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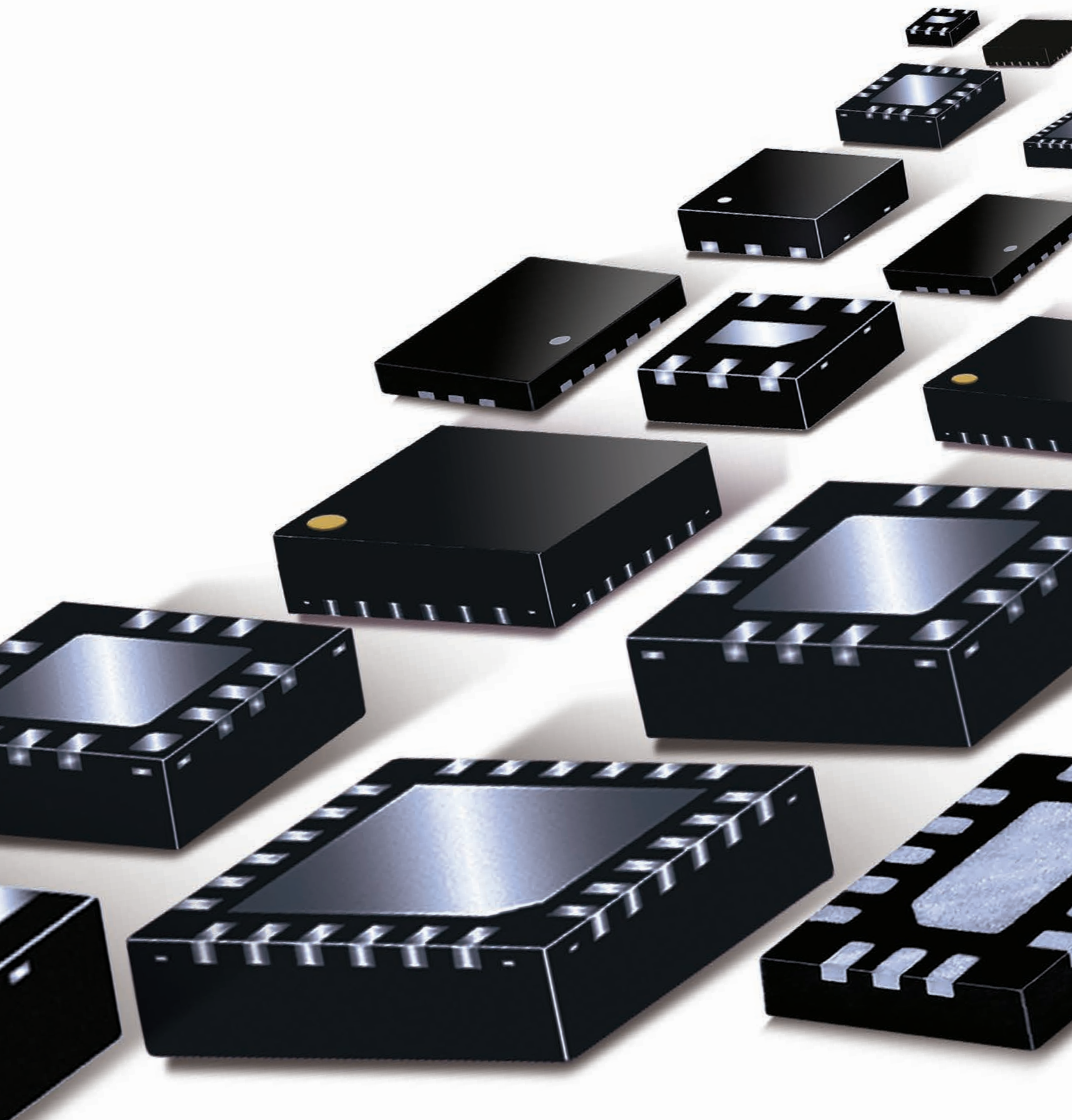

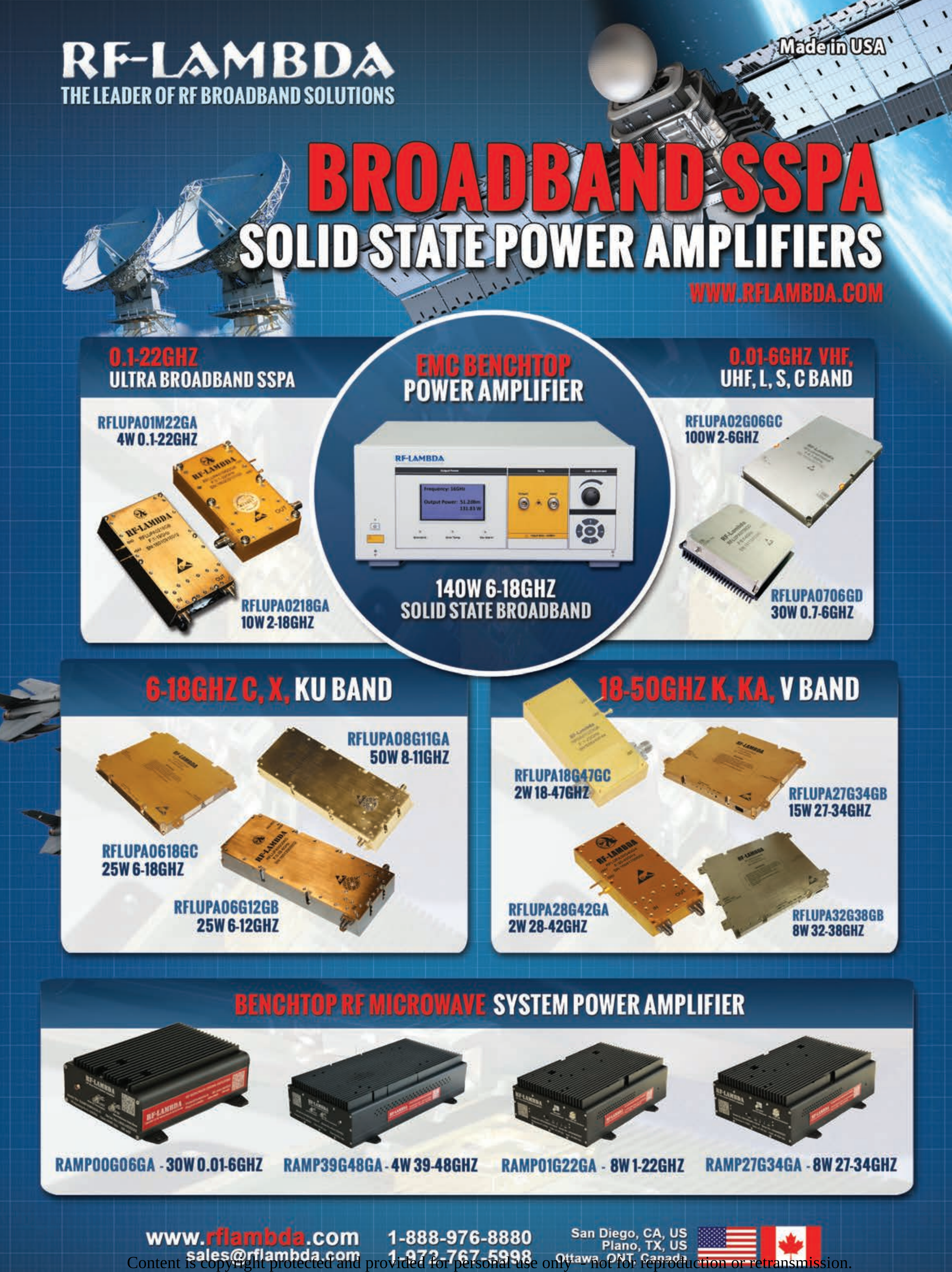
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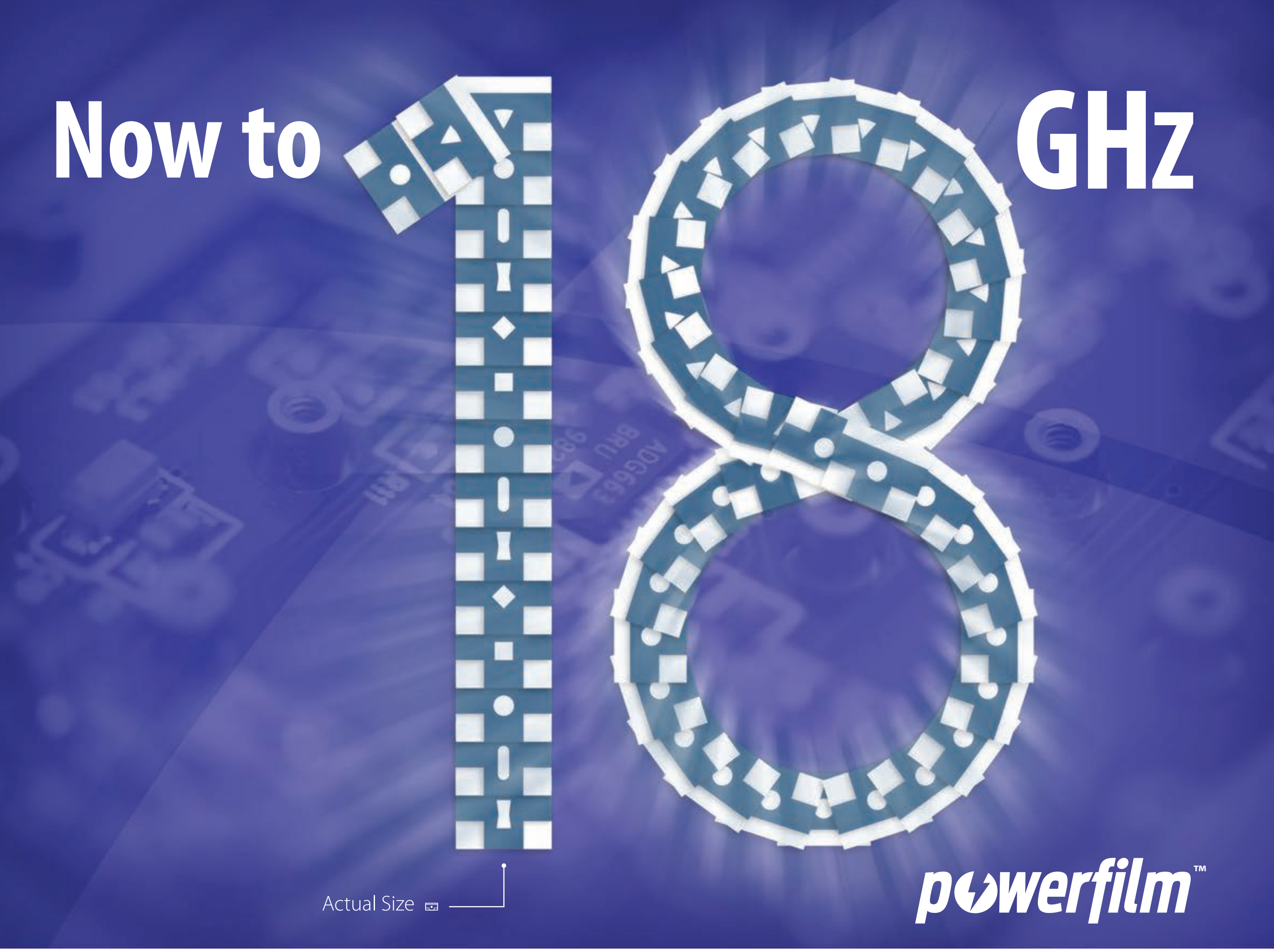

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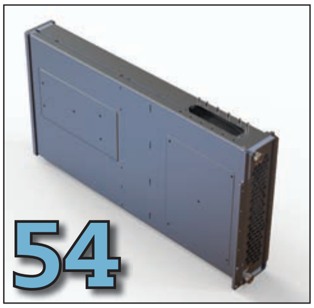

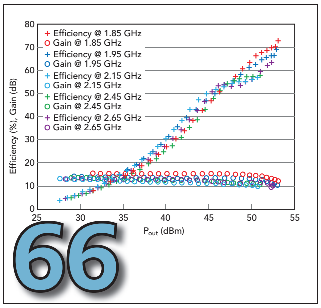

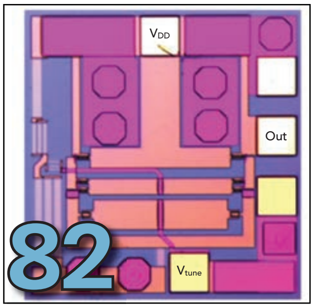

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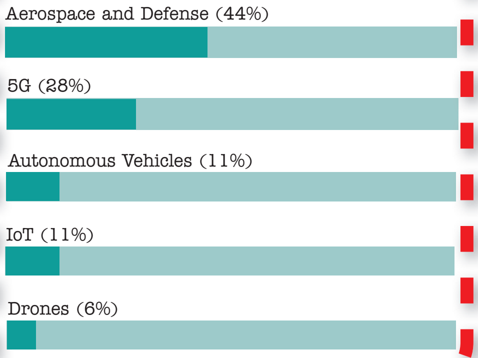

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COVER FEATURE
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Defense Opportunities and Challenges in 2019

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The 2019 defense budget seems to have something for everyone—including the first pay raise for troops in nine years—and sailed through the House with a 361 to 74 vote and was signed by the President. It is the first time in a decade this was achieved before the end of the fiscal year. By any unit of measure, 2019 should be a good year for the RF and microwave industry as the Defense Department's Third Offset Strategy requires a heavy dose of fields and waves.

PHASED ARRAY RADAR

The U.S. has never faced the type and level of threats present today that require what only RF and microwave technology can deliver. For example, until recently, the U.S. and some NATO countries were the sole purveyors of active electronically-steered array (AESA) radars, but that is changing fast, as Russia and China have demonstrated their own formidable AESA systems. This is bad news for radar warning receivers (RWR) that are attempting to keep up with these shape-shifting electronic chameleons, whose lightning-fast reflexes and highly-developed brains can dispatch older RWRs with ease.

Even though phased-array radars have been in the inventories of the most advanced countries for a decade or more, the latest crop can exploit advances in signal processing to deliver astonishing performance. They can provide almost-instantaneous 360 degree coverage, and are versatile enough to perform in any role, from fire-control to synthetic aperture radar (SAR) mapping, sea surface search, ground moving target indication and tracking and air-to-air search and track. An AESA radar (see ***Figure 1***) can randomly change frequency with every pulse, rapidly vary its output power, change its pulse repetition frequency and waveform, use spread-spectrum techniques and suddenly become passive, using the RWR's own signal to defeat it. And that is the short list.

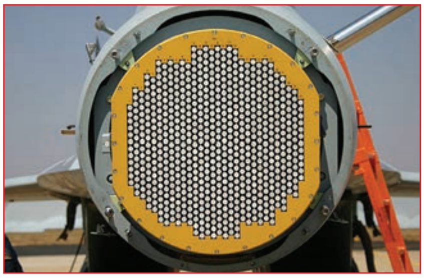


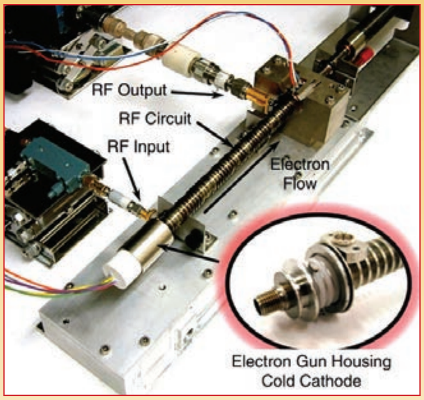
Fig. 1 **An AESA radar is smaller, lighter and vastly superior to legacy radars on this F-16, which is currently being upgraded to GaN-based radars (Source: U.S. Air Force).**

The Triumph of the TWT

The imminent demise of the traveling-wave tube (TWT) has been predicted since the first GaAs MMICs led to the AESA radar and the last nail in the TWT's coffin was supposed to be GaN. Neither of these pronouncements has occurred and is not likely to for many years. In fact, the vacuum electron devices (VED) that helped win World War II and make SATCOM and radio and television broadcasting possible are experiencing resurgence with interest at mmWave frequencies, and DoD is a driving force.

No solid-state device can produce as much power in the mmWave frequencies and above than a TWT. However, the small size of solid-state devices allows phased-array antennas with hundreds of elements to produce a reasonable EIRP of perhaps 10 W at 60 GHz using a 64-element array. While this is more than adequate for commercial communications applications such as IEEE 802.11ad, more power is needed for EW systems. At higher frequencies above 100 GHz, the EIRP would be even less, and in all cases, heat dissipation is a major challenge.

The TWT that can deliver RF power of several hundred watts at frequencies up to 100 GHz and tens of W at 200 GHz, which makes it not only appealing but a necessity if EW systems are to defeat adversaries at these frequencies. Microwave Power Modules (MPM) that are even smaller at these high frequencies than their lower-frequency counterparts that potentially make them usable in airborne radar and imaging applications where SWaP requirements are severe. When fed to a high gain reflector-type antenna an EIRP of more than kW is achievable.



SB Fig. 1 **Anatomy of a 100 W cold-cathode TWT developed by L-3 Communications Electron Devices.**

The power available from new TWTs may make them more enticing in the future, especially for remote sensing applications at higher frequencies. An example is a MPM designed by L-3 Electron Devices has an instantaneous bandwidth of more than 3 GHz from 231.5 to 235 GHz (G-Band) and produces a peak RF output power of 32 W with 10 mW of drive and efficiency of about 9 percent (see **SB Figure 1**).

Cold Cathode Coming

The most noteworthy achievement in TWTs of late is the previously insurmountable challenge of producing a cold-cathode device, development of which has been ongoing since Charles "Capp" Spindt and Kenneth Shoulders of SRI International published a seminal paper in 1966. The benefits are significant, as a cold-cathode tube operates at ambient temperature without the need for a cathode heater, a traditional factor limiting tube life so that theoretically, tube life could be almost infinite. It would also eliminate warm-up time, making operation almost instantaneous. Current density could be much higher as well because emission would no longer be limited by operating temperature, making it easier to focus the electron beams.

The biggest challenge has always been reliability, as the cathode consists of tens of thousands of micrometer-size molybdenum cones deposited on a circular silicon substrate with an area of about one square millimeter. The high fields within the structure and the thin film gate electrode make it possible for an electrical short to occur between the gate and one of these cones. When that happens, the entire array of emitters burns up and the device fails catastrophically. In a traditional thermionic TWT degradation is "graceful," allowing its end of life to be predicted by the amount of barium remaining.

However, L-3 Electron Devices has developed a way to reduce the damage caused by such a short, and were able to interrupt the breakdown path between the base of the cones and the gate by adding a dielectric layer between them. The company believes that at its current rate of development, the cold-cathode TWT could become a commercial product within about five years.

AESA radars are also rapidly expanding their range, thanks in no small measure to GaN MMICs that are poised to complement or perhaps replace GaAs in the T/R modules of most next-generation radars, and many electronic warfare (EW) systems, as they too may use the AESA architecture. In fairness, without GaAs MMICs, the military might still be using traveling-wave tube (TWT) powered amplifiers for want of a broadband, solid-state alternative. GaAs is a mature, cost-effective technology whose future remains somewhat secure, if not in AESA radars, than in dozens of other applications that it has either enabled or enhanced.

However, GaN has advantages that cannot be matched by GaAs, silicon or any other current semiconductor technology capable of producing RF power. It can operate at about 5× the voltage of GaAs and has 10× the power density per unit of die area, twice the current handling ability and higher power-added efficiency above about 10 GHz and higher than silicon above about 1 GHz. And while both GaAs and GaN can cover broad bandwidths, a GaN-based amplifier can have an instantaneous bandwidth 4× wider than a GaAs with the same output power.

Compared to silicon LDMOS, GaN has a power density advantage and can potentially operate far into the mmWave region. In short, GaN will power most of the radar systems and possibly EW systems in the future and has a long roadmap before it reaches maturity. LDMOS will continue to serve some radar as well as many communications applications for many years, at least for narrowband applications below about 4 GHz. LDMOS is the hands-down winner in terms of ruggedness and cost, with the ability to operate in a load mismatch or more than 65:1 while current commercial

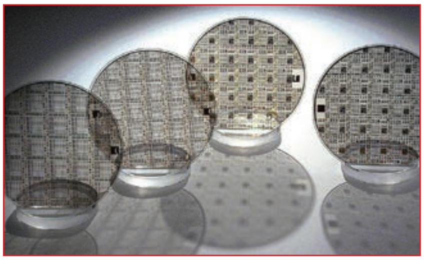
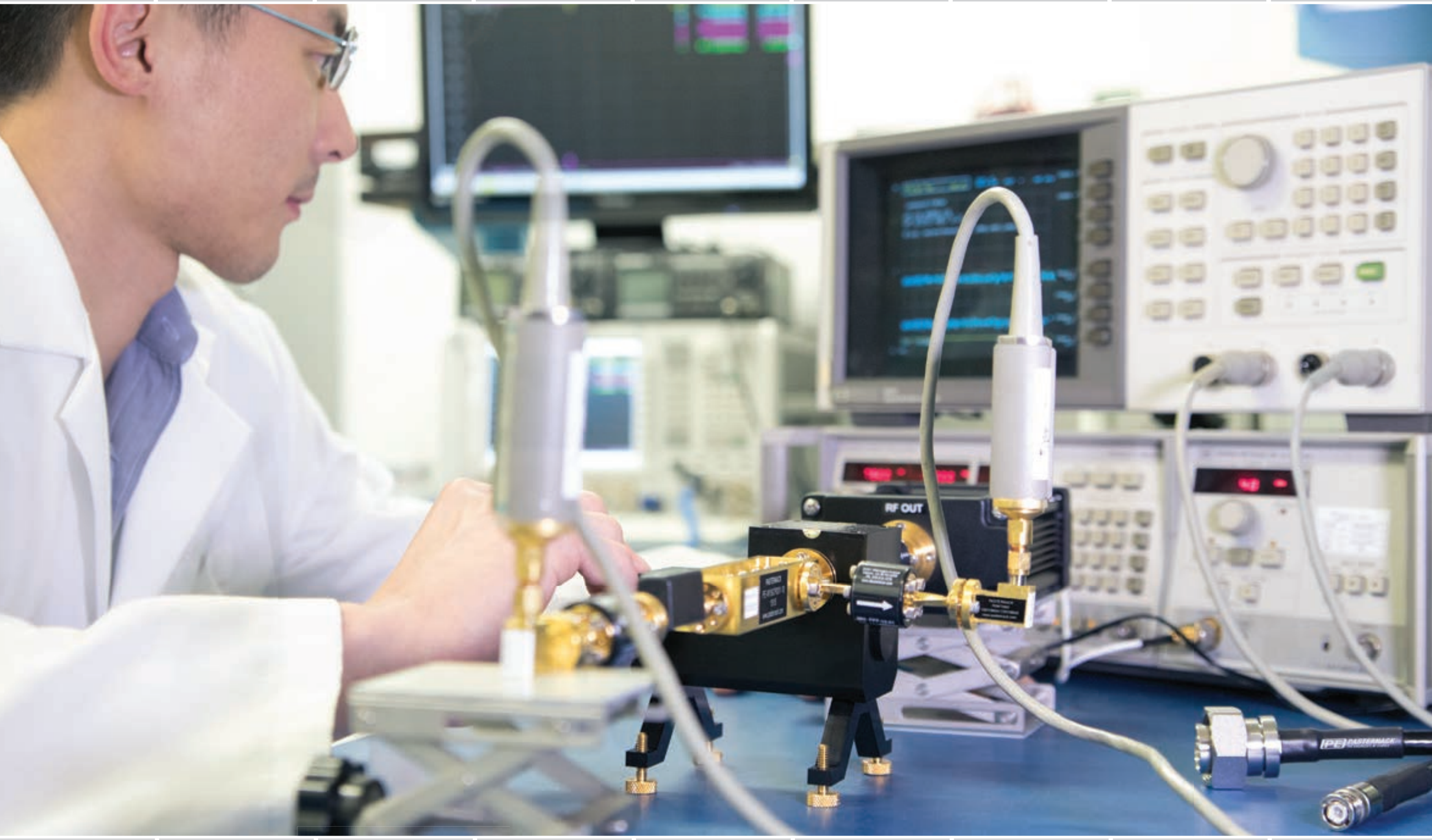


Fig. 2 **GaN on SiC wafers, shown here by the European Space Agency, have reached 6-in. in diameter.**


RF OUT

GaN on SiC devices (see ***Figure 2***) are rated at 20:1 or less.

LDMOS discrete transistors can achieve high RF power levels, currently up to 1.8 kW with a bias voltage of 65 VDC as well. However, as LDMOS is a more narrowband technology so multiple amplifiers are required to cover a wide frequency range. LDMOS is still used in L-Band radar, IFF and avionics systems where it is competitive with GaN, and this market is highly competitive. GaN is also currently more expensive, but that may change as volumes increase.

Manufacturers of discrete GaN RF power transistors are actively pursuing the opportunities at L-Band with devices at various power levels. Qorvo's QPD1025 GaN on SiC transistor, for example, is currently the highest power, commercially available GaN on SiC device, delivering 1800 W from 1 to 1.1 GHz. Although narrowband, so are the key applications at L-Band that cover only 1030 to 1090 MHz. The device also operates at 65 VDC, directly targeting 65 VDC LDMOS with power-added efficiency up to 77 percent and gain up to 22.5 dB.

MACOM is a notable exception to the GaN on SiC trend as the company has dedicated its development efforts exclusively to GaN on silicon (Si) substrates and has a GaN on Si device that delivers 1 kW of pulsed power at L-Band. Although generally considered GaN's "second-tier," MACOM believes it can make GaN on Si a formidable competitor for all but bleeding-edge (i.e., defense) applications. The primary advantage of silicon is its low-cost and proven high-volume manufacturability, as it can use standard CMOS fabrication processes, dramatically increasing product capability and reducing cost.

Current GaN devices have a power density of about 11 W/mm^2 but several special processes have reported even higher levels. Fujitsu currently has the highest reported power density at 19.9 W/mm, although the DARPA GaN on diamond project reported results similar to this level a few years back. The ability to produce so much power from a tiny semiconductor device is remarkable and sure to increase in coming years. That is particularly appealing in an AESA radar where the ability to produce more power at each antenna element is highly desirable.

Advances in GaN's power density will result from enabling the technology to get as close as possible to its theoretical maximum. One of the ironies of GaN is that its enviable high-power density also results in the creation of heat in a very small area, so future achievements will be directly the result of getting rid of it, quickly as it is thermally limited in many cases.

This process begins at the die level, where silicon carbide (SiC), the material to which it is most often attached as a substrate, has thermal conductivity 6× that of GaAs and 3× that of silicon. Other material combinations such as copper-tungsten, copper molybdenum and copper-molybdenum-copper are used with silicon and GaAs devices, but currently only copper (and diamond in the future) can compete with SiC in thermal conductivity.

Once the heat is moved away from the die, the next stop for the heat is a structure that moves it further away, where it can be dissipated naturally or with liquid cooling. This can be a heat sink or heat spreader. The material that will allow GaN to achieve its potential is diamond as its thermal conductivity is 4× that of SiC or copper, in fact, higher than any other material on Earth.

There are some devices currently using diamond as a substrate material and aluminum-diamond metal-matrix composites (MMC) are used as heat spreaders. As applied to RF applications, chemical vapor deposition (CVD) diamond is the near-exclusive domain of Element Six (a subsidiary diamond goliath De Beers), which has achieved thermal conductivity of an astonishing 2200 W/mK. Their process for GaN on diamond devices was recently sold to RFHIC which plans to commercialize it. Nano Materials International (NMIC), which makes aluminum-diamond metal matrix composites used for heat spreaders, has achieved thermal conductivity of about 500 W/mK, and the composite is becoming more popular as GaN moves toward higher power

densities. Akash Systems is using GaN on diamond exclusively to address satellite/space applications.

The DoD also wants GaN to operate at voltages higher than 50 VDC to increase efficiency and a few 65 VDC devices are available, including several from Integra Technologies, one of which operates between 420 and 450 MHz with a 150 VDC supply and delivers more than 1 kW with a 100 µs pulse width at a 10 percent duty cycle and drain efficiency greater than 70 percent. Several device manufacturers are offering these 65 VDC devices, such as Qorvo and Sumitomo, with others following.

ELECTRONIC WARFARE

Since the end of the Cold War, there has been surprisingly little emphasis by DoD on increasing EW capabilities, especially in the Army, which spent little money in this area other than for IED jammers—until now. For the recent and almost feverish interest in EW, the West mostly has Russia to "thank," as it demonstrated in Ukraine and Syria how far it has come in EW development and anti-access/area denial capabilities in general. It also got a boost from China's effort to ramp up its anti-access/area denial capabilities in the South China Sea. The result is more attention to EW than at any time since the end of the Cold War. The DoD is working to "reinvent" electronic attack, protection and support across all the services, with a particular focus on the Army.

Providing effective EW has never been easy and today it is more difficult than ever, requiring a modular, scalable, adaptive, more selective and precise approach over a wider range of frequencies into the high millimeter wavelengths with greater resistance to interference, whether from friend or foe. EW systems must be able to capture huge amounts of data, process it and deliver a response in near real-time from more sources than ever as the spectrum is densely packed with legal emitters. As the electromagnetic environment varies from country to country, there is no one-size-fits-all solution.

