGA utilization numbers are shown in ***Figure 12***. As a consequence of how the design was decomposed and given the symmetry of data movement throughout the system, each of the 64 FPGAs in the system runs with the exact same FPGA image. This greatly reduces overall design complexity.

LIFE AFTER SC2

It should be evident that Colosseum is likely to remain one of the largest and most powerful channel emulators on the planet for some time. After DARPA's SC2 has completed, Colosseum will hopefully enter service as a testbed for the research community, enabling researchers across the U.S. to continue to pose and address challenging problems that cannot be effectively answered using limited, small-scale experimentation.

In this article, we have introduced the need for, and shown the achievability of large-scale, controlled experimentation and testing of burgeoning wireless communication concepts. We hope continued availability of this testbed and perhaps future testbeds like it will engender renewed and expanded research in spectrum autonomy and other new challenging wireless endeavors.■

Reference

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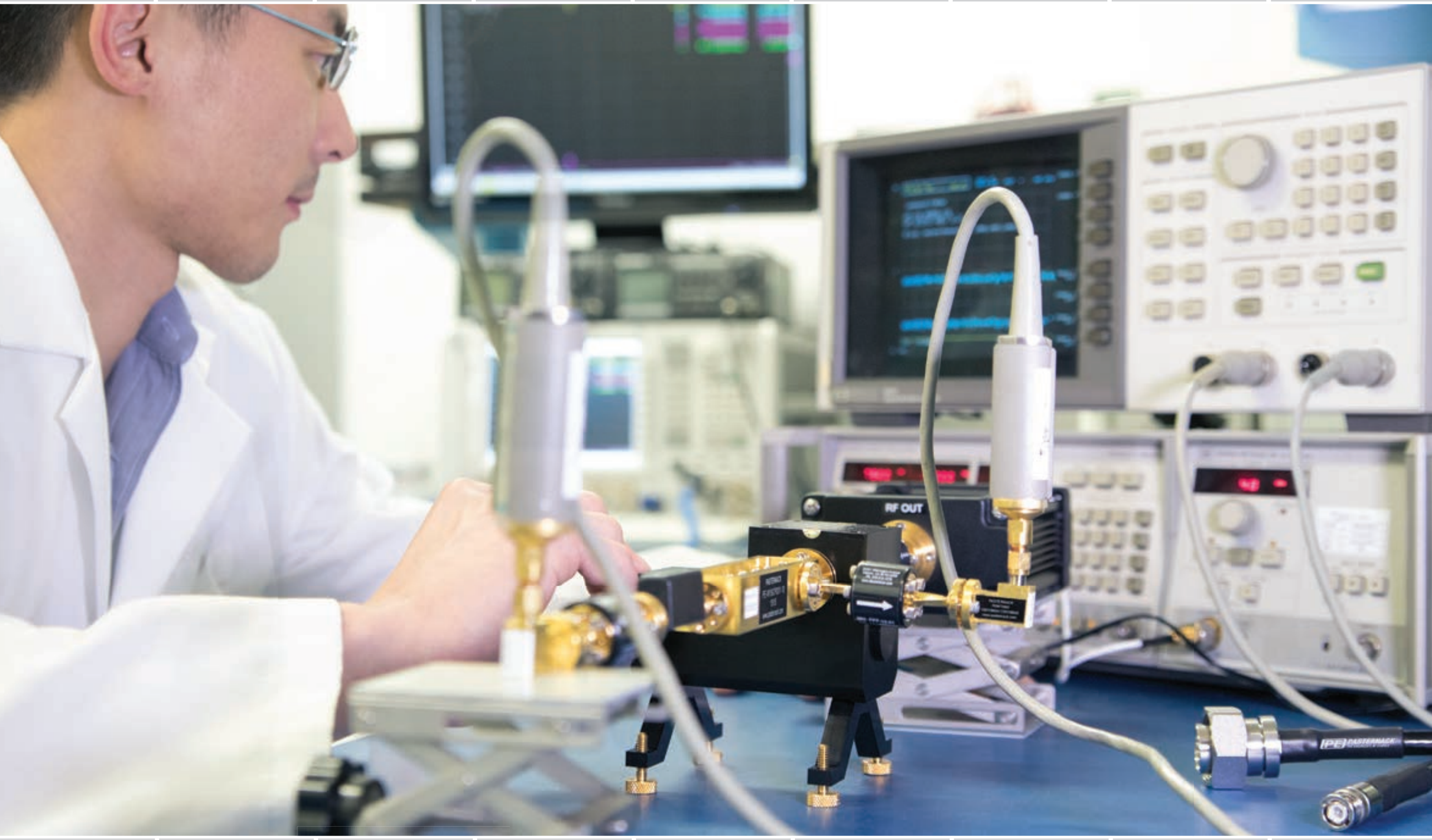

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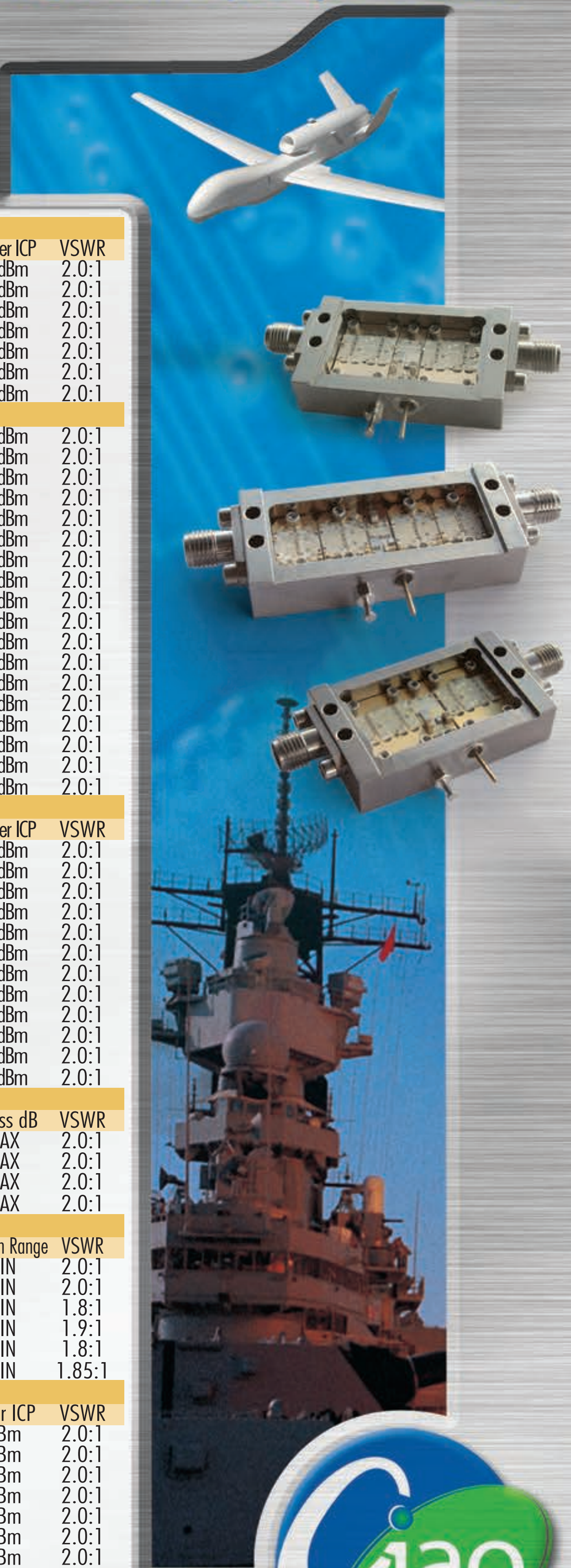

OCTAVE BAND LOW NOISE AMPLIFIERS

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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DefenseNews
Cliff Drubin, Associate Technical Editor

Research Teams Selected to Lower Barriers to Modern SoC Design

A once highly manual process, circuit design has been transformed by the advent of electronic design automation (EDA) tools and modular design methodologies. Despite continuing advances in automation technologies, the demand for increasingly complex system on chip (SoC) platforms has shown no sign of slowing. Today's SoCs incorporate billions of transistors with miles of electrical wiring that are integrated within a tiny chip. This technological feat requires large teams and complex software. As a result, the cost of circuit design continues to skyrocket, narrowing the competitive field to large, multinational companies capable of keeping up with the demand for capital and skilled talent. It is becoming increasingly difficult for small entities, as well as the DoD, to leverage the high performance technology it needs to design complex circuits for defense applications.

Under DARPA's five-year, $1.5 billion Electronics Resurgence Initiative (ERI), research teams from academia, commercial industry and the defense industrial base have been selected to address today's SoC design complexity and cost barriers. The goal is to create an environment that could catalyze the next wave of U.S. semiconductor innovation and broaden the competitive field for circuit design. As a part of the ERI Design research thrust area, the list of research teams selected to take on two new programs—the Intelligent Design of Electronic Assets (IDEA) program and the Posh Open Source Hardware (POSH) program—include the University of California, San Diego; Northrop Grumman Mission Systems; Cadence Design Systems; Xilinx Inc.; Synopsys Inc.; University of Southern California; Princeton University; and Sandia National Laboratories.

The IDEA and POSH research teams were unveiled recently during the first annual DARPA ERI Summit in San Francisco. The three-day event brought together hundreds of members of the electronics community to explore the future of the industry and the criticality of the sector in national security.

Announced initially in September 2017, IDEA and POSH are two of six ERI "Page 3" programs—so named for their adherence to the guidance shared by Gordon Moore on the third page of his seminal 1965 research paper that articulated the technology trend that became known as Moore's Law. Although Moore could not have foreseen the extent to which his observations on transistor scaling would be stretched, he predicted even then that newly designed automation procedures would be needed to lay out circuits too complex for manual design. In response, the ERI "Page 3" Design programs seek to answer this question: Can we dramatically lower the barriers to modern SoC design and unleash a new era of circuit and system specialization and innovation?

Through the creation of a software-based, completely automated physical layout generator and an open-source (OS) intellectual property (IP) ecosystem, the IDEA and POSH programs seek to usher in an era of the 24-hour design cycle for DoD hardware systems, shorten upgrade cycles and enable the proliferation of custom commercial and DoD-specific SoCs.

With the support of 11 research teams from across the electronics R&D community, the IDEA program aims to create a "no human in the loop" layout generator that would enable users with limited electronic design expertise to complete the physical design of electronic hardware within 24 hours. The software created under IDEA would be capable of automatically creating circuit design files ready for manufacturing, reducing design time from years to a single day. By applying machine learning methodologies, IDEA hopes to continuously evolve and improve the performance of the layout generator for digital circuits, mixed-signal integrated circuits (IC), systems-in-package (SiP) and printed circuit boards (PCB).

The research teams selected to participate in the IDEA program include the University of California, San Diego; University of Illinois at Urbana-Champaign; Princeton University; The University of Utah; Northrop Grumman Mission Systems; University of Michigan; Yale University; Cadence Design Systems; University of Texas at Austin; University of Minnesota; and Purdue University.

POSH, the second program under the ERI "Page 3" Design research thrust area, seeks to significantly reduce the effort required to start a new mixed-signal SoC design by building a foundation of verified IP building blocks with known functionality. Drawing from the best practices of the software design community, the POSH program is designed to create an OS SoC design and verification ecosystem that will enable the cost-effective design of ultra-complex SoCs. Although there are significant benefits to the reuse of IP blocks in circuit design, the current licensing model has limited the scope of reuse. To create a sustainable OS hardware ecosystem, researchers are tasked with developing the hardware assurance technology required to validate the quality of OS, mixed-signal SoCs and develop the critical OS IP components.

The teams selected to take on POSH's research challenges include Xilinx Inc.; Synopsys Inc.; University of Southern California; Princeton University; University of Washington; The University of Utah; LeWiz Communications; Brown University; Sandia National Laboratories; and Stanford University.

NGC Delivers First GaN G/ATOR System to USMC

Northrop Grumman Corp. (NGC) has delivered the first AN/TPS-80 Ground/Air Task-Oriented Radar (G/ATOR) that incorporates advanced high-power and high efficiency GaN an-

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G/ATOR (Source: Northrop Grumman)

tenna technology, further improving the system's operational capabilities. This system was delivered ahead of schedule and is the seventh G/ATOR system delivered in the low rate initial production (LRIP) phase of the program.

GaN technology provides cost savings and multiple performance benefits including enhanced system sensitivity and increased reliability. All subsequent G/ATOR LRIP and full rate production systems will now incorporate this advanced GaN technology.

Delivery of the first GaN G/ATOR system follows the delivery of six LRIP systems to the U.S. Marine Corps (USMC) that began in early 2017. Utilizing two of those six systems, the Marine Corps achieved G/ATOR Initial Operational Capability (IOC) of the air surveillance mission in February of this year. The remaining four systems will establish IOC for the counter-battery mission later this year. As a result, G/ATOR systems, trained Marines and associated logistics support are now in operational service with Marines.

"The Marine Corps are the first to take delivery of a production ground-based multi-mission Active Electronically Scanned Array (AESA) radar that incorporates this advanced GaN technology," said Roshan Roeder, vice president, land and avionics C4ISR division, Northrop Grumman. "The incorporation of this advanced technology in production radars is unique to the Marine Corps and enables G/ATOR to provide additional mission capability to the warfighter at an affordable cost."

Both the Marine Corps and NGC continue to make detailed preparations to successfully execute the full rate production program, which is scheduled to begin in early 2019.

The AN/TPS-80 G/ATOR is an advanced AESA multi-mission radar that provides comprehensive, real-time, 360 degree situational awareness against a broad array of threats including fixed wing aircraft, helicopters, cruise missiles, unmanned autonomous systems (UAS) and rockets, artillery and mortar. It is rapidly deployable worldwide to meet USMC needs and includes the latest cyber and digital beamforming technology that enables the radar to perform multi-mission tasks at significantly lower operation and maintenance costs compared to existing USMC radar systems.

LPWA Technologies Double-Edged Sword for European Network Operators

The highly competitive and fragmented European cellular M2M market will grow to 416.5 million connections by 2023, according to a new report by ABI Research. To differentiate themselves in this market, European network operators must turn toward new business models and increasingly competitive LPWA technologies to keep and grow their existing market share.

"While cellular LPWA connections such as NB-IoT and LTE-M will make up the largest portion of M2M connections in Europe in 2023, operators will face increased competition from non-cellular technologies such as SigFox and LoRa," says Ryan Harbison, research analyst, ABI Research. "By focusing on defining use cases and providing value-added solutions that go beyond just the connectivity piece of the value chain, operators can provide differentiated offerings in their respective domestic and international markets."

> "Network operators must maximize the value that their connections and solutions provide."

Additionally, network operators need to understand that the European market is also heavily influenced by EU initiatives and regulations. Of the 86 million cellular connected M2M devices at the end of 2017, 67.4 percent were related to telematics and other transportation applications partly due to the EU's eCall initiative, for having connected devices in each new vehicle to relay airbag deployment and impact sensor information to emergency agencies in the event of a crash. Likewise, 22 percent of total connections were related to smart city and other infrastructure industries partly due to the EU's Smart Grids Task Force on spurring smart energy deployment and development. Operators like Orange, Deutsche Telekom and Vodafone that have deployed NB-IoT networks have done so because connections within these larger vertical categories fit the NB-IoT use case of generally transmitting small amounts of data infrequently.

"Vodafone's M2M strategy is focused on putting a greater emphasis on its own cloud services than on just the connectivity component, while Deutsche Telekom and Orange have opened IoT labs to develop and test application-specific IoT prototypes. European operators are largely realizing that connectivity is the lowest common denominator and are shifting their focus to the long-term value these connections generate," concludes Harbison."

Technology Transitions on Road to 5G Propel Cellular RAN Equipment Market

According to ABI Research, the global RAN base station equipment market will grow at a CAGR of 5 percent to exceed $26 billion in 2023. These sales take into account both outdoor and indoor RAN equipment including macro base stations, outdoor small cells, indoor small cells and DAS.

"Today the RAN equipment market is undergoing multiple technology transitions as network operators move to densify macro networks with small cells, tackle in-building wireless and evolve to new technologies such as 5G, LAA, unlicensed and shared spectrum technologies such as OnGo in the U.S. and MulteFire," said Nick Marshall, research director, ABI Research. "These transitions are occurring against a backdrop of continuous technology evolution as networks upgrade to include MIMO, massive MIMO, 256-QAM and carrier aggregation," continued Marshall.

> "The underlying technology transitions are complex and only those vendors that can leverage them stand to benefit..."

Spending on indoor equipment, which represents 27 percent of this market today, will grow at a CAGR of 15.5 percent to represent a value of 42 percent of the total by 2023. The Asia-Pacific region will continue to dominate the market with a share of 58 percent of the market, with North America and Europe ranking a distant second and third, respectively. Sales of infrastructure equipment in the North American and Asia-Pacific regions will continue to be dominated by replacement and upgrades to LTE with the addition of 5G equipment gaining share starting in 2019.

"While the overall market is healthy, the underlying technology transitions are complex and only those vendors that can leverage them stand to benefit—these vendors include Ericsson, Huawei, Nokia, Samsung and ZTE," Marshall concluded. However, it is not only the traditional vendors which will benefit as these technology transitions take hold; many specialist vendors stand ready to compete for share. These vendors include small cell specialists Acceleran, Airspan, Airvana/CommScope, Comba, Contela, ip. access, Parallel Wireless, Ruckus/Arris and SpiderCloud Wireless/Corning.

AR, VR Over Wireless Networks Gaining Momentum in Industrial Sector

AR is growing in presence in industrial applications such as smart manufacturing and remote operation of industrial machinery. To

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serve workers that use devices in a wider range of locations or on the move, cellular connectivity is the better option. The 5G network, with extreme throughput, ultra-low latency and uniform experience, will be the ideal solution for connected AR/VR experiences. ABI Research forecasts that almost 10 percent of industrial smart glasses and standalone VR devices will have a 5G connection by 2026.

"Wearing smart glasses, rather than using AR on handheld screens, empowers the worker to use both hands and look directly at the work that needs doing," says Marina Lu, senior analyst, ABI Research. "AR will enable shop-floor workers to see a digital twin overlaid on a physical object with assembly or repair instructions according to customized needs. Remote applications that connect field engineers to a remote expert require high-accuracy interaction and low end-to-end latency for time-sensitive applications, and thus continuous connectivity is vital. When users in field service and maintenance are in remote locations where Wi-Fi is nonexistent, devices can leverage 4G and eventually 5G networks to keep these workers connected and safe."

Connectivity vendors, such as Qualcomm, Huawei, Ericsson and Nokia, as well as telcos, such as Verizon, SK Telekom and Orange, view AR/VR as one of the prime use cases for the 5G network. Ericsson has recently used AR troubleshooting (ART) at its own production sites in Tallinn, Estonia, and is expanding its use to other Ericsson sites in China. By using ART, the engineers can solve tricky issues with just-in-time fault-finding data and immediate information sharing, which can boost productivity by 50 percent.

Cellular connectivity could expand the possible working area of AR/VR. LPWAN can efficiently support simple remote devices that do not communicate frequently while remaining ultra-energy efficient. The combination of IoT and AR/VR improves the entire value chain for use in manufacturing. Some manufacturers have already started to adopt LPWA, as shown by Huawei and Toshiba's NB-IoT solution for smart factory monitoring.

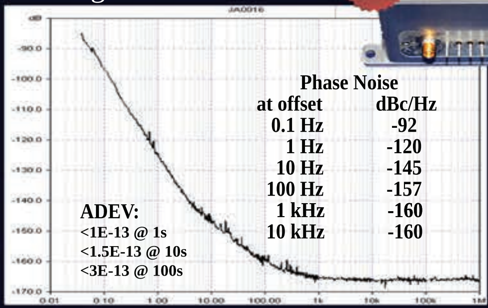
> "Mobility is the key to enhance user AR/VR experiences and industry market penetration."

"Mobility is the key to enhance user AR/VR experiences and industry market penetration, which poses new requirements on an operator's network structure and services, but also create new opportunities because only operators can create value in connecting the supply chain, connecting the factory and the product and understanding the end customers," adds Eric Abbruzzese, principal analyst, ABI Research.

Ultra-Low Phase Noise OCXOs

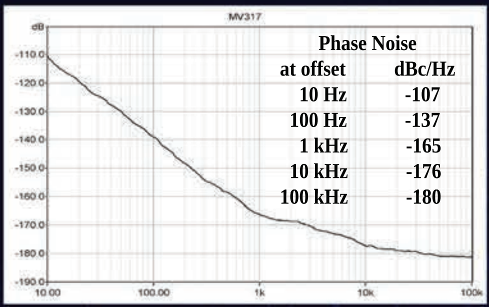
10 and 100 MHz

MV336 10 MHz, +12V
- Temperature Stability: 2E-11
- Aging: ±1E-8 per year
- Package: 92x80x50 mm



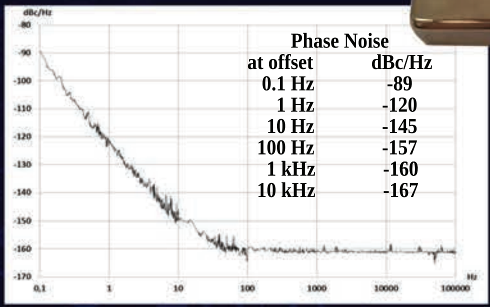
Phase Noise at offset	dBc/Hz
0.1 Hz	-92
1 Hz	-120
10 Hz	-145
100 Hz	-157
1 kHz	-160
10 kHz	-160

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



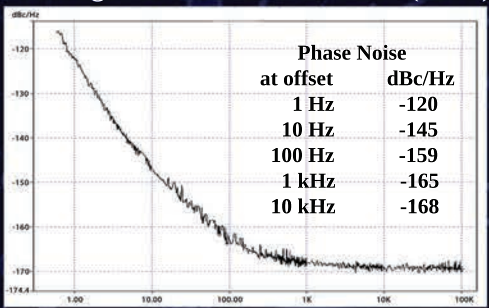
Phase Noise at offset	dBc/Hz
10 Hz	-107
100 Hz	-137
1 kHz	-165
10 kHz	-176
100 kHz	-180

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



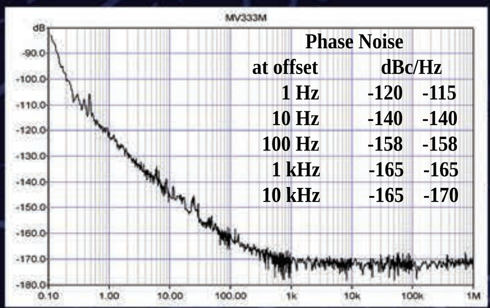
Phase Noise at offset	dBc/Hz
0.1 Hz	-89
1 Hz	-120
10 Hz	-145
100 Hz	-157
1 kHz	-160
10 kHz	-167

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



Phase Noise at offset	dBc/Hz
1 Hz	-120
10 Hz	-145
100 Hz	-159
1 kHz	-165
10 kHz	-168

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



Phase Noise at offset	dBc/Hz	
1 Hz	-120	-115
10 Hz	-140	-140
100 Hz	-158	-158
1 kHz	-165	-165
10 kHz	-165	-170

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1750 Meridian Ave. #5128
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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Skyworks Solutions, Inc., an innovator of high performance analog semiconductors connecting people, places and things, closed its acquisition of **Avnera Corporation**, a leading developer of Analog System on Chips (ASoC). The companies entered into a definitive agreement on August 3, 2018. Per the terms of the agreement, Skyworks paid cash for the acquisition, which was approved by the boards of directors of both Skyworks and Avnera. Excluding any non-recurring acquisition-related charges and amortization of intangibles, Skyworks expects the acquisition to be immediately accretive to diluted earnings per share.

TTI Inc. announced that it has entered into a letter of intent to acquire **RFMW Ltd.**, a privately held, specialty distributor headquartered in Silicon Valley. Upon completion of the acquisition, RFMW will continue to operate under the RFMW brand name, reporting through the TTI Semiconductor Group (TSG). Joel Levine will continue to serve as president of RFMW, and will report to TSG President Michael Knight. Consummation of the transaction is subject to entering into a definitive agreement regarding the transaction and to the satisfaction or waiver of the conditions to closing to be specified in such definitive agreement. The transaction is expected to close October 1, 2018.

COLLABORATIONS

T-Mobile and **Nokia** have announced a landmark $3.5 billion agreement to accelerate the deployment of a nationwide 5G network. Nokia will provide T-Mobile with its complete end-to-end 5G technology, software and services portfolio, assisting the carrier in its efforts to bring a 5G network to market for customers in the critical first years of the 5G cycle. As part of the agreement, Nokia will help build T-Mobile's nationwide 5G network with 600 MHz and 28 GHz mmWave 5G capabilities compliant with 3GPP 5G New Radio (NR) standards.

Mini-Circuits announced a new partnership with 3D imaging sensor company **Vayyar Imaging** to offer microwave transceiver project kits with broad applicability for students and university programs spanning topics in electromagnetic theory, RF/microwave engineering, RF systems and radar technology. The first project kit, UVNA-63 includes all the elements students need to build a fully functioning vector network analyzer, develop S-parameter algorithms and perform real-time measurements of 2-port RF devices. The kit comprises Vayyar's high performance transceiver chip with a variety of RF components from Mini-Circuits, along with control software and a development environment for Python and MATLAB®.

MediaTek Inc. and **Anritsu Corp.** have agreed to forge a partnership for 5G development and physical layer verification. MediaTek selected Anritsu's Radio Communication Test Station MT8000A as a prioritized test platform for the verification of standard-based 5G NR chipsets targeting upcoming global 5G deployment. Anritsu, a leader in mobile communications testing, will support MediaTek's development of 5G devices, such as baseband chipsets, by providing powerful and efficient test solutions from early phase of pre-silicon verification to commercial validation stage of RF, protocol and function to enable the launch of high-quality 5G chipsets to the market.

Menlo Micro, along with **Corning Inc.**, have achieved a major milestone in the development of its revolutionary Digital-Micro-Switch (DMS) technology platform. The two companies have demonstrated the successful integration of Through Glass Via (TGV) packaging technology, enabling the expansion of Menlo's high performance RF and power products to ultra-small wafer scale packaging. TGV allows Menlo to shrink the size of its products by more than 60 percent, compared to traditional wire-bond packaging technologies, making it particularly well-suited for applications where increased channel density and reduction of SWaP-C are critical. In addition to the significant size reduction, TGV brings major benefits in performance to Menlo's DMS products.

Italian telecom giant, **TIM** has partnered with **Ericsson** to deploy a virtual radio access network (vRAN) platform using a live advanced LTE network in Turin. The deployment of vRAN in a live advanced LTE network is the first of its kind for a city as large as Turin, and is part of an ongoing transformation set to digitalize TIM's RAN nationwide, readying for early 5G adoption. The vRAN technology, developed by both companies, will support the evolution of the network into a flexible cloud platform that enables the management of innovative services and automation while reducing associated costs and offering 5G-ready applications and services to Turin's customers and businesses.

ACHIEVEMENTS

Keysight Technologies Inc. received the 2018 Excellence in Engineering Education Collaboration Award from the **American Society for Engineering Education (ASEE)**. The award recognizes Keysight's collaboration with universities primarily through the Keysight RF/Microwave Industry-Ready Student Certification Program which serves to produce and recognize industry-ready engineers. This allows potential employers to hire with confidence, knowing the productivity of the new employee is assured from their first day. More than 40 universities around the globe have adopted and use Keysight's program in their curriculum.

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Around the **Circuit**

RFMW Ltd. marked July 1 as the 15-year anniversary of their company. With worldwide headquarters in San Jose, Calif. and sales offices throughout North America, Europe, the Middle East and Asia, the company has seen a continual acceptance of their "niche" philosophy in that "RFMW is a specialty electronics distribution company focused on RF and microwave technology."

NAI, a leading manufacturer of global connectivity solutions for high performance systems used in the industrial technology, telecom, data and medical industries, announced they have achieved zero-defect manufacturing in their Hermosillo, Mexico Plant 2 for one year. The event also signifies a one-year period without customer returns or complaints. During this period, NAI produced 25,000 fiber optic riser cable assemblies, 200,000 fiber optic jumpers and more than 3 million cable terminations. A total of 2,800 km of fiber optic cable was processed in 840,000 man hours.

Teledyne LeCroy Inc., a business unit of **Teledyne Technologies Inc.**, has advanced its leadership in the 24G SAS market with the addition of an industry-first analysis capability for dynamic channel multiplexing (DCM) from Microsemi Corp. This new cost-effective testing feature simplifies the DCM verification process for users of Teledyne LeCroy's Sierra T244 protocol analyzer. Following several major milestones by Teledyne LeCroy in the 24G SAS arena, including the introduction of the first 24G SAS analyzer, jammer and exerciser system, Teledyne LeCroy has now assembled the most complete line of protocol layer test tools for storage vendors targeting 24G SAS development.

Qorvo has now received certification for the multi-sensor and generic switch features of Zigbee Green Power v1.1. The Green Power feature of Zigbee PRO allows battery-less Zigbee products such as sensors, switches, dimmers and many others to securely join Zigbee PRO networks. These devices can now be powered just by using widely available, but often missed sources of energy like motion, light or vibration. These new features greatly expand the types of smart home sensors that can be powered by energy harvesting, eliminating the need for batteries or enabling ultra-long battery life.

CONTRACTS

General Dynamics Missions Systems in Fairfax, Va., has named nine rugged computer companies as partners in the **U.S. Army-General Dynamics** $3.9 billion five-year Common Hardware Systems 5th Generation (CHS-5) project to provide U.S. warfighters with rugged, commercial off-the-shelf (COTS) computers and networking equipment modified for military operations.

Harris Corp. has been awarded a $400 million increase to the ceiling value of a single-award IDIQ contract to supply EW systems for international F-16 fighters—help-

ing to protect allied aircraft against evolving radar and electronic threats. The new ceiling value is $491 million and was received during the fourth quarter of Harris' fiscal 2018. Harris will provide AN/ALQ-211(V)4/9 Advanced Integrated Defensive Electronic Warfare Suite (AIDEWS) systems, spares and engineering support to several allied countries as part of a Foreign Military Sales contract through the U.S. Air Force, further expanding the system's presence on F-16s worldwide.

SRC Inc., a not-for-profit research and development company, has received a $32 million contract to provide the **U.S. Army** with next-generation, multi-mission EW systems. SRC combines information, science, technology and ingenuity to solve impossible problems in the areas of defense, environment and intelligence. Under the contract, SRC will provide a range of research, development, test and evaluation (RDT&E) services to extend the life of the Army's CREW Duke Systems through the next decade.

Envistacom announced the company has been awarded a task order under the **Army Contracting Command (ACC) Deployable Adaptive Global Responder Support (DAGRS)** contract vehicle, expanding the Georgia-based defense contractor's rapidly growing partnership with the DoD. Envistacom is one of 10 companies selected to compete for task orders on the DAGRS IDIQ contract vehicle, worth up to $480 million over five years. Representing $18 million over three years, Envistacom will act as prime contractor under this most recent task order. To support both U.S. Army and Navy customers, Envistacom will satisfy requirements for engineering and technical assessment enhancements through rapid-prototyping initiatives.

Ultra Electronics USSI, a subsidiary of **Ultra Electronics Holdings plc**, and **Sparton Corp.** announced the award of subcontracts valued at $9.3 million from their ERAPSCO/Sonobuoy TechSystems joint venture. ERAPSCO/Sonobuoy TechSystems will provide manufacturing subcontracts in the amount of $4.5 million to Sparton DeLeon Springs LLC and $4.8 million to Ultra Electronics USSI. Production will take place at Ultra Electronics USSI's Columbia City, Ind. facility and Sparton's DeLeon Springs, Fla. facility. ERAPSCO/Sonobuoy Tech Systems was awarded multiple foreign contracts for the manufacture of passive and active sonobuoys to support various underwater missions for detection, classification and localization of adversary submarines during peacetime and combat operations.

DARPA has selected **BAE Systems** to develop data-driven, cyber-hunting tools that detect and analyze cyber threats to help protect extremely large enterprise networks. The contract for Phase 1, 2 and 3 of the program is valued at approximately $5.2 million. Because most current tools do not offer the scale and processing speed needed to adequately defend enterprise networks, the goal of DARPA's Cyber-Hunting at Scale (CHASE) program is to develop, demonstrate and eval-

uate new, automated cyber-defense tools for use within and across these types of networks.

Comtech Xicom Technology, a **Comtech** subsidiary, has received a contract for more than $2.6 million from a domestic military system integrator. The contract is for Ku- and Ka-Band high-power traveling wave tube amplifiers (TWTA) for a transportable satellite communications ground system. Comtech Xicom Technology has a vast portfolio of TWTAs optimized for military applications. These amplifiers are highly efficient and compact, representing the best that industry has to offer. The company manufactures a wide variety of tube-based and solid-state power amplifiers for military and commercial satellite uplink applications.

Sweden based defense company, **SAAB**, will be supplying its Giraffe AMB Multi Mode Radar (MMR) for the **U.S. Navy's Expeditionary Sea Base (ESB)** class ship USNS Hershel "Woody" Williams, ESB 4. The sale also includes SAAB's 9LV Naval Combat System for radar control and display delivering enhanced situational awareness as well as Identification Friend or Foe (IFF) capability. The ship will be operated by the Navy's Military Sealift Command. In 2017, the U.S. selected SAAB's Sea Giraffe MMR for the U.S. Coast Guard's newest class of ship, the Offshore Patrol Cutter.

Triumph Group Inc. announced that its Aerospace Structures business has been awarded a multi-year airframe component contract for **Lockheed Martin's** C130J Super Hercules program. Under initial terms of the contract, **Triumph Fabrications** in San Diego, Calif. will provide 108 different part numbers for the C130J program. The parts include fabricated sheet metal structures made from a combination of aluminum, steel and titanium materials that will be fitted to the nacelle, wing and fuselage sections of the aircraft. The contract, which runs from 2021 through 2024, was awarded to Triumph based on past performance, on schedule delivery of high quality products, as well as Triumph's ability to manufacture a wide variety of structures in a wide range of materials.

AppTek announced that the **U.S. Army** has chosen AppTek's Machine Translation software, support and engineering services for its digitized foreign language translation needs, following an open market bid for the best technical and value offering. The Army requires a stable platform that is trained to multiple linguistic domains, and will apply AppTek's technology in a variety of settings. Using AppTek, the Army will benefit from accurate, automated translation to and from English and a breadth of other languages. AppTek's continuous learning system, which integrates proprietary AI technology, will provide the Army with greater speed and accuracy of translation, including custom vocabularies and dialects for each designated language.

Around the **Circuit**

Specialty foundry **TowerJazz** is ramping a 65 nm version of its RF-SOI process on 300 mm wafers at Fab 7 in Uozu, Japan. To support the ramp, the company has signed a contract with long-term partner, **Soitec**, guaranteeing a supply of tens of thousands of 300 mm SOI silicon wafers, securing wafer prices for the next years and ensuring supply to its customers, despite a tight SOI wafer market.

PEOPLE


▲ *Thomas M. Rosa*

Custom MMIC Design Services Inc. announced it has hired **Thomas M. Rosa** as senior vice president and CFO effective immediately. Rosa, who has been consulting with the company for 14 months prior to his hiring, will lead all aspects of the company's finance and accounting operations. Rosa has more than 30 years of progressively more responsible financial management experience at public and private companies, with significant experience at companies focused on materials and material based solutions. His primary strengths lie in capital markets, investor/analyst relations, SEC filings, mergers and acquisitions, budgeting and long-range planning, manufacturing cost accounting and government accounting.


▲ *Pete Mastin*

Norden Millimeter Inc. announced that **Dr. Pete Mastin** has joined the company as CTO. Dr. Mastin will support Norden's growth in advanced and emerging technologies. The product growth includes frequency conversion products, 5G modules and mmWave subassemblies. He has over 30 years of experience in RF design and development leadership in both military and commercial markets. Prior to joining Norden, Dr. Mastin worked for Sierra Nevada Corp., HP/Agilent, Texas Instruments and was a co-founder of EM Research. Dr. Mastin's goal is to provide sound technical leadership in all aspects of Norden's business, along with leadership for front-end and back-end engineering, testing, UX, product management, infrastructure and delivery.


▲ *Vadim Yakovlev*

Vadim Yakovlev, associate research professor of mathematical sciences at Worcester Polytechnic Institute (WPI), has been named a fellow of the International Microwave Power Institute (IMPI). The prestigious honor, which has been awarded only 34 times during the organization's 52-year history and only four times in the last decade, was presented at the IMPI general membership meeting in Long Beach, Calif., on June 27. Yakovlev, who directs the Industrial Microwave Modeling Group, part of WPI's Center for Industrial Mathe-

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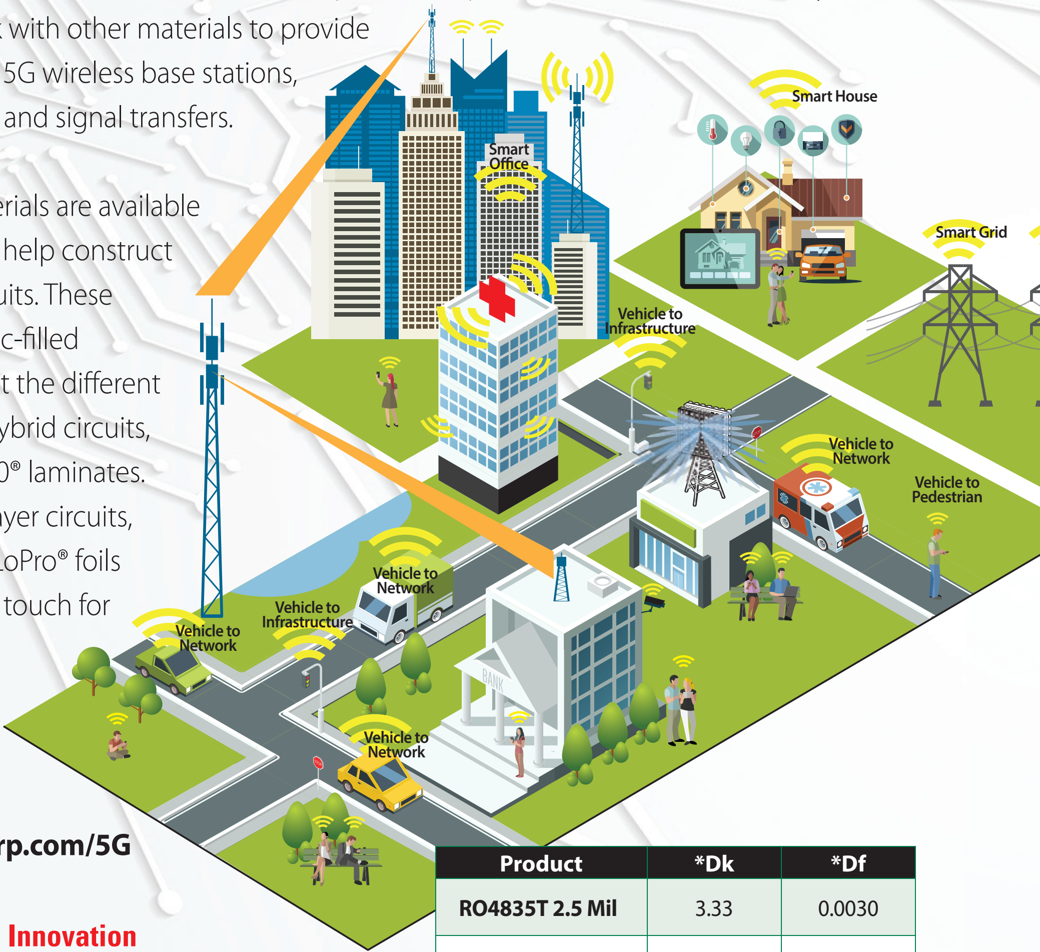

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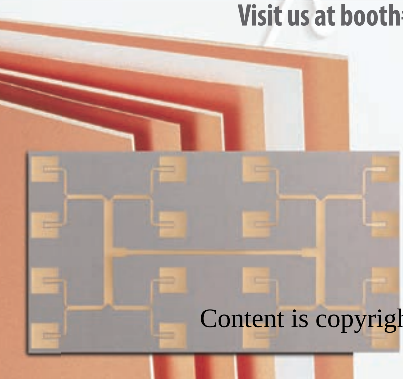

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REP APPOINTMENTS

Avnet has been named a global distribution partner for **Microsemi Corp.**, a wholly owned subsidiary of **Microchip Technology Inc.** As an extension of Avnet's multi-year relationship with Microchip Technology Inc., Avnet customers now have immediate access to the complete Microsemi portfolio of semiconductor and system solutions for aerospace and defense, communications, data center and industrial markets. Microchip completed its acquisition of Microsemi earlier this year.

RFMW Ltd. announced a distribution agreement with **SiTime**, the market leader in MEMS timing. Under the agreement, RFMW is franchised for worldwide marketing and sales of SiTime's portfolio of MEMS based timing solutions. RFMW is a specialized distributor providing customers and suppliers with focused distribution of RF and microwave components as well as specialized component-engineering support.

Richardson Electronics Ltd. announced a new distribution agreement with **MS Power GmbH**, a leading manufacturer of bipolar semiconductor products. The agreement aligns with both companies commitment to provide the highest reliability and quality products into various applications including motor drives, power supplies, solar and wind energy systems, smart grid and others. MS Power GmbH offers a broad range of distributed gate SCRs, phase control SCRs, diodes, power modules and power bridge devices. Its broad range of diodes contain pellets in voltages up to 7000 V and a current range of 25 and 13500 A. SCRs are available in voltages up to 8500 V and a current range from 16 to 5000 A.

PLACES

Raytheon Co. announced the opening of a $72 million, 30,000 square foot facility on its Andover, Mass.-based campus, which is now home to some of the industry's leading innovations in manufacturing. The new space features advanced automation technology to support complex radar testing and integration. The new facility is the primary location for integration and testing of current and future radar programs for U.S. and international customers. AN/SPY-6, the U.S. Navy's next-generation integrated air and missile defense radar, now in low rate initial production, is the first system to enter the space.

