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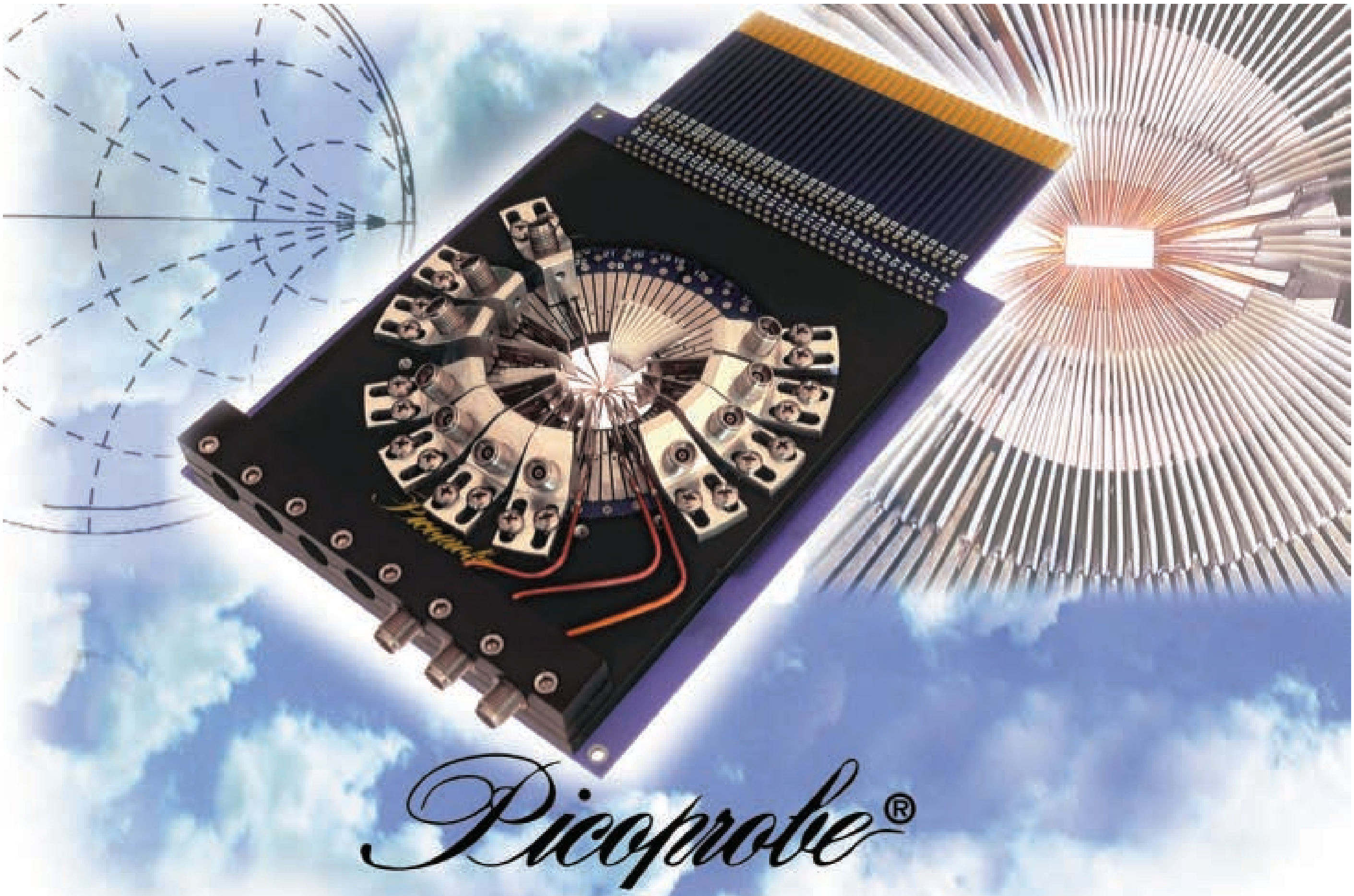

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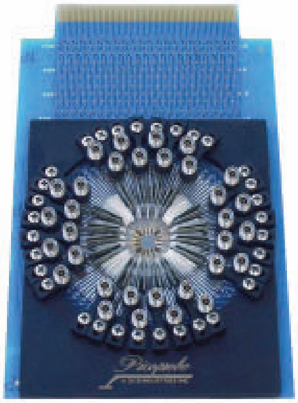

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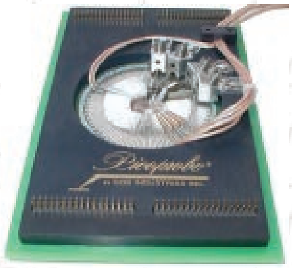

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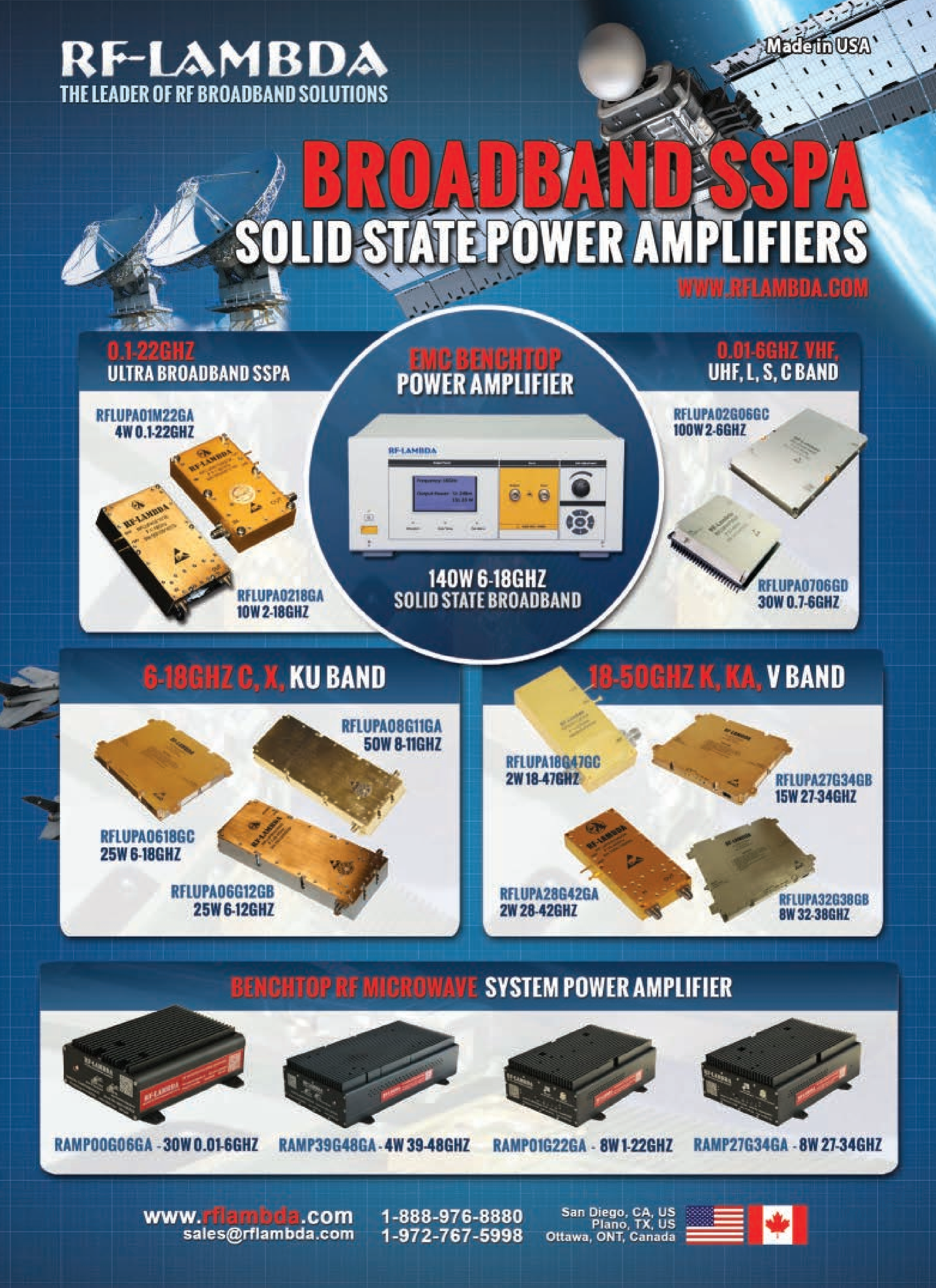

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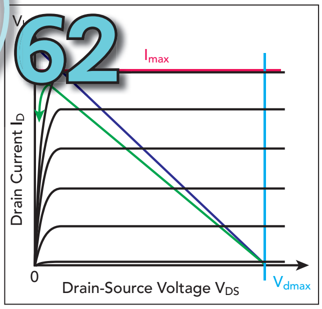

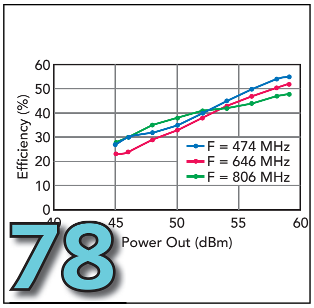

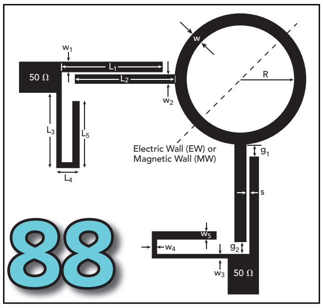

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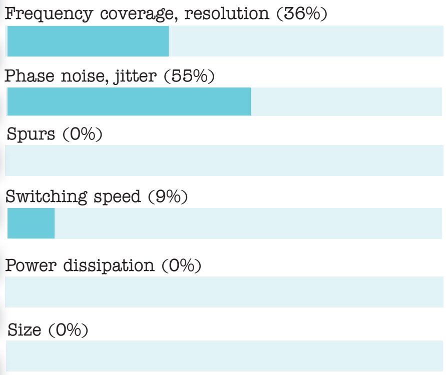
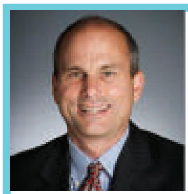


Executive Interviews



5G Americas' president, **Chris Pearson**, discusses the organization's mission and member companies along with some of the major trends in 5G technology, spectrum allocation and regulation.

Jim Morgan, president and CEO of **SemiGen, Inc.**, describes the vision that started the company and how SemiGen's RF/microwave assembly services, portfolio of diodes and chip capacitors and responsive customer service are fueling growth.

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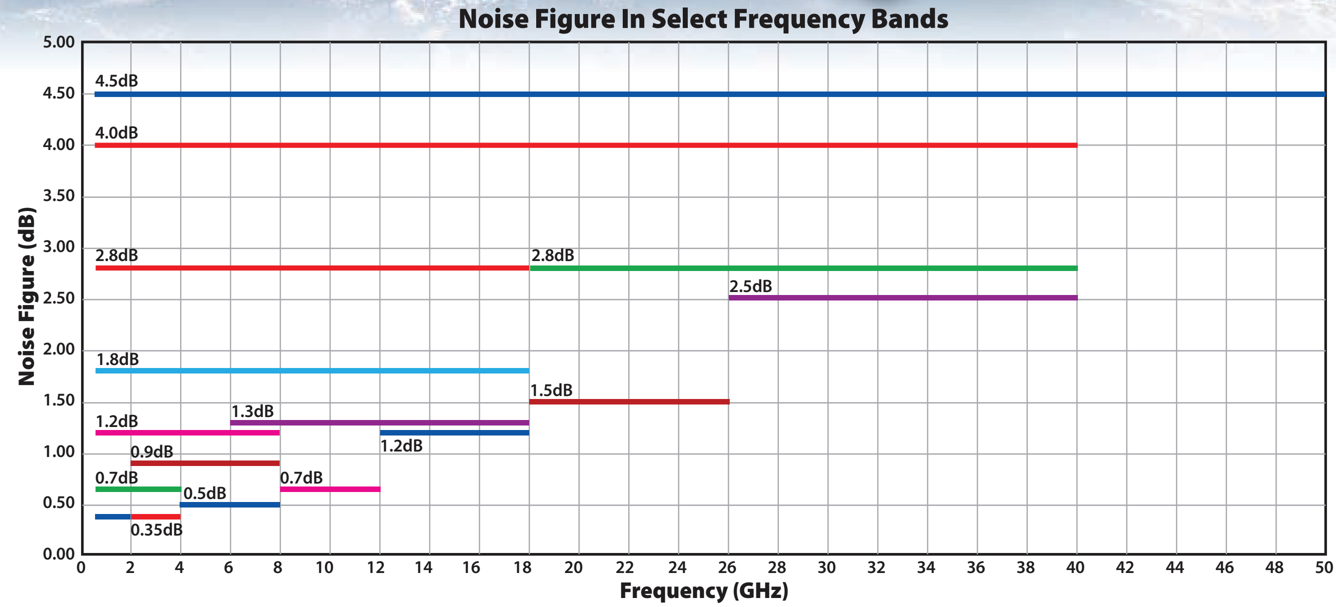

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Cover Feature
Invited Paper

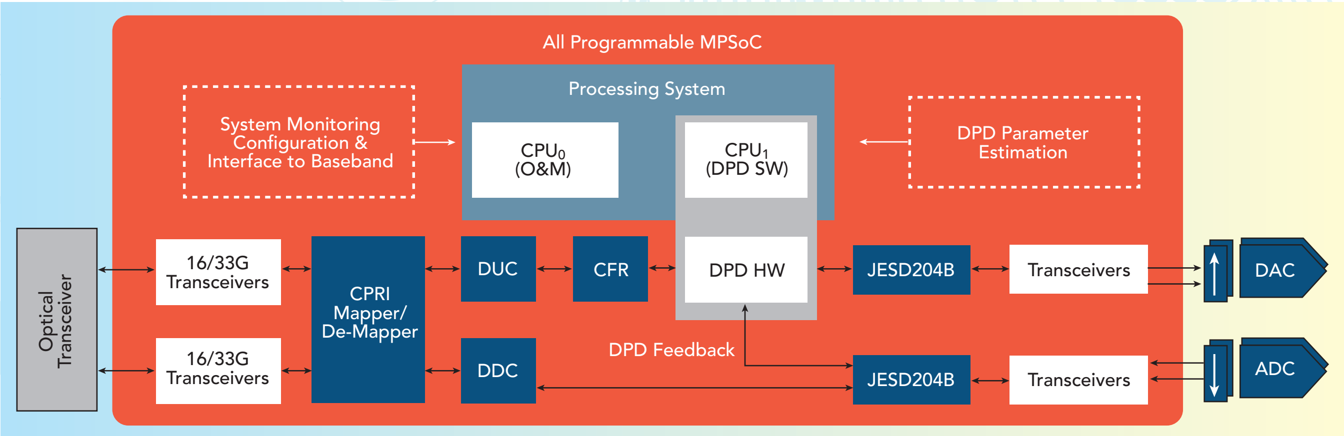
RFSoC Integrates RF Sampling Data Converters for 5G New Radio

Anthony Collins, Harpinder Matharu and Ehab Mohsen
Xilinx Inc., San Jose, Calif.

Fifth generation wireless access networks are expected to meet system and service requirements of new use cases and applications in 2020 and beyond. 5G new radio (NR) envisages providing 10 Gbps peak data rates per user, roughly 100x improvement over the fourth generation wireless access network. 4G LTE-Advanced Pro, also termed by some vendors as 4.5 to 4.9G, can achieve up to 1 Gbps peak data rates using wider bandwidths and carrier aggregation. Sustained data rate per user in LTE-Advanced Pro typically ranges between 25 to 50 Mbps. 5G NR targets 100x improvement by pushing sustained data rate per user to 500 Mbps.

Significant increase in spectral efficiency and tapping into underutilized spectrum above 6 GHz are key enablers of multi-gigabit data rates for enhanced mobile broadband (eMBB). Massive MIMO, or large arrays of antennas, is the keystone technology for realizing this improvement. Massive MIMO adds spatial dimension in addition to frequency and time to significantly boost spectral efficiency. The resulting signal-to-noise ratio (SNR) improvements brought about by the array gain and orthogonality of multiple beams means the same time and frequency allocations can be used by multiple users.

Time-division duplexing (TDD) bands with wider bandwidths, such as band 41 (2496 to 2690 MHz) and band 42 (3400 to 3600 MHz), are the prime candidates for massive MIMO deployments below 6 GHz bands. Tapping into underutilized centime-



▲ **Fig. 1** All programmable MPSoC as a DFE platform.

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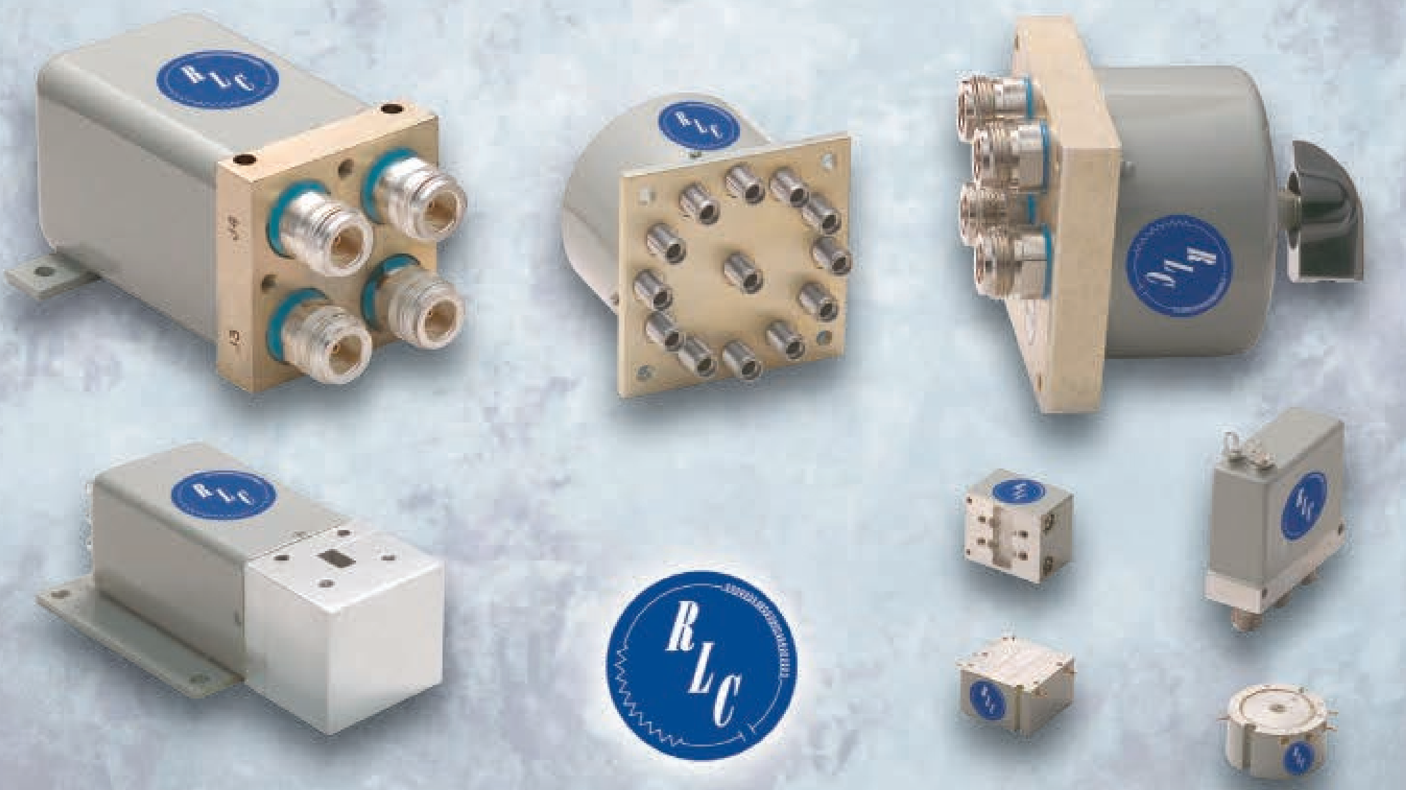

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ter and millimeter wave bands, with large swaths of available bandwidth in frequencies such as 15, 28, 39 and 70 to 80 GHz, are critical components of 5G NR massive MIMO deployments above 6 GHz.

Total transmitted power by the full antenna array could typically range from 40 to 100 W, but power per antenna based on the number of antennas used in the array drops down to few hundreds of milliwatts. This allows use of low cost and lower precision analog components in the final stages of a typical RF line up. Instead of using active signal chains per antenna with fully digital beamforming, hybrid schemes are proposed, where a single active signal chain is shared by a set of antennas, with beamforming functionality performed partly in the digital domain and partly in the analog domain using phase shifters.

The power, footprint and cost associated with deploying very high channel counts along with wider signal bandwidths are significant hurdles. Increased integration along with significant power reduction is required for commercial deployments. Integrating RF-class or RF sampling data converters into radio digital front-end system on chip (SoC) overcomes this hurdle by lowering power, footprint and cost of the total system.

IMPLEMENTING A VIABLE 5G NR WITH RF SoC

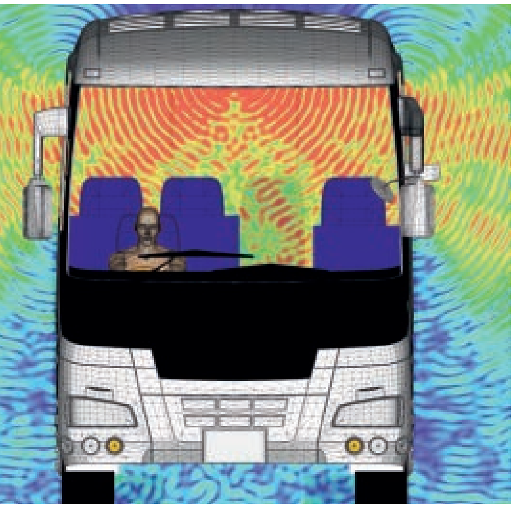
A 5G NR massive MIMO implementation requires a large number of active signal chains in the radio to connect to each antenna or a subset of antennas in the array. These active signal chains are traditionally comprised of data converters, filters, mixers and power amplifier or low noise amplifier, and can lead to significant increase in power, form factor and cost of the system. The large number of active signal chains in massive MIMO systems—for digital or hybrid beamforming—makes system power and footprint too high to realize commercially viable systems. The costs associated with moving data between the RF front-ends (RFFE) and the digital front-end (DFE) is one of the key challenges that must be resolved in 5G—at the software, hardware and system level.

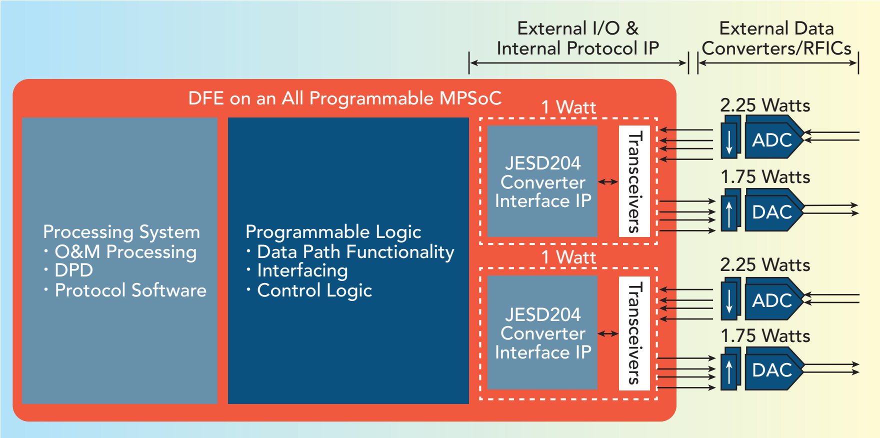
A newly introduced SoC technology tackles this through device integration. The platform, based on a 16 nm FinFET silicon process, monolithically integrates RF-class analog technology into a multi-processor SoC (MPSoC) for a fully hardware and software programmable radio frequency system on a chip, or RFSoC. Based on an ARM-class processing subsystem merged with FPGA programmable logic, the architecture features 12-bit, 4 GSPS RF sampling analog to digital converters (ADC), and 14-bit, 6.4 GSPS direct RF digital to analog converters (DAC), along with optimized digital down-conversion and up-conversion signal processing.

The RFSoC is built on an all programmable MPSoC architecture, an established platform for radio DFE implementations. As shown in ***Figure 1***, the base architecture can employ the ARM processing subsystem for O&M functionality, digital predistortion (DPD) and protocol software, while the FPGA fabric can be utilized for high performance data path functionality, control logic and high speed interfacing. Now with the integration of communication-grade RF sampling ADCs and DACs and the removal of multiple discrete components, RFSoCs enable compact radio form factor with potential for embedding DFE functionality within or behind antenna arrays. The result is new levels of power efficiency, form factor reduction, shortened design cycles and design flexibility urgently needed for LTE-Advanced Pro, 5G active antenna systems and massive MIMO radios.

POWER REDUCTION

Figure 2 illustrates the high-power cost of moving data from a wideband (1 GHz) 2 × 2 RFFE into the DFE for processing using discrete RF sampling data converters. Even with integrated digital down-conversion (DDC) or digital up-conversion (DUC) in the data converters, large amounts of data still need to be sent to and from the DFE. The I/O power number shown for each quad transceiver (1 W per four lanes) includes the power associated with implementing JESD204B Protocol—on 16 nm MPSoC devices. In addition to interface power, the power con-

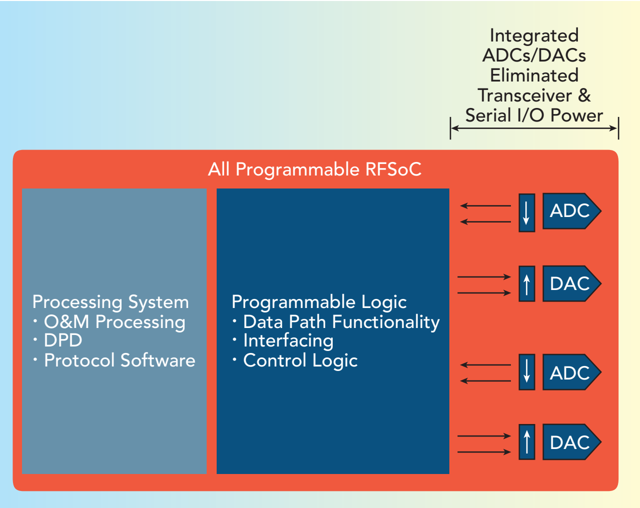




▲ **Fig. 2 Radio DFE interfacing to external wideband data converters.**

sumption of the discrete data converter components remains high. A typical single channel RF sampling ADC may consume ~2.25 W, and an RF sampling DAC ~1.75 W.

DFE signal processing, as shown in Figure 1, has leveraged the latest deep-submicron CMOS technologies to reduce power, while RF and other analog components have traditionally leveraged older-process technology. The older CMOS and even BiCMOS technology offered the required performance at the right costs for these predominately analog ("Big A") discrete components. However, the move to a more digitally dominated SoC ("Big D") means that it is now commercially viable to build data converters on the latest advanced CMOS technologies, allowing huge power and cost savings. Integration of these data converters is represented in ***Figure 3***.



▲ **Fig. 3 Elimination of RF component power and interface power.**

On the SoC device itself, the integration of the data converters eliminates the need for the JESD204B IP cores and use of the device's high speed serial transceivers. With the elimination of components, interfacing, IP and use of transceivers—as channel count increases so does system power reduction. Based on single channel RF data converters, elimination of all these factors results in 40 percent power reduction in a 4 Tx/4 Rx radio and over 50 percent power reduction for an 8 Tx/8 Rx system, as shown in ***Table 1***.

SYSTEM FORM FACTOR REDUCTION

Radio form factor (size or volume) is a critical attribute for securing deployment in terms of rental fees, wind loading and compliance to the local government's regulations and restrictions. Reducing radio unit volume is an important system design criteria. Integrating RF-class data converters results in significant saving, as shown in ***Figure 4***. Form factor reductions are proportional to the number of antennas in the system. PCB area savings can range from 40 percent and reach 75 percent. An example of an 8 Tx/8 Rx radio using quad channel ADC and DAC are shown in Figure 4.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SHORTENED DESIGN CYCLES AND ELIMINATING JESD204 INTERFACE

Beyond power and form factor benefits, elimination of discrete data converters shortens the design cycle in several ways. Because most modern converters currently use high speed serial interfaces from 12.5 to 25 Gbps based on the JESD204 protocol, design closure is impacted at the digital, analog and system level. The JESD204 IP cores must be implemented in digital FPGA fabric, but arguably the more difficult task is ensuring a stable serial data link between the data converter and the radio's DFE. At 12.5 Gbps and up to 25 Gbps, signal distortion is a serious concern mostly due to running high line rates over low cost, lossy interconnect. Eliminating the DFE and RFFE interface removes this burden and

TABLE 1

POWER SAVINGS IN DIGITAL RADIO (WITH DPD) USING AN INTEGRATED SUBSYSTEM

	4x4 100 MHz	4x4 200 MHz	8x8 100 MHz
Discrete Implementation			
Programmable Device	15 W	23 W	23 W
ADC/DAC Components	16 W	16 W	32 W
TOTAL POWER	**31 W**	**39 W**	**55 W**
Integrated RF-Analog			
Programmable Device + RF Subsystem	18 W	25 W	27 W
TOTAL POWER SAVINGS	**41%**	**37%**	**51%**

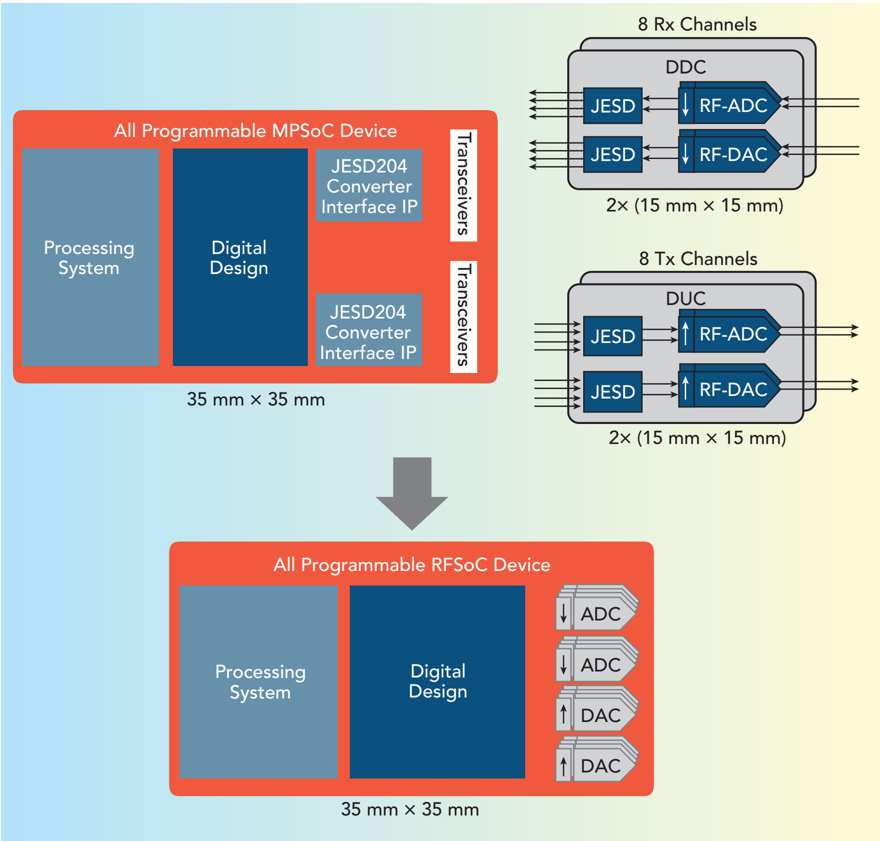
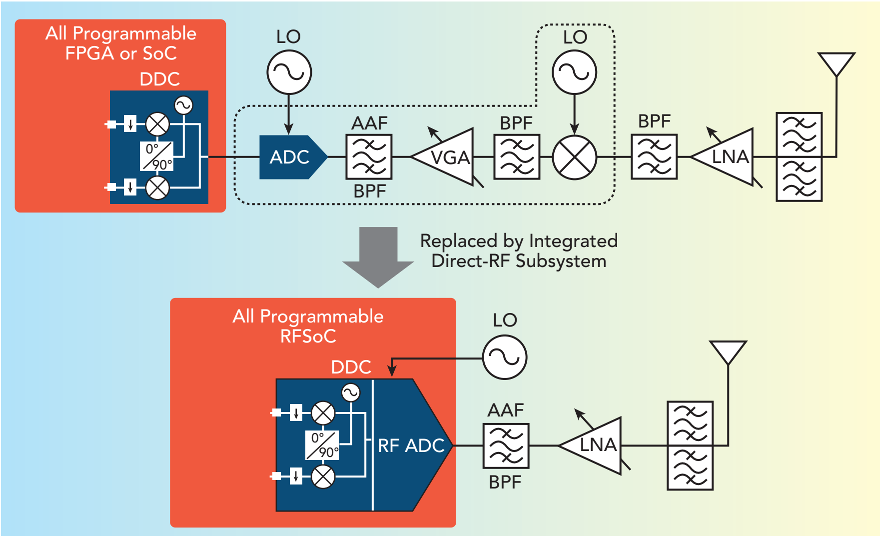


Fig. 4 PCB area savings in 8 Tx/ 8 Rx radio.

reduces the number of board layers, complexity of routing the clocks on the PCB and synchronization of the communication links.

DESIGN FLEXIBILITY WITH RF SAMPLING ON 16 nm FinFET

Direct RF sampling DACs and RF sampling ADCs in the RFSoC eliminate the need for intermediate frequency (IF) stage sampling for 5G Radios implemented in sub-6 GHz frequency bands, thereby reducing the complexity of the RFFE, as shown in ***Figure 5***. Direct RF sampling, integrated with highly optimized RF digital signal processing engines (i.e., DDC and DUC) offers a much more flexible approach to traditional analog frequency translation and filtering. The higher sample rates simplify the analog filtering requirements and allow a better trade-off between dynamic range (SNR) and signal bandwidth in the digital domain by decimating and filtering the ADC output to extract only the signal bandwidth of interest.[1] Implementing the signal conditioning in the digital domain also yields better performance and ease of use. Some of the traditional RF impairments in the IF approach are greatly reduced or eliminated (e.g., passband ripple, group delay variation, matching and local oscillator (LO) leakage issues).



▲ **Fig. 5** Comparison of superheterodyne and direct sampling receivers.

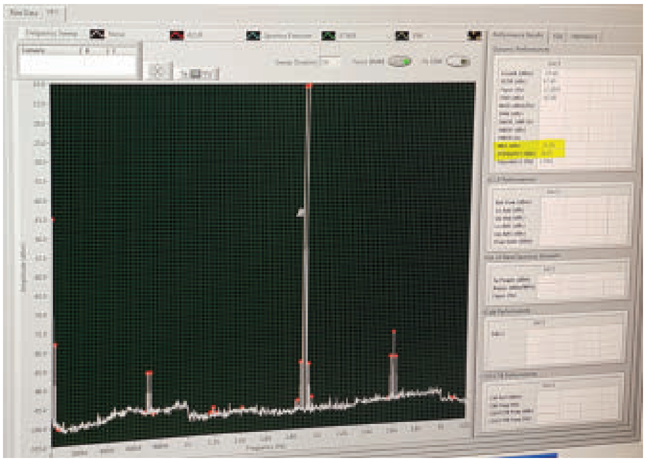
With advanced CMOS technology, namely 16 nm FinFET, RF signal processing can be implemented in the digital domain with excellent power and cost efficiency. At 16 nm, the RF sampling solution in the RFSoC architecture delivers a flexible RF front-end while supporting wide bandwidths—up to 2 GHz—at a much lower power draw than required by analog technologies.

DEMONSTRATING ADC AND DAC PERFORMANCE

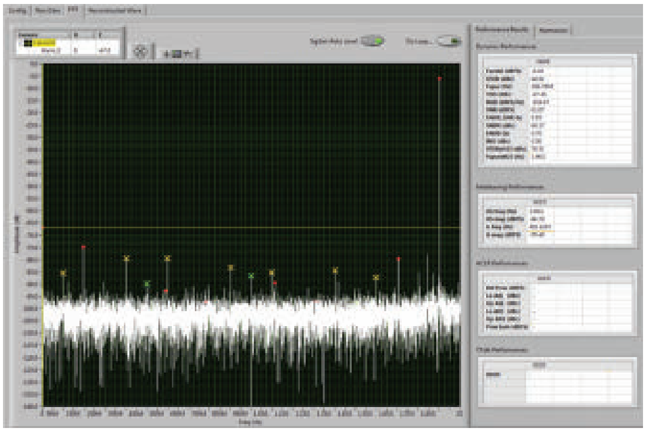
New digitally assisted techniques allowed designers to address the challenge of integrating state-of-the-art RF sampling converters using advanced CMOS technology.[2] By using very cost and power efficient 16 nm FinFET digital transistors, it is possible to add very sophisticated digital calibration to correct for any analog circuits impairments. This approach to implementing advanced RF sampling converters delivers large benefits in terms of power and area reduction. It also provides a platform technology that will scale with Moore's Law to 7 nm and beyond.

Results from a 16 nm FinFET test chip featuring the RFSoC's direct RF sampling converters show excellent performance, linearity and analog characteristics of a 6.8 GSPS RF DAC and 4 GSPS RF ADC—evaluated across process, temperature and power supply variation.[2] The built-in calibration and digitally assisted techniques deliver very consistent and stable performance across PVT.


REMOTE HOME CONTROL
22°C



▲ **Fig. 6** RF DAC generating two tones at 1.9 GHz separated by 20 MHz.



▲ **Fig. 7** FFT of a continuous wave tone sampled at 4 GS/s by the RF ADC.

The output of the DAC generates two tones at a carrier frequency of approximately 1.9 GHz separated by 20 MHz, as shown in the output of the Rohde & Schwarz FSW Spectrum Analyzer in ***Figure 6***. The 3rd order intermodulation illustrates the very high linearity of the DAC at approximately -75 dBc. This is within the first Nyquist zone, which extends up to 3.2 GHz. The 2nd and 3rd order images folded back also show excellent performance of the DAC.

For the ADC, a high quality signal sourced by the Rohde & Schwarz SMW200A vector signal generator is used to synthesize both CW and modulated waveforms. Additional analog filtering by the signal source provides the signal purity required to evaluate the ADC. The captured data is analyzed using fast Fourier transforms (FFT) implemented with LabView Software from National Instruments, as shown in ***Figure 7***. The FFT of a -3 dBFS 1.9 GHz CW signal is sampled at 4 GSPS, and the plot shows the first Nyquist zone of the ADC. The 2nd and 3rd order distortion components are aliased into the first Nyquist zone as indicated by the red markers. Other distortion components shown are interleaving artifacts which are greatly suppressed using built-in calibration.

MEETING THE DESIGN CHALLENGES AND APPLICATION CONSTRAINTS FOR RFSoC

As with any complex SoC, there were tradeoffs and design choices made when developing the all programmable RFSoC. This ranged from meeting challenging power targets, to careful consideration of the constraints hardware designers face when realizing their end application, to providing a platform with the correct mix of optimized and programmable signal processing.

Power Density

With reduced form factor and significantly greater performance, 5G NRs face tough power density challenges and present a thermal engineering problem. The system is typically passively cooled with high operating ambient temperatures generated by the power amplifier and other components. In order for components to stay within their specified operating temperature range, they typically cannot dissipate more than 35 W before the thermal solution becomes complex and costly.

While integrating RF sampling data converters greatly reduces the system power, it must also not significantly increase the power dissipation of the SoC. Ideally, the solution would be power neutral with the converter power being similar to the power dissipated by the external IO interfaces like JESD204B. This drove many of the design choices and techniques used in developing the RFSoC, including digitally assisted analog and interleaving to reduce the power consumption of the converters.

Practical Hardware Solutions

The RFSoC needed to meet key requirements like channel to channel RF isolation (which typically needs to be greater than 70 dB) and immunity to other sources of noise in what is a highly mixed signal environment. The SoC is a predominately digital (Big "D") device that supports external memory interfaces, along with system interfaces like 100GE and common public radio interface (CPRI). Through careful design and floor planning of the SoC, along with package and PCB co-design, RFSoCs can achieve very robust performance without costly PCB design rules or nonstandard manufacturing techniques.

Maximizing Flexibility

Traditional SoC implementation involves tradeoffs in functionality, cost and power consumption. Developing the RFSoC was no exception but benefited from significantly more degrees of freedom. Generic functionality like DDC was implemented in highly power efficient 16 nm FinFET logic; however, much of the application specific functionality can be efficiently implemented in the programmable logic. The RFSoC achieves a balance between dedicated hardened digital signal processing and user configurable high performance processing. The result is an all programmable platform for implementing a range of applications beyond just radio.

The choice of advanced CMOS technology like 16 nm FinFET is a key part of maintaining this flexibility to adapt to changing standards and allow designers to react quickly to emerging requirements. The direct RF sampling moves the RF into the digital signal processing domain as soon as possible, where it can be processed very efficiently in the digital domain using advanced CMOS technology.

ALIGNED WITH 3GPP SPECIFICATION TIMELINES

The introduction of all programmable RFSoCs is well aligned with 5G NR specification timelines. The draft of the 5G NR non-standalone specification (release 15) is targeted to be available by December 2017. The Standalone 5G NR portion of the release 15 specification is expected to be completed by June 2018. Non-standalone mode will use LTE as the control plane anchor. 5G NR control plane for standalone mode will be defined in the June 2018 release. The 3GPP industry workgroup is debating on the extent of the ultra-reliable low latency communication (URLLC) use case to be covered in release 15. Due to tight timelines for release 15, many facets of the URLLC use case are targeted in the 5G NR release 16 specification scheduled to be available by end of calendar year 2019.