To accomplish all that DoD wants to achieve will require a more tightly managed approach, making EW systems a more integrated part of the battlespace (see ***Figure 3***). One way to accomplish this is by allowing an AESA system to handle both radar and EW, requiring a level of integration that currently does not exist. It will be difficult to achieve because EW systems must have 12 to 16× the bandwidth of a radar system, which among other things presents significant challenges for antenna designers and at the lowest frequencies make the two applications fundamentally incompatible. However, DoD is considering the approach as it would significantly reduce hardware requirements.

Another trend in EW is toward cognition—machine learning, an artificial intelligence that would allow RF systems to change their characteristics in near real-time to adapt to conditions as they are experienced by the system. In contrast, EW systems currently use lookup tables to sort out what they have ingested and applying a rules-based approach to determining what to do about them. However, the increasing use of digital signal processing and radar systems make it necessary for future EW systems to complement current threat databases with this real-time informa-

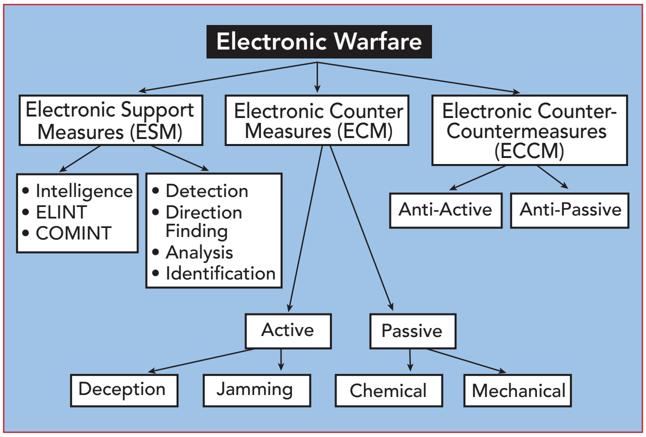


Fig. 3 **DARPA, other agencies and defense contractors are working to first integrate the many elements of EW, for which machine learning and artificial intelligence are the essential ingredients (Source: DARPA).**

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tion that would be gathered during operation. This not only addresses the need for greater situational awareness but allows EW system to adapt to new threat signatures immediately.

The most recent program attempting to accomplish this is the Reactive Electronic Attack Measures (REAM) program for which Northrop Grumman was awarded a $7.2 million contract to develop machine algorithms that would ultimately be used on the EA-18G Growler EW aircraft that, coincidentally, will also be the first recipient of the Navy's GaN-powered Next-Generation Jammer (see ***Figure 4***). The REAM program is designed to produce detection and classification techniques for identifying waveform-agile radar threats and responding automatically with electronic attacks.

Fig. 4 **The Navy's Next-Generation Jammer, represents the future of EW as it uses state-of-the-art GaN devices in an electronically-steerable architecture (Source: U.S. Navy).**

A QUANTUM LEAP

In the long-term, the greatest threat to EW systems comes from quantum technology and how it is employed in radar systems. The technology has so many benefits that whoever deploys it first will have a huge (if temporary) advantage, making their EW systems as well as stealth technologies potentially useless. China seems determined to deploy this first and has been loudly claiming it has demonstrated the first "single-photon quantum radar system" that skeptics consider dubious. The accomplishment has been attributed to the development of single-photon detectors that very efficiently capture returning photons.

The Chinese say they tested such a system in an outdoor environment and it demonstrated the ability to detect stealth aircraft at 62 miles with accuracy high enough for missile targeting. China's media was quick to point out that this was 5× what a laboratory prototype jointly developed by researchers from Canada, Germany, Britain, the U.S. achieved a year earlier. DARPA is funding research with the University of Waterloo, Lockheed Martin and several other companies to develop quantum radar systems as well.

Quantum radar takes its name from the theory of quantum entanglement (see ***Figure 5***) in which two particles can share a relationship (and are thus "entangled") that allows analysis of one to be used to learn about the other, even though the two are a long distance away from each other. A crystal is used to split a photon into two entangled photons, creating what is called

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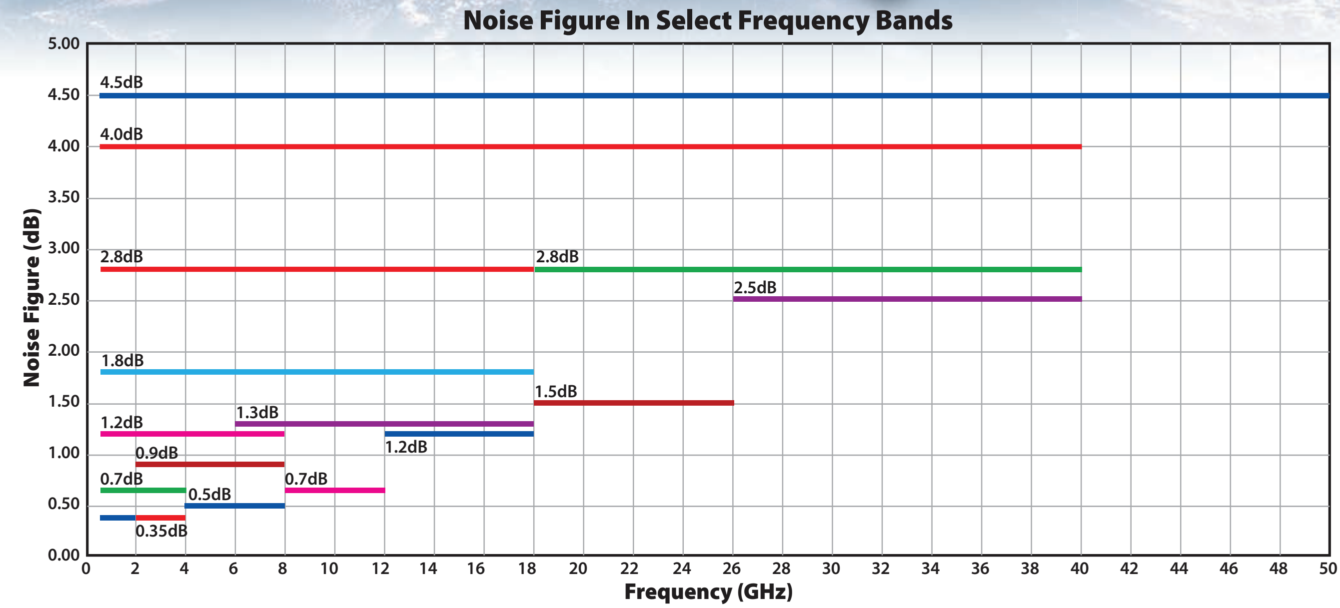

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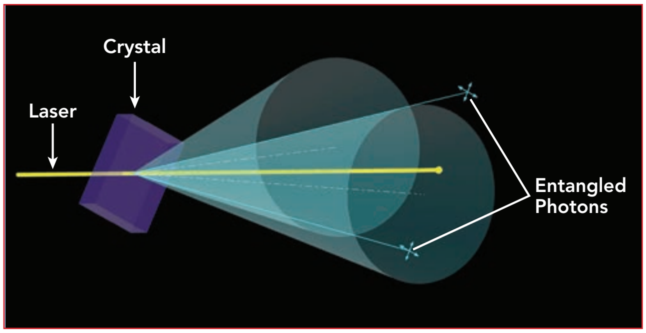

▲ Fig. 5 Whatever country manages to develop a "quantum radar" will be able to render EW systems and most stealth technologies obsolete (Source: China Electronics Technology Group).

parametric down-conversion, and in a radar, multiple photons will be created in entangled pairs.

The first pair, for example, is sent at microwave frequencies like a conventional radar, and the second set is retained in the transmitting system. By studying the second set of photons, it is possible to learn a lot of about the first. This data includes if the pair struck an object and if so how far away, how fast, how large it is as well as its direction. In addition, as quantum radar uses subatomic particles rather than electromagnetic energy, it is not constrained by materials technologies used to create stealth by reducing radar cross-section. In the same vein, it will ignore jamming and spoofing including chaff.

Although stealth aircraft can be identified over short distances using systems operating at VHF and UHF frequencies, they can only do so over short distances and have difficulty determining range. Consequently, the quantum radar has enormous potential advantages in detecting stealth aircraft and could effectively render current techniques useless.

SUMMARY

A complete discussion of all the technologies and defense programs and platforms of the microwave community would fill a novel-sized book, as there are so many legacy, current and development programs. Consider, for example, that the HF region that gets little attention but is becoming the focus of SIGINT. It is the perfect "place" for both state and non-state actors to send messages over long distances, at little cost and with very low probability of intercept. There is also remote sensing, IFF, avionics, air-traffic control, attempts to create a workable solution for battlefield communications, missile seekers, ballistic missile defense, UAS payloads and whatever is behind the doors of the many black programs. With all this on the table, there should be plenty of opportunities for the microwave industry as far as anyone could safely project.■

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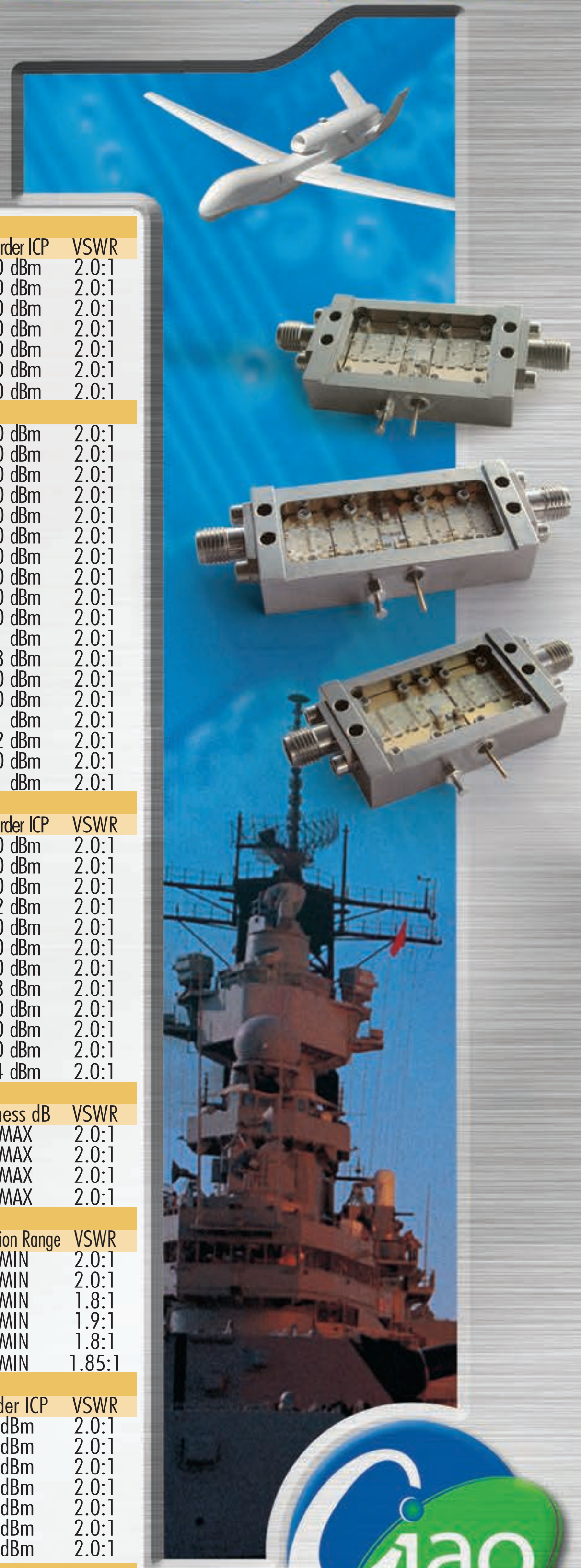

OCTAVE BAND LOW NOISE AMPLIFIERS

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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BAE Systems Receives Contract to Mature Air Force GaN Semiconductor Tech

BAE Systems has signed a cooperative agreement with the Air Force Research Laboratory (AFRL) for the first phase of a technical effort to transition GaN semiconductor technology developed by the U.S. Air Force to BAE System's Advanced Microwave Products (AMP) center.

BAE Systems will transfer and further enhance the technology, scale it to 6-in. wafers to reduce per-chip cost and improve the accessibility of the technology. Under the agreement, BAE Systems will work with AFRL to establish a 140 nm GaN MMIC process that will be qualified for production by 2020, with products available to DoD suppliers through an open foundry service.

Work will primarily take place in BAE Systems' 70,000 sq. ft. Microelectronics Center (MEC) in Nashua, N.H. There, the company researches, develops and produces compound semiconductor materials, devices, circuits and modules for a wide range of microwave and mmWave applications. MEC has been an accredited DoD Category 1A Trusted Supplier since 2008 and fabricates ICs in production for critical DoD programs.

The AMP Center team will work closely with the company's FAST Labs™ research organization and MMIC design experts from ENGIN-IC, a fabless design company based in Plano, Texas and San Diego, Calif.

"mmWave GaN technologies today are produced in R&D laboratories in low volumes at high associated costs or in captive foundries that are not broadly accessible to defense suppliers. This effort will leverage AFRL's high performance technology and BAE Systems' 6-in. manufacturing capability to advance the state-of-the-art in GaN MMIC performance, reliability and affordability, while providing broader access to this critical technology," according to Scott Sweetland, Advanced Microwave Products director at BAE Systems.

The effort to commercials AFRL's technology recognizes that GaN provides broad frequency bandwidth, high efficiency and high transmit power in a small footprint, making it ideal for next-generation radar, EW and communications systems.

US Army Awards Northrop Grumman IBCS Contract

The U.S. Army has awarded Northrop Grumman Corp. (NGC) a $289 million contract to continue system design and development toward fielding of the Integrated Air and Missile Defense (IAMD) Battle Command System (IBCS).

"IBCS creates a paradigm shift for IAMD, and we have proven many transformational capabilities that will be game-changers on the battlefield. IBCS maximizes the combat potential of sensors and weapons while allowing future modernization at lower overall lifecycle costs," said Dan Verwiel, VP and general manager, Missile Defense and Protective Systems, NGC. "From integrating weapons developed decades ago with capabilities still in-development, to rapidly adding protection against emerging threats and enabling seamless multi-domain operations, through logistics, training and lifecycle support, IBCS is solving some of the most difficult defense challenges confronting our nation and allies today."

Under the contract, NGC will upgrade IBCS engagement operations centers and integrated fire control network relays to enhance performance, reliability and maintainability. NGC will also develop and deliver IBCS software version 4.5 that integrates Patriot system updates and incorporates updates for evolving threats. Among other contract deliverables, the company will provide logistics, training and support for tests, including a flight test planned for late 2019.

Recent joint warfighting exercises and soldier checkout events under dynamic, stressing threat conditions have already confirmed IBCS' ability to: integrate radars and weapons over a vast area and efficiently and effectively maintain voice and data connectivity; consistently deliver integrated air pictures and target information with unprecedented accuracy and contribute to a Link 16 network with Navy, Air Force, Marine Corps and Army participants; enable resilient, net-centric operations as counter to electronic attacks; and provide much higher success and effectiveness handling multiple and complex engagements than existing legacy systems.

IBCS (Source: Northrop Grumman)

IBCS has also successfully completed flight tests and defeated live targets, having conducted an intercept on its inaugural flight test and a more difficult "engage-on-remote" on its second flight test. During its third flight test, IBCS simultaneously intercepted two threat types with two interceptor types, demonstrating command-and-control for sensors and weapons not designed to work with each other. Two more successful flight tests were conducted with Sidewinder and Longbow Hellfire missiles to support the indirect fire protection capability, validating missile integration within a few short months.

By proving disparate radars and weapons can operate as nodes in a far more effective IAMD enterprise, IBCS offers the advantages of expanded sensor and effector combinations and a component-based acquisition approach.

For More Information Visit mwjournal.com for more defense news.

IBCS is the cornerstone of the Army's IAMD modernization program. The program is managed by the Army Program Executive Office for Missiles and Space, Redstone Arsenal, Ala.

Airbus Demos Manned-Unmanned Teaming for Future Air Combat Systems

These campaigns included demonstrations with five Airbus-built Do-DT25 target drones controlled from a mission group commander who was airborne in a manned command and control (C2) aircraft.

Flown in a test zone of Germany's Baltic Sea area, the MUT trial flights served multiple purposes, including validating such elements as connectivity, human-machine interface and the concept of teaming intelligence through mission group management. For the aspect of teaming intelligence, multiple capabilities and enabling technologies are required at sufficient maturity levels—from teaming/swarming algorithms and new sensors to mission management systems for C2 assistance by the manned aircraft's crew.

This unprecedented achievement for Europe is part of Airbus' future air power vision.

AIRBUS (Source: Airbus)

The ability to control unmanned systems from a manned aircraft is an important "force multiplier" in Airbus' vision for future air power that is smart, modular and connected. This know-how has been confirmed in a dynamic and interactive way during manned-unmanned teaming (MUT) test flight campaigns successfully performed by the company. A key element contributing to these successful flights was the advanced flight control and flight management system developed by Airbus for unmanned air vehicles, which combines fully automatic guidance, navigation and control with intelligent swarming capabilities.

MUT is expected to increase the mission efficiency of future airborne systems in many ways. Equipped with sensors, the swarm of unmanned systems can provide situational awareness to a mission group commander located a safe distance away aboard the manned aircraft. Expertise gained during the manned-unmanned teaming test flight campaigns will be applied by Airbus to develop Europe's Future Combat Air System (FCAS).


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LPWA Networks Will Enable IoT Asset Tracking of Over 500M Things by 2023

LPWA networks are set to unleash the next wave of growth for asset tracking solutions. Reaching 500 million tracked things by 2023, low-cost, battery-powered tracker devices that are integrated with connectivity, cloud storage and software platforms will provide seamless visibility of assets to multiple stakeholders across a supply chain.

Logistics companies have been early adopters driven by life-sciences and healthcare customers due to strict regulations and to mitigate supply chain risks, especially in the transportation of sensitive and high-value biomedical assets. Asset tracking solutions will have the most impact on tool and heavy equipment rental companies with over 45 percent penetration of rental inventory by 2023.

Device OEMs such as Calamp, Xirgo and Roambee have been early to develop solutions using cellular LPWA network technologies. Non-cellular solutions using SIGFOX and LoRa technologies from Ticatag, Sensolous, Tracknet and Viloc have also been making significant inroads through partnerships with system integrators and communication service providers. Non-cellular LPWA solutions may have been early to market, but cellular LPWA networks combined with horizontal platforms will drive much wider adoption and will account for three-quarters of the installed base of asset trackers in 2023. LTE-M will be more successful in IoT applications that require more continuous tracking capabilities with a low-latency threshold, whereas NB-IoT will address use cases that require periodic tracking of assets across multiple regions due to its energy efficiency and lower cost.

As the technology matures and the market witnesses wider adoption, more value in asset tracking services will be realized through the integration of AI and blockchain technologies. "AI will provide valuable insights from analysis of the location data gathered by the asset tracker, and blockchain will allow for decentralized control and provide greater transparency across supply chain processes," said Adarsh Krishnan, principal analyst, ABI Research.

Automotive Radar Entering A New Age

The automotive radar market is growing at a 23 percent CAGR between 2016 and 2022. Autonomous emergency braking (AEB) is the main driver for 77 GHz radar market growth. Yole Développement predicts a global radar market reaching $7.5 billion in 2022 at the module level.

"This growth should be accelerated with the autonomous car market," comments Cédric Malaquin, technology and market analyst, RF Devices & Technologies, Yole. With the recent focus on safety, the market potential for advanced driver assistance systems (ADAS) has been extended to mid-end cars resulting in a production volume increase. Radars for AEB are employed by 71 percent of brands.

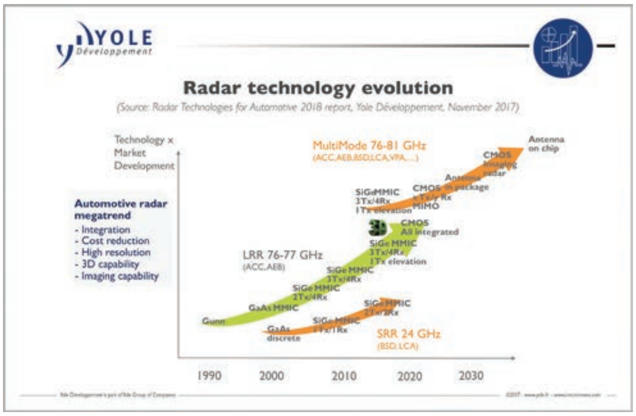
Another trend is the use of corner radar for 360 degree surveillance. These short and mid-range radars employ 24 GHz and, more recently, 79 GHz modules. The latter is more suited to high resolution tracking for tasks such as target separation and object recognition. Corner radars are a must have for redundancy with other sensors such as cameras and LIDAR in high-end robotic cars.

A majority of OEM's integrate radar technology in new ADAS applications, combining it with other sensors to enhance safety and collision avoidance. OEMs' demands are well supported by Tier1s' offerings with strong product portfolios. The market is very dynamic with strong competition and continuous product development.

"Ahead of its competitors in RFCMOS applications, TI has begun manufacturing highly integrated radar sensor chips—the latest of which is the AWR1642," asserts Dr. Stéphane Elisabeth, expert Cost Analyst, RF, Sensors & Advanced Packaging, System Plus Consulting. In parallel, semiconductor manufacturers are delivering various high performance solutions employing GaAs, SiGe BiCMOS and RFCMOS platforms that enable mmWave radar to be operated in a reliable and accurate manner critical for safety functions.

Regarding automotive 77 GHz radar chips, today it is mainly based on a 130 nm SiGe platform, with NXP and Infineon Technologies as the top suppliers. RFCMOS technology is entering the market with semiconductor companies such as TI with an intermediate technology node of 45 nm. And technology scaling has started with Analog Devices offering products based on advanced 28 nm CMOS nodes and foundries that are positioning their advanced process capabilities in this ecosystem. For example, GLOBALFOUNDRIES and its 22FDX platform supports innovative startup Arbe Robotics with a 4D high resolution radar for autonomous cars.

Innovative startups, such as Metawave and Uhnder, bring disruptive technologies to the market to support high resolution sensor requirements with ultra-thin



steerable beams and AI engines for a deep learning approach or with an unprecedented high number of channels for high resolution imaging. Those innovations are attracting newcomers to automotive radar such as Magna and well established players, as well, through the entire supply chain, such as Infineon, Denso, Toyota and Hyundai. It will certainly reshape the competition with the current leaders Continental and Bosch.

Smart Cities to be $7.6B Opportunity for MSPs in 2023

Smart cities is one of the main verticals where Mobile Service Providers (MSP) can use their strength and expertise to move up the value chain to target revenues beyond the connectivity-only space and generate substantial "UnTelco" revenues. ABI Research forecasts that by 2023, the smart cities market will be a $7.6 billion UnTelco opportunity for MSPs and network vendors.

All MSPs are interested in this market, which shows how crucial the smart cities segment is for the future of MSPs. "Smart cities is a huge and complex market, where a traditional vertical focus is now co-existing with a cross-vertical trend that is gaining momentum. The size of the market, with all its different sub-verticals, means that MSPs can target and assume various roles from system integrators to platform providers," said Pablo Tomasi, senior analyst, ABI Research.

"While the opportunity is huge, competition is mounting, as proven by network vendors' aggressive activities in the platform space. MSPs need to balance competition and prioritize innovative business models, for instance, based on advertising or performance-based revenues, rather than waiting and fostering the marketing trend centered on the role and potential of 5G in smart cities," Tomasi explained.

More than in any other vertical, MSPs are using innovative tactics to become key market players; their challenge is now to scale these offerings. For example, Verizon has a smart city strategy backed by strong M&A activity (Sensity System and LQD), AT&T is amassing a wide range of partners to deliver spotlight cities solutions, BT is betting on analytics capabilities and Deutsche Telekom is leveraging aggressive NB-IoT deployments and innovative business models.

"MSPs success in smart cities will be defined by their ability to act—owning a wide ecosystem of partners and improving customer relations while aligning various interests, assets and innovative monetization options. MSPs' success and activities will be shaped by their ability to innovate and not by 5G."


LOREM IPSUM

Around the **Circuit**

Barbara Walsh, Multimedia Staff Editor

MERGERS & ACQUISITIONS

INFICON Inc., a supplier of vacuum instrumentation and process control software to the semiconductor manufacturing industry acquired all assets of **Final Phase Systems (FPS)** of Austin, Texas. Founded in 2009 by Industrial Engineers from AMD/Spansion's Fab25, FPS has grown to a team of 22 employees who will now join the INFICON organization. Together, INFICON and FPS have developed the most comprehensive Industrial Engineering Software Suite available in the semiconductor manufacturing industry. With many successful deployments in the U.S. and across the globe, they have a proven track record of improving capital productivity and labor efficiency.

COLLABORATIONS

Rohde & Schwarz and **Spirent** announced a new partnership to provide an unrivaled, fully integrated test solution, offering full coverage of both the physical and protocol layers for automotive Ethernet TC8 ECU test specifications. As members of the One-Pair EtherNet (OPEN) Alliance Special Interest Group (SIG), both companies have been working closely with the industry and have joined forces to develop tailored solutions to address the challenges that the emerging technologies bring. The new partnership will mean customers can now have the best of both worlds when it comes to compliance testing and debugging for 100BASE-T1 and 1000BASE-T1.

Anokiwave Inc. has announced that it has joined the **O-RAN** alliance as a contributing member in support of its vision of open, interoperable interfaces that maximize the use of common off-the-shelf hardware. O-RAN, announced at MWC 2018, is an alliance formed by the world's major mobile operators such as AT&T, NTT DoCoMo, China Mobile, Orange and Deutsche Telekom to open, cooperate and to share 5G technology. The alliance aims to expand the 5G ecosystem by evolving Radio Access Network (RAN) towards using open, interoperable interface.

ACHIEVEMENTS

Custom MMIC announced the award of its inaugural **"Women In Engineering"** scholarships, which will help three young women pursue undergraduate degrees in engineering. Custom MMIC received 11 outstanding applications for this award, and due to the quality of applicants, decided to expand the scope of the scholarship. Emma Fournier of Groton, Mass., who will attend Tulane University to study chemical engineering, was awarded the full scholarship totaling approximately $112,000 over four years. Grace Remillard, also of Groton, who will attend the University of Massachusetts Lowell to study electrical engineering, and Sarah McKinley of Westford, Mass., who will attend Clarkson University to study mechanical engineering, were each awarded partial scholarships totaling $40,000 over four years.

Keysight Technologies Inc. announced that the company has been selected by **DT&C**, a Korea-based company that offers test certification services, to establish the country's first 5G New Radio (NR) Regulatory System using Keysight's industry-leading 5G test solutions. Early access to Keysight's proven 5G test solutions enables DT&C to deliver 5G testing and verification services to the Korean mobile device ecosystem. Keysight offers end-to-end over-the-air (OTA) testing capabilities by combining its network emulation solutions with customizable chambers for radiated testing. These solutions allow DT&C to address regulatory RF testing of 5G mobile devices across sub-6 GHz and mmWave frequencies in both conducted and radiated test environments.

Custom MMIC announced a Gold Supplier rating from **BAE Systems' Electronic Systems** sector in Nashua, N.H. The recognition is for the 12-month period ending June 2018. BAE Systems instituted the annual Supplier Scorecard program to recognize suppliers who have provided outstanding service and partnership in exceeding customer requirements. Suppliers are judged on certain criteria, including overall quality and on-time delivery. A Gold Medal Rating is the highest a supplier can achieve for excellence in quality and performance.

MCV Microwave Inc., DBA MCV Microwave, announced that they have passed the rigorous standards for quality management systems to earn certification to ISO standard 9001:2015 for the design and manufacture of advanced dielectric resonators, RF microwave filters and antennas. MCV Microwave was also successfully audited and certified to the AS9100 Rev D standard. This certification is necessary for all aerospace industry suppliers to meet the International Aerospace Quality Group (IAQG) quality initiatives.

Rogers Corp. announced that its Advanced Connectivity Solutions (ACS) business has achieved IATF 16949: 2016 certification, the highest international quality standard for the automotive industry. The certification covers the company's Chandler, Ariz., Rogers, Conn., Suzhou China and Belgium manufacturing and R&D facilities.