Linearity Improved Doherty Power Amplifier Using Ferroelectric Ceramics

Shiwei Zhao
Chongqing University of Posts and Telecommunications, Chongqing, China
University of Electronic Science and Technology of China, Chengdu, China

Zhenfeng Yin
Nanjing Electronic Equipment Research Institute, Nanjing, China

Yuehang Xu
University of Electronic Science and Technology of China, Chengdu, China

A Doherty power amplifier (DPA) uses ferroelectric ceramics for linearity improvement. The conventional λ/4 transmission line is replaced by ferroelectric ceramics for 90 degree phase delay compensation. The phase of the peak amplifier input can be changed by modifying the voltage on the barium strontium titanate (BST) ferroelectrics to suppress AM to PM distortion. Compared with a conventional DPA, third-order intermodulation distortion (IMD3) is reduced by 16 dB.

Power amplifier (PA) linearity over a wide dynamic range is a key performance parameter in modern wireless communication systems employing complex digital modulation. DPAs have demonstrated high efficiencies over wide output power ranges, but DPA linearity cannot satisfy the stringent requirements of modern wireless communication systems. Linearization enhancement techniques, such as the use of wideband phase inverters, composite right/left-handed transmission lines (CRLH-TL) and asymmetrical DPA structures, have been proposed;[1-4] however, phase cannot be modified to improve linearity during the debugging process.

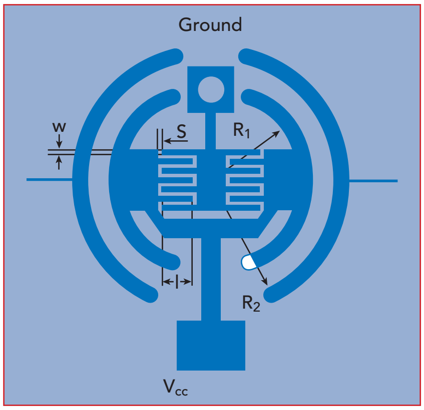

Fig. 1 Ferroelectric ceramic structure.

Ferroelectric varactors have been used as tunable elements in CRLH phase shifter applications,[5] and phased array antennas have employed tunable phase shifters based on ferroelectric ceramics, as well.[6] In this work, ferroelectric ceramics replace a conventional DPA's λ/4 transmission line to achieve a 90 degree phase shift. The result is improved linearity without affecting power-added efficiency (PAE).

HIGH LINEARITY DPA DESIGN

The BST ferroelectric ceramic resonant cell contains a series of interdigital capacitors (IDC) and a grounded stub line as a shunt inductor (see ***Figure 1***). IDCs with the following dimensions are used in the series branch: length l = 115 μm, finger width w = 46 μm and gap width s = 23 μm. R_1 and R_2 are 1.2 and 3.5 mm, respectively. The BST thick film has a height of 2 μm and is screen

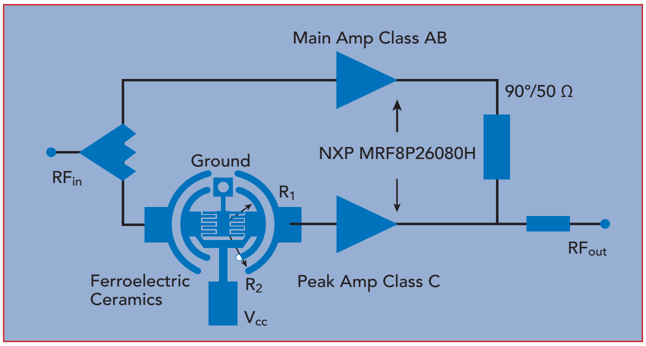

Fig. 2 DPA schematic.

printed and sintered on an Al_2O_3 substrate with a height of 620 µm and ε_r = 10.1. The relative permittivity of the BST (ε_r,BST) = 175.

The circuit architecture is shown in ***Figure 2***. The peak class C PA signal through the BST ferroelectric ceramic resonant cell is combined with the main class AB amplifier signal at the DPA output. As a result, a 90 degree phase delay, a tunable input capacitance of the peak amplifier FET and a tunable phase of the peak amplifier input are achieved at the same time.

Linearity Improvement

At high-power levels, when the peak amplifier is turned on, contributions to IMD3 are from both the main and peak amplifier; however, the peak amplifier dominates because it is operated class C. AM to PM distortion in the peak amplifier is a key factor, traceable to the signal-level dependence of the transistor model elements. Of these elements, the FET input capacitance is the biggest contributor.

The nonlinear characteristic of the peak amplifier can be expressed as[1,7]

$$i(t) = g_{m1}V + g_{m2}V^2 + g_{m3}V^3 + \cdots \qquad (1)$$

where i(t) and V are the current and voltage of the drain electrode in the peak amplifier, and g_{mn} are the transfer functions. The third-order intermodulation product (IM3) is expressed as

$$i_{out}(2\omega_2 - \omega_1) = \frac{A^3 g_{m3}}{8} e^{j(2\omega_2-\omega_1)t} \qquad (2)$$

C_{in} and g_m are related by[8]

$$C_{in} = C_{be} + C_{bc}\left(1 + g_m\left(\frac{1}{g_{ce}} // R_L\right)\right), \quad \text{where } \frac{1}{g_{ce}} \gg R_L \qquad (3)$$

where R_L is the load resistance, C_{in} is the total input capacitance, C_{be} and C_{bc} are base-emitter and base-collector capacitors, respectively, and g_{ce} is the collector-emitter transfer function.

While the phase of the peak amplifier input is controlled by modifying the voltage of the BST, the input capacitance is also modified to decrease AM to PM distortion; C_{be} is affected by the ferroelectric ceramics, according to Equation 3, so C_{in} is modified as well. The values of g_m for the main amplifier and peak amplifier are of opposite phase and

with modification to C_{in} of the peak amplifier by the ferroelectric ceramics, g_m of the peak amplifier is the same magnitude as that of the main amplifier. This reduces overall IMD3. Linearity of the DPA is therefore improved compared with a conventional DPA.

IMPLEMENTATION AND EXPERIMENTAL RESULTS

The DPA is fabricated on Rogers 4350 substrate (see ***Figure 3***). The bias voltage to the BST ferroelectric ceramic is 45 V for a 90 degree phase shift. An NXP MRF8P26080H LDMOS power transistor is used for both the main and peak amplifiers. VDS of the main amplifier and peak amplifier are both 28 V, while V_{GS} of main amplifier and peak amplifier are 2.65 and 2.28 V, respectively. The operating frequency range is from 2570 to 2620 MHz.

Simulated and measured PAE for this DPA compared to the measured PAE for a conventional DPA at 2.6 GHz are shown in ***Figure 4***. The DPA described in this work has a slightly higher PAE compared with the conventional DPA, with a maximum PAE of 46.2 percent. ***Figure 5*** shows the simulated and measured IMD3 for this DPA compared to the measured IMD3 for the conventional DPA, using a two-tone signal at a center frequency of 2.6 GHz with 5 MHz tone spacing. IMD3 of this DPA is considerably improved compared to the conventional DPA. At a low-power level, they are almost the same, because the peak amplifier is turned off. When the peak amplifier turns on, however, IMD3 is improved by as much as 16 dB.

Table 1 compares this work with recently published PAs having high linearity and efficiency.

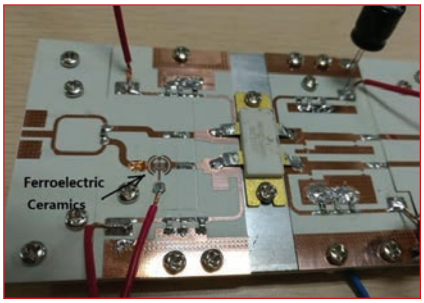

Fig. 3 Assembled DPA.

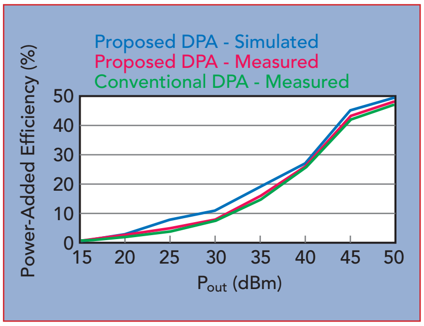

Fig. 4 Simulated and measured power-added efficiency of this DPA vs. measured performance of a conventional DPA.

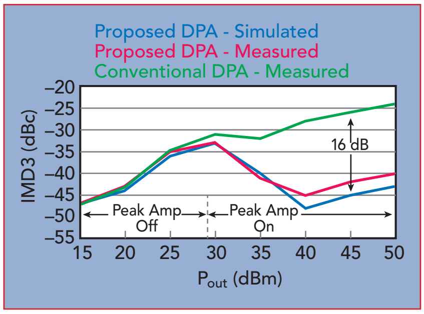

Fig. 5 Simulated and measured IMD3 of this DPA vs. measured performance of a conventional DPA.

TABLE 1

COMPARISON OF LINEAR AND EFFICIENT PAs

Reference	Frequency (GHz)	Max PAE (%)	Max IMD3 (dBc)	P_{out} (dBm)	Method
1	2.95	50	−40 (ACLR)	21	Wideband Phase Inverter
2	2.3	32.1	−47	31	CRLH
3	38 to 46	24.6	−40	21	Post-Distortion
This Work	2.57 to 2.62	45.2	−46	50	Proposed

CONCLUSION

A DPA suppresses AM to PM distortion of the peak amplifier. This is done by modifying the voltage of a BST ferroelectric ceramic resonant cell at the input. Comparisons with a conventional DPA and recently published works show the potential for improved linearity with the comparable efficiency.■

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Push-Push Oscillators Operating at G-Band Using InP DHBT Technology

Wang Xi, Muhammad Asif, Tong Zhihang and Jin Zhi
Institute of Microelectronics of Chinese Academy of Sciences, Beijing, China
University of Chinese Academy of Sciences, Beijing, China

Su Yongbo, Zhao Hua, Ding Wuchang and Ding Peng
Institute of Microelectronics of Chinese Academy of Sciences, Beijing, China

Two push-push MMIC fixed frequency oscillators operating at G-Band are fabricated using 0.8 μm InP double heterojunction bipolar transistor (DHBT) technology with peak f_t and f_{max} of 150 and 230 GHz, respectively. The push-push architecture of each oscillator consists of two sub-oscillators based on a modified Colpitts configuration. Even-mode oscillation is inhibited, and the second harmonic is extracted at the collector node. The first oscillator delivers an output power of –6 dBm at 161.6 GHz, and the second delivers an output power of –25 dBm at 204.8 GHz.

mmWave and sub-mmWave MMIC frequency sources above 100 GHz are essential building blocks for communication, radar, medical and automotive imaging systems due to the short wavelengths at these frequencies and, consequently, the wide bandwidths that can be achieved.[1-2] Several designs have been published, which include a fundamental mode oscillator,[3] an oscillator-doubler hybrid architecture[4] and a push-push oscillator.[5] Of these approaches, the push-push approach is more attractive for high frequency VCO design.[6] InP DHBT device technology offers a high breakdown voltage and high power capabilities, as well as outstanding high frequency properties,[7] making it a good candidate for frequency sources in this frequency range, as has been well demonstrated.[4]

The primary requirement for high frequency signal sources is high output power, which is desired in many applications such as automotive radar.[8] As frequency increases to near the f_{max} of the transistor, transistor gain is very low, which makes it difficult to achieve oscillation. The goal is to reach a high oscillation frequency with sufficient output power. To enable oscillator operation near its limit, in terms of frequency (f_t and f_{max}), a push-push topology is often used with two common-base sub-oscillators operating at half frequency.

This article describes the design of two push-push G-Band oscillators using 0.8 μm InP DHBT technology with peak f_t and f_{max} of 150 and 230 GHz, respectively. The first oscillator (OSC I) delivers -6 dBm output power at 161.6 GHz, while the second (OSC II) delivers −25 dBm output power at 204.8 GHz.

InP DHBT TECHNOLOGY

InP DHBT technology with an emitter width of 0.8 μm is used in the fabrication of the oscillators. The transistors are grown on a 3-inch InP wafer with an epitaxial profile designed for high frequency. The epitaxial layers consist of a 40 nm carbon-doped base layer and a composite collector.[9] Measured S-parameters of the 0.8 × 10 μm^2 DHBT demonstrate f_t and f_{max} of 150 and 230 GHz, respectively, at a bias of I_C = 14 mA and V_{CE} = 1.5 V. The device breakdown voltage BV_{ceo} is greater than 5 V.

The InP DHBT MMIC process includes MIM capacitors, thin film resistors (50 Ω/

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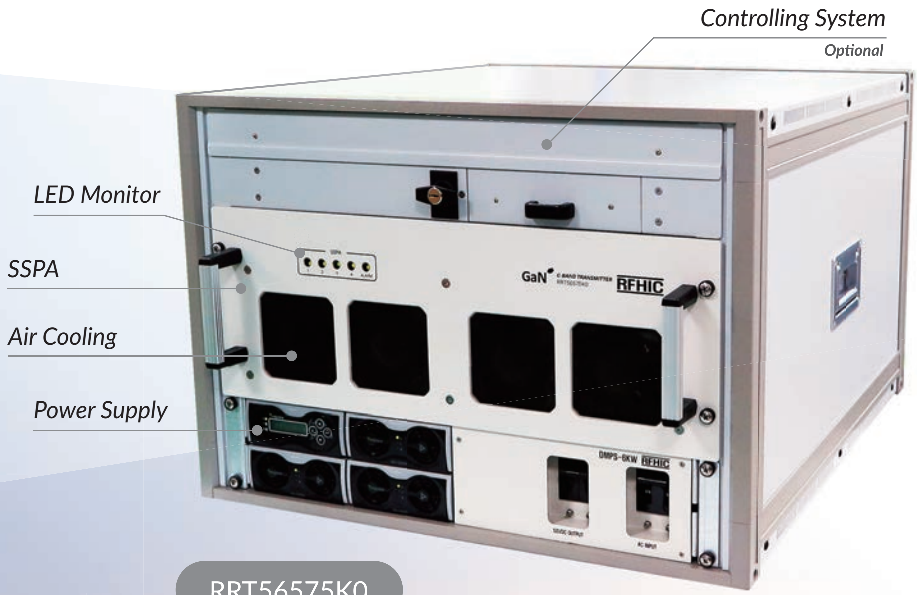

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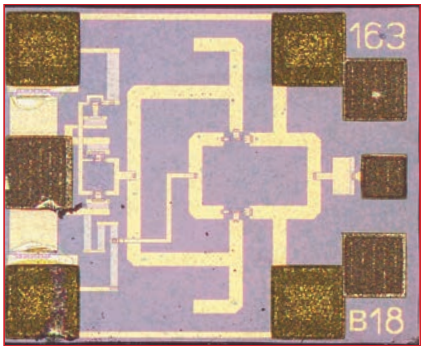


Fig. 1 Oscillator IC.

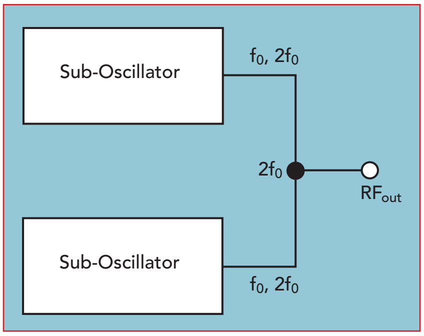


Fig. 2 Principle of a push-push oscillator.

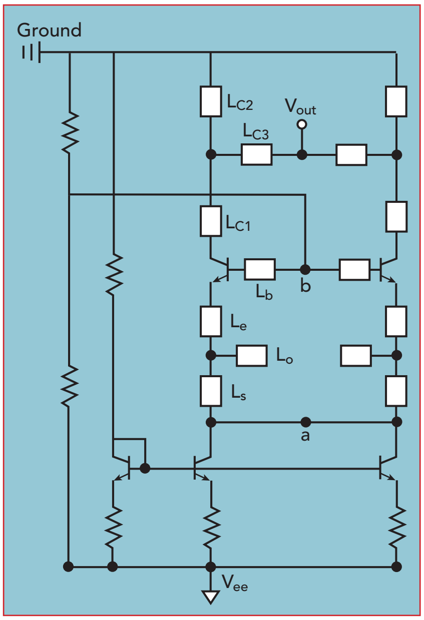


Fig. 3 Push-push oscillator schematic.

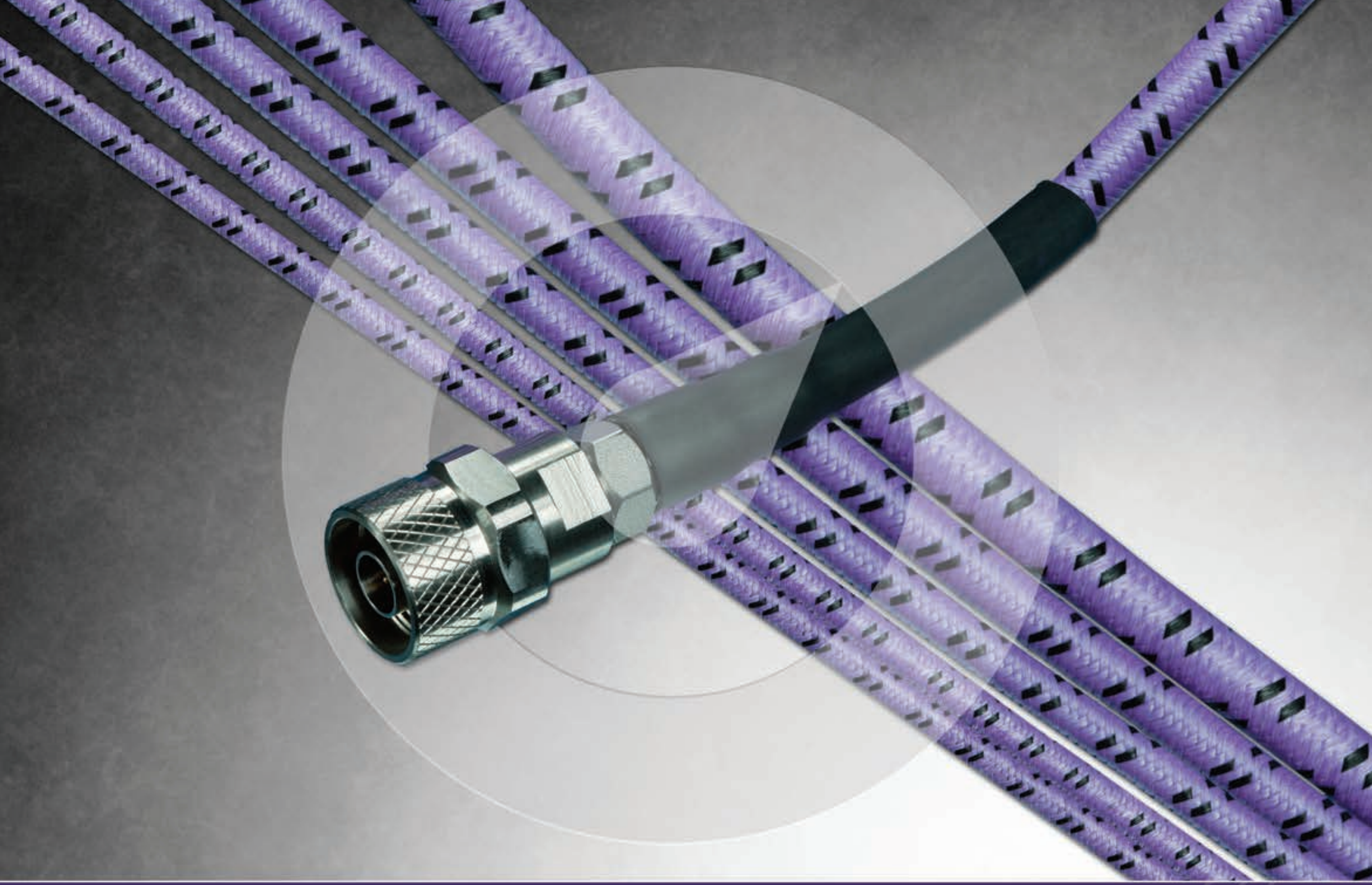
square), three levels of metal (M1, M2, M3), benzocyclobutene (BCB) passivation and wafer planarization after device formation. Microstrip is employed for low loss. A microphotograph of the MMIC is shown in ***Figure 1***. The layout is symmetric, with a total chip size of only 560 × 450 μm^2, including the DC and RF probe pads.

CIRCUIT DESIGN

The push-push approach employs a symmetric topology operating differentially at the fundamental mode, as shown in ***Figure 2***. Virtual grounds are created for the fundamental signal and all odd harmonics at the symmetry plane, while the even harmonics add in phase. Both of the two G-Band push-push oscillators are based on the schematic circuit diagram shown in ***Figure 3***. It consists of two identical Colpitts sub-oscillators operating at half the desired frequency. In one of the sub-oscillators, an inductive transmission line (L_b) below a quarter wavelength provides series positive feedback, which helps produce a negative impedance when looking into the transistor emitter and collector.[10] The open stub, L_o, acts like a capacitance, which also serves as a destabilizing element. Compared with the commonly used Colpitts designed for low frequency operation, a modified version with an added inductive transmission line (L_e) employed to improve high frequency performance.

Figure 4a is a simplified diagram of a Colpitts oscillator, and ***Figure 4b*** shows the modified version, with L_e for high frequency operation. In simulation, the additional inductive element boosts negative resistance at higher frequencies. The effect of L_e on the real part of the impedance looking into the DHBT collector is shown in ***Figure 5***. Consequently, the oscillation frequency is shifted higher.

The fundamental frequency of the push-push oscillator is set mainly by the resonators consisting of L_b, L_e and L_o. In this work, the two oscillators are fabricated with different resonator lengths L_b, L_e and L_o, for different oscillation frequencies. To ensure proper push-push operation, each sub-oscillator must oscillate in the odd mode and inhibit even-mode oscillation. In Figure 3, the fundamental signals of the two sub-oscillators at points a and b are out of phase, while the second harmonics add in phase; i.e., the fundamental signal is suppressed, and the second harmonic is easily extracted.



TechnicalFeature

The second harmonic signal can be extracted from the base, emitter or collector; however, higher output power is obtained at the collector, since the signal swing is larger. The breakdown voltage of the DHBT is larger than 5 V, which provides good potential for higher output power. The largest signal swing and highest output power are obtained by directly shorting the differential output.[10] In this paper, a harmonic matching technique is employed to enhance output power. A T-shaped, second harmonic impedance matching network is attached to the

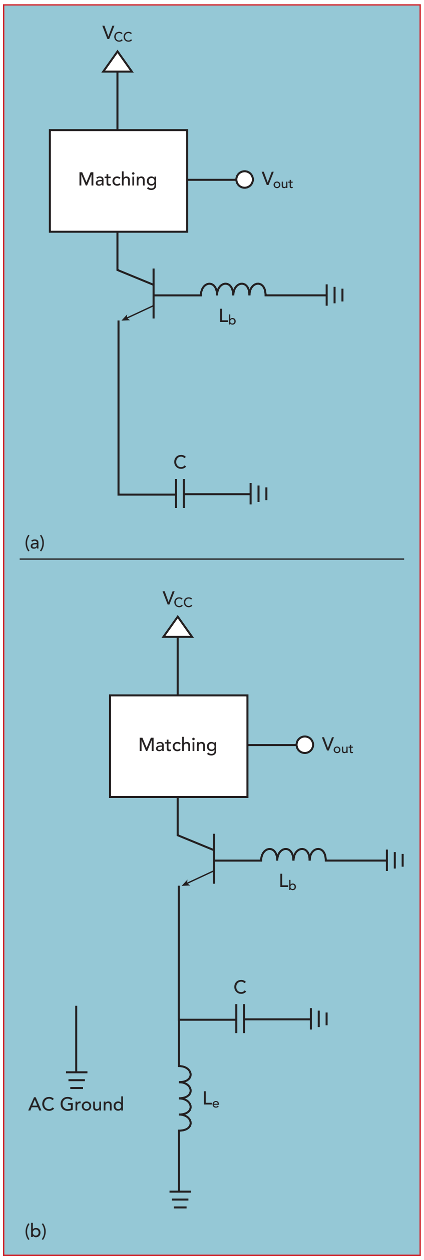
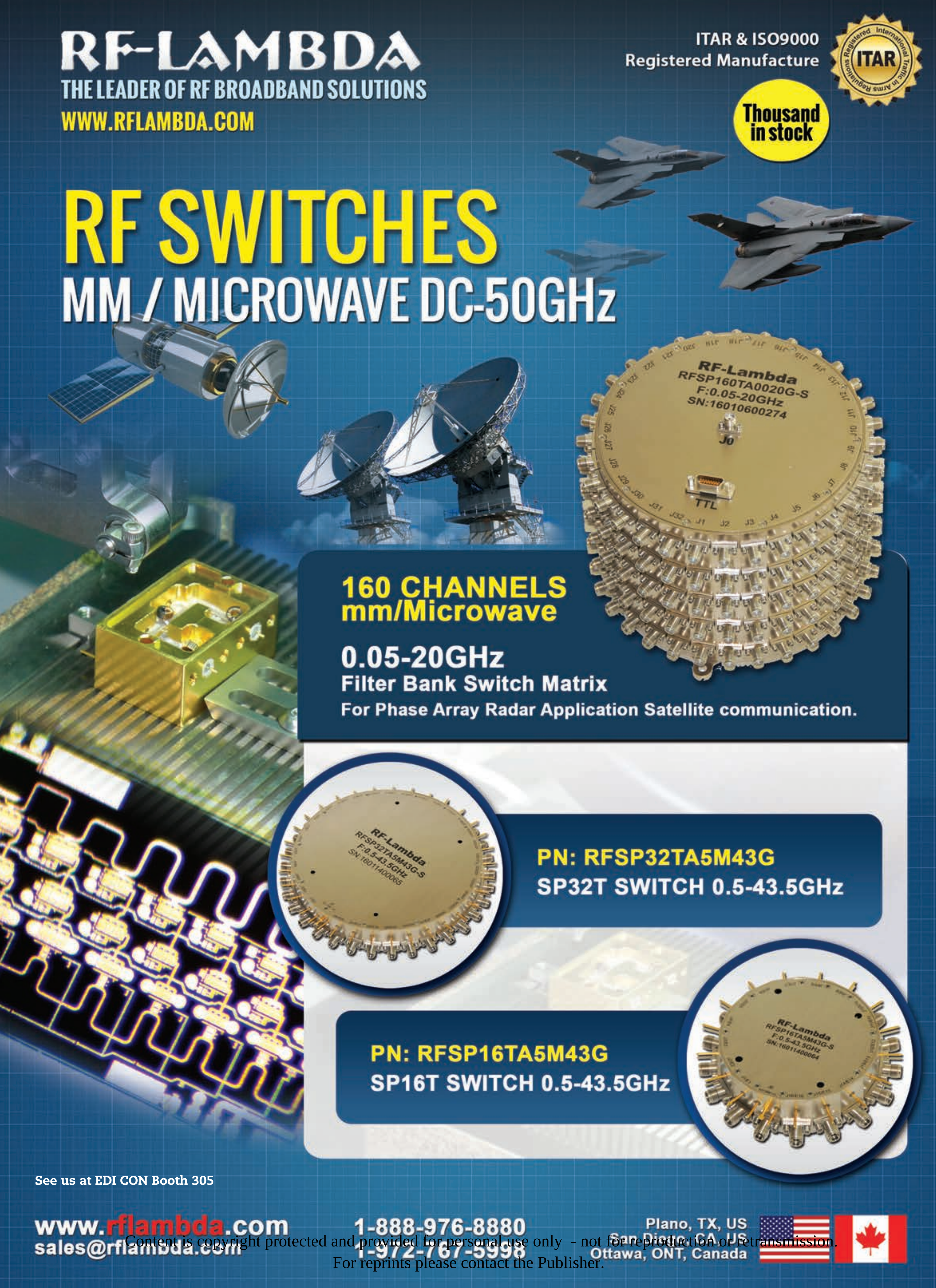


Fig. 4 Simplified Colpitts oscillator (a), modified for high frequency operation (b).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collector for each sub-oscillator. According to simulation, the output matching network—especially the shorted stub L_{c2}—affects output power significantly. With optimization of the matching network, output power at the second harmonic is increased by 5 dB.

The push-push oscillator MMIC topology enables a compact chip size that is much smaller than an oscillator-multiplier hybrid architecture. All DHBTs have 0.8 × 10 μm^2 emitters. Circuit simulation is performed using Keysight's Advanced Design System (ADS). Small-signal S-parameter analysis is used to determine the oscillation frequency; harmonic balance and transient analyses are performed to ensure oscillator functionality, and post layout simulation is performed with the Momentum 2.5D planar EM simulator.

MEASURED RESULTS AND DISCUSSION

The oscillators are characterized in two steps at room temperature. The fundamental signal measurement is done on-wafer. Spectral measurements are performed using a Keysight N9030A PXA signal analyzer extended in frequency with a W-Band harmonic mixer. The second harmonic measurement is done with the oscillator chips installed in modules. A G-Band harmonic mixer is used to extend the signal analyzer frequency range.

Figure 6 shows the measured spectrum of OSC I at the second harmonic and fundamental. OSC I delivers an output power of −6 dBm to a 50 Ω load at 161.6 GHz, while the fundamental signal output power is only -27 dBm (i.e., 21 dBc fundamental suppression). The circuit employs

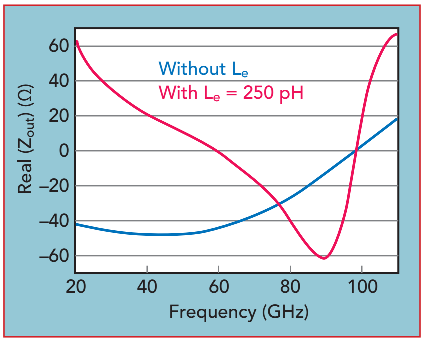

Fig. 5 Simulated real part of the impedance looking into the DHBT collector.

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Dynamic Range (BW=10Hz, dB, typ)	120	120	120	120	120	120	120	115	115	100	110	100	65
(BW=10Hz, dB, min)	110	110	110	110	110	110	110	100	105	80	100	80	45
Magnitude Stability (±dB)	0.15	0.15	0.15	0.15	0.15	0.25	0.25	0.3	0.3	0.5	0.5	0.8	0.5
Phase Stability (±deg)	2	2	2	2	2	4	4	6	6	8	8	10	6
Test Port Power (dBm)	10	13/6	13/6	11/6	6	9	-1	-2	-6	-10	-8	-25	-30

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a single supply voltage Vee = -3 V with a total current drain of approximately 40 mA; the bias current mirrors consume more than half the DC power. The oscillator core consumes about 45 mW, corresponding to a DC-to-RF efficiency of 0.56 percent. OSC II delivers an output power of −25 dBm at 204.8 GHz. The output power is low because the oscillation frequency is very close to the transistor's f_{max}.

Table 1 lists several reported HBT-based oscillators operating above 100 GHz. This design at 161.6 GHz achieves higher output power than the others, at close to f_{max}. This is attributed to the modified Colpitts topology and the harmonic matching technique.

CONCLUSION

Two monolithically integrated harmonic oscillators operating at G-Band use a push-push Colpitts topology and harmonic matching to operate at frequencies close to the transistor f_{max}. The output power of the two oscillators is −6 dBm at 161.6 GHz and −25 dBm at 204.8 GHz. DC-to-RF efficiency of OSC I at 161.6 GHz is 0.56 percent after subtracting the DC power consumption of the bias current mirrors.

ACKNOWLEDGMENTS

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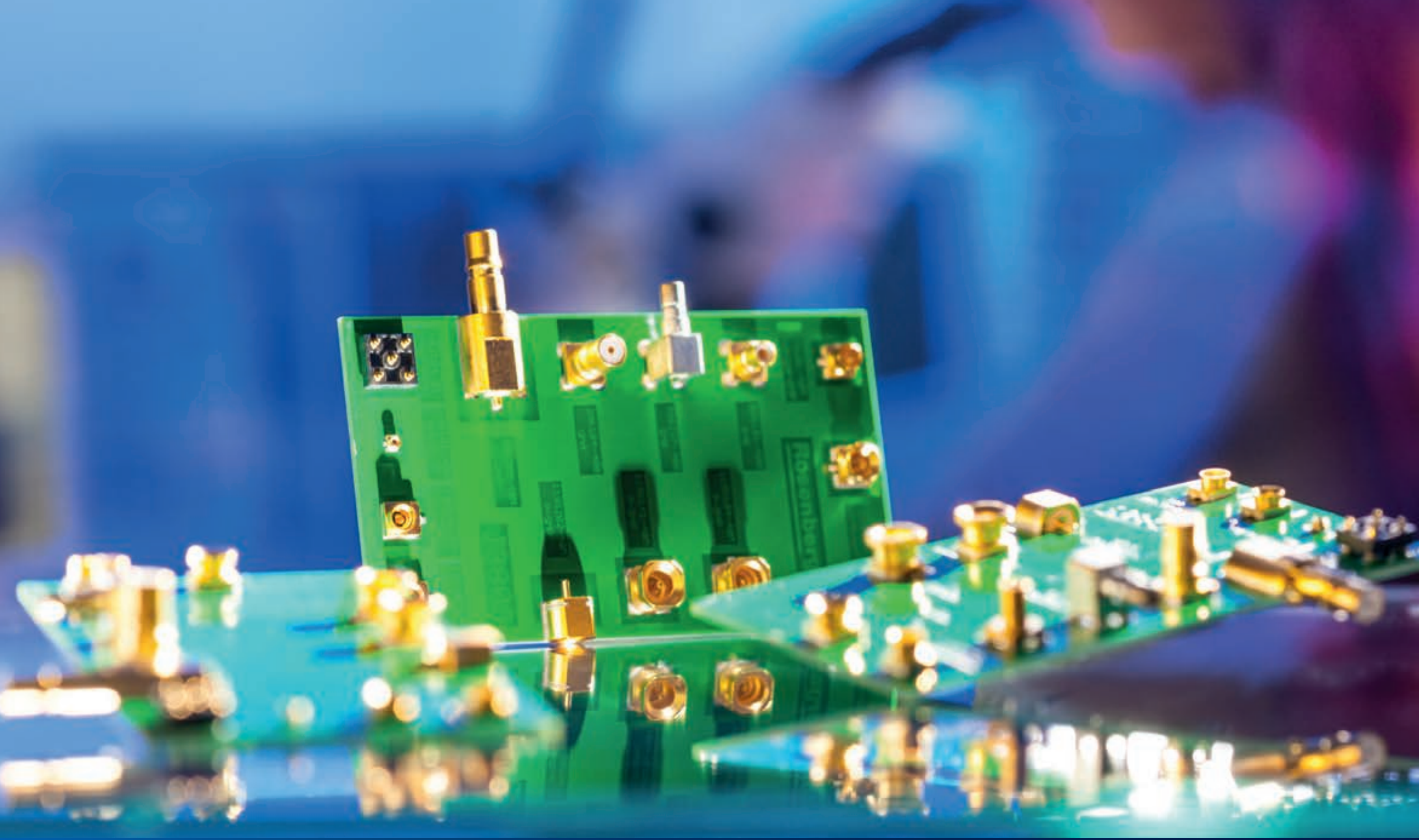

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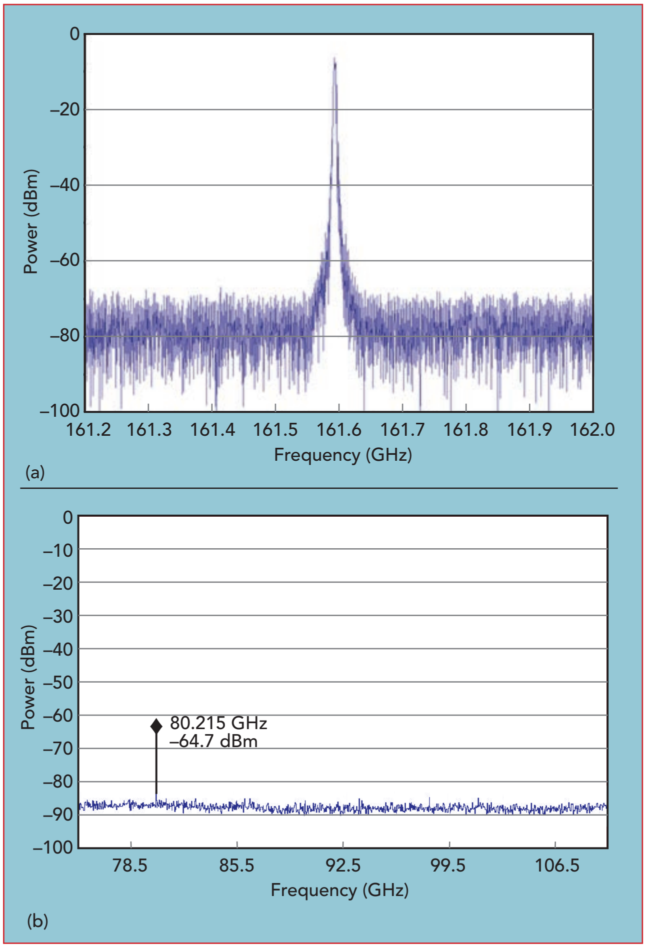


Fig. 6 Measured second harmonic (a) and fundamental frequency (b) of OSC I. The measurement of the fundamental includes 37 dB loss from the W-Band harmonic mixer used for on-wafer test.

TABLE 1

SEVERAL REPORTED > 100 GHz HBT OSCILLATORS

Ref.	Process	f_T /f_{max} (GHz)	Frequency (GHz)	Max. Pout (dBm)	Efficiency (%)	Topology
3	0.25 µm SiGe BiCMOS	280/430	157.3 to164.9	–15	0.068	Fundamental
5	0.25 µm InP DHBT	350/600	113 to 118	–0.5	-	Harmonic
11	SiGe BiCMOS	240/340	168 to 181	–9	0.21	Fundamental
This Work	0.8 µm InP DHBT	150/230	161.6	–6	0.56	Harmonic

INVITED PAPER

Measuring Differential Noise Figure

Jon Martens
Anritsu Co., Morgan Hill, Calif.

Differential noise figure has been an important measurement topic in recent years with the increasing use of fully, or nearly full, differential chains in receivers and transmitters. While a number of measurement approaches are being used, many include an external balun at the device under test (DUT) output so noise can be measured in a single-ended sense, with some de-embedding of the balun's effects, or by simply treating the DUT outputs as single-ended. While the balun-based method can be accurate, it can ignore more subtle influences of the balun on noise correlation and gives the user less visibility into the multi-mode behavior of the DUT, which can have noticeable system-level impact. Treating the DUT outputs as single-ended can miss correlated behavior entirely. A more careful treatment of the DUT's correlation behavior without over-complicating the measurement can sometimes lead to more accurate results and a clearer picture of DUT behavior. Such measurements will be analyzed in this article, both with and without the use of an external balun, showing that improved treatments can lead to noise figure results changing by 1 dB or more.

With an increasing plethora of differential devices in development and on the market, including those operating in the mmWave range, there is more of a need for differential (and common-mode, in some cases) noise figure measurements. The concept itself has had some definitional challenges,[1] but one can follow the lead of the literature and assume it is the output noise power in the given mode divided by the output noise power in that mode due to noise from uncorrelated terminations at the input at temperature T_0 = 290K, borrowing from the IEEE definition. The uncorrelated termination input assumption is practical and will arise from any passive network at thermal equilibrium.[2] The noise at the output due to input terminations requires some suitable gain definition for the mode, as many have discussed.[3] The basic noise power measurement can proceed in many different ways, although a cold source approach will be used here,[4] where an absolute power calibration is used with a mean square summation of noise wave measurements. We will also assume a vector network analyzer (VNA) is being used as the receiver. Suppressing the receiver calibration coefficients, which establish the power accuracy, and leakage signal corrections, one can write

$$\text{noise power} = \overline{|b_i|^2} = \sum b_i b_i^* / N$$

where b_i is the wave received at the i^{th} port of the VNA, * denotes the complex conjugate and N equals the number of measurements. Typically, N is very large to reduce the amount of data variation, but not so large that DUT drift has an effect (usually many thousands). Similar processes are used in noise calculations on many other receivers and instruments.

For differential noise measurement, several approaches have been commonly used. The most obvious is to connect a balun to the device output so the noise power measurement can proceed as in the two-port case, with the loss of the balun de-embedded. Procedurally, sometimes there are a few challenges: finding a sufficiently broadband balun—although this has become much easier in recent years—and interfacing to the balun in an on-wafer or fixtured environment. As we will see, handling balun imperfections is another layer to the story.

Another approach has been to simply measure the DUT outputs in a single-ended fashion, i.e., terminating the output

not being measured and perform some average analysis on the noise powers using an appropriate gain definition. For certain devices, this works quite well and is fundamentally making the assumption that the output noise waves are uncorrelated. If the noise-dominant structure of the device is similar to that shown in ***Figure 1a***, the noise mechanisms are not arising from a common node and there is weak coupling, this assumption is perfectly reasonable; there are many amplifier designs where this is the case. If, however, the noise-dominant stage is more like a differential pair (see ***Figure 1b***), the uncorrelated assumption may be more problematic. The question is whether there are additional measurement options to get around these potential issues.

METHODS: OLD AND NEW

As discussed, the use of a DUT output balun is a simple, obvious and generally successful solution to performing the measurement—as would the use of an in-phase combiner, should common-mode noise figure be needed. Many authors have pointed out[3,5-7] that there are a number of ways that even this measurement can be processed, and there are some error sources to consider. Even the most basic approach will de-embed the differential loss of the balun and perhaps consider its kTB thermal noise addition to the measurement—via the receiver noise calibration stage, for example. In terms of gain distortion, any imbalances in the balun will be captured by such an approach, but a simple method may not capture distortion in noise power correlation. Imbalances will lead to common-mode DUT noise power being coupled into the single-ended balun output and other mis-allocations. At even another level of analysis, the match interaction between the balun and the DUT could change the degree of noise power correlation.