SUMMARY

With all programmable RFSoCs, the ability to leverage the same hardware to address diverse requirements and emerging standards will allow vendors to quickly react to new market opportunities by leveraging existing developments. In the case of 5G systems it is becoming clear that no one type of radio will address the diverse needs of next generation radio access networks (RAN) and so the number of different radio types is expected to increase significantly.[3] ■

References

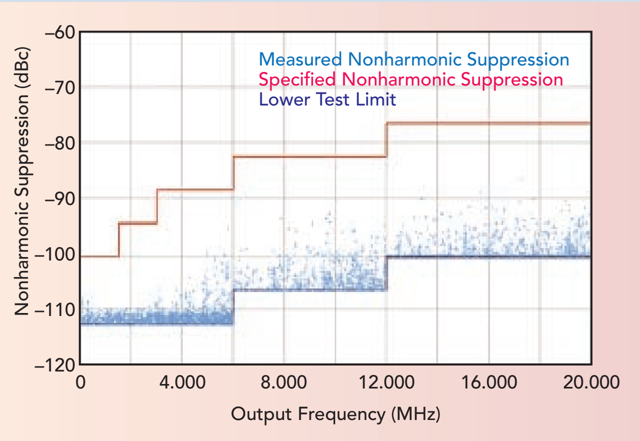
1. Boris Murmann, *IEEE Micro*, Volume: 26, Issue: 2, March-April 2006: "Digitally Assisted Analog Circuits."
2. While the test chip demonstrates a 6.8 GSPS DAC, All Programmable RFSoC specifications currently target 6.4 GSPS DAC performance.
3. "Final report on the METIS 5G System Concept and Technology Roadmap," METIS Deliverable D6.6, https://www.metis2020.com/wp-content/uploads/deliverables/METIS_D6.6_v1.pdf

Most Valuable Product

Redefining High-End RF and Microwave Signal Generation

Rohde & Schwarz
Munich, Germany

In research and development, designers often push their designs almost beyond possible limits in order to attain utmost performance, and sometimes they do not initially know how far they need to go. In the test and verification phase, often an analog signal source is the first method of choice to prove the performance of a design. Ideally, it should not limit the design margins or test results but, in reality, it often does. For example, engineers testing state-of-the-art analog-to-digital (A/D) and digital-to-analog (D/A) converters seek the highest spurious-free dynamic range and the lowest broadband noise available, while radar engineers require the lowest possible phase noise. And in large test setups with long cabling, the output power of the signal source often seems too low.



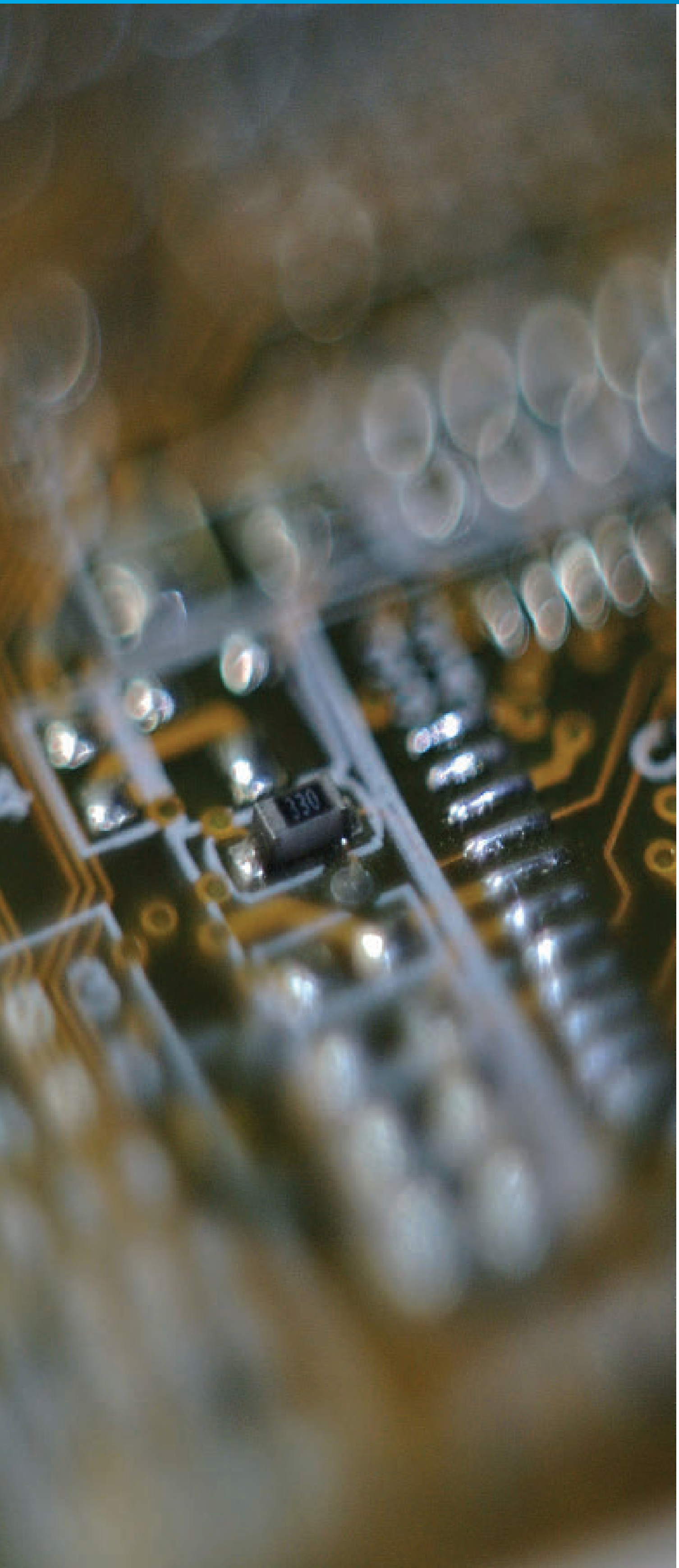
▲ Fig. 1 Measured nonharmonic suppression of the R&S SMA100B with the R&S SMAB-B711 option.

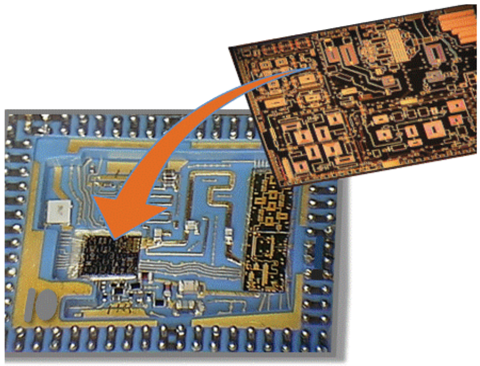
When Rohde & Schwarz decided to develop a successor to its R&S SMA100A and R&S SMF100A high-end RF and microwave signal generators, the design engineers set themselves a simple yet very challenging goal: to deliver the best possible performance for each key parameter, without any compromises or the requirement for customers to make tough decisions. The result is the R&S SMA100B, which can deliver the cleanest signals at the highest output power without any compromise. The new microwave signal generator strongly benefits three key applications:

A/D AND D/A TESTING

Integrated A/D and D/A converters deliver higher clock rates and an effective number of bits (ENOB) with each generation. Testing their performance requires clock and test signal sources exceeding the spurious-free dynamic range of device under test (DUT). Clean clock signals provide the best spectral purity for a D/A converter's analog output signal. The new R&S SMA100B specifies nonharmonics < 100 dBc for a 1 GHz carrier frequency and < 80 dBc for a 10 GHz carrier frequency, an improvement of 10 to 18 dB over its predecessors. ***Figure 1*** shows actual measurement results that are significantly lower.

High sampling frequencies and high ENOB require a signal source with very low broadband noise. Clock signals with low wideband noise do not degrade the signal-to-noise ratio (SNR) of the sampled input signal of an A/D converter. With the R&S SMA100B, an optimized RF design and a new, all digital level control loop provide a typical broad-





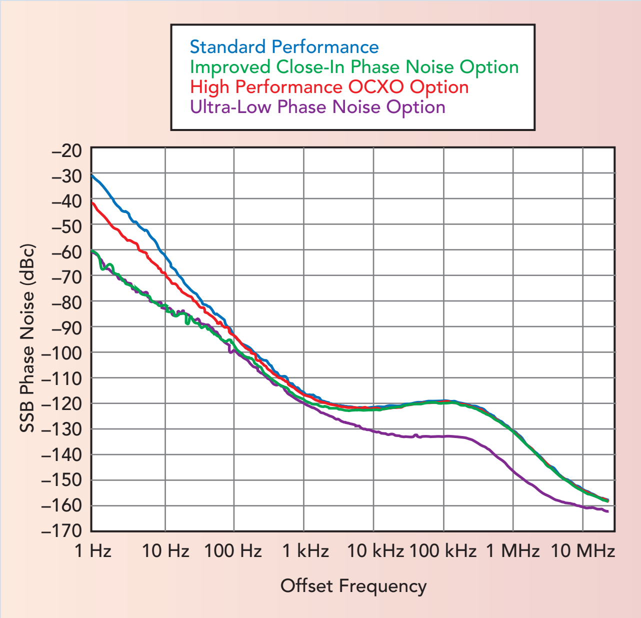
band noise of -160 dBc/Hz at 10 GHz carrier frequency, a value formerly achieved only by a few highly specialized signal sources.

Testing A/D converters often requires two signal sources: one for the DUT's clock and one for the analog signal. The microwave signal generator facilitates this by offering a high performance clock synthesizer option with ultra-low phase and broadband noise up to 6 GHz. The frequency of this additional synthesizer can be set independently of the main RF frequency. Sharing a common 1 GHz reference signal achieves very high phase stability between the output clock signal and the main synthesizer signal. To support single-ended and differential clock interfaces, the waveform, level and DC offset are programmable.

HIGH-END RADAR DESIGN

When designing and testing high-end radar systems, detection sensitivity is often limited by the phase noise of the RF signal source. The R&S SMA100B offers several low phase noise options to satisfy even the toughest requirements (see ***Figure 2***). Close-in phase noise performance can be as low as -60 dBc/Hz (typical) at 1 Hz offset and 10 GHz carrier frequency. For applications requiring the lowest possible pedestal phase noise, the signal generator offers a dedicated YIG oscillator option that enables -132 dBc/Hz (typical) at 10 kHz to 100 kHz offsets and 10 GHz carrier frequency. The R&S SMA100B defines a new, unprecedented high-end class in phase noise performance.

When testing radar systems, fast and well-controlled RF pulses are essential. With 5 ns (typical) rise/fall time and >80 dB on/off ratio, the R&S SMA100B pulse modulator is suitable for all radar applications. Modern radar equipment must be tested



▲ Fig. 2 Measured single sideband phase noise performance of the R&S SMA100B at 10 GHz.

with leveled short pulses that have high level accuracy and level repeatability. The pulse modulator of the new R&S SMA100B has been designed for that. It can deliver leveled short pulses with high level accuracy and repeatability down to the nanosecond range.

Most Valuable Product

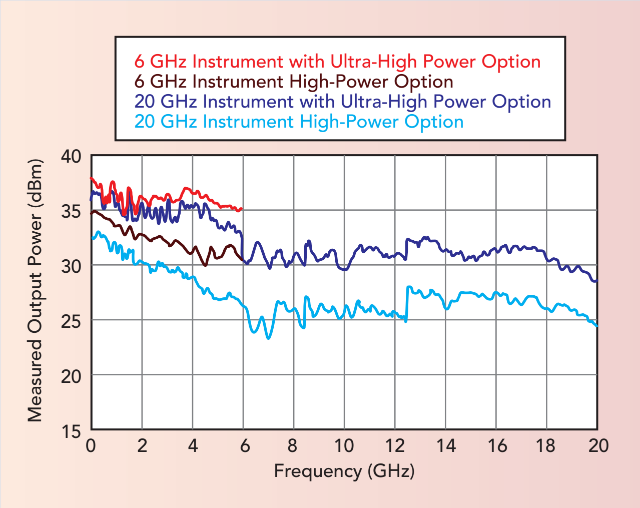
PRODUCTION MEASUREMENT OF MICROWAVE AMPLIFIERS

When testing high-power amplifiers, sufficient drive power is crucial. To satisfy cost-sensitive as well as highly demanding applications, the R&S SMA100B offers a three-stage output power option. A high output power option up to +35 dBm can be activated with an option key, even in the field. The factory fit ultra-high output power option offers power levels up to +38 dBm for the 6 GHz model (see ***Figure 3***), a performance previously unavailable from any general-purpose signal generator on the market, according to Rohde & Schwarz.

In addition, due to built-in filters, a harmonics suppression of -65 dBc (typical) is available up to high-power levels for all output power options. With this combination of very high output power, low harmonics and extremely low wideband noise, the R&S SMA100B makes external amplifiers and filters unnecessary and saves the customer from using complicated and expensive test setups consisting of multiple boxes.

In a production environment, it is important to keep down-time caused by service needs or malfunction of the automatic test equipment (ATE) system to a minimum. For signal generators up to 6 GHz, an electronic solid-state step attenuator has therefore been a de-facto standard for more than a decade. The R&S SMA100B now carries this technology into the world of microwave signal generators, offering solid-state switching for all frequency options up to 20 GHz as standard, allowing very fast and wear-free level switching.

All these features fit into a compact 19 in, 2 HU housing saving rack space. All R&S SMA100B signal generators are equipped with a convenient touch display and an easy-to-use graphical user interface (GUI), which makes operating the instrument very easy. For benchtop operation, users can optionally select a 19 in, 3 HU housing with increased 7 in touch display.



▲ Fig. 3 Measured maximum available output power of the R&S SMA100B.

VENDORVIEW

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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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Developed to address the ever-changing and proliferating threat environment, the 3DAWS suite protects aircraft during complex, multi-threat engagement scenarios through a layered countermeasure defense, allowing aircrews to safely complete their missions. It not only maximizes the effectiveness of current flare and directable infrared countermeasure systems, but it also provides the necessary tracking capabilities for future soft- and hard-kill countermeasure solutions to damage or destroy incoming threats.

"With the rapidly evolving threat environment, any future threat detection system must address a first-encounter threat scenario and must do so by efficiently and smartly utilizing fielded and future countermeasure techniques," said Cheryl Paradis, director of Threat Management Solutions at BAE Systems. "Our new 3DAWS solution provides the capability to first make a definitive threat assessment—determining whether a track is a false alarm or an incoming threat—and then quickly respond with the appropriate countermeasure."

> Product suite designed to significantly increase aircraft survivability from advanced threats

At the heart of 3DAWS is BAE Systems' passively-cued, semi-active radio frequency 3D Tracker™ technology. Serving as an adjunct to the company's Common Missile Warning System or any future passive threat detection system, the 3D Tracker technology provides the third dimension to the system's detection process and allows for definitive threat assessment.

Built to be highly modular and with open architecture standards, the 3DAWS suite integrates with all existing U.S. Army aircraft, has the flexibility to work with fixed- and rotary-wing aircraft and can be tightly integrated with existing radar or laser warning systems, providing a third dimension to those passive systems.

World's Most Powerful Emulator of Radio-Signal Traffic Opens for Business

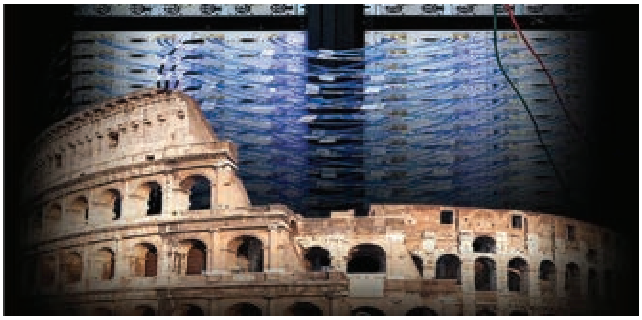
Though it resides in a mere 30 by 20 ft server room on the campus of the Johns Hopkins University Applied Physics Laboratory (APL) in Laurel, Md., the Colosseum is capable of creating a much larger and critically important wireless world. If all goes as planned during DARPA's three-year Spectrum Collaboration Challenge (SC2), competitors vying for $3.75 million in prize money will use the Colosseum as a world-unique testbed to create radically new paradigms for using and managing access to the electromagnetic spectrum in both military and civilian domains.

"The Colosseum is the wireless research environment that we hope will catalyze the advent of autonomous, intelligent and—most importantly, collaborative—radio technology, which will be essential as the population of devices linking wirelessly to each other and to the Internet continues to grow exponentially," said SC2 Program Manager Paul Tilghman. Traditional wireless communications systems are defined by a specification—a document that is the product of years of study and debate, and prescribes precisely how a radio system will work and how, if at all, it will get along with other radios. "We are asking SC2 competitors to devise fundamentally new radio systems that can learn from each other in real-time, making the need for arduous radio specifications obsolete," Tilghman said.

On the surface, the Colosseum appears as a drab set of electronic racks. Yet it is a path-breaking testbed that can emulate tens of thousands of possible interactions among hundreds of wireless communication devices—including cell phones, military radios, IoT devices and a litany of others—operating simultaneously in a square-kilometer expanse. That is an area some 40× that of the Roman Colosseum's six acres. DARPA's Colosseum amounts to an artificial, high-fidelity holodeck that can simulate invisible, fast-as-light communication signals traversing, ricocheting, echoing and otherwise making their way from transmitters to receivers wherever they might be in a wide variety of simulated environments. Said Tilghman, "The Colosseum can make the radios believe they are operating in an open field, a dense city, a suburban shopping mall, a desert or any other scenario you can dream up."

Engineers at APL assembled the Colosseum with 128, two-antenna, software defined radio (SDR) units built by National Instruments (NI). Emulating electromagnetic waves from these radios traversing the physical world is no small task. To tackle this, APL partnered with NI to put 64 field programmable gate arrays (FPGAs) to the task. The FPGAs enable the Colosseum to make the SDRs behave as though they are operating in any of countless environments, each designed like an electromagnetic movie set.

By the numbers, the Colosseum testbed is a 256-by-256-channel RF channel emulator, which means it can



Source: BAE Systems

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calculate and simulate in real-time more than 65,000 channel interactions among 256 wireless devices. Each simulated channel behaves as though it has a bandwidth (information content) of 100 MHz, which means the testbed supports 25.6 GHz of bandwidth in any instant. Moreover, each channel's transmission and reception frequency is tunable between 10 MHz (as in broadcast FM radio) and 6 GHz (as in Wi-Fi). The amount of digital RF data coursing through the Colosseum each second, more than 52 terabytes, exceeds the estimated amount of information contained in the entire print collection of the Library of Congress. In short, said Tilghman, "the Colosseum is a magnificent electronic arena and just what we need to discover how to eke more capacity from the frustratingly finite spectrum."

US Navy's Enterprise Air Surveillance Radar Completes Major Design Review

Raytheon Co. and the U.S. Navy recently conducted a Preliminary Design Review (PDR) for the new Enterprise Air Surveillance Radar (EASR), confirming system development is on track for delivery to the designated ship classes. The PDR followed several milestones completed as planned on the development schedule, including the combined Systems Requirements and System Functional Reviews, and the Integrated Baseline Review.

EASR is the U.S. Navy's advanced radar for aircraft carriers and amphibious warfare ships, providing simultaneous anti-air warfare, anti-surface warfare and air traffic control mission capabilities. It delivers increased performance, higher reliability and sustainability and lower total ownership cost than the radars it replaces. EASR is the replacement for the Volume Search Radar for the CVN 78 class, and the AN/SPS-48 and AN/SPS-49 radar systems for numerous ship classes.

The PDR validated Raytheon's scaled design leveraging the AN/SPY-6(V) Air and Missile Defense Radar, configured into a rotating and a fixed face variant to match the missions of the multiple ship classes. EASR is built on Radar Modular Assembly (RMA) technology which has been matured through development–and recent test successes–of AN/SPY-6 for the DDG 51 Flight III destroyers. Each RMA is a self-contained radar in a 2 ft x 2 ft x 2 ft box. These individual radars can integrate together to form arrays of various sizes.

The commonality, in both hardware and software, with SPY-6 offers a host of advantages, including performance, availability and reliability, maintenance, training, logistics and lifecycle support.

Consortium Demonstrates Ultra-High Throughput Transmission Over Satellite

A European consortium consisting of the Fraunhofer Institute for Integrated Circuits IIS, WORK Microwave and Avanti Communications has completed highly successful over-the-air trials on Avanti HYLAS satellite capacity employing the latest DVB-S2X modulator and demodulator equipment. The demonstrations used wideband carriers exploiting full transponder bandwidth and outperforming the target throughput of more than 1 Gbps using a single communication carrier.

The technology demonstration was part of a development funded by the European Space Agency (ESA) under the ARTES Advanced Technology via the ultra-high throughput transmission through wideband Ka transponder contract.

> "...exceptionally efficient use of spectrum."

The experiments demonstrated a variety of carrier bandwidths and modulation schemes. This included closing the forward link with a 480 MHz carrier and successfully receiving and demodulating this signal on the ground. The sustained throughput to a single end-user terminal was measured at 1.27 Gbps, leveraging from the DVB-S2X time slicing capability that allows the receiver to selectively skip and ignore parts of the incoming signal and thus save on processing power. DVB-S2X, as the latest satellite communication standard allows for, an exceptionally efficient use of spectrum.

Fraunhofer IIS developed a DVB-S2X receiver IP that was used for the technology demonstration, while WORK Microwave developed a high-performance wideband DVB-S2X modulator, which was used for the communication on the uplink. The FPGA-based, modular design of modulator and demodulator enables different products and throughput ranges, up to the maximum spectral efficiency supported by DVB-S2X on wideband carriers. U.K.-based Avanti Communications provided engineering support and HYLAS Ka-Band transponder capacity for the live demonstration.

"The successful demonstration of this next-generation technology confirms the innovation-led competitiveness of the European space industry and the capabilities of the European satellite fleet, as well as the importance of the ARTES Advanced Technology program to fund such developments," said Nikolaos Toptsidis, the technical officer managing the activity on behalf of ESA.

Finland's First 5G Development Environment Opens to Businesses

The VTT Technical Research Centre of Finland, the University of Oulu and the Centria Polytechnic will take their 5G test environment to a new stage with the emphasis on vertical business use. There is already a large number of Finnish companies with whom 5G technology has been developed that will be tested in several application areas, with new solutions targeted for field trials during 2017.

> ...the opportunity to experiment with technology...

In the 5GTN+ project, mostly funded by Tekes, future technology is applied to field testing even before commercial networks emerge. Thus, the opportunities offered by 5G technology will be utilized as early as possible, offering companies the opportunity to experiment with technology in their specific areas of application. The project, which focuses on seeking clear business benefits for partner companies, aims to strengthen the position of Finnish industry as a developer of new 5G technologies and applications.

"The 5G test environment supports corporate product development. Its benefits are reflected, for example, in high-speed and reliable connections, short delays, energy savings and connectivity," said Project Manager Atso Hekkala from VTT.

"We provide the test network and related skills for everyone to use. We are also welcoming companies outside the project who are interested in taking advantage of new technology in their business among the first," said Project Manager Olli Liinamaa from the University of Oulu.

Infineon Joins 5G Automotive Association

In its continued efforts to contribute to the introduction of the 5G standard into the car, Infineon Technologies has joined the 5G Automotive Association (5GAA), which works to introduce new communication solutions, enabling connected automated driving and intelligent transport systems. As a leading semiconductor company for automobile electronics, cellular infrastructure and data security, Infineon provides key technologies required for 5G for the autonomous car and for electromobility.

Enhanced mobile broadband access at multi-gigabit speeds requires advanced semiconductor solutions. Infineon provides high-frequency components

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that receive, amplify and transmit data, as well as components for antenna tuning and switching. In addition to its broad portfolio of automotive electronics, Infineon supplies security chips that help secure the data communication inside a vehicle and with its external world.

"Secure communication with practically zero time delay is a critical requirement for the breakthrough of autonomous driving," said Peter Schiefer, president of the automotive division at Infineon. "In close cooperation with the car industry and IT, Infineon supports the communication solutions for the automated car with its cutting-edge semiconductors and with system and security expertise."

Broadband Forum Partners with SDN/NFV Industry Alliance in China

The Broadband Forum and SDN/NFV Industry Alliance have signed a Memorandum of Understanding to jointly set up an Open Broadband Laboratory Asia (OBLA) and promote the development of network transformation and cloud evolution.

Open Broadband Labs are a collaborative resource for the integration, staging and testing of open source, commercial software, standards-based and vendor implementations where suppliers, integrators and operators can work together on new and coexisting solutions. The focus of Open Broadband Labs, such as OBLA, is acceleration of go-to-market and go-to-production for new services and applications, and the migration from existing broadband infrastructures to cloud-based ones introducing NFV and SDN technologies.

Under the agreement, the Forum will exclusively license the SDN/NFV Industry Alliance to undertake the construction of OBLA in China and to conduct conformance and interoperability testing, migration best practices, technical due diligence and training around the project. The SDN/NFV Industry Alliance will build and manage the OBLA, while the Forum will provide technical direction, testing methods, a standards framework and domain expertise. The aim of the project is to develop network cloud standards verification, testing, solution conformance and a proving ground for new services.

"This new lab facility is a strategic and natural evolution of the Forum's ongoing work on virtualization and cloud, with almost every project in our current scope now connected to these next-generation network technologies. We look forward to strengthening this work with the SDN/NFV Industry Alliance," said Broadband Forum Chairman Kevin Foster of BT.

Autonomous Vehicles and Safety Mandates Spur Increase in Automotive Radar Demand and Performance

The recent developments in autonomous vehicles and new "soft mandates" from safety agencies, such as Euro-NCAP, are raising requirements for enhanced resolution and 360-degree sensing. This will increase demand for automotive radars as well as bring about the introduction of new technologies, such as RF CMOS. This technology is used in the NXP Dolphin chipset that Hella will use in its fifth generation short range radars.

RF CMOS enables even greater integration of chipsets than current silicon germanium-based designs. It thus will allow the size of short range radars to be reduced even further, potentially enabling them to challenge the current market for ultrasonic sensors in high-end park assist applications.

In the meantime, radar resolutions are being improved by the current switch over to higher frequencies from 76 to 79 GHz and to the higher bandwidths enabled by these frequencies. Backed by learning algorithms and new modulation techniques, automotive radars will be more capable of identifying different targets. This raises the prospect of future radars recognizing pedestrians and even curb stones, as well as enhancing the robustness of detecting such targets and reducing false positive readings.

"This enhanced capability is what is required by autonomous vehicles, along with corner or surround radar concepts that provide redundant sensing, on top of cameras and lidars, and in adverse weather conditions," said Kevin Mak, senior analyst at the Automotive Practice of Strategy Analytics. "But with this increase in performance comes the challenge of processing and transmitting larger rates of data, which can pose a dilemma on how auto makers design their vehicle architectures in the run-up towards autonomous vehicles," Mak added.

Telco Cloud to Reach Critical Mass after 2020, Driven by 5G

Large-scale telco cloud deployments will reach global critical mass after 2020, in parallel with the deployment for 5G. This network generation will likely require a new core network to allow for advanced concepts, including network slicing and services geared toward different business verticals. Early 5G deployments, during which time there will not be an immediate need for a new telco core, will likely focus on enhanced mobile broadband.

"Although telcos are transforming their technology and business platforms to become more agile and to evolve past their monolithic access-based business models, they are finding it much more challenging than anticipated," said Dimitris Mavrakis, research director at ABI Research. "Software, cloud computing and open source are promising and will simplify operations, but in the short term, telcos are preferring to rely on their trusted vendors to continue this journey."

AT&T, DT, Telefonica and Verizon are honing their strategies and planning their networks as shared platforms, rather than a mix of individual network appliances. This means that network resources will be virtualized, distributed and software controlled, leading to a much more agile network. This will allow the implementation of an "Untelco" strategy, selling tailored network resources to different verticals.

However, there are a few indications that end-to-end systems are still the end goal. For example, Telefonica O2 U.K. awarded an end-to-end contract to Nokia for a cloud-native packet core, something that would be a considerable challenge to implement in-house with a true vendor agnostic, common-off-the-shelf network. ABI Research expects many more end-to-end telco cloud contracts will be awarded in the years to come.

"Although a few open source projects are contributing valuable inputs toward the evolution of telco networks, there is also competition among open source projects, and the concept is also misunderstood and in some cases, misused by several industry players," concludes Mavrakis. "The golden ratio is somewhere between end-to-end systems and open source components, if vendors provide open interfaces and flexibility to integrate third-party and smaller vendors."

China, Japan and South Korea Lead Asian Smart City Initiative Deployments

Governments in China, Japan and South Korea lead the deployment of citizen-centric, smart city initiatives in Asia. Specific leading cities in China that continue to show accelerated adoption of smart energy solutions include Dalian, Hangzhou, Nanjing and Tianjin. The smart city programs improve overall quality of life, boost enterprise operational efficiencies and enhance the effectiveness of public safety and security, transportation, citizen engagement, catastrophe management and sustainability services.

"Asia's demand for smart city solutions will heighten over the next five years with China, Japan and South Korea now accelerating adoptions of smart light, meter, building and transportation, as well as renewable energy programs," says Raquel Artes, industry analyst at ABI Research. "All three countries possess strong wireless communication networks, which likely account for

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the regions' ability to rapidly deploy many smart city initiatives in a timely and cost-efficient manner."

Estimates are that China smart meter installations will grow at a 21 percent CAGR to reach 349 million in 2020 through vendors like Itron, Echelon, Huawei, Holley Metering, Itron, Landis+Gyr and Sensus. The region also aims to have five million electric vehicles (EV) on the road by 2020. With Japan and South Korea targeting one million and 200,000 EVs, respectively, on the road by 2020. Key EV vendors include BAIC, BYD, Geely and Tesla, among others.

All three countries lead multi-applications smart card deployments that enable cashless payment for transportation, parking fees and toll road fees. Ridesharing programs are also gaining traction, as evident through car manufacturers like Hyundai deploying car sharing services in South Korea that utilize EV.

And while smart parking initiatives in Asia are still at a minimum, China acts as the region's catalyst. China Unicom, Huawei and the Shanghai government recently signed a strategic partnership to implement a smart parking solution in Shanghai International Tourism and Resorts Zone, which will deploy in a 4.5G NB-IoT based network. Smart parking enables parking operators and drivers to remotely check and locate available parking spaces in real-time. It, therefore, reduces labor requirements of parking operators, optimizes usage of parking spaces and reduce public parking costs.

> "Asia's demand for smart city solutions will heighten over the next five years..."

Japan also recently launched a smart catastrophe management program, which included an Emergency Warning System developed by NEC, to detect and issue a warning that will alert both the government and citizens of upcoming natural catastrophes and identify high-risk areas to promote quicker response times and resource dispatches.

Yet, despite significant smart city developments in China, Japan and South Korea, India and Indonesia are failing to keep pace. While both regions are deploying smart city projects designed to enhance public safety and reduce energy consumption, they struggle to lead in these market segments.

"India and Indonesia are lagging behind primarily due to a lack of infrastructure readiness," concludes Artes. "While there are vast opportunities for smart city vendors in India due to the governmental spearhead of wireless network and communications infrastructure development, the region is not fully capitalizing on those opportunities. This may soon change, as the government recently announced that it will develop 100 smart cities in the region as part of its Smart City program."

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ATC Series	EIA Size	Capacitance	Frequency Range	Insertion Loss	Voltage Rating
520 L	0402	10 nF	160 KHz to 16 GHz	1 dB max.	16 WVDC
530 L	0402	100 nF	16 KHz to 18 GHz	1 dB max.	16 WVDC
530 Z	0201	100 nF	16 KHz to 20 GHz	0.4 dB typ.	10 WVDC

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Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

Analog Devices Inc. (ADI) announced the acquisition of **OneTree Microdevices Inc.**, a privately held company based in Santa Rosa, Calif. ADI is a leading supplier of mixed signal solutions for cable access ranging from data converters through clocking and control/power conditioning. With the acquisition of OneTree Microdevices' GaAs and GaN amplifier portfolio, which offers best-in-class linearity, output power and efficiency, ADI now supports the complete signal chain for next-generation cable access networks. Financial terms of the transaction were not disclosed.

Infinite Electronics Inc., a holding company for the Pasternack, Fairview Microwave and L-com brands, announced the acquisition of **Smiths Interconnect's Microwave Telecoms** (SMT) business from **Smiths Group plc**, a London based global technology company. SMT is comprised of the Kaelus, PolyPhaser, Transtector Systems and RadioWaves brands. Each of these companies provides a unique set of capabilities and product offerings deployed in critical communications networks worldwide, while also setting global standards through innovation and customer service. Collectively, SMT is committed to ensuring reliable communications network performance from the tower to the core.

Crane Co., a diversified manufacturer of highly engineered industrial products, announced that it has acquired **Westlock Controls** from **Emerson Electric Co.** for cash consideration of $40 million. Westlock is a global leader in the manufacturing and sale of switchboxes, position transmitters and other solutions for networking, monitoring and controlling process valves. With primary operations located in Saddle Brook, N.J., Westlock had 2016 sales of approximately $32 million. Crane is a diversified manufacturer of highly engineered industrial products. Founded in 1855, Crane provides products and solutions to customers in the hydrocarbon processing, petrochemical, chemical, power generation, unattended payment, automated merchandising, aerospace, electronics, transportation and other markets.

NEW STARTS

CORWIL Technology announced that is now offering its customers RF measurement capability up to 50 GHz. CORWIL Technology provides high quality and responsive semiconductor assembly and test services focusing on hi-rel, fast-turn and wafer processing markets. Founded in 1990 and based in Milpitas, Calif., CORWIL is the premier U.S. provider of full back-end assembly services and is a key partner with leading medical, military/aerospace and commercial semiconductor companies.

ACHIEVEMENTS

Microwave engineers at **RCL Microwave Inc.** in Apalachin, N.Y. have executed their first successful test and dielectric measurement of a thin, flexible 200 micron thick glass material using novel measurement fixtures and methods capable of broadband dielectric material characterization. The test was performed and successfully completed using unique broadband measurement fixtures and the phase difference method, which provides 10,000 data points from 1 MHz to 32 GHz. A 32 GHz broadband test fixture has been combined with the Phase Difference Dielectric Characterization Method to generate data across the entire frequency spectrum of interest.

Raytheon Co. and the **U.S. Navy** conducted the Preliminary Design Review (PDR) for the new Enterprise Air Surveillance Radar (EASR), confirming system development is on track for delivery to the designated ship classes. The PDR followed several EASR milestones completed as planned on the development schedule, including the Combined Systems Requirements and System Functional Reviews and the Integrated Baseline Review. EASR is the U.S. Navy's advanced radar for aircraft carriers and amphibious warfare ships, providing simultaneous anti-air warfare, anti-surface warfare and air traffic control mission capabilities. It delivers increased performance, higher reliability and sustainability and lower total ownership cost than the radars it replaces.

CONTRACTS

CACI International Inc. announced that it has been awarded $349 million in previously unannounced awards on classified contracts with federal government customers. The awards were made during the company's first three quarters of fiscal year 2017, which ended March 31, 2017. For these contracts, CACI is delivering tailored information solutions and services to national-level agencies safeguarding our nation's security. CACI provides information solutions and services in support of national security missions and government transformation for intelligence, defense and federal civilian customers. CACI is a member of the Fortune 1000 Largest Companies, the Russell 2000 Index and the S&P SmallCap600 Index. CACI's sustained commitment to ethics and integrity defines its corporate culture and drives its success.

Engility Holdings Inc. won the re-compete of the Systems and Software Assurance Services contract from **NASA's Goddard Space Flight Center**. Engility will help NASA's Independent Verification and Validation (IV&V) program support missions to explore Earth and the universe, including future moon and Mars expeditions. Under the IV&V contract, Engility's technical efforts will help NASA procure, develop, deploy and operate systems and software to meet exacting performance demands. By employing analytical techniques,

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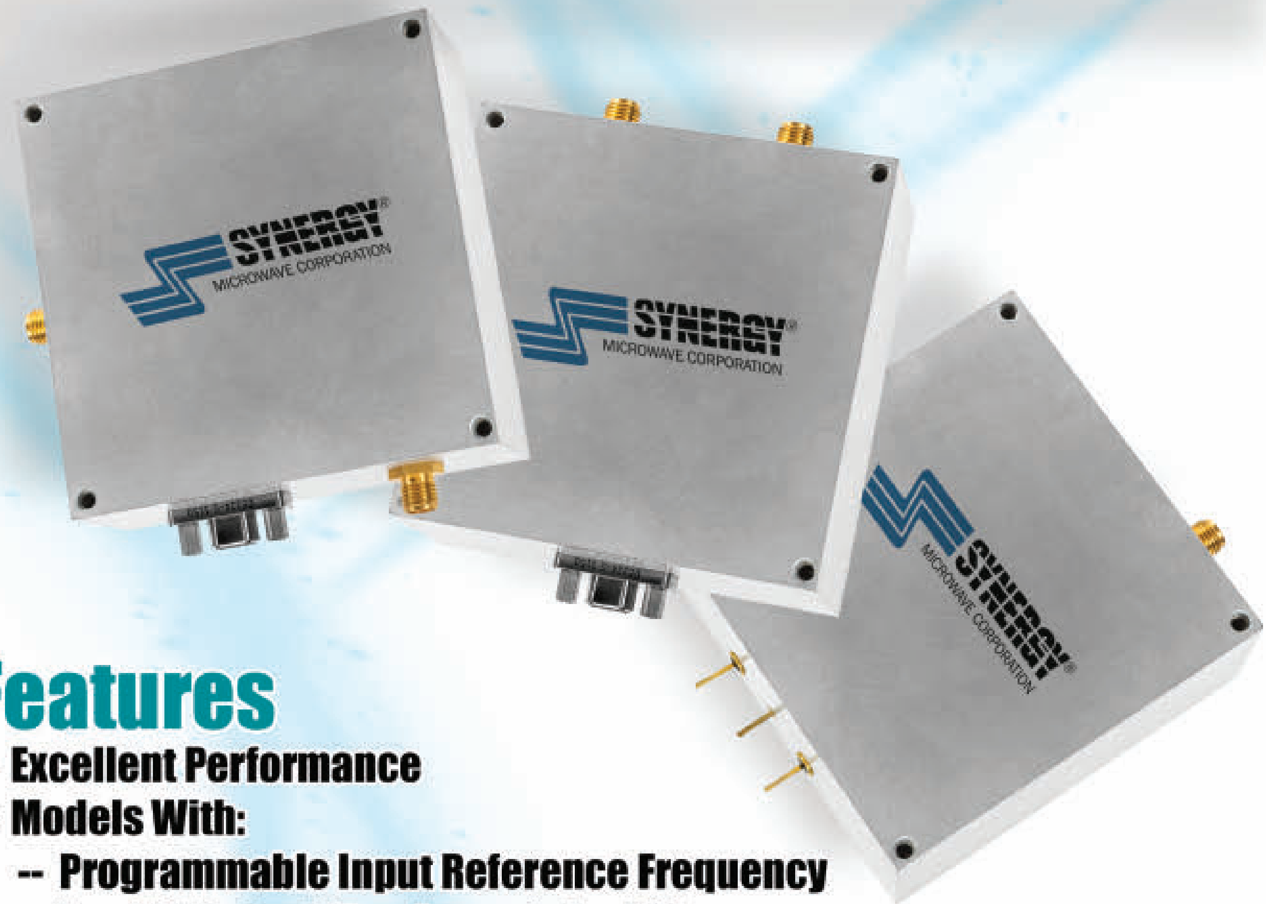
Fixed (Dual Output)	10	120 / 240	-125 / -130	LNFTD-10-120240-12
Fixed	10	1000	-110	LNFT-10-1000-15



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security assessments and independent testing, Engility will add assurance that system software will operate safely, reliably and securely to achieve mission success.

BWX Technologies Inc. (BWXT) announced that the **U.S. Naval Nuclear Propulsion Program** exercised contract options in Q1 2017 with BWXT's subsidiary **Nuclear Fuel Services Inc.** (NFS) totaling approximately $141.7 million for fuel manufacture, development activities and decommissioning work in support of the nation's nuclear submarines and aircraft carriers. NFS has been the sole manufacturer of nuclear fuel for the U.S. Navy's fleet of nuclear-powered aircraft carriers and submarines since 1964. The company employs a full-time workforce of approximately 1,000 people, including long-term contractors and security personnel.

Cubic Global Defense, a business unit of **Cubic Corp.**, announced it received a contract award worth more than $35 million to continue supporting the British Army. The three-year contract allows Cubic to deliver services and repair to the Area Weapons Effects Simulator (AWES) at Salisbury Plain Training Area (SPTA) in the U.K. and at the British Army Training Unit Suffield (BATUS) in Alberta, Canada. AWES allows the British Army to conduct large-scale, force-on-force combat exercises with realistic, but simulated effects of direct fire, artillery, mortar fire, mines and air-delivered munitions as well as nuclear, biological and chemical weapons.

OSI Systems Inc. announced that its Security division has received a Foreign Military Sales (FMS) two-year contract extension from the **U.S. Department of Defense** valued at approximately $23 million to provide training, service and logistics support for its Rapiscan® cargo and vehicle inspection systems. OSI Systems is a vertically integrated designer and manufacturer of specialized electronic systems and components for critical applications in the homeland security, healthcare, defense and aerospace industries. They combine more than 40 years of electronics engineering and manufacturing experience with offices and production facilities in more than a dozen countries to implement a strategy of expansion into selective end product markets.

Sparton Corp. and **Ultra Electronics USSI**, a subsidiary of **Ultra Electronics Holdings plc** (ULE), announced the award of subcontracts valued at $17.4 million from their **ERAPSCO/SonobuoyTech Systems** joint venture. ERAPSCO/SonobuoyTech Systems will provide manufacturing subcontracts in the amount of $11.2 million to Ultra Electronics USSI and $6.2 million to Sparton De Leon Springs, LLC. Production will take place at Ultra Electronics USSI's Columbia City, Ind. facility and Sparton's De Leon Springs, Fla. facility. ERAPSCO/SonobuoyTech Systems were awarded multiple foreign contracts for the manufacture of passive and active sonobuoys in support of multiple underwater missions for detection, classification and localization of adversary submarines during peacetime and combat operations.

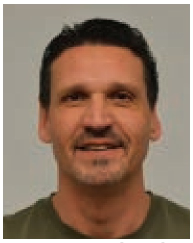
Comtech Telecommunications Corp. announced that during its third quarter of fiscal 2017, its Tempe, Ariz.-based subsidiary, **Comtech EF Data Corp.**, which is part of Comtech's Commercial Solutions segment, received a $1.8 million contract award extension for additional Advanced Time Division Multiple Access (TDMA) Interface Processor (ATIP) production terminals and Engineering Support Services from the **Space and Naval Warfare Systems Command** (SPAWAR). The contract extension also included exercising options under an Engineering Support Services option to participate in integration and test activities to validate the U.S. Navy's planned PPPoE interface between the ATIP and Automated Digital Network System (ADNS).

Elbit Systems Ltd. has announced that it was awarded a contract to provide the **Israeli Ministry of Defense** (IMOD) with dozens of satellite-on-the-move (SOTM) systems. The contract is in an amount that is not material to Elbit Systems and will be performed over a two-year period. The ELSAT 2100 SOTM family of systems allows high data rate broadband capabilities to be available to land vehicles on the move. The systems can be installed on a variety of platforms and are unique in their small footprint and its advanced tracking capabilities, providing seamless communication even in difficult terrain.