3D Glass Solutions Inc. announced the most recent patent to their growing portfolio that protects components and systems for the 5G, mmWave, microwave and high speed data communications markets. This patent protects devices and systems requiring low noise, high speed RF components with an integrated electrical isolation using a ground plane. This technology is especially useful in components such as inductors, antenna, resistors, transmission lines, transformers, oscillators, isolators and many other electronic devices in any pho-

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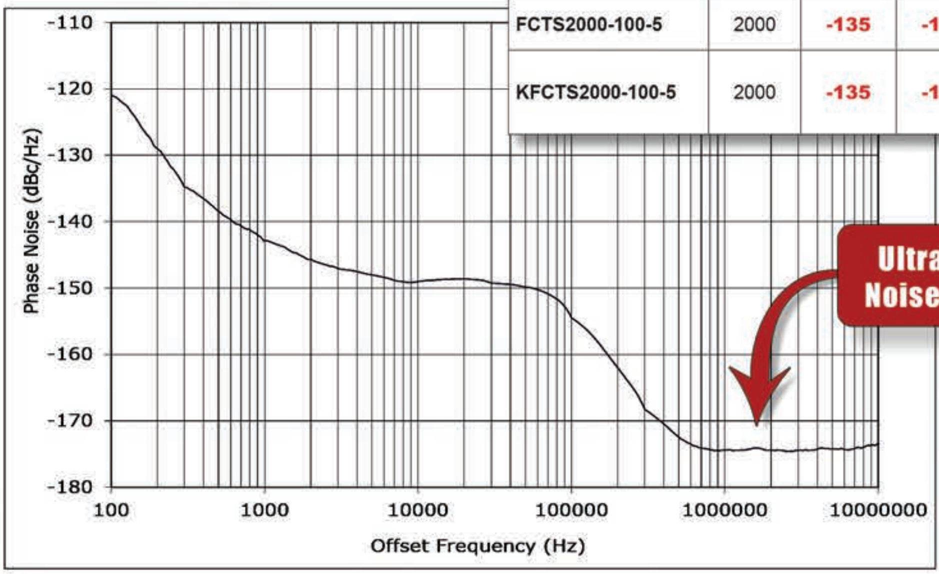
KFCTS800-10-5	800	-144	-158	
FSA1000-100	1000	-145	-160	
KFSA1000-100	1000	-145	-160	
FXLNS-1000	1000	-149	-154	
KFXLNS-1000	1000	-149	-154	
FCTS1000-10-5	1000	-141	-158	
KFCTS1000-10-5	1000	-141	-158	
FCTS1000-100-5	1000	-141	-158	
FCTS1000-100-5-H	1000	-144	-160	
FCTS2000-100-5	2000	-135	-158	
KFCTS2000-100-5	2000	-135	-158	

FXLNS-1000



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to-definable glass. This innovation prevents parasitic electrical signals from disrupting and/or degrading the performance of electronic devices.

CONTRACTS

The U.S. Department of Defense (DoD) has selected **BAE Systems** to compete for future R&D task orders awarded under a nine-year, IDIQ contract. The contract provides fast, flexible, low-cost solutions across technical disciplines to meet the current and future technology needs of the U.S. military. BAE Systems is one of 15 companies selected to compete. These task orders will be awarded by the Air Force Installation Contract Agency/KD Offutt AFB, Nebraska and support the DoD Information Analysis Center Program Management Office. The ceiling value for all future work awarded under the IDIQ is $28 billion.

Intelligent Waves LLC announced it has secured a position on the **U.S. Army's** potential nine-year, $12.1 billion Information Technology Enterprise Solutions—3 Services (ITES-3S) IDIQ contract. Managed by the Army's Computer Hardware, Enterprise Software and Solutions (CHESS) program, the hybrid (cost, firm-fixed-price and time-and-materials) contract is expected to be the Army's primary source of IT-related services worldwide. A follow-on to Army's ITES-2S, which was awarded to 16 prime contractors in 2006, ITES-3S made 135 awards, 83 of which are on the small business set-aside track.

The **U.S. Air Force** announced selection of **Lockheed Martin** for a fixed-price production contract for 22 GPS III follow-on satellites, with a total potential contract value of $7.2 billion. The first GPS IIIF satellite is expected to be available for launch in 2026. The Air Force currently operates 77 GPS satellites that provide communications, command and control (C2), missile warning, nuclear detonation detection, weather and GPS for the worl—satellites vital to U.S. national security.

The **U.S. Army** has awarded **Raytheon Co.** a more than $1.5 billion contract for production of Poland's Patriot™ Integrated Air and Missile Defense System including spare parts, support and training. Announced by the DoD, the contract calls for Raytheon to build and deliver four Patriot fire units for Poland. Patriot is the backbone of NATO and Europe's defense against ballistic and cruise missiles, advanced aircraft and drones. Fifteen other nations depend on Patriot to protect their citizens and armed forces, including the U.S. and six other European nations: Germany, Greece, the Netherlands, Spain, Romania and Sweden.

AeroVironment Inc. announced the **U.S. Air Force** awarded the company a $13 million IDIQ contract on September 30, for RQ-11B Raven® small unmanned aircraft systems (UAS) to support Latin American and Caribbean nations. The U.S. government fiscal 2018 operations and maintenance funds of $2.8 million were committed at the time of the award. The work is expect-

ed to be completed by September 28, 2023. The Raven hand-launched small UAS, the most prolific military drone in the world, will be deployed in the U.S. Southern Command Area of Responsibility, which includes Central America, South America and the Caribbean.

OSI Systems Inc. announced that its security division received an order valued at approximately $10 million for multiple units of its ZBV® mobile cargo and vehicle screening system, which are expected to be deployed overseas by a U.S. government customer. The ZBV system allows for immediate deployment and rapid inspection to reveal explosives, drugs, currency, alcohol, cigarettes and other organic threats or contraband.

Harris Corp. has received orders for 1,540 AN/PRC-163 two-channel handheld radios and related equipment and services as part of the **U.S. Army's** two-channel Leader radio IDIQ contract. The versatile AN/PRC-163 enables users to send information up and down the chain of command as well as across the battlefield network backbone. It incorporates secure two-channel connectivity in a lightweight, easy to use, handheld rugged form factor. The radio can simultaneously transmit voice, data and situational awareness through Mobile Ad-Hoc Networking applications, VHF/UHF line-of-sight and legacy SATCOM, while offering a path to future software-only updates for MUOS, SATURN and other emerging waveforms.

PEOPLE


▲ *John Kim*

The **AR** family of companies has announced that **John Kim** was promoted from vice president of corporate operations to COO of AR. Appointed COO in July, Kim has assumed responsibility for AR RF/Microwave, AR Modular RF, AR Europe and SunAR RF Motion. A major step in the company's succession plan, Kim's appointment signals a strategic move to position AR for continued success. Kim joined AR in 2016, observing the procedures and learning the culture of the brand and company before becoming COO. Prior to joining AR, he held positions at AeroVironment Inc., Ryder Inc., Bombardier Aerospace and Cessna Aircraft.


▲ *Laurie Addison*

Infinite Electronics Inc. has introduced **Laurie Addison** as vice president of marketing for the company. She will be leading Infinite Electronics' international marketing team and driving all overarching marketing initiatives to grow the business. Addison brings more than 25 years of hands-on marketing experience in the electronics industry, holding senior positions and leading diverse, global teams in every aspect of dynamic marketing for companies such as Arrow Electronics, Schneider Electric and Ingram Micro.

Her global experience spans all regions including North America, Latin America, Europe, Middle East, India and Asia-Pacific.


▲ *Abhishek Kapoor*

Anokiwave Inc. announced the appointment of **Abhishek Kapoor** as vice president of sales. This appointment comes at a strategic time for Anokiwave with tremendous opportunities for continued growth of its business in the rapidly developing mmWave 5G, SATCOM and A&D markets. Kapoor joined Anokiwave in January, and is responsible for growing Anokiwave's sales, increasing its global footprint, building and managing the sales channel and distribution teams and establishing a global brand presence. Over his career Kapoor has held various positions in sales, marketing, product management, business development and engineering, giving him a holistic view of the business.

Akash Systems Inc. has appointed industry leader **Brian Holz** as chief architect. Holz brings extensive space satellite experience from his work directing the design and construction of satellite constellations for leading commercial organizations. With extensive experience in space systems engineering, program management and executive leadership, Holz will further Akash's mission of reimagining tomorrow's communication systems by developing the next generation of small satellites and the components that power them. He was previously CEO of OneWeb Satellites, and executive vice president and CTO of O3b Networks. Holz brings expertise in startup management, global supply chain operations, multi-discipline team leadership and core technology development.


▲ *Brian Holz*

American Microwave Corp. announced the promotion of **Emily King** to acting director of sales and marketing. King joined the company in 1991 as a sales department secretary and, except for two hiatus periods, has been with the company for 22 years, rising through the ranks to become head of customer service as a sales manager just prior to her promotion. King is a native of the Frederick, Md. area, having attended Frederick Community College and graduated from Abbie Business Institute, where she holds an executive secretary certificate.


▲ *Emily King*

The Marconi Society, dedicated to furthering scientific achievements in communications and the Internet, has named four 2018 Paul Baran Young Scholars, honoring them for their outstanding research and academic performance. **Dr. Di Che** is selected for his work

Around the **Circuit**

▲ *Dr. Di Che*

▲ *Qurrat-Ul-Ain Nadeem*

▲ *Rajalakshmi Nandakumar*

▲ *Dr. Ding Nie*

on short-reach optical links for applications like data center inter-connectivity and optical access networks. **Qurrat-Ul-Ain Nadeem** is recognized for her work in full-dimension (FD) massive MIMO technology. **Rajalakshmi Nandakumar** is conducting ground-breaking work that enables the detection of potentially life-threatening health issues using commonly available smartphones. **Dr. Ding Nie** is recognized for his work in developing models and systems to greatly increase throughput in wireless systems.

REP APPOINTMENTS

Modelithics has welcomed **Murata Inc.**, a leader in the design manufacturing and supply of electronic components and solutions especially in telecom infrastructure, automotive and mobile market, and **Murata Integrated Passive Solutions**, specializing in low profile, high-reliability ultra-broadband silicon capacitors, into the Modelithics Vendor Partner (MVP) Program at the Sponsoring level. As a Sponsoring MVP, Murata is supporting the RF and microwave designers by sponsoring free extended 90-day trials (with approval) of all Modelithics models available for Murata components, as well as collaborating with Modelithics to develop new design data and models for selected components.

PLACES

Anokiwave Inc. announced the opening of its latest office in the Xinyi District in Taipei, Taiwan. The new Taiwan office offers sales and application engineering functions, allowing Anokiwave to enhance its support to its growing customer base in the region, to deepen their engagement with the local distribution partners and to expand their reach to customers by continuing to provide market-leading solutions that will commercialize mmWave active antennas with silicon ICs. The new office is in Taipei Nanshan Plaza, the second tallest building in Taipei. Its shape resembles that of both hands and has the meaning of "blessing for Taiwan."

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INVITED PAPER

Designing Ultra-Wideband Small Form Factor RF Signal Recorders

Chris Tojeira
Pentek Inc., Upper Saddle River, N.J.

A summary of the features and techniques used to provide real-time, ultra-wideband, RF signal recording in a small, rugged package optimized for size, weight and power (SWaP).

Ultra-wideband RF signal recorders have allowed engineers to capture large swaths of the RF spectrum for wide bandwidth radar systems and improved SIGINT capabilities. While real-time recording of a GHz or more of RF bandwidth is commonly available in 19 in. rack-mountable systems, shrinking this capability into a form factor suitable for UAVs, aircraft pods or other confined spaces has proven challenging for the industry. Small, rugged packages must be capable of operating in extreme environments while providing similar storage capacities and data streaming throughputs as larger systems.

RF SIGNAL ACQUISITION DESIGN

The ability to record wideband RF signals in real-time is a critical requirement of radar, SIGINT, beamforming and EW systems. Wideband RF down-converters are now capable of translating a GHz of RF bandwidth to intermediate frequencies with excellent dynamic range. These signals require high performance analog-to-digital (A/D) converters (ADC) with high enough sample rates and bit resolutions to sample the entire band effectively. ADCs paired with the latest FPGA technology in an XMC form factor provide signal conversion and processing engines that can sample signals at extremely high data rates in packages suitable for a small form factor (SFF) recorder. These XMC modules serve as the recorder's front-end interface and are used to move multiple GB/s of data through the system (see ***Figure 1***).

XMC modules are commonly available with ADCs that have maximum sample rates ranging from 200 MSPS to 6.4 GSPS. The sample rate of the ADC dictates the maximum RF signal bandwidth that can be sampled and recorded. For example, a 200 MSPS ADC with an 80 percent anti-aliasing filter can record 80 MHz of signal bandwidth, while a 6.4 GSPS ADC with a similarly shaped filter can record over 2.5 GHz of signal bandwidth. As some applications require a very wide bandwidth signal to be captured, while others require the ability to capture several channels of narrower band signals, it is important to provide an array of ADC offerings in an XMC form factor.

While the A/D sample rate is important for selecting the recorder front-end, the dynamic range of the ADC is equally as important to effectively match each application's requirement. For an RF signal recorder, dynamic range can be described as the ratio between the largest and smallest signals that can be recorded successfully. Some signal acquisition scenarios need the ability to record very small signals in the presence of potentially very large signals, requiring an ADC with excellent dynamic range. The bit resolution of the ADC and the effective number of bits help to express dynamic range to the user. However, ADC specifications like spurious free dynamic range (SFDR) and signal to noise ratio (SNR) are even more useful. High performance 200 MSPS ADCs provide 16 bits of resolution and offer SFDRs greater than 85 dB relative to full scale (dBFS) and SNRs greater than 75 dBFS, while 6.4 GSPS ADCs provide 12 bits of resolution and offer SFDRs of about 65 dBFS and SNRs of about 55 dBFS. Typically, the higher the sample rate of the ADC, the lower the dynamic range. As before, it is important to provide a wide array of ADCs on XMC modules to cover different applications.

FPGAs coupled with ADCs on XMC modules provide an excellent digital signal

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processing engine for the recorder. Digital down-converting, signal detection, radar gating and acquisition time stamping are common processing capabilities often provided in standard FPGA IP designs. A well-developed set of FPGA IP modules greatly enhances the capabilities of an RF signal recorder. Digital-to-analog (D/A) converters (DAC) are often included on XMC modules to allow users to play back acquired signals or generate radar pulses. Multi-channel A/D and D/A XMC modules provide phase coherency across all channels. This is an essential capability of any real-time signal recorder as well.

Extremely small global navigation satellite system (GNNS) receivers have emerged over the last few years with support for Galileo, GPS and GLONASS systems. These small receivers support time stamping of acquired data with nanosecond precision. They provide 10 MHz reference clocks and PPS signals to the recorder's XMC modules to allow users to capture the exact timing of gated or triggered events. GNNS receivers also allow systems to record the latitude, longitude and altitude of the recorder for logging flight paths, vehicle movements or static ground locations, if required. They often provide options for oven controlled oscillators, to enable operation across a wide range of temperatures, and accelerometers, to improve time and position accuracy during rapid acceleration. This enables operation over a wide range of environments.

OPTIMIZING THE RECORDING CAPABILITIES

Streaming data to disk in real-time at GB/s rates is achievable in large rack-mount recorders by striping data over a redundant array of inexpensive disks (RAID) of many solid-state drives (SSD). High performance RAID controllers not only provide lightning fast write speeds, they offer redundancy, protecting against the rare but disastrous disk failure that could occur during a mission. RAID controllers also use SSD features to provide data encryption and secure erase capabilities. Another feature typically seen in rack-mount recorders is front panel removable drives. An array of as many as 48 drives mounted to sleds can be inserted and removed individually from the front of the system. This allows users to remove all recorded data while allowing the recorder to remain mounted in the rack. It also allows users to maintain multiple sets of drive arrays to minimize downtime between missions.

The challenge of maintaining the features and performance of larger form factor recorders is facilitated by the growing solid-state storage demand driven by data centers. V-NAND flash technology enables increased solid-state drive capacity in very small package sizes. Advances in solid-state technology provide a path for shrinking the data storage array, enabling smaller and simpler designs with performance and features equal to that of far larger systems. Small drive packs, containing an array of solid-state devices, provide storage speed and capacity previously only available with many individually removable SSDs. By designing the packaging of a storage array into a drive pack (see ***Figure 2***), the job of managing a high drive count system is replaced with the job of managing just a single drive pack, providing a tremendous ease-of-use benefit.

A single high-insertion-cycle connector designed into the drive pack provides a far more reliable mechanism for insertion and removal than standard SATA connectors typically

Fig. 2 A storage array packaged into a single drive pack.

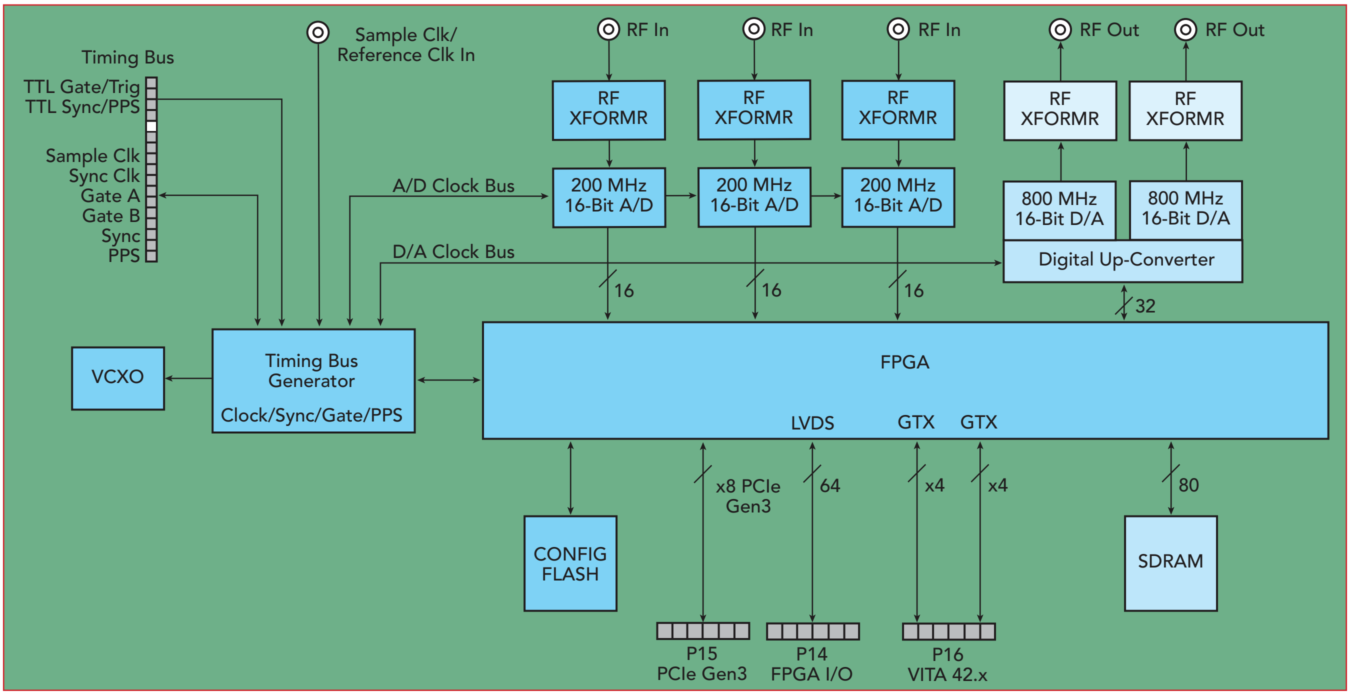
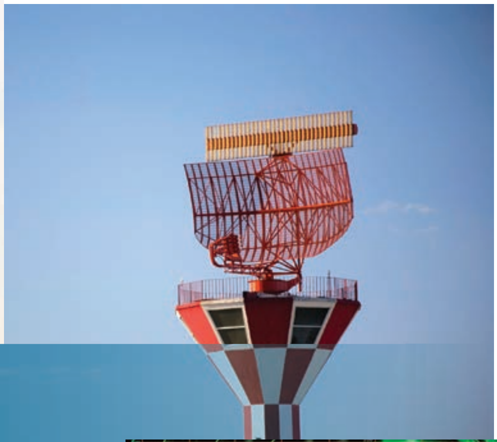


Fig. 1 An XMC module includes A/Ds, D/As and an FPGA.



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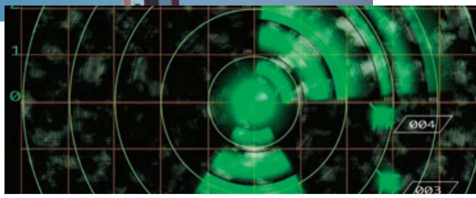

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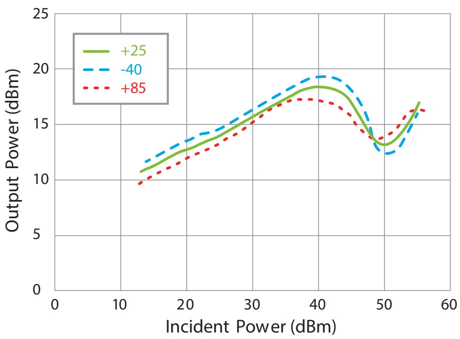

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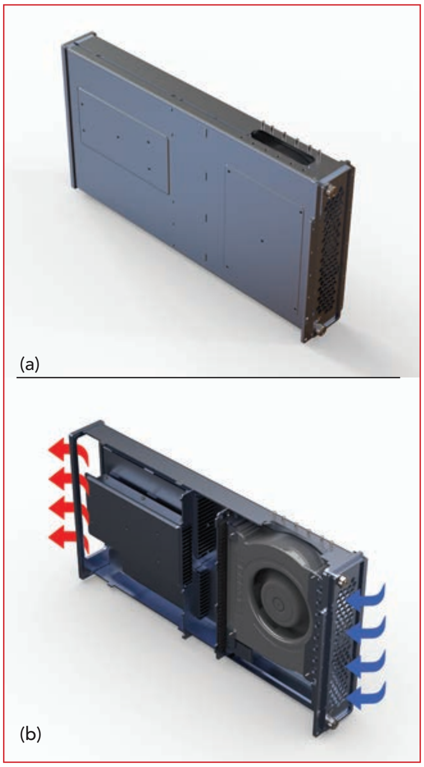
available in rack-mount systems. Well designed drive packs are capable of holding tens of terabytes of data and are capable of GB/s storage speeds. Drive packs must be designed for easy removal to allow the recorder to remain mounted in a vehicle or aircraft.

MANAGING DIFFICULT THERMAL ENVIRONMENTS

One of the issues in reducing the package size of the data storage medium is maintaining a thermal environment that allows the drive pack to perform at its highest level. Solid-state memory controllers throttle access speeds if the thermal environment is not properly managed. This issue is a concern for all SFF recorder electronics, as well. A set of ADCs can draw 10 W or more. FPGAs often draw 25 W or more. CPUs typically draw between 35 and 90 W. High performance RAID controllers draw 15 to 25 W, and drive packs can draw 10s of Watts. While efforts can be made to minimize power consumption, heat management is one of the most critical aspects of the recorder's design. Many RF signal recorders are installed in aircraft pods, naval ships or other outdoor environments with little or no protection. To operate in a wide array of environments, all electronics must be protected from environmental elements, such as water, humidity, sand, dust and salt fog. A hermetically sealed chassis is desirable, but brings with it the problem of removing heat from internally mounted electronics.

Custom designed heat sinks that provide conductive thermal paths to the walls of the recorder's chassis provide some relief, but chassis walls still require sufficient air flow to be effective. Plenums can be used to create air channels throughout the chassis, providing a more efficient cooling design (see ***Figure 3***). Custom heat sinks integrated into the plenum's walls provide efficient cooling by allowing air to be channeled directly through all of the electronics, allowing the electronics to remain sealed from


(a)
(b)

▲ Fig. 3 Plenum tubes (a) create air channels throughout the chassis, cooling the electronics mounted to their walls. The inside contains heat sinks and a fan to create air flow (b).

the outside environment while being adequately cooled. Integrating a fan into the plenum helps assure air flow through the heat sinks. This is ideal for systems running in hot environments like an aircraft idling on the tarmac or a military vehicle running in the desert. What about cold environments, like an aircraft pod at high altitude or an unpressurized UAV flying in the arctic? It is equally important that the RF signal recorder is able to run at very cold temperatures.

One of the advantages of sealing all system electronics from the outside environment is self heating. This self heating process is compromised if a fan in the plenum tube is blowing cold air across heat sinks, so it is important to provide control over the fan. Integrated fan controllers monitor the environment and switch fans off to allow for self heating and then re-engage when components become hot. This balance between hot and cold is easily calibrated, providing a recording system that can operate at both temperature extremes. While these measures for thermal management help to provide an ideal environment for the recorder's electronics, it is important to use industrial grade components whenever possible.

DESIGNING TO MILITARY SPECIFICATIONS

MIL-STD-810, "Environmental Engineering Considerations and Laboratory Tests," is a U.S. military standard for tailoring the environmental design and test limits for the conditions a system will experience during its service life. The standard also establishes test chamber methods replicating the effects of environments, rather than imitating the environments themselves. MIL-STD-810 addresses a broad range of environmental conditions: low pressure for altitude testing; exposure to high and low temperatures; temperature shock, both operating and in storage; rain, including wind-blown and freezing rain; humidity; fungus; salt fog for rust testing; sand and dust exposure; explosive atmosphere; leakage; acceleration; shock and transport shock; gunfire vibration and random vibration. The standard describes environmental management and engineering processes to generate confidence in the environmental worthiness and overall durability of a system design.[1] While operating environments vary greatly, meeting as many criteria as possible in MIL-STD-810 is imperative to provide a reliable and robust product. Anodized metal with form-in-place gaskets allow for sealed protection against rain, humidity, fungus, salt fog and sand and dust exposure. CAD software provides simulation analysis tools to assist with thermal design and structural integrity. Well executed design techniques help assure a robust laboratory testing process.

MIL-STD-461, "Electromagnetic Interference Characteristics Requirements for Equipment," is another important specification. MIL-STD-461 provides the requirements for the control of electromagnetic interference (EMI) emissions and susceptibility characteristics of electronic, electrical and electro-

mechanical equipment and subsystems designed or procured for use by activities and agencies of the DoD.[2] RF test laboratories use anechoic chambers to run a series of MIL-STD-461 tests that include radiated emissions, radiated susceptibility, conducted emissions and conducted susceptibility over a range of frequencies (see ***Figure 4***). A radiated range up to 18 GHz and a conducted range up to 10 MHz on power leads are typical. It is important to take the appropriate design steps to ensure MIL-STD-461 compliance, since iterative independent laboratory testing is expensive. Design techniques used to control EMI include the use of RF emission filters and RF gaskets to prevent radiated electromagnetic emission and susceptibility. Additionally, an in-line EMI power filter designed for the internal power supply can be used to protect against conducted emissions and susceptibility.

SWaP

The term SWaP has become a common buzzword to describe the requirement for electronic systems that are small in size, weight and power consumption. Why the obsession with SWaP? It has to do with the need for sophisticated electronics small enough for unmanned vehicles and for reducing the burden on infantrymen, who, in today's combat environment, must carry computers, displays, communications devices and sensors, in addition to their combat gear. Overall, today's focus on small, lightweight electronic systems that consume little power has to do with bringing as much capability to the forward edge of battle as possible.[3] Having focused on reducing the size of the RF signal recorder, designing for weight and power reduction require additional strategies. The good news is that reducing weight also reduces power consumption and heat dissipation. Removal of heat from the system's electronics via conduction requires conductive materials such as aluminum or copper. While copper is more effective for conducting heat, its density is far greater than aluminum, adding undesirable weight to the recorder. Designing for reduced weight requires minimizing power consumption and using lightweight materials such as aluminum with efficient thermal paths to cooling channels. High speed recording systems often do not require a tremendous amount of processing power. Since hardware direct memory access controllers are used to move data to disk, processors are often used to simply "manage" the data flow. Intel's latest i7 processors are offered in versions with lower clock rates and power consumption. An eighth generation i7, clocking at 2.4 GHz, limits power consumption to 35 W and can be configured to draw as

Fig. 4 Testing an RF signal recorder to MIL-STD-461.

little as 25 W. Efficient FPGA designs allow digital signal processing to reside in smaller, more efficient FPGAs. Xilinx's Kintex Ultrascale family offers excellent performance with significant power reduction, compared to previous generations. Component selection and an efficient design help to control the power consumption and dissipation of the recorder, enabling the use of less material for heat sinking and reducing package weight.

EASE-OF-USE

While SWaP is important, it is equally important that the system be designed for ease-of-use—both hardware and software. Designing a system in a standard form factor helps simplify installation by providing familiar mounting mechanisms in a common and proven footprint. ARINC 404 is an aeronautical standard that specifies mechanical dimensions of line replaceable units and their racking systems in aircraft. ARINC 404 specifies dimensions for several sizes of air transport racks, providing a choice of standard footprints for the signal recorder. It is important to design a system that can be permanently installed in an aircraft or vehicle and still provide user accessibility. Replaceable modular components like fans, drives and other parts of non-volatile memory within the recorder allow easy service and sanitization of classified or sensitive data. All removable components should be accessible via the system front panel using captive hardware, without the requirement for special tools. Software should include a user-friendly application programming interface (API) to control the system, as well as a suite of RF signal analysis tools to instantly analyze recorded data. RF signal recorders typically provide a Gb Ethernet interface for control of the unit from an external computer. This interface can also be used to stream data to allow users to monitor RF signals prior to, during and after a recording. It is essential to remotely control the recorder to enable operation in unmanned environments. This often requires a user-generated custom control interface. It is also desirable to provide a fully functional graphical user interface (GUI) to allow operation out of the box. The GUI should run remotely, as well.

CONCLUSION

RF signal recording is an essential component of any radar, SIGINT, beamforming or EW system. A well designed system provides RF signal acquisition hardware that is small, lightweight, low-power and capable of operating over a wide range of operating environments. Features such as drive packs and other serviceable modular components allow ease of installation and maintenance in tight spaces and enable ultra-wideband RF signal recording in places and environments never before possible.■

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200 W High Efficiency 1.8 to 2.7 GHz GaN HEMT Doherty Amplifiers for Cellular

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Sumitomo Electric Europe Ltd., Elstree, U.K.