An improved, corrected balun approach would compute the effective correlated power that is delivered to the common balun node, taking into account the balun imbalances. If the single-ended DUT noise powers are

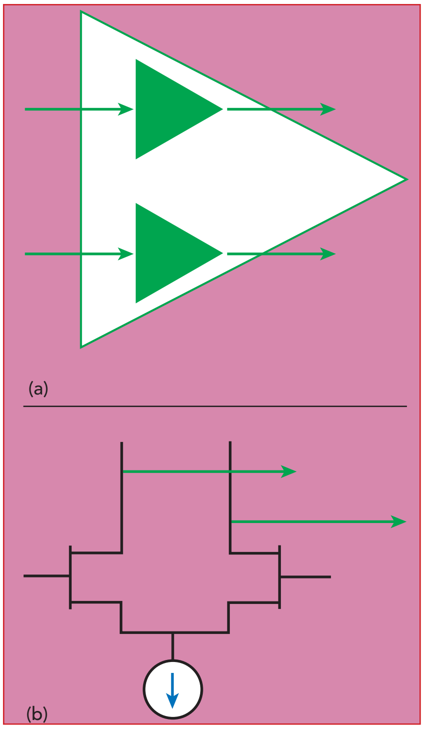


Fig. 1 DUT topologies where the output noise signals are uncorrelated (a) or, potentially, highly correlated (b).

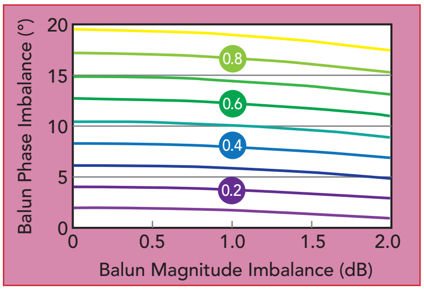
separately known—these add measurements of the DUT but require no added hardware—then the total differential power can be computed. A variety of permutations of techniques exist to do this correction.[3,5] One such approach is to calculate the amount of common-mode DUT noise power that makes it to the balun output and the amount of differential mode DUT noise power that does not. This can be done with a combination of single-ended noise power measurements and either two measurements using the balun[3] or by using a real correlation model of the DUT output and a single balun measurement.

It would be useful to have some understanding of the order of errors introduced by not doing an improved correction such as this. If the DUT outputs were uncorrelated, the error would be vanishingly small, from Bosma's theorem.[2] If the DUT outputs were highly correlated, then one can perform a simulation versus balun imbalance to see the size of the error. The results of such a simulation for a single-ended balun with nominal 4 dB insertion loss and a 5 dB noise figure, 20 dB differential gain DUT are shown in ***Figure 2***. While levels of balun imbalance vary, 10 degrees of phase imbalance for a high frequency, broadband balun may not be unusual, which could add 0.5 dB of error. Even in terms of cable length matching, 10 degrees at 50 GHz (using cables with expanded PTFE dielectric) arises from only a 125 µm length difference, so this is a practical concern. Note that the sensitivity to magnitude imbalance, at least on the levels commonly encountered, is somewhat less.

Another approach may be to directly measure the correlation signal. Expanding the mean-of-sum-of-squares of the differential signal yields the following equation, where ports 3 and 4 are defined to be the DUT output ports and receiver calibration and leakage signal calibration terms are omitted for simplicity:

$$\text{noise power dif f} = \frac{1}{2}\overline{|b_3 - b_4|^2} = \frac{\sum (b_3 - b_4)(b_3^* - b_4^*)}{2N} = \frac{\sum \left(|b_3|^2 + |b_4|^2 - 2\mathrm{Re}\left(b_3 b_4^*\right)\right)}{2N}$$

The first two terms in the numerator will form the average of the single-ended powers, just what the uncorrelated method ended up with. The last term is related to the mean of the real part of the correlation of the two waveforms. This is a physically reasonable result: if the waveforms are indeed uncorrelated, the last term will sum to zero



▲ **Fig. 2** **Simulated noise figure error from imbalance in the basic balun, where only the differential loss is considered.**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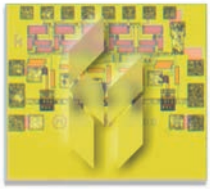

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Gain	27 dB
Noise Figure	0.6 dB
Output P1dB	16 dBm
Output Psat	18 dBm
OIP3	26 dBm
Bias Voltage Vdd/Vgg	+2 to +5/+1.5 V
Bias Current	42 mA

CMD280 **DC to 30 GHz**

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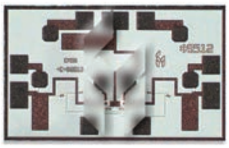

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Isolation	36 dB
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Switch Speed	4 ns
Control Voltage	0/-5 V

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Output P1dB	19 dBm
Output Psat	22 dBm
OIP3	28 dBm
Bias Voltage	+5 to +8/-0.65 V

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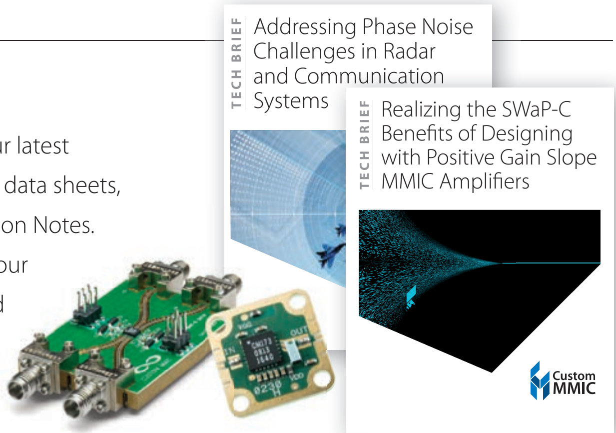

NEW PRODUCT

Low Noise Amplifiers (LNAs)

Part Number	Frequency (GHz)	Gain (dB)	Noise Figure (dB)	Output P1dB (dBm)	Output Psat (dBm)	OIP3 (dBm)	Bias Voltage (V)	Bias Current (mA)	Package
CMD228	2 - 6	30	1.2	12	14	23	3-5 / 3-5	45	DIE
CMD283C3	2 - 6	27	0.6	16	18	26	2-5	42	3x3 QFN
CMD228P4	2 - 6	28	1.5	13	14	25	3-5 / 3-5	45	4x4 QFN
CMD276C4 (GaN)	2.6 - 4	14.5	1.2	25.5	28	32	5-28 / -1.5	225	4x4 QFN
CMD185	4 - 8	15.5	1.9	15	17	29	2-5	75	DIE
CMD185P3	4 - 8	15.5	1.9	15	17	29	2-5	75	3x3 QFN
CMD270	4 - 8	15.5	1.8	16	17	30	2-5	60	DIE
CMD270P3	4 - 8	15.5	1.8	16	17	30	2-5	60	3x3 QFN
CMD219 (GaN)	4 - 8	23	1.0	18	26	28	5-28 / -2.3	75	DIE
CMD219C4 (GaN)	4 - 8	22.5	1.0	17	25.5	28	5-28 / -2.3	75	4x4 QFN
CMD277C4 (GaN)	5 - 7	20	1.2	26.5	29.5	33.5	5-28 / -1.5	200	4x4 QFN
CMD119P3	5 - 9	22	1.2	11	13	21	2-4.5	30	3x3 QFN
CMD218 (GaN)	5 - 9	22	1.1	21.5	26	30	5-28 / -2.7	80	DIE
CMD229	5 - 11	27	1.4	13	15	25	3-5 / 3-5	45	DIE
CMD229P4	5 - 11	26	1.5	13	15	24	3-5 / 3-5	45	4x4 QFN
CMD132	5 - 11	23	1.4	10	13	22	2-4.5	30	DIE
CMD132P3	5 - 11	21	1.4	10	13	22	2-4.5	30	3x3 QFN
CMD263	5 - 11	23	1.4	11	15	23	2-4.5	35	DIE
CMD263P3	5 - 11	22	1.4	11	15	21	2-4.5	35	3x3 QFN
CMD222	5 - 11	22	1.2	11	14	23	2-5	107	DIE
CMD186P3	6 - 11	18.5	2.1	17	20	28	2-5	78	3x3 QFN
CMD157	6 - 18	26	1.5	11	13.5	23	2-4.5	52	DIE
CMD157P3	6 - 18	26	1.5	11	13.5	23	2-4.5	52	3x3 QFN
CMD264	6 - 18	26	1.5	13	15	27	2-4.5	63	DIE
CMD264P3	6 - 18	26	1.7	13	15	24	2-4.5	63	3x3 QFN
CMD194	6 - 20	20	2.0	15.5	16.5	26	2-5	120	DIE
CMD194C3	6 - 20	20	2.0	15.5	16.5	26	2-5	120	3x3 QFN
CMD278C4 (GaN)	8 - 12	15	1.8	28	30	33	5-28 / -1.5	280	4x4 QFN
CMD167P3	8 - 16	16	1.8	11	13	23	2-4	50	3x3 QFN
CMD223	9 - 18	22	1.5	13.5	16	22.5	3-5	93	DIE
CMD161	10 - 14	19	1.05	5	12		2-4 / 1.5	20	DIE
CMD189P3	10 - 14	19	1.4	4	7	13	1-4 / 1.5	20	3x3 QFN
CMD159	10 - 17	26	1.1	4	10	14	2-4 / 1.5	29	DIE
CMD167	10 - 17	15	2.0	11	13	24	2-4	55	DIE
CMD224	16 - 26	23	2.2	7	13	18	2-5	110	DIE
CMD160	17 - 25	26.5	1.4	8	11	16	2-4 / 1.5	26	DIE
CMD160C4	17 - 25	26.5	1.6	8	11	16	2-4 / 1.5	26	4x4 QFN
CMD163	17 - 27	24	1.3	19	20	26	2-4 / 3	120	DIE
CMD163C4	17 - 27	23	1.7	18	19	26	2-4 / 3	120	4x4 QFN
CMD162	26 - 34	22	1.7	7	9	14	1-4	25	DIE
CMD188	26 - 34	20	1.4	6	8	15	1-4 / 2	20	DIE
CMD190	33 - 45	19	2.1	4	7	13	1-4 / 2	25	DIE

NEW PRODUCT

Low Phase Noise Amplifiers (LPNAs)

Part Number	Frequency (GHz)	Phase Noise (dBc/Hz @ 10kHz)	Gain (dB)	Output P1dB (dBm)	Output Psat (dBm)	OIP3 (dBm)	Bias Voltage (V)	Bias Current (mA)	Package
CMD245	6 - 18	-165	18	18	22	29	3-5 / 3	76	DIE
CMD245C4	6 - 18	-165	18	18	22	29	3-5 / 3	76	4x4 QFN
CMD274P4	2 - 20	-165	17	19	22	30	5 / 3	86	4x4 QFN
CMD246	8 - 22	-165	17	13	18	25	3-5 / 3	48	DIE
CMD246C4	8 - 22	-165	17	13	18	25	3-5 / 3	48	4x4 QFN
CMD275P4	DC - 26.5	-165	16	18	20.5	29	5 / 3	74	4x4 QFN
CMD247	30 - 40	<-160	13	13.5	15	21	2-4 / 2-3	28	DIE

NEW PRODUCT

Distributed Amplifiers

Part Number	Frequency (GHz)	Gain (dB)	Noise Figure (dB)	Output P1dB (dBm)	Output Psat (dBm)	OIP3 (dBm)	Bias Voltage (V)	Bias Current (mA)	Package
CMD173	DC - 20	15	2	18	20	28	5-8 / 3	78	DIE
CMD173P4	DC - 20	15	2	18	20	28	5-8 / 3	78	4x4 QFN
CMD192	DC - 20	19.5	1.9	24.5	26	31	5-8 / -1	200	DIE
CMD192C5	DC - 20	19.5	1.9	24.5	26	31	5-8 / -1	200	5x5 QFN
CMD201	DC - 20	12	3.4	29	30	38	10/-0.5/5	400	DIE
CMD201P5	DC - 20	11	3.4	27	30	38	10/-0.5/5	400	5x5 QFN
CMD249	DC - 20	13	3.4	30	31	38	10/-0.95	400	DIE
CMD249P5	DC - 20	13	3.4	30	31	38	10/-0.95	400	5x5 QFN
CMD233	2 - 20	9	4.5	20.5	22	24	3-6	120	DIE
CMD233C4	2 - 20	9	4.5	20.5	22	24	3-6	120	4x4 QFN
CMD238	2 - 20	14	4.5	26	27	34	5-8	360	DIE
CMD241	2 - 22	13.5	2.3	21	23	28	5-8/-0.65	74	DIE
CMD241P4	2 - 22	13.5	2.3	21	23	28	5-8/-0.65	74	4x4 QFN
CMD197	1 - 24	16	2.5	22	24	32	5-8	225	DIE
CMD197C4	1 - 24	16	2.5	24	25	31	5-8	225	4x4 QFN
CMD240	DC - 22	15	2.2	19	22	28	5-8/-0.65	80	DIE
CMD240P4	DC - 22	15	2.2	19	22	28	5-8/-0.65	80	4x4 QFN
CMD244	DC - 24	18	2.5	25	26.5	32	5-8 / -0.65	185	DIE
CMD242	DC - 40	11	4.4	18	21	27	5-8 / -0.32	100	DIE
CMD206	DC - 50	11	3.5	12	14.5	22	4 / 3	32	DIE

NEW PRODUCT

Driver Amplifiers

Part Number	Frequency (GHz)	Gain (dB)	Noise Figure (dB)	Output P1dB (dBm)	Output Psat (dBm)	OIP3 (dBm)	Bias Voltage (V)	Bias Current (mA)	Package
CMD231	2 - 6	14.5	4.5	13.5	16.5	23.5	3-8	45	DIE
CMD231C3	2 - 6	14.5	4.5	13.5	16.5	23.5	3-8	45	3x3 QFN
CMD232	2 - 9	15	4.5	17	18.5	23	5-6	90	DIE
CMD232C3	2 - 9	15	4.5	17	18.5	23	5-6	90	3x3 QFN
CMD191C4	4 - 10	20	4.5	21.5	22.5	30	5	123	4x4 QFN
CMD158	6 - 16	20	3.5	20	21	26	3-6	95	DIE
CMD158P3	6 - 14	19.5	4	19.5	20.5	26.5	3-6	95	3x3 QFN
CMD158C4	6 - 16	21	4	20	21	26	3-6	95	4x4 QFN

NEW PRODUCT

Driver Amplifiers *Continued*

Part Number	Frequency (GHz)	Gain (dB)	Noise Figure (dB)	Output P1dB (dBm)	Output Psat (dBm)	OIP3 (dBm)	Bias Voltage (V)	Bias Current (mA)	Package
CMD200	9 - 13	15.5	3.25	15.5	17	20.5	5	38	DIE
CMD187	2 - 20	22.5	6	14	16	29	3 / 2	115	DIE
CMD187C4	2 - 20	22.5	6	13	16	29	3 / 2	115	4x4 QFN
CMD166	20 - 40	9	4.5	17	18	27	2-4	76	DIE
CMD207	20 - 40	35	5.5	18.5	21	29	4 / 3	270	DIE
CMD199	26 - 35	15	3.5	19.5	21.5	24.5	5	72	DIE
CMD243	26 - 35	15.5	4.4	21	22.5	26	3-5	90	DIE

NEW PRODUCT

Power Amplifiers (PAs)

Part Number	Frequency (GHz)	Gain (dB)	Noise Figure (dB)	Output P1dB (dBm)	Output Psat (dBm)	OIP3 (dBm)	Bias Voltage (V)	Bias Current (mA)	Package
CMD169P4	5 - 7	19	6.5	28.4	29.4	37	7 / 3	375	4x4 QFN
CMD170P4	7.5 - 9	30	6.5	28.3	29	34	7 / 3	365	4x4 QFN
CMD171P4	9.5 - 11	21	6.5	28.4	29	35	7 / 3	380	4x4 QFN
CMD216 (GaN)	14 - 18	16		37	38	43	28 / -3.4	550	DIE
CMD262 (GaN)	26 - 28	26		37.5	38.5		28 / -4	400	DIE
CMD217 (GaN)	28 - 32	20		36.7	39.3	41	28 / -3.4	580	DIE
CMD184 (GaN)	0.5 - 20	13		34.5	36.5	42	28 /-2.8/10	700	DIE
CMD201	DC - 20	12	3.4	29	30	38	10/-0.5/5	400	DIE
CMD201P5	DC - 20	12	3.4	27	30	38	10/-0.5/5	400	5x5 QFN
CMD249	DC - 20	13	3.4	30	31	38	10/-0.95	400	DIE
CMD249P5	DC - 20	13	3.4	30	31	38	10/-0.95	400	5x5 QFN

NEW PRODUCT

Voltage Variable Attenuators

Part Number	Frequency (GHz)	Insertion Loss (dB)	Attn Range (dB)	Input P1dB (dBm)	Input IP3 (dBm)	Return Loss (dB)	Control Voltage (V)	Max. Power (dBm)	Package
CMD172	18 - 40	1.6	37	15	25	12	0 / -3	30	DIE

NEW PRODUCT

Digital Attenuators

Part Number	Frequency (GHz)	Insertion Loss (dB)	Attn Range (dB)	Input P0.1dB (dBm)	Return Loss (dB)	Control Voltage (V)	Number of Bits	Package
CMD279	2 - 30	3.5	15.5	27	42	0 / +5	5	DIE
CMD279C3	2 - 18	3.5	15.5	27	42	0 / +5	5	3x3 QFN
CMD280	DC - 30	3	15.5	24	42	0 / -5	5	DIE
CMD280C3	DC - 18	3	15.5	24	42	0 / -5	5	3x3 QFN
CMD281	DC - 40	1.2	6	28	42	0 / -5	2	DIE
CMD281C3	DC - 18	1.2	6	28	42	0 / -5	2	3x3 QFN
CMD282	DC - 40	1.5	12	23	42	0 / -5	2	DIE
CMD282C3	DC - 18	1.5	12	23	42	0 / -5	2	3x3 QFN

NEW PRODUCT

Switches (Non-Reflective)

Part Number	Part Description	Frequency (GHz)	Insertion Loss (dB)	Isolation (dB)	Input P1dB (dBm)	Return Loss (dB)	Switch Speed (nS)	Control Voltage (V)	Package
CMD272P3	DPDT	DC - 10	1	43	25	14	4	0/ +5	3x3 QFN
CMD273P3	DPDT	DC - 12	1.7	42	25	13	12	0/ +5	3x3 QFN
CMD204	SPST	DC - 20	1	50	25	17	1.8	0 / -5	DIE
CMD204C3	SPST	DC - 20	1.3	48	25	15	1.8	0 / -5	3x3 QFN
CMD230	SPDT (refl)	DC - 26	1.4	40	21	16	3.4	0/ -5	DIE
CMD195C3	SPDT	DC - 18	2	37	25	13	1.8	0 / -5	3x3 QFN
CMD196C3	SPDT	DC - 18	1.5	46	23	17	1.8	0 / -5	3x3 QFN
CMD195	SPDT	DC - 20	2	41	25	17	1.8	0 / -5	DIE
CMD196	SPDT	DC - 28	1.75	46	23	15	1.8	0 / -5	DIE
CMD234C4	SP3T	DC - 15	2	40	21	9	66	0 / -5	4x4 QFN
CMD203	SP4T	DC - 20	2.4	39	21	9	66	0 / -5	DIE
CMD203C4	SP4T	DC - 20	2.4	39	21	9	66	0 / -5	4x4 QFN
CMD235C4	SP5T	DC - 18	2.5	40	21	9	66	0 / -5	4x4 QFN
CMD236C4	SP6T	DC - 18	2.5	42	18	9	60	0 / -5	4x4 QFN
CMD215	SPDT (refl)	DC - 40	2.3	36	19	16	4	0 / -5	DIE

NEW PRODUCT

Mixers

Part Number	Part Description	Freq. LO / RF (GHz)	Freq. IF (GHz)	LO Drive (dBm)	Conver. Gain (dB)	LO-RF Isolation (dB)	LO-IF Isolation (dB)	Input IP3 (dBm)	Package
CMD251C3	Fund. Mixer	4 - 8.5	DC - 2.2	+17	-7	45	36	21	3x3 QFN
CMD252C4	I/Q / IRM	4 - 8	DC - 2.4	+20	-6.5	52	27	25	4x4 QFN
CMD182	I/Q / IRM	6 - 10	DC - 3.5	+15	-6	46	20	18	DIE
CMD182C4	I/Q / IRM	6 - 10	DC - 3.5	+15	-6	46	20	18	4x4 QFN
CMD257C4	I/Q / IRM	6 - 10	DC - 3.5	+21	-5.5	40	18	25	4x4 QFN
CMD177	Fund. Mixer	6 - 14	DC - 5	+13	-6.5	43	37	16	DIE
CMD177C3	Fund. Mixer	6 - 14	DC - 5	+13	-6.5	43	37	16	3x3 QFN
CMD253C3	Fund. Mixer	6 - 14	DC - 5	+19	-6	43	39	23	3x3 QFN
CMD183C4	I/Q / IRM	7.5 - 13	DC - 4.5	+15	-5.5	43	23	18	4x4 QFN
CMD258C4	I/Q / IRM	7.5 - 13	DC - 3.5	+21	-5.5	38	20	25	4x4 QFN
CMD178C3	Fund. Mixer	11 - 21	DC - 6	+13	-6	45	45	16	3x3 QFN
CMD254C3	Fund. Mixer	11 - 21	DC - 6	+19	-6	48	44	22	3x3 QFN
CMD179	Fund. Mixer	16 - 26	DC - 9	+13	-6.5	40	48	17	DIE
CMD179C3	Fund. Mixer	16 - 26	DC - 9	+13	-6.5	40	48	17	3x3 QFN
CMD255C3	Fund. Mixer	16 - 26	DC - 9	+19	-6.5	40	33	24	3x3 QFN
CMD180	Fund. Mixer	20 - 32	DC - 10	+13	-7	36	36	18	DIE
CMD180C3	Fund. Mixer	20 - 32	DC - 10	+13	-7	36	36	18	3x3 QFN
CMD181	Fund. Mixer	26 - 45	DC - 12	+17	-6.5	37	29	22	DIE
CMD261	Fund. Mixer	30 - 46	5 - 20	+19	-8	30	20	21	DIE

NEW PRODUCT

Multipliers

Part Number	Part Description	Input Freq. (GHz)	Output Freq. (GHz)	Input Power (dBm)	Output Power (dBm)	Fo Isolation (dB)	3 Fo Isolation (dB)	Package
CMD225	Passive Freq. Doubler	4 - 8	8 - 16	15	3	48	50	DIE
CMD225C3	Passive Freq. Doubler	4 - 8	8 - 16	15	3	48	50	3x3 QFN
CMD226	Passive Freq. Doubler	7 - 11	14 - 22	15	5	44	46	DIE
CMD226C3	Passive Freq. Doubler	7 - 11	14 - 22	15	5	44	46	3x3 QFN
CMD227	Passive Freq. Doubler	8 - 15	16 - 30	15	4	40	43	DIE
CMD227C3	Passive Freq. Doubler	8 - 15	16 - 30	15	4	40	43	3x3 QFN
CMD214	Active Freq. Doubler	12 - 18	24 - 36	13	17	32	25	DIE
CMD213	Active Freq. Doubler	15 - 20	30 - 40	17	17	46		DIE
CMD256	Passive Freq. Doubler	14 - 20	28 - 40	15	0	38		DIE

NEW PRODUCT

Phase Shifters

Part Number	Frequency (GHz)	Number of Bits	Bit Resolu. (deg)	Insert. Loss (dB)	Return Loss (dB)	Phase Error (deg)	Input P1dB (dBm)	Input IP3 (dBm)	Package
CMD175P4	2 - 4	5	11.25	7	17	+/- 5	24	37	4x4 QFN
CMD174	3 - 6	5	11.25	7.6	15	+/- 2	26	36	DIE
CMD174P4	3 - 6	5	11.25	7.6	15	+/- 2	26	36	4x4 QFN
CMD176P4	13 - 17	4	22.5	8	14	+/- 5	26	41	4x4 QFN

given enough measurements, and the whole equation reduces to the simple "assume disjoint amplifiers" case discussed earlier.

Instead of using a balun and corrections to get at this quantity, it could be useful to measure it directly and, if one has multiple synchronized receivers in the VNA, this would seem to be possible, i.e., b_3 and b_4 waveforms can be sampled at the same time. There are, however, some caveats:

- Since these are complex quantities, a phase calibration is now required, as well as a power calibration. This can be performed using a common sinusoidal source but, of course, the reference plane must be consistent relative to the DUT for both receiver paths.
- It is generally assumed that the receiver chains are single-ended, but a coupled chain could be possible with additional characterization.
- There is a danger of losing correlation information if the runs from the DUT to the receivers are too long (more than ~10 m) or in certain receiver noise level situations. The receiver paths should be kept relatively short, with gain levels not appreciably higher than those of the DUT.
- Low levels of decorrelation can be corrected by comparing inter-channel responses over small frequency scales.

A simplified diagram of the measurement setup is shown in ***Figure 3***. The key differences from a conventional setup are the coherently clocked receivers and the phase reference plane. Note that the two receiver chains need not be identical, but they typically will have similar net gain and noise levels. Since only one measurement is necessary and no balun characterization is needed, this approach does have a simplicity advantage. Also, differential and common-mode noise figures are available simultaneously, should that be important.

MEASUREMENT COMPARISONS

A logical next step is to compare measurements using the various methods discussed. As an initial comparison, consider a differential amplifier with a dominant noise stage at the output that is highly correlated (i.e., a differential pair). One might expect that an uncorrelated approach would not be appropriate since it will understate the actual differential noise power and overstate the actual common-mode noise power. The uncorrelated results are shown in ***Figure 4*** and compared to those using the direct correlated method and a balun-based method with two different levels of correction: 1) a basic approach only taking into account differential insertion loss affecting the noise power and 2) a more corrected approach taking into account the de-correlating

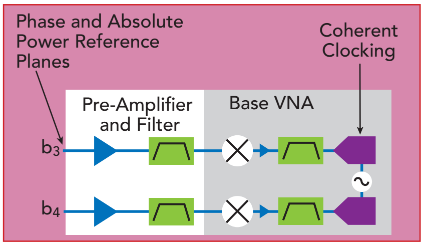

Fig. 3 Setup for correlated noise figure measurement.

influence of balun imperfections.

The uncorrelated approach does indeed produce a lower, erratic value and one that was quite unexpected based on the characteristics of the elements in the amplifier. The result is off by multiple dB. The other methods were more comparable in mean terms, with the basic balun approach showing an elevated level of scatter, on the order of 1 dB additional peak scatter. The corrected balun and direct correlated measurements agree more closely. Some disagreement is to be expected, since the balun is terminating the DUT slightly differently than the two noise receivers, for the correlated method, and the methods only partially correct for mismatch errors. The mean value for these latter methods are more consistent with the ~5 dB noise figure that was expected from the DUT.

Another comparative example is shown in ***Figure 5***, this time just between the direct correlated method and the corrected balun method, so that differences can be examined more closely. For this example, the uncertainties of both methods are on the order of 0.5 dB, based on

- Noise power repeatability, limited by finite record length.
- S-parameter uncertainties of DUT gain.
- Balun characterization for the corrected balun method.
- Phase calibration process for the direct correlated method.
- Residual mismatch errors.
- Power calibration uncertainty.

Even though some of those aspects are identical for the two measurements (i.e., same DUT S-parameters and same receiver calibration), the level of agreement in the data still seems consistent. Again, the DUT is terminated slightly differently for the two measurements, so the variance may be higher in some cases.

mmWAVE MEASUREMENTS

As application frequencies increase, there is the need to measure differential noise figure at mmWave frequencies. A W-Band example is discussed next, showing the uncorrelated method with the differential mode and common-mode noise figure using the direct correlated approach (see ***Figure 6***). As before, the uncorrelated method understates the noise power and noise figure. The common-mode noise power is actually 10 to 15 dB below the differential noise power, but since the common-mode gain of the device is very low, the common-mode noise figure does end up being quite large. Whether this common-mode noise figure will be a problem depends greatly on the system where the DUT is used. The common-mode noise power may be of interest in cases where it has a swamping effect on later gain stages. The noise power uncertainties on the non-dominant mode will be higher since the levels are typically closer to the receiver limit, and the calculation presents a subtraction-of-nearly-equal-numbers situation.

OUTLOOK

Noise figure by itself has been described as a simple figure of merit that does not take into account source impedance effects.

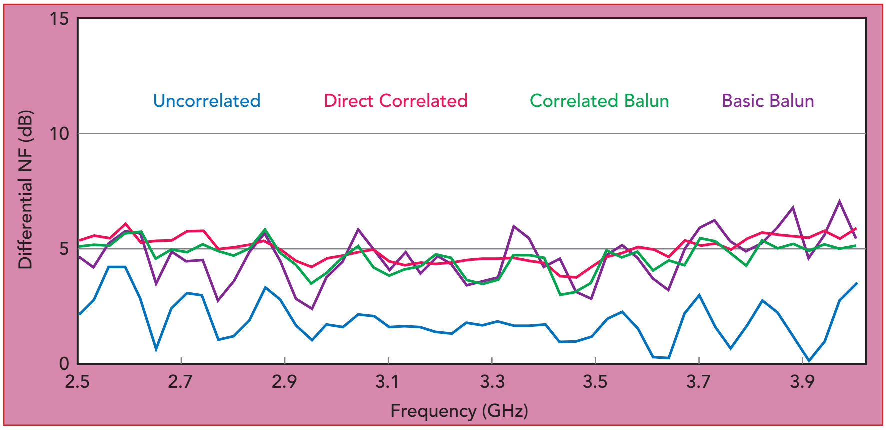

Fig. 4 Comparison of the four differential noise figure measurements using the same receiver calibration and DUT S-parameters.

Indeed, that is the measurement that has been discussed here. A more complete picture is given by the multiport form of noise parameters that has been an active research area in recent years.[8] This article has focused on the underlying noise measurement and how some improvements can be made to the differential/common-mode noise power measurement process to mitigate errors and simplify the measurement. For a highly correlated DUT, accuracies can be improved by more than a dB in some cases, with little additional hardware and with a few changes in procedure and calibration.■

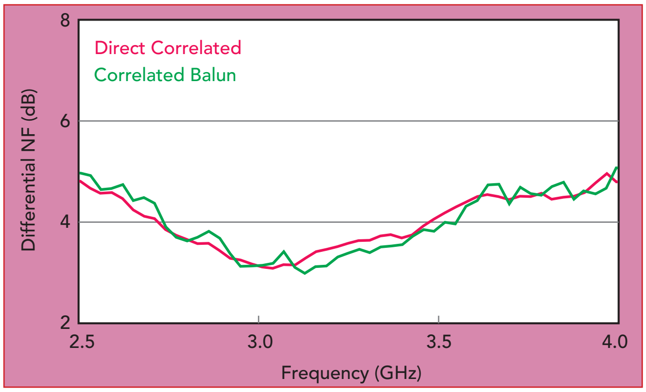

Fig. 5 Measurements using the direct correlated and corrected balun methods.

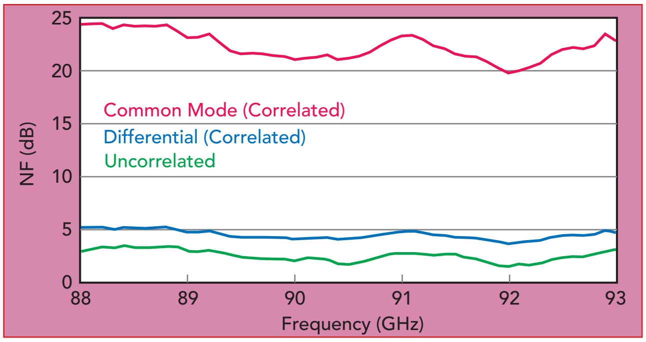

Fig. 6 Differential and common-mode noise figure measurements using the direct correlated method compared to an uncorrelated measurement.

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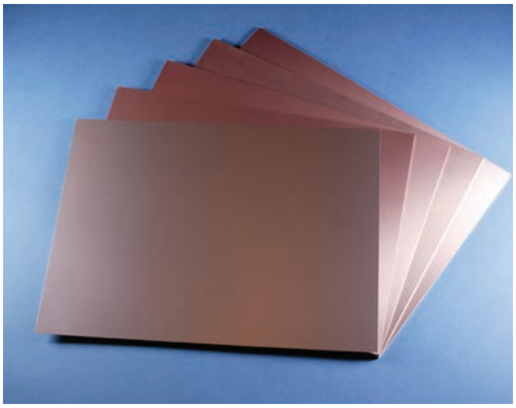

New Laminates Lower PIM for Base Station Antennas

Rogers Corp.
Chandler, Ariz.

Base station antennas have long been a critical component of wireless cellular communication systems. One of the most important performance parameters for many designs has been passive intermodulation (PIM). PIM can negatively affect receiver sensitivity, decreasing system capacity and data rates, leading to increased rates of dropped calls. While not a critical parameter in all systems, PIM is typically a design consideration in CDMA, LTE and 5G FDD systems.

In an antenna, PIM is the result of two higher power signal tones mixing, caused by various nonlinearities that occur within the system. If the two signals are f_1 and f_2, the intermodulation occurs at $2f_1-f_2$ and $2f_2-f_1$ (third-order products), $3f_1-2f_2$ and $3f_2-2f_1$ (fifth-order products) and so on (see ***Figure 1***). If the third-order or other products fall within the receive band, the PIM can prevent the receiver from detecting legitimate signals.

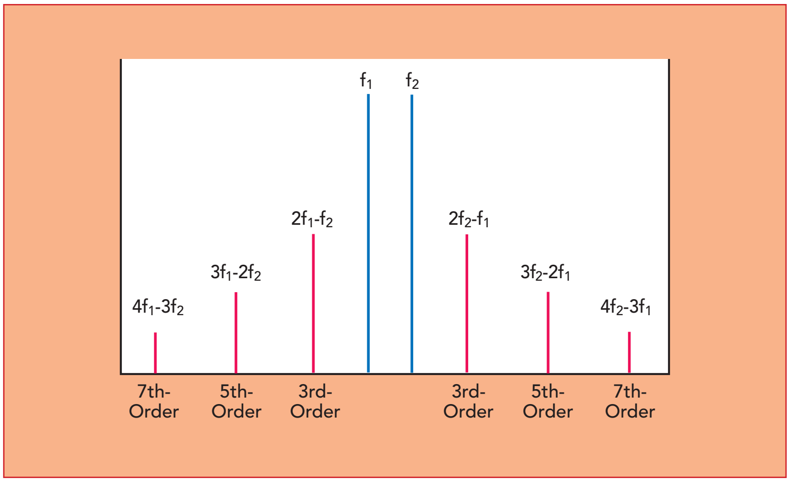

Fig. 1 **Passive intermodulation products.**

PIM values are usually expressed in dBc, the power of the intermodulation products in dB below the two fundamental signals. Testing involves two closely spaced tones of 20 W (43 dBm), so measuring third-order intermodulation products at −110 dBm equates to a PIM of −153 dBc. While


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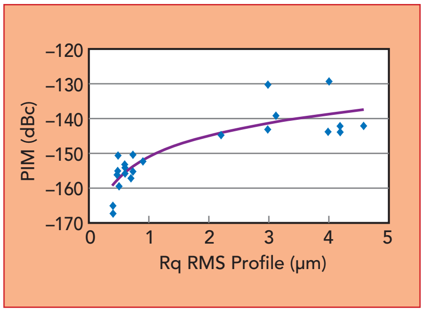

Fig. 2 PIM increases with copper surface roughness.

−153 dBc was once considered good for PIM-sensitive applications, increasingly systems are requiring −160 dBc or better. Because of the noise levels of measurement systems, PIM levels much better than −165 dBc can be hard to verify.

There are various potential sources of PIM within an antenna system: interfaces between different metals, loose connectors, poor solder joints and contamination from dirt, dust and especially traces of ferromagnetic materials. Printed circuit board (PCB) technology is often used in antennas, whether as radiating elements or feed networks, and the use is increasing. For PCB antennas, while PIM is a property of the complete circuit, the choice of RF circuit material has an impact. It is well understood that the roughness of the interface between the copper foil and the dielectric material significantly affects PIM. The ideal circuit material has low loss with a tight control of dielectric constant and, most importantly, a consistently smooth copper interface achieved with a high level of copper foil adhesion. ***Figure 2*** illustrates the relationship between PIM and copper surface roughness.

Rogers Corp. is an industry leader for high performance RF/microwave circuit materials. For base station antenna applications, Rogers typically offers the AD Series™ PTFE-based laminates and the RO4500™ and RO4700™ Series hydrocarbon laminates. The RO4000® materials are typically used where there is a greater degree of integration, for multilayer PCBs or for antenna elements where a greater degree of

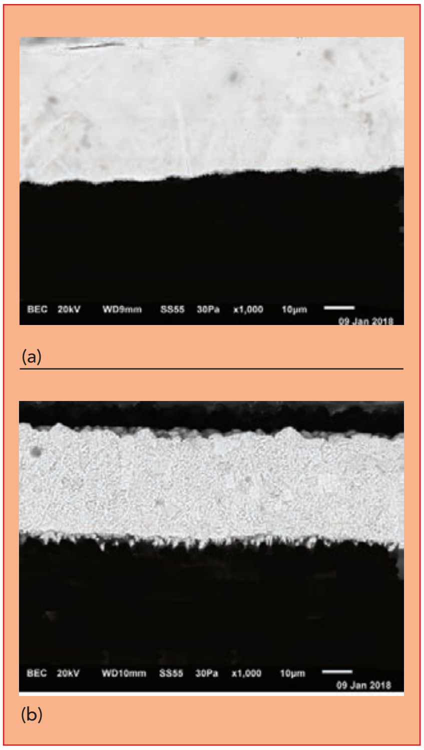

Fig. 3 0.5 µm IM copper (a) vs. reverse treat 1.0 µm electrodeposited copper (b).

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physical rigidity is required. However, for the best electrical performance, the AD Series laminates have the lowest dissipation factor for the lowest dielectric losses, as well as the widest range of dielectric constants.

While all these materials are available in low PIM versions, Rogers has introduced its newest, industry-leading low PIM products: the IM Series™ laminates. The IM™ system is now an option for AD300D™, AD255C™ and DiClad880® antenna-grade laminates. These products use an ultra-smooth electrodeposited copper foil—with an Rq of just 0.5 µm (measured with the non-contact interferometry method)—while maintaining excellent adhesion to the substrate surface (see ***Figure 3***).

The PIM performance of these materials with the IM cladding is

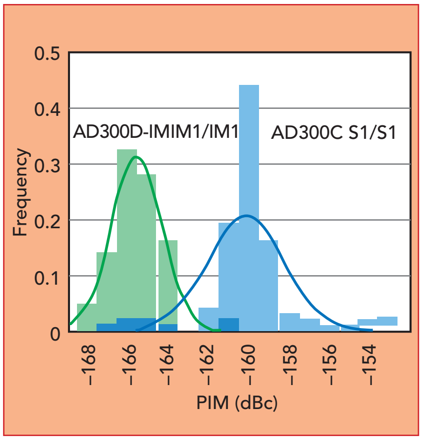

Fig. 4 **PIM distribution of AD300D-IM vs. AD300C with S1 copper.**

typically −165 dBc, measured using two 43 dBm swept tones. Yet, the real benefit of the new materials is not only low PIM, rather consistent and tightly controlled low PIM. With the introduction of new equipment and new quality control checks, Rogers is able to deliver a material which demonstrates much lower variation in PIM. The primary benefit of having consistently low PIM, in addition to meeting the PIM specification, is greater production yield and reduced scrap during antenna manufacturing. ***Figure 4*** shows a significant 6 dB average improvement in PIM compared to the previous generation AD300C™ laminate with the more tightly controlled distribution of PIM.

Rogers' specialty materials are engineered and manufactured to meet the needs of today's RF engineers. With the introduction of the new IM series of RF laminates, Rogers continues to produce leading products that enable antenna designers to meet the toughest PIM specifications while maximizing production yields.

VENDORVIEW

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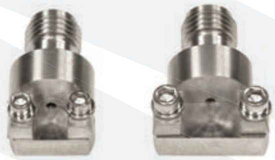

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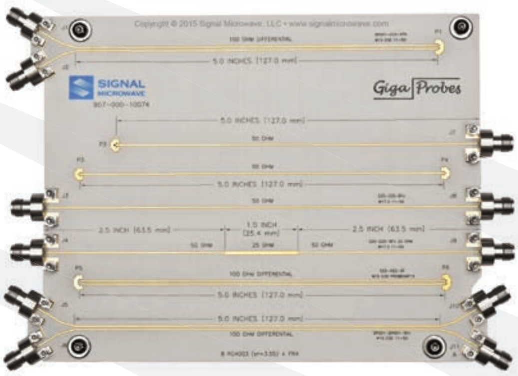

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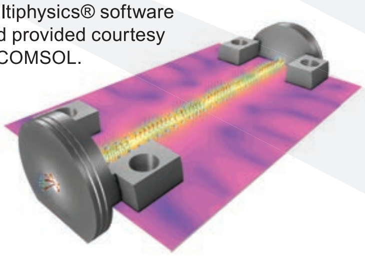

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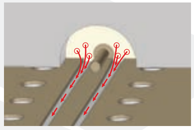

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Campbell, Calif.

Covering a 50 MHz to 32 GHz frequency range, the NK420 and NK430 synthesizers bring the performance of expensive benchtop instruments to the PXIe format. The phase noise for the NK430 with a 10 GHz carrier is −124 dBc/Hz at 10 kHz offset (see ***Figure 1***), and the noise floor is −149 dBc/Hz. The synthesizers achieve this extremely low phase noise at any frequency, even with a frequency resolution of 0.001 Hz and a maximum switching time of 50 µs for a full-range step.

The NK430 occupies only two slots in a PXIe chassis, while the NK420 is a single-slot instrument. The compact size and low cost of these YIG and VCO-based synthesizers enable practical configurations of eight or 16 signal sources in a single PXIe chassis, supporting applications from lab to production test. Applications include up- and down-converting to extend the frequency range of other instruments, low noise local oscillators for receivers, MIMO and phased arrays and clocks for A/D and D/A converters. Production testing of 5G devices and systems is an important market segment that these PXIe modules address.