PEOPLE

▲ *Robert Bagheri*

Telewave, Inc., a leading manufacturer of RF and microwave products for public safety, land mobile radio and other radio communications services, announced that **Robert Bagheri** has joined the company as chairman and chief executive officer. Mr. Bagheri has more than 35 years of experience in executive, management and engineering positions within the electronics industry. Before joining Telewave, Mr. Bagheri was founder, investor and chairman of a stealth start-up serving the wearables and mobile markets.

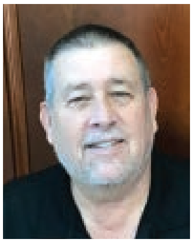


▲ *Nick Doben*

TechPlus Microwave Inc., a technology leader in the design and manufacture of RF and microwave filters, announced that **Nick Doben** has joined the company as senior program manager for aerospace, hi-rel and defense. With over 20 years of experience in the RF and microwave community, Doben will provide program management solutions and coordination in aerospace, defense and hi-rel.

Indium Corp. has named **Chris Nash** as product manager for PCB Assembly Materials. Nash is responsible for managing new solder paste product development, including strategy guidance and execution, directed to sales to the printed circuit board industry. In addition, he will provide solder paste product support, including leading marketing communications efforts, delivering field sales and technical team training and interfacing

with manufacturing for increased customer support. Nash has worked for Indium Corporation for more than 10 years and has served in a number of roles, including inside sales, product management and global technical support. His most recent role was as new product development manager for PCBA.



▲ Paul White

Modelithics announced that **Paul White** has been named as the newest member of the Modelithics Board of Directors. White brings an extensive and impressive resumé of business and technical knowledge to the company, with over 35 years in the RF and microwave industry. White's early experience includes the engineering of low noise and high power solid state amplifier systems for next generation fire control radar systems, and in sales and marketing of a Hewlett Packard test and measurement product line. He then became a partner at Applied Engineering Consultants, selling microwave hardware and software into the defense and intelligence marketplace.

▲ Ashleigh West

Ashleigh West has joined ***Microwave Journal*** as copy editor. Ms. West utilizes her specialized writing background to deliver polished editorial content in each print issue and for *Microwave Journal*'s online content. Ms. West's monthly columns include the events calendar and marketing updates. She also produces the weekly Microwave Flash newsletter and the Military Microwaves monthly newsletter, and helps to co-manage *Microwave Journal*'s social media presence across Facebook, Twitter and Instagram.

REP APPOINTMENTS

Ametherm announced that it has expanded its network of value-added representatives in the U.S. with the conclusion of a new agreement with **Unity Sales**. Effective immediately, Unity Sales is offering Ametherm's entire lineup of inrush current limiters and NTC thermistors in Ohio, Indiana, Michigan, Kentucky, Western Pennsylvania and West Virginia. Based in Fort Wayne, Ind.—with offices in all markets it serves—Unity Sales was founded in 2002 and provides cost-effective technology solutions to the transportation, medical, automotive, instrumentation, industrial, consumer and military/aerospace industries.

Anokiwave Inc., an innovative company providing highly integrated IC solutions for mmW markets and active antenna based solutions, announced that they have signed a representative agreement with **M-RF Co. Ltd.** in Japan. The agreement aligns with Anokiwave's goal to support new customers and opportunities for their

highly-integrated Active Antenna Core IC solutions in Japan. M-RF Co. has specialized in high frequency components for 21 years and is focused on sales and technical service that matches leading high frequency component manufactures to customers in Japan.

RFuW Engineering Ltd., the industry's leading supplier of high-power, high reliability SMT RF limiters and switches, announced the appointment of **RFMW Ltd.** as the company's global distributor. RFMW offers customers worldwide sales coverage from their three pronged base of operations in the U.S., Asia and Europe. There are tremendous synergies created by the partnership between RFuW Engineering's uniquely positioned products and RFMW's broad set of customer relationships.

Southwest Antennas, an industry leader in rugged RF and microwave antennas and accessory product solutions, announced the appointment of **Aerocomm Technical Sales** as their new sales representative firm for the states of Arizona, Utah, New Mexico and Colorado. Aerocomm Technical Sales is based out of Phoenix, and will be representing the full line of Southwest Antennas products, including omni-directional and directional antennas, multi-port MIMO antenna products, RF coaxial gooseneck adapters, antenna mounts, filters and other RF and microwave accessories. For more information, visit their website at www.aerocommsales.com, email sales@aerocommsales.com or call (602) 419-5422.

PLACES

NAI, a leading manufacturer of end-to-end connectivity solutions for high performance systems in industrial, telecom, data and medical industries, has announced the opening of its fourth plant in Hermosillo, Mexico, and the expansion of a current plant. The new 27,000 square foot Plant No. 4 operation is dedicated to the manufacture of copper cable assemblies and harnesses for their growing customer segments in medical device and equipment manufacturing and in industrial technology sectors. The new facility is located only two miles away from existing plant operations. Current production workers, engineers, quality control staff and management have transferred to the new facility.

Boeing has selected a site in Plano, Texas, for the headquarters of its new Global Services business unit, which will be operational in July. Boeing Global Services headquarters will be located in the Legacy West mixed-use development in West Plano. Global Services President and CEO Stan Deal, several of his leadership team members and some support staff will be located at the site, which will serve as a central hub for approximately 20,000 employees located around the globe. Boeing selected the greater Dallas area because it is centrally located within Boeing's U.S. footprint, has good proximity to major operations for commercial customers and defense partners and serves as a transportation hub that will allow the company to reach customers quickly and efficiently.

INVITED PAPER

Network Synthesis and Power Amplifiers: So Much More than Impedance Matching

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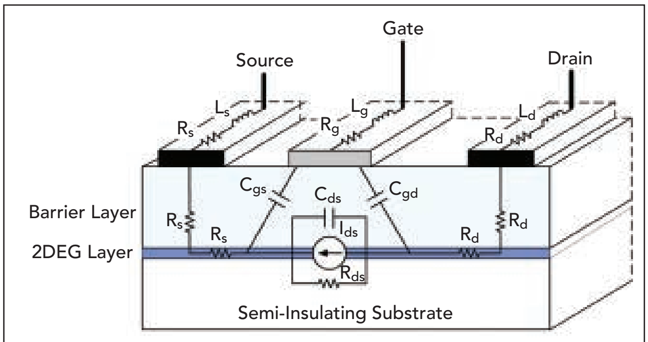
New materials and technologies are providing designers with the opportunity to produce solutions that could not be accomplished in the past, opening new avenues for innovative power amplifier (PA) design. The goal of every PA designer is to achieve the maximum performance from the transistor at hand; this is as true today as ever. Multi-standard requirements for wireless infrastructure are driving the need for broadband PAs capable of achieving performance across several bands. The requirement for power at ever-increasing frequencies is driving the development of n-dimensional power combiners and multiple-input-multiple-output systems (MIMO). The complexity of communication systems is driving a need to go beyond traditional approaches to impedance matching circuits and use such techniques as network synthesis.



▲ **Fig. 1 Classic representation and small-signal model of an HFET/HEMT transistor, such as GaN.[1]**

Network synthesis requires an understanding of the components of a dynamically interacting system and designing a network that compels the desired performance. It is used widely in control, robotics and mechanical systems and is gaining renewed interest from the electrical engineering community, the field in which it originated. However, it has been somewhat neglected in the field of PA design: the output matching network is often considered to be just a passive circuit rather than part of a dynamic nonlinear system. Network synthesis provides a method of designing an interactive system, given a desired frequency or time domain response, with metrics such as power, efficiency and linearity. Such a system may include a passive or non-passive network that interacts with an active, often nonlinear device, the PA in this case. Let's begin with the motivation for why network synthesis techniques are needed for PA design, considering the behaviors of transistors in a few popular PA architectures.

MOTIVATION: PA DESIGN FOR DIFFERENT APPLICATIONS

In any approach to designing a PA, consideration must be given to how the active

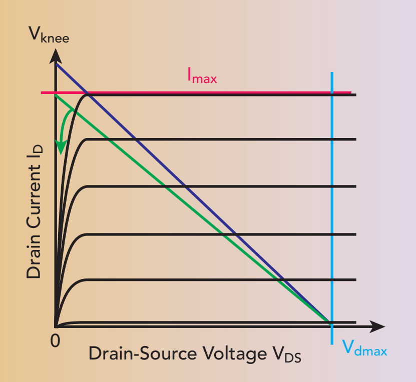


Fig. 2 DC IV characteristics of a typical device.

device behaves in the intended environment. There are many approaches to PA design, including load modulation, envelope tracking, harmonic termination and design for a varying load. While these techniques all have a different approach to shaping the performance of the active device, it really is all about the interaction between the device and the driving point impedance that it "sees." The HFET or HEMT device, typical of modern GaN RF power transistors, illustrates the active device (see ***Figure 1***).

What is going on in the transistor? The driving point impedance defines the interaction of the voltage and current at the terminals of the device and determines the power and efficiency. In an ideal device, the maximum output power and maximum efficiency occur at the same driving point impedance. What prevents this in a real device? The answer is harmonics, which shape the time domain waveforms and give the ideal efficiencies of the different classes of PAs, but can also reduce the amount of power generated by the amplifier. The time domain waveforms are defined by the impedances presented to the device over frequency. The harmonics are generated by the clipping that occurs from the knee voltage in the device and at V_{dmax} (see ***Figure 2***), where the voltage is limited.

The gate and drain voltages control how the charge flows in the channel of the transistor. By shaping these voltages with the driving point impedances, the behavior of the amplifier is shaped. Remember that the charge we are talking about is a combination of the mobile charge in the channel and the stored charge. The mobile charge is resistive and the stored charge is reactive, so the mobile charge can be manipulated with the real part of the load and the reactive charge can be manipulated with the imaginary part of the load.

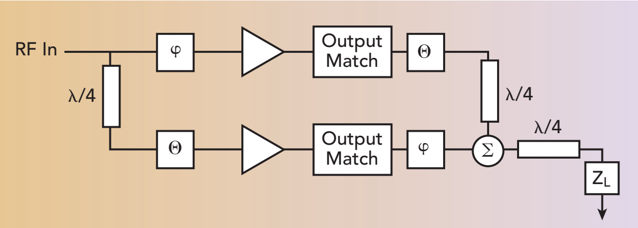


Fig. 3 Two-way Doherty PA.

Doherty Amplifier Design

The Doherty principle[2] is an efficiency enhancement technique that relies on modulating the driving point impedance presented to a transistor using active load-pull techniques. The Doherty PA combines the outputs of two or more transistors that are offset by a quarter-wave transformer (see ***Figure 3***). At low power, only the carrier amplifier is on, resulting in a greater efficiency than with a single transistor amplifier designed for full power. As the input power increases, the carrier amplifier is driven into saturation, and the peaking amplifier is driven on, changing the driving point impedance presented to the carrier amplifier, and hence its behavior. In an ideal Doherty PA design, the carrier amplifier's load is pulled from its maximum efficiency point to its maximum power point.

Under Doherty load modulation the current through the transistor changes, so the charge in the channel changes. The carrier device can be viewed as a current source until it reaches saturation, when its behavior becomes that of a voltage source. When the peaking device turns on, it also behaves as a current source until saturation. As the peaking device is driven to maximum power, the Doherty PA can be represented as a voltage source (carrier device) in parallel with a current source (peaking device).

Supply Modulation Amplifiers

In dynamic supply modulation schemes such as envelope tracking (ET), the supply voltage V_d is varied to maintain high efficiency for all input power levels, by keeping the voltage swing at the maximum value of V_d–V_{knee}. Under drain modulation, the gate voltage is usually kept constant, so C_{gs} stays roughly constant, and the voltage across the channel of the device changes with the voltages across C_{ds} and C_{gd}. As a result, two things happen: the charge on these capacitors will change, and generally the capacitance itself is voltage dependent and changes under supply modulation.[3] Two effects are seen from this: The simple capacitance model is not good enough, because it is charge that is being manipulated by the drain modulation, so a fully charge-conservative model is desirable.[4,5] Second, for GaN devices, the variation of C_{ds} with drain voltage is very small, making the GaN process attractive for drain modulated PAs; C_{ds} behaves more like a parallel-plate capacitor, making the simple approximation a good starting point. This is in contrast with LDMOS devices, where C_{ds} exhibits a large variation with drain voltage. The variation in C_{gd} with drain voltage is often minimized in PA technologies by the use of field plates. For the PA designer, the power transistor under drain supply modulation can be thought of as a current source with a bias-dependent output admittance. The impedance of the output match is chosen to give the best performance over the changing output admittance of the device.

PA Design for Varying Loads

In applications such as wireless power transfer, radar and heating, the loading of the PA varies. Both the real and imaginary parts of the load can vary over a large range. Load variation is often dealt with by switching devices or components in and out and can lead to transients in the system. The power transistor will then be presented with impedances on various time scales, increasing the design challenge for the PA designer.

These examples of PA architec-

tures establish that the core of any PA design is the driving point impedance at the points of interaction of the active device and the network within which it is placed.

NETWORK SYNTHESIS

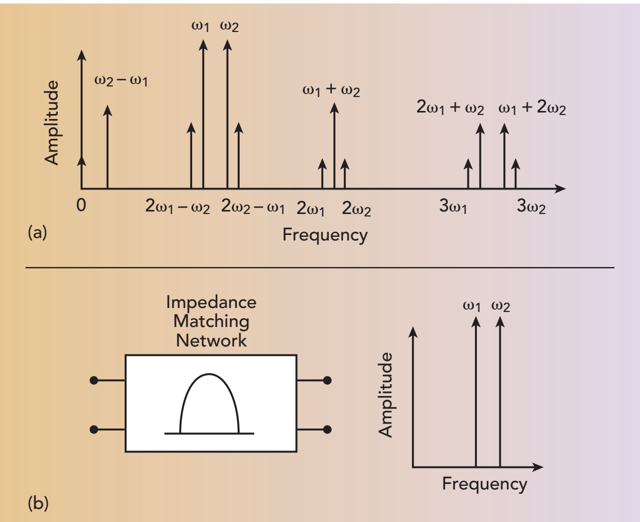
By reviewing some basics of network theory, we can see how to adopt and adapt these methods for the design of the impedance environment that will get the best out of the power transistor.

Network synthesis is the art of realizing a network, once the desired frequency response in the form of a transfer function or driving point impedance is known. The synthesis problem for electric networks was solved with Cauer's and Foster's theorems. The oldest and most widely used network synthesis procedures apply to two-element networks: LC, RC or RL. One of the starting points of network synthesis was Foster's reactance theorem,[6] which provides the necessary and sufficient conditions for the class of all functions that can be realized as driving point impedances of one-port networks. Foster's theorem can be realized as the driving point impedance of a generalized network made up of shunt-series LC branches or series-parallel LC branches. The technique uses partial fraction expansion to decompose the desired rational function into inductance or capacitance. Next, the realization of a one-port network with a defined driving point impedance based on continuous fraction expansion was developed.[7] The network synthesis theory was developed to include the positive real approach,[8] driving point impedances synthesized as RLC networks[9] and the insertion loss technique.[10]

Realization Techniques in Network Synthesis

The rapid development of techniques for the synthesis of two-port networks soon followed. Bode developed a technique based on the image parameter method,[11] where the various sections of the network are defined as either bandpass or bandstop, and the filter sections are designed based on those specifications. This technique does not allow for the synthesis of an arbitrary frequency response but is useful in the design of simple structures.

Foster's LC one-port theorem was extended to LC two-ports, initially assuming a symmetrical network. Cauer demonstrated the validity of Foster's theorem for LC n-ports and showed that through linear transformations, all equivalent LC networks could be derived from one another. Belevitch[12] developed three methods for the synthesis of LTI reciprocal n-ports. The first consisted of the sequential extraction of reduced impedance matrices and was too cumbersome to be of much practical value, but it led to the proof that any positive real impedance or admittance matrix is realizable,[13,14] showing that a complete n-port system can be formed with RLC elements and the ideal transformer. The initial development came as an extension of Darlington's method for one-ports, (i.e., the realization of a n-port as a reactive 2n-port with terminating resistors). This led to a formulation using scattering parameters and the scattering matrix for both reciprocal and nonreciprocal n-ports and, through this, solving the equivalence problem.[14]



▲ **Fig. 4 Distortion products generated by a transistor driven by a large two-tone input signal (a). The impedance matching network can be designed to minimize distortion (b).**

WHY PA NETWORK SYNTHESIS?

PAs are designed with input and output matching networks that transform one impedance to another for performance, i.e., efficiency, power and gain. Additional requirements, such as bandwidth and linearity, can be improved with the deterministic design approach afforded by network synthesis. A single-stage PA design will have a two-port network on both the input and the output of the transistor and, with careful design, can mitigate the distortion. ***Figure 4*** shows the distortion products generated by the transistor in response to a large two-tone signal. If the impedance matching network is designed as a bandpass filter, the distortion products can be minimized. The output shown in Figure 4 is for an ideal brickwall filter to illustrate the concept.

Bode-Fano Criterion

One important performance aspect is the bandwidth of the PA. The Smith chart gives a good match at a single frequency, but often a broadband design is required. The Bode-Fano criterion[15] (see ***Figure 5***) relates the quality of the match to the bandwidth of the match. The criterion shows that a perfect match is only possible if the bandwidth is a single frequency.

Cauer Networks

Let's explore some of the basic LC filter building blocks, beginning with Cauer. For the examples, lumped element filters will be used while acknowledging that these filters can be converted or extended to microstrip or waveguide. Cauer networks are ladder networks and can be expressed as a continued fraction. PA designers familiar with the Smith chart may be surprised that they have been using the continued fraction technique, albeit at a single frequency: the series elements are summed on the impedance circles and the shunt elements on the admittance circles. The difference between the Smith chart method and the network synthesis approach is that the network synthesis approach takes frequency into account.

Figure 6 shows the structure of a Cauer filter. The input impedance,

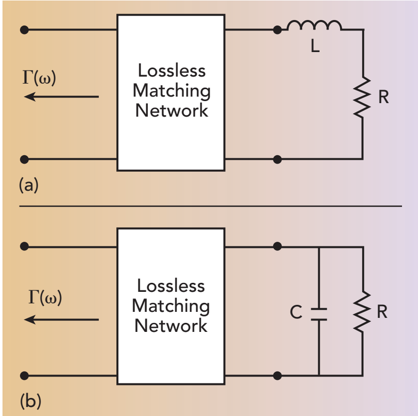


Fig. 5 Bode-Fano criterion for series LR (a) and parallel RC (b) networks.

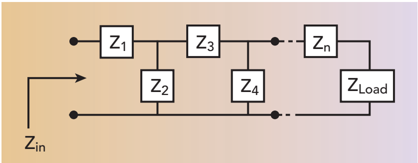


Fig. 6 Structure of a Cauer filter.

Z_{in}, is calculated with a continued fraction:

$$Z_{in} = Z_1 + \cfrac{1}{Y_2 + \cfrac{1}{Z_3 + \cfrac{1}{Y_4 + \vdots + Z_n + \cfrac{1}{Y_{Load}}}}} \quad (1)$$

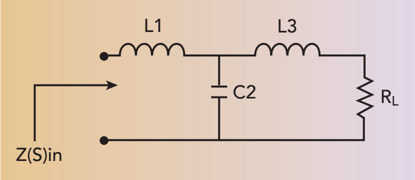
Using the circuit in ***Figure 7*** as an example, the frequency domain function of the input impedance, $Z(s)_{in}$ is as follows, where s = jω:

$$Z(s) = \frac{a_3 s^3 + a_2 s^2 + a_1 s + a_0}{b_2 s^2 + b_1 s + b_0} = \frac{s^3 L1C2L3 + s^2 L1C2RL + s(L1 + L3) + RL}{s^2 C2L3 + sC2RL + 1} \quad (2)$$

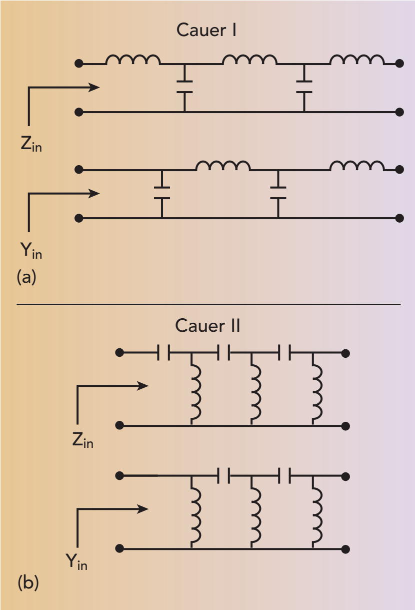
Dividing the numerator by the denominator, beginning with the highest power, gives:

$$Z(s) = sL1 + \frac{sL3 + RL}{s^2 C2L3 + sC2RL + 1} = sL1 + \cfrac{1}{\cfrac{s^2 C2L3 + sC2RL + 1}{sL3 + RL}} \quad (3)$$

where the second term is inverted. Next, the division is carried out on the denominator of the second term, resulting in the final form of:



▲ Fig. 7 Example Cauer LC filter.



▲ Fig. 8 Cauer I (a) and Cauer II (b) networks, showing two topologies for each.

$$Z(s) = sL1 + \cfrac{1}{sC2 + \cfrac{1}{sL3 + RL}} \qquad (4)$$

All rational functions can be formulated as a continued fraction by sequentially dividing and inverting the fraction. The two types of Cauer forms are shown in ***Figure 8***, with two realizations of each. To realize a rational function, any of the four forms can be used provided the function meets the realizability conditions for the driving point immittance of a passive network: it must be positive real. This simply means that the function Z(s) or Y(s) is real for all real values of s and that the real part is greater or equal than zero when the real part of s is greater than or equal to zero. The Cauer I filter example of Figure 7 is a lowpass ladder network that is often used in the design of PAs.

Foster Networks

Foster networks are synthesized by the break down of the desired function of the driving point immittance of a passive network through partial fraction expansion. Foster I networks (see ***Figure 9a***) provide open circuits to the transistor through series-parallel resonances and are realized from the partial fraction expansion of Z(s), while Foster II networks (see ***Figure 9b***) provide short circuits through the use of shunt-series resonant components and are realized from the partial fraction expansion of Y(s).

The expression for the Foster I realization is:

$$Z(s)_{in} = \frac{s^2 + \frac{1}{C_1L_1}}{\frac{s}{L_1}} + \frac{\frac{s}{C_2}}{s^2 + \frac{1}{C_2L_2}} + \frac{\frac{s}{C_3}}{s^2 + \frac{1}{C_3L_3}} + \cdots + \frac{\frac{s}{C_n}}{s^2 + \frac{1}{C_nL_n}} \qquad (5)$$

From this form, the locations of the short and the opens of the network can by found by inspection. The first element is a short at $\omega = 1/\sqrt{L_1C_1}$, and the parallel elements are opens at $\omega = 1/\sqrt{L_iC_i}$.

The Foster II realization is:

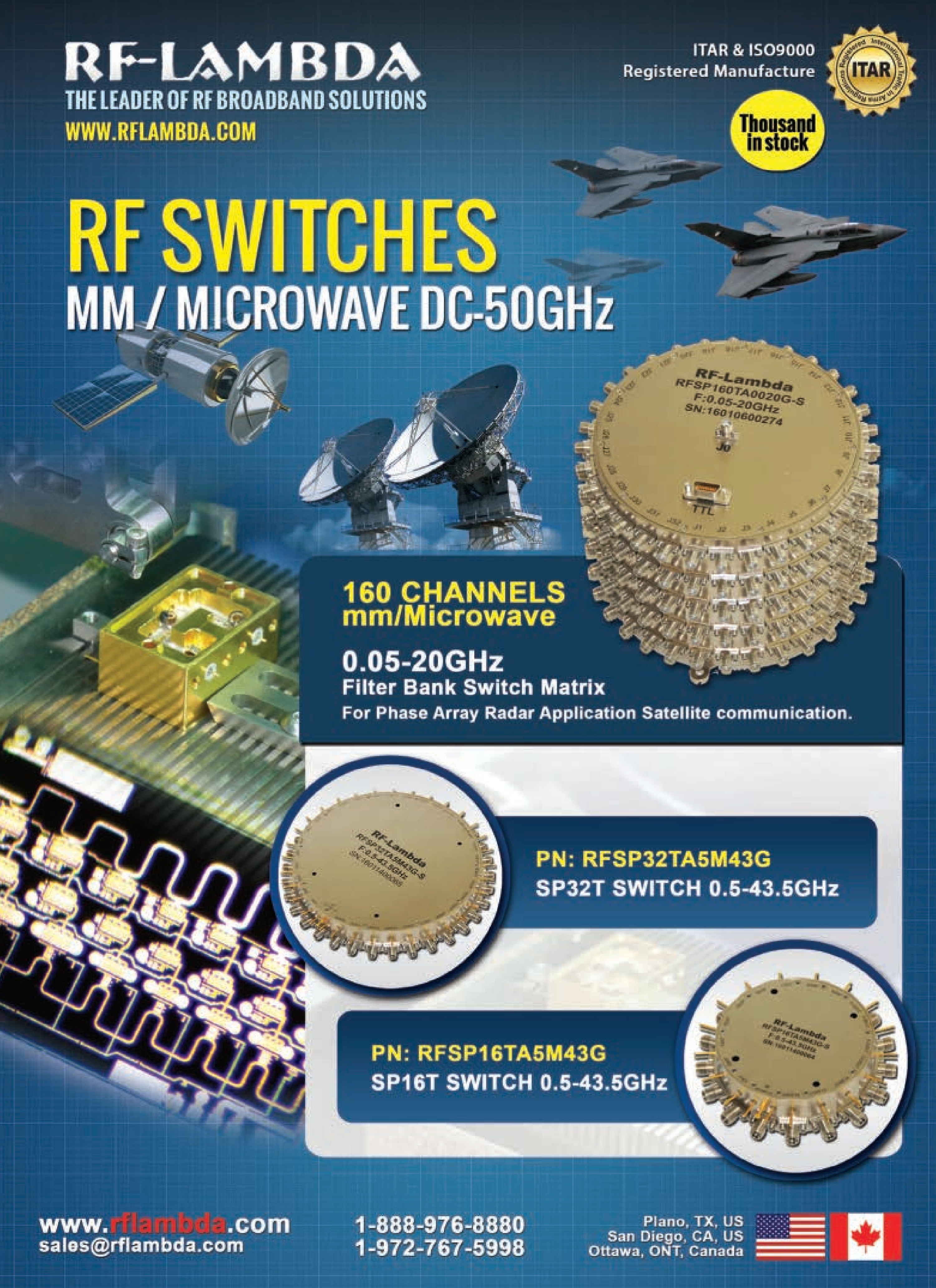
$$Y(s)_{in} = \frac{s^2 + \frac{1}{C_1L_1}}{\frac{s}{C_1}} + \frac{\frac{s}{L_2}}{s^2 + \frac{1}{C_2L_2}} + \frac{\frac{s}{L_3}}{s^2 + \frac{1}{C_3L_3}} + \cdots + \frac{\frac{s}{L_n}}{s^2 + \frac{1}{C_nL_n}} \qquad (6)$$

This form also allows identifying the locations of the short and open circuits of the network by inspection. The first element is an open at $\omega = 1/\sqrt{L_1C_1}$, and the series elements are shorts at $\omega = 1/\sqrt{L_1C_1}$.

The different realizations can be combined to realize any given driving point immittance function.

Multiport Network Synthesis

The Cauer continued fraction expansions are useful for synthesizing a two-element one-port network, given a desired driving point im-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mittance function. The extension of the continued fraction expansion to a transfer function matrix is applied to two-element multiport networks with a specified driving point immittance matrix.[16] The n × n driving point impedance matrix that describes an LC, RC or RL n-port network is a symmetric and positive real matrix. The partial fraction expansion of an RC driving point impedance matrix is in the form:

$$Z_{RC} = A_{\infty} + \frac{A_0}{s} + \sum_{i=1}^{m} \frac{A_i}{s + a_i} \quad (7)$$

If $T_{RC}(s)$ is defined as

$$T_{RC}(s) = \sum_{i=1}^{m} \frac{A_i}{s + a_i} \quad (8)$$

then

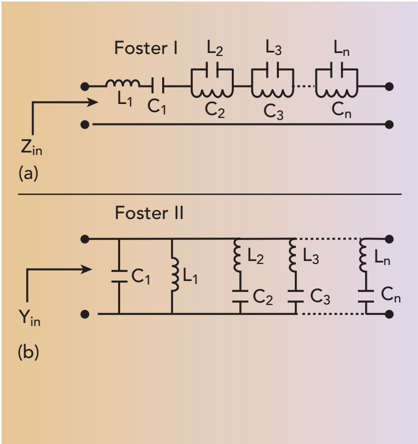
$$T_{RC}(s) = Z_{RC} - A_{\infty} - \frac{A_0}{s} \quad (9)$$

The impedance matrix, $T_{RC}(s)$ can be obtained from Equation 9 and expanded in the Cauer matrix form.[16] From this, the elements of the network can be determined.

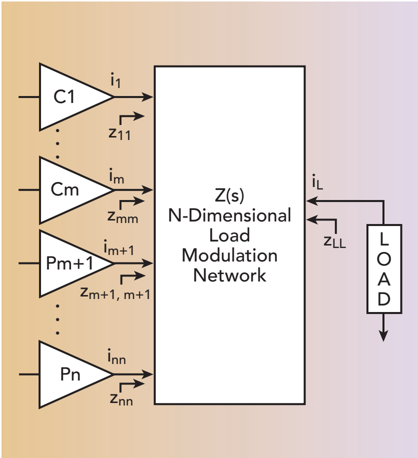
MIMO DOHERTY PA DESIGN

We illustrate the network synthesis approach to PA design using an N-way Doherty PA (DPA).[17] A DPA is usually realized by designing a match to 50 Ω for each amplifier, and using phase offsets and quarter-wave transformers to obtain the required load modulation. The MIMO approach to the synthesis of the load modulation presents the output network in a generalized form (see ***Figure 10***).

For a general n-dimensional system of amplifiers, where the carrier amplifiers are numbered 1 to m, the peaking amplifiers numbered m+1 to n and the load is the n+1th node L, the output network is represented by an n+1 × n+1



▲ **Fig. 9** **Foster I (a) and Foster II (b) networks.**



▲ **Fig. 10** **MIMO Doherty PA.**

matrix of frequency-dependent impedances or transfer functions. In this impedance matrix, the diagonal terms are the impedances presented to each individual amplifier when it is on and the others are off. The off-diagonal terms represent the load modulation from the other amplifiers as they switch on. The synthesis of the combining network is then cast in terms of the complex driving point impedance and the load modulation, or Doherty action. The first matrix in Equation 10 describes the driving point impedances of each amplifier, and the second matrix is the load modulation matrix that describes the interactions between the amplifiers. The impedances are complex frequency-dependent transfer functions.

$$\begin{bmatrix} Z_{C\,mod} \\ Z_{P\,mod} \\ Z_{L\,mod} \end{bmatrix} = \begin{bmatrix} Z_{CC} & 0 & 0 \\ 0 & Z_{PP} & 0 \\ 0 & 0 & Z_{LL} \end{bmatrix} + \begin{bmatrix} 0 & \frac{I}{i_C} Z_{CP} & \frac{I}{i_C} Z_{CL} \\ \frac{I}{i_P} Z_{PC} & 0 & \frac{I}{i_P} Z_{PL} \\ \frac{I}{i_{LC}} Z_{LC} & \frac{I}{i_{LP}} Z_{LP} & 0 \end{bmatrix} \begin{bmatrix} i_C \\ i_P \\ i_L \end{bmatrix} \quad (10)$$

Here, C indicates the carrier amplifiers, P the peaking, L denotes the load node(s), ii indicates the driving point impedances and ij the cross impedances. This results in a generalized approach for DPA synthesis.

The driving point impedances for the carrier amplifiers are chosen to give the maximum efficiency in back-off. The modulation impedances are designed to modify the load of the amplifiers to give the desired efficiency and power during drive-up. This formulation of the modulation matrix is symmetrical, which reduces the number of equations to be solved by half. This is a powerful construct and can be modified to account for active load and phase modulation. The effectiveness of the load modulation on the complete PA can be optimized using this matrix approach, to maximize the efficiency of the PA at a prescribed back-off power, for example. The frequency response of the diagonal terms of the impedance matrix determine the bandwidth of the DPA. With the impedances in the matrix represented by transfer functions, the amplitude and phase are shaped to achieve the desired frequency response, enabling an approach to wide bandwidth DPA design.

SUMMARY

PA systems are made up of dynamically interacting components, whether they are standard class A amplifiers, voltage supply modulated architectures or systems with intentional or unintentional load modulation. PA design requires

a network to compel the desired performance, and the driving point impedances are at the core of this design. As PA systems grow more complex, there is an increasing interest in network synthesis techniques. A general review of network synthesis has been presented, demonstrating historical highlights of the development of this important field from early beginnings to a current application.

There are many more insights that can be found in the references for the interested reader, such as Carlin and Youla's work on n-port synthesis[18] and Fano on broadband matching networks.[14] Carlin's short article on unconventional circuit theory also contains a feast of references.[19] ■

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INVITED PAPER

Ultra-Wideband Doherty Amplifier for Digital TV Transmitters

Bill Goumas and Peter Forth
Ampleon, Nijmegen, The Netherlands and Smithfield, R.I.

A proof of concept LDMOS ultra-wideband Doherty (UWD) amplifier enables fractional bandwidths greater than 50 percent. It covers a frequency band from 470 to 803 MHz with peak power greater than 750 W, digital video broadcasting-terrestrial (DVB-T) power greater than 115 W and efficiencies of 38 to 47 percent. Predistortion capability is demonstrated by satisfying the digital TV linearity requirement of -38 dBc with a commercial DVB-T exciter. The impact of the UWD amplifier on transmitter operating cost is presented.

The standard for terrestrial digital video broadcasting, DVB-T, was set in 1997 and put into use in 1998 for the transmission of digital terrestrial television. It provides an advanced method of transmission compared to the previous analog format used before 1998. The entire TV signal has a bandwidth of about 6 MHz. Typical TV broadcast transmitters produce 1 to 10 kW of average power. DVB-T is an orthogonal frequency division multiplexing (OFDM) signal which contains carriers that are approximately 4 kHz apart. This signal has a high crest factor (or peak-to-average power ratio) of around 13 dB. High peak power creates design challenges, such as determining the size and shape of RF components suitable for short voltage peaks.

It has been empirically determined that a power amplifier that compresses a DVB-T signal to a crest factor of 8 dB can still be effectively linearized with digital predistortion (DPD). For characterizing a power amplifier for a DVB-T application, 8 dB is the approximate peak-to-average ratio (PAR) that is typically used when considering peak power requirements. Predistortion is used almost exclusively in the broadcast transmitter market. Design goals typically achieve -35 dBc shoulders at a 4.3 MHz offset. A block diagram of the signal chain is shown in ***Figure 1***.

Transmitting UHF digital TV signals[1] is typically accomplished through the use of wideband push-pull class AB power amplifiers.[2] As such, the achieved average efficiency is limited to 25 to 30 percent.[2,3] Due to the very high output power levels involved, where the average power is typically 0.5 to 30 kW, maximizing broadcast efficiency is extremely important in reducing electricity use and the overall operating cost. The broadcast industry is looking for high efficiency alternatives to their current RF power amplifier blocks. Although various high efficiency architectures exist to provide wide RF bandwidth along with high efficiency,[2,3] such as envelope tracking and envelope elimination and restoration, application to broadcast transmitters is complicated and costly due to the very high output powers involved. Doherty amplification[2] is a cost-effective technique that is widely used in cellular base station transmitters;

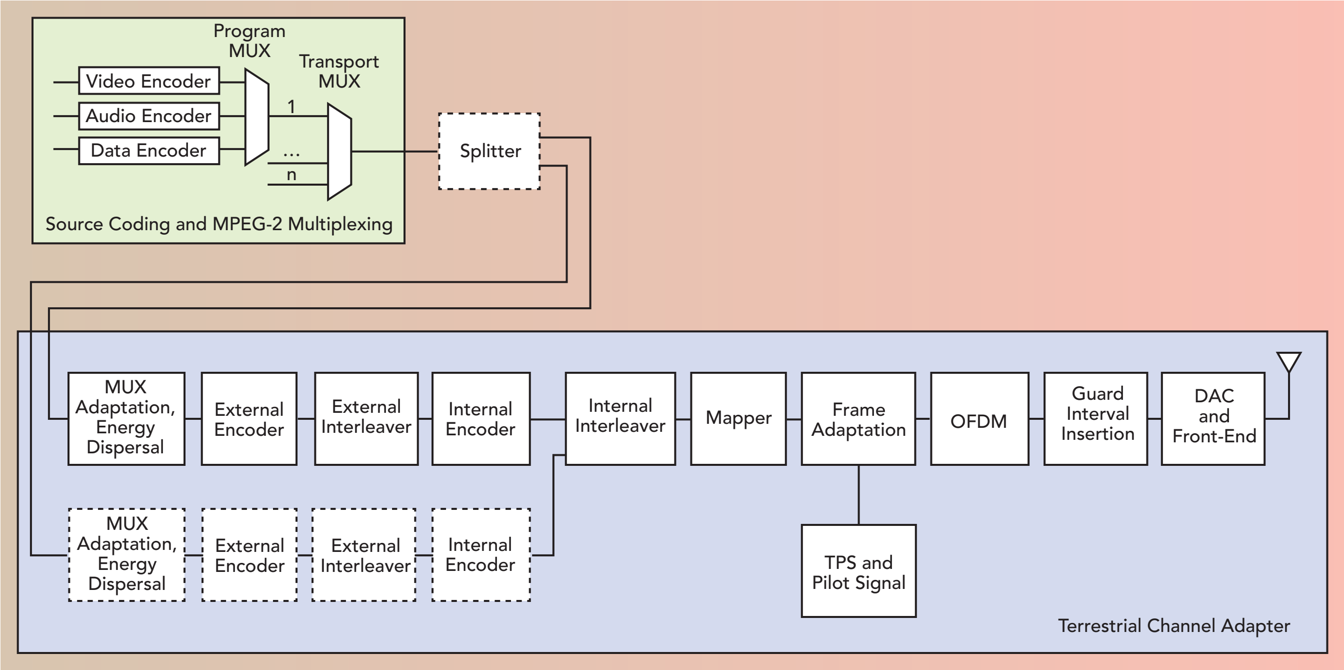

Fig. 1 DVB-T transmit signal chain.

however, high-power Doherty amplifiers are notorious for having narrow RF bandwidth, typically 5 to 10 percent fractional.[4] The solution to this problem is a wideband Doherty amplifier—greater than 30 percent fractional bandwidth.

WIDEBAND DOHERTY AMPLIFIERS

Although there have recently been a number of wideband Doherty amplifier techniques presented in the literature,[3-6] most are inherently low power and require complex input signal conditioning, such as dual input drive and drain voltage control. This article addresses the needs of broadcast transmitters by presenting a simple but effective design technique that allows the development of wideband Doherty amplifiers with up to 60 percent fractional bandwidth that are suited for high-power levels. The approach presented here is verified with a 115 W (750 W peak) power Doherty amplifier covering the entire broadcast frequency band with average efficiencies of 38 to 47 percent while maintaining a minimum output PAR of 8 dB.[7] This is achieved using standard 50 V LDMOS technology without any added costs or increased complexity. The amplifier circuit described here can be used as a building block

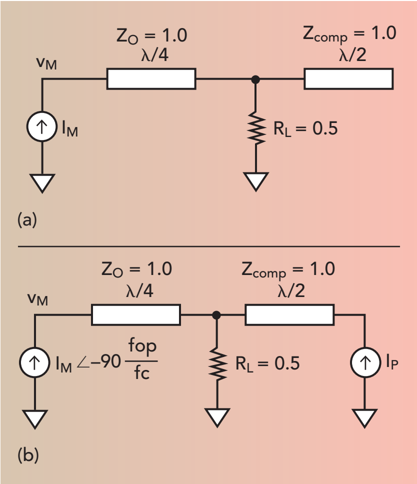

Fig. 2 Wideband impedance inverter (a) and connection of the peaking amplifier to the impedance inverter (b).

for achieving power up to multi-kW levels by combining similar amplifier stages.

Factors affecting the bandwidth of the Doherty power amplifier (DPA) are quite well known and documented. It was shown by Qureshi, et al.,[4] that by (1) compensating the output capacitance of the PA devices in a wideband fashion and (2) interchanging the position of the power combiner and impedance transformation, it is possible to increase DPA bandwidth significantly. Overall bandwidth is still limited, however, by the bandwidth of the impedance inverter, which for a λ/4

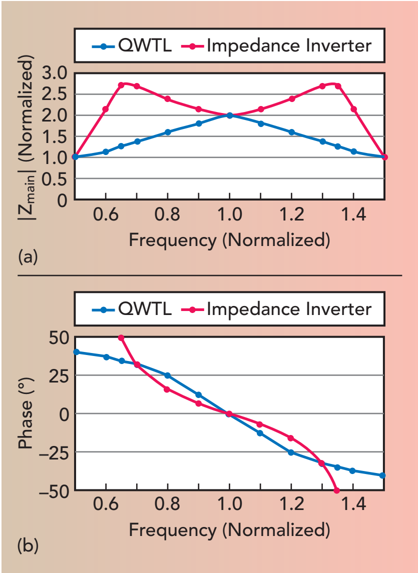

Fig. 3 Magnitude (a) and phase (b) of the normalized impedance seen at the device end of the wideband impedance inverter.

transmission line (QWTL) impedance inverter is 28 percent, using a 10 percent relative efficiency drop condition at the band edges.[3,4] In order to address the bandwidth requirements of the broadcast industry, the techniques presented by Qureshi, et al., are extended using a wideband impedance inverter to achieve a fractional RF bandwidth greater than 50 percent.