Eiji Mochida
Sumitomo Electric Industries Ltd., Osaka, Japan

In next-generation 4G/5G telecommunication systems, it is required that the radio transmitter and the power amplifier—the key part of the transmitter—operate with high efficiency over a wide frequency range, to provide multi-band and multi-standard concurrent operation. In these systems, with increased bandwidths and high data rates, the transmitting signal is characterized by high peak-to-average power ratio (PAPR) due to wide and rapid variations of the instantaneous transmitting power. It is very important to provide high efficiency at both maximum output power and lower power levels, typically ranging from 6 dB back-off and less, over a wide frequency bandwidth. Different 3GPP LTE-Advanced bands for 4G/5G systems, with up to 40 MHz channel bandwidths, are expected to be covered: tri-band (SMH, CLR, GSM) from 0.7 to 1 GHz, tri-band (DCS, PCS, IMT) from 1.8 to 2.2 GHz, dual-band (IMT and IMT-e) from 2.1 to 2.7 GHz or multi-band from 1.8 to 2.7 GHz. By using GaN HEMT technology and innovative Doherty architectures, average efficiencies of 50 to 60 percent for output powers up to 200 W can be achieved, significantly reducing transmitter cost, size and power consumption.

For a conventional Doherty amplifier with a quarter-wave impedance transformer and a quarter-wave output combiner, the measured power-added efficiency of 31 percent at about 43 dBm—6 to 7 dB back-off from the saturated output power—has been achieved across the frequency range from 1.5 to 2.14 GHz.[1] To improve the broadband performance of the conventional Doherty amplifier, the output network can be composed of two quarter-wave impedance inverters with reduced impedance transformation ratios.[2] For broadband combining, an output quarter-wave transmission line with fixed characteristic impedance can be replaced by a multi-section transmission line with different characteristic impedances and electrical lengths, which enables frequency coverage from 2.2 to 2.96 GHz.[3] In this case, broadband matching is realized by applying the simplified real frequency technique with the desired frequency-dependent optimum impedances. However, nonlinear optimization of the entire Doherty amplifier system makes the design complicated to simulate

and results in a large size for the final board implementation.

A high peak power of 350 W has been achieved across the lower frequency band of 760 to 960 MHz using a modified combining scheme with two quarter-wave lines in the peaking path.[4] Using an asymmetric Doherty architecture, saturated power greater than 270 W, linear gain greater than 13 dB and a drain efficiency greater than 45 percent at 8 dB back-off has been achieved across 2.5 to 2.7 GHz.[5]

ACHIEVING BROADBAND PERFORMANCE

A multi-band Doherty amplifier can be achieved when all of its components are designed to provide their corresponding characteristics over the required bandwidth of operation. The carrier and peaking amplifiers should provide broadband, high efficiency performance when, for example, their input matching circuits are designed as broadband. The load network generally comprises a lowpass, lumped or transmission line structure with two or three matching sections. Therefore, it is very important for matching circuits to be partly implemented inside the device package to achieve an average output power of 40 W and higher, especially for the input matching circuit, given the very low device impedance across the required frequency range.

Figure 1 shows the equivalent circuit of a device with input matching elements inside the package and the small-signal $|S_{11}|$ at the input of the internal input matching circuit, including the package lead frame. The 50 V device, fabricated by Sumitomo Electric Device Innovations, has six basic 15 W GaN HEMT cells connected in parallel and capable of providing a combined saturated output power of more than 80 W across the entire band from 1.8 to 2.7 GHz. The three-section microstrip transformer is implemented using an alumina substrate with a high permittivity of 250 and a thickness of 0.16 mm, yielding a compact structure transforming the device input impedance to 10 Ω, with an $|S_{11}|$ less than −25 dB.

Generally, the multi-band impedance transformer required for broadband operation is represented as a configuration of N cascaded transmission lines ($N \geq 2$) with different characteristic impedances.[6] For example, to match the output impedance of 25 Ω to a load impedance of 50 Ω, the broadband output transformer can be realized using a two-section microstrip line, where the characteristic impedance of the first quarter-wave section is 30 Ω, and the characteristic impedance of the second quarter-wave section is 42 Ω. In this case, the input impedance magnitude variation of ±0.5 Ω and phase variation of ±1 degree can be achieved from 2 to 2.8 GHz, simultaneously covering the 2.1 GHz (2.11 to 2.17 GHz) and 2.6 GHz (2.62 to 2.69 GHz) WCDMA/LTE bands.[7] At the same time, magnitude variations of ±1 Ω and phase variations of ±2 degrees can be achieved over a 1 GHz bandwidth from 1.9 to 2.9 GHz, which means that reducing the mid-band frequency to 2.3 GHz can result in simultaneous tri-band operation, i.e., including an additional 1.8 GHz DCS/WCDMA/LTE band (1805 to 1880 MHz).

Figure 2a shows the simplified schematic of a single-ended, 80 W GaN HEMT power amplifier operating in class AB mode, with external input and output matching circuits, which operates from 1.7 to 2.7 GHz. The input and output matching circuits, implemented on an RO4350 substrate, represent a two-stepped microstrip line transformer, with each line section a different characteristic impedance and electrical length. The matching network provides a conjugate-match with the device input and equivalent output impedance at the fundamental frequency. With this design, an output power at 1 dB gain compression (P_{1dB}) of greater than 48 dBm, a power gain greater than 12 dB and drain efficiency greater than 52 percent were measured across 1.8 to 2.7 GHz, as shown in ***Figure 2b***. Previously, drain efficiencies greater than 60 percent were reported be-

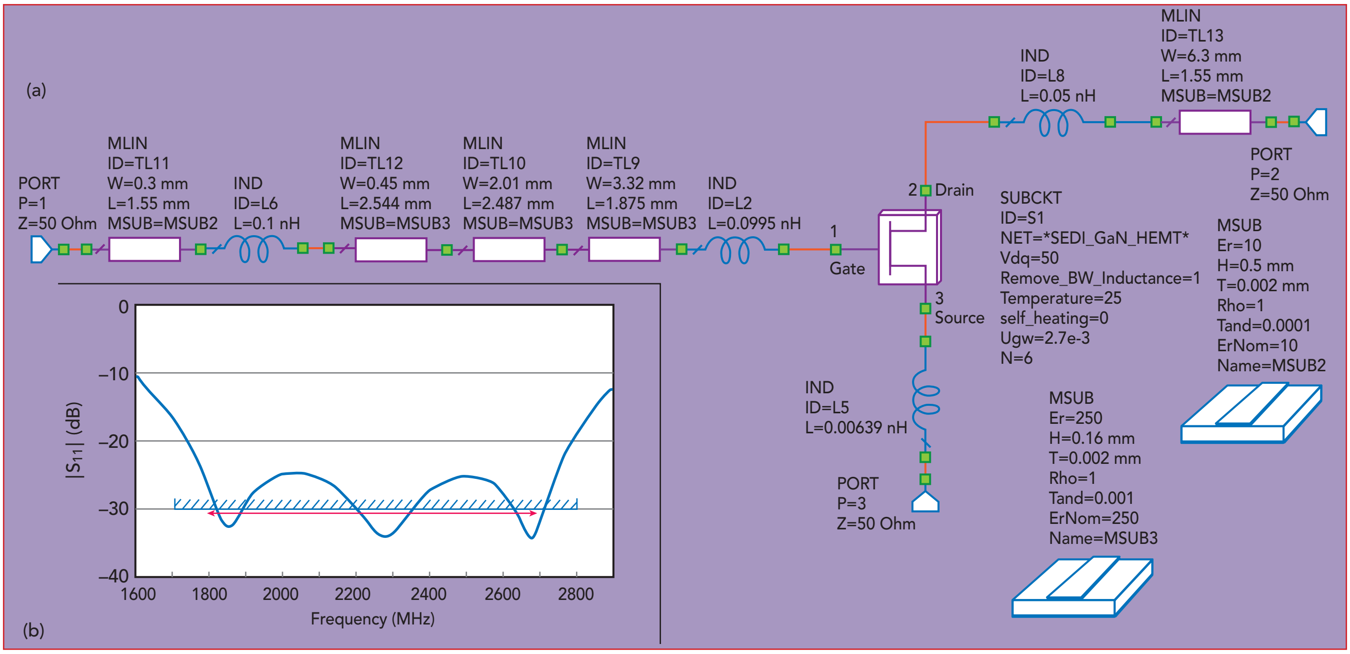

Fig. 1 Equivalent circuit of the packaged device (a) and $|S_{11}|$ performance (b).

tween 1.9 and 2.9 GHz with commercial 45 W GaN HEMT transistors, using the simplified real frequency technique to determine optimum impedances and element values for the highest efficiencies across the frequency range.[8]

The classic two-stage Doherty amplifier has limited bandwidth in the low-power region, since it is necessary to provide an impedance transformation from 25 to 100 Ω when the peaking amplifier is turned off. This results in a loaded quality factor $Q_L = \sqrt{100/25 - 1} = 1.73$ at 3 dB output power reduction, which is sufficiently high for broadband operation. At high-power levels, achieving broadband output matching of the carrier and peaking amplifiers with a broadband output quarter-wave transformer, it is possible to maximize the frequency bandwidth.

Figure 3a shows the circuit diagram of a conventional two-stage Doherty amplifier implemented on 20 mil RO4350 substrate and using two, 80 W GaN HEMT power transistors with internal input matching

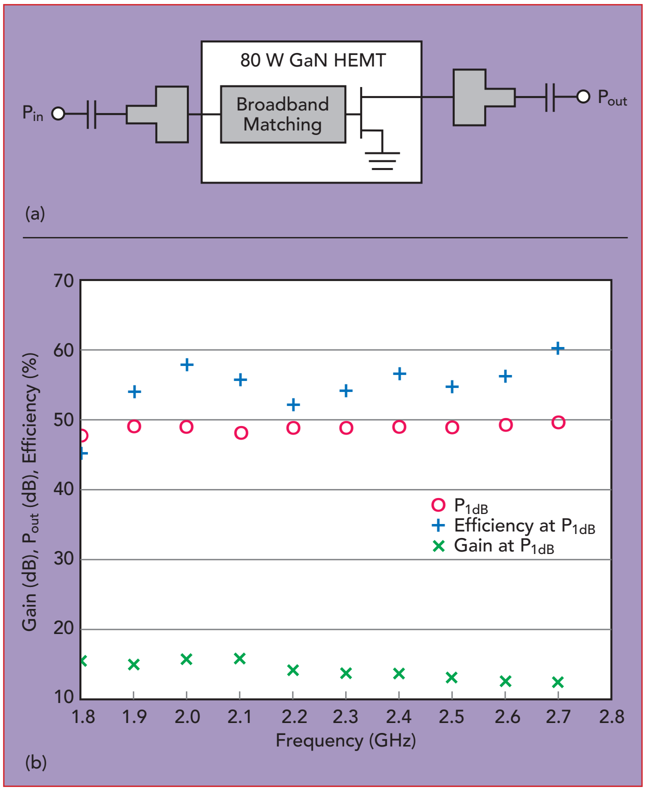

Fig. 2 Class AB PA with broadband conjugate matching (a) and measured performance (b).

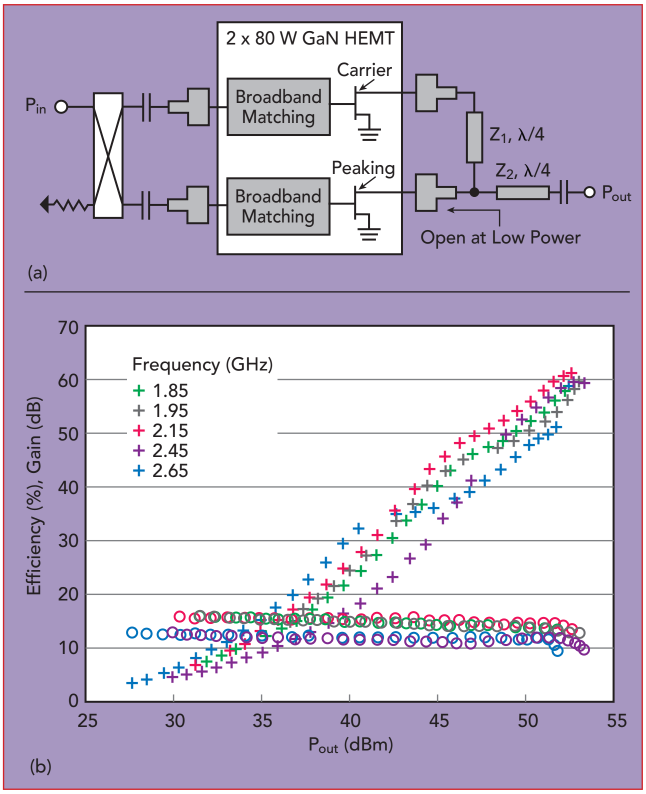

Fig. 3 Doherty PA using dual-path packaged transistor (a) and measured performance (b).

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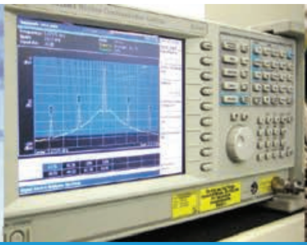
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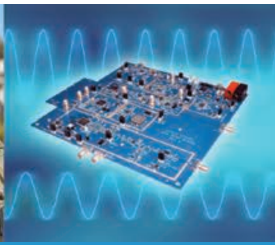
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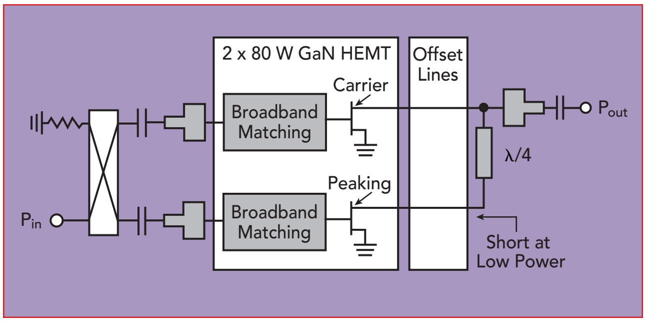


Fig. 4 **Broadband inverted Doherty PA.**

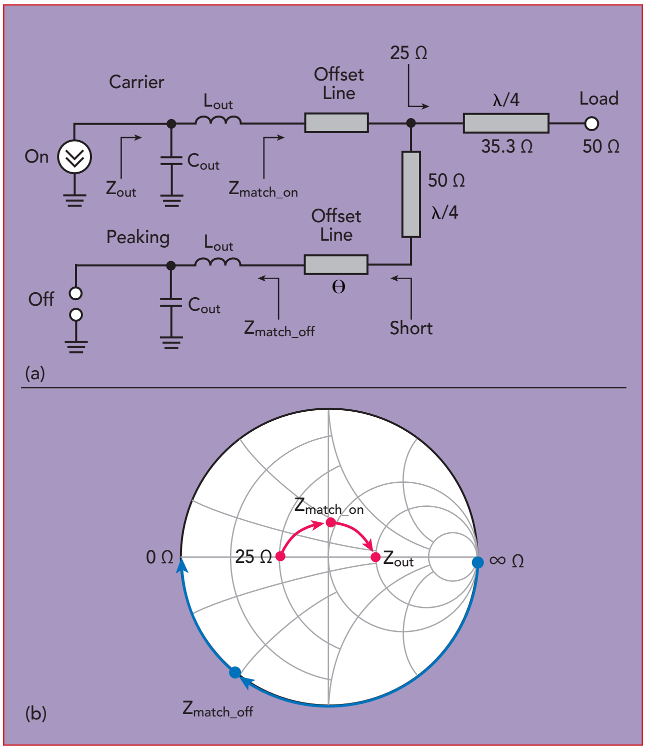


Fig. 5 **Load network (a) and impedance transformation (b).**

and metal-ceramic flange packages. The input and output matching circuits are microstrip lines of different electrical lengths and characteristic impedances for the two-stepped structures. The input splitter is a broadband coupled-line coupler from Anaren (model X3C17A1-03WS), which provides a maximum phase balance of ±5 degrees and an amplitude balance of ±0.5 dB from 690 to 2700 MHz. ***Figure 3b*** shows the measured power gain and drain efficiency at five in-band frequencies. A power gain of more than 9 dB is achieved from 1.8 to 2.7 GHz, with drain efficiencies of about 60 percent at an output power corresponding to 3 dB gain compression (except at the high end of the band) and between 40 and 50 percent at 6 dB back-off. Given the bandwidth limitations of the conventional structure, the Doherty effect is not strong across the full band, with lower efficiency at the higher frequencies.

INVERTED DOHERTY

Figure 4 shows the schematic of an inverted broadband Doherty amplifier with an impedance transformer using a quarter-wave line connected to the output of the peaking amplifier. This architecture can be helpful if, in the low-power region and depending upon the characteristics of the transistor, it is easier to provide a short circuit rather than an open circuit at the output of the peaking amplifier.[9] In this case, a quarter-wave line is used to transform a very low output impedance after the offset line to a high impedance seen from the load junction. Taking into account the device package parasitics of the peaking amplifier, an optimized output matching circuit and a proper offset line can be designed to maximize the output power from the peaking device in the high-power region and approximate a short circuit in the low-power region.[10]

To better understand the operating principle of an inverted Doherty amplifier, consider the load network (see ***Figure 5a***) when the peaking amplifier is turned off. In the low-power region, the phase adjustment of

the offset line with electrical length θ causes the peaking amplifier to be short-circuited (ideally 0 Ω), and the matching circuit with offset line provides the required impedance transformation from 25 Ω to the high output impedance Z_{out} seen by the carrier device output at 6 dB power back-off (ideally 100 Ω with the quarter-wave transformer), as shown in ***Figure 5b***. In this case, the short circuit at the end of the quarter-wave line transforms to an open circuit at its input, preventing power leakage to the peaking path when the peaking transistor is turned off. In the high-power region, both carrier and peaking amplifiers are operating in parallel in a 50 Ω environment, and the output quarter-wave line with a characteristic impedance of 35.3 Ω transforms 25 Ω to the 50 Ω load.

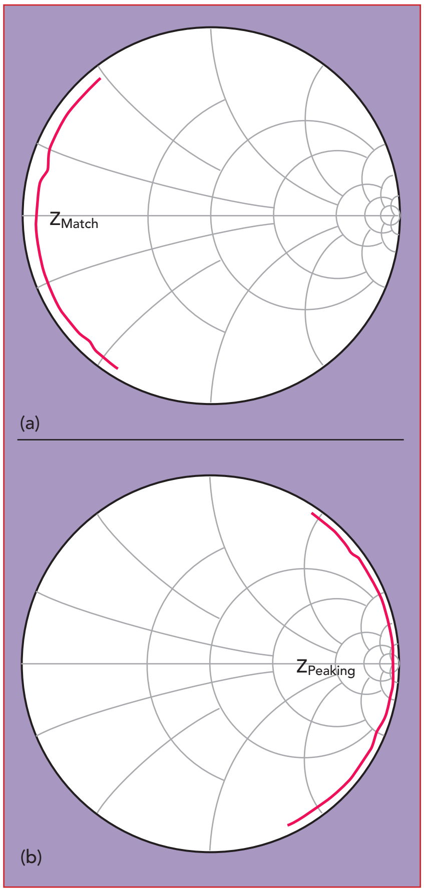
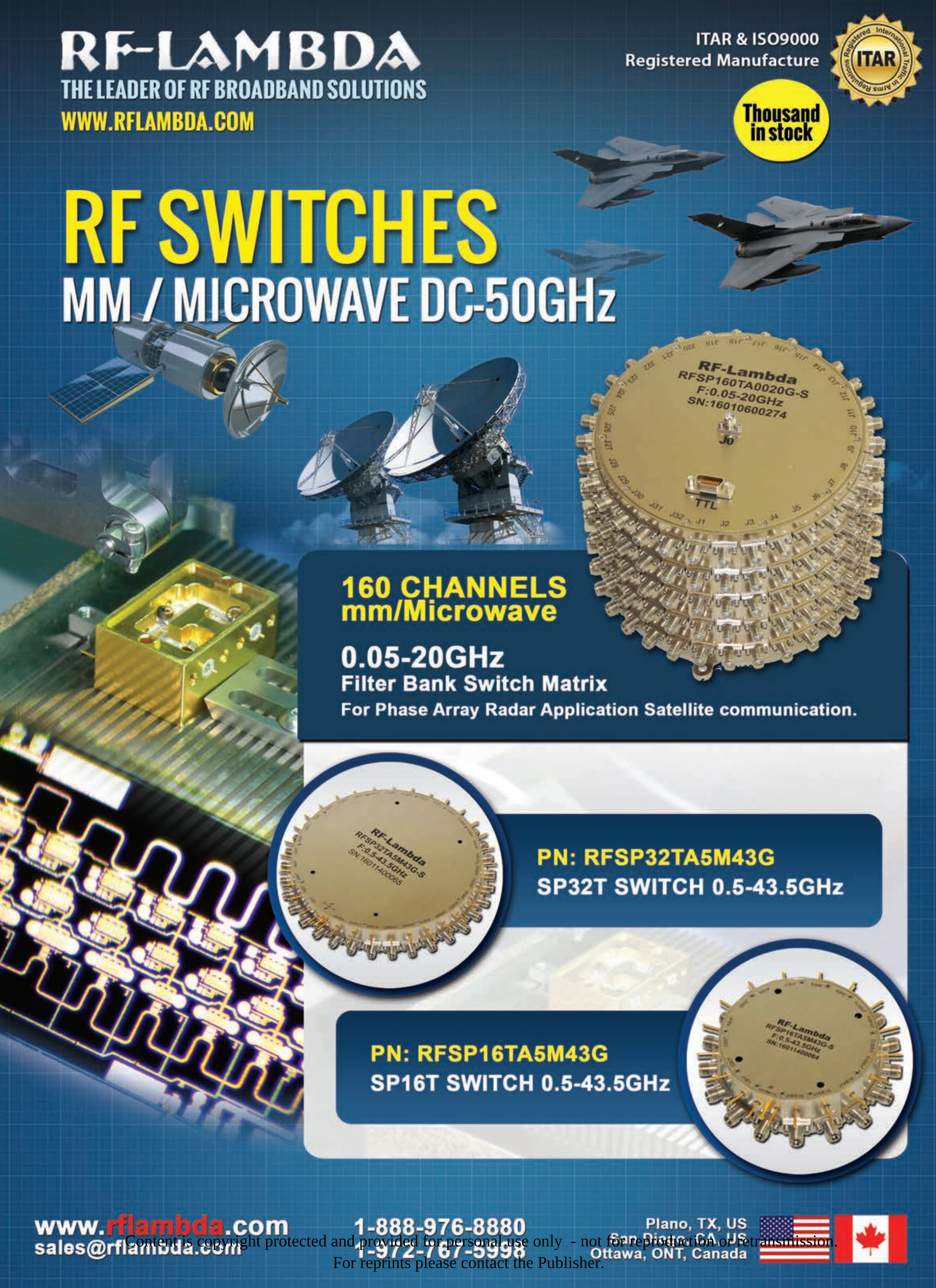


Fig. 6 Z_{Match} **(a) and** $Z_{Peaking}$ **(b) of the peaking amplifier from 1.8 to 2.7 GHz.**

Using this configuration and two commercial 10 W GaN HEMT power transistors, the broadband inverted GaN HEMT Doherty amplifier was designed to achieve an average drain efficiency of 47 percent, average output power of 38 dBm (saturated power of 44 dBm) and a power gain of more than 11 dB across 1.8 to 2.7 GHz.[7,11] The impedance at different points of the load network of the peaking amplifier when it is off are shown in ***Figure 6***, where Z_{match} (see Figure 6a) indicates low reactance at the output of the load network over the frequency range from 1.8 to 2.7 GHz, having near zero reactance at the mid-band frequency and some inductive and capacitive reactances when the operating frequency approaches the edges. By using a quarter-wave series transmission line, at higher frequencies an open circuit condition is provided with sufficiently high inductive and capacitive reactances across the band, indicated by $Z_{peaking}$ in Figure 6b. Hence, the broadband performance of the inverted Doherty structure can be achieved in a practical realization.

Figure 7a shows the load network equivalent circuit for the carrier amplifier with the impedance $Z_{carrier}$ seen by the carrier device, whose real component varies slightly around 10 Ω (see ***Figure 7b***). Taking into account the device output shunt capacitance C_{out} of about 5 pF and series output inductance L_{out} provided by the bond wire and package lead frame inductances, the impedance seen by the device multi-harmonic current source across the frequency bandwidth of 1.8 to 2.7 GHz is increased by 2x from 5 Ω at the input of the broadband output impedance transformer, which is large enough to achieve high efficiency at back-off output power levels. In this case, the device output capacitance and bond wire inductor constitute a lowpass L-type matching section, increasing the load impedance seen internally by the device multi-harmonic current source at the fundamental frequency.

Figure 8 shows simulation results for the small-signal $|S_{11}|$ and $|S_{21}|$ versus frequency, demonstrating the bandwidth capability of a modified inverted transmission line GaN HEMT Doherty amplifier, covering 1.6 to 3 GHz with a power gain greater than 11 dB.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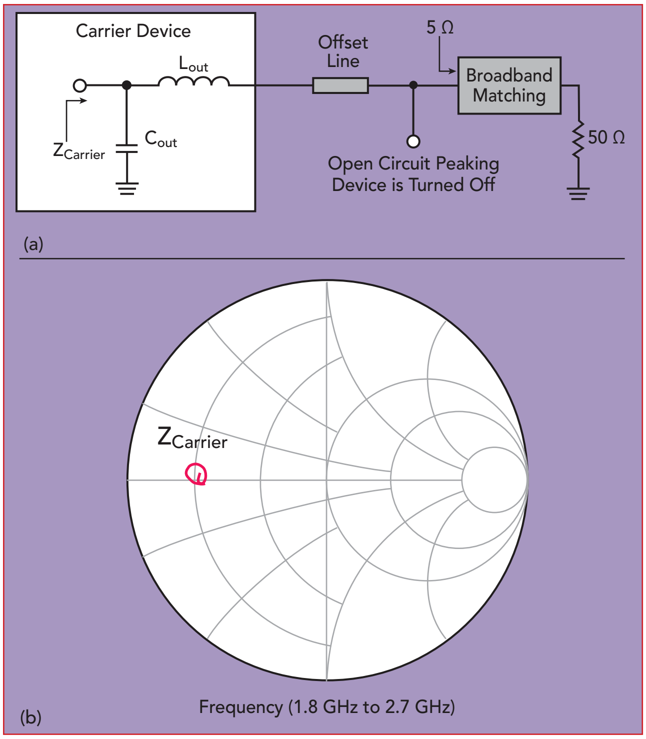
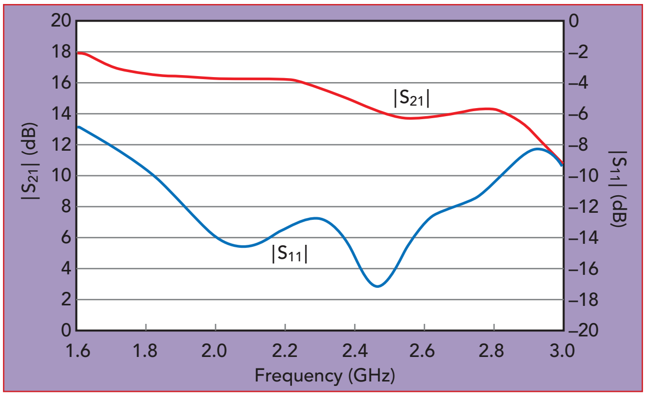
TRI-BAND DOHERTY PERFORMANCE

Figure 9 shows the simulated large-signal power gain and drain efficiency of a transmission line GaN HEMT tri-band inverted Doherty amplifier using a 20 mil RO4350 substrate, with the carrier gate bias V_{gc} = −2.5 V, peaking gate bias V_{gp} = −5.5 V and DC supply voltage V_{DD} = 50 V. The design has an output power greater than 53 dBm and a linear power gain greater than 10 dB across the entire 1.8 to 2.7 GHz range. Drain efficiencies greater than 50 percent at saturation and 7 dB back-off are simulated at the center of the three bands—at 1.85, 2.15 and 2.65 GHz—with maximum drain efficiency greater than 70 percent at the lower frequencies and peak efficiency at maximum back-off output power of around 6 dB over the entire frequency range.

A test board of the tri-band inverted Doherty amplifier using two 80 W GaN HEMT power transistors with internal input matching and in metal-ceramic flange pack-



▲ Fig. 7 Matching network (a) and load impedance (b) for the carrier amplifier.



▲ Fig. 8 Simulated small-signal S-parameters vs. frequency.

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ages was fabricated on a 20 mil RO4350 substrate. The input splitter, a broadband Anaren model X3C17A1-03WS 90 degree hybrid coupler, has a maximum phase balance of ±5 degrees and amplitude balance of ±0.5 dB from 690 to 2700 MHz. The input matching circuit, output load network and gate and drain bias circuits (having bypass capacitors on their ends) were microstrip lines of different electrical lengths and characteristic impedances. The output lead inductances of the packaged GaN HEMT device were minimized.