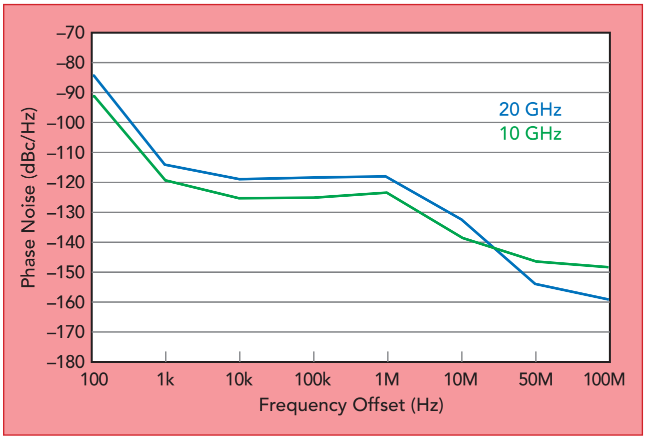

Fig. 1 NK430 phase noise.

Software for Windows and Linux is included with the products and consists of a ready-to-run virtual front panel graphical interface (see ***Figure 2***) and driver for users who want to write control software in LabVIEW, C++, C#, Basic or Python. Sample programs are provided to serve as starting points. The same driver runs all products from Carmel Instruments, including frequency counters, time interval analyzers and clock generators.

The high performance, two-slot NK430 product line (see ***Table 1***) consists of models covering two frequency ranges: 50 MHz to 10.5 GHz and 50 MHz to 21 GHz, with a full-band switching speed of 50 µs max. The output level is +15 dBm ±2 dB over the full frequency range and spurs are typically −60 dBc. The lower cost, single-slot NK420 line consists of six models (see ***Table 2***). The step size of the NK420 is 1 kHz and the full-band switching speed is 3 ms maximum. All models include built-in frequency stepping and sweeping and a "list mode."


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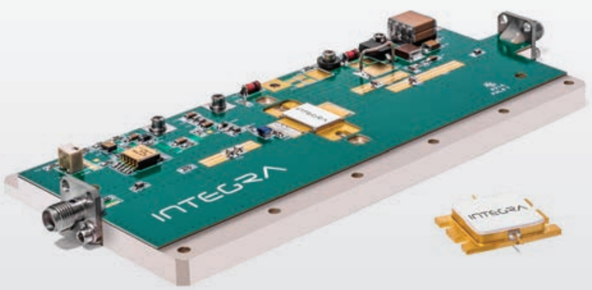

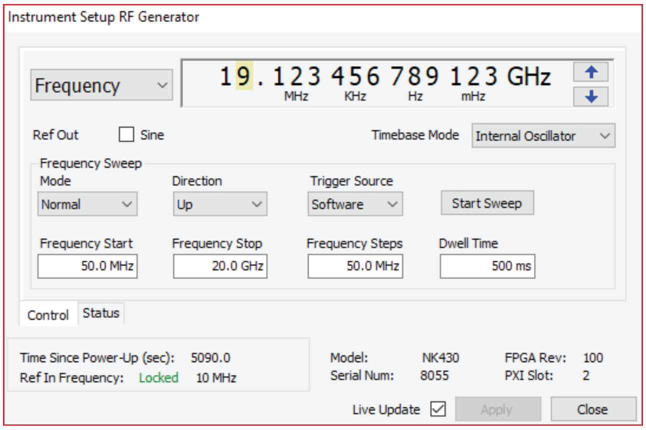

Fig. 2 Front panel graphical user interface.

All models accept an external frequency reference. For the NK420, the reference frequency can range from 10 to 200 MHz, while the external reference must be 10 MHz for the NK430. The NK420 has an option for an ultra-high performance internal 10 MHz frequency reference with phase noise of –140 dBc/Hz at 10 Hz offset, temperature stability of 5 ppb (0.005 ppm) over 0°C to 65°C and Allen Deviation of 5×10^{-12} with 1 s tau (i.e., short term stability). This optional NIST-traceable internal reference greatly improves the close-in phase noise of the synthesizer and its absolute frequency accuracy. It is available on a front panel SMA and can drive the reference clock on the PXI backplane, so all instruments in the chassis can use the same reference without connecting external cables.

With these products, Carmel Instruments set out to address the growing demand for higher volume testing created by the emerging markets for RF and microwave devices and systems. These markets require lower cost and smaller size as the applications become mainstream. High volume testing of semiconductor devices requires parallel testing of 16 or more devices to achieve cost-of-test targets. The fast tuning speed enables much higher throughput in applications with frequency sweeps.

Carmel Instruments has a 14-year record specializing in time and frequency measurement instruments for high speed production testing and scientific applications. The instruments are widely used in 24/7, high volume semiconductor test environments and high-reliability aerospace and atomic clock monitoring applications, such as at NIST, JPL and the U.S. Naval Observatory.

Carmel Instruments LLC
Campbell, Calif.
www.carmelinst.com

TABLE 1
NK430 MODELS

Model	Frequency Range (GHz)	Minimum Output Power (dBm)	Phase Noise @ 10 kHz Offset, 10 GHz Carrier (dBc/Hz)
NK430-0510	0.05 to 10.5	15	125
NK430-0520	0.05 to 21	15	124

TABLE 2
NK420 MODELS

Model	Frequency Range (GHz)	Minimum Output Power (dBm)	Phase Noise @ 10 kHz Offset, 10 GHz Carrier (dBc/Hz)
NK420-0260	0.25 to 6	11	–96
NK420-2080	2 to 8	13	–95
NK420-6013	6 to 13	10	–90
NK420-1014	10 to 14	8	–90
NK420-8020	8 to 20	8	–88
NK420-2832	28 to 32	10	–83

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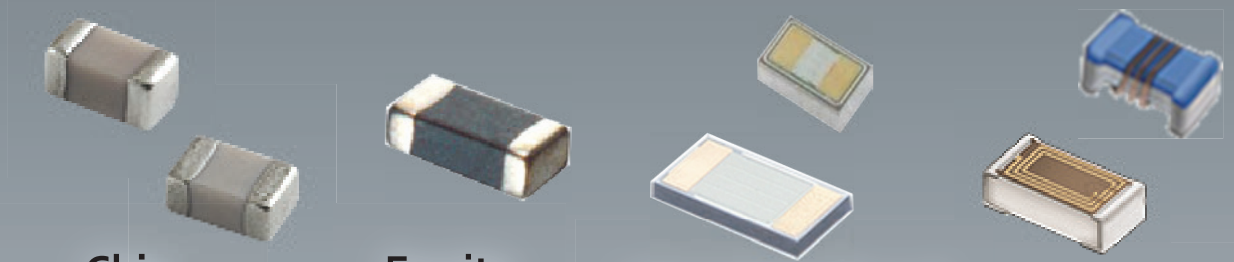
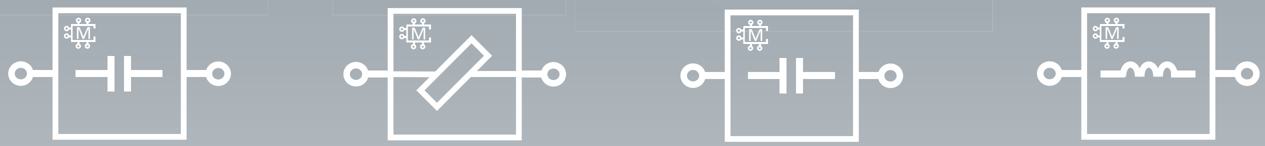


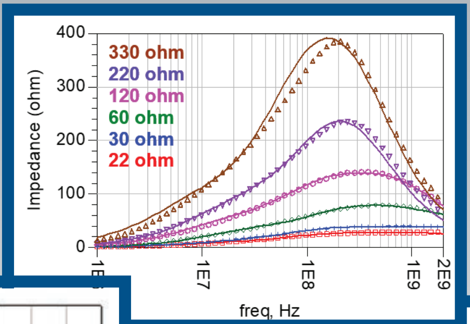
Chip Capacitor Models

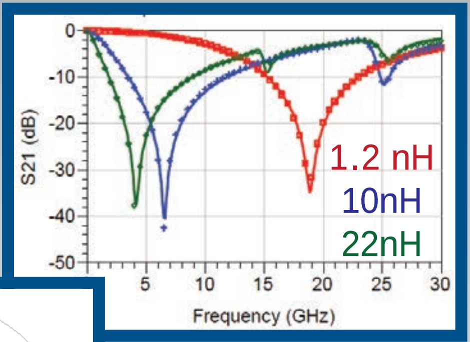
Ferrite Bead Models

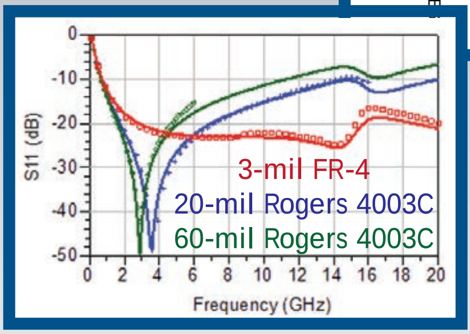
Ultra Broadband Silicon Capacitor Models

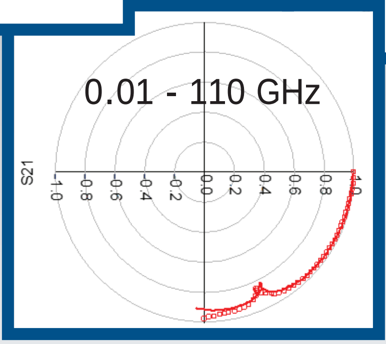
Inductor Models











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mmWave Anechoic Chamber in a Box

MilliBox™ is a family of affordable, compact and modular radiation pattern measurement systems designed specifically for mmWave testing. This innovative system comprises a modular anechoic chamber providing 40 to 50 dB of absorption from 18 to 95 GHz, with a 3D gimbal capable of 360 degree rotation in both the horizontal and vertical planes. The unique, tangle-free gimbal design is attached to a USB dongle and controlled using Python scripts, which are provided in source code. The MilliBox can be integrated with any existing measurement equipment if the instrument has an interface from a PC.

MilliBox is an essential lab component for semiconductor or system designers working on 5G systems at 24, 28 and 39 GHz; 802.11ad/ay systems at 60 GHz; and automotive radar at 77 and 81 GHz. The MilliBox family accommodates various far fields: the MBX02 has a far field of 0.8 m, the MBX03 1.4 m and the MBX04 2.0 m. All models will sit on a lab bench, with test equipment conveniently placed underneath the chamber's deck. This arrangement saves lab space and reduces the length of coaxial cables.

Using MilliBox improves design quality and time-to-market. Unlike a traditional microwave anechoic chamber, which is usually onerous and large, the small size and low cost of MilliBox enable development activities to occur in parallel, increasing productivity. In addition to measuring static radiation patterns, MilliBox can be used to characterize the over-the-air performance of phased array beamforming antennas, radios and the underlying algorithms and components.

The MilliBox was developed by Milliwave Silicon Solutions, formed in 2016 by founders with more than 15 years of mmWave design and test experience, including SiBEAM. Milliwave Silicon Solutions is on a mission to help the industry accelerate mmWave development by offering design, consulting and advisory services.

Milliwave Silicon Solutions Inc.
San Jose, Calif.
www.millibox.org
millibox@milliwavess.com

Handheld Spectrum Analyzer for Distributed Antenna Systems

To support the growth of distributed antenna systems (DAS), SAF Tehnika has developed another product in the company's Spectrum Compact portfolio of spectrum analyzers: the J0SSAP33 covers 300 MHz to 3 GHz and features instant-on functionality, an ultra-compact form factor, lightweight and an intuitive graphical interface.

The analyzer has switchable internal attenuation up to 30 dB and handles a maximum input power of +27 dBm, allowing it to work close to the transmitter. The resolution bandwidth (RBW) is adjustable from 10 to 300 kHz, which provides the flexibility to quickly check the spectrum with a wider RBW, then closely examine a narrowband signal. The receiver's high sensitivity—a noise floor of −128 dBm at 10 kHz RBW—enables very weak signals to be observed.

Housed in a rugged anodized aluminum case, the J0SSAP33 does not require an external controller, and 8 GB of internal memory provides the storage needed for spectrum scans during space mapping. The built-in recording feature can save hundreds of hours of data for deeper analysis and reporting using SAF's Spectrum Manager PC software. Spectrum Manager can also be used to run the spectrum analyzer remotely from a PC.

Designed to be the ultimate tool for easy physical layer investigation, the J0SSAP33 spectrum analyzer is built for the rigors of the field. The lightweight and handheld design make it easy to perform walk tests. Experienced RF engineers will appreciate the efficiency gaining insight and quickly getting accurate measurements and data, while an RF novice can be trained to be proficient using the analyzer in a few hours.

The J0SSAP33 is the latest addition to SAF Tehnika's handheld spectrum analyzer family, joining seven models covering 2 to 40, 56 to 67 and 70 to 87 GHz and extending low frequency coverage to 300 MHz.

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Antenna Tuning Switches for LTE-A and 5G

Skyworks Solutions has unveiled its latest solutions from its Sky5™ portfolio, the company's unifying platform enabling 5G applications. Skyworks' new wideband 16-state antenna aperture tuners are compact and designed to deliver improved efficiency and enhanced bandwidth coverage—from 600 MHz to 6 GHz for LTE Advanced Pro to sub-6 GHz 5G—for a wide range of mobile devices.

Antenna tuning plays a critical role in maintaining smartphone power efficiency and battery life, particularly as signal processing complexity continues to rise with the onset of 5G. With smartphone manufacturers adding new features such as 4 × 4 MIMO and 5G new radio (NR), next-generation architectures must embed significantly more antennas. New bezel-less smartphones integrate anywhere from four to seven antennas to support data demand, versus the two to four average antenna count within today's platforms. At the same time, the migration to full screen infinity displays and expanded functionality limit the amount of board space available.

The SKY5−9256-701LF advanced aperture tuner features reliable linear operation and extremely low R_{on} (1.1 ohm) and C_{off} (145 f_F) to deliver superior antenna performance, allowing system designers to recover the 1.5 to 3 dB gain degradation caused by shrinking antenna sizes. The MIPI®-controlled, 16-state capability of the tuner also gives engineers the ability to combine arms for even smaller R_{on} and C_{off}. Excellent harmonics are delivered throughout the operating range, assisting customers with achieving RSE requirements and passing certification.

The Skyworks family of aperture tuners offers V_{PEAK} ratings from 35 to 80 V, allowing customers to choose the aperture tuner that is right for each specific application.

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New Video from Analog Devices Inc.

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Analog Devices introduces the LTC5594, a direct conversion quadrature demodulator optimized for high linearity zero-IF and low-IF receiver applications. The video takes a closer look at the company's newest reference design for an IQ Demodulator signal chain, with industry-leading 1 GHz bandwidth. Its compact, high performance design directly supports complex demodulation of RF signals with a carrier frequency range up to 9 GHz, with at least 40 dB image rejection over the entire DC-coupled 1 GHz bandwidth.

Analog Devices Inc.
www.analog.com/LTC5594-video

EuMW 2018 App

Using the official European Microwave Week (EuMW) 2018 mobile app, you will be able to access EuMW information before, during and after the event. The EuMW 2018 App will, among other things, provide you with access to the full agenda and all the conference documentation—including the papers, allow you to navigate the exhibitors' area and stands and give you the opportunity to participate in the general discussion. The EuMW 2018 App is sponsored by Rohde & Schwarz.

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New and Improved

K&L Microwave's website provides information and tools, such as the Filter Wizard® web application, to speed the identification of custom design solutions from a full range of company products. The latest web update features a new look, mobile device support and social media links. Research capabilities, access data sheets, submit quote requests, read the latest news and download K&L's new Product Catalog and new Space Brochure.

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Updated Website

KRATOS General Microwave, one of the largest suppliers of microwave products to the defense and non-defense markets, has updated its website to better reflect their various capabilities and product lines. Each product line page provides easy access to the various COTS microwave products in each category. To help their customers better utilize their microwave products, they have added a link to White Papers that provide greater detail about some of their product lines. The website also now includes archived GMC product catalogs.

KRATOS General Microwave
http://gmcatalog.kratosmed.com/Kratos-General-Microwave-Product-Catalog

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Laird's web-based Thermal Wizard™ employs proprietary application calculators to determine the optimal thermal management solutions at the thermoelectric module (TEM), thermoelectric assembly or liquid cooling system level. Building upon Laird's popular AZTEC™ TEM simulation software, the Thermal Wizard enables thermal designers to input their known cooling requirement (Qc). If the cooling requirement is unknown, the Thermal Wizard can calculate the Qc based on the defined application: device cooling, enclosure cooling, air cooling or liquid cooling.

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DIY Vector Network Analyzer Kit

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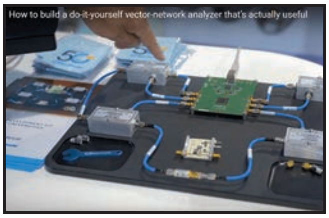

The first of the University Project kits, UVNA-63, includes all the elements students need to build a fully functioning vector network analyzer, develop S-parameter algorithms and perform real-time measurements of 2-port RF devices. It comprises Vayyar's high performance transceiver chip with a variety of RF components from Mini-Circuits, along with control software and a development environment for Python and MATLAB®.

Mini-Circuits
www.minicircuits.com/WebStore/uvna_63.html

EDI CON USA Comes to California!

Janine Love, *Microwave Journal* Contributing Editor

Two full days of technical programming, the EDI CON University, panels, exhibition, networking and show floor presentations covering RF, microwave, signal integrity, power integrity and EMC/EMI await this year's attendees in sunny Santa Clara, California.

This October 17-18, EDI CON USA 2018 brings its unique blend of engineering to the Santa Clara Convention Center. In this centrally located venue, engineers working in RF, microwave, signal integrity and power integrity will all come together to learn about new techniques and technologies as well as see the latest product innovations. This year's two-day conference is packed with technical papers, workshops, panels, case studies, plenary keynote talks and the newly created EDI CON University, where attendees can earn IEEE CEU/PDHs for their attendance.

Wednesday, October 17 begins with three, two-hour EDI CON University sessions: "Antenna Design for IoT," presented by Henry Lau of Lexiwave; "How to Measure Ultra Low Impedance PDNs," presented by Steven Sandler of Picotest; and "Millimeter Wave Measurement Insights," presented by Gennady Farber and Suren Singh of Keysight. EDI CON University sessions require pre-registration to guarantee seating.

These in-depth sessions will be immediately followed by Day One's plenary keynote talk, "Looking Deeper: Using Radar to Save Lives and Improve the World," given by Ovi Jacob of Vayyar Imaging, the makers of the Walabot brand. Jacob will cover life-changing imaging technology ranging from breast cancer screening to detecting water leakage, people tracking, vital signs and more, presenting some of the future promise of radar technology. Immediately following the plenary keynote, the exhibition hall will open, showcasing the latest products, services and technologies from leading companies in the RF, microwave and high speed digital arenas.

The afternoon schedule includes the much-anticipated 5G Symposium, which begins with a talk from Analog Device's Thomas Cameron on "RF Technology for 5G mmWave Basestations," and includes talks from representatives from Qorvo, Remcom, ETS-Lindgren, ANSYS Canada and NI/AWR. The 5G Symposium concludes with a panel moderated by *Microwave Journal*'s Patrick Hindle, "What is the Best RF Architecture for 5G?"

Day One also includes technical sessions across the following tracks: Signal Integrity, mmWave, Power Integrity, Simulation & Modeling, Radar & Defense and RF & Microwave Design Workflow. Franck Nicholls and Coen Centen of the RF Energy Alliance will also give a talk

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from 5:00-6:00 p.m. on "Solid State Technology—Inroads to the Industrial Market." Forty minute workshops will be presented on Day One by Copper Mountain, ANSYS, SemiGen, Cadence and RF Lambda.

Over on the show floor, exhibits will remain open from 12:00-6:00 p.m., with lunch time concessions on the show floor and a full afternoon of programming in the Frequency Matters Theater, as well as exhibitor demonstrations and products on display in our sponsored booths. The day concludes with the Welcome Reception for conference pass holders, held around the Hyatt Regency Pool (weather permitting; if raining, signage will indicate alternate location).

Day Two of EDI CON USA, Thursday, October 18, also includes a full day of programming and exhibits, beginning at 9:00 a.m. with more EDI CON University sessions. These sessions include: "Build Your Own VNA," a hands-on workshop designed for people who want to learn more about how a VNA works, sponsored by Mini-Circuits and presented by Aleksey Amitai, Vayyar Imaging and Aaron Vaisman, Mini-Circuits; "Real Time Spectral Analysis of Power Rail Noise," sponsored by Teledyne LeCroy and presented by Eric Bogatin; and "High-Speed Board Design Rules to Get Your PCB Designed Right the First Time," presented by Shalom Shlomi Zigdon, iTech iCollege Israel.

Thursday's keynote will be given by Ransom Stephens, author, technologist, physicist and an EDI CON USA 2018 Technical Advisor Committee co-chair. Stephens will take on the "I" in EDI CON—innovation—in his talk "Innovation, Incorporation, and Integrity" from 11:30-12:00 p.m. Anyone who has heard him talk before can confirm that Ransom Stephens is an engaging speaker who entertains, educates and causes us to think about things in new ways. This is sure to be an interesting talk and should be a definite on your agenda.

The exhibit hall opens at 11:00 a.m. on Day Two, and, in addition to booth visits, attendees can take in some sessions in the Frequency Matters Theater. Day Two highlights include "Panel Discussion: Skills Employers Will Want the Most in 2020" at 12:30 p.m., Student Paper Finalists at 1:40 and 2:15 p.m. and the EDI CON USA Outstanding Paper Awards at 4:30 p.m.

Over in the conference area, Day Two will host the popular High Speed Digital Symposium, led by *Signal Integrity Journal*'s editor Eric Bogatin, with talks from Larry Smith (PDN Power Integrity), Brian Hostetler (Cray Inc.) and Steve Sandler (Picotest). The Symposium ends with a panel on "Putting Power Integrity in Perspective: How Do We Know When to Apply Which Guidelines to What Types of System?"

Day Two's other technical sessions will include papers in extended tracks on mmWave, Test & Measurement and RF & Microwave Design. Workshops will be presented by Samtec, National Instruments/AWR and Qorvo. Also, do not miss the panel "A Pit Stop for Self-Driving," moderated by *Microwave Journal*'s Gary Lerude, which takes a closer look at the status of self-driving automobiles and the technologies behind them from 3:20-4:30 p.m.

EDI CON USA 2018 ends with a craft beer and hot pretzel Happy Hour on the show floor for all attendees starting at 4:30 p.m. It is the perfect opportunity for attendees to take one last pass through the exhibit hall, and for EDI CON to thank all of its exhibitors, technical advisory committee members, attendees, speakers and staff for their commitment to once again producing a quality conference and engaging exhibition.

See the online technical program for a full listing of presentations at EDICONUSA.com

EDI CON 2018

PROGRAM - Wednesday, October 17

Registration: 8:00 am - 6:00 pm

Time	Ballroom G	Ballroom H	RM 203	RM 204	RM 209
9:00 - 11:15			**EDI CON University** **Antenna Design for IoT (14)** Henry Lau, Lexiwave	**EDI CON University** **How to Measure Ultra Low Impedance (100uOhm and Lower) PDNs (10)** Steve Sandler, Picotest	**EDI CON University** **Millimeter Wave Measurement Insights (36)** Sponsored by Keysight, Gennady Farber & Suren Singh, Keysight

Coffee Break: 11:15 - 11:30 am

11:30 - 12:00

Plenary Keynote:

Looking Deeper: Using Radar to Save Lives and Improve the World

Ovi Jacob, Vayyar Imaging

Ballroom G

Lunch Break & Dedicated Exhibit Time, Exhibition Floor: 12:00 - 1:00 pm

Time	5G Symposium	Signal Integrity	RF & MW Design/ Workflow	Radar and Defense	Sponsored Workshops
1:05 - 1:35	**RF Technology for 5G mmWave Basestations (13)** Thomas Cameron, Analog Devices	**COM for PAM4 Link Analysis (26)** Geoffrey Zhang, Xilinx	**A Traceable Workflow for Software Defined Radio Development (32)** Andrei Cozma, Analog Devices	**Challenges and Solutions for Addressing Size and Environmental Constraints in Precision Guided Munitions (47)** Sean D'Arcy, Analog Devices	12:55 - 1:35 **Testing an IoT Antenna (29)** Copper Mountain
1:45 - 2:15	**RF Front-End Technology and Tradeoffs for 5G mmWave Fixed Wireless Access (51)** Bror Peterson, Qorvo	**Comparison of Embedded Coplanar Waveguide and Stripline for Multi-Layer Boards (15)** Milica Markovic, CSU Sacramento	**Why it Makes Great Sense to Combine RF, High Speed, and Fabrication Expertise Into a Design Center of Innovation (55)** Daniel Everitt, Lark RF Technology	**Reliability Without Hermeticity: Further Development in Commercial Vapor Deposited Coatings for High-Frequency RF Microelectronics (30)** Scott Morrison, GVD Corporation	1:40 - 2:20 **Profiling Heat with an Integrated Coupled Electro-Thermal Simulation (65)** ANSYS
2:25 - 2:55	**Using Modeling and Simulation to Assess Challenges and Solutions for 5G Fixed Wireless Access (50)** Greg Skidmore, Remcom Inc.	**Via Characterization and Modeling By Z Input Impedance (23)** HEESOO LEE, Keysight Technologies	**Design of Edge-Launch Connectors and Formulation for Board Laminates for Up to 110 GHz Applications (72)** Eric Gebhard, Signal Microwave Svetlana Sejas Garcia, Isola Group	**Design Automation Supports Physical Realization of Phased Array Antenna for MIMO and Beam-Steering Applications (19)** Joel Kirshman, National Instruments	2:25 - 3:05 **Eutectic Die Attach of GaN and MMIC Chips (67)** SemiGen
3: 05 - 3:35	**5G and mmWave Device Measurement Challenges (75)** Michael Foegelle, ETS-Lindgren	**Practical Application of the IEEE P370 Standard for Measurement of Interconnects Up to 50 GHz (49)** Jay Diepenbrock, SiRF Consultants	**Power Integrity** **The 2-Port Shunt-Thru Measurement and the Inherent Ground Loop (7)** Anto Davis, Picotest	**Radar Technology for IoT Applications (11)** Henry Lau, Lexiwave	3:10 - 3:50 **Mitigating Receiver Desensitization Through System-Level Simulation (22)** ANSYS
3:45 - 4:15	**Realistic Antenna Array Modeling for 5G Communications (46)** Laila Salman, ANSYS Canada	**Demystifying Edge Launch Connectors (27)** Raul Stavoli, Carlisle Interconnect Technologies	**Causality in Power Delivery Network (PDN) Extractions in Package & Board (6)** Vinod A H, Western Digital	**mmWave** **Overcoming the Challenges of mmWave, On-Wafer Load-Pull Measurements for 5G (70)** Maury Microwave	3:55 - 4:35 **Better Noise Characterization of Dynamic Comparators (66)** Cadence
4:25 - 4:55	**Designing a Narrowband 28 GHz Bandpass Filter for 5G Applications (18)** David Vye, NI/AWR	**Signal Integrity Analysis on Integrated Thin Film High Density Organic Package Technology for Next Generation Applications (35)** Surender Singh, Cadence Design Systems	**Simulation & Modeling** **Cut-Off Frequency Prediction for MMW Coaxial Interconnects (40)** Thomas Clupper, W.L. Gore	**Advances in Technology and Design of UWB mmWave Planar and Non-Planar Diplexers for Applications Up to 100 GHz (59)** Irfan Ashiq, NI Components	4:40 - 5:20 **Digital Controlled Wideband PA and its Application in Phased Array Systems (71)** RF Lambda
5:00 - 5:30	**PANEL: What is the Best RF Architecture for 5G? (57)** Pat Hindle, *Microwave Journal,* Moderator	**IEEE P370: A Fixture Design and Data Quality Metric Standard for Interconnects Up to 50 GHz (28)** Jay Diepenbrock, Si RF Consultants	**Advances in Recent PCB Design Verification Flows (16)** John Dunn, NI/AWR	**Solid State RF Energy–Inroads to the Industrial Market** Franck Nicholls, RF Energy Alliance Chairman/ NXP Semiconductors Coen Centen, RF Energy Alliance Chairman/Ampleon	
5:30 - 6:00		**Practical Channel Modeling for High-Speed Design (73)** Bert Simonovich, Lamsim Enterprises	**Design of a Compact, Planar Triplexer Covering DC to 9 GHz and Implemented on Low Cost Software (48)** Utkarsh Unnikrishna, National Instruments		

Exhibition: 12:00 - 7:00 pm

Welcome Reception: 6:00 - 8:00 pm

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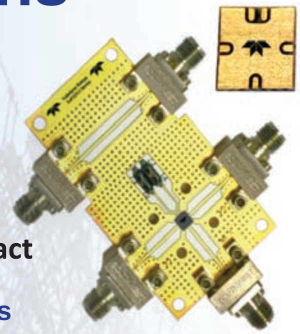

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- DC to 40 GHz
- SPDT, Transfer, Multi-Throw
- SP3T-SP10T
- Low PIM Switching
- 5M Cycle-life
- Custom products

ELECTROMECHANICAL RELAYS

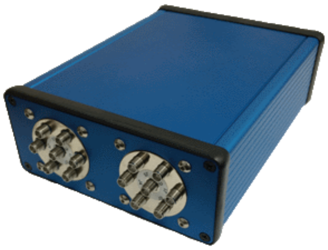
- 40 Gbps Signal Integrity, DC-18GHz Bandwidth
- Loopback Relays with bypass path for ATE Applications
- SPDT, DPDT, 4PST Configurations
- Magnetic Latching and Failsafe Options

RF SWITCH MATRIX

- Multiple Standard and Custom configurations
- Failsafe, Latching, or Normally Open Configurations
- Integration with Filters, Attenuators, Splitters, Dividers, etc.

MINIATURE SWITCH MATRIX

- DC-18GHz, 26.5 GHz, or 40 GHz options
- USB/Ethernet Mini-Switch Modules
- SPDT, Multi-throw, and Transfer switch options
- Multiple RF Connectors Available
- USB/Ethernet Controllable
- Off-The-Shelf Product, Short Lead Times



TELEDYNE RELAYS Everywhereyoulook™

TELEDYNE COAX SWITCHES Everywhereyoulook™

See us at EDI CON Booth 419

EDI CON 2018

PROGRAM - Thursday, October 18

Time	Ballroom G	Ballroom H	RM 203	RM 204	RM 209
9:00 - 11:15		EDICON UNIVERSITY — Where High Frequency Meets High Speed	EDI CON University **Build Your Own VNA (60)** Sponsored by Mini-Circuits, Aleksey Amitai, Vayyar Imaging & Aaron Vaisman, Mini-Circuits	EDI CON University **Real Time Spectral Analysis of Power Rail Noise (25)** Sponsored by Teledyne LeCroy, Eric Bogatin	EDI CON University **High-Speed Board Design Rules to Get Your PCB Designed Right the First Time (54)** Shalom Shlomi Zigdon, iTech iCollege Israel

Coffee Break: 11:15 - 11:30 am

11:30 - 12:00

Plenary Keynote:

Innovation, Incorporation, and Integrity

Ransom Stephens, Author, Technologist, and Physicist

Ballroom G

Lunch Break & Dedicated Exhibit Time, Exhibition Floor: 12:00 - 1:00 pm

Time	mmWave	High Speed Digital Symposium	Test & Measurement	RF & MW Design	Sponsored Workshops
1:20 - 1:50	**Advanced GaAs Integration For mmWave Front-Ends (53)** David Danzilio, WIN Semiconductor	**Linear Voltage Regulator Model (VRM) for Power Integrity Simulations (45)** Larry Smith, PDN Power Integrity	**Methods for Permittivity, Permeability, and Loss Measurements of Polymer Composite Materials (21)** Allen F. Horn III, Rogers Corp.	**Optimizing RF Filters for 5G Applications (58)** Ian Campbell, OnScale	12:55 - 1:35 **Evaluating Connector Crosstalk Impact on System Crosstalk at 32 Gbps (PCIE Gen5) (61)** Samtec
2:00 - 2:30	**All-Silicon Active Antennas for High Performance mmWave Systems (52)** Alastair Upton, Anokiwave	**Power Distribution Network (PDN) Impedance and Target Impedance (43)** Larry Smith, PDN Power Integrity	**Settling Time Measurements on PLL Circuits Used in Radar and Communication Systems (8)** Kay-Uwe Sander, Rohde & Schwarz	**Frequency Dependency IQ Impairments and Correction Techniques (44)** Shannon Wanner, iDirect	1:40 - 2:20 **EM Verification Within a Custom IC Design Platform (63)** NI/AWR
2:40 - 3:10	**mmWave Antenna Array Modeling for Autonomous Vehicle Radar Applications (39)** Laila Salman, ANSYS Canada	**100uΩ Probing Methods (42)** Brian Hostetler, Cray Inc.	**EMC Management and Lab Accreditations (4)** Poojita Rao Bhattu, Cisco	**Network Synthesis Accelerates Impedance Matching Circuit Design (17)** Ben Parry, National Instruments	2:25 - 3:05 **Increasing Broadband Interconnect Characterization Up to 60 GHz (62)** Samtec
3:20 - 3:50	**PANEL: A Pit Stop for Self-Driving? (56)** Gary Lerude, *Microwave Journal*, Moderator	**Designing and Measuring 100uOhm Power Rails (9)** Steve Sandler, Picotest	**High Speed/mmWave Measurement-Based Model Development: Uncertainties and Model Sensitivities (31)** Jon Martens, Anritsu	**Spatial Filters for Wireless Communication (12)** Edward Liang, MCV Microwave	
4:00 - 4:30		**PANEL: Putting Power Integrity in Perspective: How Do We Know When to Apply Which Guidelines to What Types of System? (64)** Eric Bogatin, *Signal Integrity Journal*, Moderator	**A Systematic Approach to Optimize Calibration of Active Phased Array Structures (41)** Kaan Temir, Aselan Inc.	**Significance of Digital Controlled Tunable Filters for Receivers and Optimization Approachment (33)** Yarkin Yigit, Aselan Inc.	

Exhibition: 11:00 - 6:00 pm

Happy Hour: 4:30 - 6:00 pm
Show Floor

Additional programming in the Frequency Matters Theater on the EXPO floor (all pass holders) during exhibition hours daily.

Highlights:

- Oct. 18: 12:30-1:30 pm Panel Discussion: Skills Employers Will Want the Most in 2020
- Oct. 18: 1:40-2:10 pm Student Paper Finalist
- Oct. 18: 2:15-2:45 pm Student Paper Finalist
- Oct. 18: 3:00-3:30 pm Fast Butler Matrix Evaluation for a Phased Antenna Array, COMSOL Inc.
- Oct. 18: 4:30-5:00 pm Outstanding Paper Awards

Visit **EDICONUSA.com** for more details.

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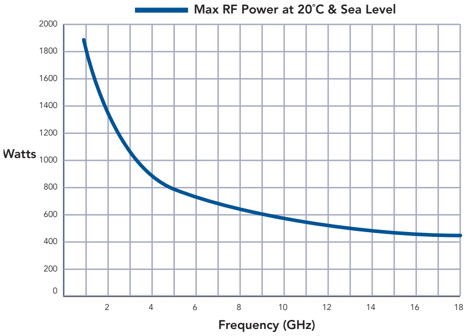
See Us At
EDI CON
Santa Clara, CA
Oct 17-18,
Booth #415

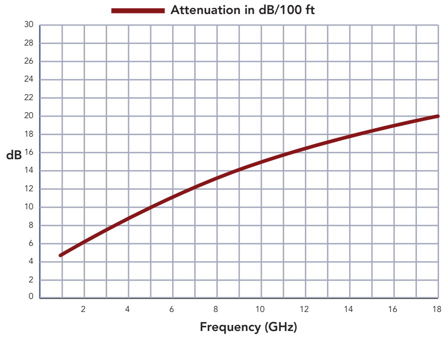
Specifications

Impedance:	50 ohmΩ	**RF leakage, min:**	-100 dB to 18 GHz
Time delay:	1.2 ns/ft.	**Temp range:**	-65°C to +165°C
Cut off frequency:	18 GHz	**Cable outer diameter:**	0.31"
Capacitance:	24 pf/ft.	**Velocity of propagation:**	83%
Weight:	7.8 lb./100 ft.	**Flame retardant rating:**	UL94-V0

Max RF Power in Watts
20°C at Sea Level



Attenuation in dB/100 ft



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These booth numbers are complete as of August 3, 2018. Exhibitors in red have an ad in this issue.

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Analog Devices	311
Anritsu	310
ANSYS	211
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AR RF/Microwave Instrumentation	412
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Cadence Design Systems	511
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EDI CON 2018

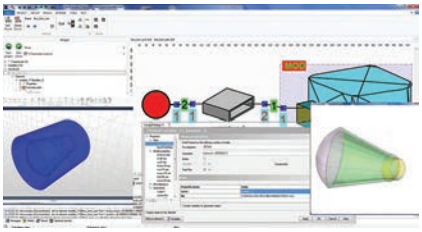
AISLES 100-200

PRODUCT SHOWCASE

For complete coverage of the EDI CON USA conference, event news, exhibitor product information and special reports visit EDICONUSA.com

Mician — Booth 101

EM Software Tools

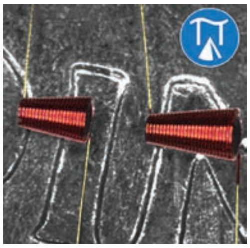


Mician is a globally recognized leader in the development of EM software tools for passive waveguide components and horn antennas, parabolic, hyperbolic and ellipsoid antennas. The µWave Wizard product line combines the flexibility of 2D/3D FEM with the speed and accuracy of mode matching techniques. Complementing their fast, powerful proprietary numerical methods, µWave Wizard software tools also offer an appealing ergonomic GUI enabling flexibility and openness including CAD export formats interfacing with most mechanical design tools.

www.mician.com

Piconics — Booth 105

50 Awg Broadband Conical Inductors

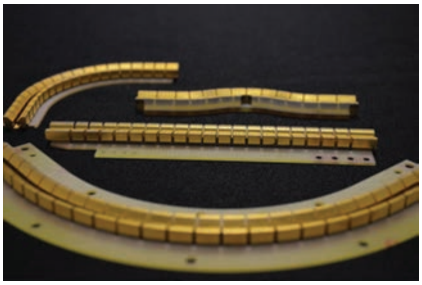


Piconics Inc. has introduced a new line of broadband conical inductors utilizing ultra-fine 1 mil (50 Awg) diameter wire. This inductor series offers increased inductance in a smaller size than traditional conical inductors while maintaining broadband performance past 40 GHz. The ultra-fine wire reduces capacitance build-up at the terminations and along the coil to minimize loss across the frequency band. Typical applications: bias tees, broadband amplifiers, high speed switches, optical linear drivers and isolation circuits on semiconductor test boards.

www.piconics.com

Accurate Circuit Engineering — Booth 200

3D PCB



Accurate Circuit Engineering (ACE) announces the first 3D printed circuit board (PCB). Most PCBs are 2D and flat with a milled area or cavity. ACE, using its unique routing, milling and beveling technology, has successfully produced a circuit board that actually has a 3D topography. There is nothing mounted or attached to the PCB, and it is all machined and plated at ACE.

www.ace-pcb.com

Planar Monolithics Industries, Inc.