A very wideband impedance inverter can be created by adding an

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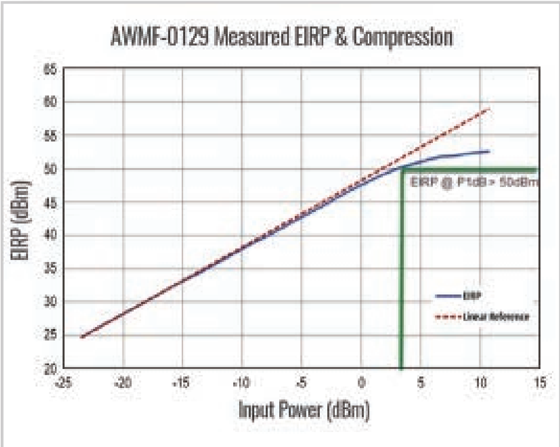

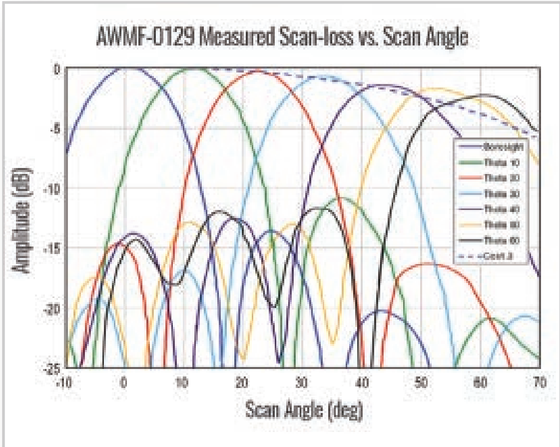

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www.anokiwave.com | innovation@anokiwave.com open circuited half-wave line (λ/2) to the load end of the QWTL, as shown in ***Figure 2a***. The resulting loading conditions for this DPA are shown in the ***Figure 3*** compared to a DPA based on a conventional QWTL impedance inverter. Figure 3 shows that the addition of the λ/2 line results in a much wider load modulation bandwidth. This circuit structure also helps to flatten the efficiency bandwidth in practical designs. The related achievable efficiency bandwidth is estimated to be more than 60 percent. This compares to approximately 25 percent fractional bandwidth for a simple QWTL inverter. The peaking device is connected to the open end of the λ/2 compensation line without any loss in functionality at the back-off power level, as shown in ***Figure 2b***. The impedance of the compensation line must be chosen to be equal to the optimum load impedance of the peaking device. If the proper input phase relations are enforced, there is no bandwidth restriction on the wideband DPA under full power conditions (assuming the use of ideal PA devices).

UWD DESIGN

The analysis has so far considered ideal PA devices without any output capacitance. Practical devices, however, do have significant output capacitance along with package parasitics. It has been shown that these can be compensated in a wideband manner by absorbing them in the impedance inverter.[3,4] Note that in this design, in order to absorb all parasitics in the "artificial" transmission line, the addition of external capacitors) is still required (see ***Figure 4***).

An Ampleon (formerly NXP) BLF888D high voltage LDMOS device is used to demonstrate this concept. These devices provide wide bandwidth in combination with high-power and excellent ruggedness. A schematic of the wideband impedance inverter and wideband output capacitance compensation network is shown in Figure 4. The DPA is matched from the combining point impedance (1.25 Ω in this case) to 50 Ω using a wideband multi-segment impedance transformer.[8] The circuit is fabricated using standard Rogers 3000 series PCB material (see ***Figure 5***).

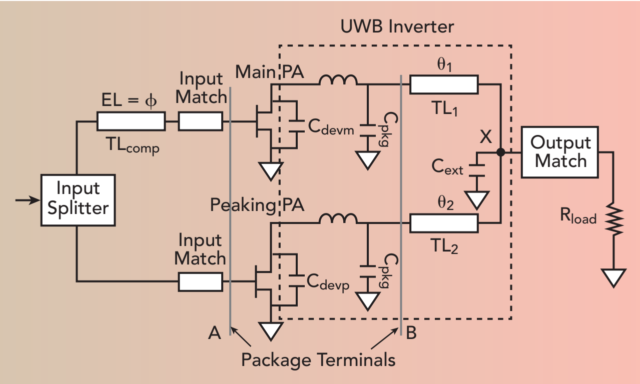

Fig. 4 Simplified schematic diagram of the UWD amplifier.

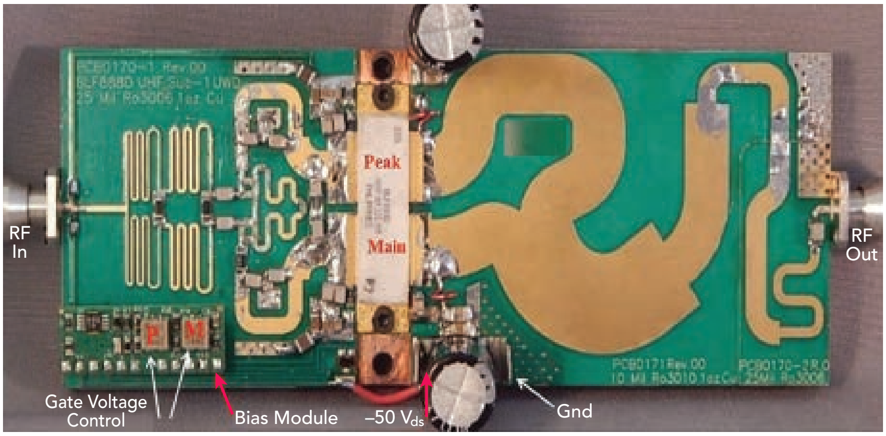

Fig. 5 Assembled UWD amplifier.

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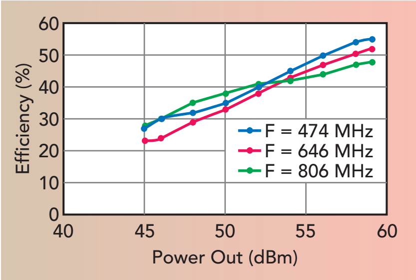

Fig. 6 UWD amplifier pulsed RF efficiency vs. output power.

To achieve maximum peak power, the output power of both devices is combined in phase at the power combining node (node X in Figure 4). It can also be deduced from Figure 2a that these phase relationships can be achieved by adding a λ/4 transmission line in front of the main device combined with an in-phase power splitter, as shown in Figure 4. Note that for the λ/4 transmission line to work properly as a phase compensator, it is important that the inputs of the PA devices are reasonably matched; otherwise, reflections from the PA devices will disrupt the actual phase relationships at the gates and, thus, at the PA outputs. Broadcast amplifiers, when aiming for a flat gain versus frequency response, however, are typically designed with high reflection losses (approximately -2 dB) at lower frequencies to compensate for the 6 dB/octave gain slope inherent in LDMOS PA devices. For this reason, it is essential to use an input splitter that isolates the PA devices from each other over the desired bandwidth, to minimize the impact of input reflections. The use of a two-stage Wilkinson power divider[9] with a λ/4 transmission line in front of the main device keeps the phase error below 5° over the desired bandwidth and achieves the required isolation.

MEASUREMENTS

The prototype UWD amplifier shown in Figure 5 was measured using pulsed RF, with a pulse width of 100 μs and 10 percent duty cycle and DVB-T signals. In order to measure the performance of the UWD amplifier with the modulated signals, a commercially available DVB-T exciter was used. The measured pulsed RF efficiency (see ***Figure 6***) shows the capability of the UWD amplifier

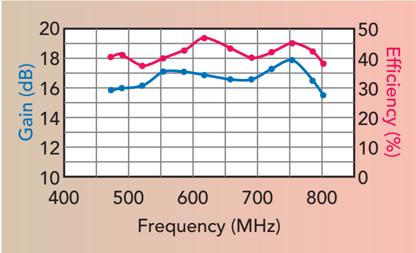

Fig. 7 UWD amplifier gain and efficiency vs. frequency at 115 W average output power.

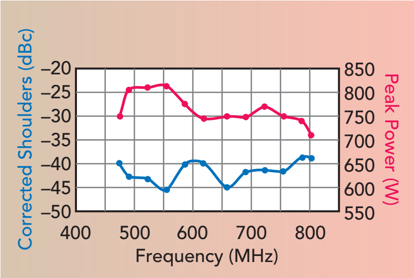

Fig. 8 Corrected shoulders of the UWD amplifier with 115 W average output power, using a commercial DVB-T exciter. Peak output power is also shown.

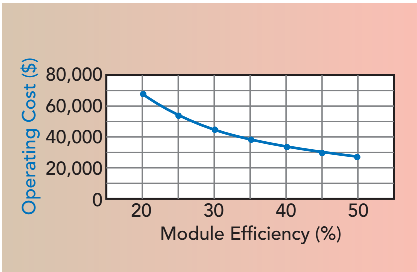

Fig. 9 Transmitter operating cost per year vs. module efficiency, assuming 10 kW transmit power, 1 dB combining loss, 90 percent AC to DC power conversion efficiency and $0.11/kWh.

to maintain high efficiency at back-off power levels over a wide range of frequencies. Measured pulsed RF efficiencies versus frequency are shown in ***Figure 7***, demonstrating average efficiencies ranging from 38 to 47 percent over the desired UHF band.

Note that the input PAR of the DVB-T signal is 9.5 dB and the PA is allowed to compress at most by 1.5 dB, so the resulting PAR at the output of the PA is always more than 8 dB over the desired band. All efficiency, gain and power measurements are performed under these constraints. Predistortion is also performed using the same DVB-T exciter. As shown in ***Figure 8***, the UWD amplifier meets the -38 dBc linearity requirement for broadcast over the entire 470 to 803 MHz band.

TechnicalFeature

OPERATING COST BENEFIT

Power usage is a big concern for the TV operator. The benefit of the UWD and its efficiency improvement compared to conventional class AB operation is significant. ***Figure 9*** shows the impact of efficiency on operating cost, where the efficiency shown is at the 150 W UWD amplifier module level. Implementation of the 150 W UWD amplifier reduces the operating cost of a 10 kW transmitter by approximately $25,000 per year.

SUMMARY

A design approach for the realization of high-power wideband Doherty amplifiers exhibits 50 to 60 percent fractional bandwidth. This is enabled through the use of a wideband impedance inverter along with a wideband capacitance compensation and matching strategy. The key achievement, and the importance to the industry, is that these results are achieved using standard 50 V LDMOS devices along with an easy-to-implement passive input splitter. The approach enables low cost efficient high-power wideband amplifier implementations and simple system integrations.

A UWD prototype amplifier covering the entire UHF TV band (470 to 803 MHz) achieved an average efficiency of 38 to 47 percent (for P_{avg} = 115 W), while maintaining a peak power capability greater than 750 W over the entire band. It offers 15 to 20 percent more efficiency than the currently used wideband class AB power amplifiers in today's broadcast transmitter systems.[10,11] This is the best demonstrated bandwidth for a DPA. An operating cost estimate shows the potential for a $25,000 reduction in annual operating costs for a 10 kW transmitter.

Since this proof of concept development, Ampleon has made considerable progress in increasing UWD amplifier power levels, with the recent focus on the 470 to 608 MHz range and development of a 150 W average DVB-T stage which uses a new LDMOS device. The focus on 470 to 608 MHz is driven by migration of the upper end of the UHF TV band in the U.S. to mobile wireless applications. The latest UWD amplifier in this frequency range has achieved 47 percent efficiency with less than -38 dBc shoulders. ■

ACKNOWLEDGMENT

The authors wish to acknowledge our colleagues J.H. Qureshi, W. Sneijers, R. Keenan, L.C.N. de Vreede and F. van Rijs for the initial design.[7]

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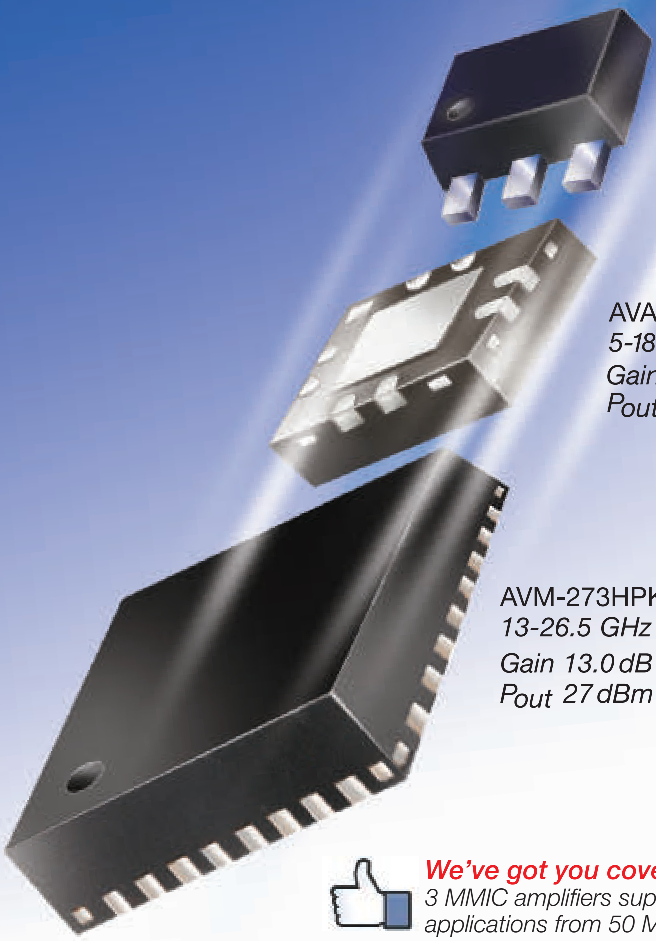


Dual-Band Bandpass Filter with Multiple Controllable Transmission Zeroes and Wide Stopband

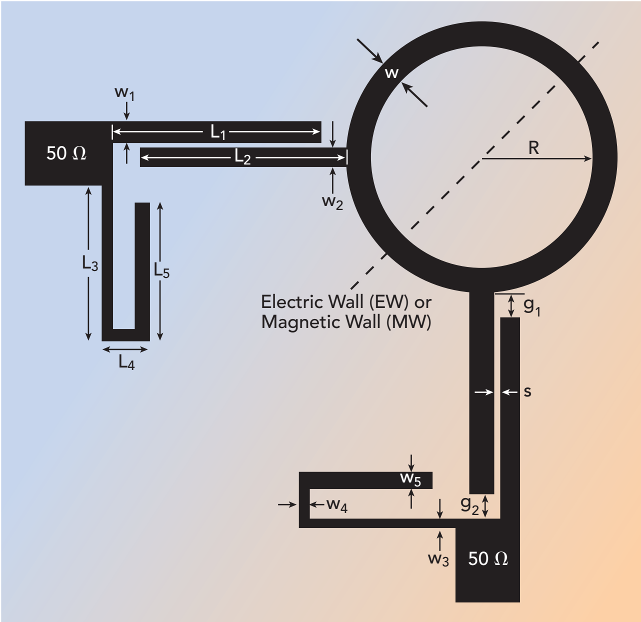
Daotong Li, Yonghong Zhang, Jing Ai, Kaijun Song and Y. Fan
University of Electronic Science and Technology of China, Chengdu, China

A dual-band bandpass filter with multiple controllable transmission zeroes (TZ) and wide stopband performance is based on a single quadruple-mode circular ring resonator (Q-CRR). The two passbands are generated by using degenerate modes. After installing two parallel-coupled feed line sections on a ring at the two ports with 90 degrees separation and two open-ended tri-section stepped-impedance resonators (OT-SIR) loaded on the I/O ports, eight TZs are produced in the stopband. By tuning the length and the impedance ratio of the OT-SIR and the length of the parallel-coupled feed lines, the locations of the TZs are adjusted. Measured results show good agreement with simulation.

Dual-band bandpass filters (BPF) with good selectivity and wide stopbands are highly desired in modern dual-band wireless communication systems.[1,2] Various design approaches have been used. Microstrip ring resonators have been employed in microwave circuits such as filters, mixers and oscillators.[3,4] A dual-band ring resonator bandpass filter, can be realized by using co-existing degenerate orthogonal modes.[5,6] Due to their compact size, high-Q factors and sharp rejection skirts, ring resonators have been comprehensively analyzed. Two dissimilar ring resonators with different resonant frequencies can be used to achieve dual-band passband performance, although the stopband is narrow and the size is relatively large.[7-9] Dual-band BPFs have been designed using multilayer structures; however, a complex feed is usually required.[9,10] Huang et al.,[11] describe a dual-band bandpass filter using stepped-impedance ring resonators with an adjustable first- and second-order resonator; however, there is only a single transmission pole in the second passband, while the isolation between the two passbands and the suppression of the stopband are not good because there are only three TZs. Dual-band BPFs using ring resonators loaded by open-circuited stubs do not have sharp rejection skirts and good rejection in the stopband because there are only two TZs.[12-15] Luo et al.,[5,6] report on a class of dual-mode dual-band ring resonator BPFs using microwave C-sections, but these structures need many perturbation elements to be installed along the ring. Chiou et al.,[16] describe a dual-band bandpass filter with four TZs based on a signal ring resonator, however, the upper stopband is narrow and this structure also needs many perturbation elements installed along the ring. Dual-band BPFs using a single rectangular ring resonator exhibit poor out-of-band rejection and selectivity.[17]

In this article, we describe a dual-band BPF using a single Q-CRR. After installing two coupled-line sections at the two excitation ports, two transmission poles are generated in each passband. With a two-port excitation angle of 90 degrees, parallel-coupled

feed lines and OT-SIRs at the I/O ports, eight controllable TZs are generated and provide a good isolation and a wide upper stopband. By tuning the length and the impedance ratios of the OT-SIRs, TZ locations are adjusted, extending the upper stopband.



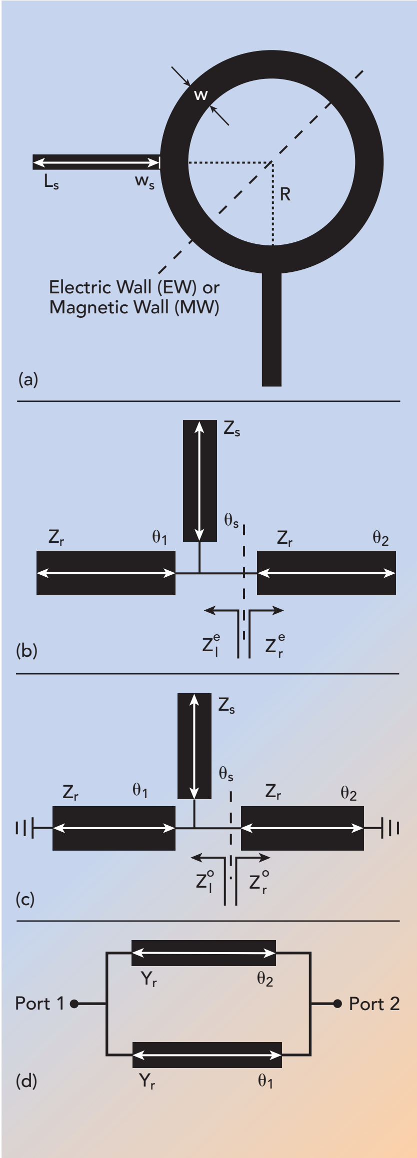
▲ **Fig. 1** **Configuration of a dual-band bandpass filter using a single Q-CRR.**

FILTER DESIGN

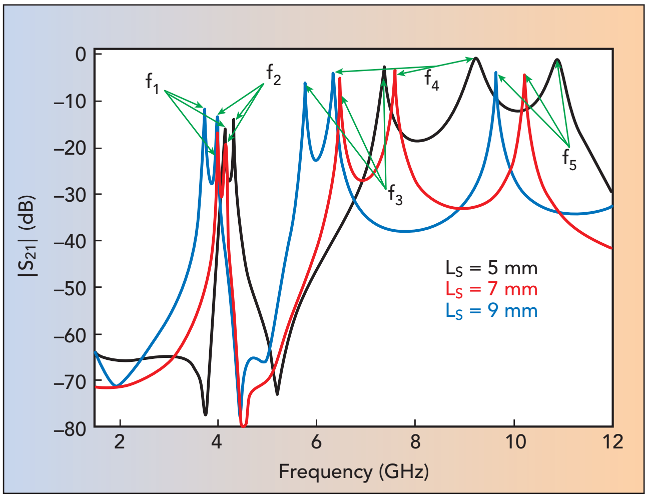
Figure 1 shows the filter configuration. It consists of a quadruple-mode circular ring resonator (Q-CRR) connected to parallel-coupled feed lines and OT-SIRs loaded at the input/output (I/O) ports.

Q-CRR

The Q-CRR (see ***Figure 2a***) consists of a circular ring resonator with two orthogonally separated open-ended stubs, where R, w and w_s are the radius and the widths of the circular ring and open stubs, respectively. The operating mechanism is discussed by using even and odd mode analysis because of the resonator's even symmetrical structure. The even and odd mode equivalent circuits are shown in ***Figures 2b*** and ***2c***. Z_s and θ_s are the characteristic impedance and



▲ **Fig. 2** **Q-CRR layout (a), even mode equivalent circuit (b), odd mode equivalent circuit (c), circuit for obtaining TZ frequencies (d).**



▲ **Fig. 3** **Simulated transmission response of the Q-CRR with different line length (L_s) under loose coupling.**

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Recovery Time	1 μs Max - Measured 100 ns
Maximum Flat Leakage	16 dBm Max (40 mW) - Measured 15.35 dBm
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the electrical length of the loaded open-circuited stub on the ring. Z_l and Z_r represent the two oppositely oriented input impedances at the same position. The input impedances with superscript "e" and "o" are the even and odd mode impedances, respectively. According to transmission line theory and the odd-even mode analysis method, the resonant frequencies under even and odd mode excitation satisfy[18]

$$Z_l^e + Z_r^e = 0 \tag{1}$$

$$Z_l^o + Z_r^o = 0 \tag{2}$$

where

$$Z_r^e = -\frac{jZ_2}{\tan\theta_2},$$

$$Z_l^e = \frac{jZ_s Z_r \tan\theta_s}{Z_r - Z_s \tan\theta_s \tan\theta_1},$$

$$Z_r^o = jZ_r \tan\theta_2,$$

$$Z_l^o = \frac{jZ_s Z_r \tan\theta_s \tan\theta_1}{Z_s \tan\theta_s + Z_r \tan\theta_1}$$

Due to transverse interference between the two signal paths from one port to the other port, some TZs are generated.[19] ***Figure 2d*** is the equivalent circuit. The TZ frequencies are obtained by applying $Y_{21} = Y_{12} = 0$, where the admittance matrices are calculated by adding upper and lower Y-parameters of the two paths connected in shunt between ports 1 and 2. The calculated results are expressed by

$$\sin\theta_1 + \sin\theta_2 = 0 \tag{3}$$

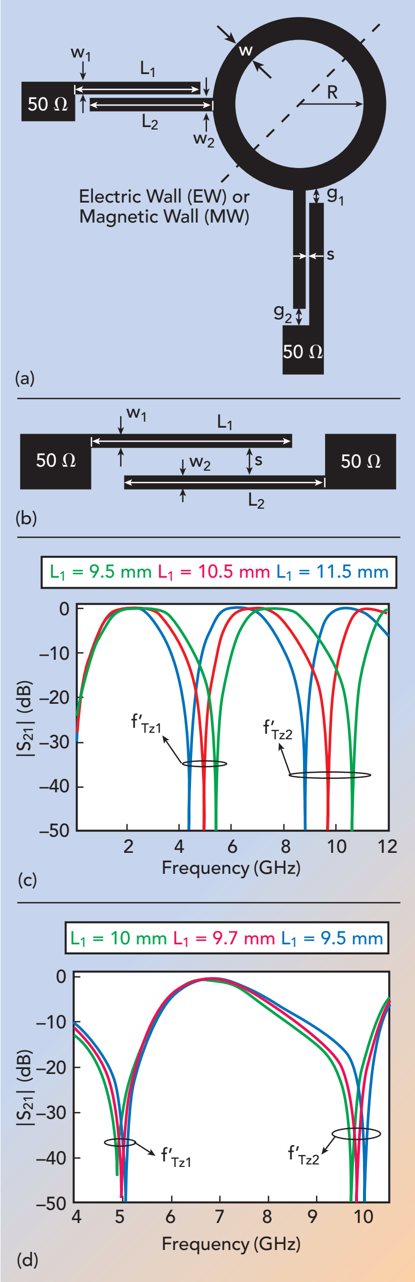
where $\theta_2 = 3\theta_1$; so, the TZs appear at $\theta_1 = (2n-1)\times 90°$, n = 1, 2, 3,......

Figure 3 shows the frequency responses of the Q-CRR with loose coupling for various values of L_S. It can be seen that all the resonant frequencies become smaller as L_S increases. The first two resonant frequencies, f_1 and f_2, split from each other as L_S increases, while the third and fourth resonances, f_3 and f_4, move closer to each other and thus form a second passband. The fifth resonance f_5 is the first spurious frequency.

Parallel-Coupled Feed Lines

Figure 4a shows the layout of Q-CRR dual-band BPF fed by the parallel-coupled feed lines. L_1, w_1 and L_2, w_2 are the length and width of the parallel-coupled feed line connecting with input/output ports and the loaded open stub on the circular ring resonator, respectively, while s is the gap between the two coupled lines.

To examine their characteristics, the parallel-coupled feed line struc-



▲ **Fig. 4** Q-CRR layout (a), parallel-coupled feed line (b), simulated $|S_{21}|$ for the parallel-coupled feed lines using three values of L_1 in the case of $L_1 = L_2$ and $w_1 = w_2$ (c), variation of TZs vs. length of L_1 (d).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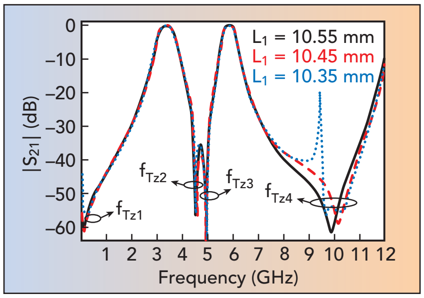
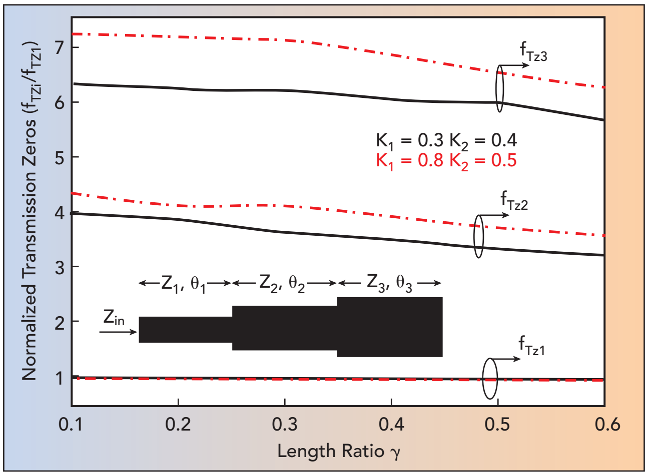


▲ **Fig. 5** **Simulated $|S_{21}|$ for the Q-CRR fed by the parallel-coupled feed line vs. length of L_1.**

ture shown in ***Figure 4b*** is simulated with three different values of L_1. The results are shown in ***Figure 4c***. When $L_1 = L_2$ and $w_1 = w_2$, the TZs are distributed in the stopband. The TZs shift lower in frequency when the length of L_1 increases. The transmission zero f'_{Tz2} is changed significantly by altering the length of L_1 while leaving the length of L_2 unchanged (see ***Figure 4d***), while f'_{Tz1} varies slightly.

The effect of these overlaps is seen when the circular ring resonator and the parallel-coupled lines are used together. ***Figure 5*** shows the simulated results of the Q-CRR fed by the parallel-coupled feed lines with three different lengths of L_1. The TZ overlap shown in Figure 5 causes suppression of the fifth resonant frequency in Figure 3, and produces sharper rejections at cut-off regions, further extending the upper stopband.



▲ **Fig. 6** **Location of transmission zeroes vs. length ratio γ and different impedance ratios K_1 and K_2.**

TZs Introduced By Stub-loaded OT-SIR

Figure 6 shows the OT-SIR consisting of three sections. The impedance ratios (K_1, K_2) and the length ratios (α, γ, ζ) are defined respectively as $K_1 = Z_1/Z_2$, $K_2 = Z_1/Z_3$, and $\alpha = \theta_1/(\theta_1+\theta_2+\theta_3)$, $\gamma = \theta_2/(\theta_1+\theta_2+\theta_3)$, $\zeta = \theta_3/(\theta_1+\theta_2+\theta_3)$. The input impedance of the OT-SIR is

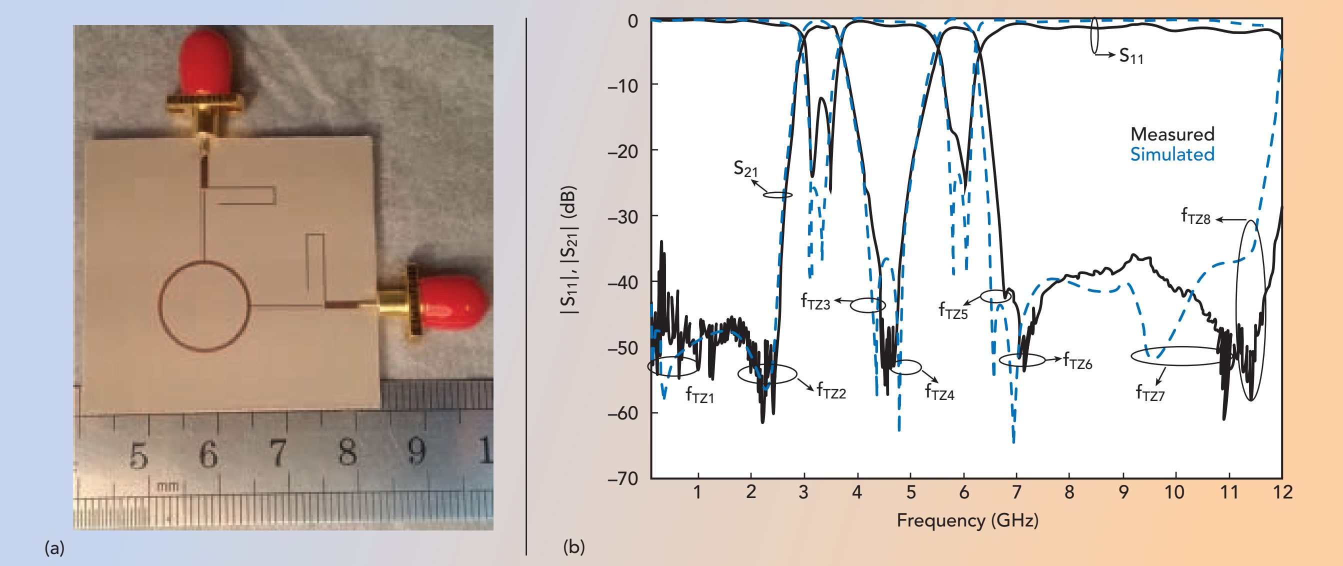
$$Z_{in} = Z_1 \frac{Z_L + jZ_1 \tan\theta_1}{Z_1 + jZ_L \tan\theta_1} \quad (4)$$

where

$$Z_L = Z_2 \frac{jK_2 \tan\theta_2 \tan\theta_3 - jK_1}{K_2 \tan\theta_3 + K_1 \tan\theta_2}$$

when the Z_{in}= 0, the first three TZs of the OT-SIR are obtained.

To verify the design concept, a resonator is simulated on a substrate with relative dielectric constant of 3.5 and thickness of 0.508 mm. Two microstrip lines with 50 Ω characteristic impedance are utilized to feed the OT-SIR. The length is fixed at 19.5 mm, corresponding to $\lambda_g/2$ at the fundamental resonant frequency, where the λ_g is guided wavelength, while the length ratios α = ζ. Figure 6 shows the simulated result of normalized TZs f_{TZi}/f_{TZ1} (i = 1, 2, 3) versus the length ratio γ under the condition of (K_1 = 0.3, K_2 = 0.4) and (K_1 = 0.8, K_2 = 0.5). The gaps between the first three TZs are tuned by altering the impedance ratios K_1 and K_2 and the length ratio γ. The adjustment of K_1 can be used to enlarge the spans between the first three TZs, for example, as the K_1 increases, the spacings between the first three TZs decrease. Similarly, the spans between the three TZs become smaller when the impedance ratio K_2 is enlarged. It is also apparent that the spans between the first three TZs decrease when



▲ **Fig. 7** Fabricated dual-band BPF (a), with simulated vs. measured results (b).

the length ratio γ increases. The relationship of the spans between the first three TZs and the length ratios α and ζ can also be seen by using the same method. Changes in the length ratio ζ have similar effects as changes in the length ratio γ, while the spans between the first three TZs become larger as the length ratio α increases. So, the location of the TZs can be adjusted by tuning the impedance ratios (K_1, K_2) and the length ratios (α, γ, ζ), which improves selectivity and rejection in the stopband.

EXPERIMENTAL RESULTS

The dual-band BPF with multiple controllable TZs is fabricated on Taconic RF-35 substrate with relative dielectric constant of ε_r=3.5 and thickness of h = 0.508 mm. The dimensions are L_1 = 10.26 mm, L_2 = 10.4 mm, L_3 = 10 mm, L_4 = 2.74 mm, w_1 = 0.12 mm, w_2 = 0.24 mm, w_3 = 0.24 mm, w_4 = 0.26 mm, w = 0.6 mm, g_1 = 0.49 mm, g_2 = 0.3

TABLE 1

COMPARISON OF DUAL-BAND BANDPASS FILTERS

Reference	Number of TZs	Isolation (dB)	Substrate ε_r/h	Size (mm^2)	Center Frequency (GHz)	Fractional Bandwidth (%)	Insertion Loss (dB)
5	4	15	10.8/1.27	13 × 13	2.38/4.87	6.7/8	2/2
9	3	27	10.2/0.635	25 × 20	5.2/5.8	6/5.6	2.5/2.76
10	4	20	10.2/0.635	36 × 36	1.1/1.86	7.7/5.9	1.07/1.1
11	3	17	3/0.76	14 × 14	2.4/5.2	6/6	3.2/3.4
12	2	15	3.5/0.508	15 × 15	3.46/5.2	2.8/2.1	1.8/2
14	5	40	2.45/1	31.6 × 25	1.5/2.44	8.24/7.27	1.12/1.37
15	0	25	2.5/1	30 × 30.5	1.8/2.36	2.22/1.7	2.5/2.5
15	3	50	2.5/1	30 × 49	2/2.76	7.5/5.43	2.5/3
15	1	20	2.5/1	30 × 29.1	1.8/2.36	2.22/1.7	2.3/2.7
17	3	32	10.8/1.27	19.1 × 19.1	2.3/4	8.6/7.5	0.65/1
20	3	40	9.8/1.19	Unknown	1.38/2.55	18.7/8.9	0.73/1.5
This Work	**8**	**48**	**3.5/0.508**	**24.6 × 24.6**	**3.5/5.8**	**20/11.5**	**1/1.4**

mm, s = 0.21 mm and R = 6.75 mm. A photograph of the filter is shown in ***Figure 7a***. It is measured with a Keysight 8757D network analyzer. Simulated and measured frequency responses are compared in ***Figure 7b***. Good agreement is achieved. The measured minimum insertion loss is 1 dB in the first passband and 1.4 dB in the second passband. The 3 dB fractional bandwidths are 20 percent and 11.5 percent, respectively. Passband return losses are larger than 13.6 dB in the first passband and 18 dB in the second passband. Eight TZs are generated at 0.32, 2.31, 4.32, 4.75, 6.73, 7.12, 10.92 and 11.44 GHz, respectively. The TZs located at 0.32, 4.32 and 10.92 GHz are generated by the parallel-coupled feed lines, the TZs of 2.31, 6.73 and 11.44 GHz are generated by the OT-SIR and the others are achieved through transverse interference of the Q-CRR. With the aid of additional controllable TZs provided by the parallel-coupled feed line section and the loaded OT-SIR, the fifth resonance located in the upper stopband is fully suppressed. Meanwhile, the span of the upper stopband is also enlarged. In the measured upper stopband response, 20 dB rejection in the frequency range of 6.5 to 12.25 GHz is obtained. ***Table 1*** shows some reported performance of dual-band BPFs in recent years for comparison. Selectivity, suppression in the stopband and the width of the stopband are improved through this work.

CONCLUSION

A dual-band BPF with multiple controllable TZs using a single Q-CRR and a pair of OT-SIRs is presented. Two TZs are placed between the two passbands and six TZs are created in the stopband which results in a good selectivity and a wide upper stopband. Two transmission poles are generated in each passband after installing two parallel-coupled-line sections at the two excitation ports. The spurious frequency at the fifth resonance of the resonator is suppressed by an additional zero from the parallel-coupled-line section. When the TZs generated by the Q-CRR are combined with the TZs introduced by the stub-loaded OT-SIR and parallel-coupled feed lines, performance in the upper stopband is improved.

ACKNOWLEDGMENT

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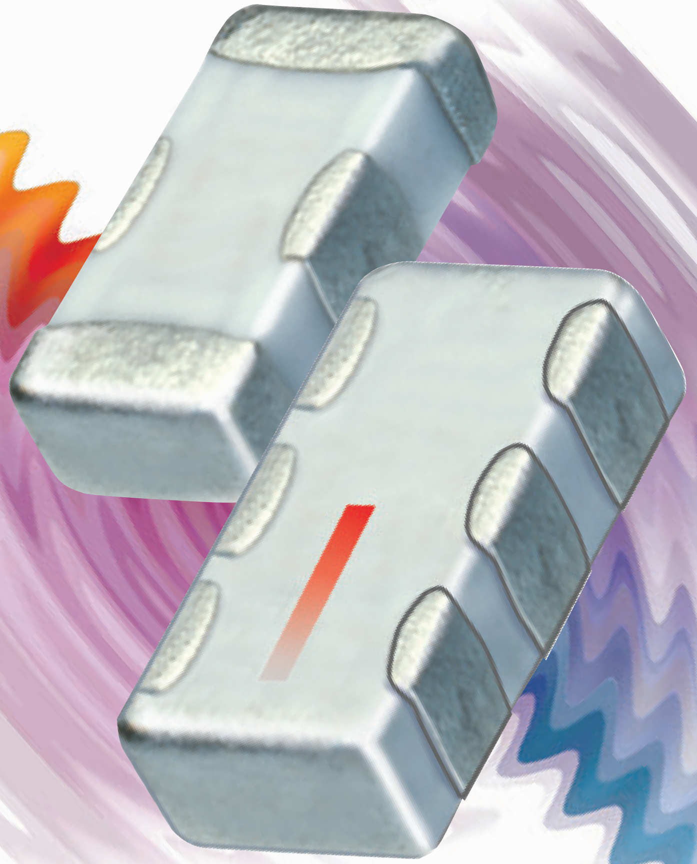

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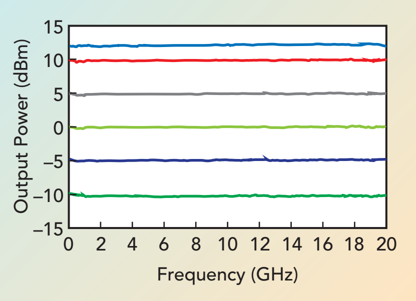
With the availability of low-cost integrated phase-locked loop (PLL) ICs, many families of miniature and low-cost frequency synthesizers are available. However, integrated and embedded test systems have always faced challenges in utilizing these new offerings. The conditions that small, portable applications face—especially those within the military and aerospace markets—are not limited to environmental factors such as flightline location, elevated temperature and vibration. The RF setting presents additional challenges because of load impedance uncertainties due to switches, varied lengths of transmission lines and other effects that degrade embedded systems testing and measurement accuracies. Miniature frequency synthesizers typically do not have closed-loop automatic level control (ALC), which mitigates the impact of an uncertain output impedance. While small synthesizers may have partial coverage at RF frequencies, imposing demands such as extended low frequency coverage or calibrated amplitude modulation (AM) makes miniature synthesizers impractical for embedded test requirements in many instances. Consequently, engineers are forced to either use benchtop synthesizers or develop internal designs, which increases the size, power consumption, cost and development time, and decreases the portability and flexibility of test systems.

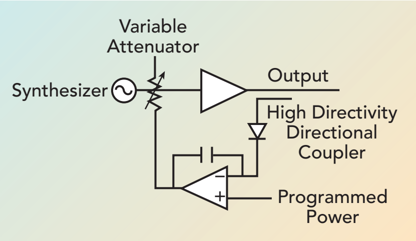
To address these demands, National Instruments is introducing the QuickSyn X, the industry's smallest, fast switching, full-function frequency generator. The QuickSyn X provides closed-loop ALC, extended low frequency coverage, calibrated AM and low power consumption, as well as being compact and low cost—without compromising any key performance metrics such as phase noise and frequency switching speed.

EXPANDED FREQUENCY RANGE

QuickSyn X covers from 250 kHz to 20 GHz and does so without compromising any of its key performance metrics, including harmonic performance. ***Figure 1*** shows the frequency coverage and output power; the synthesizer provides more than 20 dB output power control across its frequency range.



▲ **Fig. 1 Leveled output power across the QuickSyn X's frequency range from 250 kHz to 20 GHz.**

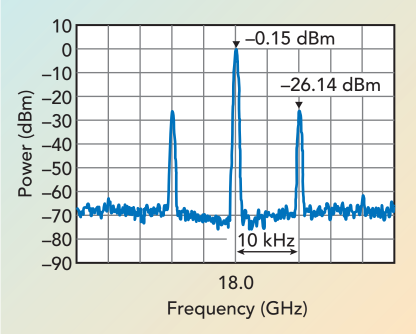


▲ **Fig. 2 Simplified block diagram of the QuickSyn X's ALC implementation.**

CLOSED-LOOP POWER CONTROL

Closed-loop ALC was one of the most requested features, and the QuickSyn X allows both open-loop and closed-loop ALC. When fast frequency switching is desired, the unit can be placed in an open-loop mode; when more power control accuracy is desired or when the output power must be insensitive to varying load impedance, the closed-loop ALC can be used. ***Figure 2*** shows a simplified block diagram of the ALC implementation in the QuickSyn X. The forward power is measured at the coupled port of a high-directivity directional coupler using a precision detector. This measurement is compared to the power programmed by the user, and an error signal is applied to a variable attenuator that adjusts the output power to compensate for any difference. Because of the high directivity of the directional coupler, the power delivered to the output is insensitive to load impedance variation.

The closed-loop ALC amplitude control is greater than 10 dB, which is not possible with many small synthesizers. Also, by using an external attenuator module that allows for attenuation adjustment in 10 dB steps, the closed-loop ALC range of the QuickSyn X can be extended to



▲ **Fig. 3 Spectrum of an 18 GHz carrier with 10 percent AM.**

a broad dynamic range from -100 to +10 dBm.

The synthesizer offers the power accuracy of closed-loop ALC when the carrier is being modulated. This is achieved using the conventional standard instrument protocol of the power search function. Using power search, carriers modulated with AM, pulse modulation or frequency modulation (FM) have the same power accuracy as with closed-loop ALC, without the closed-loop ALC conflicting with the modulation.