Figure 10 shows the measured power gain and drain efficiency of the transmission line GaN HEMT inverted Doherty amplifier at five frequencies. A power gain greater than 9 dB was achieved from 1.8 to 2.7 GHz. Drain efficiencies greater than 55 percent at saturation (P_{3dB}) and around 50 percent at 7 dB back-off were measured across the entire band, with the maximum drain efficiency greater than 70 percent at the frequencies below 1.95 GHz and peak efficiency points at maximum back-off power around 6 dB over the entire frequency range. The test conditions for concurrent transmission of a four carrier GSM signal and a 10 MHz LTE signal with a PAPR of 8 dB are shown in ***Table 1***. A drain efficiency of 51 percent with an average total output power of 45.5 dBm (18.2 W for the GSM signal and 17 W for the LTE signal) were achieved using in-house

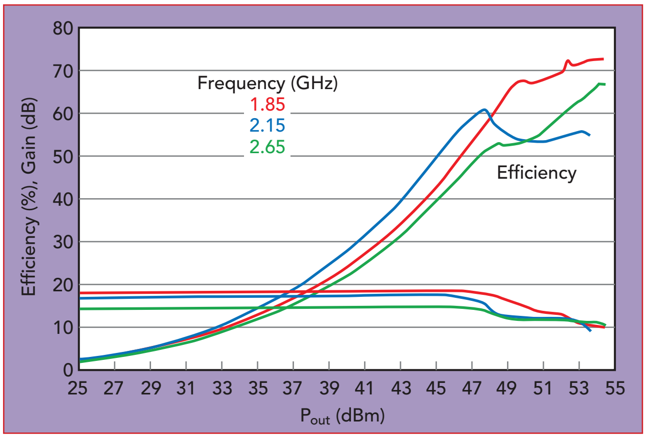

Fig. 9 Simulated power gain and drain efficiency of the broadband inverted Doherty PA.

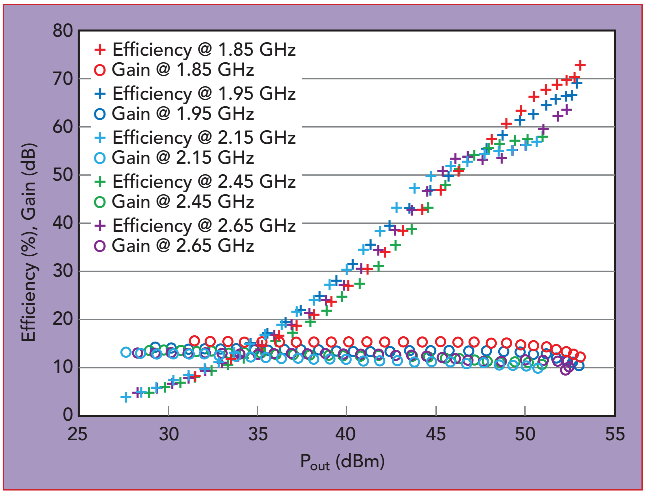

Fig. 10 Measured performance of the broadband inverted Doherty PA.

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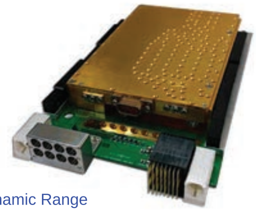

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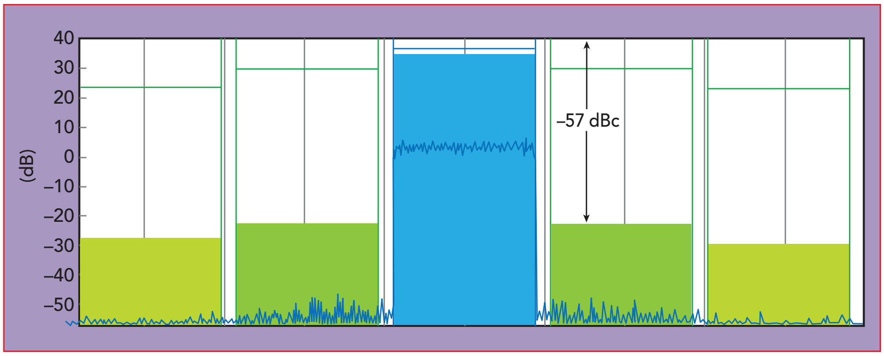

Fig. 11 DPD linearization of the inverted Doherty amplifier with a 10 MHz LTE signal.

TABLE 1

TEST CONDITIONS FOR CONCURRENT SIGNAL TRANSMISSION

Test Conditions	
Device Under Test	2 x 80 W GaN HEMT, 1.8 to 2.7 GHz
Signals Tested	1850 MHz, 4-Carrier GSM 2650 MHz, 10 MHz LTE
GSM 4-Carrier Power	42.6 dBm (18.2 W)
LTE 10 MHz, 1-Carrier Power, 8 dB PAR	42.3 dBm (17 W)
Composite Signal PAR	7.1 dB
Total RF Power	35.2 W (45.5 dBm)
Drain Efficiency	51%

digital predistortion (DPD) linearization. With dual-band DPD and the four carrier GSM signal, the out-of-band intermodulation levels were lower than −70 dBc. With the 10 MHz LTE signal, the adjacent channel leakage ratio (ACLR) was better than −57 dBc (see ***Figure 11***).

SUMMARY

To provide multi-band and multi-standard operation, LTE and 5G base stations are requiring that a power amplifier operate with high efficiencies over increasingly wide frequency ranges. Using GaN HEMT transistors and innovative Doherty architectures, tri-band coverage (1.8 to 2.7 GHz) with powers to 200 W and average efficiencies of 50 to 60 percent can be achieved, significantly reducing transmitter cost, size and power consumption.■

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A Ka-Band Low Phase Noise VCO Implemented in 1 μm GaAs HBT Technology

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Yuming Zhang, Hongliang Lu and Yimen Zhang
Xidian University, Xi'an, China

A Ka-Band voltage controlled oscillator (VCO) using GaAs Heterojunction Bipolar Transistor (HBT) technology in a fully differential Colpitts configuration achieves low phase noise at a high oscillation frequency. It operates from 29.71 to 30.43 GHz and its phase noise is −110.7 dBc/Hz at 1 MHz offset at 30.07 GHz. It consumes 51 mW from a 5 V supply and occupies an area of just 0.65 mm × 0.68 mm. Its figure of merit (FOM) is −183.2 dB/Hz.

Ka-Band systems have many applications.[1-2] Compared to Ku- and K-Band, the main advantages are a wider available bandwidth for faster communication and shorter wavelengths for higher radar/imaging resolution. In Ka-Band transceivers, VCOs are key components, with most systems requiring low LO noise (jitter) to minimize system errors. In particular, resolution and quality are degraded by high phase noise in imaging systems, and signal-to-noise ratio (SNR) improvement is hampered in beam forming systems. Data-acquisition rates can also be significantly reduced due to high jitter.[3]

At mmWave frequencies, two topologies, the cross-coupled VCO[4-6] and the Colpitts VCO,[3,7-8] are widely used. Andreani et al.[9] have shown that both topologies are capable of very good phase noise; however, it is well known that the maximum oscillation frequency of a Colpitts VCO is higher than that of a cross-coupled VCO.[3]

The design of a fully differential Ka-Band Colpitts VCO is described in this article, which achieves low phase noise at a high oscillation frequency. At high frequencies, the differential VCO offers unique advantages over a single-ended configuration. These include a simplified front-end due to the directly fed differential LO inputs to the double balanced down-conversion mixers, substantially reduced on-chip noise generation and less sensitivity to supply voltage variations and noise.

The VCO is implemented in 1 μm GaAs HBT technology, which has a competitive performance advantage over other technologies. Compared with CMOS, GaAs HBTs offer potentially higher f_T, higher transconductance and lower 1/f noise. In addition, GaAs HBTs have been shown to be inherently radiation hard, making them well suited for use in space.[10]

CIRCUIT DESIGN

The technology used in this work is the GaAs HBT process from WIN Semiconductors Corp. The process offers four types of NPN transistors—Q1H051B1, Q1H101B1, Q1H151B1 and Q1H201B1—with different emitter lengths (5, 10, 15 and 20 μm, respectively). The main electrical features for these devices are the breakdown collector-emitter voltage BV_{CEO} = 9 V, the maximum unit current gain frequency f_T = 65 GHz and

the maximum unit power gain frequency f_{max} = 80 GHz. Passive components, including two metal layers, two types of capacitors, resistors, varactor diodes, inductances and back side via holes are available in the process. Passive and active device models have been implemented and validated through simulation with Keysight Advanced Design System (ADS) software.

The VCO schematic, based on a differential Colpitts architecture, is shown in ***Figure 1***. The inductor (L_B) and the capacitors (C_{var} and the base-emitter junction capacitor of the HBT CBE) form the resonating tank. The oscillation frequency is given by

$$\omega_{osc} = \frac{1}{\sqrt{L_B\left(C_{BE} \parallel C_{var}\right)}} \quad (1)$$

To achieve a wide tuning range, C_{var} is usually set to be far less than C_{BE},[3] so that

$$\omega_{osc} \approx \frac{1}{\sqrt{L_B C_{var}}} \quad (2)$$

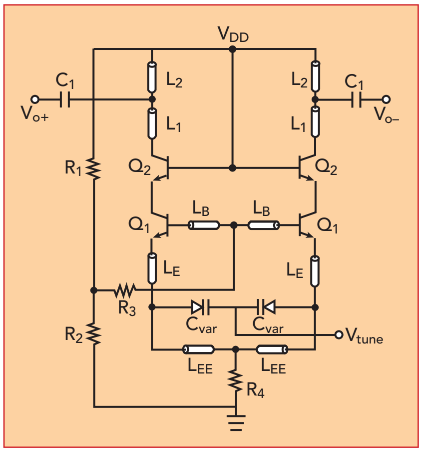

Fig. 1 **Differential Colpitts VCO schematic.**

To improve phase noise and design robustness, a number of developments borrowed from LNA designs are simultaneously applied:

1) A cascode buffer (Q_2) is stacked on top of the VCO tank circuit such that they share the DC current to reduce overall current consumption. With this approach, additional buffers are not needed for tank isolation because of the cascode-style isolation of the tank.[3]
2) An emitter degeneration inductor L_E is inserted to increase transistor linearity.
3) An inductor L_{EE} is used to isolate the half circuits, thereby allowing for a single tail bias.
4) The current source is replaced with a resistor to minimize DC noise.[11]

It is easily demonstrated that resistor bias contributes less noise than a current source by first considering the spectral noise densities of the two bias circuits shown in ***Figure 2***. For the spectral noise density of the resistor (S_R) to be lower than the spectral noise density of the current source (S_{CS}), Equation 3 must be satisfied.

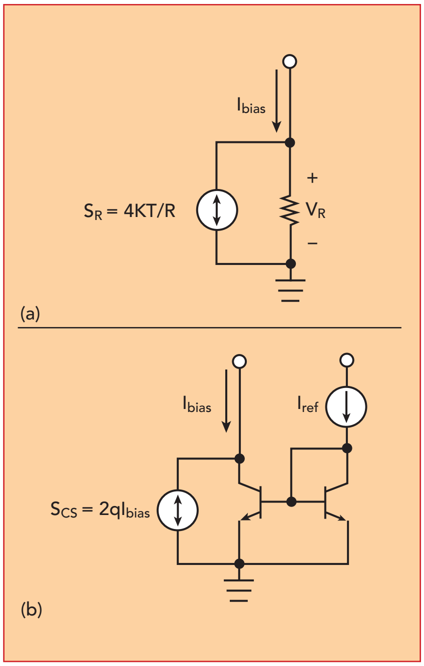

Fig. 2 **Circuit representation of resistor bias (a), current source (b).**

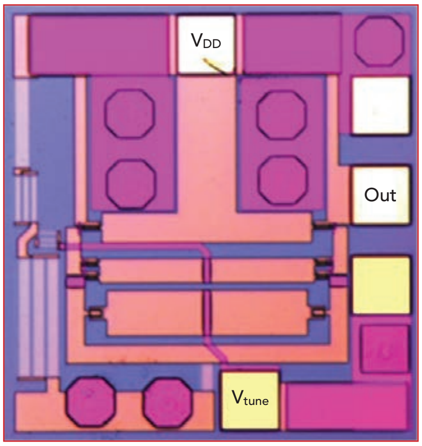

Fig. 3 **VCO die photo.**

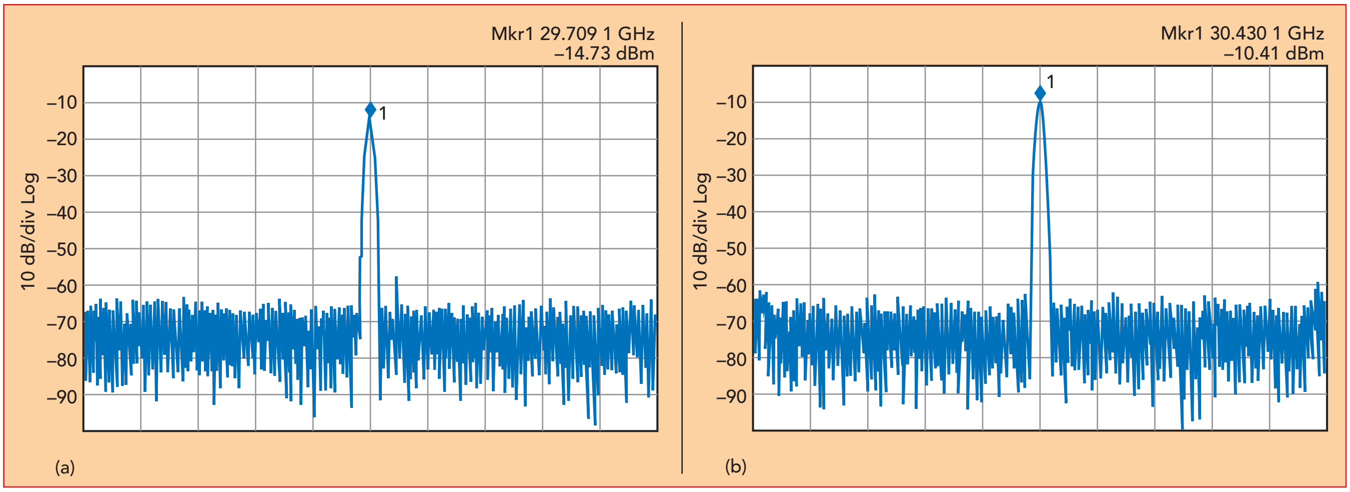

Fig. 4 VCO output spectrum, V_{tune} = 0 V (a) and V_{tune} = 5 V (b).

$$
\begin{aligned}
&S_R < S_{cs}\\
&\frac{4KT}{R} < 2qI_{bias}\\
&\frac{4KTI_{bias}}{V_R} < 2qI_{bias}\\
&\frac{2KT}{q} < V_R
\end{aligned}
\qquad (3)
$$

V_R, the voltage drop across the bias resistor, is typically greater than 150 mV to provide sufficient headroom for tuning the varactors.

DESIGN FOR LOW PHASE NOISE

The phase noise for a Colpitts oscillator is given by Equation 3,[12] where V_{tank} is the voltage swing in the tank, I_n represents all noise sources of the HBT and $\Delta\omega$ is the frequency offset from the carrier. It is apparent that V_{tank} must increase and I_n must be reduced to minimize oscillator phase noise.

$$
\text{phase noise} = 2 \cdot \frac{\langle |I_n|^2 \rangle}{|V_{tank}|^2} \cdot \frac{1}{C_{BE}^2\left(\frac{C_{BE}}{C_{var}} + 1\right)^2} \cdot \frac{1}{\Delta\omega^2} \qquad (4)
$$

Three effective ways to obtain high V_{tank} are by maximizing the bias current, by biasing at the peak f_T/f_{max} current density of Q_1 and by maximizing the Q of the resonating tank (Q_{tank}). In addition, care must be taken not to exceed the breakdown voltage of Q_1. The size of the transistors should be selected large enough to be able to apply high bias current; however, maximizing the bias current leads to high power consumption. There is always a compromise, therefore, between the high V_{tank} of an LC VCO and its power dissipation. Because this work focuses on absolute performance rather than low power consumption, the largest HBT (Q1H201B1), with a bias current of 9 mA, is used.

Q_1 should be biased at the optimal noise figure current density (J_{NFMIN}) that minimizes I_n. In the mmWave band, correlation between base and collector noise currents pushes J_{NFMIN} close to the peak f_T/f_{max} current density.[13] Furthermore, biasing at the peak f_T/f_{max} current density also increases V_{tank}.


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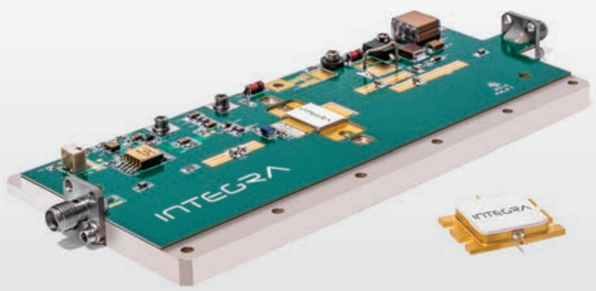
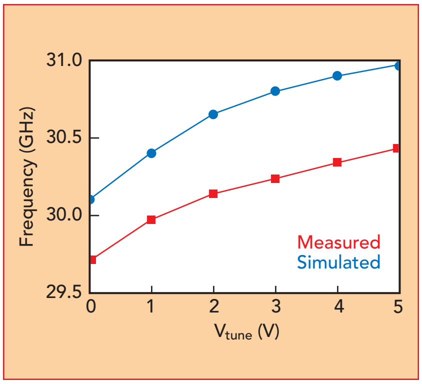
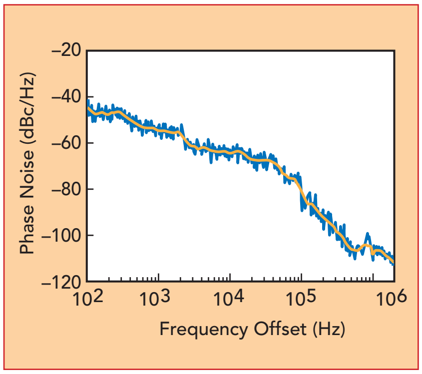




▲ Fig. 5 **Simulated and measured VCO frequency vs. voltage.**



▲ Fig. 6 **Measured VCO phase noise.**

TABLE 1

COMPARISON OF K-BAND AND KA-BAND VCOS

Ref.	f_{osc} (GHz)	PN (dBc/Hz)	TR (%)	P_{DC} (mW)	Technology	FOM (dB/Hz)
4	23.1	–94 @ 1 MHz	5	2.5	0.18 µm SiGe BiCMOS	–177.3
5	20.89	–97.2 @ 1 MHz	10.5	40	0.13 µm SiGe BiCMOS	–167.6
6	24.27	–100.3 @ 1 MHz	2.2	7.8	0.18 µm CMOS	–179.1
7	21.89	–108.2 @ 1 MHz	N/A	32	0.18 µm CMOS	–180
14	25	–103.1 @ 1 MHz	2.4	13.2	0.18 µm CMOS	–179.9
15	19	–112 @ 1 MHz	11	200	0.13 µm SiGe BiCMOS	–174.6
This work	**30.07**	**–110.7 @ 1 MHz**	**2.4**	**51**	**1 µm GaAs HBT**	**–183.2**

For these reasons, the optimum phase noise bias current density of the Ka-Band VCO shifts towards the peak f_T/f_{max} current density.

Q_{tank} is another important parameter. It affects most VCO properties, including overall tank loss, power dissipation and phase noise. In lower frequency bands (< 10 GHz) the tank is dominated by the Q of the inductor (Q_L). However, as the frequency increases to above 30 GHz, the Q of the varactors (Q_{var}) decreases significantly.[3] Thus, Q_{var} determines Q_{tank} at the mmWave frequencies.

$$\frac{1}{Q_{tank}} = \frac{1}{Q_c} + \frac{1}{Q_L} \approx \frac{1}{Q_{var}} \quad (5)$$

At the same time, the tuning range is also determined by varactor size. Thus, it is critical to obtain high-Q and large-ratio (C_{max}/C_{min}) varactors to achieve better VCO performance. There is a tradeoff, however, between Q_{var} and capacitance ratio.[3] If a large capacitance ratio is chosen, the tuning range is maximized but Q_{var} is minimized, thereby degrading the phase noise.

In addition, the varactor should be carefully placed in the circuit to

reduce parasitics. In this work, a varactor diode with a length of 20 μm and a width of 10 μm is chosen to balance Q_{var} and capacitance ratio.

MEASUREMENT RESULTS AND DISCUSSION

All of the passive components, such as the microstrip lines, capacitors and resistors are simulated with the Keysight Momentum electromagnetic simulator. Layout is accomplished using the Cadence Virtuoso layout suite based on transient and harmonic simulations of the design using ADS software. After rule checking and electromagnetic simulation, the designed VCO is fabricated in WIN 1 μm GaAs HBT technology. All devices are arranged symmetrically to have a differential output without the common node noise effect.

Figure 3 is a die photo of the entire circuit. The chip size is 0.65 mm × 0.68 mm including probe contacts. VCO performance is evaluated on wafer with a Cascade Microtech probe station. An HP4142B voltage and current source is used to supply the DC voltages ("V_{DD}" and "V_{tune}"), meanwhile the output ("Out") is connected through a ground-signal-ground (GSG) probe with a 150 μm pitch width to a Keysight N9030A spectrum analyzer. With no differential measurement equipment available, the measurements are single-ended. The negative output is terminated with a 50 Ω load. The VCO is biased at V_{DD} = 5 V (I_{DD} = 10.2 mA), consuming 51 mW of DC power.

Figures 4a and ***b*** show the VCO output spectrum with tune voltage V_{tune} of 0 and 5 V, respectively. The oscillation frequency variation as a function of control voltage sweep is plotted in ***Figure 5*** from 29.71 to 30.43 GHz with control voltages between 0 and 5 V. The VCO exhibits a tuning range of 2.4 percent around a 30.07 GHz center frequency. A small (0.4 to 0.55 GHz) frequency discrepancy between simulated and measured results is due to parasitic effects of the layout. To improve simulation accuracy, software such as FastCap and FastHenry might be used for more precise simulation of the capacitors and inductors. In addition, some capacitance and inductance should be introduced in the simulation between the output and the termination load to account for parasitic effects produced by the contact between the probe and the tested chip.

The phase noise of the VCO is difficult to measure, due to jitter caused by noise on the power supply and tuning voltages. The Keysight N9030A spectrum analyzer provides better phase noise accuracy at higher offset frequencies, so phase noise measurements are conducted from 100 Hz to 2 MHz offset (see ***Figure 6***). The measured phase noise is −110.7 dBc/Hz at 1 MHz offset.

Table 1 compares the performance of this VCO with previously reported K- and Ka-Band VCOs. The commonly used FOM, which accounts for phase noise (PN), oscillation frequency (f_{osc}), frequency offset (Δf) from f_{osc} and power dissipation (P_{VCO}),[6] is used for comparison.

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$$FOM = PN - 20\log\frac{f_{osc}}{\Delta f} + 10\log\frac{P_{DC}}{1\,mW} \quad (6)$$

The VCO described in this article yields a lower FOM than others reported, demonstrating the capability of this design approach to achieve low phase noise performance at a high oscillation frequency.

CONCLUSION

A VCO employing a WIN 1 μm GaAs HBT and utilizing a fully differential Colpitts structure achieves low phase noise in Ka-Band. It demonstrates phase noise of −110.7 dBc/Hz at 30.07 GHz and 1 MHz frequency offset, with a DC power consumption of 51 mW from a single 5 V supply. Its FOM of −183.2 dB/Hz is better than others recently reported. ■

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INVITED PAPER

Network Synthesis Wizard Automates Interactive Matching-Circuit Design

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Reducing product development time requires design tools and a flow that support and expedite all stages of development, from translating performance requirements into an initial design through to optimization, physical layout and final EM verification, all before fabrication and test. This article examines new electronic design automation (EDA) software technology in the domain of network synthesis for the development of impedance-matching circuits. Network synthesis technology is used for RF/microwave applications to ensure that the input impedance of an electrical load or the output impedance of its corresponding signal source maximizes the power transfer by minimizing signal reflection from the load that occurs from impedance mismatch.

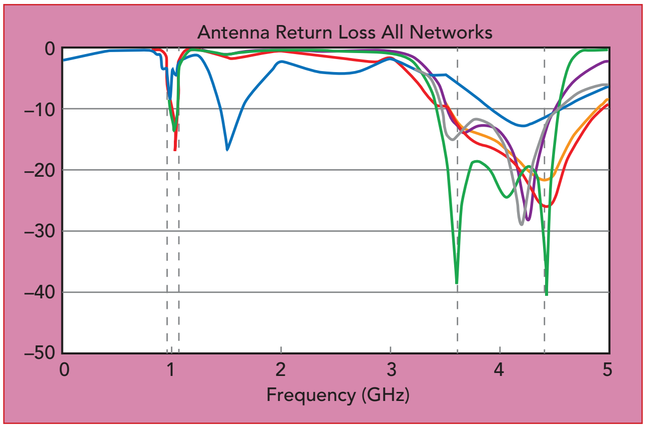


Fig. 1 Network synthesis addresses multi-band matching challenges.

An RF/microwave component design flow must offer design entry (most often schematic-based), nonlinear simulation, the ability to view/review results, the ability to generate physical (layout) design from the schematic and support for electromagnetic (EM) analysis for characterization/verification of the electrical response of the physical design. The network synthesis tool should leverage this flow using device data that is incorporated in any given design project and generate networks in a schematic form that is recognizable to the simulator. As an example, such a flow is offered by the NI AWR Design Environment platform as it provides engineers with capabilities to tackle design entry and simulation prior to manufacturing, while allowing a smooth transition to fabrication and test with minimal design iterations.

A network synthesis tool should leverage this flow using device data that is incorporated in any given design project and generate networks in a schematic form that is recognizable to the simulator.

NETWORK SYNTHESIS WIZARD

Complementing these capabilities are advances in the platform specific to design automation and initiatives in specialized design wizards such as load-pull analysis. This most recent release introduces the network synthesis wizard for the development of impedance-matching networks, as shown in ***Figure 1***. This functionality accelerates design starts and enables designers to more fully explore design options through the creation of optimized two-port matching networks with discrete and distributed components based on user-defined performance goals. Network synthesis is helpful at the earliest stages of a design to help determine reasonable performance targets based on device performance limits, device sizing (decisions on active device periphery), part selection for discrete packaged transistors and other early design decisions.

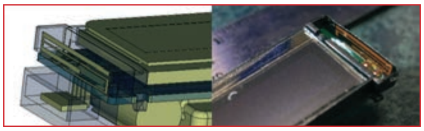
A synthesis solution is particularly helpful for challenging broadband single- and multi-stage amplifiers and antenna/amplifier-matching networks and is available as an add-on module. The tool also aids designers in developing impedance-matching networks between front-end components. As the footprints of RF components shrink in order to meet market demand for smaller embedded radios such as IoT smart devices (see ***Figure 2***), the network synthesis wizard helps designers save space, consolidating component-to-component-matching networks by directly transforming the impedance between each component rather than to an intermediary characteristic impedance (such as 50 ohms).

Furthermore, networks can be optimized for noise, power or interstage matching. The optimum reflection coefficients are specified over frequency and can be provided in the form of load-pull data, network parameter data files or circuit schematics. Specifications for network topology include series and shunt component types and maximum number of sections. With a given set of user input specifications (performance requirements), the synthesis algorithm searches circuit topologies and optimizes component parameter values to generate candidate matching networks for power and low noise amplifiers, as well as inter-stage and inter-component impedance-matching networks.

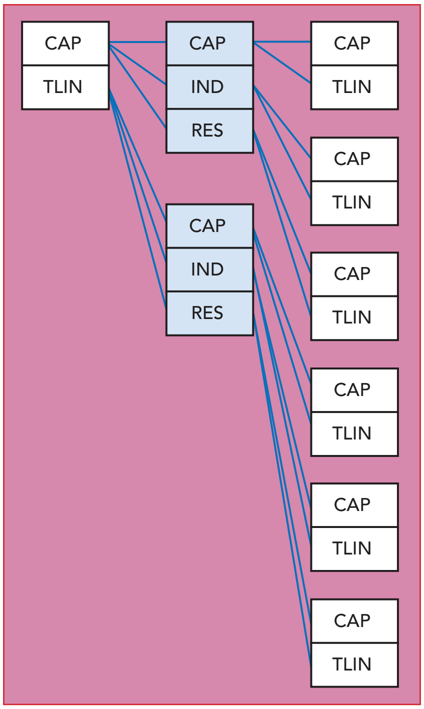
OPTIMIZATION TECHNOLOGY

The new network synthesis wizard is made possible with recent advances in computer processing power and the introduction of genetic algorithm methods, which have proven very effective in addressing circuit response problems. This technology leverages the algorithms first employed within AntSyn™ antenna design, synthesis and optimization module and results in a rigorous optimizer. The optimizers use recombination and selection to rapidly and robustly explore numerous points randomly distributed over the design space. This results in a more efficient and faster approach to investigating design possibilities and identifying optimum solutions.