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- Switch Matrices
- Switched Filter Banks
- Switches – Solid State
- Systems - Radar Sense & Avoid
- Systems – Fly Eye Radars
- Threshold Detectors
- USB Products

PMI offers a full line of Ultra-broadband & mmWave Low Noise Amplifiers that provide operating frequency up to 40 GHz. These LNAs are supplied with internal voltage regulation, internal reverse voltage protection, DC blocked RF ports and unconditional stability. PMI offers many standard models with various options that are available at: http://www.pmi-rf.com/categories/amplifiers

PE2-16-300M20G-1R7-15-12-SFF
PE2-19-6G18G-1R6-16-12-SFF
PEC-22-24G40G-4R0-24-292FF
PEC-30-24G40G-4R0-24-292FF

PEC-42-500M40G-20-12-292FF
PEC-30-500M40G-20-12-292FF

PEC3-40-30M26R5G-6R0-12-12-SFF

PEC-12-50M40G-4R0-15-24FF
PE2-15-30M26R5-5R5-18-12-SFF
PEC-30-0R2520R0-5R0-22-12-SFF

PMI Model No.	FREQ Range (GHz)	GAIN (dB)	Noise Figure (dB)	DC Voltage Supply / Current Drtaw	OP1dB	Size (Inches) / Connectors
PE2-16-300M20G-1R7-15-12-SFF http://www.pmi-rf.com/products-details/pe2-16-300m20g-1r7-15-12-sff	0.3 - 20	16 dB Typ (0.3 - 10 GHz), 14.5 dB Typ (10 - 16.GHz) 13.5 dB Typ (16 - 18 GHz) 13 dB Typ (18 - 20 GHz)	2 dB Typ (0.3 - 16 GHz), 2.5 dB Typ (16 - 18 GHz) 2.7 dB Typ (18 - 20 GHz)	+12 to +15 VDC @ 100 mA	25 dBm Typ (0.3 - 10 GHz), 23.0 dBm Typ (10 - 16 GHz) 20.0 dBm Typ (16.0 - 20 GHz)	1.08" X 0.71" X 0.29" SMA Female
PE2-19-6G18G-1R6-16-12-SFF http://www.pmi-rf.com/products-details/pe2-19-6g18g-1r6-16-12-sff	6 - 18	19 dB Typ	2 dB Typ, 2.5 dB Max	+12 to +15 VDC @ 91 mA	25 dBm Typ, 23 dBm Min	1.08" X 0.71" X 0.29" SMA Female
PEC-42-500M40G-20-12-292FF http://www.pmi-rf.com/products-details/pec-42-500m40g-20-12-292ff	0.5 - 40	42 dB Typ	5.5 dB Typ (Up - 26.5 GHz)	+12 to +15 VDC @ 450 mA	+19 dBm Typ (1 - 18 GHz), +17 dBm Typ (18 - 40 GHz)	1.37" x 1.0" x 0.6" 2.92mm Female
PEC-30-500M40G-20-12-292FF http://www.pmi-rf.com/products-details/pec-30-500m40g-20-12-292ff	0.5 - 40	30 dB Typ	5.5 dB Typ (Up - 26.5 GHz)	+12 to +15 VDC @ 350 mA	+19 dBm Typ (1 - 18 GHz), +17 dBm Typ (18 - 40 GHz)	1.37" x 1.0" x 0.6" 2.92mm Female
PEC-12-50M40G-4R0-15-24FF http://www.pmi-rf.com/products-details/pec-12-50m40g-4r0-15-24ff	0.5 - 40	12 dB Typ	4.0 dB Typ	+12 to +15 VDC @ 230 mA	+15 dBm Min	1.08" X 0.71" X 0.29" 2.92mm Female
PE2-15-30M26R5-5R5-18-12-SFF http://www.pmi-rf.com/products-details/pe2-15-30m26r5-5r5-18-12-sff	0.03 - 26.5	15 dB Typ	5.5 dB Typ	+12 to +15 VDC @ 230 mA	+16 dBm Min	1.08" X 0.71" X 0.29" SMA Female
PEC-30-0R2520R0-5R0-22-12-SFF http://www.pmi-rf.com/products-details/pec-30-0r2520r0-5r0-22-12-sff	0.25 - 20	26.5 dB Typ	5.5 dB Max	+12 to +15 VDC @ 230 mA	+22 dBm Min	1.08" X 0.71" X 0.29" SMA Female
PEC3-40-30M26R5G-6R0-12-12-SFF http://www.pmi-rf.com/products-details/pec3-40-30m26r5g-6r0-12-12-sff	0.03 -26.5	35 dB Min	6.0 dB Typ	+12 to +15 VDC @ 700 mA	+12 dBm Min	1.92" x 0.78" x 0.36" SMA Female
PEC-22-24G40G-4R0-24-292FF http://www.pmi-rf.com/products-details/pec-22-24g40g-4r0-24-292ff	24 - 40	22 dB Min	6.0 dB Max	+8 VDC @ 500 mA	+24 dBm Min	1.08" X 0.71" X 0.29" 2.92mm Female
PEC-30-24G40G-4R0-24-292FF http://www.pmi-rf.com/products-details/pec-30-24g40g-4r0-24-292ff	24 - 40	30 dB Min	6.0 dB Max	+8 VDC @ 650 mA	+24 dBm Min	1.08" X 0.71" X 0.29" 2.92mm Female

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Reactel Inc. Booth 201

VENDORVIEW

Ultra-Low Profile RF Filters

Reactel will highlight their series of ultra-low profile RF filters, which exhibit equal performance to many of their larger connectorized designs at EDI CON USA 2018. Utilizing innovative machining and material optimization techniques, these devices offer the highest Qs in frequencies up to 30 GHz. They are ideal for portable and aerospace applications where size and weight are critical. Package heights are as low as 0.125 in., weight as low as 0.5 oz and a choice of gull wing pins or axial/radial pin configurations.

www.reactel.com

RFMW Booth 205

VENDORVIEW

High Efficiency Pallet Amplifier

Ampleon's BPC-2425M9X250Z RF power module offers 250 W CW power for RF cooking applications at 2450 MHz. With 61 percent efficiency and 17 dB gain, this high efficiency module has integrated temperature sensing and bias temperature compensation networks. Operating from a 32 V supply, RF input and output are matched to 50 ohms for ease-of-use, providing a cost effective solution with minimum design work and easy connectivity in multi-pallet applications that include heating and drying, plasma lighting and other ISM related designs.

www.rfmw.com

Transline Technology Inc. Booth 210

Printed Circuit Boards

TTI Industries, a manufacturer of RF/microwave, hybrid and standard printed circuit boards (PCB) located in Anaheim, Calif., serves the RF, microwave, aerospace, defense, medical and satellite industries to create solutions for ever-advancing concepts and designs. TTI offers services such as RF and microwave applications, hybrid and exotic materials, oversized (large) PCBs, FEP bonding and fusion bonding, Rigi-Flex and Flex PCB, PCB thermal applications, heavy metal back PCB, PCB heat-sink, manufacturing and lamination and photo chemical etching and RF shielding products.

www.translinetech.com

National Instruments/AWR Booth 212

NI AWR Design Environment V14

Visit Booth #212 for a demo of NI AWR Design Environment V14, introducing network synthesis for impedance matching multi-band amplifiers and front-end components. V14 also offers advanced design editing/selection for fast EM verification of RF/mixed-signal PCBs, as well as the industry's first phased-array generation wizard for antenna-array design. NI AWR software includes Visual System Simulator™ system design software, Microwave Office/Analog Office circuit design software and AXIEM and Analyst™ EM simulators. Demos of AntSyn™ antenna synthesis and AWR Connected™ third-party solutions will also be featured.

www.ni.com/awr

Tabor Electronics Booth 215

RF Analog Signal Generators

Tabor introduces its new line of RF analog signal generators. The all-new Lucid Series offers 3, 6 and 12 GHz single channel versions, in a compact, small footprint module. Featuring fast switching speed, excellent signal integrity and purity, all the necessary modulated signals for analog communication systems, and with built in SPI and micro-USB interface, the Lucid Series is designed to meet today's most demanding specifications, needed from the R&D benches to the production lines.

www.taborelec.com

Berkeley Nucleonics Booth 216

Signal Generator

The Model 855 Series is a multi-channel, phase coherent, fast switching, low phase noise microwave signal generator with output frequency ranges from 10 MHz to 6, 12, 20 or 40 GHz in any combination from 2 to 8 outputs in one system. Frequency and power switching sweep times down to 10 µs with excellent phase noise makes this instrument line ideally suited for a broad range of applications where very high signal quality, accuracy and wide output power range is required.

www.berkeleynucleonics.com

Roos Instruments Booth 217

Modular ATE Systems

Roos Instruments integrates over 30 years of research into modular ATE systems that lead the industry in reliability and test accuracy from DC to 81 GHz and beyond. Powerful hardware and expert software maximize PIN efficiency and time-to-market for the world's most advanced technology. Use Cassini to quickly test your high frequency devices.
www.roos.com

Custom Microwave Components Booth 218

12 Channel Attenuator/Monitor

Each of 12 channels contains an attenuator in series with a solid-state sampler/amp switch (SAS) module. The attenuator modules provide independent control of their respective channel's loss by 70 dB in 0.5 dB steps. The SAS modules resistively samples the respective channel's output and selects/deselects the sample's routing to the monitor port for signal analysis.
www.customwave.com

Morion Inc. Booth 219

Ultra Precision OCXO

Morion released the MV336M, ultra precision OCXO with ultra low short-term stability, phase noise and excellent temperature stability in a 92 × 80 × 50 mm package. Available with a frequency of 10 MHz, the MV336 has phase noise of <-93 dBc/Hz at 0.1 Hz and -120 dBc/Hz at 1 Hz, short-term stability < $1E^{-13}$ at 1 sec and < $3E^{-13}$ until 100 sec which is accompanied by temperature stability of < $4E^{-11}$ vs. -10… +70°C. The MV336M operates at 12 V.
www.morion-us.com

EDI CON 2018 PRODUCT SHOWCASE

AISLE 200

LadyBug Technologies — Booth 220

VENDORVIEW

Thermally Stable Wide Dynamic Range Power Sensor

LadyBug's thermally stable LB5918A True-RMS, a 1 MHz to 18 GHz, wide dynamic range power sensor delivers fast accurate measurements on any signal with any modulation including wideband digital signals. Its unique two path design delivers better dynamic range than many three path sensors. SCPI commands and use either USBTMC, USBHID or connect directly with I2C or SPI.
www.ladybug-tech.com

Carmel Instruments — Booth 221

PXIe Synthesizers

Replace expensive RF generators in your system with these PXIe synthesizers ranging from 50 MHz to 32 GHz. Choose the NK430 for the lowest phase noise in the industry and fast switching or the NK420 for great value. It is now easy to add high performance and quality signal sources to your system for use as local oscillators for up-/down-conversion, frequency extension for 5G frequencies and reference clocks.
www.carmelinst.com

SAGE Millimeter — Booth 222

VENDORVIEW

Omnidirectional Antenna

Model SAO-2734030810-KF-S1 is a full band, WR-28 omnidirectional antenna that operates between 26.5 and 40 GHz. This

vertically polarized antenna offers 360 degrees azimuth coverage with a 7.5 dBi typical gain and ±1 dB nominal gain flatness. The antenna features a half power beamwidth of 45 degrees in its vertical direction. The RF port of the antenna is equipped with K(F) coaxial connector. The version with WR-28 waveguide interface is offered under model number, SAO-2734030810-28-S1.
www.sagemillimeter.com

StratEdge — Booth 224

Packaging

StratEdge features two options for packaging GaN and high-power semiconductor devices—the LL family of leaded laminate copper-moly-copper (CMC) base packages and now its off-the-shelf line of molded ceramic packages that can be configured to meet the requirements for chips with frequencies up to 18 GHz. These packages dissipate heat and come in fully-hermetic versions in over 200 standard outlines. StratEdge offers complete automated assembly and test services in San Diego, Calif. for these packages, including gold-tin solder die attach.
www.stratedge.com

WIN Semiconductors USA — Booth 225

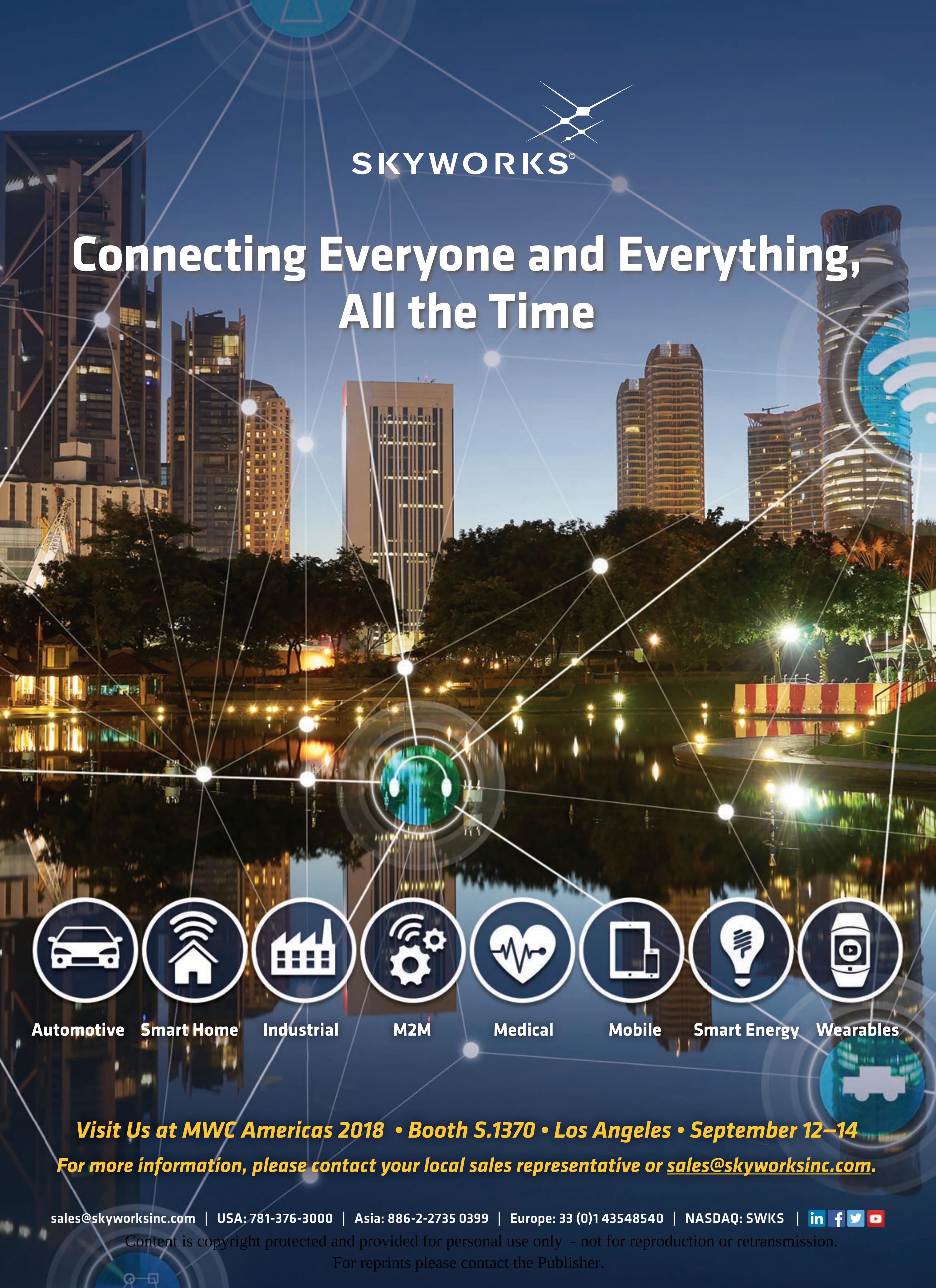
GaN Process Capabilities

WIN Semiconductors has expanded its GaN process capabilities to include a 0.45 µm-gate technology that supports current and future 5G applications. The NP45-11 GaN on SiC process provides 50 V operation with superior power density and efficiency. It allows customers to design hybrid Doherty power amplifiers used in 5G applications including massive MIMO wireless antenna systems. Similar to macro-cell applications, MIMO base stations often combine Doherty power amplifiers with linearization techniques to meet demanding linearity and efficiency specifications of today's wireless infrastructure.
www.winfoundry.com

Signal Microwave — Booth 226

Solderless Connectors

The ELF110 series of 1 mm interface connectors operate mode free through 125 GHz. Test boards also mode free through 125 GHz are available. The proven and innovative design techniques that Signal Microwave is known for were incorporated to successfully develop this design in only four months. The connector body design is streamlined and available in standard and narrow profiles and built with a minimum of components. The technical details of the connector, including 3D models, can be found online.
www.signalmicrowave.com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Anritsu — Booth 310

VENDORVIEW

Signal Analyzer

MS2850A is a spectrum/signal analyzer with maximum analysis bandwidth of 1 GHz and frequency range of 9 kHz to 32 or 44.5 GHz. With a wide dynamic range up to > 140 dB and excellent amplitude/phase flatness, it provides high-end performance at a mid-range price for improved cost-of-test. Software options provide engineers with a cost-efficient and accurate solution to verify RF Tx characteristics of next-generation 5G base stations and mobile devices, SATCOM equipment and wideband communications systems.

www.anritsu.com/en-US/test-measurement/products/ms2850a

Analog Devices — Booth 311

VENDORVIEW

RF Transceiver

Model ADRV9009 is a 200 MHz bandwidth RF transceiver. Tunable over a range of 75 MHz to 6 GHz, this single-chip transceiver provides a common radio platform that supports all 2G/3G/4G standards, while meeting the antenna density and network capacity requirements of 5G wireless infrastructure equipment and aerospace and defense systems. It features fast frequency hopping for enhanced link security and spectrum efficiency.

www.analog.com

MOSIS — Booth 312

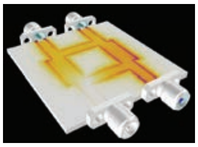
Prototype and Volume-Production

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

www.mosis.com

COMSOL — Booth 315

COMSOL Multiphysics®



COMSOL Multiphysics® is an integrated software environment for creating physics-based models and simulation apps. A particular strength is its ability to account for coupled or multiphysics phenomena. Add-on products expand the simulation platform for electrical, mechanical, fluid flow and chemical applications. Interfacing tools enable the integration of COMSOL Multiphysics® simulations with all major technical computing and CAD tools on the CAE market. Simulation experts rely on the COMSOL Server™ product to deploy apps to their design teams, manufacturing departments, test laboratories and customers throughout the world.

www.comsol.com

Integra Technologies — Booth 316

VENDORVIEW

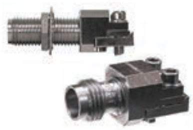
RF Power Modules

Integra announces the formal launch of their new line of standardized RF power modules (aka pallets). Differentiating these modules from custom or build-to-print, PCB amplifier assemblies or "pallets," these new, ultra-efficient RF power modules are being developed to offer a new level of integration which results in powerful yet simple, higher-level building blocks for creating SWaP-C optimized high-power amplifiers (HPA) found in pulsed and CW radar systems. Built-in functions can include RF matching, GPS, temperature compensation and VSWR protection.

www.integratech.com

Southwest Microwave — Booth 317

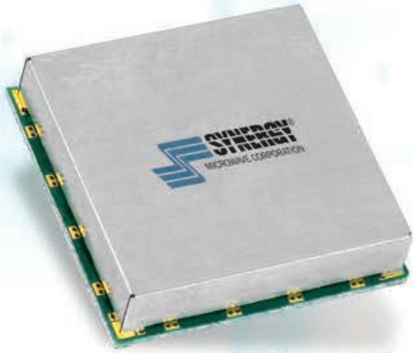
Narrow Block and Panel Feed-Through End Launch Connectors



Recognized worldwide for mmWave end launch connectors to 110 GHz with unmatched performance, Southwest Microwave has added two new models to their PCB connector product array. New narrow block end launch connectors, available in SMA, 2.92 mm, 2.4 mm, 1.85 mm and 1.0 mm, are $^1/_3$ smaller than the

Amazingly Low Phase Noise

SAW VCO's



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| Small Size Surface Mount *

Model	Frequency [MHz]	Tuning Voltage [VDC]	DC Bias VDC @ I [Max.]	Phase Noise @ 10 kHz (dBc/Hz) [Typ.]
HFSO640-5	640	0.5 - 12	+5 VDC @ 35 mA	-151
HFSO745R84-5	745.84	0.5 - 12	+5 VDC @ 35 mA	-147
HFSO776R82-5	776.82	0.5 - 12	+5 VDC @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 VDC @ 20 mA	-146
HFSO800-5H	800	0.5 - 12	+5 VDC @ 20 mA	-150
HFSO800-5L	800	0.5 - 12	+5 VDC @ 20 mA	-142
HFSO914R8-5	914.8	0.5 - 12	+5 VDC @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 VDC @ 35 mA	-141
HFSO1000-5L	1000	0.5 - 12	+5 VDC @ 35 mA	-137
MSO1000-3	1000	0.5 - 14	+3 VDC @ 35 mA	-138
HFSO1200-5	1200	0.5 - 12	+5 VDC @ 100 mA	-140
HFSO1600-5	1600	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO1600-5L	1600	0.5 - 12	+5 VDC @ 100 mA	-133
HFSO2000-5	2000	0.5 - 12	+5 VDC @ 100 mA	-137
HFSO2000-5L	2000	0.5 - 12	+5 VDC @ 100 mA	-133

** Package dimension varies by model. (0.3" x 0.3" to 0.75" x 0.75")*

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original models. A new 2.92 mm female, bulkhead panel feed-through end launch connector with extended threaded length allows users to achieve equivalent performance in their packaged end product and engineering models.
www.southwestmicrowave.com

MCV Microwave — Booth 318

VENDORVIEW

Filters

MCV Microwave introduces a new series of suspended substrate bandpass filter, diplexer, triplexer and quadruplexer from 300 MHz to 30 GHz. These filters feature low PIM, low profile and high-power handling (100 W) in either surface mount or connectorized package. Wideband coverage such as 2 × Fc are particularly useful for transition from 4G to 5G applications. Choice of various low loss substrates from low dielectric constant Duroid to high dielectric constant ceramic type makes this a versatile solution for 5G system integration. Contact MCV Microwave at 1-858-450-0468.
www.mcv-microwave.com

Exodus Advanced Communications — Booth 320

VENDORVIEW

Solid-State Module

Exodus Advanced Communications announced their AMP3132 compact 26.5 to 40 GHz, 38 dB gain solid-state module. Featuring instantaneous wideband operation, 6 dB peak to peak flatness and 16 A max consumption operating from an 8 VDC source, the unit is suitable for all single channel modulation standards and has built-in protection circuits. Other notable characteristics of the AMP3132 are its high-reliability and ruggedness. It is suitable for EW, EMI/RFI testing, phased arrays and any application requiring small size and high-power density.
www.exoduscomm.com

American Technical Ceramics — Booth 321

Broadband Multilayer Capacitor

ATC's new 531Z broadband multilayer capacitor is an excellent solution for applications requiring coverage from 16 KHz through 30 GHz while providing low insertion loss with a voltage rating of 16 WVDC. The 531Z is ideal for broadband DC blocking, coupling, bypassing and feedback applications in optical communications systems and equipment using high speed digital logic. This RoHS compliant product is available in an EIA 0201 case size and is compatible with high speed automated pick and place SMT manufacturing.
www.atceramics.com

Marki Microwave — Booth 322

Triple-Balanced MMIC Mixer

Marki Microwave introduces the first triple-balanced MMIC mixer covering X-, Ku- and K-Bands in a small QFN package. The high linearity MM2-0530HSM features massive overlapping bands with RF/LO from 5 to 30 GHz and IF from 2 to 20 GHz. This mixer provides IIP3 of +28 dBm, high spurious suppression and exceptional port-to-port isolations. For lower LO drive applications they offer the MM2-0530LSM. Both are available in 4 × 4 mm QFN, evaluation board, bare die or a high performance connectorized module.
www.markimicrowave.com

Micro Lambda Wireless — Booth 324

LUXN™ Synthesizer

The fast-switching frequency LUXN™ Synthesizer keeps the spurious and phase-noise levels low across a total frequency tuning range as wide as 50 MHz to 21 GHz. The synthesizer features high speed tuning from 50 MHz to 21 GHz in frequency steps as small as 0.001 Hz in a package that is only 4.0 × 3.6 × 0.9 in. and weighs only 15 oz. It is a fit for a wide range of applications, from broadband communications systems to test and measurement equipment. It provides spectrally pure output signals that can feed most measurement applications.
www.microlambdawireless.com

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LPKF Laser & Electronics — Booth 325

Desktop Prototyping System

The ProtoMat S63 is a desktop prototyping system designed to help microwave engineers make PCB prototypes in minutes or hours, instead of waiting for a design to come back from the board house weeks later. The system's high speed spindle can produce structures as small as 100 µm. Other features of the ProtoMat S63 include automatic tool change (15 tools), automatic milling width adjustment, optical fiducial recognition (camera) and an optional vacuum table.

www.lpkfusa.com/pcb

Maury Microwave — Booth 326

Measurement and Modeling Device Characterization Solutions

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

www.maurymw.com

Applied Thin-Film Products — Booth 327

Thin Film Manufacturing

ATP is a leading ISO/AS9100 certified thin film manufacturer that offers complete in-house circuit fabrication services and engineered solutions. Quick turn engineering prototyping is available as well as mass production jobs. ATP offers a wide range of ceramic/special materials and metallization schemes including solderable and bondable films. Features include laser diode submounts, edge defined wraps, conductors, integrated resistors (with or without laser trimming), hollow and solid filled vias, double-sided patterning, backside burnishing treatment and serialization capabilities.

www.thinfilm.com

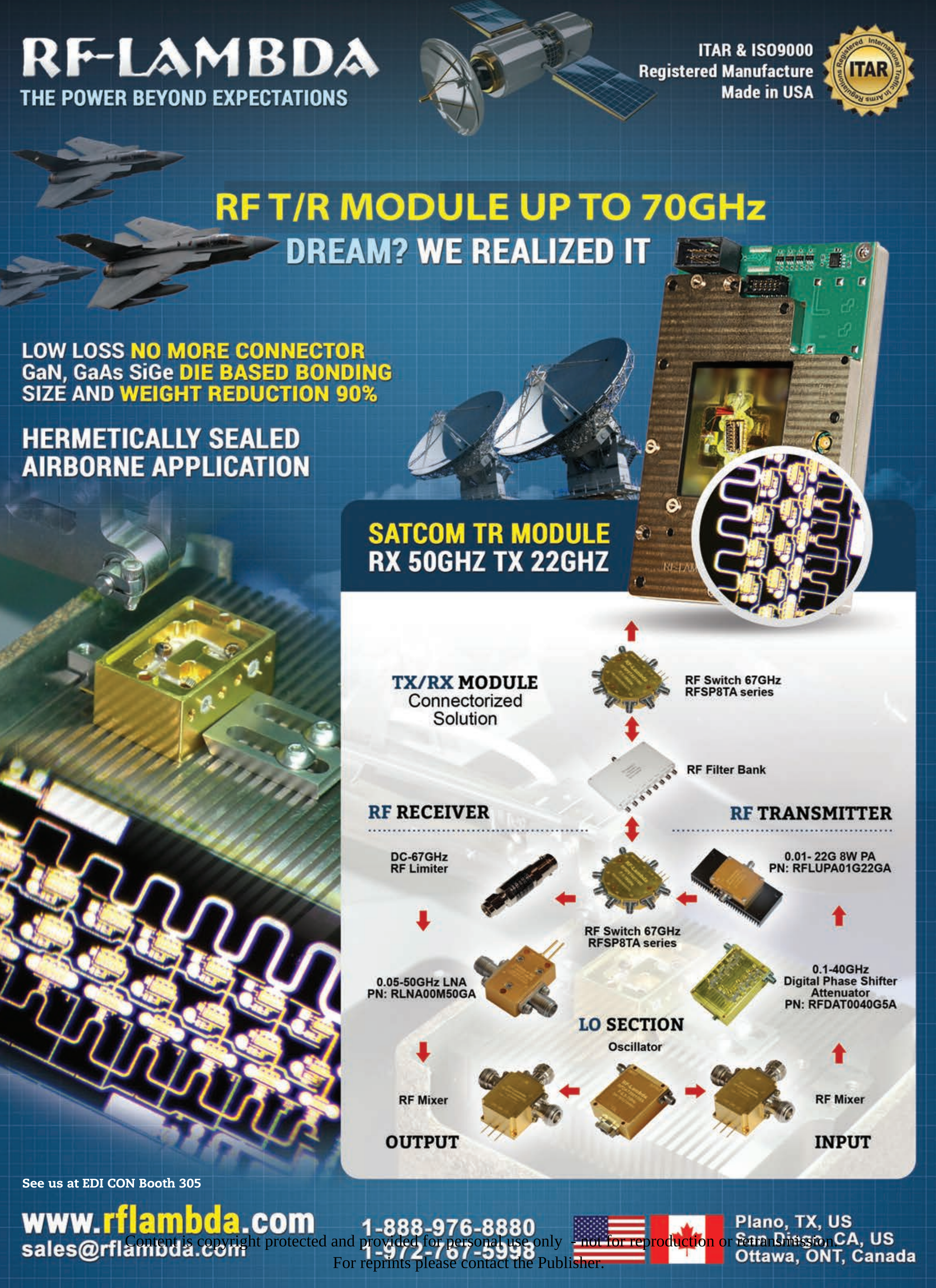
MACOM — Booth 400

VENDORVIEW

Wideband Distributed Amplifier

MACOM's wideband distributed amplifier, MAAM-011275-DIE, is an easy-to-use, wideband amplifier that operates from 100 kHz to 40 GHz. The amplifier provides 16 dB gain, 22 dBm output power and 4.5 dB noise figure. It is matched to 50 Ω with typical return loss better than 13 dB. The MAAM-011275-DIE is suitable for a wide range of applications in instrumentation and communication systems.

www.macom.com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Passive Plus Inc. — Booth 401

Capacitors

Passive Plus Inc. (PPI) now offers the 0708N series capacitor. With vertical electrodes which increase bandwidth, these capacitors have low ESR/ESL and high self-resonance. Uniquely designed for excellent heat transfer in high RF applications, the 0708N offers ultra-stable performance over temperature and are 100 percent RoHS compliant. With over 30 years in the RF/microwave industry, PPI manufactures high quality, high-power passive components using state-of-the-art manufacturing techniques for the military, medical, semiconductor, broadcast and telecommunications industries.

www.passiveplus.com

Samtec Microwave — Booth 405

Bulls Eye® High Performance Test Point System

Samtec Bulls Eye high performance test point systems are now available in 50 and 20 GHz designs, with systems up to 65 GHz in development. A compression interface, small footprint and high cycle count make Bulls Eye ideal for high performance test applications. The high density array design significantly saves PCB space compared to traditional test points.

www.samtec.com

Copper Mountain Technologies — Booth 410

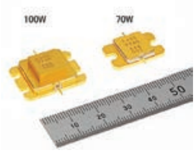
IoTest™ Antenna Testing Kit

IoTest™ Antenna Testing Kit helps IoT device designers select and test the right antenna. The Kit includes Antenna Analyzer, testing software, sample antennas and cable assembly to connect antennas to the Analyzer. IoTest™ software is easy to use and walks you step-by-step through calibrating the Antenna Analyzer and testing sample antennas, and then through a similar process of testing your own antenna on its own and in the device. PulseLARSEN backs the IoTest™ kit with years of antenna design expertise.

www.coppermountaintech.com

Mitsubishi Electric — Booth 411

Ku-Band GaN-HEMT



The demand for SATCOM is increasing, especially in Ku-Band, which enables high speed communication. Mitsubishi Electric is expanding its Ku-Band GaN-HEMT lineup to meet the growing demand for higher output power levels with the introduction of its MGFK50G3745 (100 W) and

MGFK48G3745 (70 W) models. Both models boast industry-leading output power with very high linear gain (10 dB). Additionally, Mitsubishi Electric deploys 20 W GaN MMIC MGFG5H1503 with great linearity to support the design of PA lineup in BUC applications.
www.mitsubishielectric.com/products/devices

AR RF/Microwave Instrumentation
Booth 412

VENDORVIEW

Single Band Amplifiers

AR's new 20S6G18A and 40S6G18B are self-contained, air-cooled, broadband, class A solid-state amplifiers designed for applications where instantaneous bandwidth, high gain and linearity are required. The Model 20S6G18A, when used with a sweep generator, will provide a minimum of 20 W of RF output power instantaneously from 6 to 18 GHz, while the 40S version delivers 40 W. These instruments are suitable for radiated immunity testing, TWTA replacements and EW applications.
www.arworld.us

Wenzel Associates Inc. **Booth 417**

Slow Transition Phase Locked Crystal Oscillator

The Slow Transition PLO crystal oscillator provides smooth frequency transition on loss and reacquisition of external reference. This innovative design features a low PLL BW (≤ 0.1 Hz), guaranteed maximum slew rate, automatic aging correction and frequency holdover upon loss of reference, while maintaining excellent close-in noise of -145 dBc at 10 Hz.
www.wenzel.com

Cernex Inc. **Booth 418**

VENDORVIEW

Benchtop Amplifiers

Cernex's BenchTop Amplifiers are designed for use in a wide range of general purpose applications such as laboratory test equipment, instrumentation and other applications. Reliable operation is achieved using rugged stripline circuit construction with selected GAsFETs, PHEMTs and MIMICs.
www.cernex.com

Teledyne Wireless **Booth 419**

VENDORVIEW

Non-ITAR GaN Amplifiers

With dimensions of 2.5 × 2 × 0.42 in. and 2.1 cubic in., these modular, non-ITAR GaN amplifiers from Teledyne Wireless maintain rugged design characteristics needed for harsh airborne and land based requirements in the smallest footprint possible. The calculated MTBF of these amplifiers is greater than 40,000 hours at +85°C, manufactured to optimal thermal requirements to deliver high-reliability and performance for challenging military and commercial applications.
www.teledynewireless.com

TechPlus Microwave
Booth 422

1U High VHF Duplexer

The TM1003 is a VHF duplexer operating between 135 to 172 MHz which will fit in a 1U 19 in. rack mount. Space is a premium, so the company designed this duplexer with the lowest profile possible. T/R spacing, 5 MHz min. passband, 500 KHz min. insertion loss 3.6 dB max. Return loss 20 dB min. rejection at Fc ±20 MHz 60 dB min. Max power 40 W. They also make a Bandpass version.

www.techplusmicrowave.com

West-Bond Inc. Booth 424

Wire Bonders

Introducing the most flexible, complete wire bonders system available today. 7KE and 4KE series wire bonders: bonding at 45 degree feed for tail control, 90 degree for ribbon and deep access and ball bonding without changing heads. Wedge bonding Au, Al, Cu; ball bonding Au, Cu. Automatic, semiautomatic and manual all ESD protected. Ultrasonic, thermosonic and thermocompression wire/ribbon bonders; eutectic and epoxy die bonders, insulated wire bonders and pull testers.

www.westbond.com

Top Dog Test Booth 500

Test Equipment

Top Dog Test specializes in the sale, rental, leasing, purchase, repair, calibration and liquidation of test equipment which includes oscilloscopes, spectrum analyzers, network analyzers, function generators, logic analyzers and telecommunications test equipment. Find equipment on Top Dog's site or call the company's qualified technicians for professional assistance at 510-324-3001. They will help you decide on what specific model or product will best meet your needs and budget.

www.topdogtest.com

Mini-Circuits Booth 504

VENDORVIEW

Ultra-Wideband MMIC Precision Fixed Attenuator

Mini-Circuits' KAT series of MMIC precision fixed attenuators extends coverage to a wide array of applications from DC to 40 GHz including 5G systems, microwave communications, satellite, defense and aerospace and more. These fixed-value, absorptive attenuators are fabricated through highly repetitive MMIC processing with thin film resistors on GaAs substrates and achieve ultra-wideband performance. Model KAT-9+ provides 9 dB nominal attenuation with ±0.2 dB flatness, 1.1 W RF power handling and 1.11:1 typical VSWR.

www.minicircuits.com

Holzworth Instrumentation — Booth 505

VENDORVIEW

Real-Time Phase Noise Analysis

The HA7000 series real-time phase noise analyzer products resolve the historical speed and accuracy issues in both R&D and high throughput (ATE) manufacturing test environments. The HA7000 series includes the HA7062C and the HA7402C real-time engine. These versatile phase noise analyzers offer ease of test setup and blazing fast acquisition times without compromising on data accuracy or limitations in the measurement floor. An input range to 40 GHz and 100 MHz measurement offset capabilities will be demonstrated at EDI CON USA 2018.
www.HOLZWORTH.com

Times Microwave Systems — Booth 510

Coax Test Cables

Times Microwave introduces its new Clarity™ series of 18, 26.5 and 40 GHz coax test cables. Clarity™ boasts steel torque, crush and overbend protection with abrasion resistance—while not compromising flexibility. The cable is ultra-stable through 40 GHz with exceptionally low attenuation. The design includes an ergonomic, injection molded strain relief and Times' new, SureGrip™ coupling nut to significantly improve the user's everyday experience. Clarity™ is appropriate for use as VNA test port extension, R&D lab, production test or system interconnect cables.
www.timesmicrowave.com

Cadence — Booth 511

Integrated IC/Package/Module Design Flow

The new Cadence® Virtuoso® RF Solution increases productivity and eliminates design failures caused by poorly integrated tools. It streamlines the RF design flow by using a single "golden" schematic to drive layout implementation, simulation and physical verification of the RF module while enabling simultaneous editing of multiple RFIC on the complex RF module. The environment also includes smart integration of electromagnetic (EM) analysis tools that automates hours of manual work required to run EM simulations.
www.cadence.com

EDI CON 2018 PRODUCT SHOWCASE

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OnScale — Booth 513

Solver-as-a-Service Platform

OnScale's Solver-as-a-Service Platform combines sophisticated Computer-Aided Engineering (CAE) Multiphysics solvers with the limitless power of cloud High Performance Computing (HPC) to remove performance and cost constraints of legacy CAE/HPC, reduce design cycles from months to weeks or even days and deliver unequalled solver performance that easily scales to meet ever-changing CAE workloads.

www.onscale.com

JFW Industries Inc. — Booth 517

4 Channel Attenuator Assembly

JFW model 50BA-032-31 SMA is a 4 channel attenuator assembly that covers 100 MHz to 18 GHz. Each RF channel consists of a solid-state programmable attenuator with attenuation ranging 0 to 31 dB in 1 dB increments. These attenuators can be controlled individually or as a group. This benchtop attenuator assembly is remotely controlled via Ethernet or RS-232 (GUI provided) and manually via momentary toggle switches on the front panel.

www.jfwindustries.com


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EDI CON 2018 PRODUCT SHOWCASE
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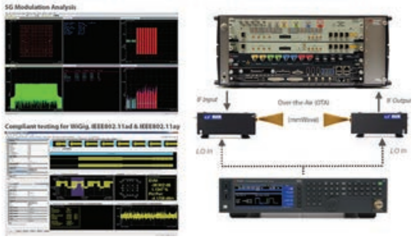
Guzik Technical Enterprises — **Booth 523**

10 GHz Wide Test Solution



The compact 10 GHz wide test solution includes Guzik ADP7104 10-bit Digitizer with Real-Time FPGA processor, Keysight M8195A Arbitrary Waveform Generator and VDI WR-15 compact up/down converters. 5G, WirelessHD, WiGig, IEEE802.11ad and IEEE802.11ay signal generation and analysis with Keysight software.

www.guzik.com

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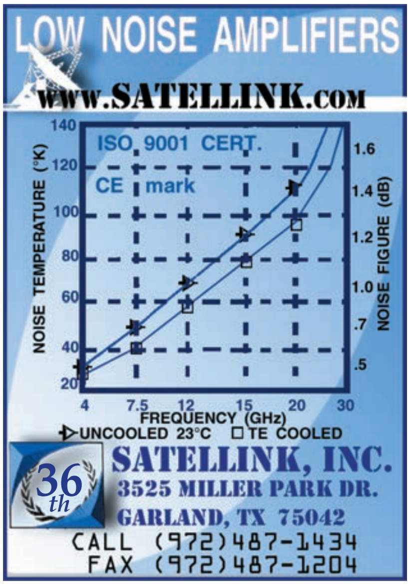
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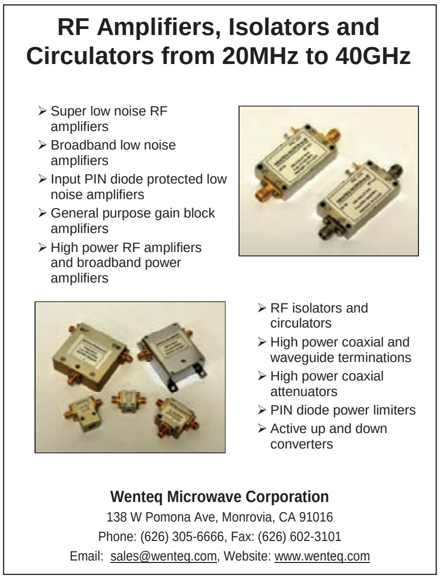
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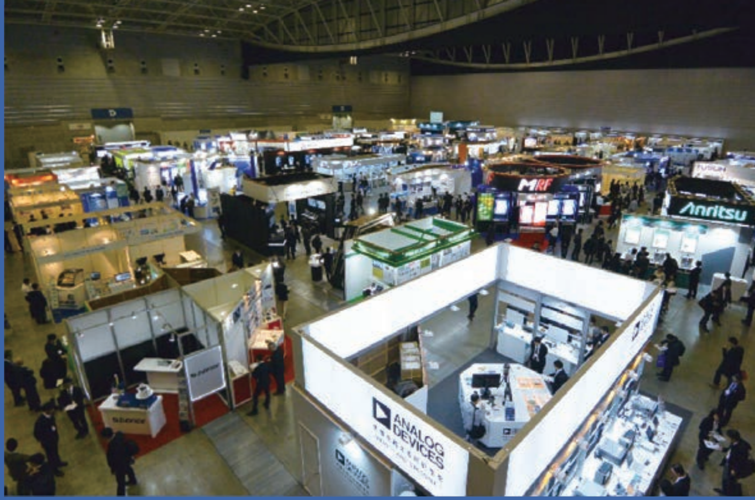

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- The largest Microwave Exhibition in Japan, which has been held every year since 1991, to support the microwave industry.
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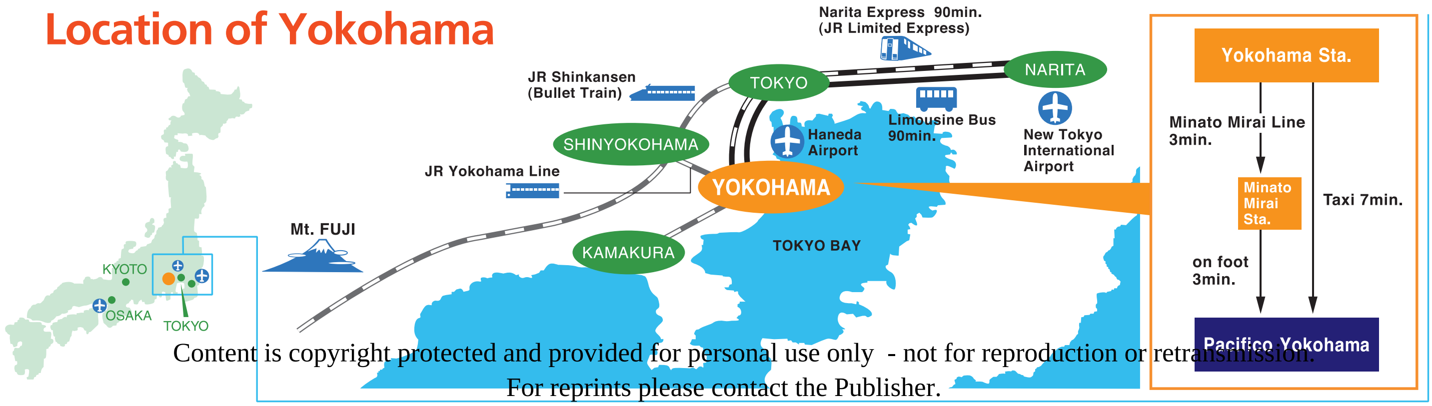
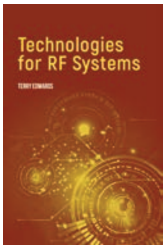
Location of Yokohama





Technologies for RF Systems

Terry Edwards

View Terry Edwards' "Top 10" RF technologies as part of *Microwave Journal*'s Microwave Basics eLearning resources at mwjournal.com/microwavebasics.

"This book introduces the concepts and pieces involved in RF engineering and microwave technology, offering engineers tips on design, circuitry, amplification, active electronics arrays, noise figures for cascaded blocks and more. Equations pack discussions that review practical applications and terms for understanding parameters, expressions and the fundamentals of RF system operations."