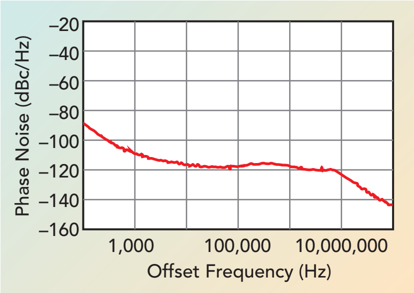
INSTRUMENT-GRADE AM

Instrument-grade or calibrated AM can be critical for many use cases. QuickSyn X offers calibrated AM across its entire frequency range and a large power control range. ***Figure 3*** shows an 18 GHz carrier with a power level of 0 dBm, modulated with 10 percent AM. A carrier-to-sideband level of -26.14 dB is observed, which reflects an AM index of 9.86 percent and an error from the programmed value of 1.4 percent.

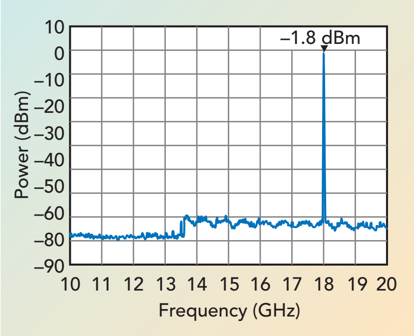
Instrument-grade pulse modulation is one of QuickSyn X's extended features, with a typical on-off ratio of 80 dB across the frequency range. The synthesizer provides multiple modes of FM and phase modulation, and each modulation may be used individually or in combination with any other modulation format. For example, pulse modulation may be combined with FM.

SPECTRAL PURITY, FAST FREQUENCY SWITCHING

QuickSyn X provides both fast frequency switching and low phase noise (see ***Figure 4***). The typical phase noise at 10 kHz offset is bet-



▲ **Fig. 4 Phase noise of a 20 GHz output signal.**



▲ **Fig. 5 Spurious-free dynamic range of the QuickSyn X.**

ter than -116 dBc/Hz. QuickSyn's phase refining technology, which is based on fundamental VCOs up to 20 GHz, enables phase noise performance that is normally achieved with YIG technology and without the penalty of slow-tuning YIGs. In many cases, QuickSyn synthesizers have better phase noise than YIG-based synthesizers.

Using advanced direct digital synthesis spur-reduction technology, a frequency resolution of 0.001 Hz is achieved without incurring elevated spurs. A wide loop bandwidth makes the unit insensitive to microphonic effects. ***Figure 5*** shows the spurious-free dynamic range of the QuickSyn X, with the synthesizer generating a CW signal at 18 GHz and the output measured with a spectrum analyzer from 10 to 20 GHz. Spurious emissions are better than -65 dBc. Due to the difficulty measuring spurious levels below this level, the spurious levels of the QuickSyn X are verified during manufacturing test at -60 dBc.

Good harmonic performance is achieved through harmonic filtering. At an output power of +10 dBm, the QuickSyn X's harmonic levels below 100 MHz are roughly -30 dBc; above 100 MHz, harmonic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performance is typically better than -40 dBc.

The synthesizer offers list mode operation, where the power and frequency can be incremented between consecutive measurements in any sequence, achieving extremely fast 200 μs switching times. The list mode is also available with external trigger control.

The QuickSyn X synthesizer uses a highly stable internal oven-controlled crystal oscillator (OCXO), factory calibrated to a GPS standard to ensure the accuracy of the synthesized signal. The internal oscillator frequency can be adjusted for aging and temperature variation. The unit provides a 10 MHz reference output, and the internal OCXO can be locked to an external reference.

COMMUNICATIONS

The QuickSyn X supports multiple communication modes, including SPI, USB, Ethernet, GPIB and RS232. Like all QuickSyn synthesizers, it can also be controlled via a USB-based virtual-instrument graphical-user interface. The QuickSyn X family is capable of being controlled using the most-often used standard commands for programmable instruments (SCPI), since many legacy systems with aging frequency synthesizers are supported by SCPI programming platforms. This compatibility reduces the time and cost of integrating the latest synthesizer technology with SCPI software platforms.

CONCLUSION

The QuickSyn X gives system engineers tremendous versatility and flexibility by providing powerful capabilities in a small, light and power-efficient package, including closed-loop ALC and without compromising excellent phase noise and fast frequency switching. Measuring only 2 in × 7 in × 5 in, the QuickSyn X is a highly capable synthesizer on its own or a versatile building block in test and measurement systems for military and commercial applications.

VENDOR**VIEW**

National Instruments
Santa Clara, Calif.
www.ni-microwavecomponents.com

Multi-Gbps Modem Enables mmWave Fixed Wireless Access

Integrated Device Technology Inc.
San Jose, Calif.

As mobile operators continue to trial various technologies, it seems clear that 5G deployments will begin with fixed broadband wireless access in the millimeter wave (mmWave) band. This is driven by the large amount of spectrum available in both licensed and unlicensed bands, and the maturity of technologies that facilitate mmWave solutions. The combination of advanced wireless signal processing technology and the extensive spectrum available increases the bandwidth capacity of infrastructure networks that will offer the end user an immediate increase in data rate. This increase in capacity benefits operators by generating additional revenue from new business models built around various 5G use cases, such as virtual reality, real-time distributed ultra-high definition gaming and tactile internet for remote surgery.

FIXED BROADBAND ACCESS

Operators today offer fixed wireless access via fiber, DSL, cable, wireless and satellite media, which have data rates between a few and 100s of megabits per second (Mbps), depending on the location and the access technology. For example, xDSL offers data rates in the range of 100s of Mbps. However, the services are geographically challenged and cannot uniformly guarantee the required quality of service or throughput over distance in both urban and suburban areas. Satellite access technology, on the other hand, has the potential to cover remote areas and is able to reach 100s of Mbps, based on the DVB-S2x specification. However, due to the inherent delay in geostationary earth orbit (GEO) satellite networks, this type of fixed access service will always have limitations. Among all the available technologies, an end-to-end fiber network offers multi-gigabit fixed access to the user today. A fiber network's biggest hurdle is delivery of that fiber access to the end user. In communities where fiber is nonexistent, it can be time-consuming and costly to deploy, resulting in operators experiencing long delays in realizing a return on their investments. In most cases, the fiber is never seen at the end user's location; the fiber based link is terminated at a central hub, and the "last mile" access is provided by either xDSL or wireless.

During the last several years, wireless technologies and spectrum allocation have seen radical changes. In particular, the availability of mmWave spectrum from 26 to 90 GHz has opened significant opportunity to deliver multi-gigabit wireless access to the user. For example, in July 2016, the FCC opened up around 3.85 GHz of licensed spectrum between 27.5 and 40 GHz (i.e., 27.5 to 28.35, 37 to 38.6 and 38.6 to 40 GHz). The FCC also added 7 GHz of

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Telephone: +49-89-3548-040
Facsimile: +49-89-3548-0490
WWW.SPECTRUM-ET.COM
Email: sales@spectrum-et.com

TABLE 1

27.85 of U.S. SPECTRUM ALLOCATED by FCC

	Ka-Band		***V-Band***	***E-Band***	
Designated Band (GHz)	27.5 to 28.35	37 to 40	57 to 71	71 to 76	81 to 86
Spectrum (GHz)	0.85	3	14	5	5

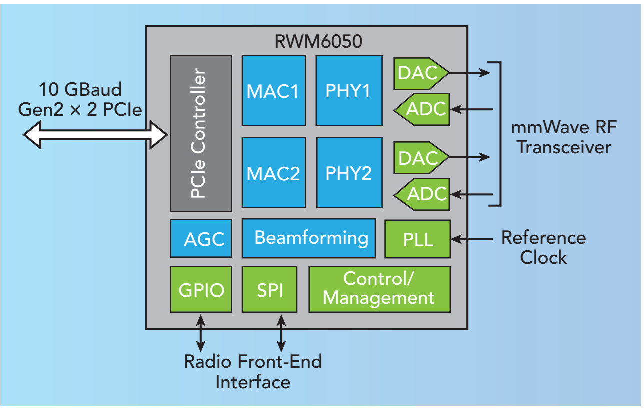


Fig. 1 IDT mmWave modem block diagram.

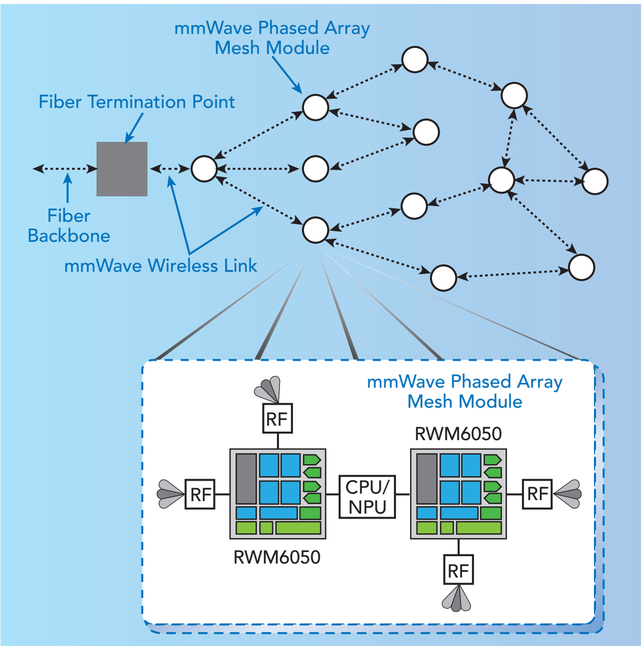


Fig. 2 Mesh network example for fixed wireless broadband access.

spectrum in the unlicensed V-Band (64 to 71 GHz) to the existing unlicensed V-Band spectrum (57 to 66 GHz). Ten GHz of spectrum is available in the lightly licensed E-Band (71 to 76 and 81 to 86 GHz). In total, this provides nearly 28 GHz for radio access technologies (see ***Table 1***).

The access to spectrum is an important first step to enable wireless technology as a solution for fixed access networks. The second "wave" or step is the significant technology advancement in antenna design and wireless communications protocols, based on beamforming and phased arrays for mmWave channels. Lastly, fueled by an industry-driven ecosystem and standardization bodies such as Wi-Fi Certified WiGig, IEEE 802.11, ETSI ISG mWT and 3GPP, there have been considerable improvements in signal processing techniques that have created opportunities for commercially feasible mmWave solutions.

mmWAVE MODEM

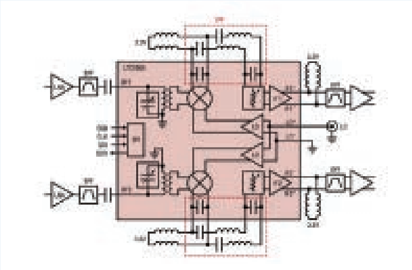
IDT recently introduced mmWave-based wireless modem technology to address the emerging fixed broadband wireless market (see ***Figure 1***). The solution closes the last mile gap for 5G and offers a true multi-gigabit wireless fiber experience for the end user. The modem technology offers a range of innovative features such as beamforming, channelization and flexible medium access control schemes. With these features, operators and network equipment manufacturers can take advantage of the large wireless spectrum available in the mmWave band and offer real-time 5G services in an interference limited environment, expected in the unlicensed band. The solution is equally applicable to the licensed mmWave bands (e.g., Ka-Band) and can enable multi-gigabit solutions based on higher order modulation and strong forward error correction (FEC) schemes such 64-QAM and low-density parity-check (LDPC) encoding, respectively.

Operators benefit from a simplified deployment model enabled by a range of network topologies offered by the solution. For example, the dual modem architecture with support for time-division duplex (TDD) and frequency-division duplex (FDD) allows operators to deploy fully redundant wireless fixed broadband access for home and enterprise users in both mesh and hub-spoke architectures. With support for beamforming with phased-array antennas, operators can design a scalable sectorized cell architecture of varying sizes, as the number of users grow over time. ***Figure 2*** illustrates an example topology of a multi-gigabit fixed wireless broadband access mesh network based on the mmWave solution.

Deploying multi-gigabit speeds to the last mile needs to be practical and profitable. The greatest advantage both operators and network equipment manufacturers will experience is the speed and low cost to deploy a RapidWave-based module. A chipset including the RapidWave modem paired with a mmWave phased-array front-end provides critical functionality, including digital beam alignment and sub-channelization, that accelerates the deployment and simplifies frequency planning, even in densely distributed networks.

Nearly 28 GHz of new mmWave spectrum, algorithm and antenna technology advancements and standardization have enabled new innovations, such as the RapidWave modem, that will fuel the 5G vision of multi-gigabit fixed broadband wireless access.

Integrated Device Technology Inc.
San Jose, Calif.
www.idt.com



Dual-Channel Mixer for 5G New Radio

Linear Technology's LTC5566 is a wideband, high dynamic range, dual-channel mixer with programmable variable gain IF amplifiers. The LTC5566's input frequency range covers 300 MHz to 6 GHz, optimized and characterized at the 4G and emerging 5G bands (i.e., 3.6 and 4.5 GHz). To meet 5G sub-6 GHz requirements, the signal chain bandwidth is 400 MHz.

The LTC5566 is built on an active, double balanced mixer core with no conversion loss and excellent port-to-port isolation, which reduces external RF filtering requirements. Each mixer input contains an integrated wideband balun transformer, enabling a simple single-ended interface. Using the SPI or parallel pins, the mixers' inputs can be digitally tuned for optimum return loss over several wide, overlapping frequency bands, ranging from 1.3 to 5.3 GHz.

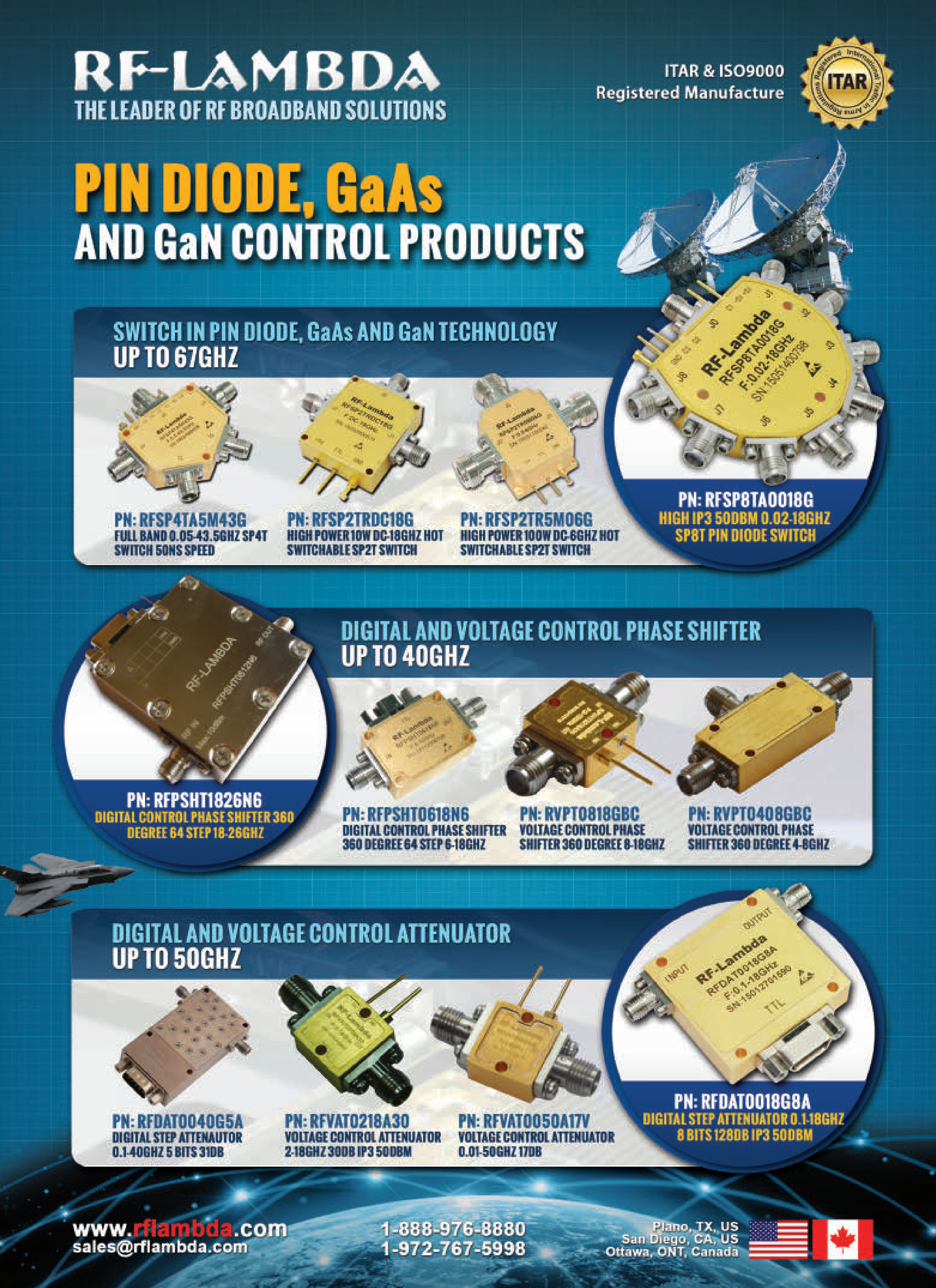
The mixer has high dynamic range, with an input 1 dB compression point of +11.5 dBm and an input IP3 of +25.5 dBm at 3.6 GHz. Up to 5.8 GHz, the input IP3 remains greater than +24 dBm. The device's integrated IF amplifier provides a maximum conversion gain of 12 dB, and each channel's gain can be independently programmed from –3.5 to 12 dB in 0.5 dB steps using the on-chip SPI bus. The LTC5566 has 50 dB channel-to-channel isolation up to 3.6 GHz and 40 dB at 4.5 GHz. Both channels exhibit very low phase shift over the full 15.5 dB attenuation range, a critical parameter for MIMO receivers.

The LTC5566 operates from a single 3.3 V supply, drawing a nominal 384 mA with both channels on. A low power mode is available, reducing the supply current to 294 mA with a slight decrease in IP3 performance.

The mixer is rated for –40°C to +105°C case temperature operation and is offered in a 5 mm x 5 mm 32-lead plastic QFN package.

VENDORVIEW

Linear Technology Corp., now part of Analog Devices, Inc.
Milpitas, Calif.
www.linear.com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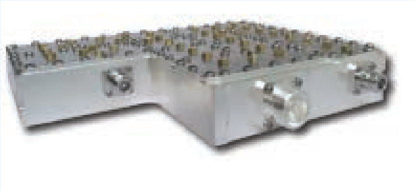


Ultra-Low PIM Cavity Filters

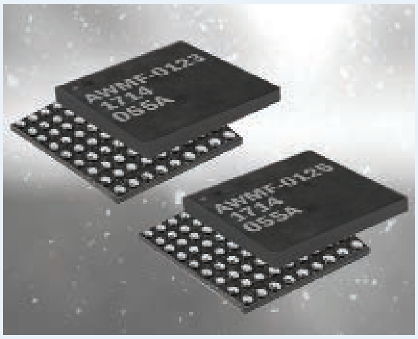
MCV Microwave has developed a line of ultra-low passive intermodulation (PIM) cavity filters and multiplexers covering frequency bands from 250 MHz to 6 GHz. The typical PIM performance in production is -163 dBc measured with two CW tones, each at 43 dBm. An even lower PIM filter with a maximum of -168 dBc is available, if requested. The filter line has low passband insertion loss, high-power handling and, for multiplexers, high isolation between bands.

These high-power, low PIM filters are suitable for use in small cells, tower-mounted amplifiers, combiners, multiplexers, DAS systems and PIM test benches. To illustrate the typical performance, MCV Microwave's 700 MHz high band duplexer design covers the 728 to 757 MHz transmit and 776 to 787 MHz receive bands. Insertion loss is 1.2 dB maximum at room temperature and less than 1.5 dB over the operating temperature range of -40°C to +85°C. Return loss is better than 20 dB. Transmit signal rejection in the receive band is 100 dB minimum, and receive signal rejection in the transmit band is 95 dB minimum. Two-tone IMD performance is -168 dBc maximum and -163 dBc typical. Maximum power handling is 200 W CW and 1500 W peak. This duplexer measures 282 mm × 190 mm × 55 mm.

Low PIM series PBCC cavity filters, PBCCD dielectric resonator loaded cavity filters, PRCC notch filters, PMCC combiners and multiplexers can be ordered in standard and miniature sizes, and custom requirements are welcome. MCV Microwave designs and manufactures their products with precision and practicality, employing a robust design approach with high yields to guarantee competitive pricing and on-time delivery. MCV is vertically integrated, with proprietary, in-house ultra-high Q dielectric resonators and 3D electromagnetic modeling.

VENDORVIEW

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



39 GHz Tx/Rx ICs for 5G Phased Arrays

Expanding its family of Ka-Band beamforming ICs for 5G, Anokiwave has introduced 39 GHz transmit (Tx) and receive (Rx) ICs that complement their 28 GHz offering. Operating from 37.1 to 40 GHz, the AWMF-0123 and AWMF-0125 "quad core chips" support four radiating elements, with 5-bit phase and 5-bit gain beam steering at each antenna element. The AWMF-0123/5 ICs offer adjustable Tx output power, with a 1 dB compression point of +12 dBm and a 5.0 dB Rx noise figure. The ICs are assembled in a 3.7 mm x 3.7 mm wafer level chip scale packages (WLCSP) for low inductance, flip chip integration in a 39 GHz planar phased array. The devices have ESD protection on all pins and are biased with +1.8 V.

The focus of 5G millimeter wave development is currently at 28 and 39 GHz, two bands garnering the most investment by operators and network equipment manufacturers. Working with Ball Aerospace, Anokiwave recently announced the availability of a 64 element, 28 GHz active electronically scanned array using their Tx and Rx beam steering ICs. The AWMF-0129 is the first commercially available array, developed to aid operators and equipment manufacturers quickly prototype and evaluate the 28 GHz spectrum for 5G use. The AWMF-0129 achieves 50 dBmi EIRP and offers users real-time active beam steering, timing control and choice of waveforms.

Anokiwave has been developing silicon ICs for microwave and millimeter wave systems since 1999. Their products are used in radar, satellite communications and wireless infrastructure.

VENDORVIEW

Anokiwave
San Diego, Calif.
www.anokiwave.com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EuMW 2017 will see an estimated 1,700 - 2,000 conference delegates, over 4,000 visitors and in excess of 300 international exhibitors (inc. Asia & US).

REGISTRATION TO THE EXHIBITION IS FREE!

Pivotal to the week is the European Microwave Exhibition, which offers YOU the opportunity to see, first hand, the latest technological developments from global leaders in microwave technology.

The exhibition will provide an unrivalled opportunity for visitors to view and ask questions related to the latest products, components and materials from our extensive selection of international exhibitors. It will also feature exhibitor demonstrations, Industrial Workshops and the annual European Microwave Week Microwave Application Seminars (MicroApps).

- **International Companies** - meet the industry's biggest names and network on a global scale
- **Cutting-edge Technology** - exhibitors showcase the latest product innovations, offer hands-on demonstrations and provide the opportunity to talk technical with the experts
- **Technical Workshops** - get first hand technical advice and guidance from some of the industry's leading innovators

BE THERE

Exhibition Dates	Opening Times
Tuesday 10th October	09:30 - 18:00
Wednesday 11th October	09:30 - 17:30
Thursday 12th October	09:30 - 16:30

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Entrance to the Exhibition is FREE and attending couldn't be easier.

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- Register as an Exhibition Visitor online at **www.eumweek.com**
- Receive a confirmation email with barcode
- Bring your barcode with you to the Exhibition
- Go to the Fast Track Check In Desk and print out your visitor badge
- Alternatively, you can register onsite at the self service terminals during the Exhibition

Please note NO visitor badges will be mailed out prior to the Exhibition.

CONFERENCE REGISTRATION INFORMATION

EUROPEAN MICROWAVE WEEK 2017, 8th - 13th October, Nuremberg, Germany

Register Online at www.eumweek.com

ONLINE registration is open from 1st June 2017 up to and during the event until 13th October 2017.
ONSITE registration is open from 16:00 on 7th October 2017.
ADVANCE DISCOUNTED RATE (up to and including 8th September) STANDARD RATE (from 9th September & Onsite).

Reduced rates are offered if you have society membership to any of the following*: Eu*M*A, GAAS, IET or IEEE.

Eu*M*A membership fees: Professional € 25/year, Student € 15/year.

If you register for membership through the EuMW registration system, you will automatically be entitled to discounted member rates.

Reduced Rates for the conferences are also offered if you are a Student/Senior (Full-time students 30 years or younger and Seniors 65 or older as of 13th October 2017).

The fees shown below are invoiced in the name and on behalf of the European Microwave Association. Eu*M*A's supplies of attendance fees in respect of the European Microwave Week 2017 are exempted from German VAT under Article 4 no. 22a German VAT Act.

ADVANCE REGISTRATION CONFERENCE FEES (UP TO AND INCLUDING 8TH SEPT.)

CONFERENCE FEES	ADVANCE DISCOUNTED RATE			
	Society Member (*any of above)		Non Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 470	€ 130	€ 660	€ 190
EuMIC	€ 360	€ 120	€ 510	€ 170
EuRAD	€ 320	€ 110	€ 450	€ 160
2 Conferences				
EuMC + EuMIC	€ 670	€ 250	€ 940	€ 360
EuMC + EuRAD	€ 640	€ 240	€ 890	€ 350
EuMIC + EuRAD	€ 550	€ 230	€ 770	€ 330
3 Conferences				
EuMC + EuMIC + EuRAD	€ 810	€ 360	€ 1140	€ 520

STANDARD REGISTRATION CONFERENCE FEES (FROM 9TH SEPT. AND ONSITE)

CONFERENCE FEES	STANDARD RATE			
	Society Member (*any of above)		Non Member	
1 Conference	Standard	Student/Sr.	Standard	Student/Sr.
EuMC	€ 660	€ 190	€ 930	€ 270
EuMIC	€ 510	€ 170	€ 720	€ 240
EuRAD	€ 450	€ 160	€ 630	€ 230
2 Conferences				
EuMC + EuMIC	€ 940	€ 360	€ 1320	€ 510
EuMC + EuRAD	€ 890	€ 350	€ 1250	€ 500
EuMIC + EuRAD	€ 770	€ 330	€ 1080	€ 470
3 Conferences				
EuMC + EuMIC + EuRAD	€ 1140	€ 520	€ 1600	€ 740

WORKSHOP AND SHORT COURSE FEES (ONE STANDARD RATE THROUGHOUT)

FEES	STANDARD RATE			
	Society Member (*any of above)		Non Member	
	Standard	Student/Sr.	Standard	Student/Sr.
Half day WITH Conference registration	€ 100	€ 80	€ 130	€ 100
Half day WITHOUT Conference registration	€ 130	€ 100	€ 170	€ 130
Full day WITH Conference registration	€ 140	€ 110	€ 180	€ 130
Full day WITHOUT Conference registration	€ 180	€ 140	€ 240	€ 170

Other Items

STATE RECEPTION – 11TH OCT 2017

Tickets for the State Reception are free, but are limited. They are available for delegates on a first-come, first-served basis.

Proceedings on USB Stick

All papers published for presentation at each conference will be on a USB stick, given out FREE with the delegate bags to those attending conferences. The cost for an additional USB stick is € 50.

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€ 67 for Professionals or € 57 for Students.

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Full details and contacts for the Partner Programme and other Social Events can be obtained via the EuMW website www.eumweek.com.

EUROPEAN MICROWAVE WEEK WORKSHOPS & SHORT COURSES

SUNDAY 8th October		
Half Day	SS-01	EuMC
Full Day	WS-01	EuMC
Full Day	WS-02	EuMC/EuMIC
Full Day	WS-03	EuMC
Full Day	WS-04	EuMC
Full Day	WS-05	EuMC/EuMIC
Full Day	WS-06	EuMC/EuMIC
Full Day	WS-07	EuMC
Full Day	WS-08	EuMC/EuMIC
Full Day	WS-09	EuMC/EuMIC
Full Day	WS-10	EuMC
Full Day	WS-11	EuMC
Half Day	WS-12	EuMC
Full Day	WS-13	EuMC
Half Day	WS-14	EuMC
Half Day	WS-15	EuMC

MONDAY 9th October		
Full Day	WM-01	EuMC
Full Day	WM-02	EuMC
Full Day	WM-03	EuMC
Half Day	WM-04	EuMC
Half Day	WM-05	EuMC
Half Day	WM-06	EuMC
Half Day	WM-07	EuMC
Full Day	WM-08	EuMC

TUESDAY 10th October		
Full Day	WTu-01	EuMC/EuMIC

WEDNESDAY 11th October		
Half Day	SW-01	EuMC/EuRAD
Half Day	WW-01	EuMC
Half Day	WW-02	EuMIC/EuRAD
Half Day	WW-03	EuMC/EuMIC

THURSDAY 12th October		
Half Day	WTh-01	EuMC/EuRAD
Full Day	WTh-02	EuRAD
Full Day	WTh-03	EuMC/EuMIC

FRIDAY 13th October		
Full Day	SF-01	EuRAD
Half Day	SF-02	EuMC/EuRAD
Half Day	SF-03	EuRAD
Full Day	WF-01	EuRAD
Half Day	WF-02	EuMC
Half Day	WF-03	EuMC/EuRAD
Half Day	WF-04	EuRAD
Full Day	WF-05	EuMC
Full Day	WF-06	EuMC/EuRAD
Half Day	WF-07	EuMC/EuRAD
Half Day	WF-08	EuMC/EuRAD

SPECIAL FORUMS & SESSIONS

Date	Time	Title	Location	No. of Days	Fee	
Wednesday 11th October	08:30 - 18:30	Defence, Security & Space Forum	St. Petersburg	1	€ 20 for delegates (those registered for EuMC, EuMIC or EuRAD)	€ 60 for all others (those not registered for a conference)
Monday 9th - Wednesday 11th October	08:30 - 17:50	European Microwave Student School	Neu Delhi	3	€ 40	
Monday 9th - Wednesday 11th October	08:30 - 17:50	European Microwave Doctoral School	Singapur	3	€ 80	

Web and Video Update

New Website Look

Ciao Wireless is proud to announce a new website look that is modern, informative and responsive. The latest web update features a new look, mobile device support and improved navigation throughout the website. You can easily browse through the company's various applications to find a solution for your project. The website also features an option to download catalog sections or the company's entire catalog.

Ciao Wireless Inc.
www.ciaowireless.com

Introducing MyCST

VENDORVIEW

With the introduction of MyCST, users will be able to customize their experience of the CST website. CST STUDIO SUITE® is used across a wide range of industries and markets, and CST provides webinars, workshops and articles for all of them. Users can now select what kinds of CST events they want to be notified about, manage their event registrations, view past webinars and save interesting CST articles for future reference. Try it out for yourself today on the CST Website.

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New and Improved

K&L Microwave's website provides information and tools to speed the identification and specification of custom design solutions from the full range of company products. The latest update features mobile device support and introduction of the AB series of printed bandpass filters on the Filter Wizard® design tool. K&L is part of the Microwave Products Group, a premier global supplier of mission/system-critical engineered electronic components and subsystems. Research capabilities, access data sheets, submit quote requests and download catalog sections.

K&L Microwave
www.klmicrowave.com

New Website Details

Norden Millimeter released their updated website detailing "Who We Are and What We Do". Norden designs and manufactures products 500 MHz to 110 GHz including amplifiers, frequency multipliers, frequency converters, transceivers, switched filters and custom integrated assemblies. Product application areas cover military, commercial, scientific, microwave test equipment, ultra-secure communication systems, ELINT, RADAR and airborne. The website provides information on Norden's "State of The Art Microwave and Millimeter Wave Products" and related test data.

Norden Millimeter
www.nordengroup.com

New Product Finder

VENDORVIEW

SPINNER has released a new online product catalog with a dedicated web address: products.spinner-catalog.com. It clearly presents each product with the relevant data, a description, images, drawings and downloads. A search function with a suggestion list leads straight to the information on any desired product. Products can be easily added to a comprehensive comparison list. The content automatically adjusts to the screen resolution of the user's device.

SPINNER GmbH
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New Video

For quick and easy microwave path alignment, see Sunsight Instruments' revolutionary end to end patent-pending Path Alignment Kit. Huge labor and project time savings, you save a lot of time on tower, reduce climber fatigue and do more links per day than you can using traditional methods—which all need to find signal first. The company aligns path in minutes using extremely accurate GPS position data—no signal, power or frequency needed, can do with or without ODU/radio installed.

Sunsight Instruments
www.sunsight.com/index.php/microwave-path-alignment

NEW PRODUCTS

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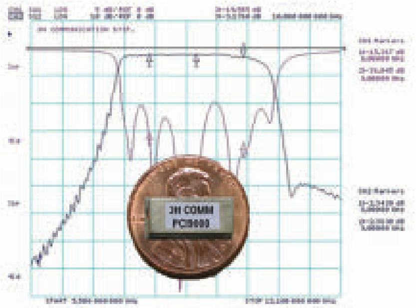
COMPONENTS

Pico Series Bandpass Filter



3H's new X-Band, miniature, leadless, SMT, Pico filter offers low passband insertion loss of < 3.5 dB with a VSWR 2.0:1. The filter size is 0.43 in × 0.28 in × 0.15 in. The filter is manufactured for automated assembly processes and is designed to meet Mil-Std-202 conditions.

3H Communication Systems
www.3Hcommunicationsystems.com

Broadband Absorptive PIN Diode Switch

Amplical's SW12A003 SP12T 2 to 18 GHz broadband absorptive PIN diode switch features low insertion loss, low VSWR, high isolation and fast switching speed. Input ports

are terminated in 50 Ω when switched in the isolation (off) state. All RF ports incorporate DC blocks. An on-board TTL-compatible driver provides convenient logic control. Additional frequency ranges, configurations and features are available upon request. Hermetic seal, MIL and hi-rel screening are available on request.

Amplical
www.amplical.com

RF Switches

Dow-Key Microwave is a leading manufacturer of RF switches offering an extensive line of SPDT and DPDT (Transfer) switches for a wide range of RF and microwave applications. Designed with one to five million life cycles, the break-before-make coaxial switches operate from DC to 40 GHz, offer latching or fail-safe actuators while including a variety of control options. Standard coil voltages of 12, 24 and 28 V are available and may also be designed to include RoHS compliance.

Dow-Key Microwave Corp.
www.dowkey.com

SPDT 40 GHz Switch - DK1 Series

The DK1 series features K connectors and a frequency range of DC to 40 GHz. This series is available with fail-safe, latching self-cut-off or pulse latching functions. At frequency between 32 to 40 GHz, it is rated to perform at: VSWR at 2:1, ILO at 1.0 dB, ISO at 50 dB and switching time of 15 ms max at extreme temperatures of -35°C to +85°C. This SPDT is designed in accordance to MIL-DTL-3928 (Testing and Operation Modes).

Ducommun
www.ducommun.com

Coaxial Voltage Variable Attenuators

Fairview Microwave Inc., a supplier of on-demand microwave and RF components, has introduced a new line of voltage variable attenuators (VVA) that offer up to 60 dB of attenuation across a broad range of frequencies from 400 MHz to 18 GHz. These voltage variable attenuators are frequently used in applications such as electronic warfare, instrumentation, point-to-point and point-to-multipoint radios, fiber optic and broadband telecom, microwave radio and VSAT, military radios, radar, ECM, SATCOM and sensors and R&D.

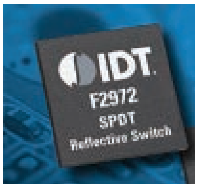
Fairview Microwave Inc.
www.fairviewmicrowave.com

High Power Limiters

High power limiters feature 200 W CW, 10 to 500 MHz, frequency range down to very low frequency (10 MHz), low insertion loss and VSWR, 200 W CW and 1000 W peak, (1 microsec pulse width) power handling capability, built-in DC block at input and output and a hermetically sealed module.

Herotek
www.herotek.com

SPDT Reflective RF Switches



IDT has introduced a new family of high performance single-pole, double throw reflective RF switches in compact 2 mm x 2 mm packages. The F2972 and F2976 operate from 5 MHz to 10 GHz, offering an industry-leading mix of low-insertion loss, high isolation, low distortion and high-power handling. Specified for use in either 50 or 75 ohm systems, the switches offer versatility for a wide range of applications, including BTS wireless communications equipment, DOCSIS 3.1 CATV applications, drones and general purpose consumer products.

Integrated Device Technology
www.idt.com

Low PIM Termination Brackets

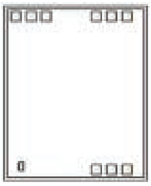
VENDORVIEW

MECA offers mounting brackets for their full line of Low PIM Terminations. From 10 through 250 W models in all connector styles/configurations, designed for in-building, tower top or desktop configurations. Available in various weatherproof IP 67 standard, IP68 available. Made in the U.S. with a 36 month warranty.

MECA Electronics Inc.
www.e-MECA.com

Wideband Double Balanced MMIC Mixer Die, Level 15, 5 to 21.5 GHz

VENDORVIEW

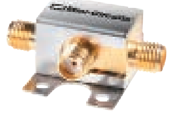


Mini-Circuits' MDB-24H-D+ is a wideband, double-balanced, level 15 MMIC Mixer die with an IF bandwidth from DC to 5 GHz and LO/RF bandwidth from 5 to 21.5 GHz, supporting a wide range of applications including satellite up and down converters, defense radar, VSAT and more. This model provides low conversion loss (6.9 to 10.3 dB), 44 dB L-I isolation, 28 dB L-R isolation and good input/output return loss over its full frequency range without the need for external matching components.

Mini-Circuits
www.minicircuits.com

Ultra-Wideband, Coaxial 2-Way 0° Splitter/Combiner, 500 to 8500 MHz

VENDORVIEW



Mini-Circuits' ZX10-2-852+ is a wideband coaxial 2-way, 0° splitter combiner covering over eight octaves from 500 to 8500 MHz. This model handles up to 2.5 W RF input power with low insertion loss (from 1.1 to 3.0 dB), 1.4:1 typical VSWR, 0.2 dB amplitude unbalance, 3° phase unbalance and DC passing up to 0.4A. It comes housed in a compact case (0.74 x 0.90 x 0.54) featuring rugged, unibody construction for high reliability and excellent survivability and SMA connectors at all ports.

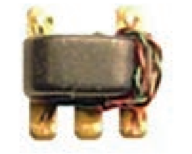
Mini-Circuits
www.minicircuits.com


5 W TYPE-N
1 W
2.4mm
20 W TYPE-N
2 W SMA
50 W & 100 W models
NEW
BW-V Series
50 GHz models

NewProducts

MRFXF0032 Transformer

VENDORVIEW



The MRFXF0032 transformer is designed for applications that require very small, low cost and highly reliable surface mount components. Applications may be found in broadband, wireless and other communications systems. These units are built lead-free and RoHS compliant and feature welded wire construction for increased reliability. S-Parameters are available on request.

MiniRF
www.minirf.com

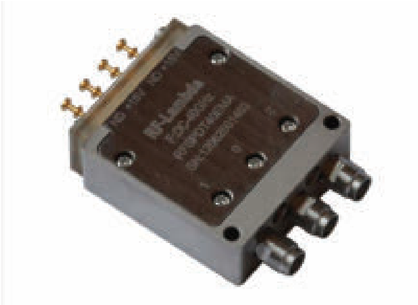
8-Bit Digital Phase Shifter

VENDORVIEW

PMI Model No. PS-2G6G-8B-SFF is a 8-Bit digital phase shifter that operates over the 2 to 6 GHz frequency range. This model offers 360° of phase shift having a LSB of 1.4°. The insertion loss is 10.5 dB typical with a typical phase accuracy of ±0.5°, amplitude error of ±1 dB typical. Supplied in a housing measuring 3.25 in × 3.25 in × 0.94 in with SMA female connectors.

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

Multiport Switch



RF-Lambda multiport switch improves insertion loss repeatability and isolation, which is necessary for higher performance test systems. The repeatability and reliability of this switch is vital to ATS measurement accuracy and can cut the cost of ownership by reducing calibration cycles and increasing test system up time. The RF-Lambda terminated multiport switch provides the long life and reliability required for automated test and measurement, signal monitoring and routing applications. Highly repeatable switching capability is made possible through RF-Lambda's rigorous design and tight manufacturing specifications.

RF-Lambda
www.rflambda.com

MHz Tunable Bandpass Filter

Richardson RFPD announced the availability and full design support capabilities for a new 30 to 520 MHz tunable bandpass filter and associated evaluation board from NewEdge Signal Solutions Inc. The SAX239 offers an industry-leading combination of power handling (+33 dBm) and DC power consumption (< 100 mW) in a small form factor. The new device also features low insertion loss and fast-tuning across the band to 1 MHz resolution.

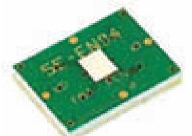
Richardson RFPD
www.richardsonrfpd.com

M68-3X2B Frequency Converter

To serve the 5G/WiGig research efforts, Spacek Labs is offering their model M68-3X2B, a frequency converter/mixer which operates in V-Band and accepts an RF input frequency from 64 to 71 GHz. The LO input frequency/power is 32 to 35.5 GHz at +15 dBm. An integrated LO X2 multiplier generates the 64 to 71 GHz LO. The IF output frequency is 0.01 to 7 GHz. The mixer conversion loss is 6 dB typ, 8.5 dB max, with an input P1dB of 0 dBm typ.

Spacek Labs
www.spaceklabs.com

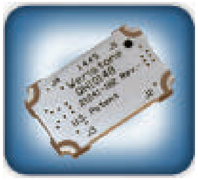
Surface Mount Mixer



Synergy Microwave's popular, small size and high reliability wide bandwidth mixer model SGM-2-13 has a RF/LO frequency coverage of 0.25 to 3.25 GHz and an IF port operating from DC to 700 MHz, making this an ideal device for up or down conversion. Standard LO drive of +13 dBm provides a typical +14 dBm IP3. The typical conversion loss is just 6.5 dB. The typical isolation for LO/RF is 25 dB, LO/IF is 12 dB and RF/IF is 25 dB.

Synergy Microwave Corp.
www.synergymwave.com

SMT 90° Hybrid Coupler



Werlatone's Model QH10148, a 90° hybrid coupler covers the full 2 to 6 GHz band, at 100 W CW, and delivers best-in-class amplitude balance, specified at ± 0.5 dB max. An amplitude balance measuring half that of competing products, insures that your transistors run more evenly and thus, more efficiently. Measuring just 0.75 in x 0.45 in x 0.79 in, the QH10148 is robust and highly repeatable.