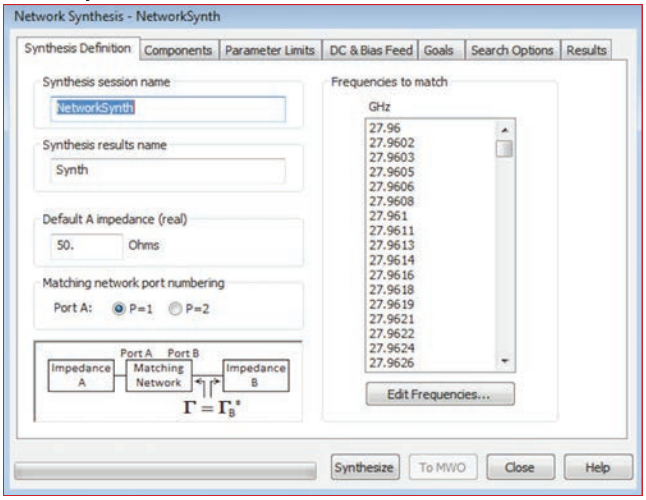
The method used by the search-based synthesis engine to determine candidate circuit topologies is based on input from the user-specification of which element type, such as capacitors, inductors and transmission lines, is to be used in the series and shunt slots. The synthesis tool then performs an exhaustive search, exploring all possible topologies by expanding the solution up to a maximum number of sections as defined by the user, as shown in ***Figure 3***. Heuristic methods are used to determine what element can follow an existing element. Through this self-learning process, the synthesizer understands that certain elements can be placed serially, such as two different width transmission lines to form a stepped-impedance transformer or a fully-distributed transmission line network for higher frequencies. On the other hand, two serial capacitors would not make sense from a matching



▲ **Fig. 2** **Embedded antenna and RF front-end in wireless wearable device (images courtesy of Striiv).**



▲ **Fig. 3** **The search engine explores possible topologies by expanding the solution up to the maximum number of sections as defined by the user.**



▲ **Fig. 4** **The synthesis definition dialog allows users to specify basic network parameters.**

perspective; consequently, those search efforts are not pursued.

The optimization goals are specified in the wizard using a dedicated set of synthesis measurements, much like optimization goals are normally defined in the design environment platform. Specialized measurements are provided for input noise matching, amplifier output-power matching and inter-stage matching. The optimum reflection coefficients are specified over frequency and can be provided in the form of load-pull data, network parameter-data files or circuit schematics.

Additional practical considerations coded into the synthesizer include the ability to constrain the DC open and short paths in the topology search. For instance, the user can stipulate that the side of the matching circuit next to the device will be DC open, so as not to short the drain or collector. Users can also stipulate minimum and maximum component limits and discrete values to reflect actual available (discrete) vendor parts as well as place constraints on the first and last components in the network. This constraint enables designers to ensure the physical practicality of the synthesized network, such as making sure that a low-impedance transmission line adjacent to a large periphery device is not too wide as to be practical. In addition, the impact of existing bias or feed networks can be incorporated into the synthesis network. The search results are then presented from best to worse (in addressing the performance goals) as each expansion is added.

INTERACTIVE USER INTERFACE

It is advantageous to have a network synthesis user interface (UI) that lets designers interactively develop an unlimited number of networks optimized for noise, power or matching networks between amplifier stages or between different components, such as an amplifier and antenna. The optimum reflection coefficients can be specified over frequency and provided in the form of load-pull data, network parameter data files or circuit schematics. Within the synthesis definition tab (see ***Figure 4***), users can specify a default impedance or the impedance of the desired source/load network as well as the desired match frequencies.

The components tab lets users specify the two target networks to be matched from an automatically populated list of project networks (schematics), as well as a set of constraints on the matching network including the number of sections, topology, component type and configuration (series/shunt). Valid topologies are determined by the types of components selected and the value specified for the "maximum number of sections." Each section is either a series component or a shunt component. The wizard considers topologies having the maximum number of sections, such as N, and with fewer, down to N-3 sections.

LOAD-PULL EXAMPLE

The synthesizer is able to interface directly with load-pull data within the software for the instances where designers want to develop matching networks based on nonlinear, load-sensitive performance data. For example, the locus of impedances resulting in power-added efficiency (PAE) and power contours over a given frequency range are plotted on a 5 ohm Smith chart (63 percent PAE and 1 dB power compression point at ~125 W or 51 dBm, five frequencies from 1.8 to 2 GHz), as shown in ***Figure 5***. Alternatively, the designers could plot the overlapping contours, which represent the intersection of the PAE and 1 dB gain compression contours, as shown in Figure 5b.

Instead of providing impedance goals, designers can optionally specify load-pull results directly from within the software. The user simply needs to stipulate the goals,

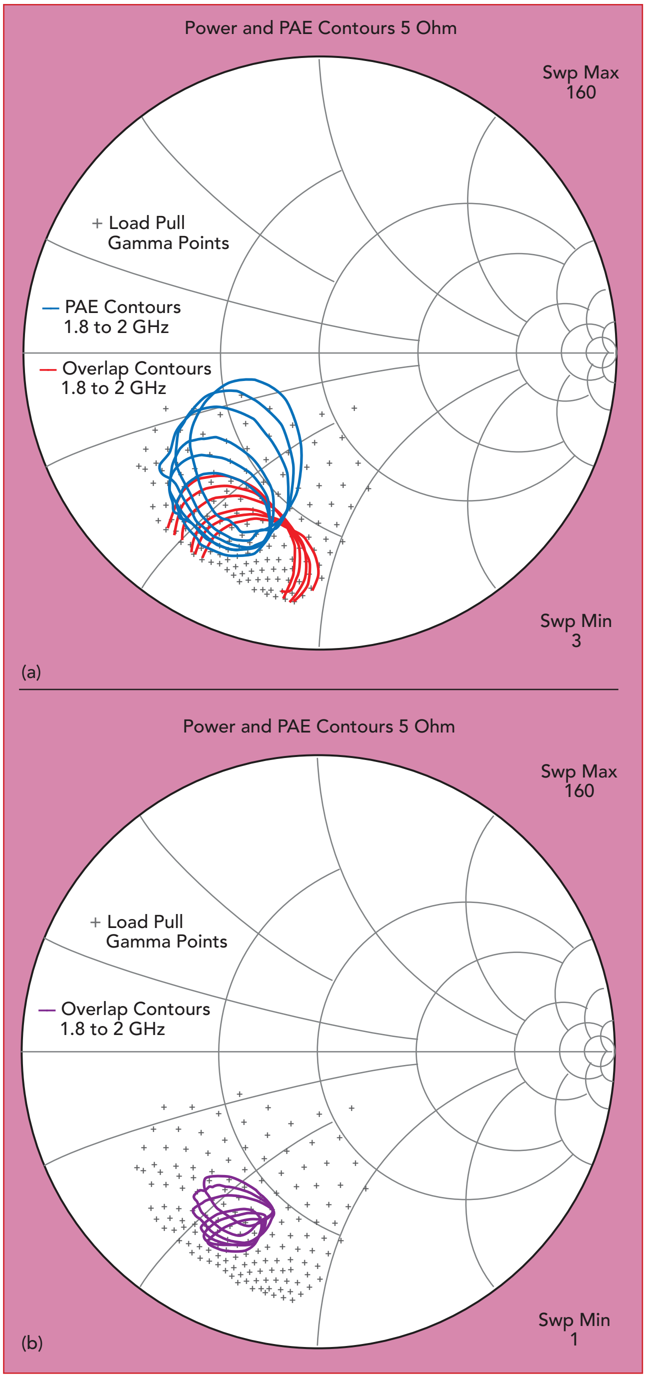
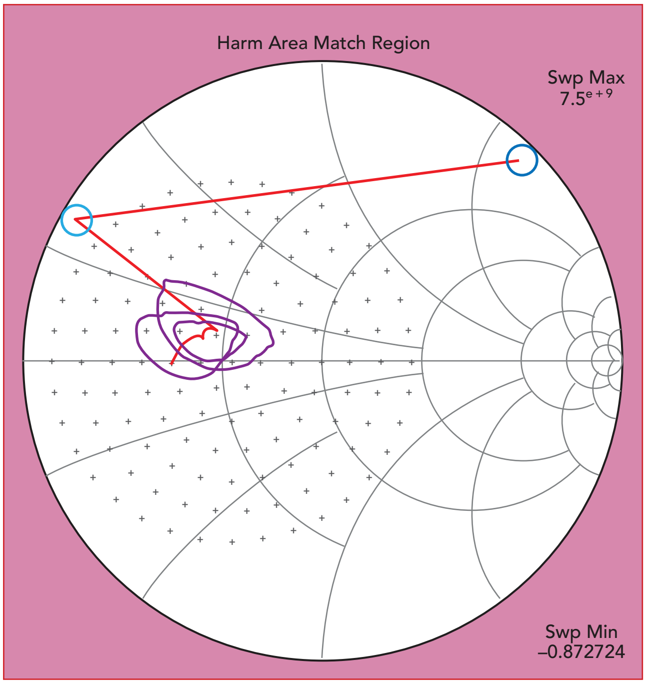


Fig. 5 Load-pull contours for power and PAE (a), as well as the intersection of these contours (b), which will provide the impedance targets for the network synthesizer.

in this case 63 percent PAE and 51 dBm output power, instead of a specific impedance for each frequency point. In this instance, the automation built into the synthesizer tool works from performance goals rather than impedances, which is a much more intuitive approach. The synthesizer provides this capability for sub-bands in support of multi-band matching networks. Goals can be weighted differently, with all the available functionality that is built into the optimizer, such as sloped goals, being supported by the network synthesizer as well.

Additional goals that are not load-pull based can also be added. ***Figure 6*** shows the overlap load-pull contours versus frequency and the initial synthesized-matching network which follows the frequency trajectory of the contours over the desired bandwidth. User-specified target goals can be added to address harmonic terminations to improve linearity and efficiency. Extending the frequency range of the analysis shows that the synthesizer has generated a matching network to provide the desired impedance at the targeted fundamental frequencies as well as the second and third harmonic frequencies.



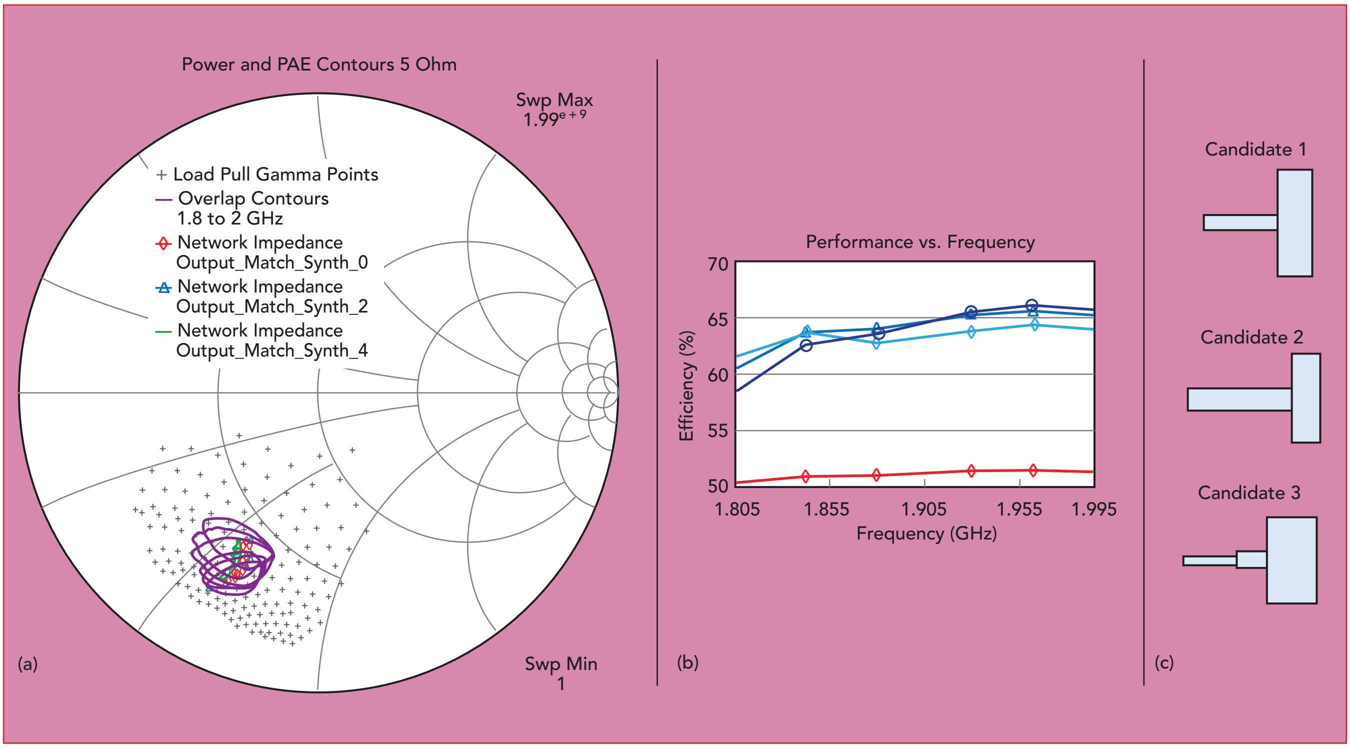
▲ Fig. 6 PAE/power overlap load-pull contours at three fundamental frequencies and user-defined additional goals for second and third harmonic terminations.

POST-SYNTHESIS REVIEW

At the end of the synthesizer run, a user-defined number of candidate networks are generated. This provides the designer with an easy and quick method to compare performance results for each network along with a pictogram of the generated layout to provide a visual aid to the designer, as shown in ***Figure 7***.

CONCLUSION

To help expedite the entire design cycle, a new network synthesis wizard has been added to NI AWR software for the efficient and automated generation of impedance-matching circuits. The synthesis tool generates candidate networks based on user-defined goals, suggested element types to be utilized in the topology search, element constraints/limits and more. The search engine explores possible topologies by expanding the solution up to the maximum number of sections as defined by the user.■



▲ Fig. 7 Candidate matching networks and corresponding performance provide users with a method to compare different results and help select the most appropriate circuit.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Breaking Through the Cost Barrier for Phased Arrays

Doug Carlson
MACOM, Lowell, Mass.

For the U.S. military and contractor ecosystem that services it, intensifying security threats at home and abroad are being met, in part, with increased investments in phased array radar systems. Phased arrays promise enhanced threat detection and mitigation and faster, more agile communication across the modern battlefield. But, where legacy radar systems were afforded massive government funding and ample time for development and deployment, next-generation phased array radar technology does not have nearly the same luxury.

The growing proliferation of unmanned aircraft systems (UAS)—drones—spells a perilous new front in modern warfare and homeland security, whether they are state funded or off-the-shelf recreational varieties, particularly as swarming techniques come to the fore. To answer this threat, a more agile phased array radar platform is required, one that is easily and quickly manufacturable, deployable, field replaceable and adaptable to changing needs. Much like the drones, these radars must be nimble and affordable.

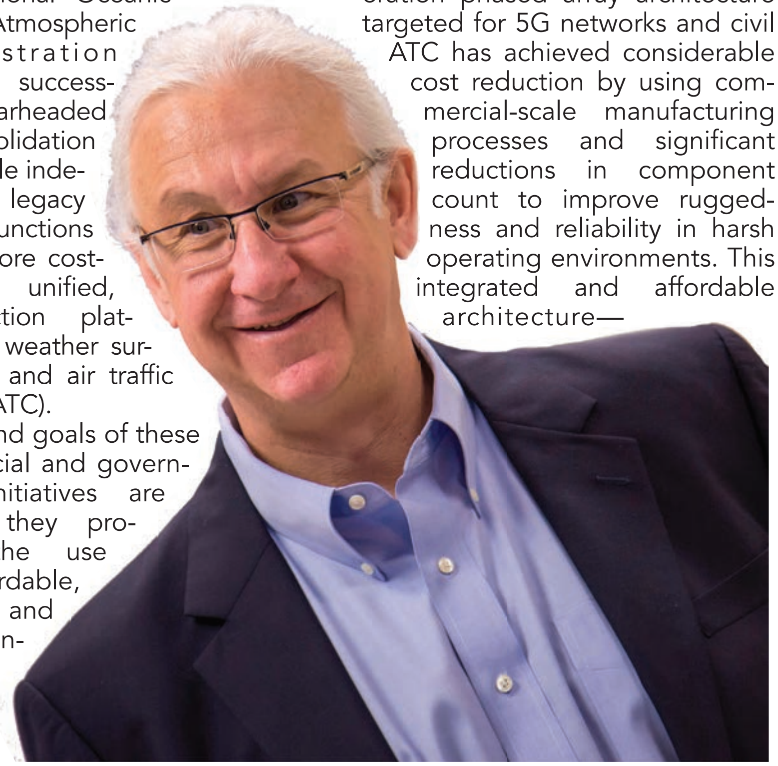
Drones are not the only threats driving this development effort, of course. Continued advancements in traditional warcraft and weaponry require a similar evolution toward more flexible and precise radar platforms. In all cases, the strong need to invest in scalable radar technology is counterbalanced by an equally strong need to reduce strain on the defense budget.

INTERESTING BEDFELLOWS

The development of next-generation phased array radars has followed two parallel paths, which are bending toward convergence. The advent of commercial 5G wireless infrastructure is fueling considerable innovation in massive MIMO antenna designs and software-defined beamforming. In the government domain, the Multifunction Phased Array Radar (MPAR) program, sponsored by the U.S. Federal Aviation Administration (FAA) and National Oceanic and Atmospheric Administration (NOAA), successfully spearheaded the consolidation of multiple independent legacy radar functions into a more cost-effective, unified, multifunction platform for weather surveillance and air traffic control (ATC).

The end goals of these commercial and government initiatives are similar: they promote the use of affordable, scalable and highly integrated phased array antenna technologies to enable faster, more accurate and more sensitive transmit and receive (T/R) capabilities. This, in turn, allows wireless operators to increase subscriber coverage and affords civil radar with expanded fields of view to encompass aircraft, airborne objects and weather systems.

Although it might seem unlikely that commercial and government defense entities can reconcile their respective requirements for ultra-low-cost and battlefield ruggedness, the gap between them is, perhaps surprisingly, not that far apart. The prevailing next-generation phased array architecture targeted for 5G networks and civil ATC has achieved considerable cost reduction by using commercial-scale manufacturing processes and significant reductions in component count to improve ruggedness and reliability in harsh operating environments. This integrated and affordable architecture—



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the tile-based planar array—is poised for mainstream adoption in commercial 5G and civil ATC applications alike and is already deployed in the field, with defense trials set to commence.

INCREASED INTEGRATION

To better understand how tile-based planar phased array radars map to the specific end needs of defense applications, it is helpful to discuss the underlying architecture. The salient architectural goal of the planar array is to allow for a flat design where layers are oriented parallel to the face of the array (see ***Figure 1a***)—not perpendicular as with legacy slat/brick-based configurations (see ***Figure 1b***). The key reasons why the planar architecture is more cost-effective than the slat/brick architecture are because it is:

- Easier to manufacture.
- Significantly reduces cabling and connectors.

By moving to a planar configuration, the array can be built like a PCB, with surface-mount attachment of components to the back of the aperture board. The RF content —T/R modules comprised of highly integrated MMICs—is mounted to the back of the board, with an additional layer housing the DC voltage regulation and capacitor components (see ***Figure 2***), which enables a single voltage to be fanned out within the system. This more elegant approach to channeling the RF, DC and control signals eliminates copious cabling and the associated cost, weight and layout complexities, while simultaneously providing a compact airflow design.

Further cost and weight reduction can be achieved within the planar array by eliminating the conventional super heterodyne (superhet) receiver in favor of a direct sampling, high speed data architecture, enabled by RF SOCs with integrated RF, analog and digital

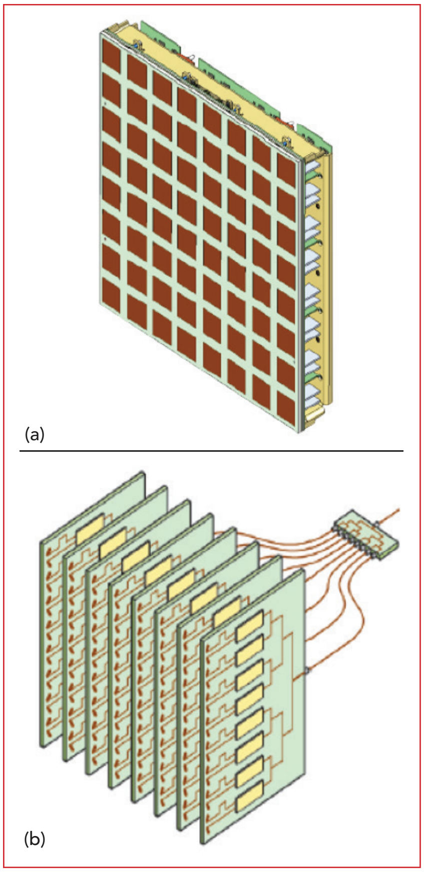

Fig. 1 Tile-based planar phased array (a) vs. slate or brick configuration (b).

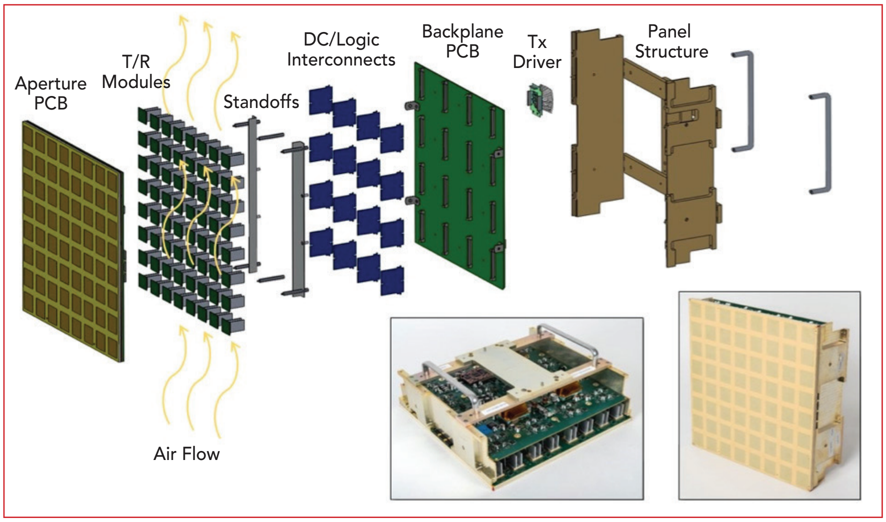

Fig. 2 Construction of the tile-based planar array.

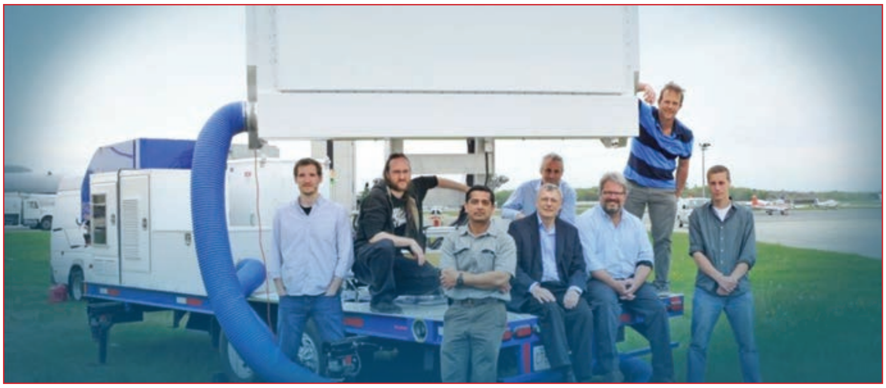

Fig. 3 MPAR 10-tile array deployed at the National Severe Storms Laboratory in Oklahoma.

Fig. 4 The SENSR program aims to address multiple U.S. radar needs with a single phased array radar. Source: Raytheon.

circuitry. RF SOCs preclude the need for cumbersome analog down-conversion. The capability to sample signals up to 56 GSPS enables direct RF sampling at very high frequencies, with the option to down-sample, which eliminates the need for a superhet receiver and discrete data converters tied to very specific frequency plans. This architecture also eliminates the exciter technology needed for superhet frequency conversion.

At the board level, this architecture yields a smaller system footprint, with digital flexibility and increased I/O across a very wide frequency range, streamlining the data pipeline and providing a scalable pathway for increasing the number of RF channels. Ultimately, RF SOCs eliminate a significant amount of legacy electronics and the associated power consumption from the array, playing a key role in enabling the software-defined coherent beamforming essential for efficient and precise radar tracking.

From the array architecture to the RF SOC layer, the higher integration achievable with tile-based planar arrays translates into significant reductions in component and connector count, reducing cost while simultaneously boosting system reliability and ruggedness. The ease of manufacturing with the "PCB-like" planar architecture ensures radar tiles can be produced quickly and cost-effectively, leveraging commercial, high volume best practices.

FIELD PROVEN

The viability and scalability of the planar array radar architecture is being demonstrated through initial deployments, successfully underway. The first planar array-based radar system deployed in conjunction with the MPAR program is in use today by the National Severe Storms Laboratory (NSSL) in Oklahoma (see ***Figure 3***). It features a 10-tile planar architecture that is radiating and actively supporting NOAA weather tracking. A 76-tile array is being installed at the NSSL to support program software development, and another large-scale array is being tested at Hanscom Air Force Base.

The MPAR program has now been integrated into the Spectrum Efficient National Surveillance Radar (SENSR) program, a U.S. government-sponsored, cross-agency

planning and coordination initiative aimed at two goals: consolidating the national radar infrastructure into a single multifunction platform and freeing up valuable radio spectrum for reallocation to 5G services. The SENSR program brings together the FAA, DoD and the Department of Homeland Security (DHS) in a joint effort to radically streamline civil radar infrastructure (see ***Figure 4***) and minimize the spectrum constraints on future 5G wireless roll-outs.

In addition to servicing traditional civil applications like airport terminal and weather surveillance, the SENSR program is addressing coastal and border surveillance, assessing airborne threats to homeland security—focusing on drones and missiles. Leveraging its earlier investment in the successful MPAR program, the government agencies spearheading SENSR may reasonably see planar arrays as a strong candidate for the underlying phased array radar platform.

In parallel, tile-based radar technology is set for use by SRC, a not-for-profit research and development company, to underpin its advanced SkyChaser multi-mission radar system, which is being optimized for military applications. The SkyChaser radar is designed to detect and track close-in and long-range targets while on the move in vehicle-mounted configurations, if desired. This impressive capability distinguishes SkyChaser as an extremely versatile means of conducting air surveillance, counter-fire target acquisition, short-range air defense and drone sensing and avoidance.

SUMMARY

The higher levels of integration, affordability and manufacturing efficiency inherent to the planar array radar architecture, from the system to the component, positions it uniquely to help address the evolving military and homeland defense needs. Early deployments have demonstrated scalability and flexibility, and parallel advancements in commercial 5G infrastructure will drive the cost structures needed to adopt planar phased array radar for mass deployment for civil radar and the modern battlefield.■


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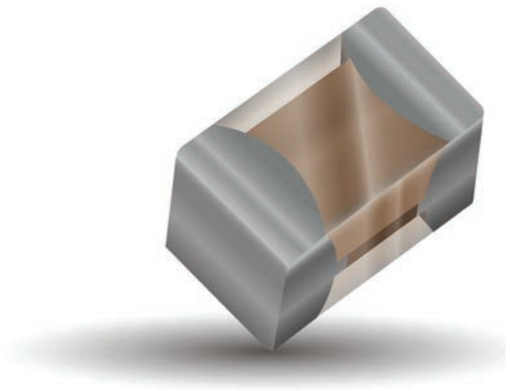

Thin Film Resistors Extend Frequency Coverage in Small Form Factors

AVX Corp.
Fountain Inn, S.C.

The electronics industry continues to push manufacturers to develop smaller passive components capable of higher frequency performance. To meet these demands, traditional passive component designs are being stretched to beyond their limits. AVX recently pushed the boundary of traditional high frequency resistors with its new UBR series ultra-broadband thin film resistors. These ruggedly constructed, ultraminiature (EIA 0402, 1005 metric), ultra-broadband resistors are made with high performance tantalum nitride materials. The substrate and cover use the company's proprietary, automotive-qualified, glass-sandwich FLEXITERM® surface-mount technology, instead of the typical alumina ceramic or aluminum nitride, which reduces the traditional relative permittivity to just 4.4 F/m and helps extend the frequency range to 20 GHz.