Midwest Book Review, July 2018

- Provides an introduction to the main concepts, technologies and components of microwave and RF engineering;
- Presents details about how to design various amplifiers, circuits and chips for communication systems;
- Offers insight into selecting appropriate ADC and DAC technology;
- Provides a summary of 21st century RF systems and electronics and discusses the challenges of frequency bands and wavelengths, software-defined radio (SDR) and cognitive radio.

Contents: 21st Century RF Systems and Electronics; RF Semiconductors; Passive RF Components; Passive RF Circuit Elements; Switches, Attenuators and Digital Circuits; Radio-Frequency Filters; Antennas; Small-Signal RF Amplifiers; Noise and LNAs; RF Power Amplifiers; RF-Oriented ADCs and DACs; Radio-Frequency Sources; Frequency-Band Conversion; Modulation Techniques and Technologies.

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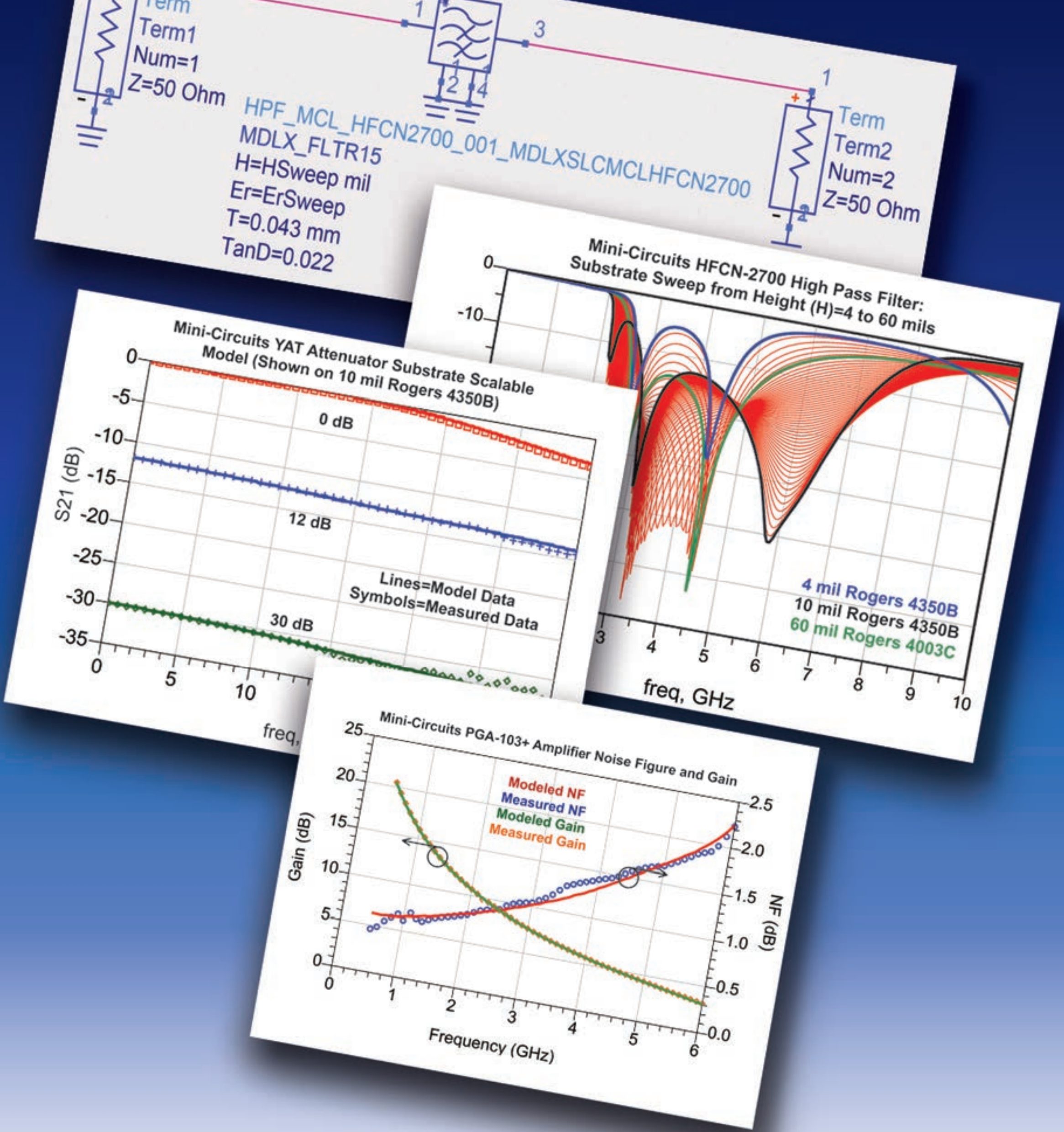

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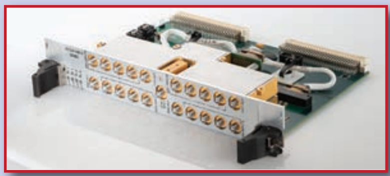
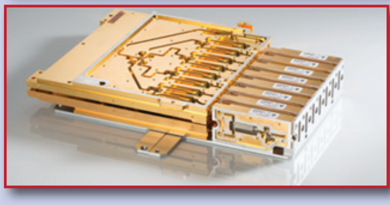


On a quiet street in Eatontown, New Jersey, inside an attractive yet nondescript building, is a quintessential example of the microwave industry and a testament to the health of American manufacturing. A unit of Cobham Advanced Electronic Systems, the 90 people working here primarily manufacture diode-based microwave components and subassemblies for U.S. and international defense programs—historically radar, now increasingly electronic warfare. The manufacturing capability, design knowledge and underlying technology in this building reflect decades of expertise by well-known microwave companies—Engelmann Microwave, KDI/Triangle, Aeroflex, Advanced Control Components—now, through the evolution of the industry, part of Cobham's Microelectronic Solutions business.

To support the low volume and high mix nature of the defense market, the Eatontown operation is organized into four value streams: receive protection, passive components, control components and multi-function assemblies. Receive protection products are, at their core, limiters that protect sensitive receivers from damage by high-power signals. Passive products include traditional Wilkinson power combiners/dividers and couplers fabricated in stripline. Control components comprise various configurations of PIN diode switches, some products incorporating control circuitry. Multi-function assemblies integrate several circuit functions to create complex circuits or subsystems such as switch matrices, synthesizers and up- and down-converters.

Each of the value streams has one or more dedicated manufacturing cells, and each cell is optimized for lean manufacturing, including the use of Kanban to manage work-in-process. The local Kanban work flows are supplemented with quality, safety and operational metrics, including Pareto charts of defects, so team members are fully apprised of the cell's performance and opportunities for continuous improvement. The assembly operators use online drawings, ensuring each production lot is built to the latest revision, and each part in an assembly is bar coded and recorded in a custom shop floor tracking system to ensure complete traceability.

The products built in Eatontown reflect classic microwave manufacturing techniques: machined housings integrating stripline, microstrip and chip-and-wire assemblies using softboard, alumina, aluminum nitride and diamond materials. While the low volume of most products does not justify automation, the facility has an automated wire bonder and plans to add an automated die bonder for the products that warrant it. An automated wire bond/die sheer tester provides statistical data to monitor the variability of the wire bond and die attach processes across all manufacturing cells. Seam sealing and laser welding hermetically seal the packages to ensure reliability in military environments. The operation has extensive automated test capabilities to streamline product testing and internal capabilities for all but a few environmental tests.

For the Eatontown operation, manufacturing is the core competency, and the product development process emphasizes design for manufacturability. Combining this manufacturing strength with a commitment to transparency and open communication with customers distinguishes the business unit in a crowded field of microwave component and subsystem suppliers. Many examples reflect the success of this approach. Citing one, a lean project with Raytheon to increase manufacturing capacity for components used in a key surveillance radar tripled capacity with only a 33 percent increase in staff. The project won a corporate award, judged the most impactful of all the continuous improvement projects submitted by Cobham business units that year.

On a quiet street in Eatontown, New Jersey, inside an attractive yet nondescript building, 90 people are dedicated to the success of the warfighter, maintaining the capabilities of the microwave industry and the strength of American manufacturing.

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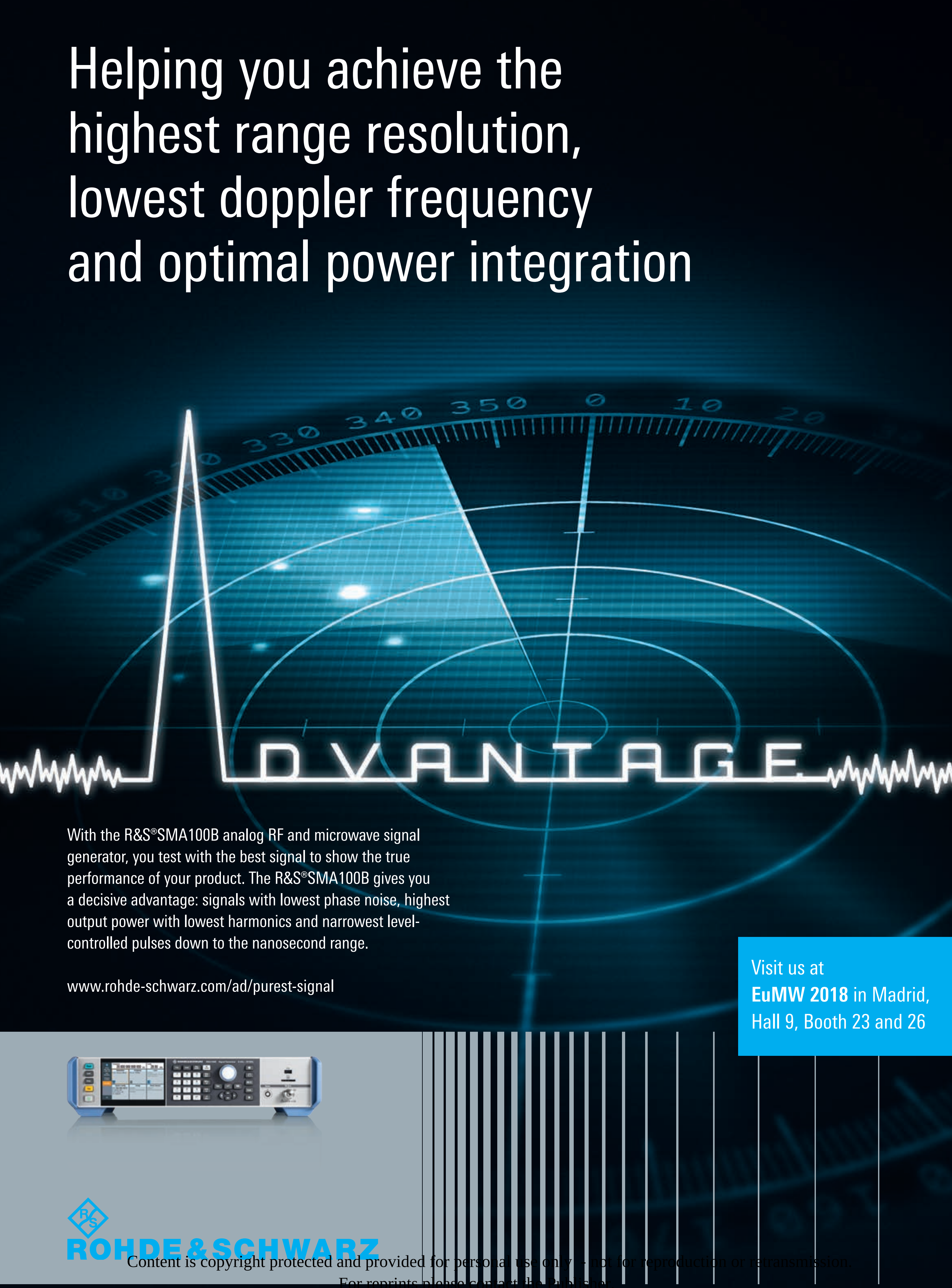
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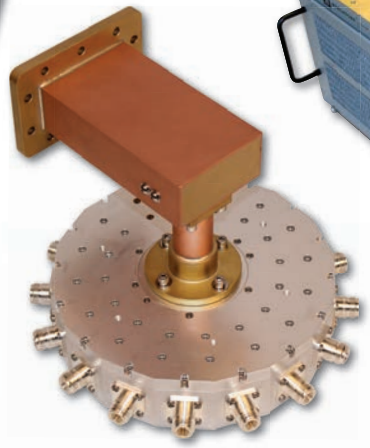

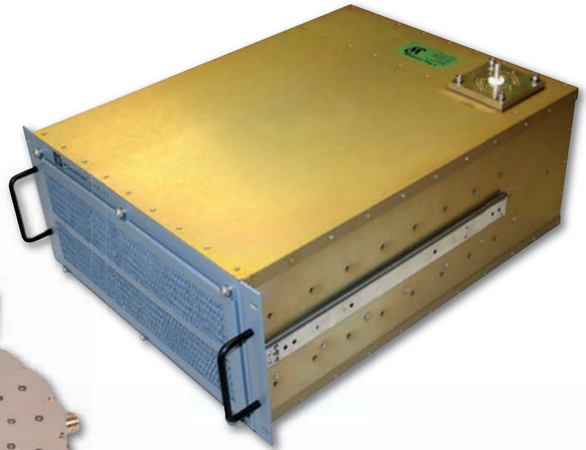

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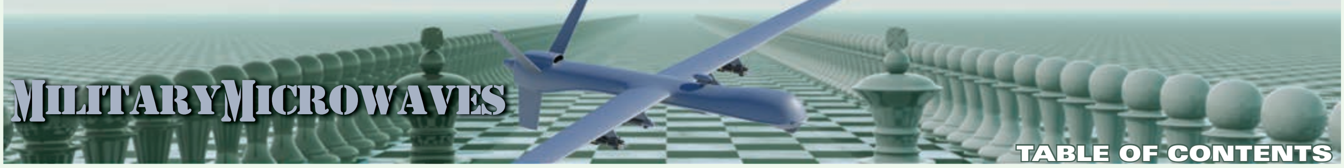

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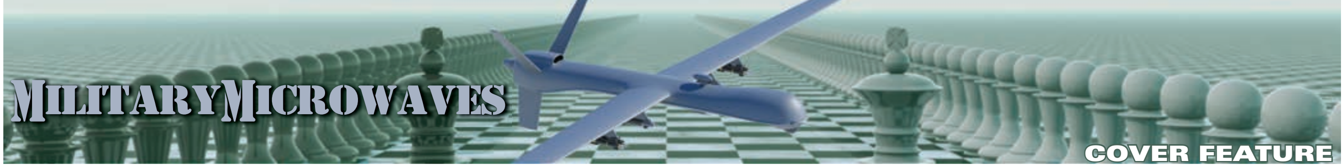

With Contributions From:
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Drone Detection and Counter Measures Take the World Stage

Patrick Hindle
Microwave Journal *Editor*

The commercial drone market is rapidly growing, making them widely available as a threat to security for both commercial and military institutions and gatherings. The recently reported drone attack in Venezuela is the first possible attempt to assassinate a government leader but shows how dangerous this threat is to open air speeches and public gatherings.

According to Global Market Insights, the commercial drone market in 2016 was more than 100,000 units with a market value of more than $2 billion and is anticipated to grow at around 25 percent CAGR through 2023. According to MarketsandMarkets, the overall drone market is expected to grow from $17.8 billion in 2017 to $48.9 billion by 2023, at a CAGR of 18.32 percent during the forecast period. The market research firm sees the driving factors as the increase in venture funding, rise in demand for drone-generated data in commercial applications and rapid technological advancements.

While the development of commercial UAVs has primarily been for video and photography, their capabilities are now being used in agriculture, real estate, construction, delivery and media. But civil drones that are used for non-military purposes bring vulnerability to cyber-attack and misuse. Hackers can take control of them for criminal activity, and terrorists can use them to deliver weapons so demand for detection and counter systems is growing rapidly. Two leading RF test & measurement companies leading the way in this market are Rohde & Schwarz and Aaronia. Each company has supplied details about their systems which we have consolidated here.

ROHDE & SCHWARZ— MEETING THE CHALLENGE OF DETECTING AND COUNTERING DRONES

In response to increasing demand from governmental authorities, ESG Elektroniksystem- und Logistik-GmbH, Diehl Defence and Rohde & Schwarz formed a partnership in 2015. The objective was to set a global benchmark for new drone detection and countering solutions. This cooperation resulted in the three companies creating GUARDION, an effective solution for detecting and countering drones. GUARDION has been successfully deployed at several events, such as the G7 summit in 2015, the G20 summit in 2017 and the ILA Berlin in 2018. Based on this early experience, the partners identified the following requirements as crucial for effective drone detection and countering:

- **Modularity, scalability and flexible system configurations:** Due to the broad range of potential scenarios, systems need to incorporate various sensors and countermeasures, be individually scalable to meet the requirements of both client and operations and provide deployment capabilities for manportable, vehicle-based, container-based and stationary platform integration.
- **Automatic and reliable multi-sensor detection and classification:** To minimize both operator interaction and the false alarm rate, systems must offer automatic detection and also classification of both drone and drone pilot, reliably differentiating drones from other flying objects.
- **Full-scale command and control system:** To improve shared situation awareness, systems must be equipped with a command and control (C2) platform providing a comprehensive operational picture, fusing all data from sensors and disruptors, showing all assets on a digital map and offering means of communicating this information among all forces, securely and in real-time.
- **Effective countermeasures:** To effectively tackle identified threat assessments, systems must provide a broad portfolio of multiple countermeasures targeting all common control mechanisms with minimal to no effect

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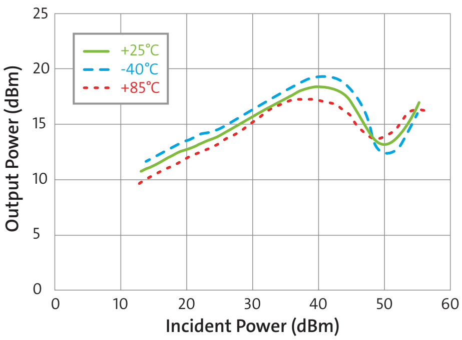

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Fig. 1 GUARDION is a field proven solution for detecting and countering drones available in mobile configurations.

Fig. 2 ESG's TARANIS® connects all sensors and disruptors.

on other uninvolved third parties within reach and optimized use cases for the national legal framework they are to be operated in.

Total System Solution

The three companies have combined their relevant solutions in the GUARDION system that consists of the following subsystems (see ***Figure 1***):

- ESG's TARANIS® C2 system
- R&S®ARDRONIS RF drone identification and countering system
- Diehl HPEMcounterUAS electromagnetic pulse sources

For technologies not covered by the alliance companies, they searched the market for the most suitable and reliable products from other suppliers. Their continuous and competitive market research included not only constant testing and portfolio development, but also active operation. The following summarizes the results in the areas of C2 (connectivity and interoperability, data fusion and situational awareness), multi-sensor (RF remote control analysis and DF, radar detection, acoustic recognition and camera verification) and multi-counter capabilities (smart


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▲ Fig. 3 The R&S®ARDRONIS remote control jammer can stop drones by interrupting the command signal.

RF control link disruption and high-power electromagnetic pulse).

Command and Control

Sophisticated C2 systems provide the advantage of connecting all subsystems, sensors and disruptors. ESG's TARANIS® makes particularly complex large-scale scenarios with multi-sensor setups and potential multiple threats more manageable (see ***Figure 2***).

Interoperability with national and international military command and control centers enhances communication and allocation of forces and facilitates their interaction and coordination, even in a dispersed or remote setup. Network-capable C2 systems allow crisis centers and mobile mission forces on the ground to assess, share and communicate relevant information securely and in real-time.

Data Fusion and Situational Awareness

The core intelligence must fuse and analyze all incoming sensor data, visualize the incoming drone and the threat location and track the movement of the drone pilot, own assets and security personnel in real-time. Ideally, all relevant additional geo-information from the scenario (grid reference, etc.) can be integrated and fed into the C2 system.

The C2 system displays all information on a comprehensive map-based situational picture, so a single operator can monitor and control the overall system. This improves situational awareness, enhances operators' capacity to launch and coordinate appropriate countermeasures ranging from organizational action to technical jamming to lethal deactivation.

RF Analysis and Direction Finding

Drones are usually remote controlled via a radio link. RF sensors can intercept these specific emissions that reveal the presence of a drone. The R&S® ARDRONIS system not only detects the remote control transmission, it also classifies the type of the drone and the manufacturer of the remote control unit signal (see ***Figure 3***). When using direction finders as RF sensors, it can also determine and visualize the direction or location of the remote controller. This is usually the location of the drone's pilot, which is often as important as the drone's position.

If the drone streams video or other data, RF sensors can also intercept these emissions. The systems can take bearings on the drone and visualize them on a digital map. With two direction finders, RF sensors can take cross-bearings, allowing them to calculate both the pilot's and the drone's geographic location. When demodulating/decoding the video downlink, they can view the content on the workstation or operator's laptop. Security personnel can then monitor what the drone pilot sees on their screen.

A main advantage of the RF sensor is that it receives the remote control link as soon as the remote controller is switched on. At this point, the drone is still on ground. Alerting security personnel even before the drone takes off is a benefit that only an RF sensor can provide. RF sensors detect the remote control link as soon as it is switched on and alerts operators early, before the drone becomes a threat.

RF sensors continuously scan all relevant frequency bands used by commercially available drones. Common frequency bands of drones' remote control are 2.4 and 5.8 GHz, but other bands are also possible, such as 433 MHz. The system allows individual configuration.

The detection range of a typical remote control unit with 100 mW output power is around 1.5 km, depending on the type of drone, the frequency band used, the transmission power, antenna height and other factors. Some drones use Wi-Fi technology, which allows them to be controlled via smartphone or tablet, though the remote control range is reduced. In this case, the radio control cannot be detected by analyzing the physical layer. It is necessary to analyze the WLAN protocol itself. Special RF sensors can detect and recognize these Wi-Fi signals from drones and also indicate the drone manufacturer.

RF sensors automatically analyze the intercepted signals. They can distinguish between the different manufacturers and even the type of the commercially available drones by comparing the detected emission with a profile library where typical technical parameters of commercial drone RF remote

▲ Fig. 4 Diehl's HPEM counter UAS immediately stops the drone intrusion.

controls are collected. Users can record unknown remote control transmissions to extend the system's signal library. This allows them to later recognize previously identified signal profiles.

Radar

Radar can detect distant objects and determine their position, speed and material composition. The main advantage is their wide range, but they do need line-of-sight with the target. For drones that are not controlled via RF data-links, radars are the primary sensor for drone detection and location.

GUARDION uses drone detection radar units specifically designed to meet the challenges of drone detection. Its antenna rotates at a speed optimized for high update rates in order to track targets while scanning and has a high signal-to-noise ratio to prevent false alarms. The preferred radar is an enhancement of FMCW radar that is widely used for detecting birds at airports. It is optimized for recognizing non-metal objects with small radar cross sections. With the implementation of special micro-Doppler technology and software algorithms, the X-Band radar is now optimized to recognize the rotating propellers on drones. This results in excellent distinction between drones and birds and other small flying objects. It also provides distance information for drones already detected with the RF direction finder and is able to detect and track multiple targets.

The radar covers the full 360 degree field of view in azimuth with 10 degrees in elevation. It can detect larger fixed wing targets at a range of up to 5 km and professional multi-rotor drones at up to 3 km with a classification range up to 1100 m. Typical commercial drones, such as the Phantom III, can be classified within a range of 700 m. An integrated PTZ camera allows instantaneous verification of detected drones.

Complementary Sensors

By cueing cameras and disruptors to the radar, operators can optically verify the presence and threat potential of detected objects before launching countermeasures and log video recordings to preserve evidence. With open system architecture, EO and IR sensors can be integrated as needed to meet the individual requirements of customers and scenarios. Examples include dome network cameras and surround cameras based on CMOS sensors as well as high performance sensors. However, advanced optical equipment and sophisticated algorithms are needed to support optical tracking and identification.

In urban scenarios, acoustic sensors are often used to cover the blind spots of the radar or RF sensors since they provide non-line-of-sight (NLOS) drone detection capability. If, for example, a building is blocking the view of primary radar sensors, an additional acoustic

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Fig. 5 Example Aaronia AARTOS system.

sensor behind the building can be used for coverage. Acoustic detection also lowers the overall system false alarm rate when used in combination with other detection sensors. As a passive sensor, the acoustic sensor has the advantage that it does not emit a signal. All flying systems produce specific sound patterns that are difficult to conceal. The sound patterns of drones are highly recognizable and completely different from the patterns of other flying objects.

The detection range of an acoustic sensor greatly depends on the size of the drone. A typical acoustic sensor used with the GUARDION system offers excellent detection and sensing capability based on advanced multi-microphone arrays. The system is able to scan the horizon by calculating time-of-flight differences in the acoustic patterns. These phased microphone arrays can extract the azimuth and elevation angle of incoming sound sources at distances of up to 500 m.

Disrupting the Drones Control Link

The R&S®ARDRONIS remote control jammer can stop drones by interrupting the command signals. If the drone loses its remote control signal, it usually goes into a fail-safe mode that causes it to land or return to its takeoff position. Jamming therefore prevents drones from entering a specific airspace.

The drones' remote control units usually use frequency hopping methods instead of fixed frequencies. Smart jammers follow these frequency hops and disrupt only those bursts that control specific drones. These jammers minimize the effect on other drones or radio transmissions in the same frequency band.

Wi-Fi controlled drones require a different method for countering. Once detected by the RF sensor, their network parameters are known. This allows systems to transmit a command that disconnects them from the remote control unit. This will force them into fail-safe mode, preventing the drone from continuing on its course.

Jamming is successful when the jamming signal is powerful enough to disrupt the RC signal when it arrives at the drone. This depends on many factors such as the distance between the antennas (and their height), the orientation of the antennas (especially the RC antenna), line-of-sight conditions, the presence of other strong signals in the area and environmental effects such as reflection and refraction.

Smart jammers need much less power than other types of jammers. The low power approach means jamming is possible at a distance about twice as far as the distance between the drone and the pilot's RC—under good line-of-site propagation conditions.

In waypoint mode, drones fly their course without a remote control signal. In this mode, they usually rely on a global navigation satellite system (GNSS). To stop the drones in such a case, a GNSS jammer can interrupt the reception of the weak satellite signals to prevent navigation. Directional antennas are used to direct interference signals toward the drone on the relevant GPS, GLONASS or Galileo frequencies.

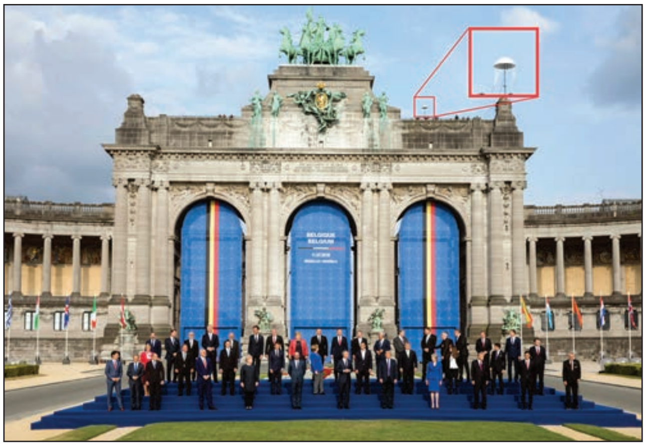

Fig. 6 AARTOS deployed at NATO Summit.

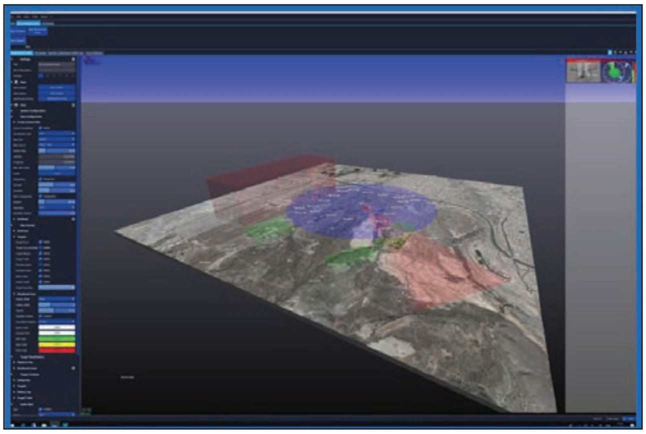

Fig. 7 Example Topographic View map.

High-Power Electromagnetic Pulses

High-power electromagnetic (HPEM) pulses are a new generation of disabling technology for countering drones. Developed and manufactured by Diehl, the HPEM disruptor disables the drone's ability to fly—a last resort measure (see ***Figure 4***). Unlike other systems based on jamming the drone's remote control links or navigation aids, the HPEM source directly impacts the semiconductors of the control electronics on the printed circuit boards inside the drones by means of electromagnetic pulses high enough in power to disable their operation. HPEM is effective in all flight modes, whether flying autonomously or radio-controlled, the drones become inoperable upon impact of HPEM pulses. There is no time delay. HPEM systems offer scalable ranges and can simultaneously eliminate the threat of entire swarms of mini-drones. HPEM systems are capable of disabling the drone's control electronics, regardless of the control method. The system immediately stops drone intrusion. The Diehl HPEM counter UAS does not cause harm to individuals and is approved for use in civil areas.

AARONIA AARTOS—PROTECTING THE WORLD STAGE

After four years of development, Aaronia recently introduced its newest drone detection system—the AARTOS DDS. It is used to detect the incursion of unwanted drones, based on the directional real-time measurement of the electromagnetic emissions of the drone and its remote control. It warns the operator when drones are in the area and sends alerts.

The Aaronia AARTOS systems (see ***Figure 5***) are in use by various govern-


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ment agencies, police departments and military to protect high value critical national infrastructure and personnel or strategically important sites/events. These include nuclear power stations, borders, political or VIP events, airports and airbases. In 2017, over 50 systems had been deployed, and as of July 2018, Aaronia has received more than 300 new orders, so the system is selling very well.

In July 2018, Aaronia announced that the Belgium Police selected the system to protect the 2018 NATO summit from the growing threat posed by UASs. Multiple AARTOS systems have been used and positioned in locations such as the roof of the NATO headquarters and on top of the Triumphal Arch in Brussels Jubelpark (see ***Figure 6***), the place where the NATO delegation had dinner. This contract with the Belgium Police followed the successful mission deployment of multiple AARTOS systems during the U.S./North Korean Summit in June 2018.

According to the company, the AARTOS system can detect, track, identify and defeat a drone in approximately 3 seconds at a range of up to 15 km or 9 miles (a special airport version has a reported range up to 50 km). AARTOS even detects multi-band drones using RF detection in real-time before using a RF jammer to defeat the drone. A fully integrated, long range auto target tracking camera backs up the RF detection and is used to verify the drone type and payload.

Using Aaronia AARTOS Sector Jammer Solutions, the operator can effectively take control of a drone and force a safe landing. The AARTOS system is military grade, designed and proven to operate in harsh environments. It works in all weather, day or night and the disruption is flexible, proportional and operator controlled.

Hardware

The drone detector is based on the Aaronia IsoLOG 3D antenna, a real-time Spectrum Analyzer (XFR V5 PRO, RR or RF Command Center) and special software plug-in for the RTSA Suite software. These combined subcomponents provide a system solution that allows 24/7 monitoring and recording with a gapless data-streaming. The system saves considerable measurement time and is compact and flexible. The AARTOS Drone Detector gives an alarm as soon as a remote control is on the air, so even before the drone is in the airborne. Countermeasures can therefore be initiated at an early stage even prior to takeoff.

One of the newest additions to the AARTOS DDS is the optional Visual Detection System—a fully integrated optical and thermal drone detection solution, working in unison with the RF detection mechanisms of the AARTOS Drone Detection System. The optional system enables the user to actually see detected drones even at long distances and makes it possible to identify potentially dangerous modifications to the drone, such as attached explosives.

The single site solution is ready to use within a few minutes. Based on a stationary or mobile spectrum analyzer and the 3D direction finding antenna IsoLOG 3D, this solution is a good choice for surveillance of smaller areas like a single building or structure. The multi-solution consists of several antennas (IsoLOG 3D) and analyzers (Spectran V5 Rugged

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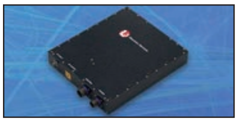

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Rack), coupled together to one centralized monitoring PC which manages all systems simultaneously. The advantage of the multi-solution is the possibility to triangulate the signals. This leads to a very high tracking accuracy. The multi-solution can combine an unlimited number of receivers so can protect very large areas such as industry plants, stadiums, government complexes, etc.

Software

The system has an AI-based complex RF classification capability including a database displaying emitter type, brand, weight, payload, etc. No operator is required as the system is fully automatic. It has simple and easy to use GUI that is continually updated and improved. The scalable software is able to handle even very complex multiple-site systems (e.g., countrywide solution) with flexible integration into third party software.

The system can display 2D and 3D maps. The most commonly used drone detection view is the 2D View from a simple top-down perspective. It is clearly structured, easy to understand and navigate, very similar to some map-solutions that offer satellite images. The 3D View expands the 2D View by allowing the altitude information of the drone to be displayed visually, when using multiple drone detection systems. In addition, the 3D space makes it easier to see the distances between different objects on the map. Even more sophisticated than the 3D View, the Topographic View can load the height information of the surrounding terrain, making hills, mountains, peaks and valleys visible (see ***Figure 7***). Combined with the 3D-Building system, the Topographic View creates the most accurate representation of the surrounding area.

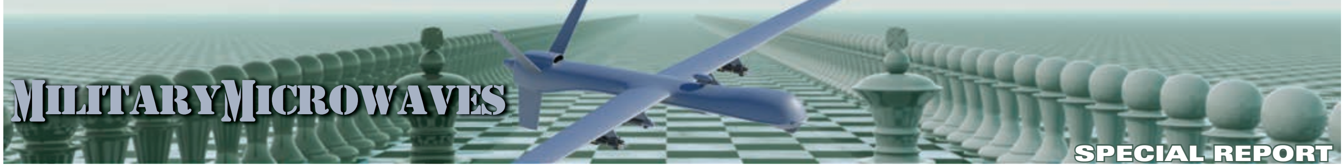
Drone Protection

The system can be extended by a jammer that can effectively prevent RF contact to a drone to force it into the fail-safe mode, e.g., to land or hover. The interference is very selective so that other RF channels are not impaired. Besides the selectivity, the jammer is highly directional and only jams in the direction of the incoming UAV. Of course, the AARTOS Counter-Measure Solutions can only be sold to entities that have proper government permits for the deployment of jammers.

Aaronia has many improvements planned such as integration with radar and night-vision systems. They plan to offer RF mapping and extending the range to 50 km plus AI-based optical classification and a smart watch solution.

SUMMARY

There are many drone detection and countering systems on the market from various companies ranging from startups to defense contractors to RF test & measurement companies as the commercial drone market has expanded rapidly and represents a serious threat to security of institutions, government buildings, utilities, stadiums and more. Rohde & Schwarz and Aaronia are two of the RF test & measurement companies leading the field in this area with their expertise to monitor, detect, identify and counter drone systems as they use their expertise in spectrum analysis to form the core of a complete solution using other subsystems.■



INVITED PAPER

Strong Defense Outlook Offers Continued Growth for RF Technologies

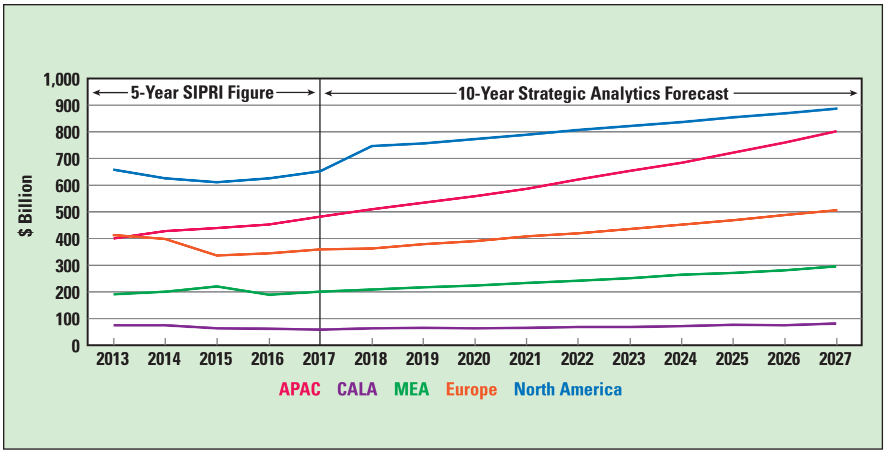
Asif Anwar
Strategy Analytics, Newton, Mass.

The defense sector has been a technology incubator for RF technologies for decades. This article explores the latest market forecasts from Strategy Analytics and how spending on military systems will dictate demand for RF technologies such as GaN.

Strategy Analytics forecasts global defense spending will continue to grow, driven by force modernization requirements and political intent in the U.S., Western European and other advanced nations. A need to counter both resurging conventional threats from near-peers, coupled with ongoing asymmetric wars against non-state or pseudo-state actors, will drive military equipment and capability and support procurement opportunities for the defense industry supply chain to a forecast of $827 billion, part of the projected $2.58 trillion global defense budget in 2027 (see ***Figure 1***).

The U.S. will remain the largest defense market in the world. Strategy Analytics' model forecasts U.S. defense spending will grow to $866.6 billion in 2026. The emphasis by the Trump administration to renew U.S. leadership across the world was reflected in the fiscal year (FY) 2018 budget and has been further cemented by the most recent FY 2019 budget request: $686 billion for the U.S. DoD with a number of major warfighting investments across airborne, naval, ground and space platforms and systems (see ***Figure 2***). This will maintain momentum behind the U.S. defense industry, sustaining growth for major suppliers like Boeing, General Dynamics, Lockheed Martin and Raytheon, as well as the enabling technology supply chain epitomized by companies such as Microsemi, Qorvo, Teledyne and Wolfspeed.

Globally, an emphasis on improved capabilities at the system level will drive demand for military radar, military communications and electronic warfare (EW), and capabilities will continue to provide opportunities for enabling technologies such as GaN.



▲ Fig. 1 Global defense spending outlook, by region.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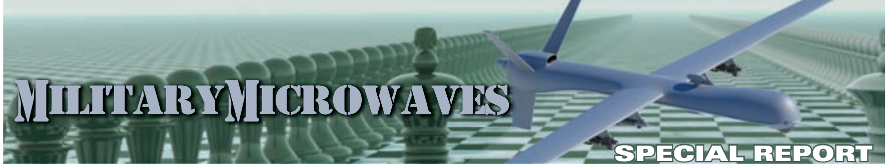

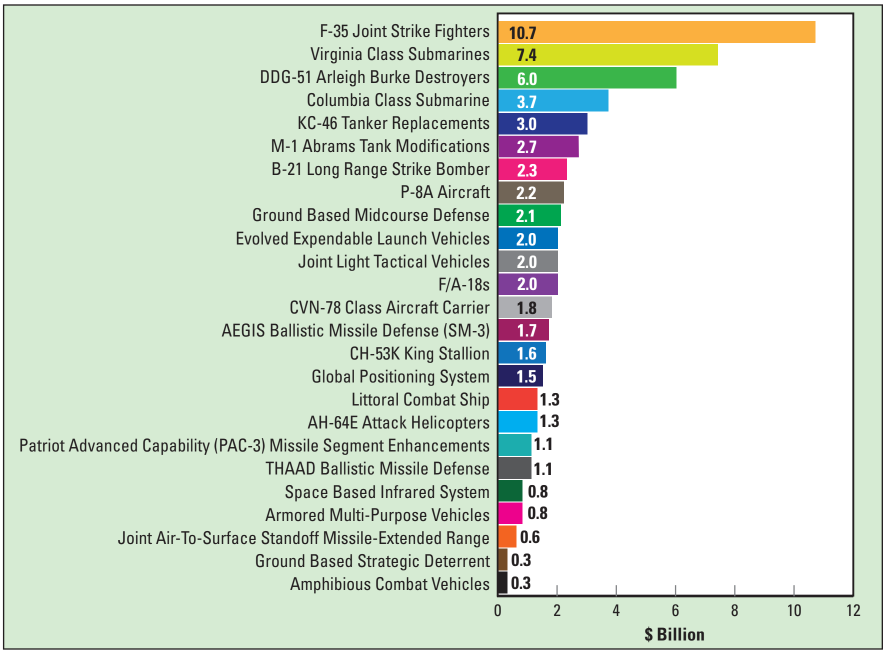

▲ Fig. 2 Major U.S. defense program investments in FY19.

RADAR

Active electronically scanned array (AESA) architectures enabled using GaN and GaAs semiconductor technologies will continue to underpin radar systems and serve to catalyze military radar market growth through 2027. Strategy Analytics Advanced Defense Systems service's forecasts for the global military radar market, covering expenditure as well as system shipments across the land, air, sea and space domains, projects the global military radar market will grow at a compound average annual growth rate (CAAGR) of 4.6 percent over the 2017 to 2027 timeframe to be worth over $21.5 billion.

Suppliers of military radar systems are increasingly implementing AESA architectures at the core of their product offerings, highlighting advances in performance as well as lifecycle and total cost of ownership advantages over traditional radar designs. An AESA radar comprises a large number of transmit-receive modules that feed and collect multiple signals via an antenna array. Potential advantages of an AESA architecture include high beam steering agility, very low radar signature when illuminated and extremely low side lobes. Being able to digitally control transmit-receive module gain allows for refined power management, which is vital for reduced or low probability of intercept (RPI, LPI) operation. Beam steering agility also facilitates reduced or low probability of intercept scan patterns. From an operational perspective, the implementation of AESA architectures in military radar systems enables improvements in system reliability and reductions in total cost of ownership. Use on fast jet platforms is often cited as a good example where these metrics are best exemplified with mean time between failures being improved significantly from the 300 hours typically cited for conventional radar systems. Coupled with "graceful degradation," where a radar system continues being functional even as individual transmit-receive modules fail, means that aircraft can stay operational with repairs being performed alongside the regular maintenance schedule of the platform.