Werlatone Inc.
www.werlatone.com

CABLES & CONNECTORS

Compact Waveguide Rotary Joint

MDL introduced its new compact waveguide rotary joint series. Model 28RU199 WR-28 "U" style with mounting flange. Frequency range is 34 to 36 GHz, VSWR 1.30:1 max, WOW 1.05 max, insertion loss 0.30 dB max, over 360° rotation. It can be pressurized. Let the company's designers know how you need yours optimized and customized. Model styles "U", "I", "L", "F" are currently available in WR-22, WR-28, WR-34, WR-42, WR-51.

Microwave Development Laboratories Inc.
www.mdllab.com

Precision Compression Mount Connector Line

SV's top selling solderless precision compression mount connector line is now available with screws. SV's solderless high frequency RF install fast, easy and without damaging the PCB board. SV offers cost effective coaxial PCB mount SMA, 2.92 mm and 2.4 mm connector series. Additionally, SV can customize a PCB footprint design for your application using its latest simulation technology. These are all readily stocked through distribution.

SV Microwave
www.svmicro.com

AMPLIFIERS

Single Band Amplifiers

VENDORVIEW

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.

AR RF/Microwave Instrumentation
www.arworld.us

Wideband Low Phase Noise Amplifier

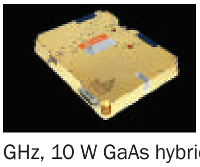
VENDORVIEW

Custom MMIC, a leading developer of performance driven monolithic microwave integrated circuits (MMIC), has added a new category to their rapidly expanding standard product offerings. Custom MMIC's new GaAs MMIC low phase noise amplifier family offers previously unattained phase noise performance. Phase noise is a critical requirement which defines the performance level of most radars and communications systems. The five product family achieves phase noise performance as low as -165 dBc/Hz at 10 kHz offset.

Custom MMIC
www.custommmic.com

GaAs Hybrid SSPA Module

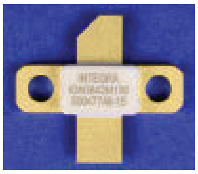
VENDORVIEW



Exodus Advanced Communications announced the release of their best in class SSPA model AMP3060—a 32 to 40 GHz, 10 W GaAs hybrid SSPA module. It provides 10 W CW Psat over the full bandwith 4 dB peak to peak flatness. This amplifier is designed for any application that requires wide band coverage such as EMI/RFI, Ka-Band radar, EW and high-power millimeter testing.

Exodus Advanced Communications
www.exoduscomm.com

130 W, 3.8 to 4.2 GHz, GaN/SiC Transistor



Designed for low C-Band applications, this high-power GaN-on-SiC HEMT transistor supplies 145 W of typical peak pulsed output power at 50 V drain bias, with 14 dB of gain and 57 percent of efficiency at 100 us-2 percent pulse conditions.

Integra Technologies
www.integratech.com

NewProducts

Low Phase Noise Amplifiers

VENDORVIEW

Pasternack, a leading provider of RF, microwave and millimeter wave products, has released a new line of low phase noise amplifiers that incorporate GaAs HBT MMIC semiconductor technology to deliver ultra-low phase noise performance over a wide dynamic range. These amplifiers can be used to help optimize the sensitivity and dynamic range of higher performing test, radar and communication receiver designs where performance is dependent on how effectively the smallest and largest signal levels can be processed.

Pasternack
www.pasternack.com

SOURCES

RF Signal Generator

DS Instruments introduces the SG6000F, a harmonic-filtered version of the popular SG6000 compact and economical RF signal generator covering 25 MHz to 6 GHz. Output power is adjustable and pre-calibrated to +10 dBm. Harmonic levels are now -30 dBc across the entire instrument output range. The USB serial port requires no drivers or API, only simple text commands.

DS Instruments
www.dsinstruments.com

OCXO + Rubidium Ruggedized Frequency Source

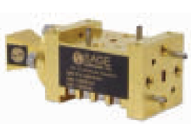
Wenzel Associates offers the QRb Sync Series products, which includes a low noise OCXO coupled with a very stable disciplined rubidium oscillator and combined within a small ruggedized housing. This combination offers exceptional phase noise performance as well as excellent stability. There are many options to choose from, depending on the application, including HF and VHF frequencies from 10 to 500 MHz as well as low g-sensitivity and internal vibration isolation.

Wenzel Associates
www.wenzel.com/model/ocxorubidium-assemblies

ANTENNAS

Dual Polarized Antenna Horn Assembly

VENDORVIEW



For communication and radar applications, SAGE Millimeter has released a new full band, dual polarized horn antenna assembly. Model SAR-5037531530-15-S1-DP covers the frequency range of 50 to 75 GHz and features an integrated orthomode transducer (OMT) that provides high port isolation and cross-polarization cancellation. Features include high isolation, low insertion loss, full band performance and dual polarization.

SAGE Millimeter
www.sagemillimeter.com

TEST & MEASUREMENT

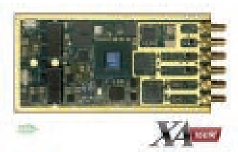
Phase Noise Testing Solution

VENDORVIEW

The Model 7330 is a compact integrated phase noise testing solution offering an indispensable set of measurement functions for evaluating signal sources ranging from 5 MHz to 33 GHz. Fully turnkey, compact and broadband with both additive and residual measurements. This instrument is capable of measuring some of the most difficult devices such as unstable free-running VCO or pulsed amplifiers.

Berkeley Nucleonics
www.berkeleynucleonics.com

XMC I/O Module



The XA-160M is an XMC I/O module featuring two 16-bit, 160 MSPS A/D channels and two 16-bit, 600 MSPS DAC channels designed for high speed stimulus-response, ultrasound and servo control applications. It provides an extremely economical solution for real-time, FPGA-accelerated stimulus-response applications such as RADAR, LIDAR, optical servo or medical scanning. When mated with one of the company's rugged, embedded PCs, the XA-160M becomes an autonomous, self-booting instrument with dual, 10 GbE connectivity—perfect for distributed instrumentation.

Innovative Integrations
www.innovative-dsp.com

IoT Technical Challenges and Solutions

Arpan Pal and Balamuralidhar Purushothaman

The mention of the IoT may warrant a roll of the eyes by the RF/microwave community. We have heard about it ad nauseam, usually oversimplified in catch phrases such as "connecting everything to everything." Unless we are working on an IoT application, we may not appreciate the complexity of the ecosystem required to make the IoT work. It is much more than a Zigbee or LoRa wireless connection from a battery-powered sensor. An IoT system design includes communications, computing, storage, mobility, security, privacy, data analytics and, most importantly, it must provide a return on investment for the ecosystem players and users. As authors Arpan Pal and Balamuralidhar Purushothaman write, "The challenges with IoT go beyond making and connecting devices that work. The integrated product and services need to work seamlessly, almost invisible to an end user." They quote Mark Weiser, from a 1991 article published in *Scientific American*: "We need machines that fit the human environment instead of forcing humans to enter theirs."

With this fragmentation of the IoT, the authors seek to integrate the multiple dimensions of a successful implementation. In seven, very readable chapters, they provide an overview of the IoT today (Chapter 1), the scalability of networks and computing (Chapter 2), security and privacy (Chapter 3), sensor informatics (Chapter 4), mobile sensing (Chapter 5), analytics as a service (Chapter 6), the requirements for a realistic IoT deployment today and future IoT technologies (Chapter 7). Chapter 4 is perhaps the most interesting, as the authors claim that sensor informatics are the main driving force for successfully creating a value-add business model. Although the book is technical, the reader does not need a technical background, simply an interest in the IoT.

Pal and Purushothaman are both principal scientists with Tata Consultancy Services. Pal is the head of the Kolkata Innovation Lab, and Purushothaman leads the Bangalore Innovation Lab. Both received Ph.D. degrees from Aalborg University in Denmark.

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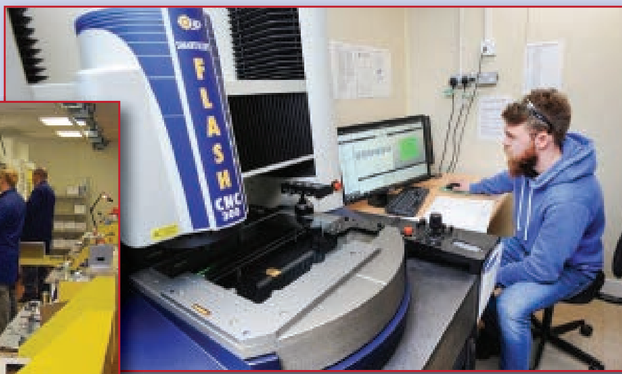
FABS and LABS

Flann Microwave–Rural Location, Global Player



Suppliers, customers and partners of Flann Microwave will be aware of the company's location in Bodmin, Cornwall—the U.K.'s most south westerly peninsular. However, the company's origins lie closer to London than Land's End, as Flann was founded in Kingston upon Thames, Surrey in 1956 by engineer Bernard Fleming, who took his experience in radar and combined it with his passion for innovation and insight into the potential of waveguide technology.

Since then, the company has grown to secure a global reputation for innovation and the production of precision microwave and millimeter wave passive waveguide components, sub-assemblies, calibration kits and instrumentation to 500 GHz.

In 1970, Fleming relocated the business to a new, purpose-built headquarters and engineering facility in Cornwall—a picturesque county renowned for agriculture, craggy cliffs and sandy beaches, but more associated with waves than waveguides. The move necessitated that all of the key capabilities be brought "in-house," to make them vertically integrated and more self-contained. With a workforce that is currently 66 strong, the company exports more than 80 percent of production.

The facility provides the latest engineering, production and test capabilities. 3D finite element electromagnetic simulators are used, together with mode matching design software, enabling the transfer of 3D models direct to the CAD office where the parts are mechanically designed. Full 3D models are then transferred electronically to the machine shop and the parts are machined on one of seven CNC mills or two CNC lathes, or manually by an experienced technician.

The facility is equipped with a full suite of the plating and surface finishing processes needed for microwave devices including Gold, Silver, Copper, Tin, Nickel and Chromate, as well as RoHS conversion coatings for Aluminum.

RF testing of products is a priority. Flann has vector network analyzer capability in-house from 500 MHz to 500 GHz, and it works with National Measurement Institutions around the world to improve the traceability of RF measurements. The company is working toward achieving ISO 17025 recognition.

Over the last 60 years, Flann has been at the forefront of innovation, playing a major role in landmark projects such as equipping the Goonhilly Earth Station, which received the first live transatlantic television broadcasts from the United States in 1962, with Flann still supporting the facility today. Another is the 10-year National Air Traffic Services (NATS) project, completed in 2013, involving the manufacture, installation and test of precision waveguide equipment to upgrade or replace all of the U.K.'s main 23 radar stations.

At the very heart of the business and its workforce is a spirit of innovation, commitment to engineering expertise, attention to detail and customer service, which has been the foundation for Flann's success. It has an ongoing policy of maintaining the highest standards and continuing to invest, both in innovation and its workforce—15 percent of whom are in the R&D team.

The company is committed to finding and developing talented new employees. For instance, in the last six years it has trained and employed six apprentices, with three more recruited recently. Flann works closely with the materials laboratory at the University of Plymouth and has strong links with Exeter University, where the company is currently sponsoring a PhD student researching metamaterial antennas for 5G backhaul.

As a family-owned company Flann is a rarity, especially in the U.K. Although it has a rich past, it is also planning on a bright and prosperous future with the security of a succession plan in place and a determination to continue to be a pioneering force in the future.

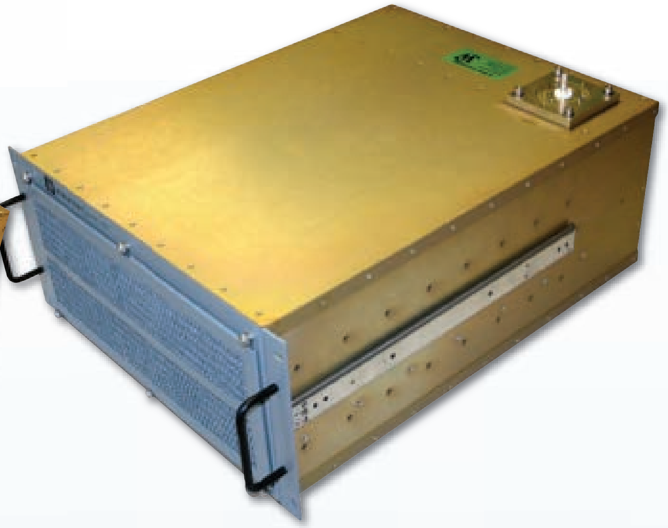
www.flann.com

WERLATONE®

We Are High Power

Big Stuff! High Power RF Combiners

- **Power Levels to 20 kW CW**
- Low Insertion Loss
- Send Us Your Specs!
- Isolated & Non-Isolated Designs
- Rack Mount, Drawer Mount, Radial Type
- Coherent and Non-Coherent Combining



Combiners/Dividers

Model	Type	Frequency (MHz)	Power (W CW)	Insertion Loss (dB)	VSWR	Isolation (dB)	Size (Inches)
D8230	4-Way	1-30	2,500	0.2	1.15:1	30	10.5 x 5.4 x 1.28
D8265	2-Way	1-50	5,000	0.3	1.25:1	20	15.5 x 11.75 x 5.25
D2076	2-Way	1.5-30	3,000	0.1	1.25:1	22	7 x 3.75 x 2.62
D5807	4-Way	1.5-30	4,000	0.25	1.20:1	25	13 x 11 x 3.7
D2075	2-Way	1.5-30	6,000	0.2	1.25:1	20	15.5 x 11.75 x 5.25
D8969	2-Way	1.5-30	12,500	0.2	1.25:1	20	17 x 17 x 8
D6139	4-Way	1.5-32	5,000	0.25	1.25:1	20	13 x 11 x 5
D6774	4-Way	1.5-32	20,000	0.3	1.20:1	20	21 x 17.25 x 11
D6846	6-Way	1.5-30	4,000	0.35	1.35:1	20	3U, 19" Rack
D8421	8-Way	1.5-30	12,000	0.3	1.30:1	20	22.5 x 19.5 x 8.75
D7685	4-Way	2-100	2,500	0.5	1.30:1	20	15 x 13 x 5.5
D10454	2-Way	3-50	5,000	0.5	1.30:1	20	15.5 x 11.75 x 5.25
D9221	4-Way	20-130	10,000	0.3	1.25:1	20	14.75 x 12 x 5
D2786	4-Way	20-150	4,000	0.5	1.35:1	20	18 x 17 x 5
D6078	2-Way	100-500	2,000	0.25	1.20:1	20	13 x 7 x 2.25
H7521	2-Way (180°)	200-400	2,500	0.3	1.30:1	20	15 x 10 x 2
D7502	2-Way	400-1000	2,500	0.25	1.20:1	NI*	9.4 x 3.4 x 1.25

*NI = No Isolating Terminations

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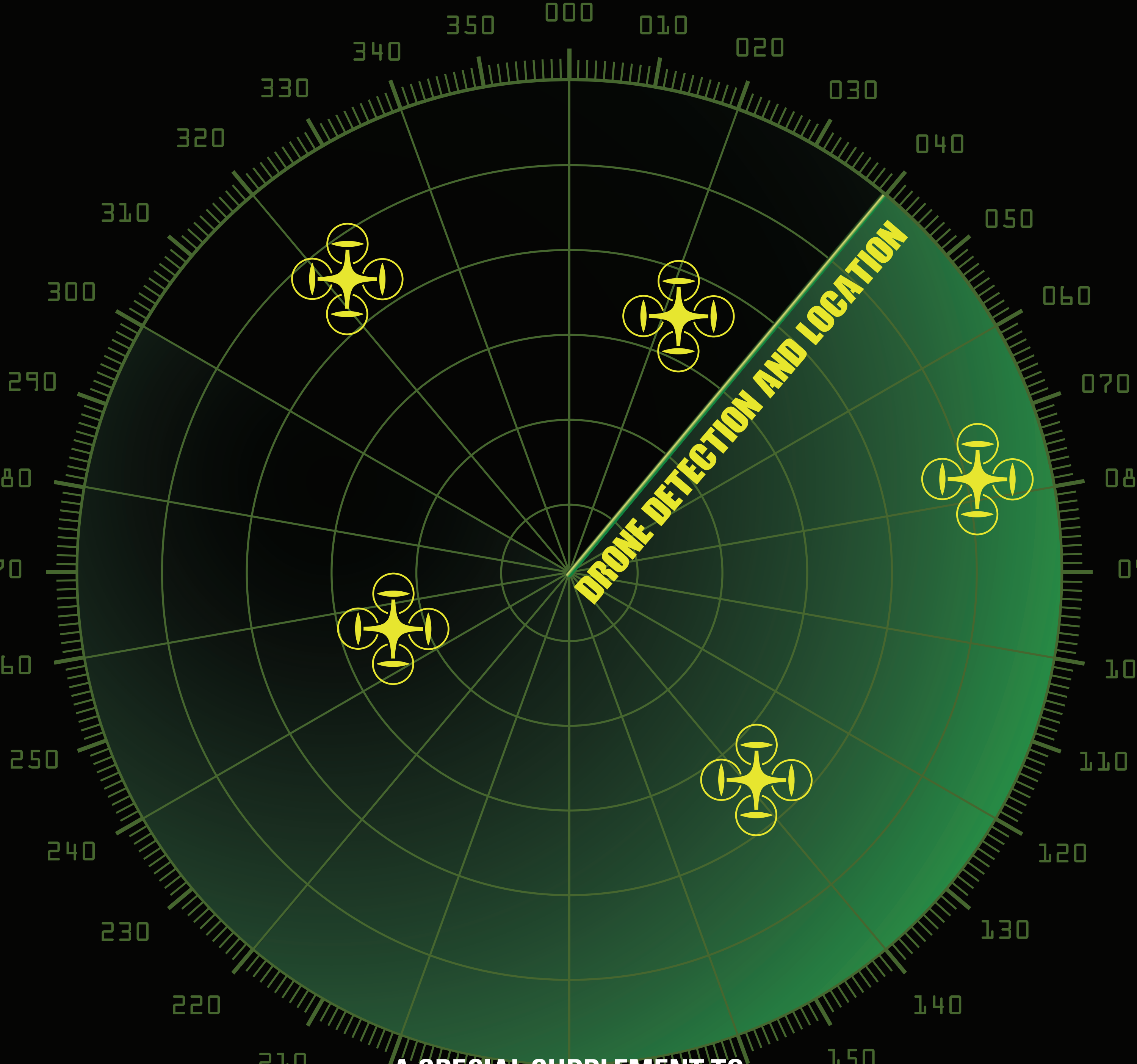
AEROSPACE AND DEFENSE ELECTRONICS 2017



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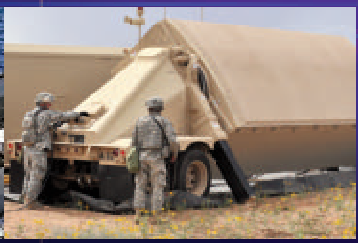

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Invited Paper
With Contributions From:
Rohde & Schwarz
Keysight Technologies
Aaronia AG

Drone Detection and Location Systems

Edited by Patrick Hindle
Microwave Journal *Editor*

Radio-controlled commercial drones have quickly caught the attention of consumers and entrepreneurs who have created many new and emerging commercial uses. From videography to inspection of crops and infrastructure to delivery of goods, drone technology has become both a pastime for the hobbyist and an essential tool for the business entrepreneur. With many commercial applications and millions of hobbyists flying drones, the commercial sales of drones is expected to reach nearly $10B globally by 2025 according to some reports.

However, with widely publicized incidents, such as a drone landing on the White House garden and near hits with landing planes at airports, the detection, location and mitigation of the possible threats posed by consumer drones presents a new challenge for securing critical or private facilities, infrastructure, public venues and even borders.

There have been about 600 drone incidents that have been recorded by the U.S. Federal Aviation Administration over the previous six months. Civilian-operated UAVs are a problem that is getting worse—on April 17 of this year, a British Airway's flight making its final approach to London's Heathrow Airport was reported to have struck a UAV. Two months earlier, another plane that had just departed from Heathrow Airport had a near collision with a UAV.

The UAVs that landed in front of German Chancellor Angela Merkel in September 2013 and on the roof of Japanese Prime Minister Shinzo Abe's office in April 2015 were flown by protestors trying to prove a point. But in the future, such UAV's could carry explosives, bio or chemical weapons to perform terrorist attacks. They can also be used to transport illegal items such as drugs, or used to jam radio signals, like GPS or Wi-Fi, interrupting service. Given these concerns, market forecasts for drone detection systems are estimated to grow to about $16B by 2022 according to ASD reports.

Drone radio controls (RC) typically operate in one of three different parts of the spectrum

TABLE 1

TYPICAL FREQUENCY BANDS FOR DRONE RADIO CONTROL (Courtesy of Keysight Technologies)

Band Name	Start Frequency	Stop Frequency	Power Limitation
UHF Short Range Device	433.05 MHz	434.79 MHz	≤ 10 mW ERP
ISM 2.4 GHz	2.4 GHz	2.4835 GHz	≤ 100 mW EIRP
ISM 5.8 GHz	5.725 GHz	5.85 GHz	≤ 100 mW EIRP

ERP – Effective Radiated Power
EIRP – Equivalent Isotropic Radiated Power

reserved for remote control devices shown in ***Table 1***. These bands can be very crowded—especially the 2.4 GHz ISM where most commercial Wi-Fi, Bluetooth and IoT (i.e., ZigBee, Z-Wave, LoRa) systems operate. Signals operating in these bands are loosely regulated, using random access rules rather than a controlled time or frequency division access scheme. Thus, there are a large number of signals occurring across the 80 MHz of the 2.4 GHz ISM band. The SRD and 5.8 GHz ISM bands are not as active, but given time they are bound to become the most populated.

Microwave Journal gathered the following three contributed pieces from Rohde & Schwarz, Keysight Technologies and Aaronia AG about RF drone detection and location systems, including the challenges to drone detection, advantages and disadvantages of these systems and some information about their systems. While there are many companies developing these systems, we chose these three leading test & measurement companies to contribute their approaches and views as experts in the area of spectrum monitoring.

RF Drone Detection and Location System Challenges and Solutions

Darren McCarthy
Rohde & Schwarz
Beaverton, Ore.

Stopping a drone from flying is not a trivial task and no single solution is a panacea. Visual and sound detection can be subject to impaired performance and errors from environmental interference. Radars may not detect drones with a small form factor and Electro/Optical (EO) sensors may not work in adverse weather conditions such as rain or fog. Even RF detection would not be effective alone on a pre-programmed drone using GPS waypoints for guidance. The presence of a radio link is necessary for RF detection. However, a RF detection system is a key trigger point for most of the consumer drone technologies in use and has a distinct advantage of speed of detection versus other technologies.

To be effective, RF detection systems must provide a high level of sensitivity, give an early warning and not create false alarms. A complete countermeasure system also requires a safe, reliable means of stopping the threat. An RF detection system can be a useful part of the complete workflow for a system that includes other sensor technologies.

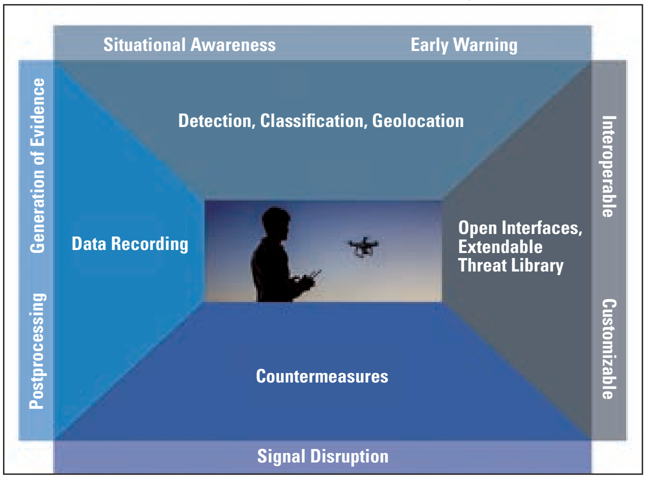
One of the critical shortcomings of protection systems has been the integrated workflow between the detection system and the immediate interaction between the detection and countermeasures systems to attain a high level of success. ***Figure 1*** gives a workflow for consideration and forms the framework for the design challenges of detecting possible threats from drones. In this article, we will focus on the detection and location drones controlled by RF links, and the need for interoperability and customization as technology advances.

Situational Awareness: Detection, Classification and Geolocation

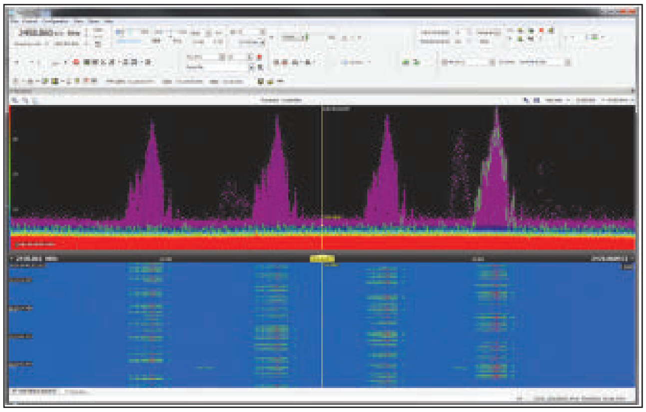
While no universal standard exists for the remote control of drones, the majority of drone technologies are radio controlled and emit an uplink (controller to device) and downlink telemetry or video signal back to the user. The RF detection system has a distinct advantage for the detection of a radio controlled drone—time!

The RF link establishment between the controller and the drone gives the RF detection system a substantial advantage in assessing the threat situation.

While most operate in the unlicensed ISM bands at 2.4 or 5.8 GHz, other frequency bands are also used including 433 MHz and 4.3 GHz. Some of the older frequencies used by radio controlled devices include 27, 35, 40.68 and 72 MHz, which could also offer an extended range of control to several kilometers. The ability to track and detect possible devices requires a broadband antenna and receiver system capable of monitoring all the critical bands of interest on the hunt for possible threats. Further, since these ISM bands and devices operate with very low power (~100 mW) and in the presence of oth-



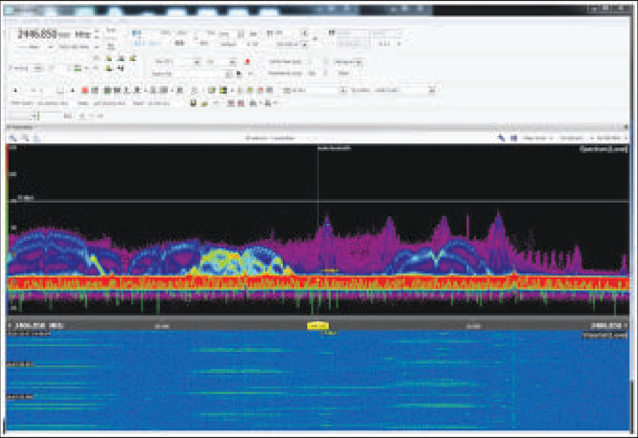
▲ Fig. 1 Framework for drone location and detection systems.



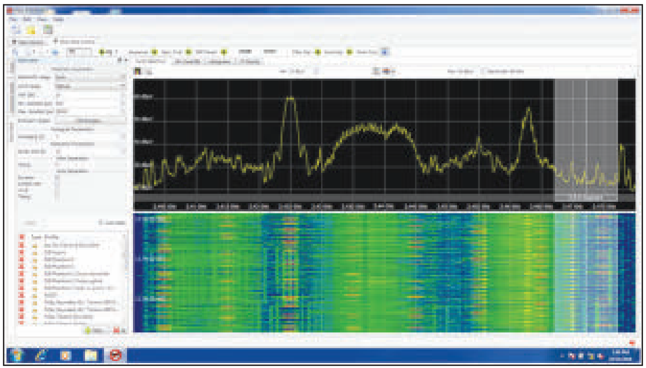
▲ Fig. 2 Example of FHSS technology used for a 2.4 GHz drone.

er legitimate RF uses with similar technologies, like WLAN, the high sensitivity to see signals at distance ranges and discern legitimate versus unauthorized threats requires operation expertise in signal analysis and automatic detection is required.

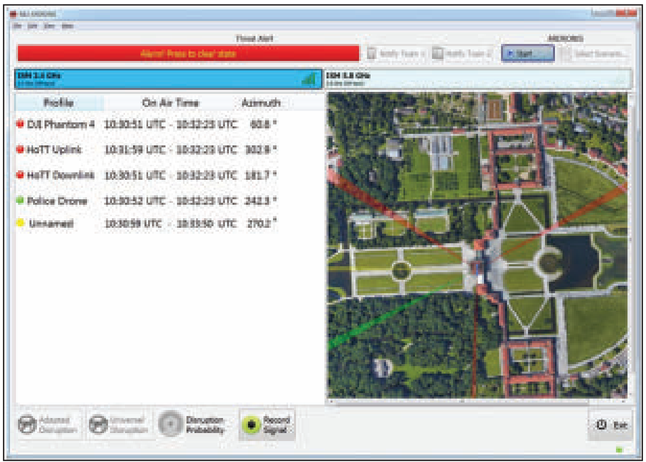
Figure 2 shows an example of a drone using FHSS technology in the 2.4 GHz ISM band. In the upper display, the RF spectrum shows the signal persistency on a temperature scale which is the presence of a signal over a period of time that is channelized into four frequency channels. The lower display shows the spectrogram, or waterfall, of the same signal over time with the color scale representing amplitude. A detailed analysis of this signal will show that this signal is hopping between the different RF spectrum channels with a specific burst duration, channel sequence or hopping pattern, and at a specific hopping rate (~ 100 hops/s). From this display, the clean spectrum and lack of other signals makes it easy to recognize the pattern of this FHSS drone, similar to what one might find in a lab or controlled environment.



▲ Fig. 3 A drone signal in the presence of normal traffic from Wireless LAN.



▲ Fig. 4 A multi-threat environment with multiple drones (uplink and downlink) identified (lower left).



▲ Fig. 5 Example Geo-location of drone threats and a "friendly" drone Interoperability and Future-Proof.

Consider the environment represented in ***Figure 3***. This now becomes a little less obvious to a system operator when in the typical environment of crowded ISM band technologies. The presence of multiple WLAN access points and user terminals, Bluetooth technologies and IoT devices, can all be present in the same spectrum and the FHSS drone can be lost in the view. Also, keep in mind that some drones utilize WLAN signals for control or downlink video, so deeper inspection and decoding of WLAN signals is warranted to detect motion.

To reliably detect a drone signal, automatic classification is essential. A human operator cannot be expected to understand and assess all signals in all

frequency bands in a timely manner. A simple threshold-based RF alarm signal, available on many basic spectrum monitoring systems, can lead to false alarms whenever a signal threshold is detected. The automatic classification system must recognize the expected environment and be able to look for the transmission system for classifying the signature, of an expected threat from a library of known drone signals. Time is the biggest advantage of an RF detection system during the link establishment, and this advantage must be used to improve situational awareness.

The multi-drone environment must also be considered. There may be situations where a "friendly" drone (white list) would be used for perimeter monitoring, police investigation or crowd observation. The individual identification of known "friendly" signals must be assessed against the environment. This presents the opportunity where a drone threat (black list) may coexist with a white list asset. This leads to the question of how many threats are expected in an environment.

There is a complex challenge to rapidly classifying signals in a multi-threat environment (see ***Figure 4***), especially considering the complexity of separating the signatures of multiple commercial drones using FHSS, WLAN and Bluetooth technologies operating on the same frequency band, and others that might operate on other frequency bands. Not only is this a challenge during the signal classification process, but it must also be noted that not all direction finding technology perform geolocation equally in a multi-signal environment. This is especially true with direction finding technologies that are not able to distinguish multiple signals at the same time on the same frequency, but emanating from different angles of arrival.

The selection of direction finding technologies must also consider the ability of the system to geolocate threats that are occurring at the same time and on the same frequencies, as well as the ability to operate over the entire expected operational band. It is important that behind the technology of the system, these threats can be presented to the user in a clear manner for them to be able to act upon the threat. ***Figure 5*** gives an example of four drones being detected at the same time and the angle of arrival of each of the threats and the friendly police drone.

RF detection systems play an essential part of a drone defense system; however, there are drone technologies that can operate based on a GPS, or other GNSS technologies, waypoint system that do not emit an RF signature. In this case, sole reliance on an RF detection system would be inadequate protection for high-valued targets.

The complete solution must consider other technologies that can work in concert to complement the advantages and overcome the disadvantages of sole technologies reliance. Therefore, an open system interface that can enable any of these other technologies to "tip" the defensive system is important. Alarms or tipping of other systems should also consider visual or acoustic methods as well as text messaging (SMS) to predefined groups of mobile phones or as an XML message via an IP network.

As drone technologies continue to advance, new RF interfaces continue to be incorporated into these commercial

devices. It is important for the detection system to have a scalable approach to extend and incorporate new RF signatures as they become available. A database is only good against known threats. Continued vigilance against the new advances in RF interfaces is essential, and the ability to augment the protection system to the latest threats remains imperative.

An example system is the R&S® ARDRONIS technology (see ***Figure 6***), which has already demonstrated itself as acceptable for the highest levels of security. At the G7 Economic Summit held in Elmau Castle, Germany and again during U.S. President Barack Obama's visit to the Hanover Trade Fair in 2016, the system's underlying technologies were used to secure the sites from unauthorized, remote controlled drones.

▲ Fig. 6 Rohde & Schwarz's R&S®ARDRONIS-D radio monitoring solution combines detection, classification and geolocation in a single, portable, highly reliable system.

The R&S® ARDRONIS automatic radio-controlled drone classification solution is a comprehensive solution with specialized capabilities for detecting, classifying, geolocating, recording and disrupting the remote control link to a drone. The solution is optimized for countering the threats arising from radio controlled (RC) drones. Through successful trials, deployments with key customers, involvement in protecting various important and public events as well as VIP persons, R&S® ARDRONIS has proven to be an effective technical approach.

R&S® ARDRONIS is a reliable approach to effectively detect and monitor drone activity and achieve early warning capability. It meets the challenge of identifying the direction of operators by finding the direction of active remote controls and drones. Effective countermeasures can be deployed in time to counter and prevent a radio controlled drone from entering a defined area by disrupting the radio communications link. The capabilities and key functionalities of R&S® ARDRONIS include classification, geolocation and countermeasures for threats imposed by radio-controlled drones.

Summary

There are many considerations to the challenges of the potential threats presented by drones. The widespread use of commercially available drones heeds warning to an increased need for vigilance these threats may possess for potential high-valued targets and critical sites.

The depth of the solution obviously needs to be weighed against the possibilities of the threat and the poten-

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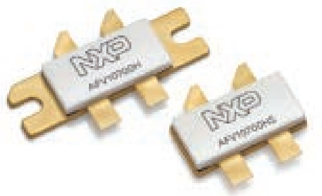

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tial of the threat to change over time. RF detection systems have a distinct advantage of reaction time along with a high probability of use. The actions and workflow of how to respond to a threat must play into how components of a defensive system can complement their actions for a complete solution.

The careful consideration of the type of RF detection system must also consider the need to be able to sift through the myriad of RF signals in a dense spectrum environment and simultaneously reduce the false alarm rate. One needs to be able to tell the difference between a Wi-Fi signal someone turns on for their own personal hotspot and the Wi-Fi signal of a drone. As new signals appear and technology advances, skilled users should be able to define their own threats to be included in the classification database, or a service level agreement to renew and keep the database current with technology should be made available.

Geolocation technology needs to be carefully considered and technology assessment should be performed against an anticipated scenario. Choosing a direction finding technology that is blind to a multi-threat environment could have disastrous consequences.

RF Techniques for Detection, Classification and Location of Commercial Drones

I.C. Tillman
Keysight Technologies
Santa Rosa, Calif.

An effective drone detection system monitors all three of the bands, 433 MHz SRD and 2.4 or 5.8 GHz ISM, while skipping over the vast spectrum in between (see ***Figure 7***). This results in a fast and efficient way to focus only on the parts of the spectrum where drones are known to operate. Each band is configured with different resolution bandwidths (RBW) and trace averaging schemes based on the typical bandwidths and features of the drone control signals. For example, drone control signals found in the SRD band (400 MHz) are usually only tens of kHz wide and have unique spectral shapes. For that reason, narrow RBW (i.e., less than 3 kHz) is appropriate in this band. The signals of interest in the 2.4 and 5.8 GHz ISM bands tend to be 1 to 2 MHz wide; therefore, a wider RBW (i.e., 20 kHz) is beneficial. The wider RBW allows for faster processing of the spectrum and higher probability of intercepting a drone RC transmission.

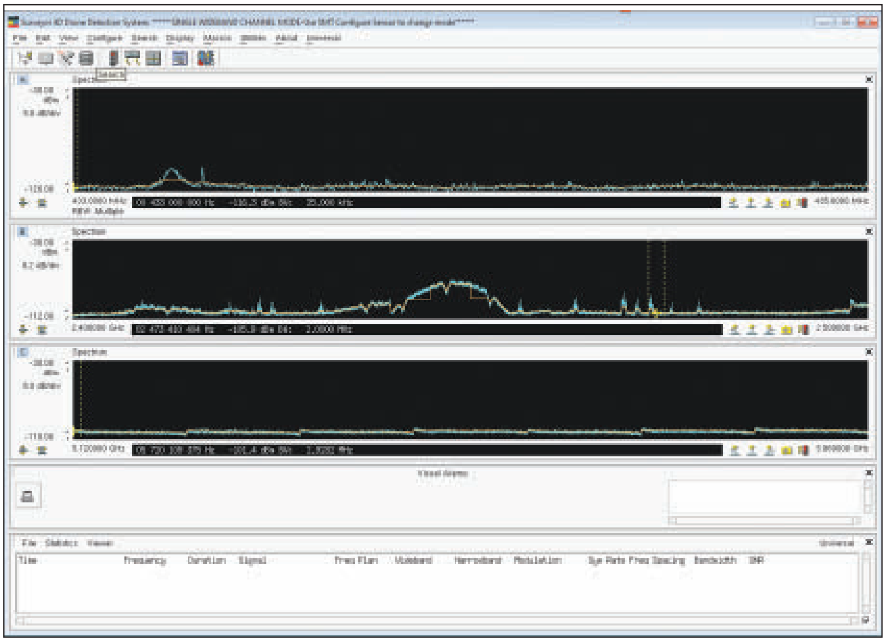
Isolating the Right Signals

A robust method for automatically detecting energy relative to the "noise" floor that can function across all three bands is needed. A noise riding technique is used that was originally developed as part of a signals development system for the HF Band (2 to 32 MHz) at Keysight. The algorithm has variables related to the margin (amplitude offset), segmentation (frequency granularity) and smoothing (a running average). By properly setting these values, the auto-threshold can "ride" up and down active Wi-Fi channels but still properly respond to and isolate drone control signals from other transmitters legally authorized to operate.

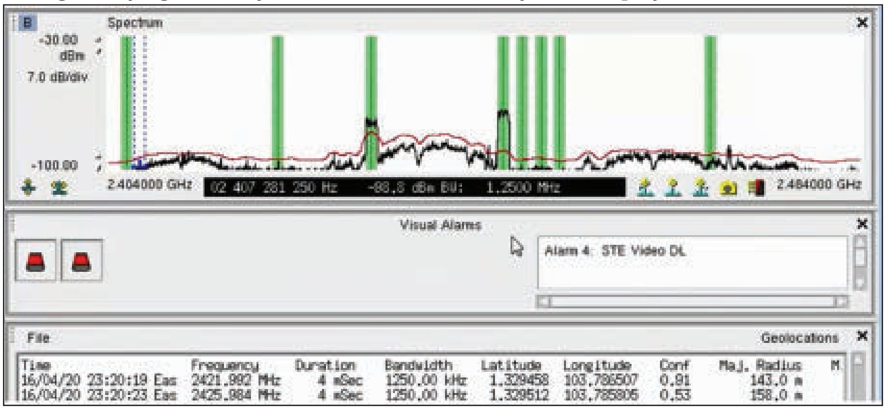
Figure 8 shows how the algorithm works. The vertical green lines show detections of frequencies with the drone RC. The red line represents the noise riding threshold which is "riding" on top of the Wi-Fi signals but detecting the control signals. The next challenge is to discriminate one type of drone control signal from another. The noise riding threshold helps by rejecting ambient Wi-Fi signals, treating them somewhat like a noise floor. However, there are other signals that may resemble the drone RF of interest. But what if more than one RC is operating, how can they be differentiated?

Differentiating Drone Control Types

This challenge can be addressed by spectral shape correlation. This isolation technique uses a spectral correlation line consisting of points horizontally separated by the frequency bin spacing (a value related to the RBW by the FFT filter shape factor). The points are verti-



▲ Fig. 7 Keysight Surveyor 4D Drone Detection System display.



▲ Fig. 8 Operation of the Auto Threshold algorithm in ISM band.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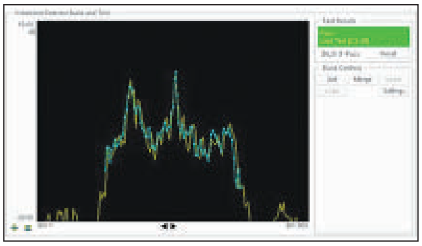
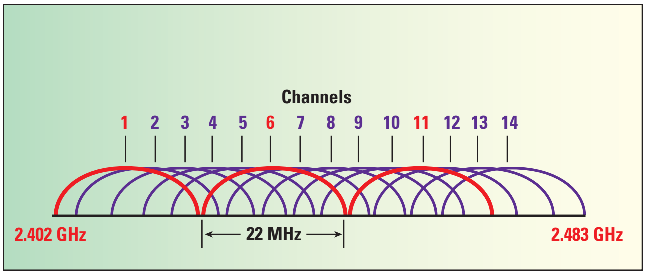
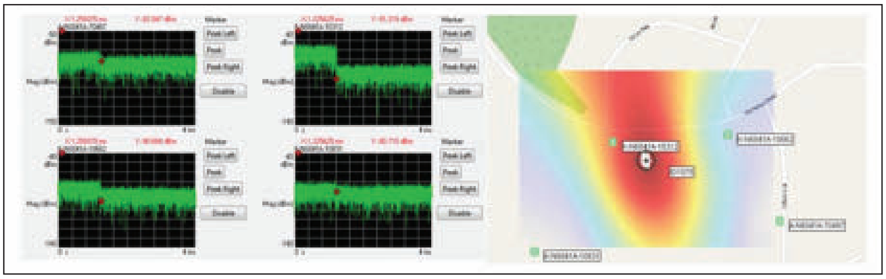


▲ Fig. 9 Spectral Shape correlator for a specific drone signature.