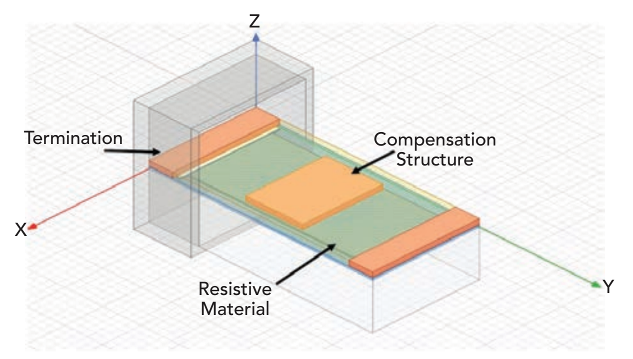

Fig. 1 **Exploded view of a UBR series resistor with AVX's patented transmission line compensation.**

The innovative design of the FLEXITERM termination provides an extra measure of protection against flexure damage during installation, and the parts are also 100 percent laser trimmed, allowing tight tolerances. Although this extension comes at the cost of overall power handling, the new UBR series ultra-broadband resistors offers a 125 mW power rating. The power rating and the wider frequency range make them ideal for use in optoelectronic, automotive, telecom, broadband and SATCOM systems, including optoelectronic transceiver modules, transmit and receive optical subassemblies, wideband test equipment, low noise amplifiers, mixers, broadband receivers, EW jammers, directional couplers and ultra-broadband splitters and combiners.

The UBR series resistors are offered in the following configurations:

- Four standard temperature coefficient of resistance values: ±25, ±50, ±100 and ±250 ppm/°C, with additional values available when requested. The rated operating temperature is from −40°C to +125°C.

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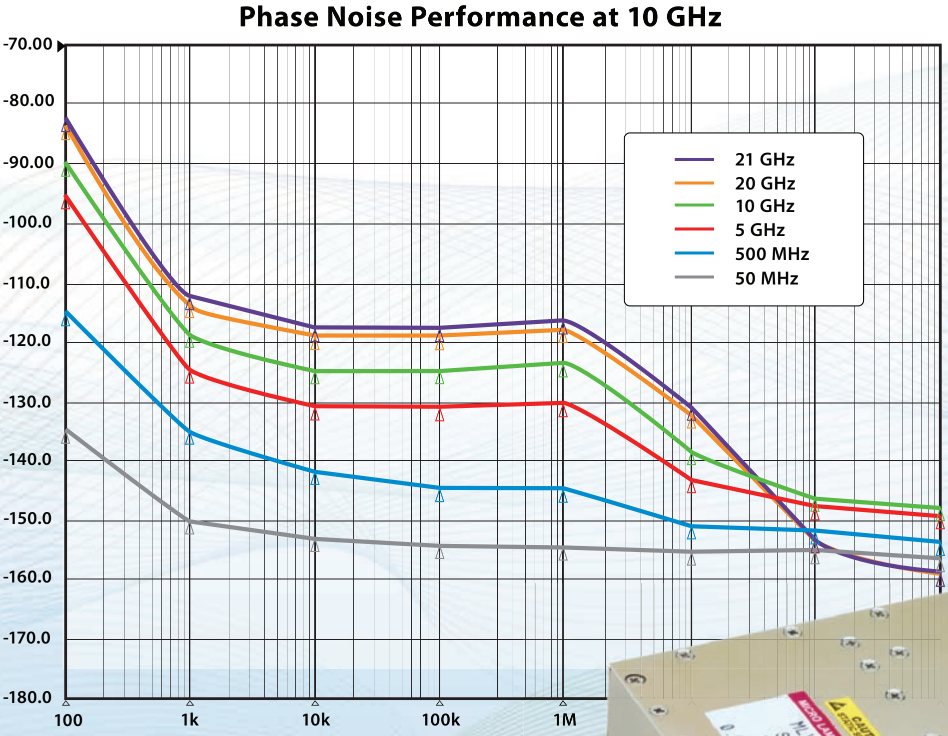

US patents #9,793,904 B1, #9,734,099 B1

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- Four standard resistance values: 25, 50, 100 and 200 Ω, with the range from 20 to 200 Ω also available if requested.
- Three standard tolerances: ±0.5, ±1 and ±2 percent, with additional values available.
- Two termination options: FLEXITERM Ag/epoxy, plated with NiSn, or gold-plated nickel (Ni/Au). They are RoHS compliant.

The 0402 resistors measure 1 mm long × 0.5 mm wide × 0.5 mm high with ±0.10 mm tolerance and have a terminal width of 0.25 mm ±0.15 mm. They are packaged on tape-and-reel for automated assembly.

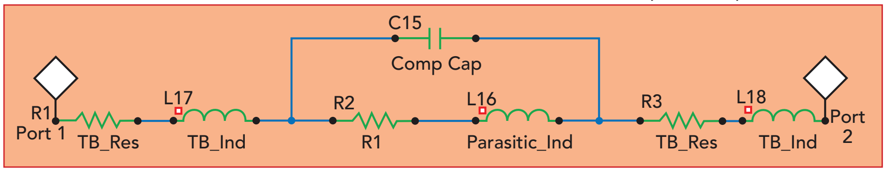

Fig. 2 Equivalent circuit of the UBR series resistor with the transmission line compensation structure, mounted on a test board with a 50 Ω line.

EXTENDING THE FREQUENCY RESPONSE

While this innovation in resistor design allows more passive components to be used at higher frequencies, continued innovation is required to achieve greater performance in the ever-smaller packages demanded. One way to extend the performance of a traditional resistor is to add transmission line compensation on the board. This improves resistor performance by countering some of the parasitic of the resistor and the board it is mounted on; however, this takes valuable board space.

To resolve this issue, AVX has created a UBR series resistor with a patented, built-in compensation structure that emulates the effect of compensating the transmission line without taking additional space (see ***Figure 1***). The equivalent circuit of the UBR series resistor with the added transmission line compensation structure with a 50 Ω line on a test board is shown in ***Figure 2***. This circuit is better matched to the 50 Ω line than a standard broadband resistor, thanks to the added capacitance across the resistor and the modified input and output transmission line equivalents, which achieve better matching to higher frequencies. ***Figure 3*** shows a simulation using ANSYS HFSS 19.1 software, comparing the $|S_{21}|$ of the uncompensated and compensated UBR series resistors, both the same value and mounted on a 50 Ω grounded

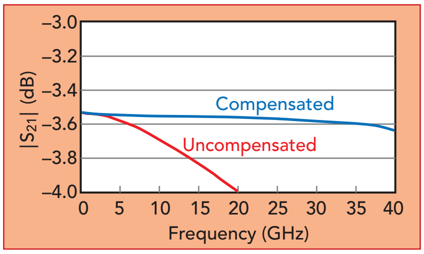

Fig. 3 Comparison of the simulated $|S_{21}|$ of compensated and uncompensated UBR series resistors on a 50 Ω grounded coplanar transmission line on a Rogers 4350 test board.

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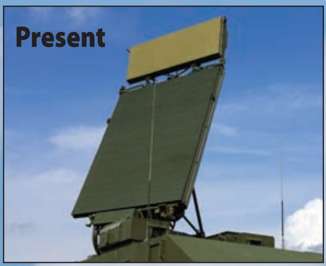

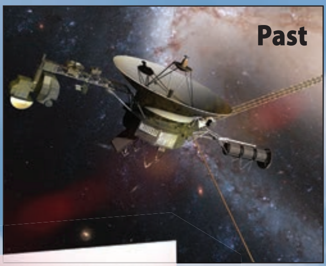

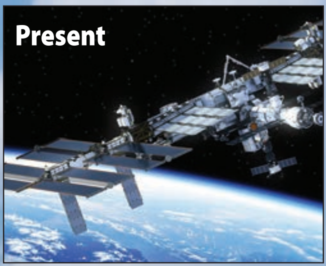

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coplanar transmission line on a Rogers 4350 test board. The response of the resistor with the optimized compensation structure through 40 GHz looks like an "ideal" resistor (assuming ±10 percent tolerance, i.e., where the resistor value is between 45 and 55 Ω), while the response of the non-optimized resistor only extends to 15 GHz.

To extend the resistor's frequency range, it is important to know the specific board characteristics, as different boards require different compensation structures to optimize high frequency performance. To illustrate, when the Rogers 4350 test board in this simulation is changed to an alumina board with a 50 Ω grounded coplanar line, the compensation structure needs to be modified to match the parasitics of the new transmission line and board. ***Figure 4*** shows the $|S_{21}|$ responses on the alumina board, comparing the standard UBR resistor with the resistor compensated for the alumina board. The compensated response extends to almost 30 GHz, versus just 12.5 GHz for the uncompensated resistor.

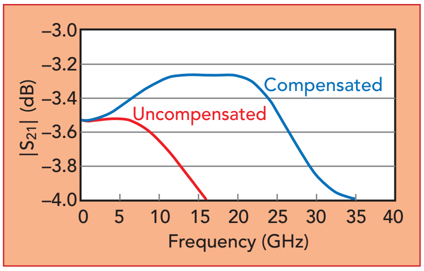

Fig. 4 Comparison of the simulated $|S_{21}|$ of compensated and uncompensated UBR series resistors on a 50 Ω coplanar line on an alumina board.

Each application is likely to require a unique board design and set of parameters. While some designs may require tighter tolerance on the swing of $|S_{21}|$ versus frequency, others may require higher frequency performance. Matching each individual requirement only using modeling software will miss some parasitics a real world board will add. To help ease the design load, AVX has several stepped values of typical compensation structures available in a kit that design engineers can use to identify the designs that best extend the frequency range of a given circuit while minimizing board space. The design kit helps assure that the correct compensation is achieved, saving time chasing performance issues through multiple board spins. This is especially beneficial where board space and vendor designs are set and qualified and need to match tight design and performance requirements and strict regulations, such as military and medical applications.

The new compensated UBR series resistors are now being released, with additional improvements underway. Future developments will shrink the component size from 0402 to 0201, increase the power rating toward 1 W and add new termination styles to meet a wider variety of customer needs.

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

Enabling High-Power, Low Loss, Low-Cost Distribution for RF Energy

HUBER+SUHNER
Herisau, Switzerland

Used for food preparation since the 1950s, heating, warming and cooking in a microwave oven still operates on the same principle as it did 60 years ago. Microwave ovens are powered by magnetrons, tubes used to generate high-power microwave energy. Magnetrons lack controllability, as they can only be switched on or off, making microwave ovens practical only for defrosting frozen foods and reheating pre-packaged meals. As foods have different energy absorption properties and inhomogeneous energy density, the inability to control the power from a magnetron explains why the typical microwave oven produces food that has inconsistent temperature—the dreaded hot and cold spots.

With control of the power, frequency and phase, the right amount of energy can be applied to each food item on a plate, overcoming these limitations. Using solid-state RF energy in future microwave ovens will offer an entirely new user experience, where the cooking is accurate and high quality, enabling someone to click a button and tailor the cooking to specific foods—even multiple foods on the same plate—without having any item over- or under-cooked.

An additional benefit using solid-state RF energy will be significantly longer oven lifetimes, without the magnetron's power degrading. This reliable cooking performance will assure food safety, which is crucial in all kitchens.

IMPROVING RF ENERGY DISTRIBUTION

Introducing a completely new technology requires many changes, beginning with design. Magnetrons are directly mounted to rectangular waveguides; however, with solid-state RF energy, power amplifiers on printed circuit boards (PCB) need to be connected to the appliance (see ***Figure 1***). Along with the common electrical challenges, such as ensuring low loss and handling

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Fig. 1 **Solid-state RF energy systems require high-power connections to PCBs.**

high-power, the design approach must cope with more filigree mechanics compared to a metallic magnetron cavity. The tolerances in the oven assembly are tighter with a PCB assembly compared to those required with the magnetron.

To develop an affordable and reliable assembly process without using cables, new interconnect concepts are needed to solve the mechanical challenges. The RF cables and connectors used to connect PCBs in other applications and industries do not meet RF energy's requirements for power handling, and they are more expensive and complicated to assemble.

Addressing these issues, HUBER+SUHNER has developed an RF energy connector, the RFEX, for optimal RF power handling and performance. The first of its kind, the RFEX is a record low-cost solution for high volume RF energy applications. It is directly integrated into the amplifier housing, as shown in ***Figure 2***, which significantly reduces the size and number of parts, simplifies shielding and minimizes electromagnetic compatibility problems. To save space, the RFEX can connect directly to an antenna, enabling direct mounting of the amplifier. Alternatively, the RFEX connector is a low loss interface to hollow or polymer supported waveguides.

POLYMER SUPPORTED WAVEGUIDES

Polymer supported waveguides (see ***Figure 3***) can be hollow structures, dielectrically loaded or partially loaded with a dielectric, allowing the size and weight to be adjusted to meet the application's power and loss requirements. Polymer supported waveguides provide a high de-

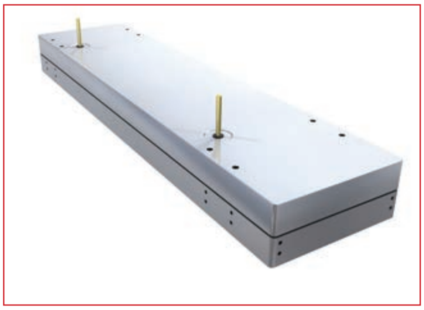

Fig. 2 **The RFEX connector is directly integrated into the power amplifier housing.**

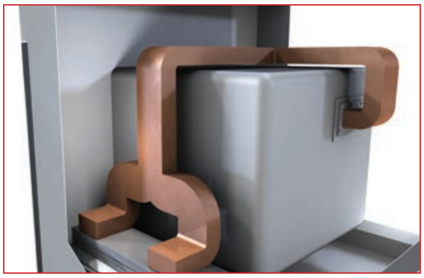

Fig. 3 **Polymer supported waveguide connecting a power amplifier assembly to a microwave oven cavity.**

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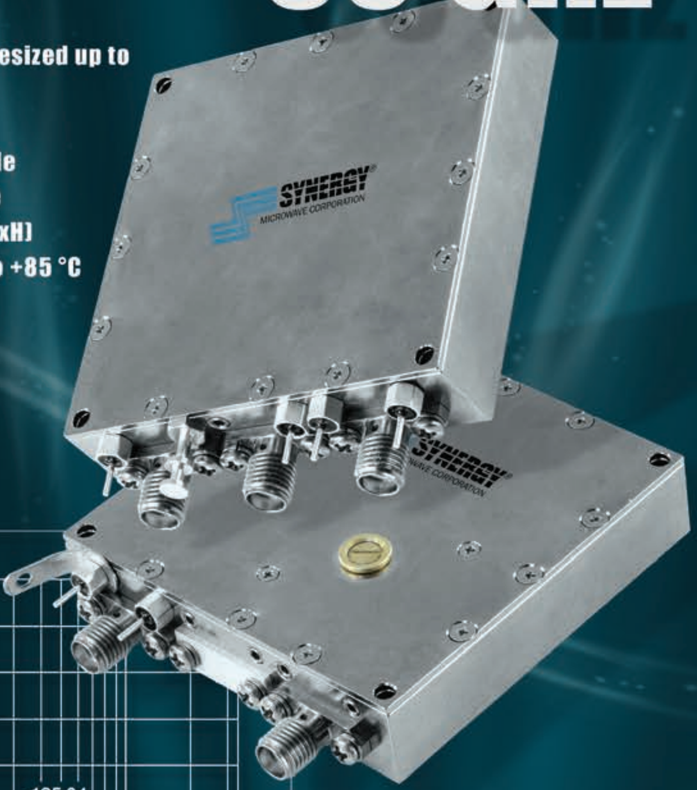

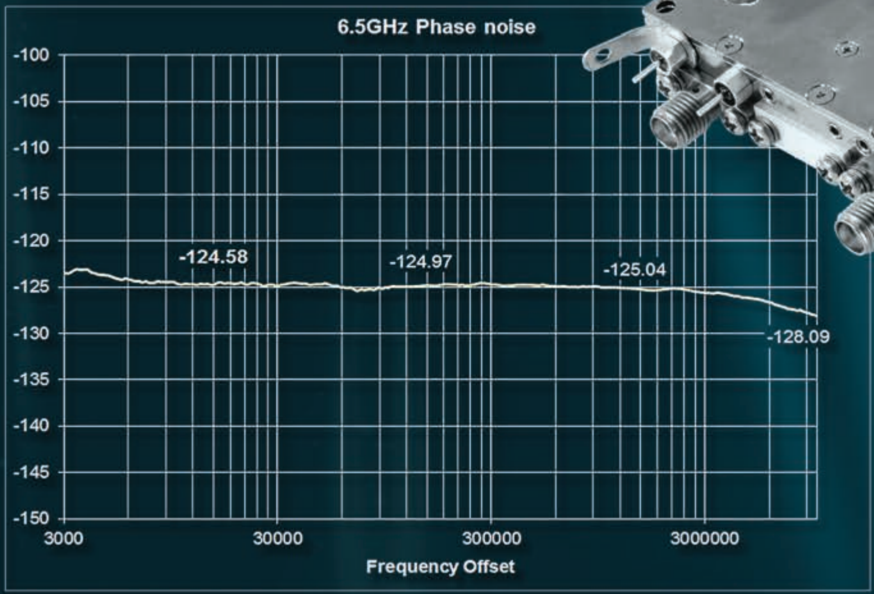

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gree of flexibility: all the mechanical structures can be designed to fit the form factor restrictions of modern oven cabinets.

To achieve the full benefit of solid-state RF energy, multiple power amplifiers are typically used, requiring multiple feed points and combining the powers from the separate amplifiers, as shown in Figure 3. The extremely high degree of design flexibility allows the connection of multiple amplifiers to multiple feeding points of the cavity, even in geometrical difficult applications. Polymer supported waveguide power combiners have distinct advantages compared to PCB-based combiners: lower losses and lower cost, with a significant reduction in PCB area.

Designed to handle the typical high-power levels with the lowest possible losses, the highest efficiency and low heating, the RFEX connector and polymer supported waveguides enable a highly reliable, long life solution. Because of the innovative design, the combination simplifies previously tedious assembly processes. By reducing the number of parts and using production concepts new to the RF energy industry, users benefit from significantly lower cost.

RF ENERGY TO CHANGE OUR LIVES

Solid-state RF energy for cooking will bring completely new features into high-end cooking devices, including faster, more repeatable and high quality cooking, which restaurants, especially, will benefit from. Solid-state RF energy will enable a range of applications, not only cooking, warming and heating food. Automobiles can have improved ignition, reducing fuel consumption. RF energy can power plasma lighting, creating a spectrum much closer to natural sunlight than provided by LEDs. In medical applications, such as the RF assemblies used for microwave ablation, RFEX can improve reliability and simplify the RF signal path. Industrial applications often require huge power levels, requiring many power amplifiers. The RFEX and polymer supported waveguides can combine from two to more than 16 amplifiers in sub-units, achieving the goal of increased flexibility, simplified maintenance and reduced total cost.

For some applications, HUBER+SUHNER RFEX interconnectivity solutions can combine polymer supported waveguides with larger diameter coaxial cables to support different geometrical distances, power levels, ambient temperatures and durations. The HUBER+SUHNER RF energy solutions comes from its extensive experience in the design and development of RF connectivity products.

Just as mobile communications completely changed our lives, RF energy will change many industries, making processes faster, more reliable and more affordable.

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Herisau, Switzerland
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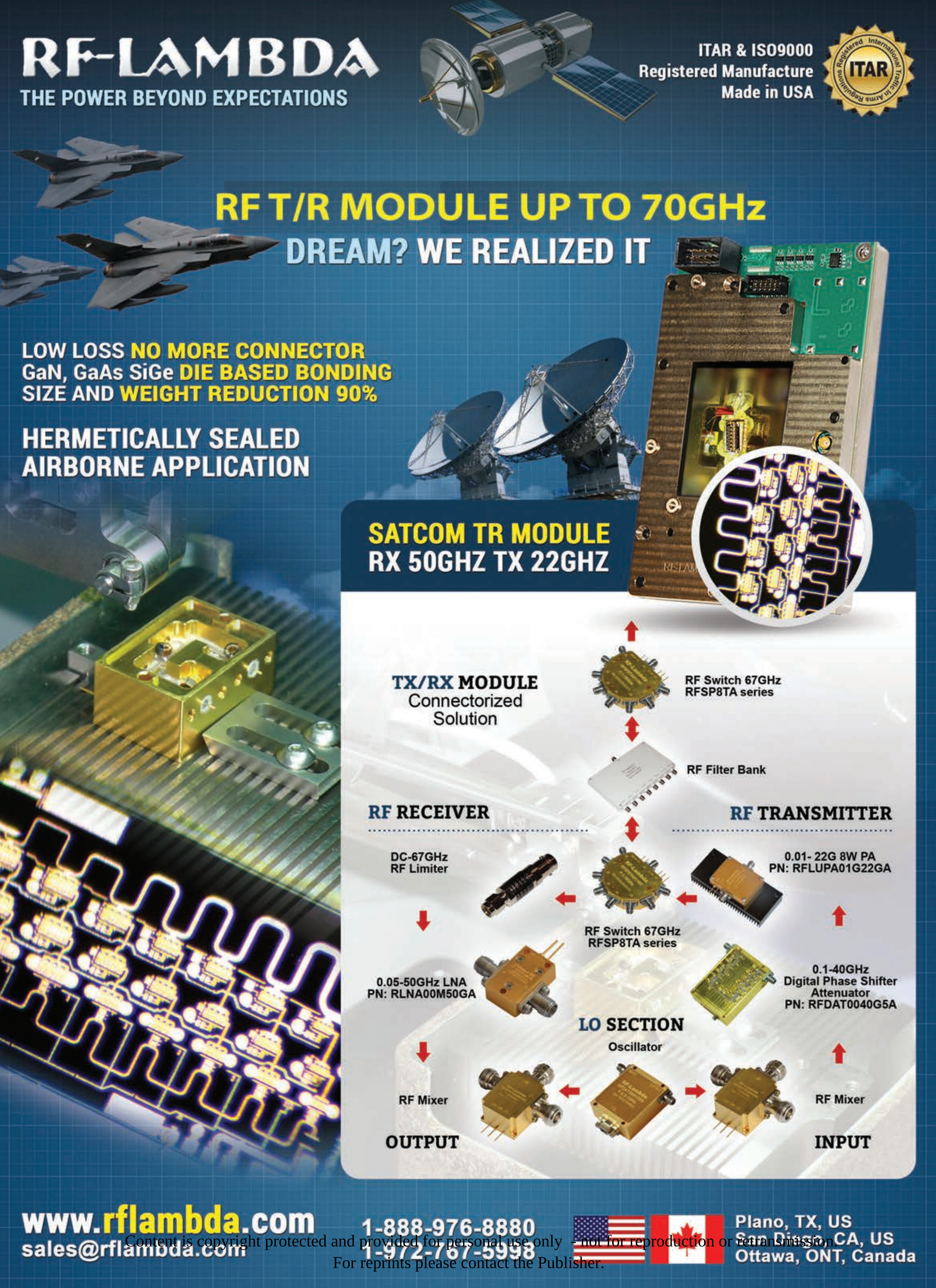
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4 kW, 7.5 to 18 GHz, Dual Tube TWTA

For electronic warfare and electronic countermeasures simulation, radar cross section measurements and other military applications requiring high RF power, dB Control has developed a 4 kW nominal, 7.5 to 18 GHz traveling wave tube amplifier (TWTA). With a 50 μs pulse and 100 kHz maximum pulse repetition frequency, i.e., 5 percent duty cycle, the dB-3911 provides 3.4 kW saturated output power across 7.5 to 11 GHz, 4 kW from 11 to 17 GHz and 3.4 kW from 17 to 18 GHz. The TWTA is not restricted to pulsed signals; it can amplify CW, AM, FM and pulse-modulated signals.

The dB-3911 TWTA achieves this high saturated output by combining two periodic permanent magnet TWTs. Power combining losses are minimized by phase matching the TWTs and other RF components over the entire frequency range. The dual TWT design improves harmonic performance, typically –10 dBc. Spurs are –50 dBc within 1 MHz of the carrier.

The single RF input is via a female type N connector, and the output uses a WRD750 flange waveguide. Forward and reflected power can be monitored using the sampled output connections. The dB-3911 is powered with a single phase 220 VAC connection and consumes a maximum of 3 kVA. The TWTA is 18 in. (w) × 36 in (d) × 21 in. (h), and weighs 175 lb.

The amplifier and power supply have built-in protection from excessive helix current, over/under voltage, high VSWR, arcing and temperatures outside the operating range of –20°C to +50°C. The front panel has an on/off switch and display showing the operating status and any faults. As an option, the TWTA can be controlled remotely using RS232, RS422, RS485, Ethernet or a custom protocol.

Established in 1990, dB Control designs and manufactures high-power TWTAs, microwave power modules, transmitters and high voltage power supplies, supplying them to military organizations, major defense contractors and commercial manufacturers.

dB Control Corp.
Fremont, Calif.
www.dbcontrol.com
email: swalley@dbcontrol.com

40 GHz Programmable Attenuator Has 31.5 dB Range in 0.5 dB Steps

API Weinschel's new 4209 series of solid-state programmable attenuators covers 0.1 to 40 GHz with an attenuation range of 31.5 dB in 0.5 dB steps, controlled using a parallel (TTL compatible), I2C, SPI, UART or USB interface. Also included is API's LabVIEW-based USB Control Center software. The nominal insertion loss at zero attenuation is 1.7 dB up to 6 GHz, increasing to 7 dB above 40 GHz, which is industry-leading performance.

The 4209 digital attenuator has extremely fast RF switching times: 35 ns rise and fall, from 10 to 90 percent (or 90 to 10 percent) of the RF signal. The switching time from the midpoint of the control signal to the 90 percent point of the RF signal is typically 5 μs. When changing attenuation values, the RF path is uninterrupted, which is an important requirement for many systems.

VSWR is less than 1.7:1 over the entire 40 GHz frequency range. Maximum input power handling is 28 dBm. The attenuator is typically biased with a 3.3 to 5 V supply and draws 15 mA. The operating temperature range is −20°C to +85°C.

The 4209 digital attenuator promises excellent repeatability and long-term reliability, making it well-suited for production test systems, simulators for telecommunications and military systems and engineering labs. Extending the series, a 63 dB version of the attenuator is being developed.

API Technologies-Weinschel
Frederick, Md.
weinschel.apitech.com

16 GHz Phase-Locked Oscillator With –82 dBc/Hz Phase Noise at 10 kHz Offset

Z-Communications has broadened its portfolio of fixed frequency, phase-locked oscillators (PLO) with a complete 16 GHz phase-locked solution. The RFS16000C-LF has a nominal output power of –7 dBm into 50 Ω and uses a ceramic resonator to deliver unmatched spectral purity of –82 dBc/Hz at 10 kHz offset and –114 dBc/Hz at 100 kHz offset.

The internal VCO is phase-locked at 4 GHz, then multiplied to produce the 16 GHz output. The PLO includes a highly stable, 10 MHz temperature compensated crystal oscillator (TCXO), eliminating the need for an external reference for locking, and the loop bandwidth of 5 kHz minimizes concerns about microphonics.

The RFS16000C-LF includes internal filtering to reduce harmonic and non-harmonic signals to better than –25 dBc, while providing a reference suppression of –65 dBc.

This low noise oscillator is biased with +5 and +3.3 V, typically drawing 95 mA and 15 mA, respectively. The PLO is available in a surface-mount package measuring 1 in. x 1 in. x 0.22 in. and operates over the industrial temperature range from –40°C to +85°C.

With the internal pre-programmed microcontroller deriving the 16 GHz output and an overall frequency stability of ±10 ppm, the PLO is simple to integrate, a benefit for any design engineer looking for a quick, plug-and-play solution. The RFS16000C-LF is an excellent choice for SATCOM, radar systems and other applications requiring a low-cost, high frequency solution. Produced in the U.S., all Z-Communications products are either available in stock or within a six week lead time.

VENDORVIEW

Z-Communications Inc.
Boulder, Colo.
www.zcomm.com

Software and Mobile Apps

Simulation-Driven Design Platform

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Altair has released Altair Inspire™. The Altair Inspire platform enables manufacturers to leverage simulation to drive the entire design process, accelerating the pace of innovation and reducing time-to-market. This new platform brings together simulation solutions for generative design, engineering analysis and manufacturability under a single, intuitive user environment, appealing to designers and engineers with little or no simulation experience. Altair Inspire is available through both Altair's HyperWorks and solidThinking suite offerings.

Altair
www.altair.com/InspirePlatform

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

K&L Microwave
www.klfilterwizard.com

DIY Vector Network Analyzer Kit

VENDORVIEW

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

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

The COMPLETE Library™ v18.2

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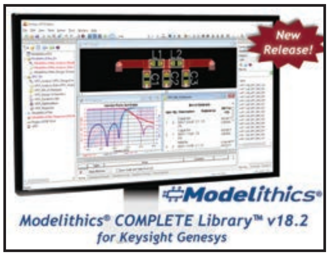

Modelithics has released version 18.2 of the COMPLETE Library for use with Keysight Genesys software. Version 18.2 includes 24 new models, and plays a key role in the new Genesys rapid design optimization tool, Vendor Parts Synthesis (VPS). The v18.2 Modelithics COMPLETE Library contains over 540 models from more than 50 vendors, representing over 16,000 total components. Along with the v18.2 release of the COMPLETE Library, the Modelithics mmWave & 5G library for Keysight Genesys contains all models that are validated to at least 30 GHz, with some validated as high as 125 GHz.