The core enabling semiconductor technologies for AESA architectures have typically been GaAs-based, but as GaN technology has matured, the defense industry has looked to GaN as the new core enabler for AESA-based military radar. GaN offers the advantages of increased power, efficiency and robustness to improve the performance of land-, air- and sea-based military radar systems. This does not mean that GaAs technology will no longer be used, any more than it would be unwise to suggest that there will no longer be demand for vacuum tube-based RF transmitters. However, GaN does arguably offer the added flexibility of being able to displace GaAs, other RF semiconductors and vacuum tube technologies as the RF transmitter source in radar systems. With these advantages, GaN is becoming a key enabling

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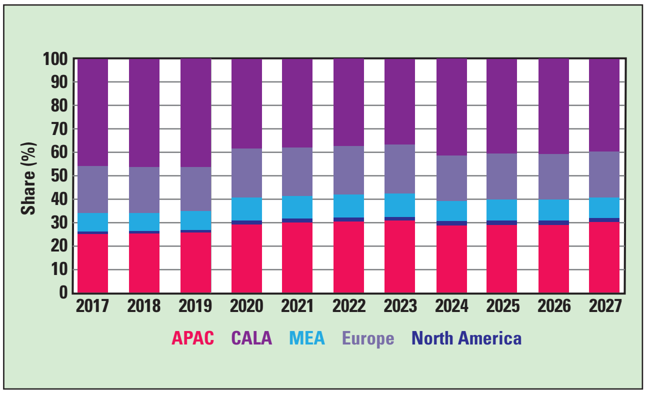

Fig. 3 Forecast share of the military radar market, by region.

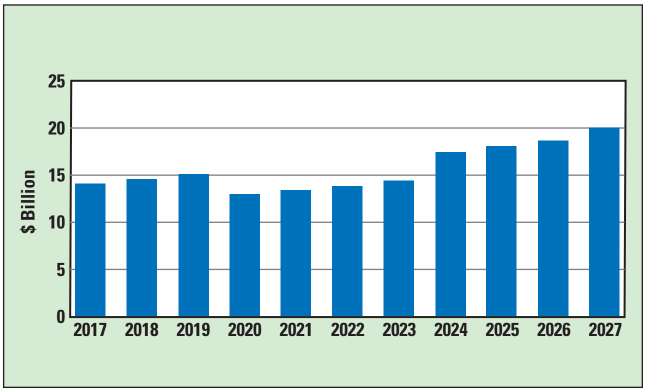

Fig. 4 Global EW market forecast.

technology and military radar demand for GaN is forecast to grow at a CAAGR of 19 percent through 2027.

Strategy Analytics also predicts:

- North America will continue to represent the largest regional end market, but the fastest growth will come from demand in the Asia-Pacific region (see ***Figure 3***).
- Airborne radar will represent the largest market, both in dollars and total shipments.
- Early warning, surveillance and fire control radars will account for around 76 percent of the global military radar market.
- L-, S- and C-Band will represent the largest market, followed by radars operating at X-Band, which reflect the primary frequencies used by surveillance, early warning and fire control radars.
- The total number of radar shipments is forecast to grow at a CAAGR of 4.6 percent through 2027 to reach 1,607 units. Fire control radar and early warning and surveillance radar shipments will account for 48 percent of 2027 military radar shipments.
- The associated market for semiconductors and other components will grow from $2 billion in 2017 to reach $5 billion in 2027.

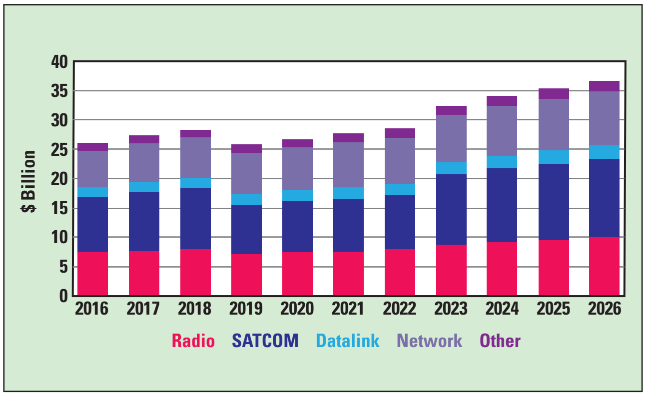

Fig. 5 Global military communications market outlook, by segment.

EW

Operational requirements to establish freedom of action in contested and congested environments, as well as the ability to counter modern agile radar and communications will drive opportunities for the EW market. There is a renewed

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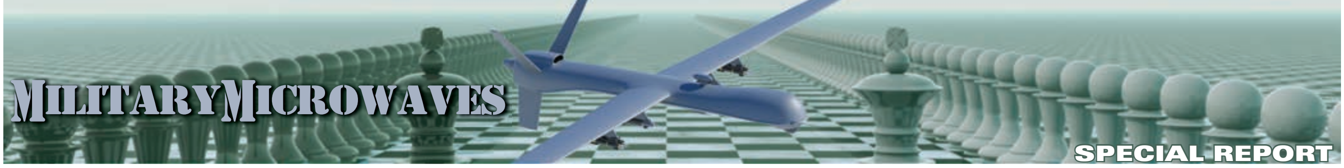

push to upgrade conventional EW capabilities that support anti-access/anti-denial (AA/AD) strategies. This will be coupled with the ongoing requirement to combat asymmetric threat scenarios. Future systems will employ wideband solid-state semiconductors to enable artificial intelligence (AI)-based machine learning algorithms to provide cognitive analysis of the threat environment. EW will play an important role in tackling the increasing complexity that comes with operating in a spectrally constrained environment.

Companies providing systems and enabling technologies will need to focus on solutions that employ wideband materials, such as GaN, and AESA architectures to enable machine learning-based cognitive analysis, planning and countermeasures activity that can either augment or circumvent the traditional threat library.

Strategy Analytics forecasts the global EW market will grow to $20 billion by 2027 (see ***Figure 4***). The associated market for semiconductors and other components for RF-based EW systems will grow at a CAAGR of 8.4 percent through 2027. Future EW program will increasingly use GaN, making this semiconductor technology a staple ingredient in EW systems. This will be coupled with requirements for direct and faster digital synthesis of RF signals across the full frequency spectrum.

COMMUNICATIONS

Military communications operate under an umbrella of heterogeneous networks that enable the provision of interoperable voice, video and data services across a global environment, segmented according to security policies, transmission requirements and the individual needs of the end user. In terms of the networked battlespace, this can be summarized as:

- Upper level networking, consisting of infrastructure and networking components.
- Mid-level networking providing high capacity backhaul.
- Support to the tactical edge for end-users and sensors.

Similarly, 5G serves as an aggregator technology that encompasses a range of network types and technologies to serve traditional voice, video and data requirements to the end user, as well as enabling capabilities for connectivity across devices, including vehicles, machines, sensors and devices.

Phased arrays, beamforming, mmWave frequencies, SATCOM, GaN, duplex communications and shared spectrum access are among the crossover technologies that will become common across both commercial and military communications.

Communicating voice, data and video simultaneously and securely over wider and higher bandwidths in an increasingly complex spectrum environment will underpin the trends in military communications system design and supporting components, including software-defined architectures, solid-state technologies such as GaN, radio-satellite communications and integration with wireless networks.

Strategy Analytics forecasts spending on global military communications systems and services will grow to over $36.7 billion in 2026, a compound annual growth rate of 3.5 percent (see ***Figure 5***).

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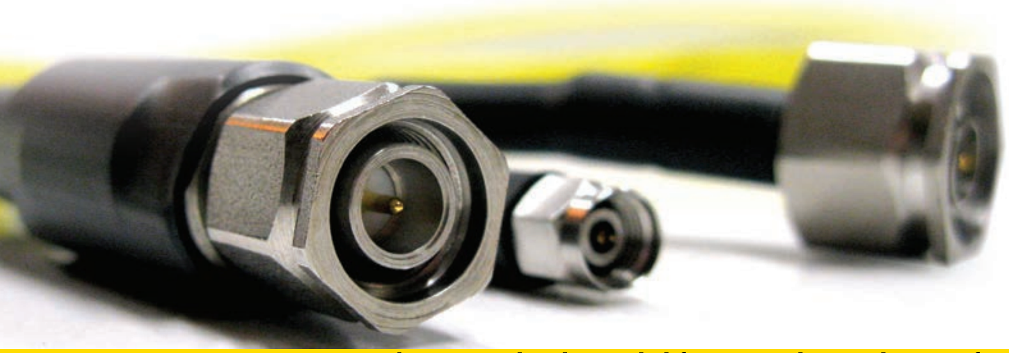

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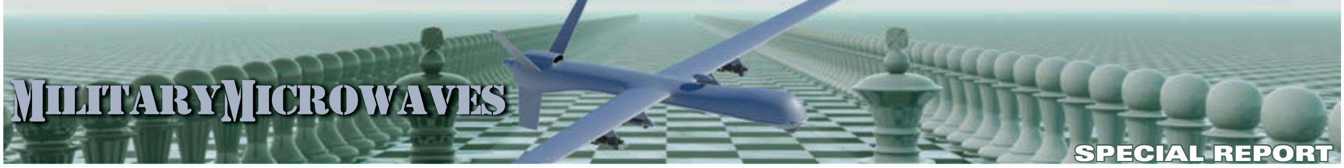
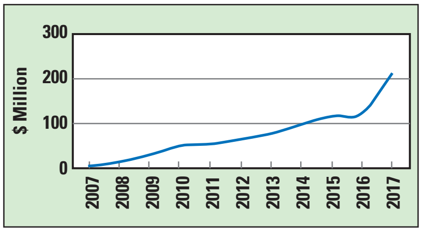




▲ Fig. 6 Historic defense system demand for RF GaN.

RF GaN GROWTH

Demand from military radar, EW and communications applications will provide the primary drivers for GaN market adoption, and this will be coupled with ongoing demand from the rollout of commercial wireless infrastructure. RF GaN market growth continued to accelerate in 2017, with revenues growing at over 38 percent year-on-year.

The military radar segment will remain the largest user of GaN devices for the defense sector. Substantial production activity in AESA radars for land-based and naval systems, in particular, is driving increasing demand for RF GaN, as many systems in development move to production. RF GaN demand from the military sector grew by 72 percent year-on-year in 2017, and this will grow at a CAAGR of 22 percent through 2022 (see ***Figure 6***).

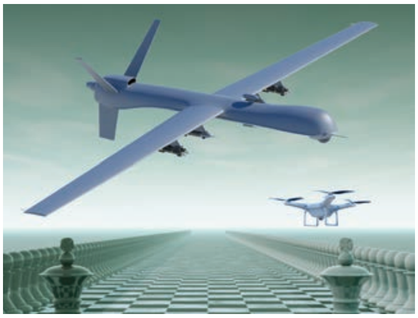
As highlighted earlier, operational requirements to operate in contested and congested environments, as well as the ability to counter modern agile radar and communications, will drive opportunities for RF GaN from the EW market. Communicating voice, data and video simultaneously and securely over wider and higher bandwidths in an increasingly complex spectrum environment will underpin trends in military communications system design and associated component demand, also increasingly favoring RF GaN.

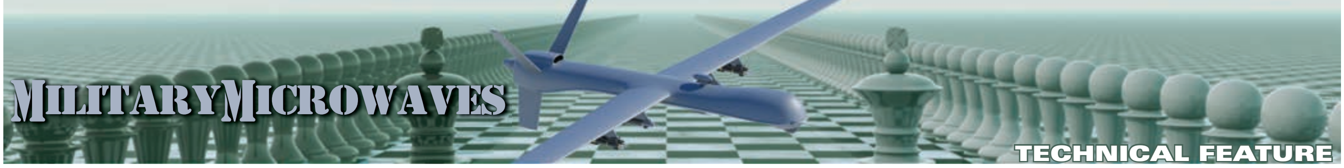
Strategy Analytics forecasts that the total RF GaN opportunity will cross the $1 billion barrier by 2022, with defense sector demand slightly greater than commercial revenue at that time.

CONCLUSIONS

As countries look to maintain a mix of both conventional and leading-edge capabilities, to counter both symmetric and asymmetric threats, global defense spending is forecast to reach $2.6 trillion by 2027. The emphasis on improving capabilities at the system level will drive demand for military radar, EW and communications systems and provide growth opportunities for enabling technologies such as GaN.

Companies will need to be able to "scale, integrate, incorporate and disrupt" to differentiate themselves in addressing the challenges and opportunities in the defense sector, as well as exploiting adjacent market growth opportunities benefiting from these same capabilities.■





INVITED PAPER

Beamforming ICs Simplify Phased Array Antenna Design

Keith Benson
Analog Devices Inc., Norwood, Mass.

Radar systems and wireless communications are facing increasing demands on antenna architectures to improve performance. Many new applications will only be possible with antennas that consume less power in a lower profile than traditional mechanically-steered dish antennas. These requirements are in addition to the desire to reposition quickly to a new threat or user, transmit multiple data streams, operate over longer lifetimes and meet aggressive cost targets. Some applications require nulling an incoming blocking signal and having low probability of intercept. These challenges are met with active electronically scanned array (AESA) designs that are sweeping the industry. Past disadvantages of phased array antennas are being addressed with advanced semiconductor technology, to reduce the size, weight and power of these solutions. This article describes existing antenna solutions and where AESAs have advantages. It will then discuss how semiconductor advancements are helping achieve the goals of improving SWaP-C, including examples of commercial technology making this possible.

Wireless electronic systems relying on antennas to send and receive signals have been operating for over 100 years. They continue to be improved as accuracy, efficiency and more advanced metrics become increasingly important. In past years, a dish antenna was widely used to transmit and receive signals where directivity was important, and many of those systems still work well at a relatively low-cost, reflecting years of optimization. These dish antennas with a mechanical arm to rotate the direction of radiation do have some drawbacks: slow to steer, physically large, poorer long-term reliability and only one desired radiation pattern or data stream. As a result, engineers have pushed toward advanced phased array antenna technology to improve these aspects and add new functionality. AESAs are electrically steered and offer numerous benefits compared to traditional mechanically-steered antenna, such as low profile with less volume, improved long-term reliability, fast steering and multiple beams. With these benefits, they are being adopted in military, SATCOM and 5G telecommunications applications, including connected automobiles.

PHASED ARRAY TECHNOLOGY

A phased array antenna is a collection of antenna elements assembled together, such that the radiation pattern of each individual element constructively combines with neighboring antennas to form an effective radiation pattern, called the main lobe. The main lobe transmits radiated energy in the desired location, while the antenna is designed to destructively interfere the signals in undesired directions, forming nulls and side lobes. The antenna array design maximizes the energy radiated in the main lobe, while reducing

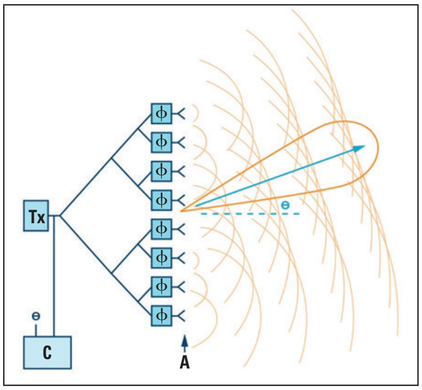


Fig. 1 Phased array concept.

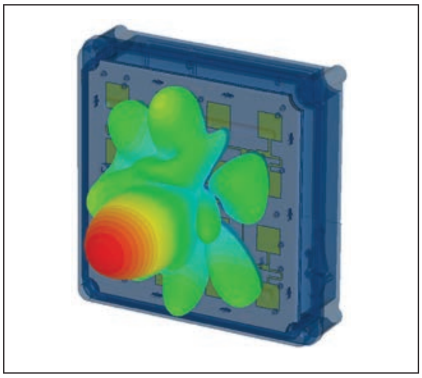


Fig. 2 Radiation pattern of a 4 x 4 element array.

the energy radiated in the side lobes to an acceptable level. The direction of radiation can be manipulated by changing the phase of the signal fed into each antenna element. ***Figure 1*** shows how adjusting the phase of the signal to each antenna in a linear array can steer the effective beam in the desired direction. Each antenna in the array has an independent phase and amplitude setting, which enables forming the desired radiation pattern.

Fast steering of the beam in a phased array is easily understood, since there are no mechanical moving parts. Semiconductor-based phase adjustments can be made in nanoseconds, such that the direction of the radiation pattern can be changed to respond to new threats or users quickly. Similarly, it is possible to change from a radiated beam to an effective null to absorb an interferer, making the object appear invisible, as would a stealth aircraft. These changes to reposition the radiation patterns or create effective nulls occur almost instantaneously because the phase settings are changed electrically with ICs, rather than mechanically.

An additional benefit of a phased array over a mechanical antenna is the ability to radiate multiple beams simultaneously, perhaps to track multiple targets or manage multiple data streams of user data. This is accomplished by digital signal processing of the multiple data streams at baseband frequencies.

The typical implementation of an AESA uses patch antenna elements configured in equally spaced rows and columns with a 4 × 4 design, equaling 16 elements (see ***Figure 2***). Antenna arrays built from multiple 4 × 4 cells can grow quite large, e.g., more than 100,000 elements in ground-based radar systems.

There are design trade-offs with the size of the array versus the power of each radiating element, which determine the directivity of the beam, effective radiated power and other parameters. Antenna performance can be predicted from some common figures of merit: antenna gain, effective isotropic radiated power (EIRP) and Gt/Tn. The relationship among these is defined by the following equations:

$$\text{Antenna Gain}(Gt) = \frac{\text{Radiation Intensity in Desired Direction}}{\text{Radiation Intensity of Isotropic Antenna (all angles)}} = 10\text{Log}N + Ge$$

where N = the number of elements and Ge = element gain.

$$EIRP = Pt * Gt$$

where the total transmitter power $Pt = 10\text{Log}N + Pe$ and Pe = the power per element.

$$\frac{Gt}{Tn} = \frac{\text{Antenna Gain}}{\text{Noise Temperature}}$$

where $Tn = [\text{Noise Factor} - 1] * \text{Temperature}$.

The antenna gain and EIRP are directly proportional to the number of elements in the array. Achieving high EIRP can lead to the large arrays seen in ground-based radar applications.

Another key aspect of phased array antenna design is the spacing between the antenna elements. Once we have determined the system goals and set the number of elements, the physical diameter of the array is largely driven by the limit that each unit

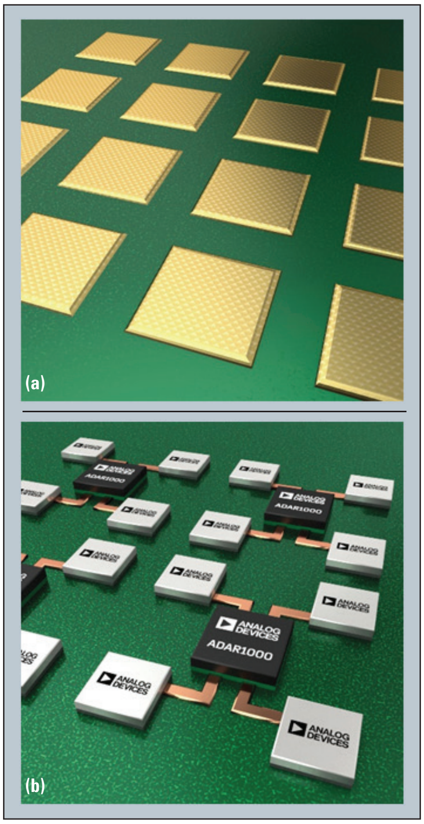


Fig. 3 Flat panel array with the antenna patches on the topside of the PCB (a) and RFICs on the backside (b).

cell should be less than approximately a half-wavelength, to prevent grating lobes or energy radiated in undesired directions. This puts strict requirements on the electronics in the array, i.e., to be small, low-power and low weight. The half-wavelength spacing creates particularly challenging designs at higher frequencies, where the length of each unit cell becomes smaller. This drives the ICs at higher frequencies to be increasingly integrated, with packaging solutions that become more advanced and with simplified—though increasingly challenging—thermal management techniques.

Constructing the entire antenna poses many challenges for the array design, including control lines routing, power supply management, pulsed circuitry, thermal management and environmental considerations. A major push in the industry is toward low profile arrays that consume less volume and weight. The traditional "plank" architecture uses small PCB planks with electronics, fed perpendicularly into the backside of the antenna PCB. This approach has been improved over the past 20 years to continually reduce the size of the plank and the depth of the antenna.

Next-generation designs move from this plank architecture to a flat panel approach, where there is sufficient integration in each IC for them to fit on the backside of the antenna board, significantly reducing the depth of the antenna and enabling it to fit into portable or airborne applications. ***Figure 3*** illustrates the flat panel approach, with the gold patch antenna elements on the topside of the PCB and the analog front-end feeding the antenna on the bottom side of the PCB. This shows only a subset of the antenna. A frequency conversion stage could be on one end of the antenna, and a distribution network routing from a single RF input to the entire array.

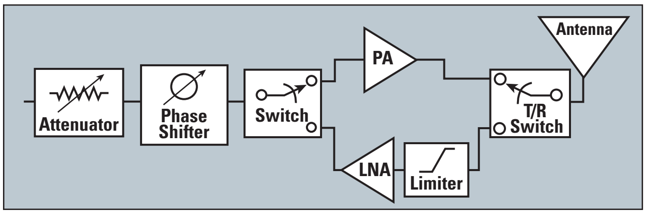
More integrated ICs significantly reduce the challenges in the antenna design. As the antenna becomes smaller, requiring more electronics be packed into a reduced footprint, more advanced semiconductor technology is needed to keep the architecture viable.

DIGITAL VS. ANALOG BEAMFORMING

Most AESAs that have been designed in past years use analog beamforming, where the phase adjustment occurs at the RF or IF frequencies, with only one set of data converters for the entire antenna. There is increased interest in digital beamforming, which uses one set of data converters at each antenna element, with the phase adjustment done digitally in the FPGA or data converter. Digital beamforming offers many benefits, starting with the ability to easily transmit many beams or change the number of beams almost instantly. This remarkable flexibility is attractive in many applications, which is driving adoption. Continuous improvements in the data converters—lowering power dissipation and expanding to higher frequencies, e.g., RF sampling at L- and S-Band—are making this technology a reality in radar systems.

Choosing between analog and digital beamforming requires multiple considerations, with the analysis usually driven by the number of beams required, power dissipation and cost targets. With a data converter at each element, the digital beamforming approach typically has higher power dissipation but offers flexibility in creating multiple beams. The data converters in digital beamforming must have greater dynamic range, since the beamforming that rejects blockers is done after digitization.

Analog beamforming can support multiple beams, however, it requires an additional phase adjustment channel per beam. Creating a 100-beam system, for example, multiplies the number of RF phase shifters by 100 compared to a sin-



▲ Fig. 4 Typical RF front-end for a phased array antenna.

gle beam system. So the cost tradeoff between data converters and phase shifter ICs will depend on the number of beams required by the application.

Similarly, power dissipation is usually lower for an analog beamforming architecture that uses passive phase shifters; as the number of beams increases, the power dissipation will increase if additional gain stages are needed to drive the distribution network. A common compromise is hybrid beamforming, with sub-arrays of analog beamforming followed by digital combining of the sub-array signals. This is an area of growing interest and will continue to evolve.

SEMICONDUCTOR TECHNOLOGY

A standard pulsed radar system transmits a signal which eventually reflects off one or more objects. The radar waits for the return pulses to map the field of view of the antenna. In prior generations, the radar front-end (see ***Figure 4***) would use discrete components, likely fabricated in GaAs. The front-end comprises a phase shifter to adjust the phase of each antenna element and steer the antenna, an attenuator to taper the beam, a power amplifier (PA) to increase the power of the transmit signal, a low noise amplifier (LNA) to boost the receive signal and a switch to toggle between transmit (Tx) and receive (Rx). In past implementations, each of these ICs could be in a 5 mm × 5 mm package; more advanced solutions would have an integrated, single channel GaAs MMIC to achieve this functionality.

The recent proliferation of phased array antennas has been enabled by advances in semiconductor technology. The advanced nodes in SiGe BiCMOS, silicon on insulator and bulk CMOS enable the digital circuitry, used to control the steering of the beam, to be integrated with the RF, which performs phase and amplitude adjustment, in a single IC. It is possible to achieve multi-channel beamforming ICs for gain and phase adjustment, from four channels for lower frequency systems to 32 channels for mmWave designs. In some lower power applications, a silicon IC can monolithically integrate all these functions. In high-power applications, GaN PAs have significantly increased the power density sufficiently to fit into the unit cell of a phased array antenna, which traditionally would have been served by traveling wave tube (TWT) PAs or lower power GaAs PAs.

In airborne applications, the trend is toward flat panel architectures adopting the power-added efficiency (PAE) benefits of GaN technology. GaN has also enabled large ground-based radars to move to AESAs from traditional dish antennas driven by TWTs. Monolithic GaN ICs are capable of delivering greater than 100 W of power with over 50 percent PAE. Combining this level of PAE with the low duty cycle of radar applications enables surface-mount solutions to be feasible, greatly reducing the size, weight and cost of the antenna array. An additional benefit beyond the pure power capability of GaN is the size reduction compared to existing GaAs MMIC solutions. A GaN PA replacing a 6 to 8 W GaAs PA at X-Band reduces

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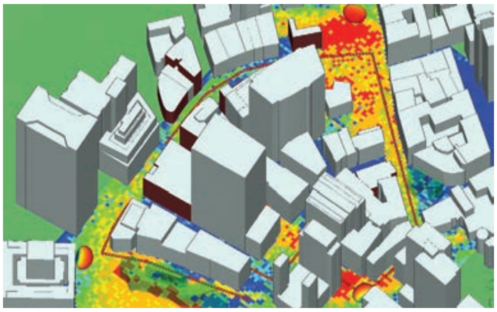

Beamforming with massive MIMO (top) shows significant improvement to throughput over links between single antennas (bottom)

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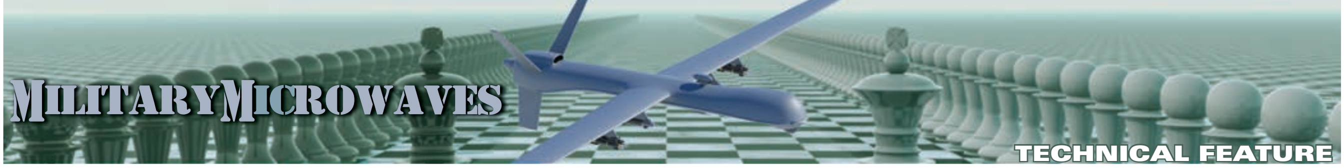
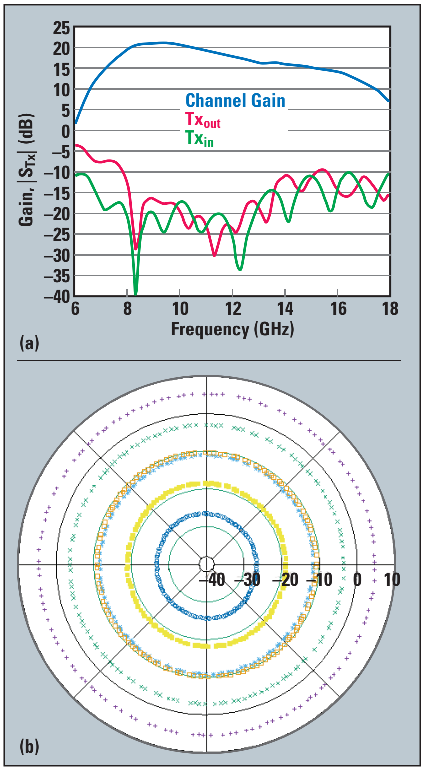


the footprint by 50 percent or more—very significant when trying to fit the electronics into the unit cell of a phased array antenna.

ANALOG PHASED ARRAY ICs

Analog Devices, among other companies, has developed integrated analog beamforming ICs aimed at a range of phased array applications, including radar, SATCOM and 5G. As one example of current technology and capability, Analog Devices' ADAR1000 X-/Ku-Band beamforming IC covers 8 to 16 GHz, which makes it well-suited for X-Band radar and Ku-Band SATCOM applications. The four-channel device operates in time-division duplex mode, with the Tx and Rx integrated into a single IC, which can be configured to operate in Tx- or Rx-only mode. The four channels are integrated in a 7 mm × 7 mm QFN surface-mount package, compatible with integration into flat panel arrays. The IC dissipates only 240 mW per channel in Tx mode, 160 mW per channel in Rx. The Tx and Rx channels are designed to mate with a front-end module, such as those offered by Analog Devices.



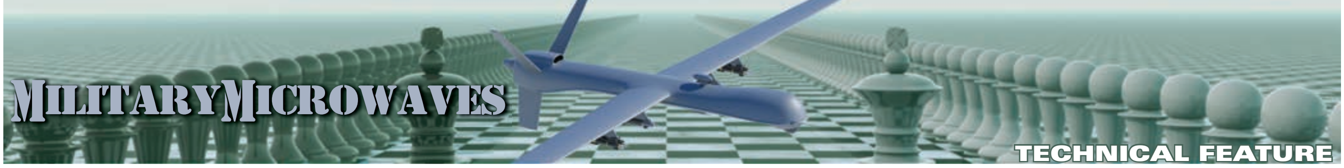
▲ Fig. 5 Transmit channel gain and match (a) and phase and gain control contours (b) of the ADAR1000 at 11.5 GHz.

Figure 5 shows the ADAR1000's gain and phase performance. It provides full 360 degree phase coverage with phase steps less than 2.8 degrees and greater than 31 dB gain control. The device contains on-chip memory to store up to 121 beam states, where one state contains all the phase and gain settings for the entire IC. The transmitter delivers approximately 15 dBm of saturated output power with 19 dB gain. Receive gain is approximately 14 dB. Phase variation with gain control is approximately 3 degrees over 20 dB of gain control range. Similarly, the gain variation with phase control is approximately 0.25 dB over the entire 360 phase coverage. This tight distribution simplifies array calibration.

SUMMARY

The availability of beamforming ICs is accelerating the adoption of analog and hybrid phased array architectures. Complementary improvements in front-end PA/LNA/switch modules, frequency conversion, data converters and digital signal processing are transforming the AESA, improving the performance and SWaP-C of military systems and enabling their use for commercial SATCOM and wireless systems applications.■





A Monolithic U-Band InP HBT Stacked Power Amplifier With On-Chip Active Biasing

Xiangmin Li and Zhuang Kang
Yangtze University College of Arts and Sciences, Jingzhou, China
Liang Jia
University of Electronic Science and Technology of China, Chengdu, China

A monolithic U-Band, stacked InP heterojunction bipolar transistor (HBT) power amplifier (PA) demonstrates a saturated output power of 26 dBm, a compact chip size of 0.88 mm × 0.67 mm and a maximum power-added efficiency (PAE) of 28.7 percent at 52 GHz. Its output power density of 670.1 mW/mm^2 is higher than other reported U-Band HBT PAs. An active biasing topology is used to enhance PAE and linearity.

PAs play an important role in wireless systems, not only because they are principal drivers of system performance, they also consume large amounts of prime power while generating heat and producing noise and interference.[1-3] High efficiency PAs are especially vital for portable devices because of limited battery capacity.

The solid state III-V compound semiconductor HBT leverages material properties for high efficiency PA applications; however, its low collector-emitter breakdown voltage (BV_{CEO}) is a major drawback. Methods proposed to overcome this include:

- A stacked topology: high speed device for a common emitter (CE) and a high breakdown device for a common base (CB) to generated high gain and high output power.[4]
- A CB topology[5-6] to increase the voltage swing to obtain high output power, because the collector-base breakdown voltage is higher than the collector-emitter breakdown voltage.
- Passive network compensation[7] to increase the effective collector-emitter breakdown voltage.

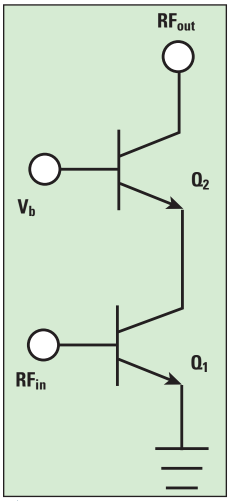
In this article, we describe a fully matched, stacked PA MMIC with an active bias circuit using only high speed HBTs. It is small in size, exhibiting a 670.1 mW/mm^2 output power density and 28.7 percent PAE. To our knowledge, this is the highest output power density demonstrated by an InP HBT PA.

InP HBT STACKED CONFIGURATION

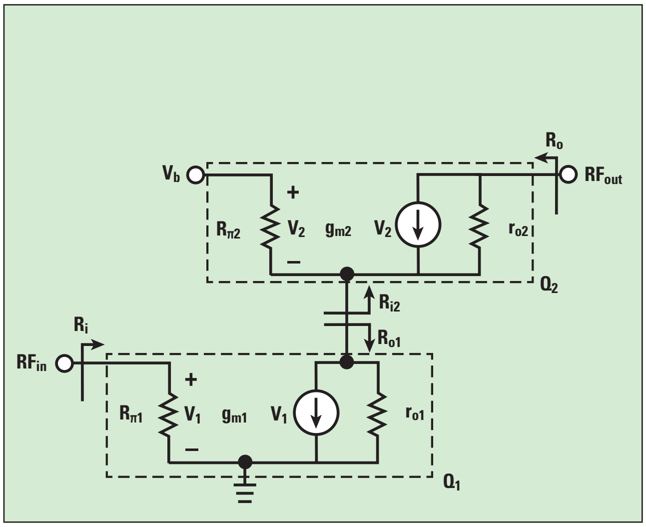
The stacked structure, comprised of a CE with high speed HBTs and a CB with high breakdown voltage HBTs, is generally used because the collector-base breakdown voltage is higher than the collector-emitter breakdown voltage. Generally, the peak current density for the high speed HBT is 2 to 10× greater than that of the high voltage devices. Because the collector current of both HBTs should be the same, the emitter area of the high voltage HBTs is several times larger than that of the high speed HBTs.

TABLE 1
HBT CHARACTERISTICS

Device	f_T (GHz)	BV_{CEO} (V)	J_C @ Peak f_T (mA/μm²)
HS HBT	421	3.7	5
HV HBT	157	8	1



▲ Fig. 1 Stacked HBT PA with two transistors.



▲ Fig. 2 Small-signal equivalent circuit for transistors Q_1 and Q_2 in the stacked configuration.

Table 1 shows high speed and high voltage HBT characteristics for the 0.5 μm InP HBT process. The 8 V BV_{CEO} of the high voltage HBT is helpful for high output power, but the peak current density is 5× smaller than that of a high speed HBT, requiring a 5× larger emitter area. So the output power, PAE and output power density of the high speed HBT are higher than those of the high voltage HBT with the same emitter area. In this work, we use only high speed HBTs for the cascode configuration, to reduce MMIC size and simultaneously maximize PAE and output power.

The U-Band stacked PA is designed using a commercial 0.5 μm InP HBT process. The schematic of the two-stacked PA is shown in ***Figure 1***. ***Figure 2*** shows the small-signal equivalent circuit of transistors Q_1 and Q_2 in the stacked configuration of Figure 1. The output resistance looking into the collector of Q_1 is given by

$$R_{o1} = r_{o1} \tag{1}$$

and the input resistance looking into the emitter of Q_2 is

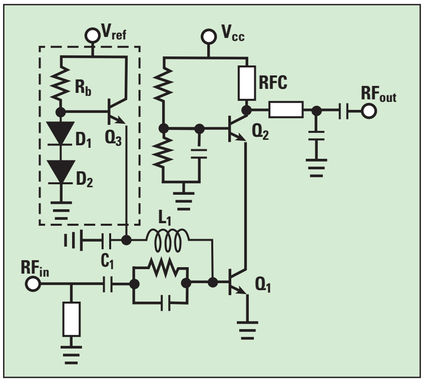
$$R_{i2} = r_{e2} = \frac{1}{1+\beta_2} r_{\pi2} \approx \frac{r_{\pi2}}{\beta_2} \tag{2}$$

The voltage gain for the first stage is given as

$$A_{v1} = g_{m1}\left(R_{o1} \| R_{i2}\right) \approx \frac{g_1}{g_{m2}} \tag{3}$$

The total output resistance of the cascode structure is given as

$$R_{o1} \approx r_{o2}\left(1 + \frac{g_{m2} r_{o1}}{1 + \frac{g_{m2} r_{o1}}{\beta_2}}\right) \tag{4}$$



▲ Fig. 3 Single stage, cascode U-Band PA.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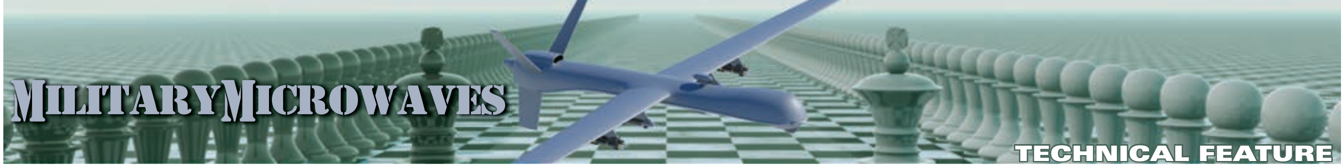
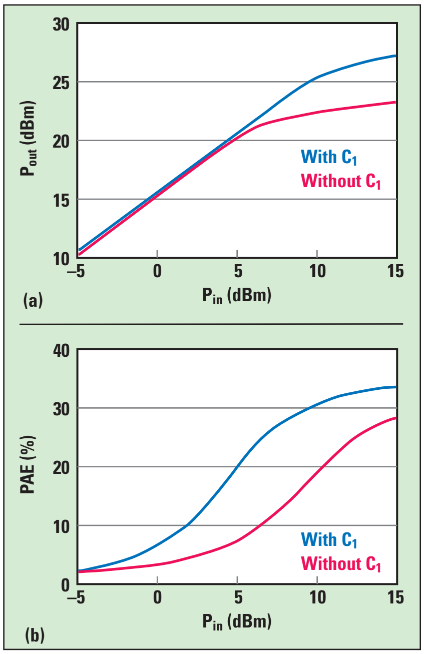


Since $g_{m2}r_{o1} >> \beta_2$ and $\beta_2 >> 1$, Equation 4 can be simplified to

$$R_{o1} \approx r_{o2}\beta_2 \quad (5)$$



▲ Fig. 4 Simulated output power (a) and PAE (b) of a U-Band PA at 52 GHz, showing the effect of C_1.

The total transconductance of the stacked structure is given by

$$G_m = g_{m1} \quad (6)$$

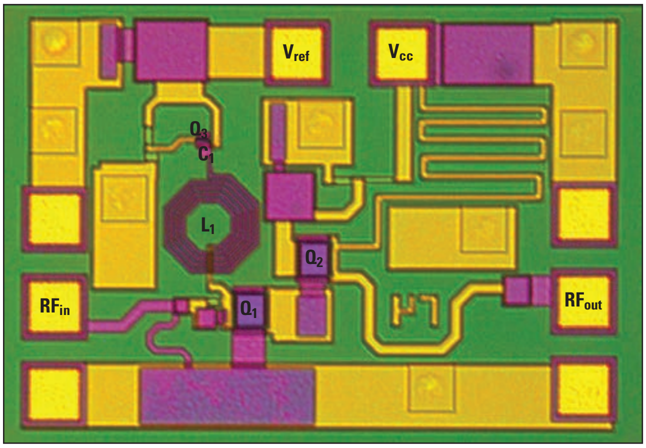
From Equations 5 and 6, the total voltage gain A_v for the cascode structure can be expressed as

$$A_v \approx G_m R_o \approx g_{m1} r_{o2} \beta_2 \quad (7)$$

Through Equation 7, it can be shown that the maximum available voltage gain of a stacked pair is higher by a factor β_2 than for the case of a single transistor. In addition, the stacked configuration helps to minimize the Miller effect and improves the isolation between the input and output of the amplifier.

U-BAND PA DESIGN

The unit emitter area of the high speed HBT is 0.5 × 10 μm^2. For a cascade active core, 18 fingers (18 × 0.5 × 10 μm^2) are used for both the CE (Q_1) and CB (Q_2) transistors (see ***Figure 3***). To regulate the DC bias current of Q_1 over process, temperature and DC supply variations, Q_3, D_1 and D_2 form a voltage compensation bias network at the base of Q_1. The active base bias transistor, Q_3, employs eight fingers of a high speed HBT (8 × 0.5 × 10 μm^2). Input and output matching circuits are composed of MIM capacitors and on-chip microstrip with top thick metal lines. For compact size, spiral inductors are not used in the matching circuits.



▲ Fig. 5 Fabricated U-Band PA MMIC.

The output power of the n-stacked PA can be expressed as[4]

$$P_{out} = n^2 \frac{(V_{ce} - V_k)^2}{2R_{opt\_PA}} = \frac{n^2}{2} I_d^2 R_{opt\_PA} \quad (8)$$

where n is 2 for this PA. R_{opt_PA}, V_{ce}, V_k and I_d are the optimum output load impedance, collector-to-emitter voltage, knee voltage and DC supply current, respectively. R_{opt_PA} is

$$R_{opt\_PA} = nR_L = n\frac{\Delta V}{\Delta I} = n\frac{V_{ce} - V_k}{I_d} \quad (9)$$

where R_L is the load impedance of each stacked transistor. From Equation 9, R_{opt_PA} increases with R_L. Since the DC currents across each transistor of the stacked PA are all the same, the output power can be enhanced by stacking the transistor.

A constant base voltage has been suggested for obtaining both high output power and high efficiency in an HBT PA.[8] To achieve this for Q_1, the simulated minimum inductance value of L_1 is 3 nH; however, a high L_1 inductance increases the size of the PA MMIC. Alternatively, a shunt capacitor, C_1, is used to reduce the MMIC size by lowering the value of L_1. Based on a load-pull simulation, two-section LC elements are designed for the output matching network. A one-section LC element is employed for the input matching network of the stacked PA, and an RC network is added to the base of Q_1 for circuit stabilization.

Figure 4 shows the simulated output power (P_{out}) and PAE of the U-Band PA at 52 GHz with and without capacitor C_1. For the simulation, 0.8 nH for L_1 and 0.1 pF for C_1 are used. Without C1, RF leakage to the bias transistor Q_3 would cause a voltage drop through the base and emitter in the negative direction, resulting in a base voltage increase for Q_1 with increasing input power. The increased collector current of Q_1 would then unnecessarily lower the P_{out} and PAE of the power amplifier in the high output power region.