▲ Fig. 10 Overlap of Wi-Fi channels in 2.4 GHz ISM band.



▲ Fig. 11 Drone RC burst capture and TDOA geolocation in the Keysight N6854A Geolocation Server Software.

cally positioned based on the unique amplitude features of the transmission. The number of points in the detector is based on the signal bandwidth, or the bandwidth of the exploitable feature of the signal. Basically, these are matched filters used to evaluate every set of frequency bins in the sweep for a match within a defined tolerance (expressed in percent or dB). Correlation lines for specific signals are built from recordings and validated in several steps prior to being put into use.

Each make of radio controller employs a slightly different scheme to communicate with the drone. It is these differences that can be exploited by a spectral shape correlator. ***Figure 9*** shows the signature of one type of controller.

A Keysight Signal Surveyor 4D feature called "Universal Signal Detector" or USD is used, which has a spectral shape correlator referred to as a wideband detector. This feature enables the user to apply signal discriminators designed to recognize various drone controllers with minimal false positive results. The USD "detector" applies three other elements that work together, or independently, to distinguish signals of different types. Once again, this feature was originally developed for use in the HF spectrum where signals often have unique spectral signatures that can be exploited. The other elements used by the USD feature are:

- Frequency plan, which can include a frequency band with or without channelization and individual frequencies,
- Bandwidth filter, with a tolerance expressed in percent,
- Narrowband confirmation of the modulation and symbol rates, not typically required for drone RC discrimination.

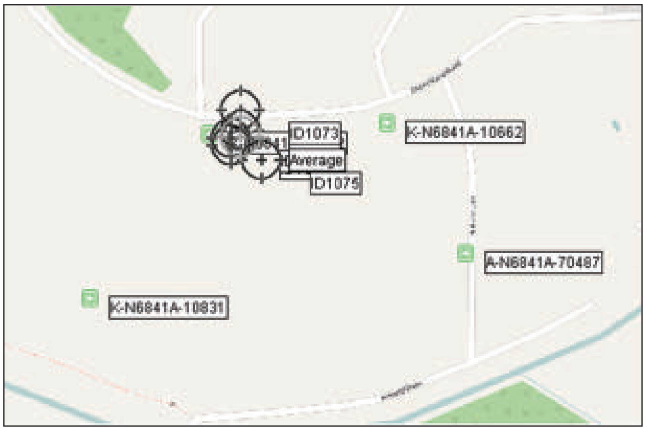
Locating the Radio Controller Using Time Difference of Arrival (TDOA)

Locating transmissions in the ISM band can be a challenge for many reasons. Ambient signal energy is literally everywhere due to the overlap of the Wi-Fi channels, Bluetooth activity and an increasing number of IoT signals presenting in this 80 MHz wide band (see ***Figure 10***). The signals are short in duration, frequency hopping (over most of the band) and relatively low power. Affordable network-enabled sensors can be distributed around an area and used to both detect and locate these signals. A distributed detection system is beneficial in expanding the coverage area. Since drone control signals will most likely be operated from the ground, at an elevation of about 1.5 meters, the detection range of any monitoring system will be less than for an elevated transmitter. Additionally, since the signals are moderately wide bandwidth (1 to 2 MHz), the power spectral density is less than that of, for example, a PMR radio (12.5 to 25 kHz). Thus, the propagation distance is less.

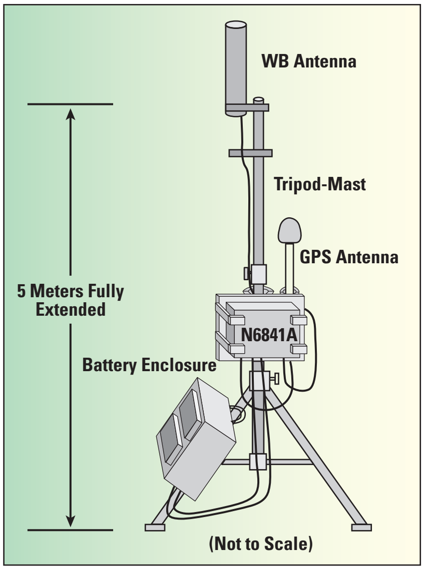
Given these conditions, for successful geolocation using TDOA, the signals must be isolated both in frequency and in time. For TDOA to work, the right "snippet" of synchronous IQ data from each sensor must be collected and correlated at a common host computer. The bigger challenge is isolating the correct samples of IQ (i.e., that contains the RC signal) from all sensors. For this to be feasible, each sensor must have precisely time-stamped IQ memory to get the right pulse. Given that drones can occur in any one of three bands, it is assumed the receiver is sweeping across all bands. This means the IQ from each frequency segment, corresponding to the tuner IF bandwidth, must be properly time-stamped and indexed in the sensor memory. When an RC signal is detected, the system must communicate the refined time to each sensor and request that data specifically from the memory. The host PC can then correlate the IQ data between all sensor pairs and estimate the position. ***Figure 11*** shows an example of how this measurement looks.

The four sensors have synchronously isolated the RC signal from the 2.4 GHz ISM band and successfully isolated, in time, the 1.2 ms burst. The host computer was able to correlate the IQ time series data to successfully estimate the location of the controller. This measurement was taken during field testing, so the time record was 3x longer than required. This "lookback" method of isolating short duration signals has proven effective for locating drone RCs.

Another challenge presented by the ISM band is co-channel interference, which presents issues for any technique used for emitter location. When using traditional direction finders (i.e., angle of arrival techniques), strong co-channel signals present during signal acquisition can produce angular errors or a result based on the interferer rather than the intended signal. Angular errors can be difficult to overcome whether they are produced by reflections or co-channel interference, both of which dominate the landscape especially considering the ISM band in urban environments. TDOA algorithms usually base the result on the strongest correlation. This is where isolation of the RC signal burst in time is critical. By triggering the geolocation measurement window on the exact RC signature, the likelihood of a strong correlation is very high. Since



▲ Fig. 12 Clustering of TDOA results around RC.



▲ Fig. 13 Keysight Surveyor 4D Drone Detection System.

the RC is hopping, several TDOA measurements will be completed in a short time increasing further the chance of a strong clustering of the geolocation results (see ***Figure 12***). A direction finding system employing multi-channel correlative techniques could overcome this situation, but at a far higher cost.

Techniques developed to detect, isolate and classify signals in the HF band can be effective against signals in the ISM band. While the HF band has a poorly behaved noise floor that varies based on environmental conditions, the ISM band also has a very active ambient signal floor consisting of a variety of overlapped wideband and frequency agile narrowband activity. This signal activity behaves somewhat like the HF band except at a much higher speed of variation. An automated noise riding threshold combined with spectral shape correlation detection makes for an effective, low cost way to detect and isolate specific signal energy. Once detected, TDOA methods using sensor memory can effectively isolate the pulsed signal data for cross-correlation to estimate the RF controller location. Such systems can be implemented with low-cost, synchronous sensor networks.

An example system is the Keysight Surveyor 4D System (see ***Figure 13***), which is effective at detecting, classifying and locating drone controllers operating within a 1 km range. Detection range can be extended by additional elevation on the system that extends line of sight. The enabling technology is in the Surveyor 4D's high-speed multiband search mode and the Universal Signal Detection (USD) wideband detector. The system can create detectors as new drone systems are introduced. This provides the user with the ability to update the library of drone detectors as new control units and drone products enter the market.

Keysight offers a modeling and simulation tool for planning RF Sensor installations called SPOT (Sensor Planning and Optimization Tool). With this tool, detection sites can be planned to provide the best possible coverage for critical infrastructure or event locations. With the deployment of four or more sensors, emitter location by Time Difference of Arrival (TDOA) is possible.

Detection of UAV's Based on Their RF Emissions

Aaronia AG
Strickscheid, Germany

A final example is Aaronia's Drone Detector, a product that exploits the RF radiation emitted by the UAV's onboard systems and by the operator's control unit (see ***Figure 14***). Aaronia recognized the need for a reliable method to detect tiny airborne intruders. Following a four-year development program, it launched the product. Real-time RF signal detection, combined with what the company terms "pattern triggering," provides rapid warning of any UAV or UAV control unit that is operating within the area being monitored.

▲ Fig. 14 Aaronia's Drone Detector System.

Military communications links often exploit techniques such as frequency agility in order to reduce the probability of interception, but the designers of UAVs are selling an inexpensive commercial products. As a result, UAV communications links are low-cost, unsophisticated sub-systems that have few clandestine qualities. Since the Drone Detector has more sophisticated receiver facilities than those of the UAV and its control unit, it has a longer range than the UAV operator.

Two types of 3D direction finding antennas are offered by the Drone Detector—the IsoLOG 3D 80 and IsoLOG 3D 160. These have eight sectors with 16 antennas, and 16 sectors with 32 antennas, respectively. Both cover from 680 MHz to 6 GHz, and extenders are available should LF, MF, HF and VLF (9 kHz to 680 MHz) and 6 to 20 GHz coverage be required.

These antennas are teamed with either an XFR V5 PRO (used for portable installations) or an RF Command Centre (for stationary use). Both cover frequencies from 9 kHz to 20 GHz, so include the frequencies commonly used for UAV control and video links—typically 433, 900, 915 MHz and 1.3, 2.4, 5.8 GHz.

Locating the UAV and its Control Unit

Using these basic components, the user can opt for systems of varying complexity. The simplest consists of a single IsoLOG 3D antenna and a stationary or mobile spectrum analyzer. This is sufficient for surveillance of an area with up to 4 to 5 km radius. If a fully mobile solution is required, the system can be installed on a vehicle and operated from battery power. Its antennas are resistant to the effects of salt water splashes or spray, allowing deployment on a boat.

Once a signal has been detected, its approximate bearing will be shown to an accuracy of 2 to 3 degrees, which depends on which model of antenna is being used. With the standard IsoLOG 3D 80, the bearing accuracy will be at least within the 4 to 6 degrees coverage of a single antenna sector.

When larger areas must be covered, several antennas and spectrum analyzers can be connected to a single centralized PC which manages these simultaneously. The larger the area to be covered, the greater the number of antennas and analyzers that must be deployed. Any threat signal is likely to be received by several antennas, so the results can be triangulated to provide detailed and accurate information on the location of the UAV and/or its operator.

The system has no limitation in detection range; usually the detection range is the same as the usable distance from the operator to the drone (or better), so it always depends on the transmitter power of the drone/operator. Depending on the drone type, it could be several kilometers/miles without a problem (e.g. approximately 5 km for a DJI Phantom 4).

Since the system is designed to recognize the RF signals

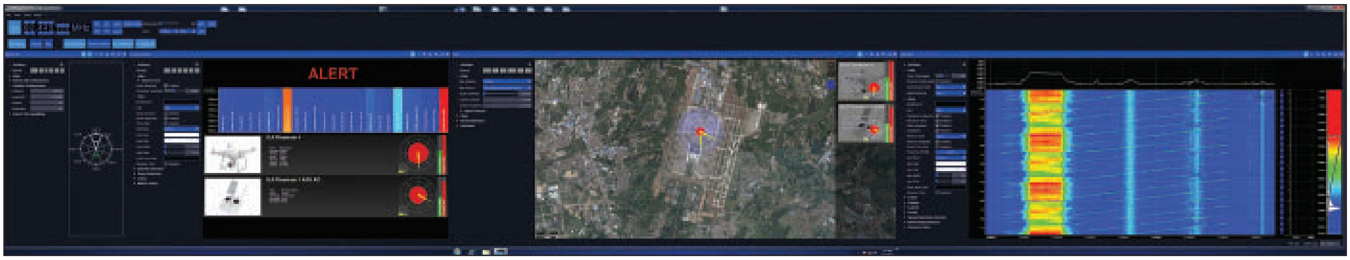


Fig. 15 Identification of multiple drones.

associated with UAVs by observing their frequency and other characteristics, it will not provide false alarms when faced with other types of RF signals. When faced with several UAVs, the system can detect these, even if the drones are the same or different types (see ***Figure 15***).

The average time needed for detection of a UAV is between 10 microseconds and 500 milliseconds. It depends on factors such as the complexity of the deployed system and the number of antenna arrays being used. While a clear line of sight between the antennas and the UAV or its operator gives the best results, the system can detect RF signals whose source is obscured by trees, bushes or a crowd of people. The system is passive, emitting no signals of its own that could interfere with the normal operation of nearby assets, such as airports, or give the UAV operator warning of its presence. System performance is unaffected by darkness or poor weather—if meteorological conditions allow UAVs to fly, they can be detected.

The Aaronia system has some unique features like 24/7 recording and playback. Further it can be equipped with multi-receivers allowing real-time measurement of each individual frequency band (e.g. 2.4 and 5.8 GHz, 434 and 868 MHz) without the need to switch between bands.

SUMMARY

While drones will enable many new exciting applications in commercial markets, they also represent a potential threat to public safety. Since they are small and agile, they can access most protected areas and are difficult to detect and prevent them from entering these areas. However, new drone detection and location systems, mostly based on RF technologies, are rapidly evolving to protect the public from these threats. Many RF test and measurement companies are uniquely positioned to leverage their spectrum monitoring capabilities to field systems in this area. ■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INVITED PAPER

Solid-State PAs Battle TWTAs for ECM Systems

Rick Montgomery and Patrick Courtney
Qorvo, Greensboro, N.C.

Electronic countermeasures or ECM systems are typically comprised of receivers, processors, displays and jamming transmitters. Until recently, solid-state amplifiers fell short of the required combination of power, bandwidth and efficiency for the transmitter of an ECM system. Maturating GaN power amplifier MMICs and low loss, broadband combining techniques now make it possible to meet the power, bandwidth and efficiency requirements of ECM systems with solid-state power amplifiers (SSPA). Compared to GaAs and other solid-state semiconductor materials, GaN provides an order-of-magnitude increase in transistor power density, and the higher impedance of the devices eases the design of matching networks.

Historically, traveling wave tubes (TWT) and other vacuum tubes have provided the microwave power for ECM transmitters. Since the 1950s, the broadband, high-power microwave amplification necessary for ECM transmitters was only feasible with vacuum tube technology and, in particular, with traveling wave tube amplifiers (TWTA). ECM jamming transmitters typically need to generate hundreds of watts of microwave power over several octaves. The efficiency of the amplifiers must be high enough to meet the limited power budget of airborne platforms and the heat generated can be dissipated. TWTAs were the only technology that could meet these critical requirements.

SOLID-STATE VS. TUBE

Solid-state devices have long been preferred to vacuum devices. Vacuum tubes, with their associated high voltage power supplies—typically in the multi-kV range—have lower reliability than solid-state devices operating with low voltage power supplies (i.e., under 50 V). Manufacturers and users of vacuum tubes face diminishing sources of supply and material shortages.

Solid-state devices generate lower noise and have better linearity than vacuum tubes. For instance, solid-state devices in "standby mode"—where the DC bias voltage is applied with no RF input signal—generate significantly less noise power across the spectrum. Noise figures for a medium power TWT can be around 30 dB, versus about 10 dB for a solid-state GaN MMIC PA. This is a significant difference in an ECM system, as the lower noise may allow the transmitter's output stage to remain in standby mode when not transmitting. The overall switching time decreases, since the main DC power to the PA does not need to be switched on and off.

Another operational benefit of a solid-state transmitter is the reduced harmonic content in the output signal. A solid-state PA that operates over an octave or greater bandwidth will typically have worst-case harmonic content about 8 dB down from the fundamental at its saturated output power. The harmonic content of a vacuum tube will only be down 2 dB from the fundamental under the same operating conditions. These higher harmonics can impose stricter filtering requirements for the transmitter, driving larger and costlier components for the overall ECM system.

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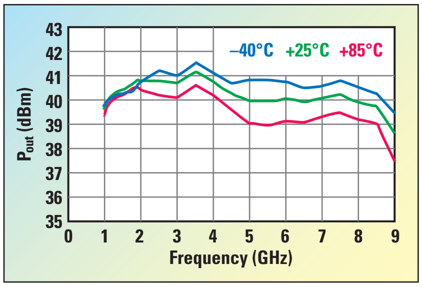

Fig. 1 Output power vs. frequency and temperature of a Qorvo QPA1003P GaN MMIC, with 15 dBm CW input power, 28 V bias and 650 mA current consumption.

width over other heterojunction semiconductor technologies, a single device or MMIC still has insufficient power for most ECM system transmitters. It is not unusual to have a requirement of 100 W or more from 2 to 7.5 GHz. ***Figure 1*** shows the output of a single Qorvo GaN power MMIC. This packaged MMIC nominally delivers 10 W from 1 to 8 GHz, but the output power decreases at 85°C backside temperature to as low as 8 W. More than 10 of these MMICs must be combined to deliver 100 W across the band and over the temperature range required in an ECM system.

There are many ways to power combine devices to make a SSPA. For an ECM system transmitter, the approach must have low loss and wide bandwidth. Many combining techniques use two-port binary combiners such as Wilkinson or magic tees. Combining two MMICs requires a single two-port combiner, four MMICs requires three combiners and 16-way combining requires 15 combining elements. Magic tees have relatively low loss; however, they typically operate over a maximum of 10 percent bandwidth, and double-ridged magic tees only have about an octave bandwidth, which is short of a 2 to 7.5 GHz ECM requirement. With two-way combining, four stages of combining are needed to achieve the desired power. A typical double-ridge magic tee has 0.3 dB of loss at these frequencies, so the total loss through the combiner would be 1.2 dB. Combining the 30 percent efficient GaN PA MMICs shown in Figure 1 through a 16-way magic tee, the efficiency of the combined output would be about 23 percent and deliver approximately 95 W output at 6 GHz at 85°C. However, the typical double-ridge magic tee network only works over an octave of bandwidth (e.g., from 2 to 4 GHz).

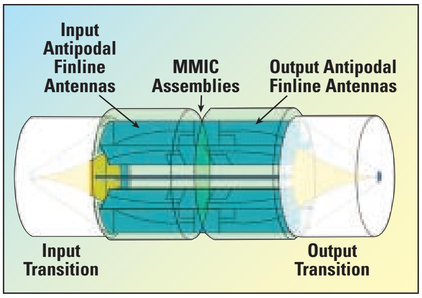

Fig. 2 Spatium amplifier structure.

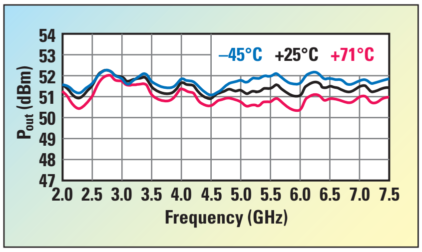

Fig. 3 Measured output power of the Spatium amplifier that combines 16 QPA1003P MMICs.

SPATIAL COMBINING

Spatial combining techniques are potentially lower loss than circuit-based techniques. Spatium® is Qorvo's patented coaxial spatial method of power combining (see ***Figure 2***). It uses broadband antipodal finline antennas as the launch to and from the coaxial mode, splitting into multiple microstrip circuits, then combining the power from those circuits after amplification with a power MMIC. It uniquely enables broadband, efficient and compact combining of multiple power MMICs in a single combining step, with free space as the combining medium. A typical Spatium design combines 16 devices in one step, with a combining loss of only 0.5 dB.

Combining 16 of the MMICs from Figure 1 yields an SSPA efficiency of 27 percent, compared to 30 percent for each MMIC. This is a significant difference compared to the 23 percent achieved with magic tee combining. The increased combining efficiency enables higher output power from a given prime power as well as reducing the heat dissipation.

An actual Spatium amplifier was designed that combined 16 radial blades with the Qorvo GaN MMIC PA on each blade. ***Figure 3*** shows the measured output power versus clamp surface temperature; the baseplate temperature below the MMIC is approximately 12°C hotter than the clamp temperature, so the maximum baseplate temperature is 85°C. This unit achieves greater than 100 W from 2 to 7.5 GHz and an average efficiency of 25 percent.

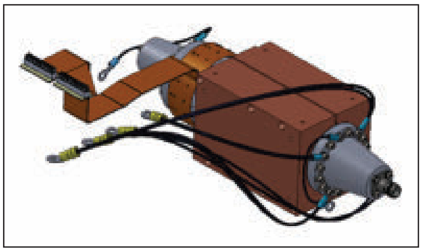

Fig. 4 Spatium amplifier with clamp to conduct heat from the MMIC PAs.

THERMAL DESIGN

Thermal management is one of the design challenges when using a solid-state amplifier in an ECM transmitter. In a typical application, the outer surface of the clamp around the Spatium SSPA is conduction cooled on one or more sides (see ***Figure 4***). For some systems, a liquid coolant may be available, for others a heat sink with fans. The clamp is designed to make contact with all of the blades in the Spatium and provide a conduction path to a cold plate or heat sink. Spatium blades and clamps can be made of different metals, including aluminum and copper. Size, weight and power trade-offs determine the appropriate material set for a given application.

The thermal resistance from the back of the MMICs to the mounting plates can be calculated and used to derive the backside MMIC temperature. From the thermal resistance of

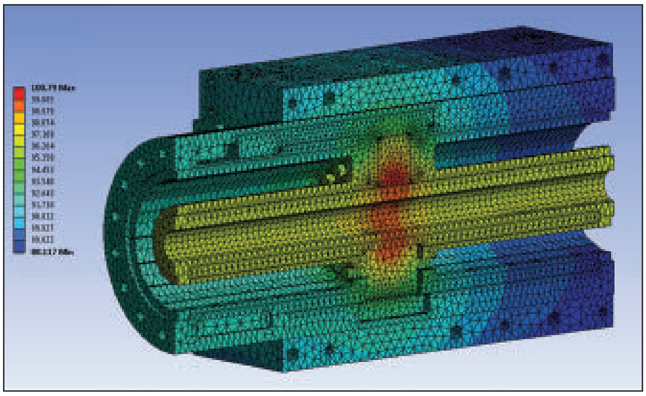

Fig. 5 Thermal simulation of the Spatium SSPA, showing cross section of the construction.

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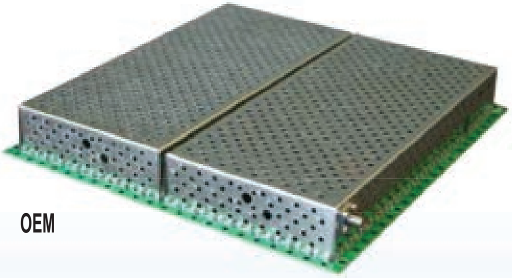

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TABLE 1
DEMONSTRATED SPATIUM SSPA PERFORMANCE

Frequency Range (GHz)	Nominal Output Power (W)	Nominal Power-Added Efficiency
2 to 6	300	30%
2 to 8	150	25%
2 to 18	60	15%

the MMIC and package, the junction temperature of the MMIC can be calculated and, from that, the reliability of the SSPA can be estimated. ***Figure 5*** is a thermal simulation of the SSPA shown in Figure 4, with the MMICs operating at saturated output power and the worst-case efficiency within the frequency band (i.e., 25 W dissipated per MMIC). The thermal model shows an approximate 12°C rise from the coolest spot of the outside surface of the clamp to the backside of the packaged MMIC and an additional 164°C temperature rise from the back of the package to the junction of the output transistor, assuming 6.56°C/W thermal resistance. The junction temperature of the MMIC is estimated to be 247°C with the surface of the clamp held to 71°C. At 247°C junction temperature, the MTBF of the MMIC is some 1.2 million hours.

The MTBF of the overall Spatium module will be the MTBF of the individual MMICs divided by the number of MMICs: 75,000 hours. The calculation deems a single MMIC failure to be a failure of the entire amplifier assembly—a worst-case assumption since the Spatium amplifier will gracefully degrade with the failure of any individual MMIC (i.e., approximately 0.7 dB reduction in output power per MMIC failure).

For a TWT, MIL-HDBK-217F Notice 2 provides the following formula to calculate the MTBF in a ground fixed environment:

$$MTBF = \frac{10^6}{16.5 \times (1.00001)^P \times (1.1)^F} \quad (1)$$

where P is the rated power in watts, from 1 mW to 40 kW, and F is the operating frequency in GHz, from 100 MHz to 18 GHz. Utilizing this formula, a TWT with an output power of 150 W at a frequency of 7.5 GHz has an MTBF of 29,609 hours. This is 2.5x lower than that of the comparable solid-state Spatium power amplifier module under similar environmental conditions.

SUMMARY

For the first time, GaN MMICs and broadband spatial combining techniques such as Spatium allow ECM system designers to use reliable, solid-state amplifiers instead of TWTAs. The ability to deliver hundreds of watts over broad bandwidths, while staying within the prime power available from the platform and dissipating the heat to ensure reliable operation, opens up new system opportunities for a solid-state ECM transmitter. ***Table 1*** shows the frequency, power and efficiency achieved with three recent Spatium amplifiers. The size and weight of these SSPAs are less than the boxes previously occupied by their respective TWTAs.■

5 W, Ku-Band GaAs T/R MMIC with Switch Topology

Ye Yuan, Yong Fan, Ziqiang Yang and Haodong Lin
University of Electronic Science and Technology of China

A power amplifier (PA), low noise amplifier (LNA) and two switches are integrated in a single GaAs PHEMT Ku-Band transceiver (T/R) MMIC, which can be used for phased array systems. A novel topology increases the power handling capability of the switch without increasing insertion loss. High saturated power (greater than 5 W) and very low noise figure (less than 3.3 dB) are achieved in the frequency range of 14.5 to 17 GHz. The size of the MMIC is 3 mm × 4 mm.

Market growth in active phased array (AESA) radar has created a large need for multi-function T/R chips.[1-4] T/R chips based on the Si CMOS process currently enable higher integration levels than counterparts based on the GaAs PHEMT process. However, RF performance of Si-based chips, such as output power, power-added effeciency (PAE) and noise figure, is poorer than that of GaAs-based chips. Van Vliet and De Boer[3] developed a GaAs T/R chip containing a driver amplifier, LNA, phase shifter and attenuator; however, its power and noise figure are not given. A T/R chip with wide bandwidth was presented by Bettidi et al.,[4] but its output power was only 20 dBm. The limited output power was due mainly to low P1dB performance of the traditional GaAs FET switch.[5-8]

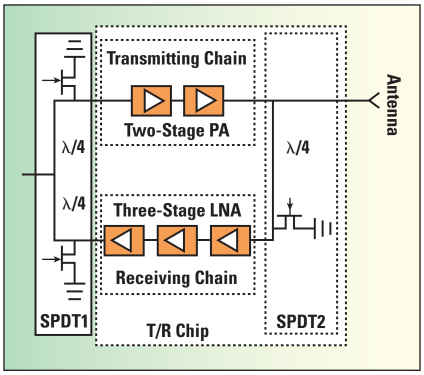


Fig. 1 T/R chip block diagram.

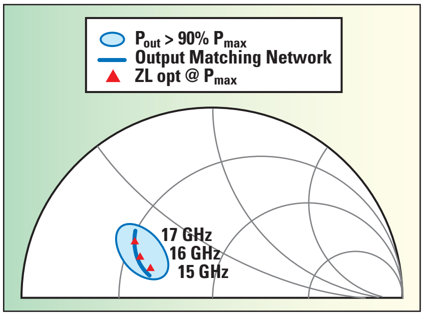


Fig. 2 Output matching network frequency response.

To address these problems, a T/R chip with high output power and low noise figure is presented here. The switch is based on a novel topology, which increases its power handling capability without increasing insertion loss. Measurement results show that saturated power (Psat) and gain of the transmitting branch of the T/R chip are more than 5 W and 15 dB, respectively, while noise figure and gain of the receiving branch are better than 3.3 dB and 18 dB, respectively, in the frequency range from 14.5 to 17 GHz.

CIRCUIT CONFIGURATION AND DESIGN

The T/R chip architecture contains a PA, LNA and two T/R switches (see ***Figure 1***). The PA has two amplifier stages: 16 transistors with 8 × 125 µm gate width and eight transistors with 6 × 125 µm gate width at the output and input stages, respectively. Good input return loss is obtained by tuning the input matching network. Sufficient output power to drive the output stage is realized by proper design of the interstage matching network. Maximum output power is achieved through matching circuit design based on load-pull simulation using the nonlinear model of the active device. ***Figure 2*** shows the optimum load impedance of the output stage transistor corresponding to maximum saturated power in the range from 15 to 17 GHz, along with the output matching network frequency response; their close correspondance implies that a wide power matching bandwidth can be achieved.

The LNA contains three stages; the gate width of the transistor in each stage is 2 × 25 µm. Bias voltages are selected with the aid of Agilent ADS software to ensure that the active devices operate in their low noise regions; the gate-source voltages (V_{gs}) and drain-sources voltages (V_{ds}) are set at -1 V and +3 V, respectively. The input matching network is designed to achieve a low noise figure, while interstage

and output matching networks are designed for high gain.

At the antenna side of the circuit, a novel topology single pole double throw switch (SPDT2 in Figure 1) selects the transmit or receive branch. At the input, an off-chip SPDT switch (SPDT1) with traditional parallel topology selects transmit or receive. SPDT2 is the key device, consisting of a λ/4 transmission line and FET with a gate width of 4 × 100 µm (see ***Figure 3***). When transmitting, the FET is turned on and is equivalent to a small shunt resistor (R_{on}), as shown in Figure 3a. RF power leaks to the FET through the λ/4 transmission line. If the voltage magnitude of the leaked RF signal is greater than the knee voltage of the FET, the switch is compressed. In this design, the leaked RF power at the FET can be decreased by tuning the characteristic impedance (Z_r) of the λ/4 transmission line to increase the power handling capability of SPDT2, enabling increased output power from the T/R MMIC. An optimized Z_r of 112 Ω is chosen. The shunt capacitor (C_1) is also designed to tune the impedance at point B. When receiving, the FET is turned off and is equivalent to a shunt capacitance (C_{off}), as shown in Figure 3b. The active devices in the last stage of the PA are equivalent to a parallel resistor and capacitor (R_{ds} and C_{ds}). All of these components are used as part of the input matching circuit of the LNA. A low LNA noise figure is obtained by tuning transmission lines TL_1 and TL_2.

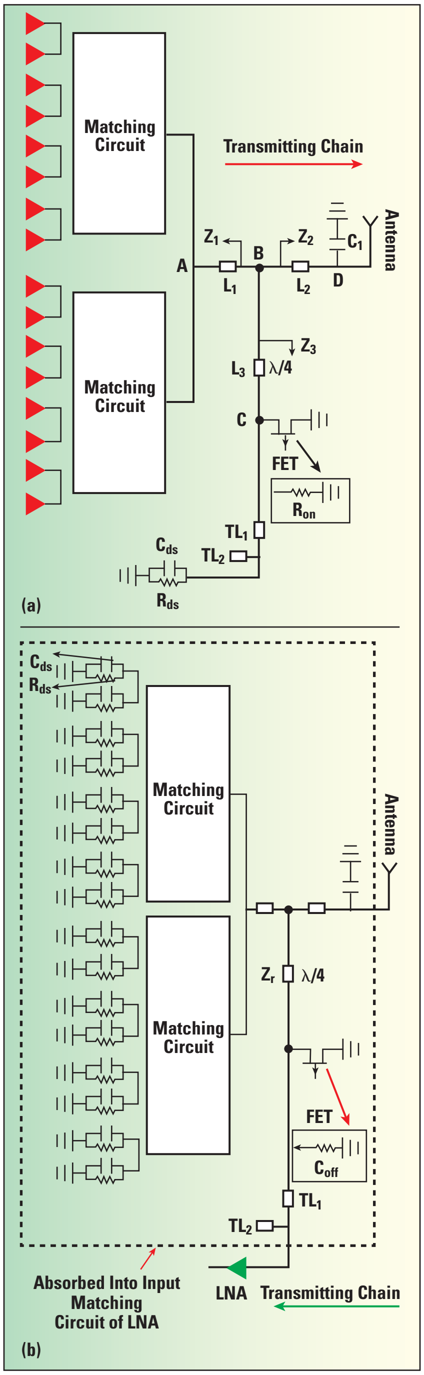
This design decreases the insertion loss of the output matching network due to the shorter transmission line. By optimizing the impedance at point B, the power handling capability of the switch can be improved without widening the gate width of the FET. This is explained as follows: Assume that the characteristic impedances of stubs L_1 and L_2 are both Z_t. The characteristic impedance of the λ/4 transmission line (L_3) at the receiving branch is Z_r, and the on resistance of the switching FET is R_{on}. In the transmitting branch, the impedance Z_1 at point B is given by:

$$Z_1 = Z_t \frac{Z_A + jZ_t \tan\beta L_1}{Z_t + jZ_A \tan\beta L_1} \quad (1)$$

In the receiving branch, the impedance Z_3 is given by:

$$Z_3 = \frac{Z_r^2}{R_{on}} \quad (2)$$

Because R_{on} is very small, Z_3 is a very high impedance compared to Z_1. In the design, therefore, it is just necessary to ensure that impedances Z_1 and Z_2 are conjugately matched:



▲ Fig. 3 Equivalent circuit of the SPDT switch, LNA input stage and PA output stage when transmitting (a) and receiving (b).

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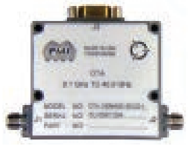

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Connectors: 2.92mm (F) &
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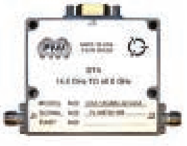
Switching Speed:
Measured 0.25 µs



Package Size: 2.0" x 1.8' x 0.5"
DC Voltage: +15 VDC @ 38 mA
Connectors: 2.92mm (F) &
15 Pin Micro-D-Female
Switching Speed:
Measured 0.266 µs

Specfications	DTA-100M40G-30-CD-1	DTA-14G40G-32-CD-2
Frequency	0.1 to 40.0 GHz	14.0 to 40.0 GHz
Attenuation Range	30 dB	32 dB
Insertion Loss	5.0 dB Typ. (to 20 GHz) - Measured 4.9 dB 8.0 dB Typ. (to 40 GHz) - Measured 7.1 dB	9.0 dB Typ. - Measured 8.62 dB
VSWR	2.5:1 Max. - Measured 2.49:1	2.0:1 Typ. - Measured 1.75:1
Attenuation Flatness	±1.5 dB Typ. Measured: @ 10 dB: ±0.95 dB @ 20 dB: ±1.47 dB @ 30 dB: ±2.13 dB	±1.5 dB Typ. Measured: @ 8 dB: ±0.61 dB @ 16 dB: ±1.01 dB @ 32 dB: ±1.77 dB
Attenuation Accuracy	±2.5 dB Typ. Measured: 0 to 10 dB: ±0.59 dB 10 to 20 dB: ±0.09 dB 20 to 30 dB: ±0.20 dB	±2.0 dB Typ. Measured: 0 to 8 dB: ±0.28 dB 8 to 16 dB: ±0.05 dB 16 to 32 dB: ±0.15 dB
Operating Temperature	-50 ºC to +85 ºC	-40 ºC to +85 ºC

Model: DTA-18G40G-30-CD-1 & DTA-18G40G-50-CD-1

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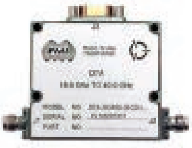

Package Size: 2.0" x 1.8' x 0.5"
DC Voltage: +15 VDC @ 38 mA
Connectors: 2.92mm (F) &
15 Pin Micro-D-Female
Switching Speed:
Measured 0.30 µs

Package Size: 2.0" x 1.8' x 0.5"
DC Voltage: +15 VDC @ 38 mA
Connectors: 2.92mm (F) &
15 Pin Micro-D-Female
Switching Speed:
Measured 0.12 µs

Specfications	DTA-18G40G-30-CD-1	DTA-18G40G-50-CD-1
Frequency	18.0 to 40.0 GHz	18.0 to 40.0 GHz
Attenuation Range	30 dB	50 dB
Insertion Loss	6.0 dB Typ. - Measured 6.1 dB	8.5 dB Typ - Measured 10.4 dB
VSWR	2.5:1 Max. - Measured 2.11:1	2.5:1 Typ. - Measured 2.27:1
Attenuation Flatness	±1.5 dB Typ Measured: @ 10 dB: ±0.98 dB @ 20 dB: ±1.27 dB @ 30 dB: ±1.93 dB	±1.5 dB Typ Measured: @ 16 dB: ±2.10 dB @ 32 dB: ±2.10 dB @ 50 dB: ±3.88 dB
Attenuation Accuracy	±2.0 dB Typ. Measured: 0 to 10 dB: ±0.39 dB 10 to 20 dB: ±0.54 dB 20 to 30 dB: ±0.76 dB	±2.0 dB Typ. Measured: 0 to 16 dB: ±0.14 dB 16 to 32 dB: ±0.18 dB 32 to 50 dB: ±0.48 dB
Operating Temperature	-40 ºC to +85 ºC	-40 ºC to +85 ºC

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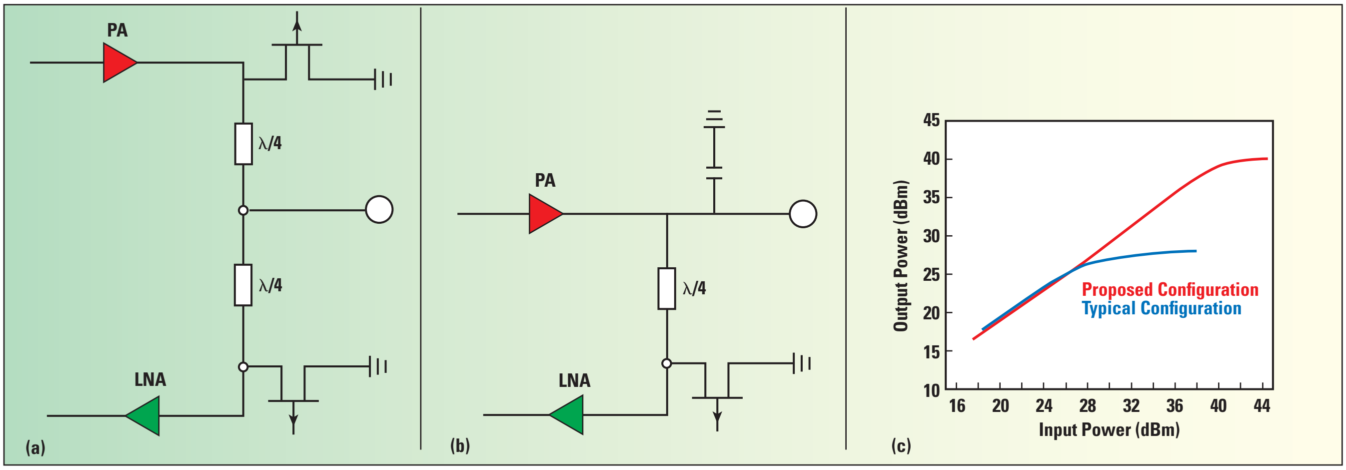


▲ Fig. 4 Typical SPDT switch configuration (a), new SPDT switch configuration (b), simulated output power of the two configurations (c).

$$Z_1 = Z_2^* \tag{3}$$

The voltage magnitude at point D of the RF signal in the transmitting branch is given by Equation 4:

$$V_D = \sqrt{100 \times P_A} \times \frac{|Z_3|}{|Z_2| + |Z_3|} \tag{4}$$

where P_A is the output power at point A. The voltage magnitude of the leaked RF signal at the switching FET in the receiving branch is given by Equation 5.

$$V_C = \sqrt{100 \times P_A} \times \frac{|Z_2|}{|Z_2| + |Z_3|} = \tag{5}$$

$$\sqrt{100 \times P_A} \times \frac{R_{on}|Z_1|}{R_{on}|Z_1| + |Z_r^2|}$$

$$= \sqrt{100 \times P_A} \times$$

$$\frac{R_{on}\left|Z_t \dfrac{Z_A + jZ_t tg\beta L_1}{Z_t + jZ_A tg\beta L_1}\right|}{R_{on}\left|Z_t \dfrac{Z_A + jZ_t tg\beta L_1}{Z_t + jZ_A tg\beta L_1}\right| + |Z_r^2|}$$

To keep the switch operating in the linear region, $V_C \le V_{knee}$, where V_{knee} is the knee voltage of the switching FET. Equation 5 shows that for a given P_A, V_C is affected mainly by three parameters (R_{on}, Z_1 and Z_r). R_{on} is determined by the gate width of the switching FET, Z_1 is determined by the output matching network design and Z_r is determined by the width of transmission line L_3 in the receiving branch.

Equation 5 also shows that V_C is proportional to P_A, R_{on} and Z_1 and is inversely proportional to Z_r. For a given P_A, the switch can be operated without being compressed by carefully choosing Z_1 and Z_r. The shunt capacitor C_1 is optimized to decrease the modulus of Z_1. The gate width of the FET is chosen to be 2 × 100 µm. The knee voltage of the 0.15 µm PHEMT process is about 0.9 V, which means that if the RF leakage voltage at the drain port of the FET is less than 0.9 V, the switch will exhibit good linearity.

To test the validity of this method, the power handling capability of this

switch design is simulated in Keysight ADS and compared to a typical SPDT switch. In this topology, the switch and output matching network of the PA are designed together. Unlike a typical design (see ***Figure 4a***), there is no λ/4 transmission line and shunt FET placed at the output of the transmitting branch (see ***Figure 4b***). ***Figure 4c*** shows that the 1 dB compression point of the new switch is 39 dBm compared to 25.5 dBm for the typical parallel configuration, demonstrating a significant improvement. The gate widths of the FETs in the two designs are the same.

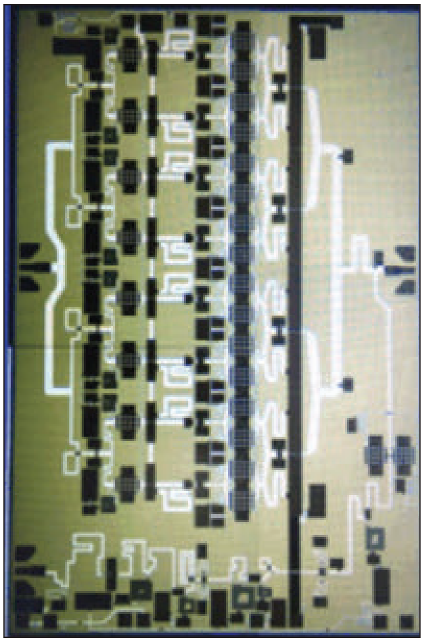


Fig. 5 GaAs T/R chip.