Modelithics Inc.
www.modelithics.com

Design Environment V14.01 Update

VENDORVIEW

NI AWR Design Environment V14 platform accelerates RF/microwave design from concept to product, with an emphasis on automated design flows and integrated simulation technology to tackle today's most challenging communications and aerospace/defense applications. Capabilities include powerful network synthesis for multi-band impedance matching circuits, advanced layout editing capabilities for PCB/module EM verification, an enhanced phased-array development wizard for configuring/optimizing MIMO/beam steering antennas, as well as enhanced analysis, automation and report/measurement management.

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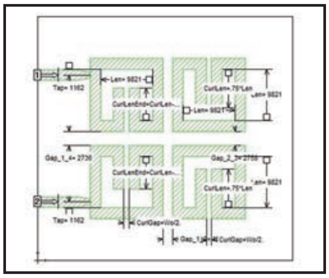

In partnership with Sonnet Software Inc., Nuhertz flagship product, FILTER SOLUTIONS® now includes full geometric-parameterization with filter layout exports into Sonnet Software. This enhances support for efficient electromagnetic (EM) optimization in Sonnet, as parameters are now immediately available for designers to tune and optimize their circuits. Nuhertz planar designs are accurately synthesized and the circuits are optimized internally to provide an accurate starting point for Sonnet's optimizer, minimizing both engineering time and compute time for an efficient and simplified workflow.

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COMPONENTS

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Anritsu Co. introduces W1 coaxial components that are metrology-grade designed and manufactured to deliver precision performance and repeatability for high frequency measurements. Comprised of a W1 connectorized power splitter, power divider, directional coupler and attenuators, the new family removes measurement complexity, reduces measurement setup time and improves accuracy, making them a superior alternative to millimeter-interfaced solutions. Unlike other solutions that are based on banded waveguide frequencies that require a waveguide interface, the W1 components are not band limited and support a frequency range from DC to 110 GHz.

Anritsu Co.
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Compact 6-Way SMA Power Dividers

VENDORVIEW

MECA Electronics' latest expanded product offering, non-binary 3- and 6-way broadband of power dividers optimized to cover 1.5 to 2.7 GHz (803-2-2.100 and 806-2-2.100) encompassing various aeronautical, satellite and mobile bands. With typical performance of VSWRs of 1.20:1, isolation 27 dB, insertion loss 0.6 dB and exceptional amplitude and phase balance of 0.3 dB and 6 degrees max. This is in addition to the family of 2-, 3-, 4-, 8-, 9-, 12- and 16-way splitters. Made in the U.S., 36 month warranty.

MECA Electronics Inc.
www.e-MECA.com

Coaxial mmWave Precision Fixed Attenuator

VENDORVIEW

Mini-Circuits' new BW-E series of precision fixed attenuators expands the coverage of its popular coaxial precision attenuator family up to 65 GHz, supporting mmWave applications including 5G test systems, Ka-Band SATCOM and more. The BW-E10-1W653+ provides 10 dB attenuation to within ±1.5 dB accuracy, RF input power handling up to 1 W and good VSWR of 1.2:1 at 26.5 GHz and 1.3:1 at 65 GHz. Measuring just 0.88 × 0.31 in., the attenuator features rugged, passivated stainless steel construction with 2.4 mm male to 2.4 mm female connectors.

Mini-Circuits Inc.
www.minicircuits.com

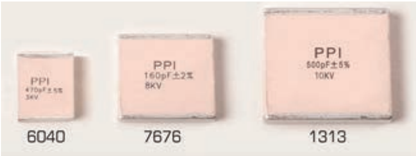
Couplers

VENDORVIEW

The RFCP5773 coupler is designed for applications that require 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. S-parameters are available on request.

MiniRF
www.minirf.com

Hi-Q Capacitors



Passive Plus Inc. offers a line of Hi-Q capacitors specifically produced for high-power/high frequency requirements. These products are available in surface mount or leaded configurations that are 100 percent RoHS compliant and are offered in magnetic and non-magnetic terminations (the 1313C Series is only available in non-magnetic terminations). With over 30 years in the RF/microwave industry, Passive Plus Inc. manufactures high quality, high-power passive components using state-of-the-art manufacturing techniques.

Passive Plus Inc.
www.passiveplus.com

SPDT High-Power PIN Diode RF Switches

VENDORVIEW

Pasternack has unveiled a new line of SPDT high-power PIN diode RF switches that offer desirable performance for transmit and receive signal routing applications. Typical applications can involve use in radar systems, EW applications, base station infrastructure, repeaters, military/microwave radios, public safety/land mobile radios, UHF/VHF radios and test & measurement applications. Pasternack's new line of SPDT high-power PIN diode switches consists of seven different models that offer excellent power handling and isolation with broadband performance and fast switching speed.

Pasternack
www.pasternack.com

0.1 to 20 GHz, Passive Limiter

VENDORVIEW

PMI Model No. LM-100M20G-18-10W-SFF is a 10 W peak, 1 W CW limiter that operates over the 0.1 to 20 GHz frequency range.

This model offers a max insertion loss of 2 dB and a max VSWR of 2.0:1. The unit is supplied with SMA female connectors in an ultra small housing measuring only 0.50 × 0.50 × 0.22 in. It is ideal for protecting low noise amplifiers from high-power (1 W CW) in a RF/microwave receiver application.

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

SP6T Switch

VENDORVIEW

RFMW Ltd. announced design and sales support for a Silicon on Insulator (SOI) single-pole, six throw (SP6T) switch designed for use in CATV, satellite set top and other high performance communications systems. Qorvo's QPC6762 operates in 75 ohm environments from 5 to 2000 MHz and offers 34 dB of mid-band isolation. Low insertion loss of 0.4 dB and IIP3 of 75 dBm highlight exceptional performance for CATV and FTTH system developers. The QPC6762 is offered in a 2 × 2 mm, low-cost, QFN package.

RFMW Ltd.
www.rfmw.com

Faraday Isolator

VENDORVIEW

SAGE Millimeter Inc.'s model STF-04-S1 is a full band Faraday isolator that operates from 170 to 260 GHz. The Faraday isolator is constructed with a longitudinal, magnetized ferrite rod that causes a Faraday rotation of the incoming RF signal. The Faraday isolator offers 30 dB typical isolation and 4 dB nominal insertion loss with good flatness. The return loss of the isolator is 15 dB. The input and output ports are WR-04 waveguides with UG-387/U-M flanges.

Sage Millimeter Inc.
www.sagemillimeter.com

NewProducts

Mixers

Mixer model M80-5X2B covers the two radio bands of 71 to 76 and 81 to 86 GHz. The mixer integrates an LO doubler, so that the customer need only supply a 39 GHz source with +16 dBm of power. Conversion loss is 6 dB typ. and 9 dB max, with an IF frequency range of 2 to 8 GHz. The input P1dB is –6 dBm typical, the bias is +12 VDC at 10 mA.

Spacek Labs
www.spaceklabs.com

26.5 GHz RF Downconverter

The SC5318A is a C to K broadband single-stage downconverter, converting frequencies from 6 to 26.5 GHz down to 50 MHz to 3 GHz. The LO frequency range is from 6 to 26.5 GHz with an input LO range from 6 to 14 GHz. An internal frequency doubler multiplies the input LO range up to 26.5 GHz. This module also features an internal 26.5 GHz synthesized LO, RF preamplifier and variable gain control, making it a standalone module.

SignalCore Inc.
www.signalcore.com

CABLES & CONNECTORS

Removable Vertical Launch Connectors

Fairview Microwave Inc. has released a new series of solderless vertical launch connectors that are ideal for high speed computing, high speed networking and telecommunications applications. Fairview Microwave's new line of vertical launch connectors is made-up of 12 models that deliver max operating frequency of up to 50 GHz and VSWR as low as 1.3:1, depending on the model. They are offered in male and female versions, covering 2.4 mm, 2.92 mm and SMA interfaces.

Fairview Microwave Inc.
www.fairviewmicrowave.com

PL-259 Connectors

VENDORVIEW

RF Superstore just announced the addition of PL-259 connectors, frequently used for amateur or ham radio applications.

RF Superstore
www.rfsuperstore.com

Gain and Line Loss Equalizers

RLC Electronics' gain and line loss equalizers combine filter and attenuator technology to achieve a desired response to 40 GHz. The typical curves that follow are representative of commonly requested responses, including both linear and half-sine responses. VSWR is dependent on frequency of operation, complexity of equalized response and bandwidth of response. Power handling is dependent on the physical size of the absorptive elements. Since these elements decrease in size with increasing frequency, power handling by 10 GHz is usually in the hundredths of W.

RLC Electronics Inc.
www.rlcelectronics.com

High-Power Adapters of Series 8058

Spectrum Elektrotechnik GmbH is introducing high-power 18 GHz adapters of product category 8058-, which shows series and in-between series adapters of types N and TNC. The units use special heat dissipating dielectric between center conductor and outer conductor, and have cooling fins to dissipate power to the environment. In addition the high-power hermetic sealed adapter series have been expanded as well, now operating to 18 GHz for N and TNC series.

Spectrum Elektrotechnik GmbH
www.spectrum-et.org

AMPLIFIERS

Baseband Module

VENDORVIEW

American Microwave Corp. introduced a baseband module with 2 RF inputs P1 (direct input), P2 (with pre-amp), bandpass filtering on the inputs and covering 2 to 6 GHz frequency range with built-in digitally controlled attenuator (31 dB gain control). It has dual output P3 (for RF processing) and P4 (input to a DLVA which AMC also supplies). The baseband module and DLVA are form fit function replacement within Litton EW receivers.

American Microwave Corp.
www.americanmic.com

Solid-State Power Amplifiers

The new single band AS0860 series of solid-state power amplifiers developed on the CTS amplifier platform follows the AS series tradition for compact upgradeable microwave power amplifiers solutions with field proven reliability. Developed to cover the frequency range of 0.8 to 6 GHz in a single band, these class A GaN-based amplifiers have market leading power density with very linear operating characteristics. Coupled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www.ims-ieee.org
IEEE
MTT-S

with a low noise power spec of 8 dB makes them ideal for industrial, instrumentation and telecom applications.
Ametek Compliance Test Solutions
www.ametek-cts.com

150 W GaN System Amplifier

VENDORVIEW

Empower RF announced the release of model 2223, a single band solid-state GaN system amplifier, capable of delivering a minimum 150 W across its entire 0.6 to 6 GHz band. Equally suited for the production floor, engineering lab or anechoic chamber, the 2223 comes complete with internal DDC, external forward and reverse sample ports and an easy to use web-served GUI with dedicated features for simplifying integration into your test application.
Empower RF Systems Inc.
www.EmpowerRF.com

Amplifier

VENDORVIEW

AMP2135B is a best in class, state-of-the-art 10 kHz to 400 MHz, 300 W rated, 350 W typ. amplifier system, featuring 56 dB min gain, type N female RF input, sample and RF output ports. Built-in VVA circuits for gain control local and remote functionality, designed for high-reliability and ruggedness. This system is suitable for all single channel modulation standards, harsh automotive BCI tests and any application requiring high-power and wideband coverage such as EMI/RFI general and specialized test equipment requirements.
Exodus Advanced Communications
www.exoduscomm.com

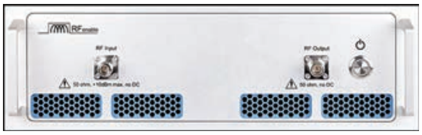
Low Noise Amplifier

L3 Technologies, Narda-MITEQ introduces a new series of low noise amplifiers (LNA) that will support the marketplace needs with frequency ranges from 100 MHz to 40 GHz. This LNA series will provide reduced delivery times along with competitive pricing. In addition, the LNA series are now available for purchase on-line using the new Web Store on the L3 Narda-MITEQ website. These high performance, low-cost LNAs are designed to offer customers the same high performance that the industry expects from L3 Narda-MITEQ, while also providing reduced lead times.
L3 Technologies, Narda-MITEQ
www.nardamiteq.com

Medium Power TWT Microwave Amplifier

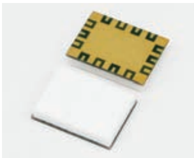
The 9400 series amplifier systems provide the maximum in performance, reliability and cost-effectiveness. The 9400 series amplifier utilizes miniature traveling wave tubes to provide incomparable RF performance for operation while having smaller exterior dimensions. Microprocessors provide the operator or computer, access to monitor TWT conditions, fault latching and control of power supply parameters.
Quarterwave
www.quarterwave.com

Amplifiers



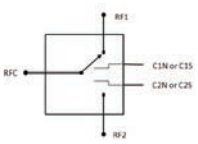
The RFenable value line of amplifiers offers solid performance with respect to output power, thermal management and reliability. The amplifiers are designed for continuous operation and all come with options for connectors in the front or back of the unit, as well as options for integrated bidirectional power couplers to allow external monitoring of power.
RFenable
www.rfenable.com

GaN SMD Amplifier



RFHIC Corp. introduces the RTH49005G, designed for 4G and 5G small cell applications. The GaN SMD amplifier utilizes a GaN HEMT process that provides high efficiency of 38 percent and an average output power of 5 W in 4.8 to 5 GHz. Its drive amplifier and 50 ohm in/out matching circuit are integrated with asymmetric Doherty configuration for small form factor package (20 × 15 mm) to provide the convenience of customer's system build.
RFHIC Corp.
www.rfhic.com

DC to 12 GHz Reflective 10 W SPDT



Richardson RFPD Inc. announced the availability and full design support capabilities for a new reflective SPDT switch amplifier from United Monolithic Semiconductors S.A.S. (UMS). The CHS7012-99F is a monolithic FET-based, reflective switch amplifier that operates in the DC to 12 GHz frequency band. It is designed for a wide range of applications from military to commercial communication systems. The new device is developed on a robust 0.25 µm gate length GaN/SiC PHEMT process and is available as bare die.
Richardson RFPD
www.richardsonrfpd.com

Radio and Wireless Week

20-23 January 2019, Rosen Plaza Hotel, Orlando, FL

IEEE MTT-S AP-S

radiowirelessweek.org

Radio and Wireless Week Highlights

Keynote Speakers
G. Michael Lester, Technical Transfer Partnership Manager, Kennedy Space Center
Alanson Sample, Associate Professor, University of Michigan

2nd IEEE IoT Summit on "The Internet of Things Meets the Internet of Space"
Sunday, 20 January 2019 and Monday, 21 January 2019
Organizers: Multi-Society IEEE IoT Initiative and MTT-S

Workshops
5G New Radio: The Prospects for GaN from Devices to Systems
Organizers: Pere L. Gilabert, Universitat Politècnica de Catalunya and Spyros Pavlidis, North Carolina State University, and Neil Braithwaite, Consultant

RF Transceiver Imperfections in Wideband and Millimeter Wave Systems
Organizer: Tomas Gotthans, Brno University of Technology and Genevieve Baudoin, Université Paris-Est, ESIEE Paris

Microwave Power Amplifier Design and High Performance Innovative Passives
Organizers: Howard Hausman, President/CEO, RF Microwave Consulting Services, Adjunct Professor, Hofstra University

Distinguished Lecturers
Terahertz Communications at 300 GHz: Devices, Packages and System
Ho-Jin Song, Pohang University of Science and Technology, Korea

Nonresonating Modes Do It Better!
Simone Bastioli, RS Microwave Company Inc., USA

Energy Efficient Future Wireless Communications
Nuno Borges Carvalho, Universidade de Aveiro, Portugal

Everything You Can Do With Vector Nonlinear Microwave Measurements
Patrick Roblin, Ohio State University, USA

Young Professionals Forum and Networking Event
Monday, 21 January 2019

Student Contest Elevator Pitches and Poster Session
Monday, 21 January 2019

Demos
Tuesday, 22 January 2019

Exhibits
Monday, 21 January 2019 and Tuesday, 22 January 2019

All accepted papers will be published in a digest and will be included in IEEE Xplore Digital Library.

NewProducts

L- and S-Band Power Amplifier

The all new TA1017 is a 50 W, L- and S-Band power amplifier that offers impressive power in a small and lightweight package, making it ideal for DBV-T applications. The TA1017 is also an excellent choice for LTE, Wi-Fi and any other L- or S-Band application where small size and high output power are essential.

Triad RF Systems
www.triadrf.com

SOURCES

Amplitude and Control Module Series Model ACM

Designed specifically for high performance simulator and ATE systems, General Microwave's amplitude control module provides precise amplitude control of signal amplitude and pulse modulation over a high dynamic range with fine resolution. With 10 BIT TTL control, modules provide up to 100 dB attenuation, harmonics < –60 dB and pulse modulation 80 dB, 25 ns control. Available in bands from 0.5 to 40 GHz and can be upgraded to include optional phase control.

Kratos General Microwave Corp.
www.kratosmed.com

Development Kits

Samtec announced the release of the two new FireFly™ FMC+ Development Kits. The first supports data rates of 25 Gbps per channel while the second runs at 28 Gbps per channel. These new solutions offer easy-to-use evaluation and development platforms for Samtec's FireFly™ optical engines. Samtec's 25/28 Gbps FireFly™ FMC+ modules provides up to 400/448 Gbps full-duplex bandwidth over up to 16 channels from an FPGA/SoC to an industry-standard multi-mode fiber optic cable.

Samtec Inc.
www.samtec.com

LTE-M/NB-IoT Front-End Solution

VENDORVIEW

Skyworks announced the release of SKY68020-11, an LTE-M/NB-IoT front-end solution for low power, low data rate IoT applications. This advanced multi-band front-end module is system on chip (SoC) agnostic and designed to meet the most difficult network operator band specifications, including harmonic performance across stringent protocols. This device also supports 20 LTE bands, enabling single SKU designs to cover future LTE-M/NB-IoT requirements.

Skyworks
www.skyworksinc.com

65 to 72 MHz Selectable Frequency Low Phase Noise PLL

The model FCPL-70 is a unique narrowband synthesizer versatile as a fixed frequency source. While standard synthesizers are based on user programming the FCPL series offers factory selectable set frequencies, as per binary table. Single or multiple set frequencies can be factory set as per user's requirement. This model offers output power of +1 dBm min over the frequency band of 65 to 72 MHz. Exceptional close-in phase noise of –120 dBc/Hz at 1 kHz offset. Requires single power supply of +5 V and 60 mA max. Other models are also available for different frequency bands and package style. This model comes in a small 0.94 in. square surface-mount package.

Synergy Microwave Corp.
www.synergymwave.com

Preprogrammed Synthesizer

VENDORVIEW

The fixed frequency SFS3200D-LF is a preprogrammed synthesizer that is phase locked to 3200 MHz. It is designed to lock with an external 10 MHz reference source while featuring very low phase noise of –130 dBc/Hz at 100 kHz offset. This remarkable PLO delivers a nominal 0 dBm of output power while operating off a 5 and 3 V supply all while packaged in a 0.6 × 0.6 × 0.22 in. miniature frame.

Z-Communications
www.zcomm.com

ANTENNAS

Diagonal Horn Antennas

A-INFO's LB-DG series diagonal horn antennas are linearly polarized and provide a symmetrical radiation pattern and extremely low side-lobes. A-INFO's diagonal horn antenna can cover from 0.75 to 220 GHz frequency range. This horn superficially looks like a pyramidal horn with a square output aperture. On closer inspection, however, the square output aperture is seen to be rotated 45 degrees relative to the waveguide. These horns are ideally suited for illumination of anechoic chamber, antenna far field test, radar cross section (RCS) measurement and other applications.

A-INFO Inc.
www.ainfoinc.com

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IEEE Advancing Technology for Humanity

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4-6 November ▪ David Intercontinental Hotel ▪ Tel Aviv, Israel

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MIMO Antenna Systems for Communications
Modulation & Signal Processing Technologies
On-Body and Short Range Communications
Radio over Fiber & Optical/Wireless Convergence
Sensor Networks and Technologies
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Space-Time Coding and Systems

Antennas, Propagation, and Scattering
Smart Antennas, Beamforming and MIMO
Wave Propagation and Channel Modeling
Wave Scattering and RCS
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EM Field Theory and Numerical Techniques
EM Interference & Compatibility, SI
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Signal Processing (SP) and Imaging
Microwave Imaging and Tomography
Acoustic/Sonar Imaging and Techniques
Radar SP and Imaging, SAR, ATR
MIMO SP for Radar
Ground and Foliage Penetration Systems
Signal Acquisition and Sensor Management
DF, Emitter Location, Elint, Array Processing
Target Detection, Identification and Tracking
Data Fusion
Time Domain and UWB SP

RF/MW Devices and Circuits, RFICs
Solid-State Devices, RFICs
μWave, mmW and Sub-mmW Circuits/Technologies
Nano and THz Devices/Technologies
Microwave Photonics
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Filters and Multiplexers
Ferroelectrics, RF MEMS, MOEMS, and NEMS
Active Devices and Circuits
RF Power Amplifiers and Devices
Tunable and Reconfigurable Circuits/Systems
Analog/Digital/Mixed RF Circuits
Circuit Theory, Modeling and Applications
Interconnects, Packaging and MCM
CAD Techniques for Devices and Circuits
Emerging Technologies
Thermal Management for Devices

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RFID Devices/Systems/Applications
Automotive/Transportation Radar & Communications
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www.comcas.org

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PS Form 3526, September 2007 (Page 2 of 3)

NewProducts

MATERIALS

Wirewound Ferrite Beads

Coilcraft wirewound ferrite beads feature a ferrite construction and heavy gauge wire for high current handling. They provide extremely low DCR while maintaining high filtering impedance across a wide bandwidth—up to GHz band. These features enhance the performance of the choke circuit while potentially reducing board space by replacing a larger chip ferrite bead with an equivalent or higher performing wirewound ferrite bead.

Coilcraft
www.coilcraft.com

Metal Bonding Epoxy Adhesive

Many assembly applications require strong structural bonds for metal to metal. The new 10-3044 epoxy adhesive bonds exceptionally well to aluminum and steel. It also bonds well to a variety of other substrates. 10-3044 is quickly becoming the industry standard as a stencil and screen adhesive due to its bonding strength, toughness and chemical resistance. It is fully compatible with cleaning solutions for stencils and screens. The 10-3044 cures within two hours at room temperature and is capable of withstanding high operating temperatures.

Epoxies
www.epoxies.com

EP30LTE-2

VENDORVIEW

Master Bond EP30LTE-2 has been developed for joining dissimilar substrates exposed to thermally or mechanically induced stresses. It can be used for sealing, coating and encapsulating, especially for small to medium sized castings where a very low coefficient of thermal expansion (CTE) is required. EP30LTE-2 is a highly dimensionally stable epoxy system with low linear and volumetric shrinkage upon curing. The compressive strength of the cured material is 24,000 to 26,000 psi and its CTE is very low at $10^{-13} \times 10^{-6}$/in/in/°C.

Master Bond
www.masterbond.com

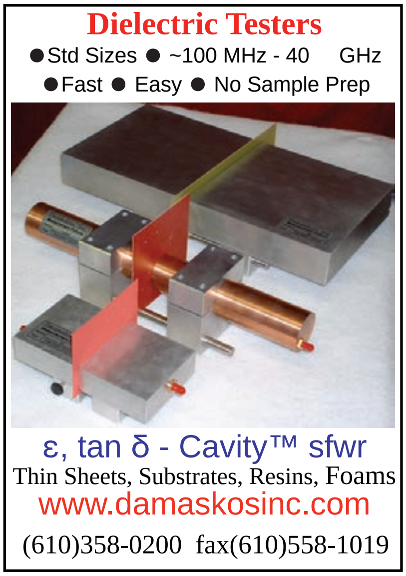
TEST & MEASUREMENT

RF Coaxial Spring Probes

Everett Charles Technologies recently launched two new high frequency test probes for the PCBA test market. The CSP-40A-024 and CSP-40G-021 RF probes are designed to mate to a variety of industry standard connectors such as MMCX, Fakra, SMB and U.FL. They combine proven RF performance with ease of use to ensure accurate and reliable testing. The CSP-40 coaxial probes provide an instrumentation quality interface for broadband RF measurements in excess of 6 GHz, and provide a cost-effective solution for high volume board testing.

Everett Charles Technologies
www.ect-cpg.com

MICRO-ADS



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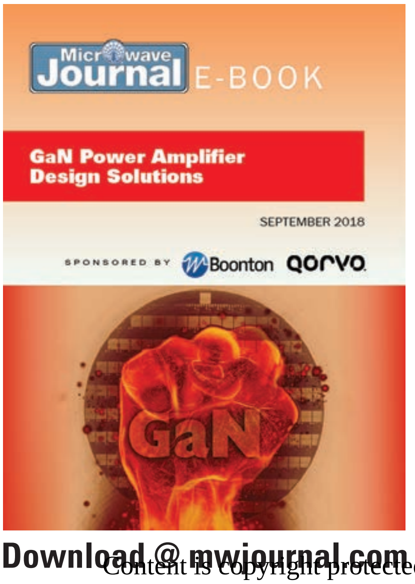

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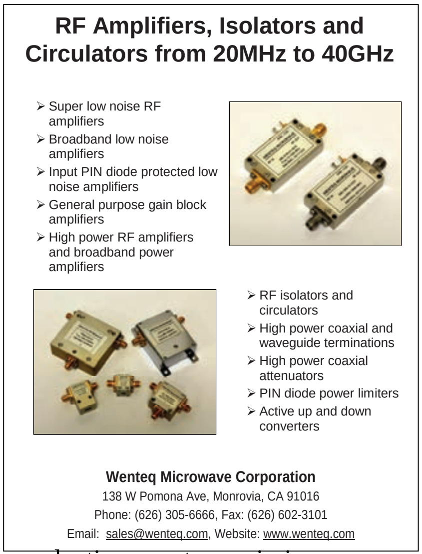

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Military Communications in the Future Battlefield

Marko Suojanen

"This book is a comprehensive study relating to the field of military communications with its specific focus on military communications in the future battlefield. As such, this book serves as a thorough handbook, and since all the substance matters discussed in the running text are given their fair share of attention, the end-product adds up to more than the sum of its subsections. Overall, this book makes a highly recommendable read, and on the basis of its thorough coverage and discussion concerning the topic, it would also well double as a set course book in the field of military communications. Its prospective readers are bound to be fully engaged by Chapter 2 with its focus on scenario-based capability planning the context of command and control."

— Tapio Saarelainen,
Major, Adjunct Professor (LUT), IARIA Fello

This book takes an applications-based view, delivering a forward-looking roadmap to military communications. Practitioners find insight into key issues related to long-term development within the battlefield communications area. Technological alternatives for communication in the battlefield in unexpected situations and environments are explored. The book discusses unstructured formations of actors using a holistic approach that considers key capability requirements.

Professionals and officers learn how to prepare for the unexpected and build the agile, adaptive and cognitive systems that are needed in future operating environments. From scenario-based capability planning to situational and context awareness, to unmanned ground and aerial platforms, the book covers critical topics practitioners need to master to achieve top performance in the battlefield.

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FABS and LABS

Gearing Up For 5G

In March, Cree bought Infineon's RF power business, combining it with the RF segment of Wolfspeed. The acquisition adds LDMOS technology and products to Wolfspeed's GaN on SiC portfolio and strengthens Cree's position in the wireless infrastructure market—well-timed for the coming deployment of sub-6 GHz 5G. The deal included a world-class assembly and test facility in Morgan Hill, Calif., on the southern edge of Silicon Valley, which has been producing RF power devices for cellular infrastructure, defense and aerospace applications since the early 1990s.

The Morgan Hill capability began under Ericsson Components, when a small team of engineers was formed to design and set up a manufacturing capability for silicon bipolar devices, the technology of choice at that time. The market quickly moved from bipolar to LDMOS, which provided superior performance in power amplifiers for cellular infrastructure. In 2000, reflecting the growth of the product line, Ericsson began constructing a 54,000 square foot building in the same business park.

The manufacturing techniques and equipment in the Morgan Hill facility have changed dramatically over the last 20 years. In the early 90s, manufacturing was predominately manual. Today, fully automated and linked manufacturing lines produce tens of thousands of products per day, with no manual handling of the individual components. For void-free die attach, Wolfspeed uses multi-wafer equipment with an ultra-fast, proprietary die attach process. Assemblies are inspected by automated optical inspection, as they move in carriers down conveyor belts between the assembly machines. Automating manufacturing processes has enabled Wolfspeed to reduce cost and compete with off-shore manufacturers, as well as improving quality and product consistency, making Wolfspeed a top choice among customers. Product testing is also highly automated to minimize test time while assuring product performance.

LDMOS dominated the power amplifier market until the commercialization of GaN on SiC, which provides higher power density and higher efficiency. GaN has largely supplanted LDMOS for defense applications and is establishing a beachhead in wireless infrastructure, where efficiency and bandwidth are key performance requirements.

As amplifier architectures for cellular infrastructure have changed over the years, so has the device topology. Today, most devices are used in Doherty configurations, and many of these devices are produced as a "Doherty in a package," with both the main and peak transistors assembled in one package. Production RF testing is performed in the Doherty configuration, which ensures high board assembly yield for the customer.

The manufacturing capability in Morgan Hill is equally adept with LDMOS and GaN power transistors. The components produced in the facility cover a wide range of frequencies and power levels: from 300 MHz to greater than 5 GHz, and from a few watts to over 1.4 kW pulsed output power for the latest GaN on SiC transistors. Wolfspeed's Morgan Hill facility is the largest U.S. manufacturer of RF power transistors, prepared to support the significant demand for power transistors from the coming ramp of 5G—both LDMOS and GaN.

www.wolfspeed.com/rf

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