MEASURED RESULTS

The fabricated U-Band PA MMIC (see ***Figure 5***) contains input and output matching circuits, an active bias circuit and probing pads and is laid out in an 0.88 mm × 0.67 mm (0.59 mm^2) area. The PA MMIC is biased with V_{cc} = 5 V and V_{ref} = 2.5 V and draws a quiescent current of 120 mA. ***Figure 6*** shows the measured small-signal performance of the PA from 45 to 60 GHz. The measured linear gain is about 14.2 dB at 52 GHz, with more than 35 dB isolation. At 52 GHz, the measured 1 dB compression output power (P_{1dB}) and saturated output power (P_{sat}) are 21.2 and 25.97 dBm, respectively, as shown in ***Figure 7a***. The measured PAE versus input power is shown in ***Figure 7b***. At 52 GHz, the peak PAE is 28.7 percent. The measured performance of the U-Band PA is in good agreement with the simulation shown in Figure 4.

A comparison of U-Band InP HBT PAs is shown in ***Table 2***.[9-11] The output power density of 670.1 mW/mm^2 is the highest demonstrated for an InP HBT PA.

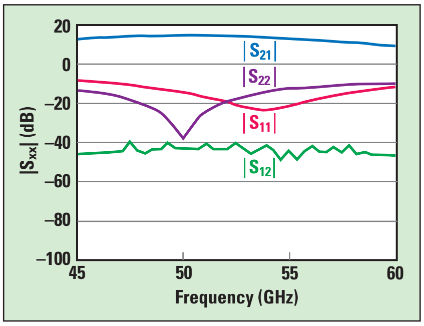


Fig. 6 Small-signal performance of the U-Band PA MMIC.

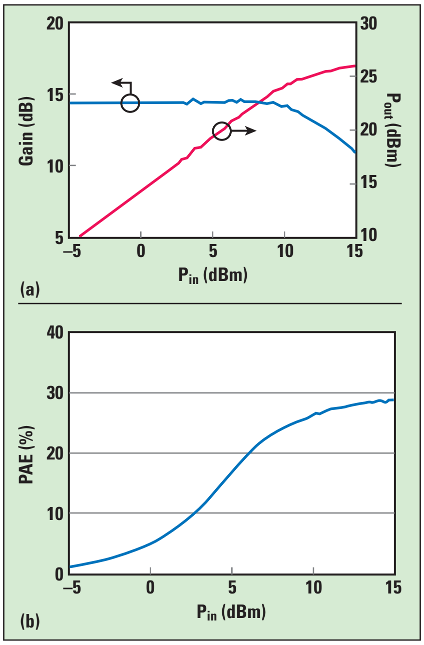


Fig. 7 Measured gain and output power (a) and PAE (b) vs. input power.

TABLE 2
U-BAND InP HBT MMIC POWER AMPLIFIERS

P_{sat} (dBm)	P_{DC} (W)	PAE (%)	Size (mm²)	P_{out} Density (mW/mm²)	Reference
25.97	0.86	28.7	0.59	670.1	This work
26.7	0.47	23.4	1.06	441.26	9
21.4	0.433	36	0.51	270.6	10
23.1	0.8	30.2	0.67	304.74	11

CONCLUSION

A compact U-Band PA with an on-chip active bias circuit using a commercial 0.5 μm InP HBT process has been demonstrated. The fully matched PA MMIC exhibits an output power density of 670.1 mW/mm^2, which, to our knowledge, is the highest value reported for a U-Band InP HBT PA.■

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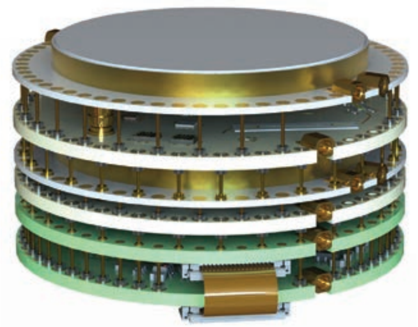

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Andover, Mass.

We all know of large, precision-guided weapons. Weighing about 3000 lb and with a unit price over $1 million, the latest-generation cruise missiles can be launched from the safety of a ship and travel over 1000 miles with the necessary precision to minimize collateral damage. They include advanced electronics such as datalinks, radar altimeters, inertial guidance and digital processing. These large, precision-guided weapons give the U.S. and allied forces a significant advantage—the long range keeps the operators away from harm, while the high precision reduces the risk of collateral damage. They represent the culmination of decades-long technology development and, while ideal for delivering large payloads, the existing technologies are heavy and expensive.

The options for surgical precision at the infantry level are far fewer, leading to the emerging need for extremely compact munitions that contain the technology for precision guidance. Commonly referred to as "smart bullets," these precision-guided munitions require a new breed of RF and digital electronics that is not only compact, but modular enough to support a wide range of applications. Developing a precision-guided capability small enough to fit into a munition that weighs less than 0.1 percent of a cruise missile, for a fraction of the cost, requires a new approach built from the ground up. This requirement for smaller precision-guided munitions is forcing the defense electronics industry to find novel ways of building extremely compact, low-cost systems. To amortize development costs and reduce production time, a standard electronics architecture that supports a variety of applications is required. This framework must include extremely dense integration, high-reliability and a modular design. Instead of racks of sensor and processing hardware, all of the electronics must be small enough to fit into the palm of a hand and be as easy to upgrade as removing and replacing a circuit card.

STACK OF QUARTERS

To address these requirements, Mercury Systems is developing a novel architecture that incorporates its expertise with compact hardware, dense integration, modular design and high-reliability. The SpectrumSeries™ Compact Multi-Band Platform combines multiple board layers using a solderless, high-reliability approach. With a diameter as small as 25 mm, six layers can be combined with a total height also about 25 mm. Using pin-and-socket interconnects, the technology-agnostic solution combines surface-mount technology (SMT) boards, alumina substrates, chip-and-wire assembly, hermetic ceramic cavities and printed antennas. This flexible architecture provides the framework for a variety of applications, such as a simple single input/output radio or a complex monopulse radar with integrated patch antenna.

As new applications require smaller electronics, it becomes more challenging to maintain a modular design. However, a modular approach is key to reducing development time through technology re-use and ensuring a future-proof system through easy upgrades. By making changes to a limited number of design elements, a modular product can easily be redesigned to accommodate a different frequency band or use an improved component. This approach enables the most cutting-edge products, since it is possible to incorporate the rapid technology growth from Moore's Law.

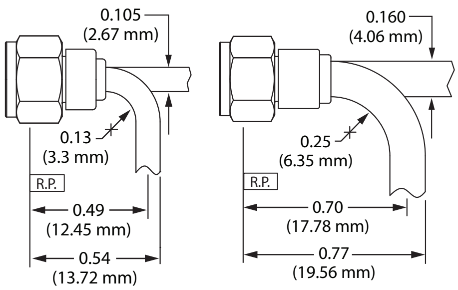
ArcTite®

Ultra-low profile bends

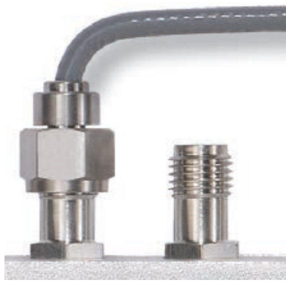
ArcTite® cable assemblies provide ultra-low profile bends without the need for supplemental strain relief boots. ArcTite® utilizes a unique 360° internal solder termination for high reliability and enhanced shielding effectiveness.

- Ultra-low profile height of 0.54 inch (13.7 mm)
- No strain relief required
- Replaces higher cost, lower performance right angle solutions
- Retains performance in bent condition
- Ideal for high density packaging
- Available in 0.086 and 0.141cable sizes
- DC-40 GHz

ArcTite 086 **ArcTite 141**



ArcTite® assemblies maintain electrical performance even after bending...ensuring optimal reliability in high density applications...without the need for supplemental strain relief boots.



Learn more at **www.dynawave.com**

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(978) 469-0555
info@dynawave.com

dynawave®

single path to optimal performance

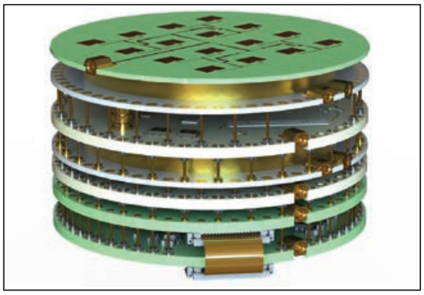
To achieve this modular design framework, the SpectrumSeries Compact Multi-Band Platform consists of multiple, compact layers that are individually manufactured and tested, then easily combined with solderless contacts. By formalizing the interconnection between layers, the designer can use a variety of technologies. Sensitive chip-and-wire components are placed in hermetic packages—a technology that has been proven on multiple programs and is small enough to fit on a single layer. This high performance, low loss approach uses bare die and wire bonds. Vias and hermetic feedthroughs on the bottom of the package provide high frequency connections to the rest of the module and outside world. Control and digital components are placed on SMT boards that use standard, automated assembly to reduce cost. For complex applications, multilayer boards allow complex signal routing for advanced digital devices. In addition to simple SMT components, these types of boards can include printed patch antennas (see ***Figure 1***) or complex ball-grid array devices.

Critical to successfully implementing this technology are the board-to-board interconnects. DC and digital contacts are through a flex harness and DC pins around the circumference of the module. This nail-and-socket approach enables high pin count while supporting easy assembly. SMP-style RF connectors are capable of high frequency operation for both board-to-board and external connections. Mercury's patented coaxial-to-microstrip transition technology enables high frequency orthogonal connections in an extremely compact space (see ***Figure 2***).

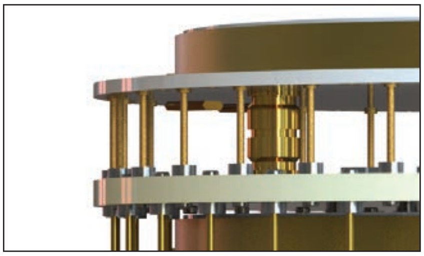
This modular, technology-agnostic framework provides a starting point for any new design. As the library grows, the design process is simplified by combining pre-existing and custom layers, reducing development time, lowering cost and enabling easy product modification.

DENSELY INTEGRATED AND COMPACT

Minimizing the size and weight of the module requires more than just a modular framework; it requires densely integrated components and interconnects. While this is critical to designing a complex sub-assembly no larger than a stack of quarters, it also presents



▲ Fig. 1 The SpectrumSeries Compact Multi-Band Platform with a printed antenna on the top layer.



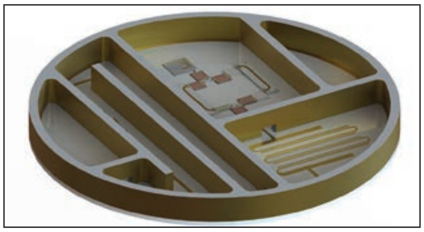
▲ Fig. 2 Orthogonal RF board-to-board connection.

challenges, such as maintaining sufficient electrical isolation. The RF circuity is often the most sensitive to noise and radiated signals. To isolate the RF and provide environmental protection, the RF section is packaged in a hermetic ceramic or metal housing (see ***Figure 3***), allowing the use of bare die, which requires significantly less space than individually packaged devices. Inside the package, metal walls provide channel-to-channel isolation and reduce electromagnetic cavity effects. Using advanced modeling during design and automated assembly during manufacturing, process variation is reduced, minimizing tuning time and cost.

To maintain performance during extremely harsh operating conditions, a few special considerations are required. Plastic encapsulated microelectronics on the SMT boards receive a conformal coating to provide environmental protection, which is smaller and lower cost than a hermetic cavity. Additionally, encapsulation of the sensitive RF components with a low dielectric material increases reliability and enables operation in extremely high G environments. Whether bare die or SMT, advanced manufacturing capabilities enable dense integration by tightly controlling device placement, which reduces the required spacing between devices and helps keep cost low.

MODULAR, MULTI-USE FRAMEWORK

This compact modular framework provides the flexibility to support a range of applications. For example, by stacking multiple RF cards, the module can support multiple frequency bands. By integrating the RF and digital blocks, the platform can integrate a complete sensor-chain solution: RF layers acquire and disseminate the signal, mixed-signal layers digitize the signal and the digital layers perform signal processing.



▲ Fig. 3 Interior detail of a hermetic RF module layer.

This scalable and modular approach supports a new breed of precision-guided munitions, as well as being used for other applications requiring compact and reliable hardware. For example, Group I unmanned aerial vehicles, with a maximum weight of 20 lb, require extremely compact payloads. This approach of integrating modular layers of RF, digital and control circuitry in a compact and ruggedized form factor applies broadly across countless applications. The modular nature of the SpectrumSeries Compact Multi-Band Platform enables solutions to be developed rapidly. Through compact modularity, the architecture is optimized to rapidly bring the latest technology to where it is most needed.

Mercury Systems
Andover, Mass.
www.mrcy.com
rf.microwave@mrcy.com

24/7 Intruder Detection Using Real-Time Spectrum Analyzer

Narda Safety Test Solutions GmbH
Pfullingen, Germany

Since the end of the Cold War in 1991, the international threat scenario has changed. Nowadays it is based on terror. The inflow of illegal refugees poses another safety risk. Thus, one of the burning issues for civil and military agencies is the protection of national borders, requiring gapless situational awareness along widely stretched lines that have to be monitored 24/7. With the new SignalShark, engineers at Narda Safety Test Solutions, an L3 Technologies company, have succeeded in developing a powerful, mobile, real-time spectrum analyzer (RTSA) that creates new capabilities for this Herculean task.

Narda's RF engineers have designed this latest, handheld, direction-finding instrument specifically for rapid and reliable detection, analysis, classification and localization of RF signals between 8 kHz and 8 GHz. ***Figure 1*** shows a partial block diagram of the instrument. Two, independent digital down-converters enable the spectrum of the signal to be observed and demodulated at the same time, independently, within the real-time bandwidth. With its high real-time bandwidth of 40 MHz, the SignalShark can display all the detected RF signals present in entire communication channels in real time. Dynamic range is another highlight of this handheld device. High dynamic range determines the ability to reliably capture low-level signals that, in inferior instruments, would be unseen in the presence of higher-level signals or hidden in the intrinsic noise.

Combining handheld RTSAs with stationary units is a proven and affordable technique for effective border control. State-of-the-art, mobile RTSAs are able to receive and reliably analyze any communication or RF signal in the area. As a commercially available instrument, the SignalShark can directly demodulate AM and FM

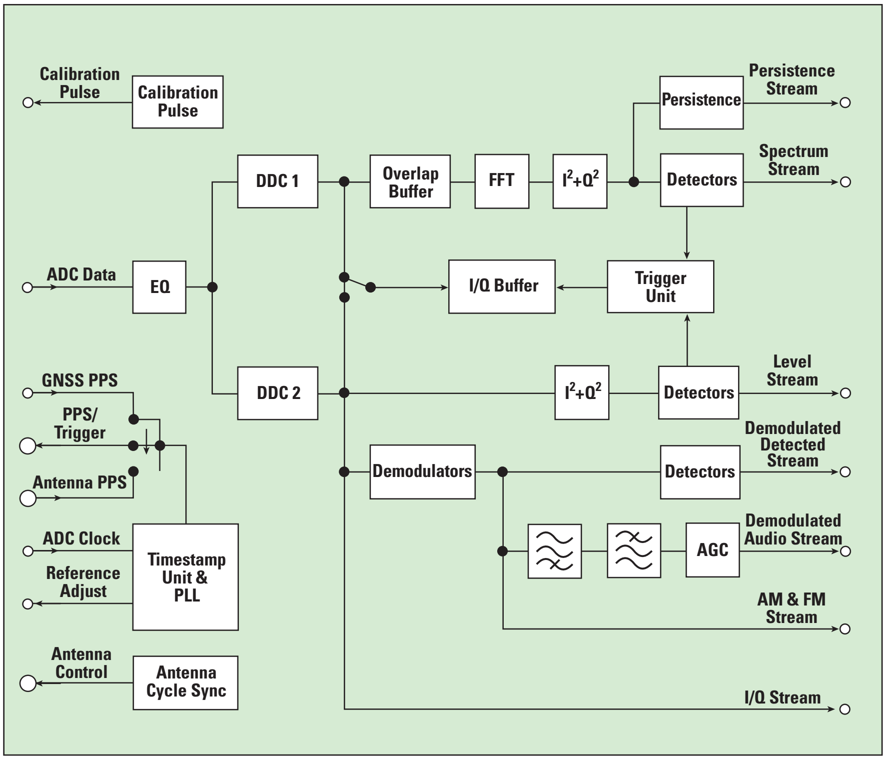


Fig. 1 Partial block diagram of the SignalShark.

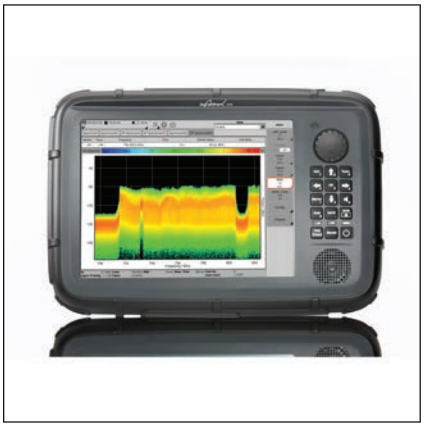


Fig. 2 SignalShark detects a low-level, 793.2 MHz signal "hidden" under a larger commercial signal.

signals and route them to the installed speakers or headphones. If border patrol agents receive the analog signals from a walkie-talkie conversation, they can listen to what the intruders are talking about. For digital radio signals, the internal solid-state drive of the RTSA records the digital data simultaneously over an extended time period. This enables the patrol to record and collect all information, i.e., all different signals in the air—even coded ones—to decode later with suitable software on a laptop or in the laboratory.

When a communication signal is detected, it is critically important to retrieve its content. Narda's new SignalShark is able to record I/Q data and stored measurement values in internal memory. By using the frequency, bandwidth and time-domain functions, it is possible to manually pre-classify GSM and private mobile radio communication signals. With the help of a connected laptop PC and special evaluation software, I/Q data with up to 20 MHz bandwidth can be streamed via the SignalShark's 1 GbE port. Coded data and meta data, such as time, date, length of communication and the identities of communication partners, are a few examples of the information that can be obtained.

REAL-TIME BANDWIDTH

Most handheld spectrum analyzers do not support real-time measurements. Any that do will usually be limited to 10 MHz bandwidth. The SignalShark has a big advantage, providing 4× this bandwidth and able to analyze and record in real-time with up to 40 MHz bandwidth. This is greater than the entire 35 MHz wideband of GSM 900, meaning the SignalShark can capture all detected signals in the GSM 900 band at once, without loss. It does not matter if the intruder changes the frequency, the border guard records the whole GSM 900 band.

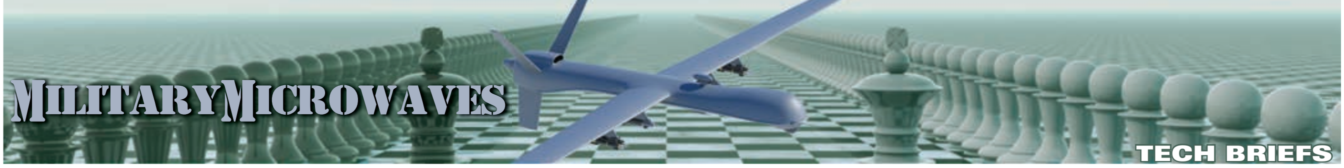
In border control, real-time spectrum analysis enables complete detection of short-term signals, i.e., signals that only occur sporadically and are easy to miss. Using conventional methods, these signals are hard to capture and a considerable time is required for detection. If the border patrol looks at a frequency band for a typical public access mobile radio communication between 410 and 430 MHz with the SignalShark handheld analyzer, every signal in this span, including all pulsed signals regardless of duration, will be captured.

If an intruder tries to "hide" under a normal commercial signal, the border patrol can still detect this in the spectral distribution. The SignalShark shows this directly on its display (see ***Figure 2***). While observing the signal, the border patrol agent can move a manual antenna to see if the small signal under the large one gets stronger or weaker, enabling the direction of the signal source to be determined. Narda's new handheld analyzer makes this signal visible in the midst of other larger signals. Tracking the signal with the help of a fully automatic direction-finding antenna, the bearing can be detected in seconds.

HIGH SENSITIVITY ENABLES COVERING WIDE AREAS

The power level of a hostile transmitter, the terrain profile and the sensitivity of the receiver determine the maximum detection distance between the surveillance station and the intruder, i.e., the maximum distance where the receiver can still detect the intruder's outgoing signal. Noise figure is one key indicator of the sensitivity and quality of the receiver; the lower the noise figure, the better the sensitivity. As a general rule, reducing the noise figure by 6 dB provides twice the detection distance between the transmitter and receiver. Higher quality analyzers typically have a noise figure of about 22 dB. In comparison, the SignalShark has a noise figure of 15 dB with the preamp off. With an antenna this improvement more than doubles the detection distance, and 4× more area can be monitored—a huge improvement in situational awareness, which makes monitoring endangered national borders much faster, lower cost and safer for the border guards.

Narda Safety Test Solutions GmbH
Pfullingen, Germany
www.narda-sts.com



Spectrum Analyzer Offers Unrivaled Value

Signal Hound has developed the SM200A RF spectrum analyzer to rival the most expensive spectrum analyzers, yet priced to provide unrivaled value. Covering 100 kHz to 20 GHz, the SM200A offers 160 MHz instantaneous bandwidth for event triggering, 40 MHz calibrated streaming I/Q, 110 dB dynamic range, 1 THz/sec sustained sweep speeds (with the resolution bandwidth ≥ 30 kHz) and phase noise low enough to contribute less than 0.1 percent error to EVM measurements. The analyzer has a 20 MHz to 20 GHz preselector using a switched bank of 21 sub-octave filters, making it well-suited for signals intelligence, surveillance countermeasures, spectrum monitoring and applications with low amplitude signals in the presence of higher power signals.

To minimize weight and offer flexibility and economy of design and maintenance, the SM200A is "headless," meaning the analyzer is connected to a laptop computer or a PC and display. Signal processing is distributed between a powerful onboard Arria-10 FPGA and the external PC with an Intel Core i7 processor. The Signal Hound SM200A can be used on the benchtop or, with its application programming interface (API), integrated in an automated monitoring or test system. The API allows customer access so the stream of I/Q data can be processed with custom DSP algorithms.

The SM200A sells for $11,900, including all the hardware to power the analyzer and connect it to a PC. Spike, Signal Hound's powerful and free PC-based spectrum analyzer software, is also included. Spike provides SM200A controls, a signal visualization display and data export tools to help accurately analyze RF measurements, with various analysis modes, tools and utilities for phase noise testing, EMC pre-compliance testing, interference hunting and digital modulation measurements.

Signal Hound
LaCenter, Wash.
www.signalhound.com

Liquid Cooled, 40 W, Ka-Band Solid-State PA

One of a series of liquid cooled, solid-state, high-power amplifiers (HPA) developed by Exodus Advanced Communications, the AMP4066A-LC, covers Ka-Band, i.e., 26.5 to 40 GHz, and provides 40 W output power at 1 dB compression. The linear GaAs FET HPA has 46 dB minimum power gain and 4 dB maximum peak-to-peak flatness when driven with a constant input of 0 dBm.

Liquid cooling yields a smaller and quieter amplifier than an air-cooled HPA with the same output power. Housed in a standard, 5U, 19-in. rack chassis, the AMP4066A-LC HPA is self contained, totally sealed and does not require any external connections to a liquid-to-air heat exchanger.

An optional controller with a front panel, touch screen LCD supports Ethernet TCP/IP, RS422 or RS485 interfaces and, if requested, GPIB or Bluetooth connectivity. The HPA operates from any standard AC power, which is specified when the unit is ordered.

The AMP4066A-LC is an ideal TWTA replacement and well-suited for EMI/RFI susceptibility testing, jammers and Ka-Band communications systems. Other power levels are available within the same family of 26 to 40 GHz amplifiers, as well as amplifiers from 1 MHz to 47 GHz and power levels from 10 W to multi-kW.

Exodus Advanced Communications' solid-state power amplifiers 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.

VENDORVIEW
Exodus Advanced Communications
Las Vegas, Nev.
www.exoduscomm.com


SQ-, TQ-, IQ-, BQ-, CQ- =
connecting 4, 7, 8, 9, 10, 12, 19, or even more coaxial RF-Lines at once
RQ23-DC26 =
connecting 23 coax RF- & 26 Signal Lines at once
Spectrum
Elektrotechnik GmbH
when Quality is needed
Hermetically Sealed Adapters
1.85mm, 2.4mm, 2.92mm, TNC, N, Feedthroughs
with venting holes for Vacuum Test Chambers
360° @ 1 GHz
230° @ 12 GHz
350° @ 18 GHz
500° @ 26 GHz
590° @ 40 GHz
400° @ 50 GHz
600° @ 63 GHz
85° @ 2 GHz
520° @ 12 GHz
770° @ 18 GHz
PHASE ADJUSTERS
Big and Small,
we have 'em all
Almost any Waveguide to almost any Coax Connector
WG Materials : Aluminum, Copper, Brass
Connectors : 1.92mm ...SMA....
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Email: Sales@Spectrum-et.com
Facsimile: +49-89-3548-0490

LC Filters for Aerospace and Defense

For demanding aerospace and defense applications, MCV Microwave offers an extensive line of LC filters in surface-mount, drop-in and "connectorized" packages that withstand rugged environments. LC filter configurations comprise lowpass, highpass, bandpass, band reject, duplexers, multiplexers and tunable filters, with center frequencies from 100 kHz to 10 GHz.

As one example of MCV's product capability, the BTL6400-900A1 is a 50 Ω, lumped element, LC bandpass filter with a center frequency of 6.4 GHz and passband of ±450 MHz. Maximum passband insertion loss is 3 dB with 1.2 dB or better flatness and 1.8:1 maximum passband VSWR. Attenuation is at least 55 dB at 5.13 GHz (820 MHz below the lower passband edge) and at least 50 dB at 7.33 GHz (480 MHz above the upper passband edge). The filter withstands average input power levels of 1 W CW. The BTL6400-900A1 is 1.25 in. x 0.38 in. x 0.38 in., with input/output pins extending the length by 0.2 in. total. The operating temperature range is from –55°C to +85°C.

In addition to catalog products, MCV welcomes custom designs, such as contiguous multiplexers, absorptive bandpass and notch filters, to improve the linearity and dynamic range of communications equipment. To reduce testing times of multi-band systems, MCV can design tunable filters and switched filter banks incorporating rugged tuning mechanisms to extend the usable life of the test system.

Founded in 1995, MCV Microwave has a rich heritage designing and manufacturing filters in multiple technologies, often incorporating proprietary, high Q materials. MCV is certified to AS9100D and can meet the requirements for high-reliability programs.

VENDORVIEW

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

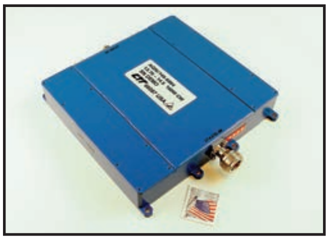
High Performance Lowpass Filter Series Covers 700 MHz to 3.8 GHz

AVX Corp.'s 8 W LP1206 Series high performance, integrated, thin film, lowpass filters feature miniature 1206 chip sizes with a sub-millimeter maximum height profile of 0.97 mm. Based on proven multilayer thin film technology, these 50 Ω SMD filters deliver low insertion loss and extremely sharp attenuation and are designed for wireless applications such as military and mobile communications, wireless large area networks, global positioning, vehicle location and satellite television receivers. Filters in the series are currently available in six standard frequencies: 700 and 860 MHz and 3.2, 3.5, 3.6 and 3.8 GHz, with intermediate frequencies between 700 MHz and 3.8 GHz available upon request.

Good for use on crowded PCBs, the LP1206 ITF filters measure just 3.08 mm x 1.6 mm x 0.87 mm (±0.1 mm) and have a rugged construction designed for reliable automatic assembly. Compatible with automatic soldering technologies, including: reflow, wave soldering and vapor phase, as well as manual assembly, they allow installers to visually inspect the solder fillet after mounting. The series has lead-free nickel/solder (Sn100) coated terminations for RoHS compliance.

The LP1206 ITF series provides a higher power complement to AVX's existing 3 W LGA-terminated 1206 LP Series offering. They are rated for 8 W continuous power, with an operating and storage temperature range from –40°C to +85°C. They are 100 percent tested for electrical parameters and visual and mechanical characteristics and are shipped on tape and reel in standard quantities of 100, 500, 1000 and 2000 pieces. The lead-time for the series is currently 10 weeks.

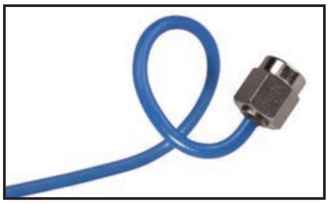
AVX Corp.
Fountain Inn, S.C.
www.avx.com



100 W Ku-BAND GaN PA

CTT introduces a new solid-state GaN-based power amplifier (PA), Model AGN/145-5064, which covers 13.75 to 14.5 GHz (Ku-Band) and provides 100 W of CW power output. The compact size of 3.76 in. x 4.55 in. x 0.77 in. makes this SSPA an exceptional choice for RF/microwave engineers designing critical systems for use in applications including SATCOM uplinks, synthetic aperture radar and data-link communications.

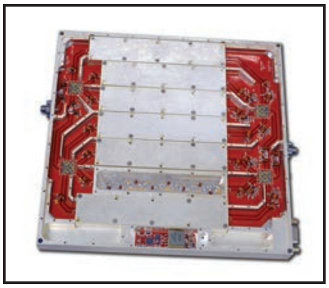
CTT Inc.
www.cttinc.com



PHASE INVARIANT CABLE ASSEMBLIES

HUBER+SUHNER recently launched the Minibend CTR/Mini141 CT family which combines the industry-renowned flexibility of HUBER+SUHNER Astrolab's bend-to-the-end connector termination technology with industry leading phase vs. temperature performance. Thus, it creates a stable, reliable, MILDTL-17 qualified interconnect solution to satisfy a huge range of customer applications where phase stability is key. The broad selection of available connector interfaces ensures a large variety of configurations to meet the unique requirements of customers.

Huber+Suhner
www.hubersuhner.com/en/solutions/space/products/minibend-series/phase-invariant-assemblies/mini-141-ct



7 CHANNEL SWITCHED FILTER

The 7SFB-225/Q512-O is a 7 channel switched filter bank designed to filter spurious and harmonic content generated by high-power amplifiers and transmitters in the UHF-Band. These interferers can degrade performance and even damage sensitive equipment. As communications band usage and amplifier technology power densities increase, this challenge becomes more formidable. K&L Microwave has leveraged core competencies in PIN diode based switches and high-power filters to develop a suite of high-power switched filter banks. Please consult the factory for custom filters, other bands or higher power levels.

K&L Microwave
www.klmicrowave.com

ACE THE TEST WITH KAELUS

The Kaelus ACE-1000A is the industry's first calibration extender that allows customers to self-calibrate their PIM analyzers in the field. Reducing down-time to less than one hour, the ACE-1000A verifies successful calibration then extends your analyzer's validation date by 12 months, eliminating costly shipping and service center charges.

Kaelus
www.kaelus.com

L3 ELECTRON DEVICES' MPMs

L3 Electron Devices' MPMs are super components that combine a solid-state driver amplifier with a micro-TWT and a power supply in one package that is much smaller, lighter and more efficient than a comparable TWTA or SSPA. Their MPMs are available in bands from 2 to 95 GHz with output powers from 40 to 200 W. All L3 MPMs are optimized for demanding defense applications that require small, lightweight and environmentally rugged, high-power microwave amplifiers.

L3 Electron Devices
www.L3T.com/EDD

DC TO 40 GHz 086 HAND-FLEX COAXIAL CABLE ASSEMBLIES

MIcable F01J (0.086 Hand Formable) microwave cable assemblies are constructed with SMP Female connectors on both sides up to 40 GHz in low VSWR within 1.40:1 at 40 GHz and low insert loss. It is tight bend radius, easily shaped by hand, ideal for interconnect of assembled system and takes place of 0.086 semi-rigid cables.

MIcable
www.micable.cn

The 2018 Defence, Security & Space Forum

At European Microwave Week

EuMA

Microwave Journal

Wednesday, 26 September – IFEMA Feria de Madrid, Spain – Room N101-N102, 08:30 to 18:30

A one-day focused Forum addressing the integration of unmanned aerial vehicles (UAV) into defence and security scenarios.

Programme:

08:30 – 10:10 EuRAD Opening Session

10:10 – 10:50 Coffee Break

10:50 – 12:30 New Concepts, Technologies and Systems for UAV Integration and Their Role in Future Hybrid Scenarios.

Technological Demonstrator of Enhanced Situation Awareness in Naval Environment with the use of Unmanned Systems
Dr. Tony Arecchi, Ocean 2020 Project Coordinator, Leonardo S.p.A. Italy.

- *UAV Integration into European Airspace: The U-Space Vision* – **Single European Sky ATM Research (SESAR) Project.**
- *Anti-UAV Defence Systems* – **Miguel Acitores, Director of Security Business Development, Indra. Spain.**

12:40 - 13:40 Strategy Analytics Lunch & Learn Session

The Implications of Expanding the UAS Mission Envelope in Military and Civilian Airspace
Asif Anwar, Strategy Analytics, UK

13:50 – 15:30 *Microwave Journal* Industry Panel Session

This session offers a perspective on the endeavour, innovation and investment that industry is committing to the development of Unmanned Aerial Vehicles in the defence and security sector. Speakers will offer an insight into such areas of activity as microwave sensors/sub-systems, the test and measurement challenges that are being addressed and the issue of UAV identification and detection.

15:30 - 16:10 Coffee Break

16:10 - 17:50 Round Table: Efforts & Investment Needs to Drive UAV Technologies to Market

High level speakers from key governmental agencies and commercial companies involved in the integration of UAV air traffic into non-segregated air spaces in the future will offer their opinions and outline the opportunities and challenges that can be expected in coming years. Speakers will also focus on the research needs and technological trends that will define the structure and technical characteristics of future unmanned systems.

17:50 - 18:30 Cocktail Reception

Registration and Programme Updates

Registration fee is €20 for those who registered for a conference and €60 for those not registered for a conference.

As information is formalized, the Conference Special Events section of the EuMW website will be updated on a regular basis.

Register online at www.eumweek.com

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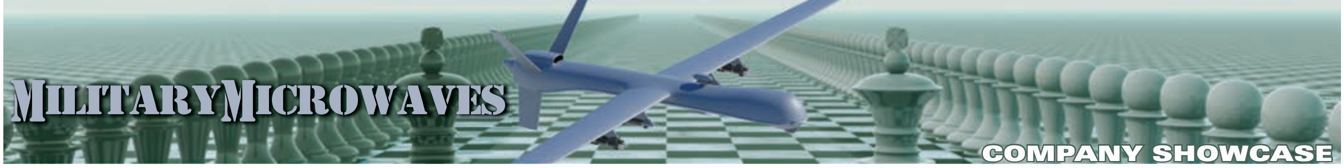
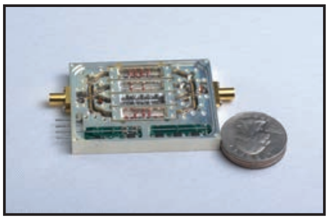


BENCHTOP TEST SOLUTIONS PRODUCT GUIDE

VENDORVIEW

Mini-Circuits' has innovated a line of products for these functions that are smaller, faster, easier to control and much more affordable than other options typically available in the industry. Their benchtop test and measurement modules offer the ease of control via USB or Ethernet and include programmable attenuators, power sensors, frequency counters, switch modules, signal generators and control products. Depending on the application, these units may be used as standalone solutions or easily integrated as building blocks to build scalable testing platforms customized to each user's individual needs.

Mini-Circuits
www.minicircuits.com



10 TO 18000 MHz, 4 CHANNEL SWITCHED FILTER BANK

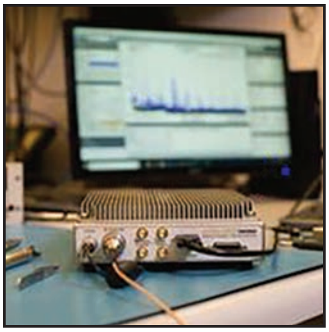
NIC introduces a low profile, high performance 4 channel switched filter bank that covers a wide frequency range from 10 MHz to 18 GHz. The bands include a 2500 to 18000 MHz highpass filter, 10 to 8000 MHz lowpass filter and two bandpass filters. This switched filter bank uses Pin-diode technology and is TTL compatible. The filter bank offers low VSWR, excellent passband flatness, fast switching speeds and is housed in a compact, ruggedized enclosure making it a perfect fit for high-reliability radar, EW and space applications. Custom designs are available from 10 to 18000 MHz.

Networks International Corp.
www.nickc.com/

COAXIAL NUCLEAR EMP SURGE PROTECTION

PolyPhaser's IS-NEMP family of surge protectors are engineered for quick turn on to protect RF equipment operating in the frequency range of 1.5 MHz to 1 GHz against fast rising electromagnetic pulse. The IS-NEMP family are configured with N-type connectors with an RF power rating of up to 200 W. These DC block surge protectors feature turn-on voltage of 330 Vdc ±20 percent, VSWR of ≤ 1.1:1 over frequency range and insertion loss of ≤ 0.1 dB.

PolyPhaser
www.polyphaser.com



20 GHz HEADLESS RF SPECTRUM ANALYZER

The SM200A is an affordable, compact and capable spectrum analyzer for a range of applications. Tuning from 100 kHz to 20 GHz, the analyzer has an instantaneous bandwidth of 160 MHz and a high dynamic range of 110 dB. A sustained sweep speed of 1 THz/s and ultra-low phase noise means the SM200A introduces only 0.1 percent error to EVM measurements. Unrivaled value at $11,900.

Signal Hound
https://signalhound.com/sm200a/

INTERFACE GAUGE KITS

VENDORVIEW

A small investment will help to avoid trouble, means checking interfaces of connectors. The connector gauge kits of Spectrum Elektrotechnik GmbH are easy to use with direct reading and self-checking, measure the interface dimensions of coaxial connectors. The kits consist of gauges with especially developed dial indicators to mate with the individual connectors. A master setting gauge adjusts the dial indicator to zero, before mating with a connector to measure the interfaces. The gauges are sold as kits, individual components or replacement parts. Calibration service is provided as well.

Spectrum Elektrotechnik GmbH
www.spectrum-et.org/

S-BAND ROTARY JOINTS FOR USE IN SPACE

SPINNER has expanded its range of rotary joints for use in space, primarily in antenna pointing mechanisms. Many of the rotary joints already available for use in space operate in the X-, K- or Ka-Band, and SPINNER has now also developed units for the S-Band. Based on its proven contactless RF transmission technology, SPINNER has surmounted the challenges involved in designing and producing S-Band rotary joints that are comparable in size to those for higher frequencies, despite the longer wavelength.

SPINNER
www.spinner-group.com

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International Sales
Richard Vaughan
International Sales Manager
16 Sussex Street
London SW1V 4RW, England
Tel: +44 207 596 8742
FAX: +44 207 596 8749
rvaughan@horizonhouse.co.uk

Germany, Austria, and Switzerland (German-speaking)
WMS.Werbe- und Media Service
Brigitte Beranek
Gerhart-Hauptmann-Street 33,
D-72574 Bad Urach
Germany
Tel: +49 7125 407 31 18
FAX: +49 7125 407 31 08
bberanek@horizonhouse.com

Korea
Young-Seoh Chinn
JES Media International
2nd Floor, ANA Bldg.
257-1, Myungil-Dong
Kangdong-Gu
Seoul, 134-070 Korea
Tel: +82 2 481-3411
FAX: +82 2 481-3414
yschinn@horizonhouse.com

China
Shenzhen
Michael Tsui
ACT International
Tel: 86-755-25988571
FAX: 86-10-58607751
michaelt@actintl.com.hk

Shanghai
Linda Li
ACT International
Tel: 86-021-62511200
lindal@actintl.com.hk

Beijing
Cecily Bian
ACT International
Tel: +86 135 5262 1310
cecilyb@actintl.com.hk

Hong Kong, Taiwan, Singapore
Mark Mak
ACT International
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Japan
Katsuhiro Ishii
Ace Media Service Inc.
12-6, 4-Chome,
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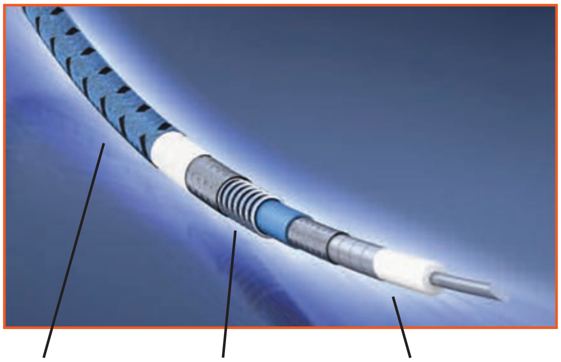

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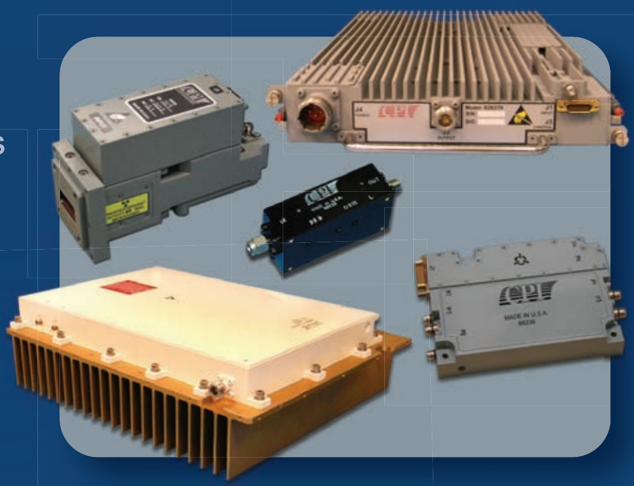

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