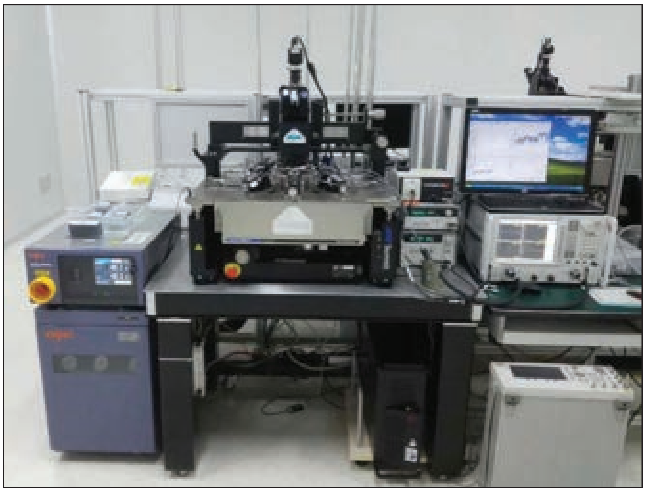


Fig. 6 Measurement setup.

MEASURED RESULTS

The Ku-Band GaAs T/R MMIC is fabricated using a 0.25 μm GaAs PHEMT process and measures 3 mm × 4 mm (see ***Figure 5***). The performance of the design is measured on wafer with a Cascade M150 probe station and a Cascade ACP40-A Ku-Band GSG probe under pulsed conditions, with 0.2 ms pulse width and 10 percent duty cycle (see ***Figure 6***). A vector network analyzer is used to measure the small-signal response and a signal generator and microwave power meter are used for the large-signal measurements. ***Figure 7*** shows the simulated and measured small-signal and large-signal responses of the transmit path. Measured small-signal gain, large-signal gain, Psat and PAE are better than 15 dB, 10 dB, 37 dBm and 17 percent, respectively. The measured small-signal gain and noise figure of the receiving branch are greater than 18 dB and less than 3.3 dB, respectively (see ***Figure 8***). ***Figure 9*** confirms that the T/R MMIC does not saturate below 5 W.

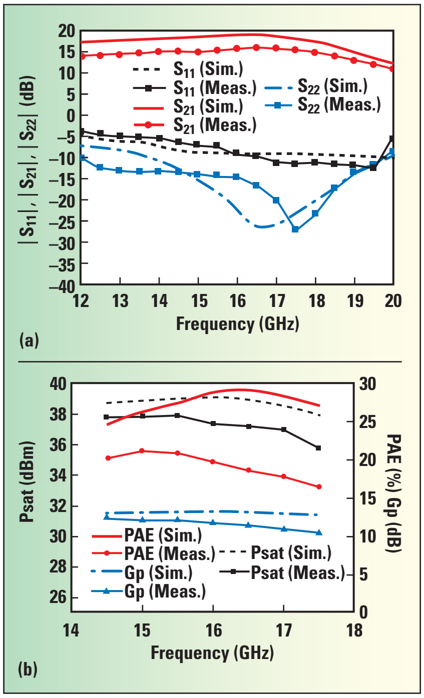
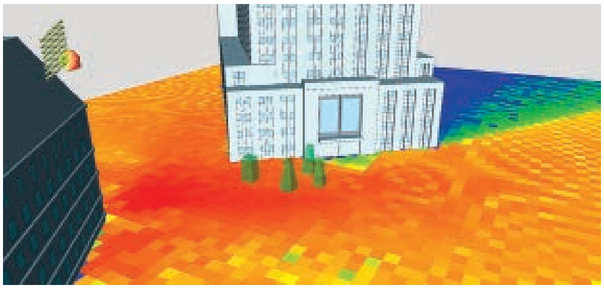


Fig. 7 Small-signal (a) and large-signal (b) performance of the transmit path.

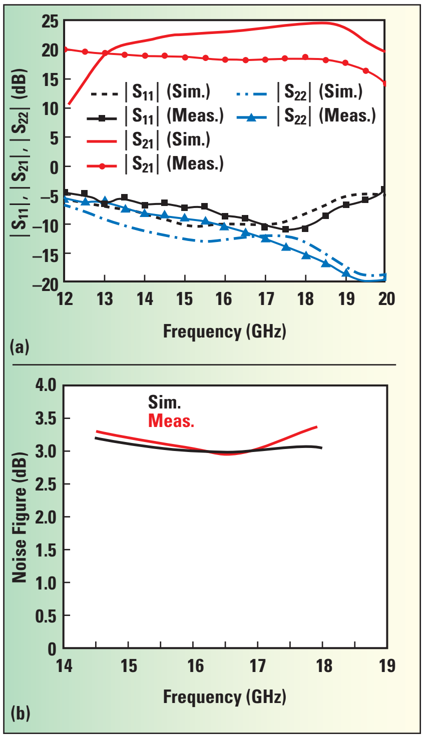


CONCLUSION

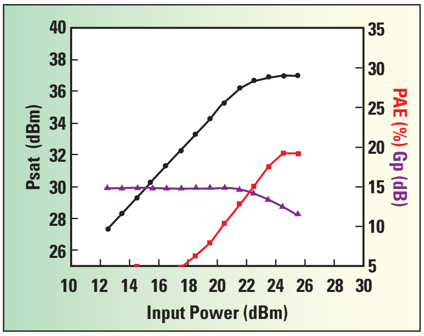
A Ku-Band T/R MMIC, proposed for use in AESA systems, employs a novel SPDT switch with improved power handling and low insertion loss to realize higher transmitter power and lower receiver noise figure.

ACKNOWLEDGMENT

T/R chip measurement was supported by RML Technology Company Ltd.■



▲ Fig. 8 Small-signal (a) and noise figure (b) of the receive path.



▲ Fig. 9 Large-signal performance of the T/R chip.

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Optimizing ASIC Designs for SWaP

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Today's aerospace and defense (A&D) systems rely on semiconductors that address mission-critical availability, performance, processing and security requirements, while balancing demands for continuous size, weight and power (SWaP) reduction in each new generation of hardware. The GLOBALFOUNDRIES® (GF) FX-14™ ASIC design system merges advanced semiconductor technology with a unique combination of ASIC development methodology, tools, services and GF yield ownership to help A&D companies meet these demands and quickly bring ASICs from concept to production.

FX-14 is designed for next-generation communications and data center hardware, including digital baseband processing solutions for A&D command and control, radar and global positioning system applications. To meet the requirements of these applications, where both SWaP and frequency are crucial, FX-14 utilizes GF's commercial 14 nm low power FinFET CMOS process technology, 14LPP.

SWaP-OPTIMIZED IP AND FEATURES

The FX-14 design system includes a library of silicon-proven IP:

- Multiple threshold voltage (Vt) FET options for managing power and performance
- Standard cell combinatorial gates, flip-flops and latches
- Phase-locked loops
- 64-bit and 32-bit ARM® processors
- A memory compiler that provides multiple embedded memory options (register arrays, register files, ROM, SRAMs and TCAM)
- An array of high speed SerDes (HSS) cores, including an advanced 56G offering.

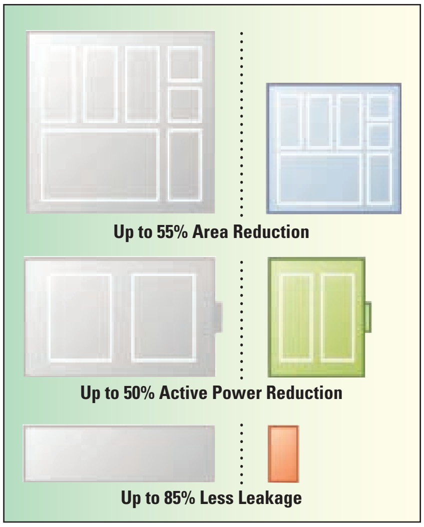
The inherent advantages of the 14LPP process technology and FinFET architecture enable significant SWaP benefits (see ***Figure 1***). In addition, the FX-14 library features SWaP-centric elements that enable extensive design flexibility in optimizing solutions for the A&D industry. The embedded memory compiler takes advantage of multiple memory bit cell designs to meet design operational (row address/bit word, single/multiport), density (die area/size) and frequency requirements. An exceptionally small memory cell can be used to optimize memory density for applications requiring minimal die area, while a performance-tuned memory cell can help maximize memory performance (frequency) for performance-driven applications.

The variety of I/Os available with FX-14 provides additional SWaP benefits, useful for reducing ASIC I/O count, die size and power. I/O choices include:

- Three-state bidirectional CMOS I/Os
- Low voltage differential signaling (LVDS) I/Os
- Multiple HSS cores for both short and long reach communication

- LPDDR4 PHY
- A high bandwidth memory (HBM) Gen2 PHY, compliant with the JEDEC HBM2 standard and supporting data rates up to 2000 Mbps per data pin.

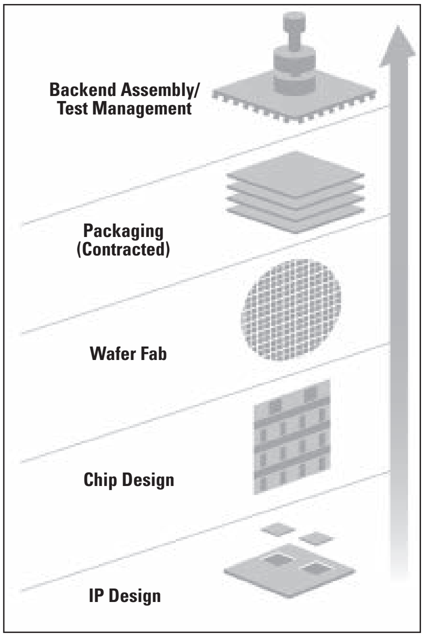
Features such as selective voltage binning and off-die switched voltage islands provide further opportunities for SWaP reduction. Voltage binning allows the ASIC supply voltage to be chosen according to the process speed, which is measured during ASIC manufacturing test and recorded within the die. Voltage islands can be used to power down circuits and IP when not in use.



▲ Fig. 1 FX-14 SWaP benefits compared to GF Cu-32 ASIC process. Results will vary with design.

END-TO-END SOLUTION

GF pairs FX-14 silicon IP with a vertically integrated and validated ASIC development methodology, optimized through decades of development experience and a strong record of first-time-right designs for a full service ASIC solution (see ***Figure 2***). This combination helps optimize customer development schedules and minimize expense risks.



▲ Fig. 2 GF offers a vertically integrated, full service ASIC solution.

The GF ASIC development methodology utilizes industry-standard design tools and a three-phase netlist signoff process (release-to-floorplanning, release-to-preliminary and release-to-layout) with highly structured entrance and exit milestones. GF is responsible for manufacturing test insertion, ASIC physical design and first-level ASIC package design. GF is also responsible for physical design checking (design rule checking and layout versus schematic), mask build, test generation, wafer manufacturing, ASIC wafer test, package manufacturing, die-package bond and assembly (module) and ASIC module test. Additional service options are available, including architecture services and detailed design services.

The GF FX-14 ASIC design system encompasses both FX-14 IP and development methodology, resulting in GF owning manufacturing yield. This further minimizes customer development risk. Customers purchase yielded FX-14 modules from GF: modules containing both die and packages that pass GF ASIC manufacturing tests.

GF's FX-14 die/package estimation tool estimates both ASIC die content and dimensions, including package (module) dimensions, based on customer and GF inputs. The tool affords valuable insights for A&D customers that need to meet specific application SWaP requirements. Additionally, GF development tools for ASIC voltage planning/selection and early ASIC power analysis enable early power estimation and trade-off analysis to help minimize power consumption in power-sensitive applications.

As part of GF's extensive commercial semiconductor portfolio, FX-14 builds on 30 years of ASIC expertise, more than a decade of A&D insights gained as a Trusted Foundry supplier and more than 2000 designs released to mask build. The high performance processing, density and power-efficient features of the FX-14 underlying 14LPP technology, combined with an extensive silicon IP portfolio, holistic ASIC methodology services and vertically integrated supply chain, are designed to enable GF FX-14 A&D customers to quickly develop differentiated solutions addressing next-generation challenges.

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Noise Injection Loop Test Translator for Satcom Systems

AtlanTecRF
Braintree, UK

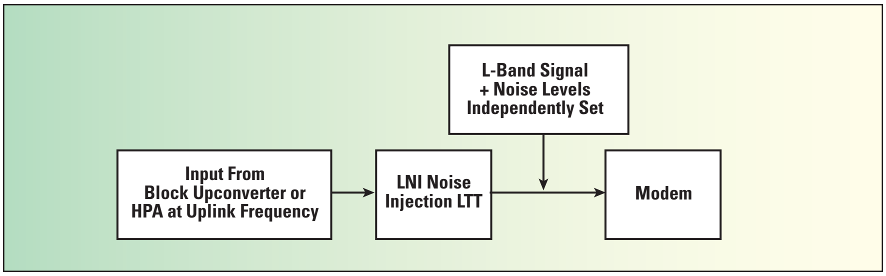
Equipment failure costs money and nowhere is this truer than in the world of satellite communications. Satellites themselves, of course, become just about the most expensive junk of all time when they fail, but ground stations of every kind can also inflict unwanted bills on owners, users and customers alike when performance of any constituent part falls below par or stops altogether.

Testing of satcom equipment and assurance of reliability is therefore a serious issue. It starts at the component level, runs through equipment manufacture and continues into system operation. Redundancy can, in some cases, cater for the catastrophic failure, but this is expensive in itself. Taking steps to avoid breakdowns and to maintain full performance is a better option. With this in mind, AtlanTecRF has introduced the LNI noise injection loop test translator (LTT) system, said to be the first combined system of loop test and noise injection.

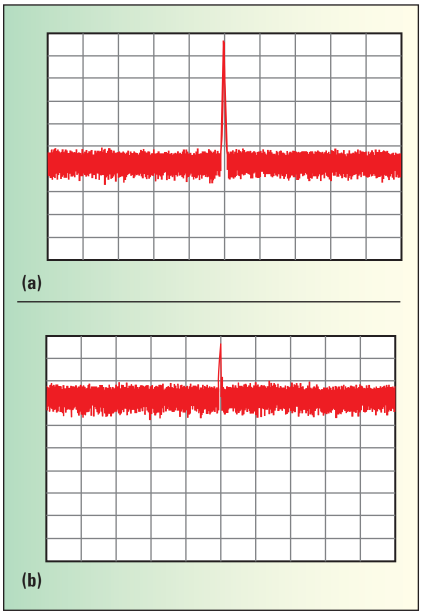
In the RF/microwave environment, there is a wealth of general purpose and immensely versatile laboratory and field test equipment available, but it comes with a pretty hefty price tag if your test regime is narrow and very focused. The RF focus in satellite communications ground stations concerns the performance of the transmitter and of the receiver. A non-performing receiver can certainly ruin the user's day, but a bad transmitter has the ability to extend the upset to many other satellite users, as well as the satellite owner.

LTT OPERATION

A long-standing item of specialized test equipment in this industry has been the LTT. It has the ability to facilitate off-satellite RF testing of ground systems (including vehicle, aircraft and shipborne) by looping back a portion of the transmit carrier to the receiver. Both arms of the system are then set up for optimum performance, such that when the switch to "live" is made, everything functions as it should. Partial tests are also possible with different loop back conversions, and these include transmit (Tx) to L-Band for transmitter alone testing and L-Band



▲ Fig. 1 Test setup for off-satellite RF testing with noise injection.



▲ Fig. 2 Spectrum analyzer plots showing a 1200 MHz signal at 0 dBm with the noise level attenuated 30 dB (a) and 0 dB (b).

to receive (Rx) for checking out just the receiver.

Another parameter that is essential in the satisfactory operation of the satcom system is receiver sensitivity. How well does the receiver distinguish the wanted signal from the all-too-abundant noise? One approach in common use in all types of RF receivers is to inject white RF noise into the receive chain somewhere downstream of the antenna and, by varying its intensity, determine the point at which the signal is no longer detectable. One of those downstream points is often at the entry to the modem at L-Band.

TEST REQUIREMENTS

Certainly it is important for the manufacturers of satellite communications systems to carry out both loop back frequency tests and receiver sensitivity tests. Loop back frequency because how else can one test a transmitter/receiver combination in a factory without a satellite? Sensitivity because this is key in supporting the claims made for the product to potential customers and users.

Of course, testing takes time and money and therefore designing test equipment to minimize this expense along with down time should be high on the priority list for the test equipment manufacturer.

LNI SERIES

These issues are all addressed by AtlanTecRF's LNI series of Ku-Band, Ka-Band and Q-Band noise injection LTT systems. The series is designed to provide the satellite communications engineer with a complete and versatile setup for off-satellite loop back testing of the transmit (Tx) signal to L-Band, combined with the ability to inject white symmetrical Gaussian noise for simultaneous receiver and modem testing.

Figure 1 shows the test setup using the LNI unit. The unit accepts an input at the Ku- (12.75 to 14.50 GHz), Ka- (27.5 to 31.5 GHz) or Q-Band (43.5 to 45.5 GHz) uplink frequency from a suitable point in the uplink chain—the block up-converter output or as a coupled signal from the high power amplifier output, for example. The test translator converts this to an L-Band signal suitable for the modem input. Noise is coupled into the signal path at L-Band; both the signal and noise levels can be independently adjusted. This enables the modem's performance under varying signal-to-noise ratios to be assessed, simulating the effects of varying system noise on link performance.

The loop test function is controllable in terms of input attenuation over a 60 dB range in 0.5 dB steps and local oscillator (LO) frequency in 25 MHz steps, while the white noise level, at the common L-Band of 800 to 2600 MHz, is variable by up to 60 dB in 0.25 dB steps with an additional mute facility. A full list of input, output and LO frequency ranges for the complete range of noise injection LTT systems is given in ***Table 1***.

The LTT has a typical 0 dB conversion loss at zero input attenuation, while the base noise level generated is nominally -84 dBm/Hz and is injected via a variable attenuator and 20 dB directional coupler into the LTT's L-Band output. The noise level can be muted completely for LTT-only operation and is also switchable to an external output for noise-only operation. ***Figure 2*** shows two spectrum plots with the same signal level and varying noise power. Filtering is included to prevent noise appearing at the Tx input port or mixing with the synthesized LO output.

Control of both LTT and noise injection is affected by either front panel controls or remotely via Ethernet with an easy-to-use graphical interface. Frequency stability of the LO is derived from either the internal oven controlled crystal oscillator (OCXO) or from a system 10 MHz reference.

In addition to the 2U × 19 in configuration, the LNI noise injection LTT systems are available in portable bench mount instruments for transportation to multiple test sites and laboratory locations.

The new system has the capability to cut testing time by combining the normal loop back signal test with noise injection at modem level, all in one compact 2U rack unit. It can greatly enhance the capability for satellite communications engineers for factory system testing or at a satcom ground terminal.

TABLE 1
NOISE INJECTION LTT OPTIONS

Noise Injection LTT Systems	Input Frequency Range (GHz)	Output Frequency Range (GHz)	LO Frequency (GHz)
LNI-1180-1305-Ku	12.75 to 14.5	0.8 to 2.6	11.8 to 13.05
LNI-2500-2700-Ka	27.5 to 31.5	0.8 to 2.6	25.0 to 27.0
LNI-4250-4400-Q	43.5 to 45.5	0.8 to 2.6	42.5 to 44.0

VENDORVIEW
AtlanTecRF
Braintree, UK
www.atlantecrf.com

Selecting the Best Fan-Out for Military Radio Testing

JFW Industries Inc.
Indianapolis, Ind.

During the past 10 years, the use of military radios has increased dramatically—so has the need to test those radios. This stems from the advent of such military-based communication applications as the land mobile radio and tactical networks, as well as the introduction of both software defined radios and cognitive/multi-user multiple-input-multiple-output (MIMO) wireless radios. Typically, these military radios are tested together in a closed mesh network, with programmable attenuators used to vary the attenuation and simulate different distances between the radios. While this test platform (i.e., military radio testbed) enables test engineers to conduct rigorous, transparent and replicable testing, it has limitations: the size of the mesh network or the number of radios that can be tested together.

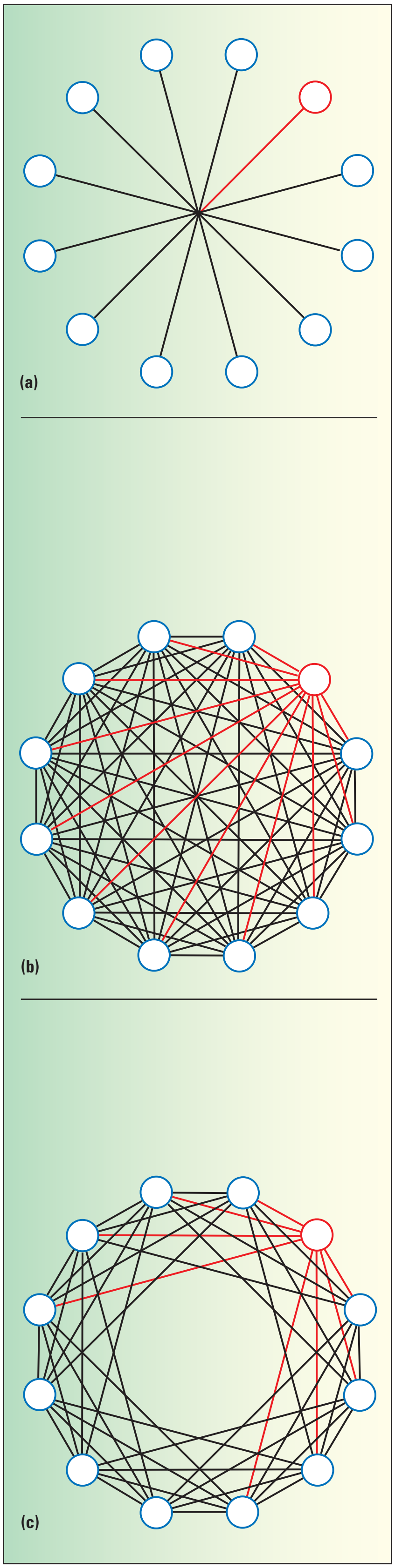
For test engineers wanting to build their own testbed with individual components, JFW provides the necessary programmable attenuators and the power divider/combiners to be cabled together. JFW also provides RF test systems with the components already packaged together with a computer interface for an all-in-one solution. These test systems are available in three different configurations, depending on how many military radios test engineers want to test together. The result is a comprehensive approach to quickly and successfully test modern military radios.

TESTBED OPTIONS

JFW offers three different test setups for testing military radios: hub, full and limited fan-out (see ***Figure 1***).

Hub Fan-Out

Most test engineers building military radio testbeds use a hub design to create a mesh network in which each radio is able to communicate with the entire network at one power level (see Figure 1a). The other ports must adjust their own attenuation to the mesh to receive the input radio at the desired power. The hub fan-out design utilizes a resistive divider/combiner with



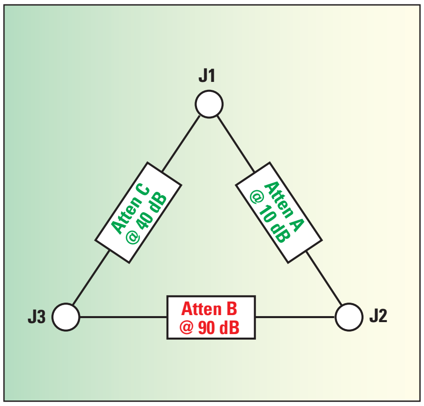
▲ Fig. 1 12-port fan-out configurations: hub (a) full (b) and LC8 (c).

TABLE 1

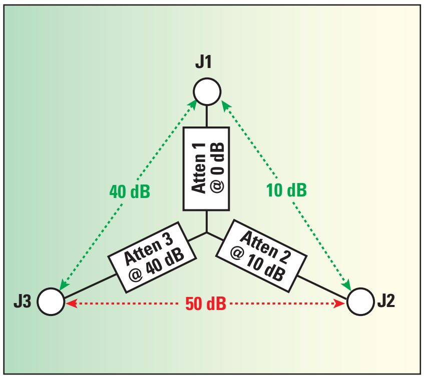
JFW CURRENT CAPABILITIES

	Hub Fan-Out		*Full Fan-Out*	*Limited Fan-Out*
# Radios/Ports	3 to 12 Radios	13 to 18 Radios	3 to 32 Radios	4 to 64 Radios
Frequency Range	DC to 6000 MHz	DC to 3000 MHz	30 to 3000 MHz or 500 to 6000 MHz	30 to 3000 MHz or 500 to 6000 MHz
# Attenuators	# Ports	# Ports	N × (N-1)/2 N= # of Ports	N × L/2 N =# of Ports L= # Adjacent Ports each Port can see

a star matrix configuration to combine all ports through a central hub. The star configuration limits the number of paths in the matrix to equal the number of ports. Each port has a single programmable attenuator that can be remotely controlled to simulate static or dynamic environments. The hub fan-out design can be used for radio-to-radio communication testing up to 18 radios. Because of the lower number of programmable attenuators—no more than 18—it is much lower in cost than the other two options.



▲ Fig. 2 With the full fan-out configuration, a unique attenuator on each path maximizes flexibility for radio-to-radio testing.



▲ Fig. 3 The hub fan-out cannot match the full fan-out's 40, 10 and 90 dB attenuator settings.

Full Fan-Out

For testing between 19 and 32 radios up to 3 GHz, the simple hub fan-out design is not viable. Instead, a test system based on a full fan-out design is recommended (see Figure 1b). The full fan-out design is constructed as a fully meshed matrix with a path between every pair of ports, each path having its own individually controlled programmable attenuator. The attenuators enable the test engineer to set a different setting for each path through the matrix. The attenuation values can be faded over time to simulate signal fading between radios. Each port can be connected to a device (e.g., a radio or handset) that can transmit/receive signals. Most JFW test systems utilizing this design cover either 30 to 3000 MHz or 500 to 6000 MHz.

Compared to the hub fan-out design, the full fan-out design uses a reactive, rather than a resistive, combiner/divider. This allows the full fan-out design to test more radios—up to 32 radios or ports—simultaneously. The design also offers the maximum signal fading flexibility. Because it allows every path to be set to a unique attenuation, the full fan-out is ideal for testing radio-to-radio communication. However, this is the most expensive of the three configurations, as the number of attenuators scales quadratically with the total number of radios.

Limited Fan-Out

To test more than 32 radios up to 3 GHz, the limited fan-out design is the best option. With this configuration, each port connects to only "L" number of its neighboring ports, where the number of neighboring ports depends on the application (see Figure 1c). The limited fan-out design is particularly

useful for reducing the size and cost of testing a large number of ports. By reducing the number of internal paths through the matrix, the size and cost of the test system is reduced. The reduced number of internal paths allows a greater number of ports to be offered, meaning that more radios can be tested simultaneously.

Where a full fan-out design with 48 ports requires 1,128 programmable attenuators, a limited fan-out LC16 design for 48 ports requires only 384 programmable attenuators. For this case, the difference in cost and size between the full fan-out and limited fan-out designs is roughly 66 percent. JFW currently offers limited fan-out models with up to 40 ports, although designs with up to 64 radios or ports are possible.

IDENTIFYING THE LIMITATIONS

The hub fan-out design is limited by utilizing a resistive divider/combiner, which effectively limits the number of radios that can be tested together. In JFW's case, two different types of hub fan-out transceiver test systems are offered. The largest resistive divider/combiner with a star configuration is an 18-port model that covers DC to 3 GHz, limiting the number of radios that can be tested together to 18. The largest JFW resistive divider/combiner with a star configuration is a 12-port model that covers DC to 6 GHz, limiting the number of radios that can be tested together to 12. The hub fan-out design is also limited by not being able to set every possible path to a desired attenuation. To illustrate, ***Figure 2*** shows a full fan-out with port-to-port attenuation settings of 40, 10 and 90 dB. ***Figure 3*** shows the hub fan-out, which cannot replicate the 40, 10 and 90 dB path settings.

In the case of the full fan-out design, the limitation is the size of the test system, which is limited to 32 radios or ports. With this design, a connection is required from any port to any other port. For 32 ports, a total of 496 internal paths are required, with each path containing a programmable attenuator. The 32-port full fan-out model offered by JFW occupies an entire 19 inch rack.

For the limited fan-out design, the limitation stems from the design. "Limited" in the phrase "limited fan-out" means not every port is connected to all other ports. In Figure 1c, each port is only connected to its eight neighboring ports. For a transmission on port 1 to reach port 9, it would have to be repeated by one of the radios that can see both ports 1 and 9—in this case, the radio connected to port 6.

Table 1 summarizes the limitations and abilities of each of the three designs and JFW's current capabilities. The relative cost and size can be estimated by the number of attenuators used in each type.

Testing as many military radios together as possible is a key goal for radio testing. There are three test setups that can be employed, each with its limitations. For testing up to 18 radios, the hub fan-out is the best option. When testing up to 32 or 64 radios, a full fan-out or limited fan-out design, respectively, should be used. For maximum flexibility, some applications may require every unique path to have its own attenuation, requiring the full fan-out configuration.

JFW Industries Inc.
Indianapolis, Ind.
www.jfwindustries.com

The 2017 Defence, Security and Space Forum

At European Microwave Week

EuMA Microwave Journal

Wednesday, 11 October – Nürnberg Convention Center – Room St. Petersburg

A focused Forum addressing the application of RF and microwave technology to The Internet of Space.

Vast areas of the globe are without sufficient Internet connectivity. Commercial and societal progress as well as safety and security are linked to access to the information superhighway, while military missions require reliable and secure data communication pathways. This one-day Forum highlights **The Internet of Space – Technologies and Applications**, a new class of satellite communication services being developed to address these needs.

Programme:

08:30 – 10:10 EuRAD Opening Session

10:50 – 12:30 The Internet of Space – Technologies and Applications

Two keynote speakers from the industry will present their view on key applications and the related technologies needed for the realisation of the **Internet of Space**. The presentations will cover commercial as well as military applications.

- The World's Largest Satellite Constellation 'OneWeb' – Redefining Satellite Communications
  Wolfgang Duerr, Airbus DS Inc.
- The Connections are Key: The Implications of the Internet of Things on Military Technology – *Joe Mariani, Deloitte*

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

This session adds a further dimension to the topics by offering a market analytics perspective, illustrating the status, development and potential of the market for the **Internet of Space**.

14:20 – 16:00 *Microwave Journal* Industry Panel Session

This session offers an industrial perspective on the key issues to be addressed in the defence, security and space sector. In accordance with this year's Defence, Security and Space theme the panel will investigate the opportunities for applications of the **Internet of Space** as well as address the technological challenges.

16:10 - 17:50 Defence, Security & Space Executive Forum

High level speakers from leading Defence and Space companies present their views and experiences on the upcoming technologies and applications in the civil and military domains. They will be complemented by speakers from a government agency, consulting company and a start-up, who will offer their views on research needs, trends and New Space opportunities and challenges. Speakers at the Forum will include:

- *Erich Auer, TeSat SpaceCom*
- *Wolfgang Duerr, Airbus DS Inc.*
- *Matthias Spott, eightyLEO*
- *Joe Mariani, Deloitte*
- *Siegfried Voigt, DLR*

17:50 - 18:30 Cocktail Reception

The opportunity to network and discuss the issues raised throughout the Forum in an informal setting.

Registration and Programme Updates

Registration fees are €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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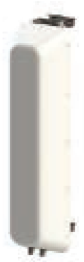


MANET/MIMO Sector Antennas Support High Data Rates

Southwest Antennas has engineered a full line of directional sector antennas designed for tactical mobile ad hoc networks (MANET) and multiple-input-multiple-output (MIMO) mesh radio systems. These antennas support high bandwidth networking for handheld radios, ground and airborne vehicles and security sensor systems. They can easily be deployed as part of a temporary communications network or installed as long-term infrastructure, and they are adaptable as situational needs change.

Standard multi-port antennas are available with two, three or four RF connector ports for use with many radio systems across a wide range of operating bands and scenarios. The sectorial radiation pattern and high gain provide directional communications, focusing network coverage in specific areas. The antennas also offer polarization diversity—slant left, slant right and vertical options—to help maximize RF link strength and data throughput. These polarization schemes benefit operating environments with powerful co-located transmitters and other sources of RF interference. Optional RF filters can be integrated into the antennas to reject unwanted transmissions, improving the performance of the attached radios.

These MANET/MIMO sector antennas are available now in many frequency range and RF connector options for a wide variety of government and military applications. Future tactical MANET radio waveforms that will become standard with next-generation military radio systems will offer operators a greater range of frequency bands. Southwest Antennas' sector antennas are forward-compatible with these future waveform updates, covering L-, S- and C-Band options that will be available domestically and internationally.

VENDORVIEW

Southwest Antennas
San Diego, Calif.
www.southwestantennas.com

High Performance GaAs and GaN From a DoD Trusted Supplier

At its 70,000-square-foot Microelectronics Center (MEC) in Nashua, N.H., BAE Systems develops and produces GaAs- and GaN-based compound semiconductor materials, devices, circuits, modules and subsystems at frequencies from below 1 to 200 GHz. The MEC supplies compound semiconductor ICs and modules to a variety of internal and external customers and has been a Department of Defense Category 1A Trusted Supplier since 2008. In addition to advanced device research and development, the company fabricates devices in production quantities for DoD programs, inserting its technology into fielded products. For example, BAE Systems delivered nearly 1 million GaAs MMICs to support F-22 production.

The MEC's advanced 100 kV e-beam lithography capability defines critical features as small as 20 nm, enabling highly repeatable definition of larger gate features. The facility uses MBE technology to precisely grow high quality PHEMT and MHEMT active device layers on GaAs substrates. GaN-on-SiC wafers grown by MOCVD are obtained from carefully-qualified suppliers. The MEC's 6-inch wafer processing line has been running production GaAs MESFET and PHEMT processes since 2004, and the company installed a facility for high rate manufacturing of high power GaN modules in 2015.

In 2016, the company consolidated microwave hardware development and production into the MEC, from material growth and wafer processing to IC and module design, test and manufacturing. This greatly enhanced the ability to design for manufacturability and affordability.

The foundry's current 4-inch GaN-on-SiC production processes leverage the enhanced uniformity and automation of its 6-inch equipment. Six-inch GaN wafer processes have recently been demonstrated with high yield, equivalent performance and excellent reliability, with an MTTF of more than 10^7 hours at 200°C channel temperature. Release to production is planned for August 2017. Producing GaN MMICs on 6-inch wafers addresses one of the last remaining challenges to making this new technology affordable.

BAE Systems
Microelectronics Center
Nashua, N.H.
www.baesystems.com

100 MHz OCXO Reference for LEO Satellites

To support the increasing number of commercial low earth orbit (LEO) satellite constellations, Bliley Technologies developed the Iris master reference oscillator. The 100 MHz oven controlled crystal oscillator (OCXO) was designed to be radiation tolerant for both the total ionizing dosage (TID) and linear energy transfer (LET) levels encountered by LEO satellites. The Iris series is tolerant to at least 40 kRAD TID and 40 MeV LET. The OCXOs' low power dissipation and small size, compared to traditional space OCXOs, supports the constraints of LEO payloads. Biased with a nominal 5 V supply, the OCXO dissipates 1.5 W steady-state (3 W maximum at start-up). Its size is 1 in x 1 in x 0.46 in.

Designing the Iris for LEO satellites did not sacrifice oscillator performance. The phase noise of the 100 MHz oscillator at 10 kHz offset is –168 dBc/Hz or better. Temperature stability over the operating temperature range of –10°C to +60°C is under ±25 ppb. Aging per day at 30 days is typically ±5 ppb and projected to be ±500 ppb after three years. Allan deviation (ADEV) is typically 1.69 x 10^{-11} with averaging (τ) of 1 s and 8.09 x 10^{-11} with τ = 10 s. Acceleration sensitivity is typically 0.3 ppb/G.

The Iris master reference can be paired with Bliley's phase-locked loop to create an oscillator subsystem with high performance, low cost and attractive size, weight and power consumption for LEO constellations.

Bliley Technologies, founded in 1930, has a longstanding reputation as a stable source of high quality frequency control products, as well as a solid heritage serving the space market. The company has a long list of quality certifications, required to supply products to the space market, and many Bliley crystal products and oscillators are flying on various military, scientific and commercial missions, accumulating decades of in-space performance.

Bliley Technologies
Erie, Pa.
www.bliley.com

Precision-Engineered MIL-Grade Products

API Technologies designs and manufactures high performance subsystems, assemblies and components for demanding RF, microwave, millimeter wave, electromagnetic, power and security applications. API products are used by global defense, industrial and commercial customers in the areas of aerospace, wireless communications, electronic warfare, C4ISR, missile defense, harsh environments, satellites and space. With diverse program experience and preferred supplier status with some of the industry's top prime contractors, the company's precision-engineered MIL-grade products are ideal for applications where uncompromised reliability and uninterrupted performance is required.

API Technologies
www.apitech.com

BNC Model 855

VENDORVIEW

The BNC Model 855 is a phase coherent multi-output ultra-fast switching and low phase noise signal generator with frequency ranges from 10 MHz to 6.2, 12.5 or 20 GHz, with excellent phase noise and spurious and harmonic rejection. A high stability OCXO reference provides excellent frequency accuracy and stability. The Model 855 provides two to eight independent outputs in a 1U or 3U enclosure. Various controls interfaces: USB, LAN or GPIB, and a rich library of API's are provided.

Berkeley Nucleonics
www.berkeleynucleonics.com

Solid-State Amplifier Solutions

CTT announced a new 48-page product catalog: Solid-State Amplifier Solutions for Military and Commercial Applications. The new catalog features over 830 amplifier products, of which over 365 are all new. Product offering includes new GaN power amplifier technology for narrowband, wideband and ultra-wideband applications. Many new GaAs-based power and low-noise amplifier designs are also listed, including new Ka-Band, low-noise amplifiers. The catalog also includes application information and case outline drawings. Visit CTT's website for a free download.

CTT Inc.
www.cttinc.com

Direct GPS-over-Fiber

VENDORVIEW

HUBER+SUHNER's Direct GPSoF solution perfectly addresses the power supply challenges within a GPS system by making use of the company's newly developed Power-over-Fiber technology. This new technology not only enables system improvements by eliminating all copper within the link, but also reduces the amount of hardware within the system by integrating the GPS-over-Fiber transmitter into the antenna's radome. The key benefits are Power-over-Fiber enabled GPSoF transmitter, truly copperless link (no EMI, RFI and EMP) and less hardware as transmitter integrated into antenna radome.

HUBER+SUHNER
www.aerospacedefense.hubersuhner.com/products

Military/Homeland Security Defense Supplier

K&L Microwave designs and manufactures a full line of RF and microwave filters, duplexers and subassemblies, including ceramic, lumped element, cavity, waveguide and tunable filters. K&L supplies many of today's most significant military and homeland security defense electronics programs. Applications include space flight, radar, communications, guidance systems and mobile radio base stations, as well as air traffic communication and control. Visit the company's website to research capabilities, access data sheets, submit quote requests and download catalog to help with your requirements.

K&L Microwave
www.klmicrowave.com

Test Solutions Product Guide

VENDORVIEW

Rapid growth in the number and variety of wireless applications and connected devices in the market has driven the need for more innovative and highly customized test solutions. Customers are looking for equipment to multiplex application-specific test systems across multiple DUTs, which requires signal routing, distribution and conditioning functions in a variety of configurations. This 2017 Test Solutions Product Guide showcases some of the company's newest, most advanced and most popular test systems developed to date.

Mini-Circuits
www.minicircuits.com

CW-Immune SDLVA

VENDORVIEW

PMI model no. SDLVA-2020 series of DC-coupled, successive detection log video amplifiers (SDLVA) are available in extended 70/75 dB dynamic range over the range of 1 to 18 GHz bandwidth, with true DC coupling. Units employ planar diode detectors and integrated video circuitry for high speed performance and outstanding reliability. The DLVA's are of superior construction using state-of-the-art MIC/MMIC technology. The size is 3 in x 3.5 in x 0.5 in.

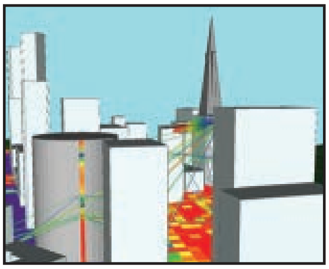
Planar Monolithics Industries Inc.
www.pmi-rf.com/products/SDLVA/SDLVA-2020-70-818.htm

Filters, Multiplexers and Multi-Function Assemblies

VENDORVIEW

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

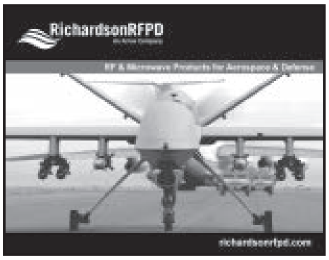
Reactel Inc.
www.reactel.com



Predictive Simulation for Wireless Networks

Wireless InSite is a suite of ray-tracing models and high-fidelity EM solvers for the analysis of site-specific radio propagation and wireless communication systems. Applications include 5G MIMO simulation, macrocell and small cell coverage, urban multipath and shadowing, indoor Wi-Fi, wireless backhaul, LTE and WiMAX throughput analysis and ad hoc networks and D2D communication. Visit the company's website to learn more.

Remcom
www.remcom.com/wireless-insite



Aerospace & Defense Selector Guide

Richardson RFPD is an AS9120-certified, global component distributor specializing in advanced connectivity solutions. With A&D as its largest market, the company's GaN technology portfolio and wide range of MMICs, RF transistors, PAs and diodes from leading brands like ADI, MACOM, Microsemi, NXP, Peregrine and WanTcom serve diverse A&D applications, including radar, avionics, EW and communications. Among the latest additions to Richardson RFPD's A&D line are Guerrilla RF, NewEdge Signal Solutions and Tagore Technology products and the Metelics diodes now offered by MACOM.

Richardson RFPD
www.richardsonrfpd.com

Test & Measurement Catalog 2017

VENDORVIEW

Almost 300 pages full of information about the Rohde & Schwarz test and measurement instruments, systems and software. It includes a short description and photos of each product, the most important specifications and the ordering information. You can download this catalog as a PDF from the Rohde & Schwarz website or order from Customer Support (Order number: PD 5213.7590.42 V 07.01).

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

Rotating Solutions for Camera Applications

VENDORVIEW

SPINNER's miniature slip ring/fiber optic rotary joint (FORJ) combinations with diameters as small as 22 mm are the perfect choice for rotating camera applications. They enable interference-free video data transmission in 4K and 8K quality, also with fast-moving images. Among other things, SPINNER has developed and implemented a globally unique solution: the SPINNER type 1.14L. It is a robust, easy-to-use rotary joint for single-mode and multi-mode fibers.

SPINNER GmbH
www.spinner-group.com

AEROSPACE AND DEFENSE ELECTRONICS

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